Cover photo:
The Abbott Run Reservoir, photo taken November 25, 2003.

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Estimated Water Use and Availability in the Lower Blackstone River Basin, Northern Rhode Island and South-Central Massachusetts, 1995–99

By LORA K. BARLOW

Water-Resources Investigations Report 03-4190

In cooperation with the
RHODE ISLAND WATER RESOURCES BOARD

Providence, Rhode Island
2003

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Multiply	By	To obtain
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 per day (ft/d)	0.3048	meter per day (m/d)
gallons per day (gal/d)	0.00378	cubic meter per day (m^3/d)
inch (in.)	2.54	centimeter (cm)
inch per acre per week [(in/acre)/wk]	6.274	centimeter per hectare per week [(cm/ha)/wk]
inch per month (in/mo)	2.54	centimeter per year (cm/yr)
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
mile (mi)	1.609	kilometer (km)
million gallons (Mgal)	3,785	cubic meter (m^3)
million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)
million gallons per day per square mile ($Mgal/d/mi^2$)	1,462.1	cubic meter per day per square kilometer ($m^3/d/km^2$)
million gallons per day per yard [(Mgal/d)/yd]	0.00414	million cubic meters per day per meter ($Mm^3/d/m$)
million cubic feet (Mft^3)	0.0283	million cubic meters (Mm^3)
square foot per day (ft^2/d)	0.0929	square meters per day (m^2/d)
square mile (mi^2)	2.59	square kilometer (km^2)

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

°C = (°F-32)/1.8

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

Electric power: The kilowatt (KW) is the standard unit for measuring electric-power generation and is used in this report.

VERTICAL AND HORIZONTAL DATUM

In this report, vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), and horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

ABBREVIATIONS AND ACRONYMS

7Q10	7-day, 10-year low flow
ABF	Aquatic Base Flow
ADAPS	Automated Data Processing System
DPW	Department of Public Works
FD	Fire District
HUC	Hydrologic Unit Code
I/I	Infiltration and Inflow
MassGIS	Massachusetts Geographic Information System
MCD	Minor Civil Division
NBC	Narragansett Bay Commission
NEWUDS	New England Water Use Database System
NPDES	National Pollution Discharge Elimination System
NRCS	National Resource Conservation Service
NWS	National Weather Service
PCD	Pollution Control District
PCS	Permit Compliance System
RIDEM	Rhode Island Department of Environmental Management
RIDOA	Rhode Island Department of Administration-Division of Planning
RIGIS	Rhode Island Geographic Information System
RIWRB	Rhode Island Water Resources Board
SIC	Standard Industrial Classification
STF3	Summary Tape File 3
T/S	diffusivity
USGS	U.S. Geological Survey
WC	Water Commission
WD	Water Department
WDI	Water District
WDIV	Water Division
WSB	Water Supply Board
WSD	Water and Sewer Department
WWTF	Wastewater Treatment Facility

Estimated Water Use and Availability in the Lower Blackstone River Basin, Northern Rhode Island and South-Central Massachusetts, 1995–99

By Lora K. Barlow

Abstract

The Blackstone River basin includes approximately 475 square miles in northern Rhode Island and south-central Massachusetts. The study area (198 square miles) comprises six subbasins of the lower Blackstone River basin. The estimated population for the study period 1995–99 was 149,651 persons. Water-use data including withdrawals, use, and return flows for the study area were collected. Withdrawals averaged 29.869 million gallons per day (Mgal/d) with an estimated 12.327 Mgal/d exported and an estimated 2.852 Mgal/d imported; this resulted in a net export of 9.475 Mgal/d. Public-supply withdrawals were 22.694 Mgal/d and self-supply withdrawals were 7.170 Mgal/d, which is about 24 percent of total withdrawals. Two users withdrew 4.418 Mgal/d of the 7.170 Mgal/d of self-supply withdrawals. Total water use averaged 20.388 Mgal/d. The largest aggregate water use was for domestic supply (10.113 Mgal/d, 50 percent of total water use), followed by industrial water use (4.127 Mgal/d, 20 percent), commercial water use (4.026 Mgal/d, 20 percent), non-account water use (1.866 Mgal/d, 9 percent) and agricultural water use (0.252 Mgal/d, 1 percent). Wastewater disposal averaged 15.219 Mgal/d with 10.395 Mgal/d or 68 percent disposed at National Pollution Discharge Elimination System (NPDES) outfalls for municipal wastewater-treatment facilities. The remaining 4.824 Mgal/d or 32 percent was self-disposed, 1.164 Mgal/d of which was disposed through commercial and industrial NPDES outfalls.

Water availability (base flow plus safe-yield estimates minus streamflow criteria) was estimated for the low-flow period, which included June, July, August, and September. The median base flow for the low-flow period from 1957 to 1999 was estimated at 0.62 Mgal/d per square mile for sand and gravel deposits and 0.19 Mgal/d per square mile for till deposits. Safe-yield estimates for public-supply reservoirs totaled 20.2 Mgal/d. When the 7-day, 10-year low flow (7Q10) was subtracted from base flow, an estimated median rate of 50.5 Mgal/d of water was available for the basin during August, the lowest base-flow month. In addition, basin-wide water-availability estimates were calculated with and without streamflow criteria for each month of the low-flow period at the 75th, 50th, and 25th percentiles of base flow. These water availability estimates ranged from 42.3 to 181.7 Mgal/d in June; 20.2 to 96.7 Mgal/d in July; 20.2 to 85.4 Mgal/d in August, and 20.2 to 97.5 Mgal/d in September. Base flow was less than the Aquatic Base Flow (ABF), minimum flow considered adequate to protect aquatic fauna, from July through September at the 25th percentile and in August and September at the 50th percentile.

A basin-stress ratio, which is equal to total withdrawals divided by water availability, was also calculated. The basin-stress ratio for August at the

50th percentile of base flow minus the 7Q10 was 0.68 for the study area. For individual subbasins, the ratio ranged from 0.13 in the Chepachet River subbasin to 0.95 in the Abbot Run subbasin. In addition, basin-stress ratios with and without streamflow criteria for all four months of the low-flow period were calculated at the 75th, 50th, and 25th percentiles of base flow. These values ranged from 0.19 to 0.83 in June, 0.36 to 1.50 in July, 0.40 to 1.14 in August, and 0.31 to 0.78 in September. Ratios could not be calculated by using the ABF at the 50th and 25th percentiles in August and September because the estimated base flow was less than the ABF.

The depletion of the Blackstone River flows by Cumberland Water Department Manville well no. 1 in Rhode Island was estimated with the computer program STRMDEPL and specified daily pumping rates. STRMDEPL uses analytical solutions to calculate time-varying rates of streamflow depletion caused by pumping at wells. Results show that streamflow depletions were about 97 percent of average daily pumping rates for 1995 through 1999. Relative streamflow depletions for six public-supply wells with different aquifer properties and distances to a stream—Cumberland Water Department Manville wells no. 1 and no. 2; Pawtucket wells no. 2, 3, and 4; and Lincoln Lonsdale well no. 4— were simulated with a constant pumping rate to illustrate the effect different aquifer properties and distance have on depletion. After 30 days of simulated pumping, relative streamflow depletions for the six wells were 90, 91, 65, 71, 59, and 82 percent of withdrawals, respectively.

A long-term hydrologic budget was calculated for the period 1957–99. Water-withdrawal and wastewater-return-flow data used in the hydrologic budget were from 1995 through 1999. Total inflows and outflows for the entire study area were 815.83 Mgal/d. Precipitation, streamflow from upstream subbasins, and wastewater-return flow constituted 55, 43, and 2 percent of the total inflow, respectively. Evapotranspiration, streamflow out of the basin, and withdrawals constituted 24, 72, and 4 percent of the total outflow, respectively.

INTRODUCTION

The Rhode Island Water Resources Board (RIWRB), a state government board charged with managing the proper development, utilization, and conservation of water resources, faces increased and competing demands for the water resources of Rhode Island. The primary responsibility of the RIWRB is to ensure that sufficient water supply is available for present and future generations by apportioning water to all areas of the state, if necessary (Rhode Island Water Resources Board, 2002). Accurate information on water-use patterns and their effects on water availability is needed for an optimal allocation of the State's water resources. For these reasons, the RIWRB decided to evaluate water use and availability within each of the State's major basins. In 2000, the U.S. Geological Survey (USGS) began a study in cooperation with the RIWRB to collect, organize, and analyze water-use and water-availability data for the Blackstone River basin.

Purpose and Scope

This report discusses water-use data for six subbasins of the Blackstone River basin in northern Rhode Island and south-central Massachusetts from 1995 through 1999. The water-use data presented includes withdrawals for public- and self-supply use, aggregate water-use by category (domestic, commercial, industrial, agricultural, consumptive, and non-account, and electric power generation), and wastewater-return flows [at National Pollution Discharge Elimination System (NPDES) surface-water-discharge sites and onsite septic]. Imports and exports of water and wastewater were calculated for each of the six subbasins and the study area as a whole from metered withdrawals, estimated use, and return flows. Base flow was calculated for the period 1957–99 by the computer program PART (Rutledge, 1998) on the basis of long-term streamflow-gaging data from the Branch River at Forestdale (01111500). Base-flow estimates at the 75th, 50th, and 25th percentiles for the low-flow period (June, July, August, and September) were combined with safe-yield estimates to calculate water availability for each subbasin and the study area as a whole. Withdrawals were then divided by availability estimates to calculate basin stress for each subbasin and the study area for the low-flow period. In addition, stream-depletion effects were simulated for six public-supply wells by using the computer program STRMDEPL (Barlow, 2000). A long-term hydrologic budget for the study area was also calculated for the period 1957–99. In addition, a water-use analysis for one minor civil division, Cumberland, Rhode Island, is appended to illustrate the types of information retrievals that can be made from the New England Water Use Data System (NEWUDS).

Previous Investigations

Several previous water-use studies have been conducted by the USGS to evaluate water use in Rhode Island and the Blackstone River basin. These reports contain information on water withdrawals and use for major basins in Rhode Island (Craft and others, 1990), and water use within the town of Cumberland, Rhode Island (Horn and others, 1994).

In addition, reports published by the Rhode Island Department of Administration-—Division of Planning (RIDOA) document total water use by type. Water use for Rhode Island by public-supply, self-supply, and irrigation is reported in Rhode Island Department of Administration-—Division of Planning (1988). Total freshwater withdrawals, water use, and management of supply and demand are described in Rhode Island Department of Administration—Division of Planning (1991).

Several studies have analyzed ground-water resources in the Blackstone River basin in Rhode Island (Frimpter, 1974; Johnston and Dickerman, 1974a and 1974b, and Lang, 1961). These reports provide information on precipitation, streamflows, recharge, and aquifer yield within the basin. The studies by Johnston and Dickerman split the Blackstone River basin into two sections, the Branch River basin (1974a), and the Blackstone River drainage area (1974b). In the Branch River basin report Johnston and Dickerman (1974a) calculated sustained yields for four different aquifer areas by mathematically simulating pumping from wells in a model of the aquifer area. Results indicated that sustained yields of 5.5, 3.4, 1.6, and 1.3 Mgal/d might be obtained from the sand and gravel aquifers near Slatersville, Oakland, Harrisville, and Chepachet, Rhode Island, respectively. In the Blackstone River report Johnston and Dickerman (1974b) modeled and simulated sustained yields from five separate areas within the basin. Total sustained yield for the five areas was 30 Mgal/d including sections of the Moshassuck and Ten Mile basins.

Description of the Study Area

The Blackstone River basin in northern Rhode Island and south-central Massachusetts includes an area of approximately 475 mi^2. The study area for this report, herein referred to as the lower Blackstone River basin, is 198 mi^2 and includes six subbasins, five of which span the Rhode Island–Massachusetts border. These subbasins include: the Clear River subbasin, the Chepachet River subbasin, the Branch River subbasin, the West River subbasin, the Peters River subbasin, and the Abbott Run subbasin (fig. 1).

The lower Blackstone River basin in Rhode Island encompasses several communities: Cumberland, Woonsocket, and sections of Burrillville, Central Falls, Glocester, Lincoln, North Smithfield, Pawtucket, and Smithfield. In Massachusetts, the lower Blackstone River basin includes sections of Attleboro, Bellingham, Blackstone, Douglas, Franklin, Millville, North Attleboro, Plainville, Uxbridge, and Wrentham. The towns of Cumberland, Woonsocket, Blackstone, Millville, and Uxbridge are entirely within the Blackstone River basin; however, only Cumberland is completely within the lower Blackstone River basin.

Sand and Gravel Aquifers and Ground-Water Reservoirs

Sand and gravel aquifers in Rhode Island are irregularly shaped deposits that occur primarily in stream valleys (fig. 2). There are six ground-water reservoirs within the lower Blackstone River basin in Rhode Island; these ground-water reservoirs have been defined by the RIWRB as areas underlain by sand and gravel with transmissivity equal to or greater than 4,000 ft^2/d and a saturated thickness equal to or greater than 40 ft (W.B. Allen, Rhode Island Water Resources Board, written commun., 1978). The six ground-water reservoirs are: the Lower Blackstone, Slatersville, Blackstone, Abbott Run, Upper Branch, and Lower Branch Blackstone. Johnston and Dickerman (1974a and 1974b) reported that the stratified thickness of the sand and gravel aquifer in the lower Blackstone River basin in Rhode Island ranged from 10 to greater than 120 ft, and transmissivity ranged from 5,000 to 40,000 ft^2/d.

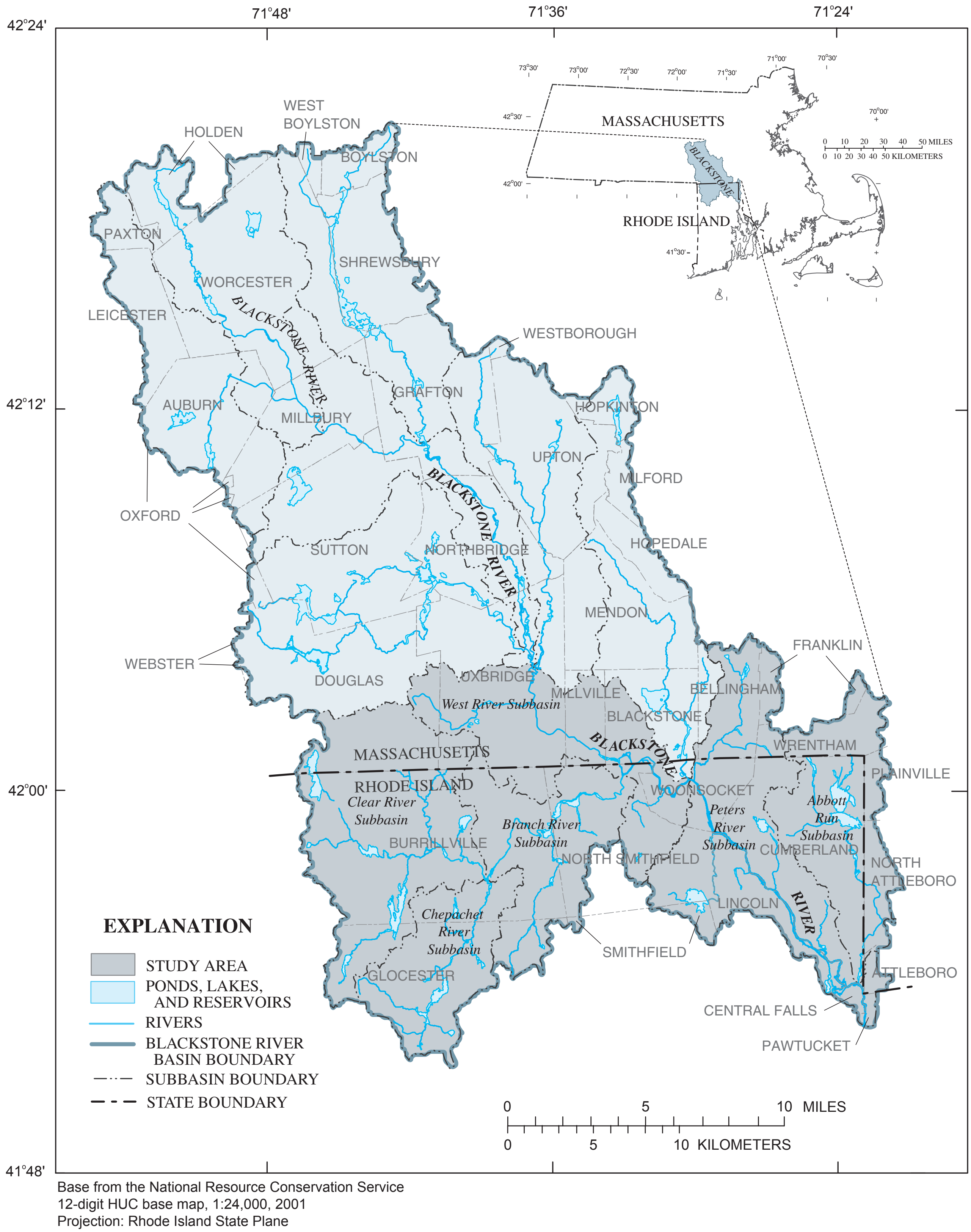

Figure 1. Blackstone River basin and study area, northern Rhode Island and south-central Massachusetts.

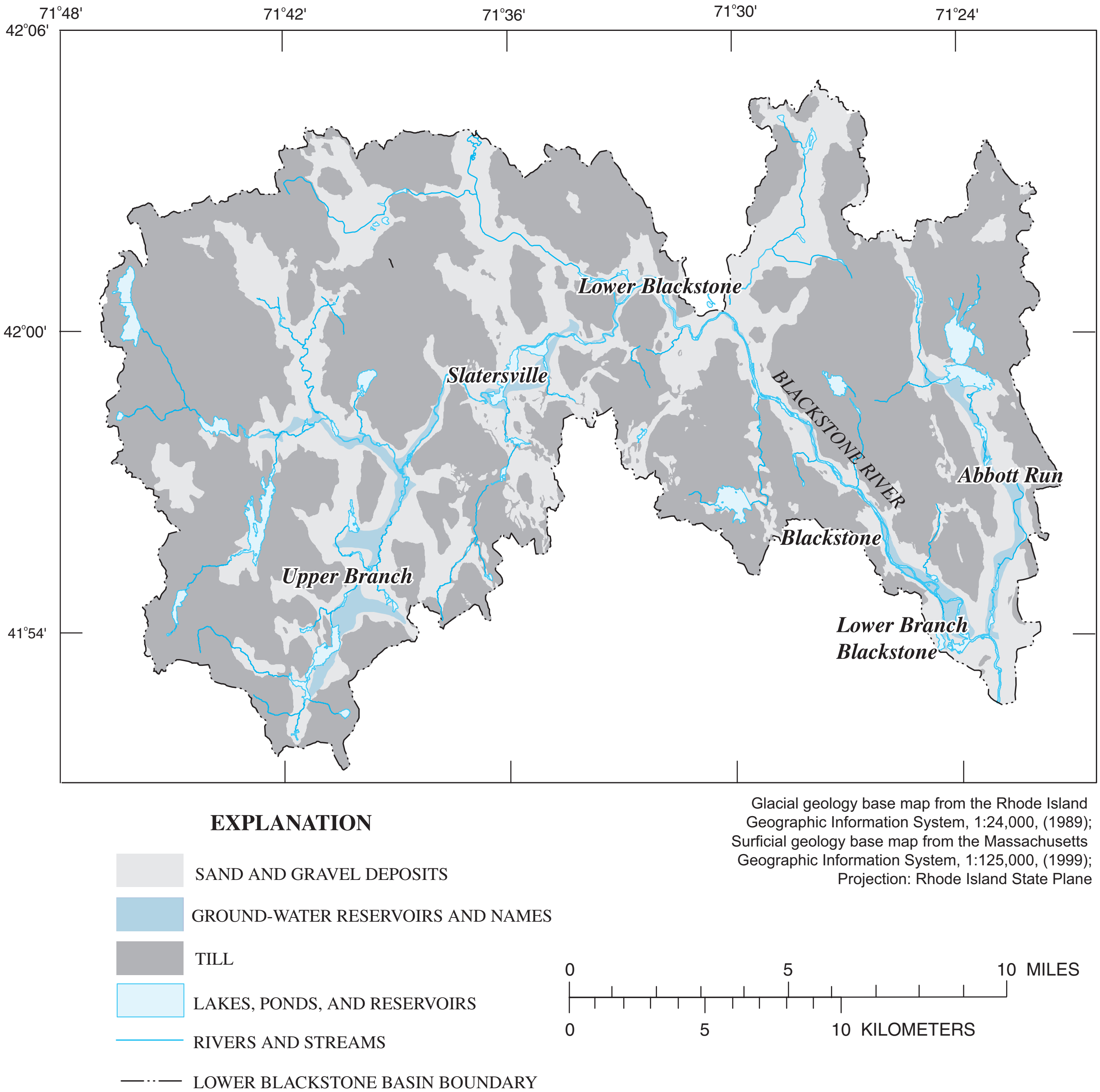

Figure 2. Distribution of sand and gravel and till deposits, and ground-water reservoirs as named by the Rhode Island Water Resources Board (Rhode Island portion only) in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

Surface Water

The 14-digit Hydrologic Unit Code (HUC) data layer from the Natural Resource Conservation Service (NRCS) (Reed Simms, GIS specialist U.S. Department of Agriculture—Natural Resource Conservation Service, written commun., 2001) was used to define the subbasin boundaries used in this report. Streamflow-gaging stations in the lower Blackstone River basin (fig. 3) include the Nipmuc River near Harrisville, RI (01111300), the Branch River at Forestdale (01111500), and the Blackstone River at Woonsocket (01112500). Ungaged sections of the lower Blackstone River basin include the Peters River subbasin south of the Woonsocket streamflow-gaging station, and the Abbott Run subbasin.

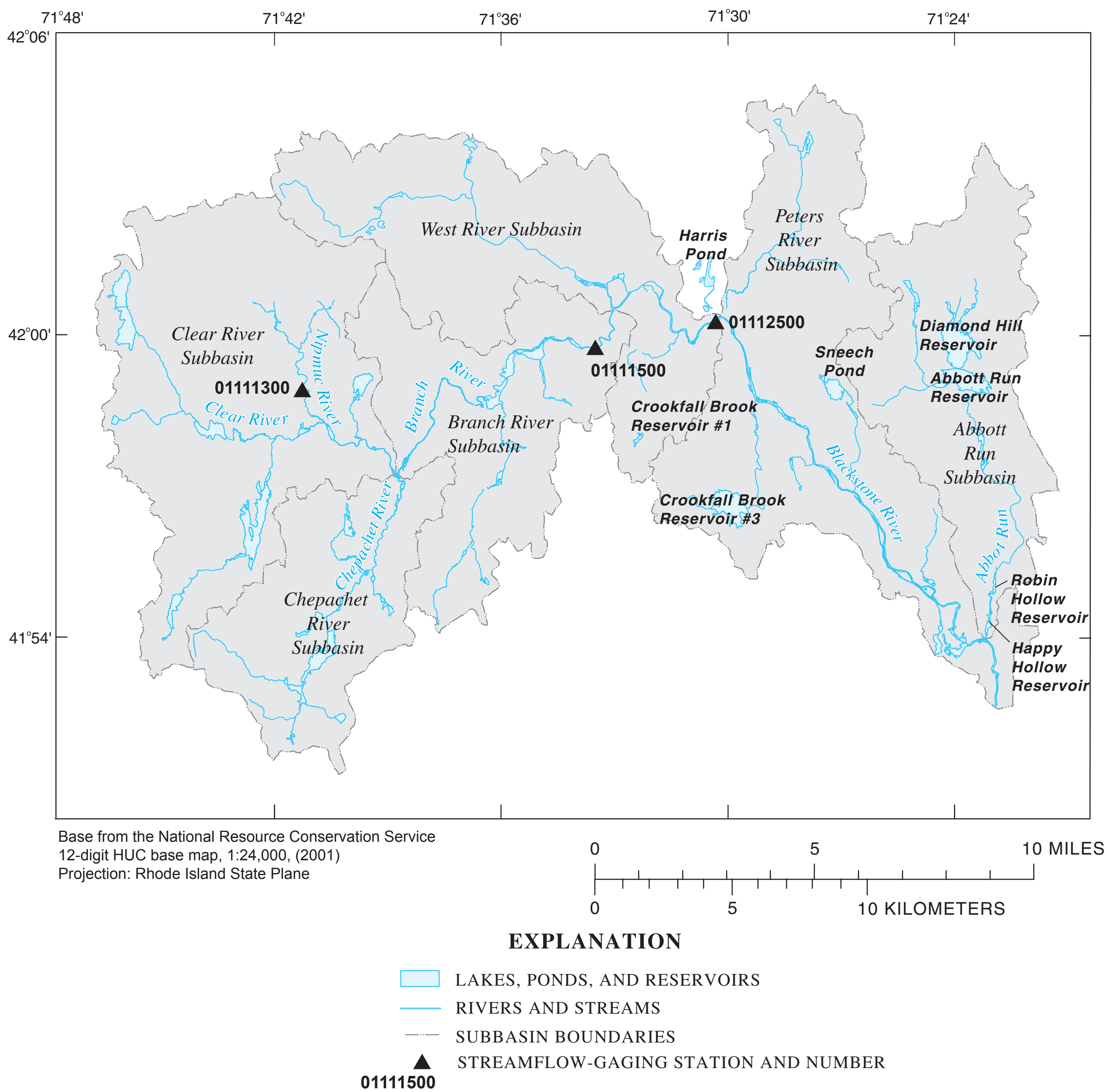

Figure 3. Streamflow-gaging stations and public-supply reservoirs within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

The largest tributary to the main stem of the Blackstone River in Rhode Island is the Branch River. The Branch River flows in a northeastern direction to its confluence with the Blackstone River in the West River subbasin (fig. 3). The two tributaries to the Branch are the Clear River and the Chepachet River. The Clear River flows east to its confluence with the Branch, and the Chepachet River flows in a northeastern direction. Abbott Run in the Abbott Run subbasin flows in a southern direction east of the Blackstone River and joins with the main stem of the Blackstone just north of its confluence with the Providence and Seekonk Rivers.

Four surface-water reservoirs and one pond in the lower Blackstone River basin are used for public supply (fig. 3). These include the Diamond Hill and Abbott Run Reservoirs of the Pawtucket Water Supply Board (WSB); Crookfall Brook Reservoirs no. 1 and no. 3 of the Woonsocket Water Division (WDIV); and Sneech Pond of the Cumberland Water Department (WD).

Climate

Rainfall records from the National Weather Service (NWS) rain gage in Woonsocket, Rhode Island, indicate that the average annual rainfall for the lower Blackstone River basin was 47.9 in/yr for the period 1957–99 (Carol LaRiviere, Assistant Superintendent for the Woonsocket Water Division, written commun., 2002). Long-term average monthly rainfall for this 42-year period ranged from 3.5 to 4.6 in/mo with the low in June and the high in November. The lowest measured monthly rainfall was 0.4 in., in October 1994. The highest measured monthly rainfall was 12.12 in., in June 1982. For the 5-year period of study, 1995–99, the average annual rainfall at the Woonsocket gage was 51.5 in/yr, which is 3.6 in/yr greater than the average annual rainfall for the period 1957–99. For the 5-year study period, average monthly rainfall at the Woonsocket gage ranged from 3.1 to 6.0 in/mo, with the low in August and the high in January. The lowest measured rainfall for this period was 0.5 in. in June 1999 and the highest measured monthly rainfall was 12.1 in. in June 1998.

A climatological station operated by the NWS at T. F. Green Airport in Warwick, RI, is about 5 mi from the mouth of the lower Blackstone River basin. This station collects temperature and rainfall data, but the Woonsocket rain gage within the lower Blackstone River basin does not collect temperature data. The Northeast Regional Climate Center at Cornell University publishes long-term climate data on their web site in 30-year increments (Cornell University, 2001); the latest available record is from 1961–90. Mean monthly temperatures at Warwick for this period ranged from 27.9°F in January to 72.7°F in July, with an annual mean of 50.4°F. Mean monthly precipitation at Warwick ranged from 3.18 in. in July to 4.11 in. in April, with an annual total of 45.53 in. During the same period, 1961–90, mean monthly precipitation at Woonsocket ranged from 3.42 in. in July to 4.19 in. in April, with an annual total of 47.4 in. Mean annual precipitation at Warwick was 96 percent of mean annual precipitation at Woonsocket.

Population

The 5-year average population for the lower Blackstone River basin was estimated to be 149,651 persons (table 1). The population within the lower Blackstone River basin generally decreases from east to west. The most highly populated subbasin is the Peters River subbasin with an estimated population of 70,641 persons, or 47.2 percent of the study-area population (table 1 and fig. 4). The next most populated subbasin is the West River subbasin with 31,862 persons or 21.3 percent, followed by the Abbott Run subbasin with 21,750 persons or 14.5 percent, the Clear River subbasin with 12,316 persons or 8.2 percent, the Branch River subbasin with 8,392 persons or 5.6 percent, and the Chepachet River subbasin with 4,689 persons or 3.1 percent. The lower Blackstone River basin includes the cities of Woonsocket and Pawtucket, with 5-year average populations of about 41,800 and 68,300, respectively (table 2). These cities and other suburban towns in the eastern subbasins of the lower Blackstone River basin have higher populations than towns in the western subbasins (fig. 4).

Land Use and Land Cover

Land within the lower Blackstone River basin is predominately forested (55.8 percent). The next largest land-use category is residential (18.4 percent), followed by wetlands (7.4 percent), agricultural (5.4 percent), water (3.3 percent), commercial (1.5 percent), industrial (1.0 percent), and transportation (1.0 percent). Other land-use categories compose the remaining 6.2 percent of the lower Blackstone River basin.

Table 1. Land area and 5-year average population for each minor civil division within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[Data sources: area and population estimates for subbasins were made by using Rhode Island Geographic Information System and Massachusetts Geographic Information System town datalayers, National Resource Conservation Service 14-digit Hydrologic Unit Code datalayer for New England, and U.S. Census Bureau census blocks and statistics updated for the period 1995–99 by using population figures from University of Massachusetts (2000) and Rhode Island Economic Development Corporation (2000). mi^2, square mile]

Minor civil division	Land area (mi^2)	5-year average population
Chepachet River subbasin		
Burrillville	5.03	1,774
Glocester	16.24	2,915
Subtotal	21.27	4,689
Clear River subbasin		
Burrillville	29.02	9,518
Glocester	5.06	758
Douglas	9.70	1,692
Uxbridge	1.68	348
Subtotal	45.46	12,316
Branch River subbasin		
Burrillville	12.67	3,624
Glocester	3.37	403
North Smithfield	9.43	4,131
Smithfield	.21	38
Millville	.19	95
Uxbridge	.48	101
Subtotal	26.35	8,392
West River subbasin		
Burrillville	1.77	479
North Smithfield	5.62	3,920
Woonsocket	2.73	18,703
Blackstone	4.37	3,234
Douglas	2.02	351
Millville	4.21	2,095
Uxbridge	13.92	3,080
Subtotal	34.64	31,862
Peters River subbasin		
Central Falls	.75	8,338
Cumberland	12.38	15,848
Lincoln	7.02	9,950
North Smithfield	5.27	1,117
Pawtucket	.55	5,667
Smithfield	1.43	497
Woonsocket	4.60	18,889
Attleboro	.91	1,864
Peters River subbasin—*Continued*		
Bellingham	7.22	6,303
Blackstone	.09	63
Franklin	1.75	1,614
Wrentham	1.14	491
Subtotal	43.11	70,641
Abbott Run subbasin		
Cumberland	15.78	13,877
Attleboro	.30	613
Franklin	.75	660
N. Attleboro	3.91	3,431
Plainville	1.60	1,020
Wrentham	4.98	2,149
Subtotal	27.32	21,750
Lower Blackstone River basin		
Burrillville	48.5	15,396
Central Falls	.8	8,338
Cumberland	28.2	29,725
Glocester	24.7	4,076
Lincoln	7.0	9,950
North Smithfield	20.3	9,168
Pawtucket	.6	5,667
Smithfield	1.6	535
Woonsocket	7.3	37,592
Attleboro	1.21	2,477
Bellingham	7.2	6,303
Blackstone	4.5	3,297
Douglas	11.7	2,043
Franklin	2.5	2,274
Millville	4.4	2,190
N. Attleboro	3.9	3,431
Plainville	1.6	1,020
Uxbridge	16.1	3,529
Wrentham	6.1	2,640
Total	198.2	149,651

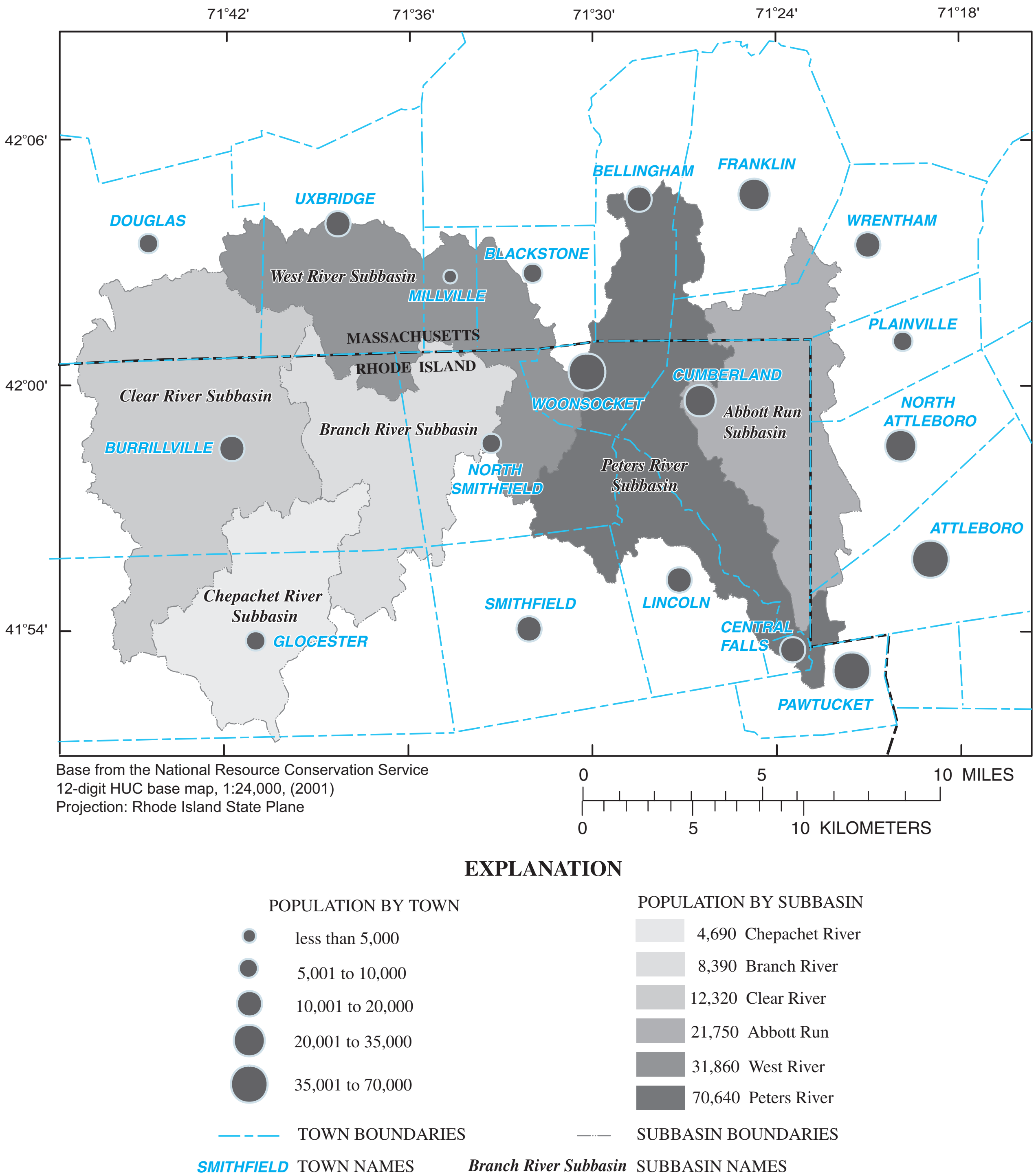

Figure 4. Estimated population by town and subbasin in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99.

Table 2. Land area and population for minor civil divisions, water suppliers (major and minor), and wastewater-treatment facilities serving those municipalities within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[**5-year average population of MCD (1995–99):** The 5-year average population for towns in the Blackstone River basin in Rhode Island and Massachusetts were made from population projections available from the Rhode Island Economic Development Corporation (2000) and the University of Massachusetts (2000). **Major/minor supplier:** Major suppliers are in bold. **Note:** Service populations for suppliers and wastewater-treatment facilities are the total for the minor civil division/municipality. Populations: are rounded to the nearest 100 persons (except for minor suppliers); DPW, Department of Public Works; FD, Fire District; MCD, minor civil division; NBC, Narragansett Bay Commission; PCD, Pollution Control District; WC, Water Commission; WD, Water Department; WDI, Water District; WDIV, Water Division; WSB, Water Supply Board; WSD, Water and Sewer Department; WWTF, Wastewater-Treatment Facility; mi^2, square miles; --, no public disposal]

Minor civil division	Total land area of MCD (mi^2)	Land area within study area (mi^2)	5-year average population of MCD (1995–99)	Population of MCD within study area	Major/minor supplier	Population on public supply	Wastewater-treatment facility	Population on public disposal
Burrillville	57.1	48.5	15,900	15,400	**Pascoag FD**	3,300	Burrillville WWTF	7,000
					Harrisville FD	2,700		
					Mohegan Water Association	50		
					Glendale Water Association	120		
					Oakland Water Association	250		
					Maplehill Mobile Home Park	530		
					Nasonville WDI	130		
MCD total						7,100		7,000
Central Falls, RI	1.3	0.8	16,600	8,300	**Pawtucket WSB**	16,600	NBC–Bucklin Point WWTF	16,100
MCD total						16,600		16,100
Cumberland, RI	28.2	28.2	29,700	29,700	**Cumberland WD**	20,500	NBC–Bucklin Point	14,200
					Pawtucket WSB	8,500		
MCD total						29,000		14,200
Glocester, RI	56.8	24.7	9,300	4,100	Hemlock Estates	200		0
					Davis Mobile Home Park	150		
					Brandy Acres	150		
					Laurel Crest Housing	40		
MCD total						540	--	0
Lincoln, RI	19	7	18,700	9,900	**Lincoln WC**[1]	17,800	NBC–Bucklin Point WWTF	12,700
MCD total						17,800		12,700
North Smithfield, RI	24.7	20.3	10,000	9,200	**Woonsocket WDIV**	20	Woonsocket WWTF	2,900
					Slatersville Public Supply	1,440		
					Deerfield Commons	90		
MCD total						1,550		2,900
Pawtucket, RI	8.9	0.6	68,300	5,700	**Pawtucket WSB**	68,300	NBC–Bucklin Point	67,200
MCD total						68,300		67,200
Smithfield, RI	27.8	1.6	18,900	500	**Smithfield WSB**[2]	8,200	Smithfield WWTF	13,300
					East Smithfield WDI[3]	7,500		
					Greenville WDI[3]	7,900		
MCD total						23,600[4]		13,300

Table 2. Land area and population for minor civil divisions, water suppliers (major and minor), and wastewater-treatment facilities serving those municipalities within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99—*Continued*

Minor civil division	Total land area of MCD (mi^2)	Land area within study area (mi^2)	5-year average population of MCD (1995–99)	Population of MCD within study area	Major/minor supplier	Population on public supply	Wastewater-treatment facility	Population on public disposal
Woonsocket, RI	7.9	7.3	41,800	37,600	**Woonsocket WDIV**	41,800	Woonsocket WWTF	40,300
MCD total						41,800		40,300
Attleboro, MA	28.3	1.2	39,300	2,500	**Attleboro WD**	38,800	Attleboro WWTF	26,700
MCD total						38,800		26,700
Bellingham, MA	18.9	7.2	15,700	6,300	**Bellingham DPW**	14,600	Woonsocket WWTF	500
							Charles River PCD	1,900
MCD total						14,600		2,400
Blackstone, MA	11.3	4.5	8,300	3,300	**Blackstone WD**	7,300	Woonsocket WWTF	2,600
MCD total						7,300		2,600
Douglas, MA	38.1	11.7	6,600	2,000	**Douglas WSD**	3,100	Douglas WWTF	2,000
MCD total						3,100		2,000
Franklin, MA	27	2.5	27,600	2,300	**Franklin DPW**	24,900	Charles River PCD	19,200
MCD total						24,900		19,200
Millville, MA	5	4.4	2,500	2,200	**Uxbridge WD**	100		0
MCD total						100	--	0
North Attleboro, MA	19	3.9	25,500	3,400	**North Attleboro WD**	24,100	North Attleboro WWTF	16,600
MCD total						24,100		16,600
Plainville, MA	11.6	1.6	7,400	1,000	**Plainville WD**	7,000	North Attleboro WWTF	3,600
MCD total						7,000		3,600
Uxbridge, MA	30.1	16.1	11,200	3,500	**Uxbridge WD**	9,100	Uxbridge WWTF	6,500
MCD total						9,100		6,500
Wrentham, MA	22.9	6.1	10,100	2,600	**Wrentham WDIV**	8,100		0
MCD total						8,100	--	0

[1]About 95, 2, and 3 percent of the water distributed by the Lincoln Water Department for the study period was from the Providence Water Supply Board, the Woonsocket Water Division, and Lincoln Lonsdale well no. 4.

[2]Only the Smithfield Water Supply Board serves residents within the Blackstone River basin; the other two suppliers serve residents outside the lower Blackstone River basin.

[3]The East Smithfield and Greenville Water Districts do not serve people within the lower Blackstone River basin.

[4]Population on public supply is greater than the population of town because the three public-supply populations include people outside of the town of Smithfield.

Land use within the lower Blackstone River basin differs from east to west (fig. 5). As of 1995, the western subbasins (the Chepachet, Branch, Clear, and West River subbasins) had lower percentages of residential land use (ranging from 10.3 to 19.8 percent) and higher percentages of forested land use (ranging from 57.6 to 72.3 percent). In contrast, the eastern subbasins (the Peters River and Abbott Run subbasins) had higher percentages of residential land use (26.0 and 25.1 percent, respectively), and lower percentages of forested land use (38.1 and 45.5 percent, respectively).

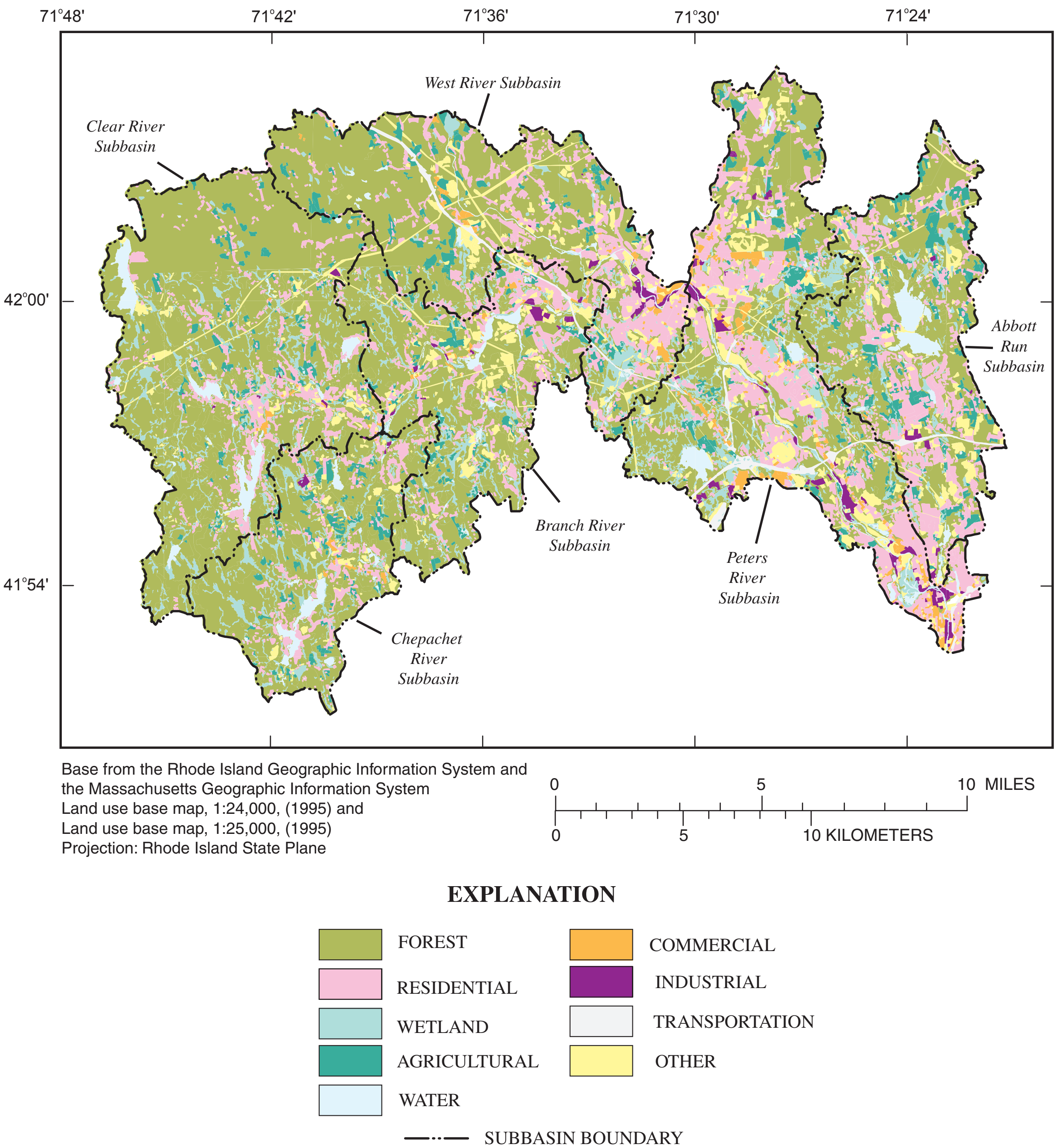

Figure 5. Land use in 1995 in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

The percentages of commercial, industrial, and agricultural land use did not vary greatly from the western to eastern subbasins. For the six subbasins, commercial land use ranged from 0.3 to 4.0 percent, industrial land use ranged from 0.1 to 2.7 percent, and agricultural land use ranged from 3.2 to 10.0 percent.

Acknowledgments

The author thanks the numerous municipal, State, and Federal agencies that provided data or assisted in the collection of data for this report: the Cumberland Water Department, the Pawtucket Water Supply Board, the Lincoln Water Department, the Woonsocket Water Division, the Slatersville Public Supply, the Smithfield Water Supply Board, the East Smithfield Water District, the Greenville Water District, the Harrisville Fire District, the Pascoag Fire District, the Massachusetts Department of Environmental Protection, the RIWRB, the Rhode Island Department of Health, the Rhode Island Department of Environmental Management (RIDEM), the RIDOA, and the U.S. Environmental Protection Agency. The author thanks the following U.S. Geological Survey employees: Paul M. Barlow for assistance with the computer program STRMDEPL, James B. Campbell for coordinating meetings and presentations, Kathryn M. Hess for reviewing the methods used in calculating ground-water availability, Stephen P. Garabedian for technical guidance and review, Albert T. Rutledge for assistance with the computer programs RECESS and PART, and Timothy P. Thies and Emily C. Wild for data collection.

WATER USE

The database used to store and retrieve water-use data for this report was NEWUDS, which is a Microsoft Access database developed by the U.S. Geological Survey for the storage of water-use information for New England. The NEWUDS database design and instructions for use are explained in Tessler (2002) and Horn (2002), respectively. The NEWUDS database gives water-resource managers access to accurate, comprehensive, and comparable water-use data. Withdrawals, use, and return flows tracked within the NEWUDS database can be used to determine current supply and demand, facilitate prediction of future demands, develop plans to ensure sufficient supplies for future use, and monitor the effectiveness of conservation measures (Horn and others, 1994).

Data for the following water-use processes were collected for the period 1995-99 and entered into NEWUDS at the town and subbasin levels: (1) withdrawals for public and self-supply, (2) treatment, (3) distribution and conveyance, (4) consumptive use, (5) non-consumptive water use, and (6) return flow. All six processes are represented as sites within the database: (1) wells and intakes, (2) potable-water and wastewater treatment plants, (3) local and regional distribution, (4) consumptive use, (5) aggregate and site-specific uses, and (6) local and regional wastewater collection; aggregate self-disposal (on-site septic); and NPDES permitted sites (including municipal wastewater-treatment facilities and commercial and industrial sites).

To represent the connections among the water-use processes, the NEWUDS database links sites to one another through a conveyance table. The quantity of water conveyed from site to site is entered into the Rate and Transactions tables within the database. The information stored within this database can be retrieved according to several variables, including water supplier, specific well or intake, and aggregate use.

Water Supply

The political subdivisions within the lower Blackstone River basin provide the basic unit by which water-use data for the study were initially collected and analyzed. The Minor Civil Division (MCD) is the smallest unit for which water use data were available for collection. Data were collected from the water suppliers and wastewater-collection agencies serving each MCD (table 2). Geographic distribution of total population and population served by public water and wastewater were estimated from data gathered from census block groups and the 1990 Census Summary Tape File 3 (STF3) available from the U.S. Census Bureau (U.S. Census Bureau, 2001a and 2001b) and town population estimates from 1995 through 1999 (Rhode Island Economic Development Corporation, 2000a and University of Massachusetts, Amherst, 2000) (table 3).

Table 3. Total 5-year average population and population served by public-water systems and public-wastewater systems by minor civil division in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[Data sources: Population estimates for total, public-supply, and public-disposal for subbasins were made using the Rhode Island Geographic Information System and Massachusetts Geographic Information System town datalayers, the Natural Resource Conservation Service 14-digit Hydrologic Uunit Code datalayer for New England, and the U.S. Census Bureau census blocks and statistics updated for the period 1995–99 by using total town population figures from University of Massachusetts (2000) and Rhode Island Economic Development Corporation (2000). --, not applicable]

Minor civil division	Estimated total population	Public supply		Public disposal	
		Number of individuals	Percent of total population	Number of individuals	Percent of total population
Lower Blackstone River basin					
Chepachet River subbasin					
Burrillville	1,774	710	--	713	--
Glocester	2,915	202	--	0	--
Subtotal	4,689	912	19.4	713	15.1
Clear River subbasin					
Burrillville	9,518	5,879	--	5,905	--
Glocester	758	51	--	0	--
Douglas	1,692	796	--	508	--
Uxbridge	348	194	--	122	--
Subtotal	12,316	6,920	56.2	6,535	53.1
Branch River subbasin					
Burrillville	3,624	444	--	352	--
Glocester	403	0	--	0	--
North Smithfield	4,131	251	--	750	--
Smithfield	38	20	--	13	--
Millville	95	0	--	0	--
Uxbridge	101	55	--	35	--
Subtotal	8,392	770	9.2	1,150	13.7
West River subbasin					
Burrillville	479	51	--	22	--
North Smithfield	3,920	365	--	2,036	--
Woonsocket	18,703	18,703	--	18,131	--
Blackstone	3,234	2,843	--	1,003	--
Douglas	351	166	--	105	--
Millville	2,095	0	--	0	--
Uxbridge	3,080	1,824	--	1,169	--
Subtotal	31,8602	23,952	75.2	22,466	70.5
Peters River subbasin					
Central Falls	8,338	8,338	--	7,991	--
Cumberland	15,848	14,879	--	9,826	--
Lincoln	9,950	9,937	--	7,838	--
North Smithfield	1,117	15	--	122	--
Pawtucket	5,667	5,667	--	5,654	--
Smithfield	497	336	--	224	--
Woonsocket	18,889	18,839	--	18,005	--
Attleboro	1,864	1,830	--	1,299	--
Bellingham	6,303	5,697	--	4801	--
Blackstone	63	56	--	20	--
Franklin	1,614	1,442	--	1,209	--
Wrentham	491	418	--	0	--
Subtotal	70,641	68,562	97.1	52,695	74.6

Table 3. Total 5-year average population and population served by public-water systems and public-wastewater systems by minor civil division in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99—*Continued*

Minor civil division	Estimated total population	Public supply		Public disposal	
		Number of individuals	Percent of total population	Number of individuals	Percent of total population
Abbott Run subbasin					
Cumberland	13,877	12,117	--	4,353	--
Attleboro	613	601	--	427	--
Franklin	660	563	--	453	--
North Attleboro	3,431	3,105	--	1,150	--
Plainville	1,020	965	--	496	--
Wrentham	2,149	1,829	--	0	--
Subtotal	21,750	20,062	92.2	7,239	33.3
Total of the lower Blackstone River basin	149,651	119,206	79.7	90,828	60.7

Site-specific withdrawals were collected for community and non-community wells. Site-specific return flows were collected for NPDES permitted discharges, including those from industrial and commercial users and wastewater-treatment facilities. Water-use data were collected for 19 MCDs in Rhode Island and Massachusetts and later disaggregated to the subbasin level on the basis of three data layers: the 14-digit HUCs, Census Blocks, and land use. The 14-digit HUCs were obtained from the NRCS (Reed Simms, GIS specialist U.S. Department of Agriculture—Natural Resource Conservation Service, written commun., 2001), the Census Blocks were obtained from the U.S. Census Bureau (U.S. Census Bureau, 2001a), and land-use data was obtained from the RIGIS and the MassGIS (Rhode Island Geographic Information System, 2001b, and Massachusetts Geographic Information System, 2001).

Public Supply

Population information from the 1990 STF3 by block group was attributed to the digital census blocks and combined with the basin boundaries from the NRCS 14-digit HUC datalayer to estimate the 1990 population on public water and public sewer. The 5-year averages of total population, population on public water, and population on public sewer in each subbasin were then estimated by adjusting the 1990 population estimates to reflect changes in population from 1995 through 1999 (table 3). Population estimates for 1995 through 1999 for Rhode Island and Massachusetts were available over the Internet (Rhode Island Economic Development Corporation, 2000a; University of Massachusetts, Amherst, 2000).

The percentage of population receiving public-supply water ranged from 97.1 percent in the Peters River subbasin to 9.2 percent in the Branch River subbasin (table 3). The percentage of the total population receiving public-supply water within the lower Blackstone River basin was 79.7 percent. The lowest populations, and percentage of individuals on public supply, occurred in the three westernmost subbasins—the Clear, Chepachet, and Branch River subbasins.

There are six major public-water suppliers in Rhode Island and two major public-water suppliers in Massachusetts that withdraw water from the lower Blackstone River basin: Harrisville Fire District (FD), Pascoag FD, Lincoln Water Commission (WC), Cumberland Water Department (WD), Pawtucket Water Supply Board (WSB), the Woonsocket Water Division (WDIV) and the Bellingham and North Attleboro WDs (table 4). "Major water suppliers" is a term often used for public suppliers who withdraw or deliver more than 50 Mgal/yr, or 0.114 Mgal/d (State of Rhode Island General Assembly, 2003; Rhode Island Water Resources Board, 2003). The 5-year average withdrawals for these public suppliers ranged from 0.116 Mgal/d to 13.17 Mgal/d. In addition to the 8 major suppliers who withdraw water from the lower Blackstone River basin, 11 minor water suppliers (10 in Rhode Island and 1 in Massachusetts) also withdraw water from the area.

Table 4. Water withdrawals for public-supply wells and surface-water intakes by subbasin in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[**Water supplier:** Major suppliers in bold. **Map ID:** Label used in figure 6. ID, identifier; No., number; Mgal/d, million gallons per day; <, actual value is less than value shown; --, information not available]

Water Supplier	Map ID(s)	Town/city (locality)	Well/wellfield description	Average water withdrawals (Mgal/d)	Percentage of public-supply withdrawals in study area
Lower Blackstone River basin					
Chepachet River subbasin					
Davis Mobile Home Park	1,2	Glocester	Well Nos. 1 and 2	0.01	<0.1
Hemlock Estates	3, 4, 16	Glocester	Well Nos. 7, 8, and 6	.014	.1
Maplehill Mobile Home Park	5, 6, 7	Burrillville	Well Nos. 1, 2, and 3	.06	.3
Subtotal				0.084	.4
Clear River subbasin					
Harrisville Fire District	8	Burrillville	Well No. 1 (emergency use only)	0	0
	9	Burrillville	Well No. 2	.108	.5
	10	Burrillville	Well No. 3	.112	.5
Pascoag Fire District	11	Burrillville	Well No. 1 (abandoned)	0	0
	12, 13	Burrillville	Well Nos. 2 and 3	[1].307	1.3
Subtotal				0.527	2.3
Branch River subbasin					
Brandy Acres	14	Glocester	Well	.014	.1
Glendale Water Association	15	Burrillville	Wells	.007	<.1
Mohegan Water Association	17, 18	Burrillville	Well Nos. 1 and 4	.003	<.1
Nasonville Water District	19, 20	Burrillville	Well fields A and B	.009	<.1
Oakland Water Association	21	Burrillville	Wells	.017	.1
Slatersville Public Supply	22	North Smithfield	Driven well field	[2].060	.3
	23	North Smithfield	Pacheco Park well No. 3	--	--
	24	North Smithfield	Well No. 1	--	--
	25	North Smithfield	Well No. 6	--	--
Subtotal				0.11	0.5
West River subbasin					
Deerfield Commons (North Smithfield Properties)	28, 29, 30	North Smithfield	Well Nos. 1,2, and 5	.006	<.1
Subtotal				0.006	<0.1
Peters River subbasin					
Bellingham Water Department	31	Bellingham	Well No. 1	.238	1
	32	Bellingham	Well No. 12	.103	.5
	33–39, 41	Bellingham	Well Nos. 13, 14, 15, 16, 17, 18, 19, and 20	0	0
	40	Bellingham	Well No. 2	.046	.2
	42	Bellingham	Well No. 3	.067	.3
	43	Bellingham	Well No. 4	.377	1.7
Lincoln Water Commission	46, 49, 50	Lincoln	Lonsdale well No. 10, and Manville well Nos. 3 and 5	0	0
	47	Lincoln	Lonsdale well No. 11	0	0
	48	Lincoln	Lonsdale well No. 4	.166	.7

Table 4. Water withdrawals for public-supply wells and surface-water intakes by subbasin in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99—*Continued*

Water Supplier	Map ID(s)	Town/city (locality)	Well/wellfield description	Average water withdrawals (Mgal/d)	Percentage of public-supply withdrawals in study area
			Peters River subbasin—*Continued*		
Cumberland Water Department	51	Cumberland	Manville well No. 1	.179	.8
	52	Cumberland	Manville well No. 2	.16	.7
	53	Cumberland	Sneech Pond intake	.838	3.7
Woonsocket Water Division	54	North Smithfield	Crookfall Brook Reservoir No. 1 intake	4.759	21
Subtotal				6.933	30.6
			Abbott Run subbasin		
Cumberland Water Department	55, 56	Cumberland	Abbott Run well Nos. 2 and 3	0	0
Pawtucket Water Supply Board	57	Cumberland	Happy Hollow intake	12.018	53
	64, 65, 69	Cumberland	Well Nos. 10, 11, and 5	0	0
	66	Cumberland	Well No. 2	.156	.7
	67	Cumberland	Well No. 3	.273	1.2
	68	Cumberland	Well No. 4	.065	.3
	70	Cumberland	Well No. 6	.13	.6
	71	Cumberland	Well No. 7	.169	.7
	72	Cumberland	Well No. 8	.179	.8
	73	Cumberland	Well No. 9	.183	.8
North Attleboro Water Department	59	North Attleboro	Adamsdale well	.155	.7
	60	North Attleboro	Hillman well	.859	3.8
	61	North Attleboro	Plainville well No. 1	.815	3.6
	62, 63	North Attleboro	Plainville well Nos. 2 and 3	0	0
Kings Grant Water Company	58	North Attleboro	Well No. 1	.032	.1
Subtotal				15.034	66.3
Total of the lower Blackstone River basin				22.694	100

[1]Pascoag Fire District well Nos. 2 and 3 are metered at one location on a quarterly basis.
[2]Slatersville Public Supply does not meter its withdrawals. A rate of 0.060 Mgal/d was estimated based on information provided by the supplier.

Withdrawals for public supply in the lower Blackstone River basin are from ground and surface water (fig. 6). The Woonsocket WDIV uses surface water as the sole source, whereas the Pawtucket WSB and the Cumberland WD use a combination of surface water and ground water. The Harrisville and Pascoag FDs use ground water as the sole source. The Lincoln WC and the Smithfield WSB receive interbasin transfers of surface water through the Providence WSB from the Scituate Reservoir in the Pawtuxet River basin; these interbasin transfers are the primary source of water for the Lincoln WC and the sole source of water for the Smithfield WSB. Public-supply withdrawal rates ranged from 0.084 Mgal/d in the Chepachet River subbasin to 15.034 Mgal/d in the Abbott Run subbasin (table 4). Public-supply withdrawal rates for the lower Blackstone River basin averaged 22.694 Mgal/d.

Six potable-water treatment plants serve water to residents within the lower Blackstone River basin: the Cumberland WD treatment plant, the Pawtucket WSB treatment plant, the Providence WSB J.P. Holton treatment plant, the Woonsocket WDIV Charles Hammen treatment plant, the Attleboro WD treatment plant, and the Plainville WD pressure-filtration plant. The remaining water departments do not have centralized treatment of their water supplies because the source is ground water.

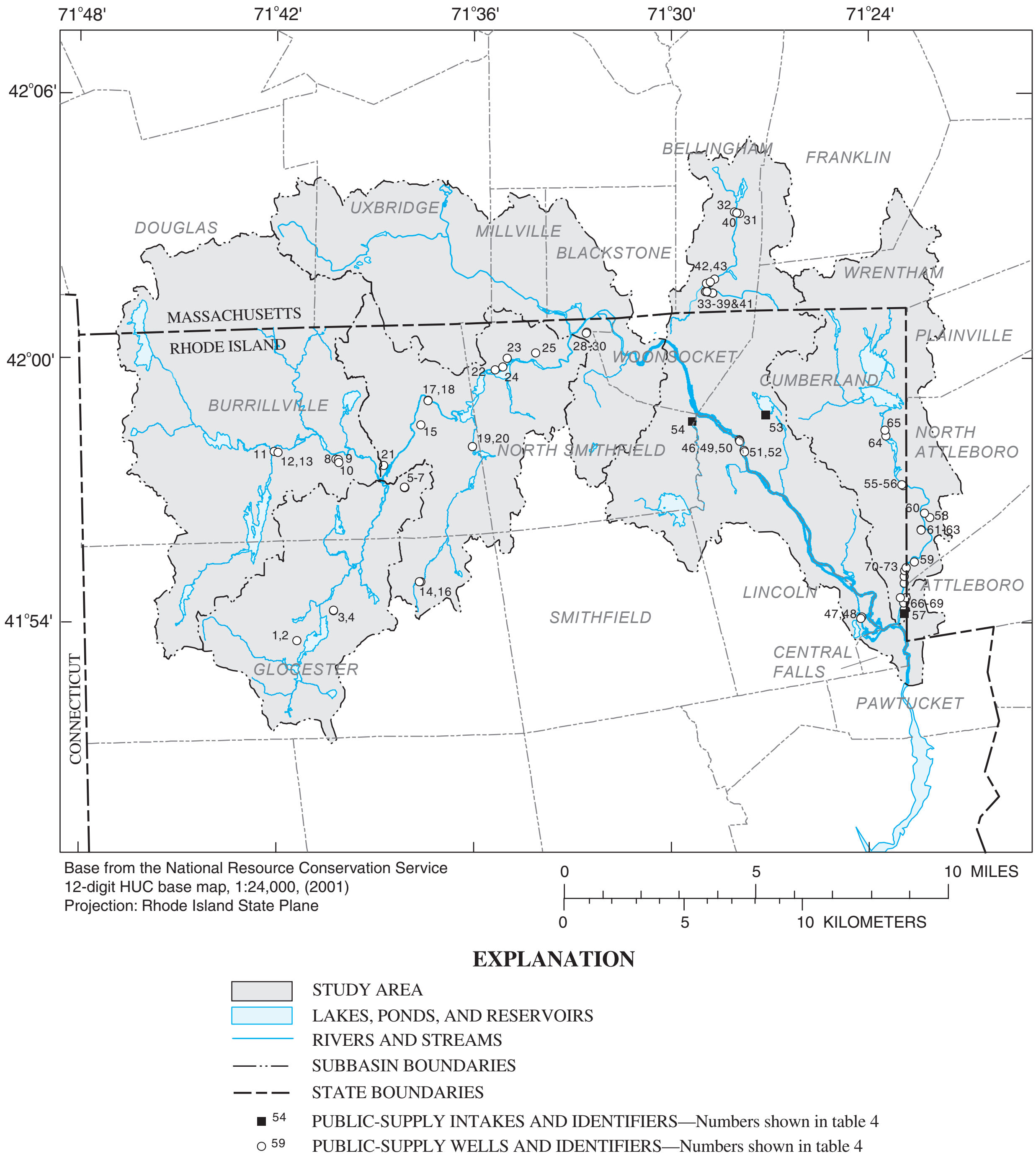

Figure 6. Public-supply wells and surface-water-intake locations within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

In general, the water supply from ground water is treated through pH adjustment and chlorination at booster stations within the distribution system and does not require a centralized water-treatment facility.

Public-supply imports and exports for the lower Blackstone River basin and each subbasin were estimated for the period 1995–99 by subtracting public-supply withdrawals from public-supply use. In the case where use is greater than withdrawals, an import of water has occurred and in the case where withdrawals are greater than use, an export of water has occurred. Average estimated public-supply imports for the six subbasins of the lower Blackstone River basin ranged from 0.005 Mgal/d in the Chepachet River subbasin to 3.951 Mgal/d in the Peters River subbasin (table 5). Public-supply imports for the entire lower Blackstone River basin were 2.852 Mgal/d. Water imported into the lower Blackstone River basin, as a whole, is less than the sum of the imports into each individual subbasin because some water is imported between subbasins within lower Blackstone River basin (table 5). Public-supply exports for 1995 through 1999 on average ranged from 0.000 Mgal/d in the West River subbasin to 13.240 Mgal/d in the Abbott Run subbasin (table 5). Public-supply exports for the lower Blackstone River basin totaled 12.327 Mgal/d.

Table 5. Public-supply withdrawals, public-supply imports, public-supply exports, public-supply use, self-supply use, and total estimated withdrawals by minor civil division and subbasin in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[Numbers may not sum correctly due to rounding. All values in million gallons per day. <, actual value is less than value shown]

Minor civil division	5-year average estimates						
	Public-supply withdrawals	Public-supply imports	Public-supply exports	Public-supply use	Self-supply withdrawals	Self-supply use	Total withdrawals
Lower Blackstone River basin							
Chepachet River subbasin							
Burrillville	0.06	0.005	0	0.065	0.101	0.101	0.161
Glocester	.024	0	.003	.021	.229	.229	.253
Subtotal	0.084	0.005	0.003	0.086	0.33	0.33	0.414
Clear River subbasin							
Burrillville	.527	0	.049	.478	.435	[1]2.814	.961
Glocester	0	.004	0	.004	.055	.055	.055
Douglas	0	.058	0	.058	.065	.065	.065
Uxbridge	0	.022	0	.022	.012	.012	.012
Subtotal	0.527	0.085	0.049	0.562	0.568	2.947	1.093
Branch River subbasin							
Burrillville	.036	.035	0	.071	.274	.274	.31
Glocester	.014	0	.014	0	.033	.033	.047
North Smithfield	.06	0	.034	.026	.436	.436	.496
Smithfield	0	.003	0	.003	.001	.001	.001
Millville	0	.001	0	<.001	.006	.006	.006
Uxbridge	0	.009	0	.008	.004	.004	.004
Subtotal	0.11	0.046	0.048	0.108	0.755	0.755	0.864
West River subbasin							
Burrillville	0	.006	0	.006	.037	.037	.037
North Smithfield	.006	.026	0	.032	.299	.299	.305
Woonsocket	0	1.833	0	1.833	4.42	[2]2.041	[3]4.420
Blackstone	0	.29	0	.29	.029	.029	.029
Douglas	0	.015	0	.015	.013	.013	.013
Millville	0	.007	0	.007	.143	.143	.143
Uxbridge	0	.243	0	.243	.104	.104	.104
Subtotal	0.006	2.421	0	2.427	5.045	2.666	5.049

Table 5. Public-supply withdrawals, public-supply imports, public-supply exports, public-supply use, self-supply use, and total estimated withdrawals by minor civil division and subbasin in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99—*Continued*

Minor civil division	5-year average estimates						
	Public-supply withdrawals	Public-supply imports	Public-supply exports	Public-supply use	Self-supply withdrawals	Self-supply use	Total withdrawals
Peters River subbasin							
Central Falls	0	0.906	0	0.906	0	0	0
Cumberland	1.177	.732	0	1.909	.015	.015	1.192
Lincoln	.166	1.08	0	1.246	.058	.058	.224
North Smithfield	.002	.005	0	.007	.106	.106	.108
Pawtucket	0	.672	0	.672	0	0	0
Smithfield	0	.087	0	.087	.011	.011	.011
Woonsocket	4.759	0	2.799	1.96	.007	.007	4.766
Attleboro	0	.277	0	.277	.003	.003	.003
Bellingham	.831	0	.25	.58	.066	.066	.897
Blackstone	0	.011	0	.011	.006	.006	.006
Franklin	0	.13	0	.13	.013	.013	.013
Wrentham	0	.051	0	.051	.006	.006	.006
Subtotal	6.935	3.951	3.049	7.837	0.285	0.285	7.226
Abbott Run subbasin							
Cumberland	13.173	0	11.704	1.469	0.105	0.105	13.278
Attleboro	0	.054	0	.054	.002	.002	.002
Franklin	0	.051	0	.051	.008	.008	.008
North Attleboro	1.861	0	1.537	.324	.036	.036	1.897
Plainville	0	.074	0	.074	.013	.013	.013
Wrentham	0	.222	0	.222	.023	.023	.023
Subtotal	15.034	0.401	13.24	2.195	0.187	0.187	15.221
Total of the lower Blackstone River basin	22.694	2.852	12.327	13.215	7.17	7.17	29.869

[1]Includes 2.379 million gallons per day withdrawn by Ocean State Power in the West River subbasin. The withdrawn water is then piped to Ocean State Power's thermoelectric facility in Burrillville, Rhode Island, which is located within the Clear River subbasin.

[2]Estimated self-supply withdrawal/use for Seville/Dorado, Company, Inc., a textile mill, 2.039 million gallons per day.

[3]Includes self-supply withdrawal from Ocean State Power.

Estimated public-supply use from 1995 through 1999 on average ranged from 0.086 Mgal/d in the Chepachet River subbasin to 7.837 Mgal/d in the Peters River subbasin (table 5). Total public-supply use for the lower Blackstone River basin was 13.215 Mgal/d.

Self-Supply

A list of self-supplied users within the lower Blackstone River basin was compiled from several sources (Rhode Island Department of Administration—Division of Planning, 1993; U.S. Environmental Protection Agency, 2000; Rhode Island Geographic Information System, 2001a; and Massachusetts Department of Environmental Protection, written commun., 2000). Non-community or self-supplied users serve both transient and non-transient populations; transient populations do not remain the same (for example, at rest stops, campgrounds, and gas stations), whereas a non-transient population remains the same, but does not use water year-round (for example, at schools). Withdrawal information for some campgrounds and private commercial users within the lower Blackstone River basin was not available; however, these uses often amount to less than 0.01 Mgal/d. In addition to site-specific self-supply use, aggregate self-supply use was estimated for domestic, industrial, commercial, and agricultural use.

Self-supply use in the lower Blackstone River basin ranged from 0.187 Mgal/d in the Abbott Run subbasin to 2.947 Mgal/d in the Clear River subbasin (table 5; 2.379 Mgal/d is the estimated self-supply use at the Ocean State Power thermoelectric facility). Self-supply use for the lower Blackstone River basin totaled 7.170 Mgal/d.

Aggregate Water Use by Category

To categorize water use by subbasin for each town as agricultural, commercial, industrial, and domestic, an estimate was made by subbasin of the land area within the various land-use categories or census-block-derived populations. The RIGIS 1995 and MassGIS 1999 updated land-use digital datalayers were intersected with subbasin boundaries to determine the distribution of three land-use categories—agricultural, commercial, and industrial—among subbasins (table 6). The numbers in table 6 are the percentages of land in a particular land-use category for towns within each subbasin. For example, 15.6 percent of the agricultural land in the town of Burrillville is in the Chepachet River basin, the remaining 84.4 percent of the agricultural land use in Burrillville is in other subbasins or outside the Blackstone River basin. Domestic water use for each subbasin was determined on the basis of 1990 census blocks and their associated statistics combined with the subbasin coverage (U.S. Census, 2001a; U.S. Census, 2001b). The resulting 1990 population in each subbasin was then updated with population estimates for 1995 through 1999 for total, public-supply, and public-disposal water use.

The land-use and population estimates for each subbasin were combined with data for aggregate water use gathered from public suppliers and towns to apportion aggregate water use for each category (agricultural, commercial, industrial, and domestic) by subbasin. In the case of site-specific use, withdrawal sites were intersected with the subbasin coverage. The 5-year average estimated withdrawal for the site was then assigned to the subbasin.

Domestic

Domestic water use was the largest aggregate water-use category for the lower Blackstone River basin. The 5-year average total domestic water use (public- and self-supply) for the lower Blackstone River basin was 10.113 Mgal/d. Domestic use by subbasin ranged from 0.347 Mgal/d or 3 percent of the total in the Chepachet River subbasin to 4.753 Mgal/d or 47 percent in the Peters River subbasin (table 7).

Table 6. Agricultural, commercial, and industrial land-use area by subbasin as a percentage of total land area for the category in each minor civil division for the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts

[--, no land use in category within subbasin]

Minor civil division	Percentage of land-use category by town within subbasin		
	Agricultural	Commercial	Industrial
Chepachet River subbasin			
Burrillville	15.6	2.9	37.8
Glocester	33.8	45.1	--
Clear River subbasin			
Burrillville	42.2	60.8	32.3
Glocester	2.5	1.5	--
Douglas	24.8	--	--
Uxbridge	3.5	--	--
Branch River subbasin			
Burrillville	34.1	36.3	29.9
Glocester	5.4	--	--
North Smithfield	16.8	38.9	78.3
Smithfield			
Millville	--	15.8	--
Uxbridge	1.2	3.2	--
West River subbasin			
Burrillville	5.9	--	--
North Smithfield	28.1	28.2	13.9
Woonsocket	27.1	31.2	48.8
Blackstone	33.4	84.7	100
Douglas	6.6	16.7	--
Millville	87.9	84.2	100
Uxbridge	36.2	64.4	1.1
Peters River subbasin			
Central Falls	--	76.5	63.1
Cumberland	39.7	85.6	69.5
Lincoln	22.1	75.5	33.3
North Smithfield	26.6	26.9	3.5
Pawtucket	--	12.6	5.8
Smithfield	0.4	.4	21.1
Woonsocket	72.9	46.5	41.9
Attleboro	0.6	5	7.4
Bellingham	52.1	25.1	19.1
Blackstone	--	15.3	--
Franklin	7	--	--
Wrentham	8.5	--	--
Abbott Run subbasin			
Cumberland	60.3	14.4	30.5
Attleboro	1.8	--	--
Franklin	6.1	--	--
North Attleboro	37.3	--	1.3
Plainville	43.4	--	--
Wrentham	--	1.3	--

Table 7. Total water use, public and self-supply, by category in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[Numbers may not sum correctly due to rounding. All values in million gallons per day. MCD, minor civil division; <, actual value is less than value shown]

Minor civil division	5-year average water use					
	Domestic	Commercial	Industrial	Agricultural	Non-account	Total
Lower Blackstone River basin						
Chepachet River subbasin						
Burrillville	0.128	0.001	0.016	0.013	0.007	0.166
Glocester	.219	.014	0	.018	0	.25
Subtotal	0.347	0.015	0.016	0.031	0.007	0.416
Clear River subbasin						
Burrillville	.672	[1]2.527	.014	.036	.043	3.292
Glocester	.057	<.001	0	.001	0	.059
Douglas	.115	0	0	.001	.007	.123
Uxbridge	.025	0	0	.001	.009	.035
Subtotal	0.869	2.527	0.014	0.04	0.058	3.509
Branch River subbasin						
Burrillville	.266	.018	.013	.029	.019	.345
Glocester	.03	0	0	.003	0	.033
North Smithfield	.293	.031	.133	.004	0	.462
Smithfield	.003	0	0	0	.001	.004
Millville	.007	0	0	0	0	.007
Uxbridge	.007	.002	0	<.001	.002	.012
Subtotal	0.607	0.051	0.146	0.036	0.022	0.863
West River subbasin						
Burrillville	.035	0	0	.005	.003	.043
North Smithfield	.278	.023	.024	.006	0	.331
Woonsocket	1.016	.211	[2]2.519	.002	.125	3.875
Blackstone	.229	.033	.005	.002	.051	.32
Douglas	.024	.003	0	<.001	.001	.029
Millville	.148	<.001	.001	.001	0	.15
Uxbridge	.219	.041	<.001	.015	.072	.347
Subtotal	1.9502	0.311	2.549	0.033	0.252	5.095
Peters River subbasin						
Central Falls	.593	.028	.249	0	.035	.906
Cumberland	1.122	.302	.174	.015	.311	1.924
Lincoln	.792	.256	.145	.008	.102	1.304
North Smithfield	.079	.021	.006	.006	0	.113
Pawtucket	.403	.095	.159	0	.016	.672
Smithfield	.038	.003	.05	<.001	.008	.099
Woonsocket	1.022	.314	.413	.007	.211	1.967
Attleboro	.149	.019	.092	<.001	.02	.28
Bellingham	.389	.025	.002	.024	.205	.646
Blackstone	.004	.006	0	0	.001	.011
Franklin	.125	0	0	.002	.015	.142
Wrentham	.036	0	0	.002	.019	.057
Subtotal	4.753	1.07	1.291	0.064	0.944	8.122

Table 7. Total water use, public and self-supply, by category in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99—*Continued*

Minor civil division	5-year average water use					
	Domestic	Commercial	Industrial	Agricultural	Non-account	Total
Abbott Run subbasin						
Cumberland	0.995	0.051	0.109	0.023	0.396	1.574
Attleboro	.049	0	0	.001	.006	.056
Franklin	.051	0	0	.002	.007	.059
North Attleboro	.269	0	.002	.013	.077	.36
Plainville	.064	0	0	.009	.013	.087
Wrentham	.16	.002	0	0	.084	.245
Subtotal	1.587	0.052	0.111	0.048	0.583	2.382
Total of the lower Blackstone River basin	10.113	4.026	4.127	0.252	1.866	20.388

[1]Includes 2.379 million gallons per day used by the Ocean State Power thermoelectric facility.
[2]Includes an estimated 2.039 million gallons per day used by the Seville/Dorado Company, textile mill.

Public Supply

Public-supply domestic water use for the municipalities within the lower Blackstone River basin was estimated with information provided in the Water Supply Management Plans in Rhode Island and Annual Statistical Reports in Massachusetts (Archer, 1994; Camp, Dresser, and McKee, 1994; Dufresne-Henry, Inc., 1997, 1999; Pare Engineering, Corp., 1992, 1998, 2000; Pawtucket Water Supply Board, 1998, 2000; Water Works Engineering and Associates, Inc., 1994; Massachusetts Department of Environmental Protection, written commun., 2000). Several plans provided a percentage estimate for domestic use in relation to total distribution, or reported the domestic use in million gallons per month.

The towns of Central Falls, Pawtucket, and Woonsocket rely entirely on public supply for domestic water use. The public-supply populations for the other towns within the lower Blackstone River basin were estimated from 1990 census data adjusted for changes in population from 1995 to 1999. Several minor water suppliers do not meter withdrawals. In these cases, an estimate of the domestic water use was calculated by multiplying the estimated population by 67 gal/d/person, which is a coefficient calculated by dividing domestic water use by the population served (Korzendorfer and Horn, 1995).

Total public-supply domestic use for the lower Blackstone River basin was 8.032 Mgal/d. Public-supply domestic use ranged from 0.054 Mgal/d in the Branch River subbasin to 4.600 Mgal/d in the Peters River subbasin (fig. 7).

Self-Supply

Self-supply domestic water use by town was estimated on the basis of the difference between the town population and the estimated public-supply population; this difference was then multiplied by a coefficient of 71 gal/d/person (Korzendorfer and Horn, 1995). The self-supplied populations were estimated from information provided in the 1990 census blocks updated for population changes for 1995 through 1999 or data on self-supplied populations provided in the Water Supply Management Plans. Total self-supply domestic use for the lower Blackstone River basin was 2.081 Mgal/d. Self-supply domestic use ranged from 0.138 Mgal/d in the Abbott Run subbasin to 0.555 Mgal/d in the West River subbasins (fig. 7).

Commercial

An estimate of commercial water use for the communities within the lower Blackstone River basin was calculated from the RI Major Employers List (Rhode Island Economic Development Corporation, 2000b) and the Massachusetts Division of Employment and Training (2001). This information was combined with water-use coefficients by Standard Industrial Classification (SIC) code and the numbers of employees for each SIC code to estimate aggregate commercial water use by town (Horn, 1999). The SIC code estimates (Appendix 1) were supplemented with estimates obtained either from the water supplier (in the case of public-supply commercial use) or from an individual facility (in the case of self-supply commercial use).

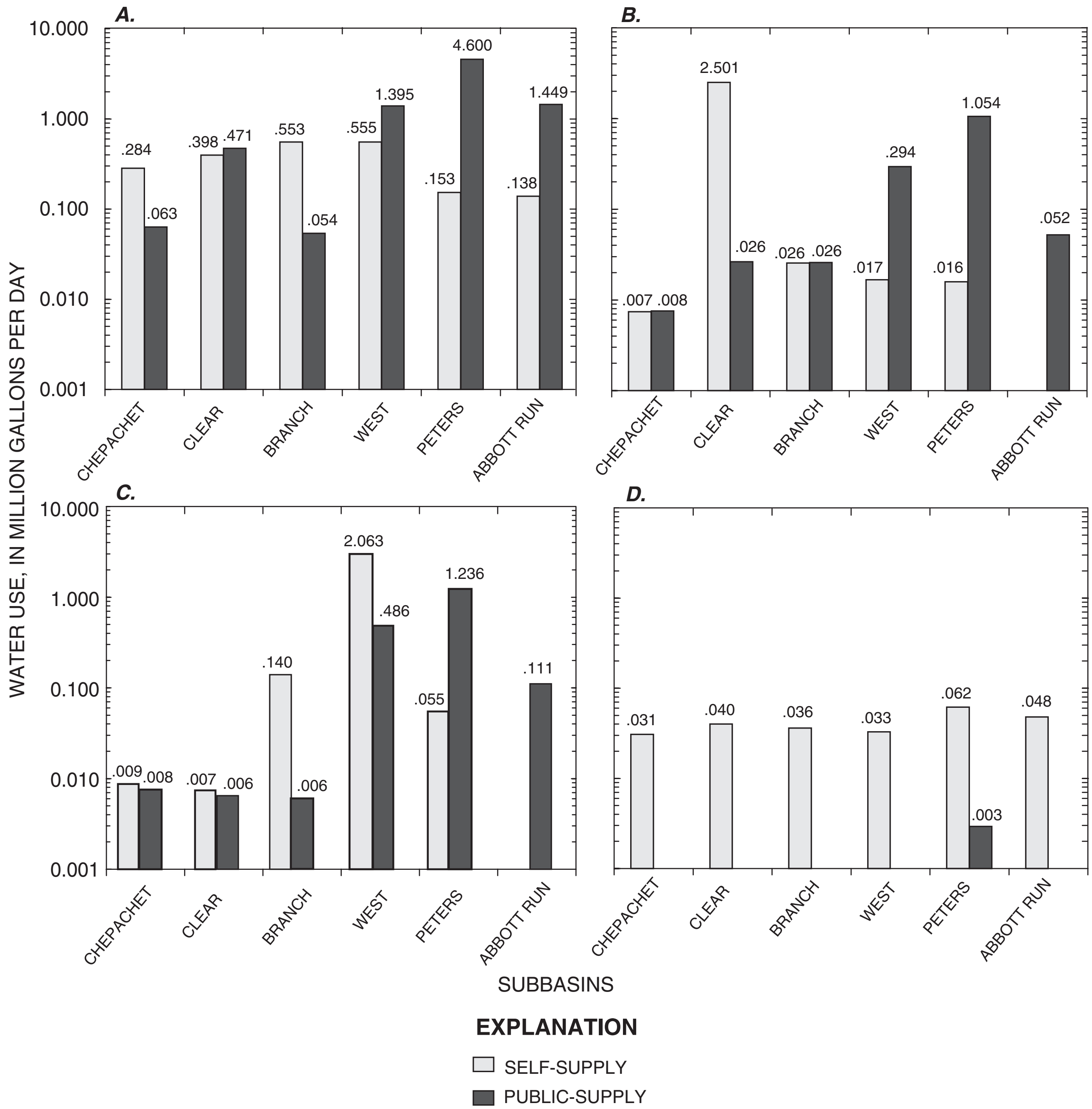

Figure 7. Public- and self-supply water use by category in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, for the period 1995–99: (*A*) domestic, (*B*) commercial, (*C*) industrial, and (*D*) agricultural.

The 5-year average total commercial water use (public- and self-supply) for the lower Blackstone River basin was 4.026 Mgal/d. Commercial water use ranged from 0.015 Mgal/d in the Chepachet River subbasin to 2.527 Mgal/d in the Clear River subbasin (table 7).

Public Supply

Public-supply commercial water use was estimated either by subtracting the known self-supply commercial use from the total commercial water-use estimate by community, or was estimated directly from the Water Supply Management Plans. Several public suppliers listed either the flow amount by use type or gave a percentage estimate of the total distribution by use type.

Total public-supply commercial use for the lower Blackstone River basin was 1.460 Mgal/d. Public-supply commercial use ranged from 0.008 Mgal/d in the Chepachet River subbasin to 1.054 Mgal/d in the Peters River subbasin (fig. 7).

Self-Supply

Total self-supply commercial use for the lower Blackstone River basin was 2.567 Mgal/d. Self-supply commercial use ranged from 0.000 Mgal/d in the Abbott Run subbasin to 2.501 Mgal/d in the Clear River subbasin (fig. 7; 2.379 Mgal/d is from the Ocean State Power thermoelectric facility in the Clear River subbasin).

Industrial

An estimate of industrial water use for the communities within the lower Blackstone River basin was calculated from the RI Major Employers List (Rhode Island Economic Development Corporation, 2000b) and the Massachusetts Division of Employment and Training (2001). This information was combined with water-use coefficients by SIC code and the numbers of employees for each SIC code to estimate aggregate industrial water use by town (Horn, 1999). The SIC code estimates (Appendix 1) were supplemented with estimates obtained either from the water supplier (in the case of public-supply industrial use) or from an individual facility (in the case of self-supply industrial use).

The 5-year average total industrial water use (public- and self-supply) for the lower Blackstone River basin was 4.127 Mgal/d. Total industrial water use ranged from 0.014 Mgal/d in the Clear River subbasin to 2.549 Mgal/d in the West River subbasin (table 7).

Public Supply

Public-supply industrial water use was estimated either by subtracting the known self-supplied industrial users from the total industrial water-use estimate by community, or was estimated directly from the Water Supply Management Plans. Several public suppliers listed either the flow amount by use type or gave a percentage estimate of the total distribution by use type.

Total public-supply industrial use for the lower Blackstone River basin was 1.852 Mgal/d. Public-supply industrial use ranged from 0.006 Mgal/d in the Branch and Clear River subbasins to 1.236 Mgal/d in the Peters River subbasin (fig. 7).

Self-Supply

Total self-supply industrial use for the lower Blackstone River basin was 2.275 Mgal/d. Self-supply industrial use ranged from 0.000 Mgal/d in the Abbott Run subbasin to 2.063 Mgal/d in the West River subbasin (fig. 7).

Agricultural and Golf-Course Irrigation

Estimates of agricultural water use by town in Rhode Island were based on a combination of the Farms List by town for Rhode Island (Rhode Island Department of Environmental Management, 2002) and the 1997 Census of Agriculture publication by county (U.S. Department of Agriculture, 1999a). The number and type of farms by town was determined for each type of livestock: beef cattle, poultry, and so forth. This value was then divided into the population total for each type of livestock in each county. From this information, the number of livestock per town was estimated and then multiplied by the respective water-use coefficient in gal/d/head (table 8).

The acreage of cropland requiring irrigation was determined by multiplying an estimate of agricultural land area by town (RIGIS land-use datalayer) by the percentage of agricultural land within the entire lower Blackstone River basin. Rainfall data available from the Woonsocket rain gage were compared to the irrigation requirement of 1 in/acre/week (Laura Medalie, U.S. Geological Survey, written commun., 1995) to estimate how much irrigation was required over the summer months during the study period. An average rainfall deficit of 0.19 in/week was estimated for the summer months from 1995 to 1999.

Determinations for agricultural water use for towns within the lower Blackstone River basin in Massachusetts were made by first determining the agricultural land area (in acres of cropland and pasture) within each town and then dividing this figure by the number of acres of agricultural land within the county (U.S. Department of Agriculture, 1999b). The acres of cropland were used to estimate the amount of irrigation required and the acres of pasture were used to estimate the number of head of livestock per town.

The rate of water used by golf courses for irrigation was estimated by multiplying the number of linear yards per course by a water-use coefficient of 0.0116 Mgal/d/1,000 yards (Laura Medalie, U.S. Geological Survey, written commun., 1995). This coefficient was included in the agricultural water-use estimate.

The 5-year average total agricultural water use (public- and self-supply) for the lower Blackstone River basin from 1995 to 1999 was 0.252 Mgal/d. Agricultural water use ranged from 0.031 Mgal/d in the Chepachet River subbasin to 0.064 Mgal/d in the Peters River subbasin (table 7, fig. 7). The only public-supply agricultural water use in the lower Blackstone River basin was in the Peters River subbasin in Massachusetts and amounted to 0.003 Mgal/d.

Consumptive and Non-Account Use

Consumptive use is that part of withdrawn water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate environment (Horn, 1999). Rates of consumptive use were estimated to be 15 percent for domestic use and 10 percent for commercial and industrial use; these percentages are consistent with traditional consumptive-use rates in New England. Nationally, conveyance losses and consumptive use during irrigation can account for 76 percent of irrigation withdrawals (Solley and others, 1993).

In addition to consumptive use for each aggregate-use type, non-account-use data from the major public suppliers were gathered from either the Water Supply Management Plans in Rhode Island provided by the RIWRB or the Annual Statistical Reports in Massachusetts provided by the Massachusetts Department of Environmental Protection (MADEP). Non-account water use often includes firefighting, inaccurate meters, flushing, major breaks, recreation, illegal connections, street washing, and leakage (exfiltration). The 5-year average non-account use for public suppliers serving people within the lower Blackstone River basin ranged from 0.027 Mgal/d for the Douglas WD to 0.683 Mgal/d for the Cumberland WD. A report prepared for the Cumberland WD by Pare Engineering (2000) gave estimates for each non-account use by type. Leakage or exfiltration was estimated as the highest at 62.0 percent of all types of non-account use. Other categories that account for more than 5 percent of non-account use were firefighting (12.0 percent) and major breaks (6.4 percent). Non-account use for the lower Blackstone River basin was estimated to be 1.866 Mgal/d (table 7). The estimates by subbasin ranged from 0.007 Mgal/d in the Chepachet River subbasin to 0.944 Mgal/d in the Peters River subbasin.

Table 8. Agricultural coefficients used to estimate livestock water use in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts

Livestock type	Gallons/day/head
Beef cattle	[1]16
Dairy cows	[1]35
Heifers	[2]3.5
Hogs and pigs	[1]4
Pullets older than 3 months	[3].05
Turkeys	[2].07
Sheep and lambs	[2]2
Horses and ponies	[3]12.5
Goats	[2]2

[1]Coefficent is from the 1990 Rhode Island Water Use Compilation.
[2]Coefficent is from the 1995 Rhode Island Water Use Compilation.
[3]Coefficent is from the 1995 Vermont Water Use Compilation.

Electric Power Generation

There are four hydroelectric power-generation facilities in the lower Blackstone River basin and one thermoelectric power-generation facility: Thundermist, Synergics, Elizabeth Webbing, and Central Falls, and Ocean State Power (fig. 8). All the water that is withdrawn by the four hydroelectric facilities is returned to the river, whereas the Ocean State Power thermoelectric facility withdrawals are 100-percent consumed (evaporated). The four instream-use facilities are considered “run of river” facilities; that is, inflow and outflow are kept as nearly equal as possible on an instantaneous basis to maintain habitat and water quality (Melissa Grader, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service, oral commun., 2002).

The Thundermist hydroelectric facility in Woonsocket can generate up to 1200 KW. The facility is just downstream of the Woonsocket Falls Dam in Woonsocket. The operating range for flow through the facility is between 250 and 850 ft^3/s. The intake for the facility is just upstream of the Woonsocket Falls Dam. A minimum of 0.10 in. of flow depth is maintained over the 200-ft-wide dam. Withdrawals are not metered; therefore, the actual amount withdrawn is unknown. Withdrawal amounts are dependent on several factors: streamflow, accumulated debris on the intake trash rack, and the mechanical efficiency at the facility (M.F. Debroisse, Thundermist, oral commun., 2002).

Ocean State Power withdrew an average of 2.379 Mgal/d from the Blackstone River in Woonsocket from 1995 through 1999. The Ocean State Power intake is located in the West River subbasin. Withdrawals are piped to the thermoelectric facility, which is in Clear River subbasin. The thermoelectric facility is permitted to withdraw as much as 4.4 Mgal/d. However, when flows in the Blackstone River are less than 102 ft^3/s, Ocean State Power must truck water to their thermoelectric facility to maintain operations. During the study period, water was trucked to the facility in September 1997; July, August, and September 1999; and November 1999 (Gary Couture, EHS Engineer, Ocean State Power, written commun., 2000). Water at this site is primarily used to cool turbines. Ocean State Power is a zero-liquid-discharge facility, and, as such, the water used at the facility is completely consumed by evaporation (Gary Couture, EHS Engineer, Ocean State Power, oral commun., 2000).

Synergics can generate up to 1724 KW. This facility is in Blackstone, Massachusetts, near the border of Rhode Island and Massachusetts. The operating range for the facility is between 40 and 1,000 ft^3/s. The Synergics facility has a 5,200-ft-long bypass channel. There is no flow requirement for the bypass; however, 10–20 ft^3/s is voluntarily released.

The Elizabeth Webbing hydroelectric facility can generate up to 700 KW. The facility is located in Central Falls, RI, and operates between 270 and 1,060 ft^3/s. The Central Falls hydroelectric facility, also in Central Falls, can generate up to 700 KW. The maximum withdrawal capacity for the facility is 920 ft^3/s. The Central Falls facility has a 1,500-ft-long bypass channel, which is required to maintain a minimum flow of 108 ft^3/s.

Wastewater-Return Flows

Wastewater-return flow is an important component in the water-use cycle. Public disposal of wastewater often results in the transfer of water from one basin or subbasin to another by means of local or regional collection. For example, the Narragansett Bay Commission (NBC) Bucklin Point wastewater-treatment facility (WWTF) collects wastewater through their regional collection system from communities within the lower Blackstone River basin. The collected wastewater is then discharged to the Seekonk River, which is outside the Blackstone River basin. Self-disposal of wastewater usually occurs at the same site where the water was used either through septic systems or discharge of the wastewater after treatment through surface-water discharge pipes, also known as outfalls.

Public Disposal

Discharge data for NPDES sites were collected from the RIDEM in Rhode Island and from the Environmental Protection Agency’s Permit Compliance System (PCS) database in Massachusetts. NPDES sites include municipal wastewater-treatment facilities and private commercial and industrial facilities. Nine wastewater-treatment facilities serve the communities within the lower Blackstone River basin (table 9 and fig. 9). However, only three facilities are within the lower Blackstone River basin: the Burrillville, RI, WWTF; the Woonsocket, RI, WWTF; and the Uxbridge, MA, WWTF. The remaining WWTFs are outside the lower Blackstone River basin. These facilities discharge wastewater to the Mumford River (in the Blackstone River basin but outside the lower Blackstone River basin), the Seekonk River, the Woonasquatucket River, the Ten Mile River, and the Charles River (table 9).

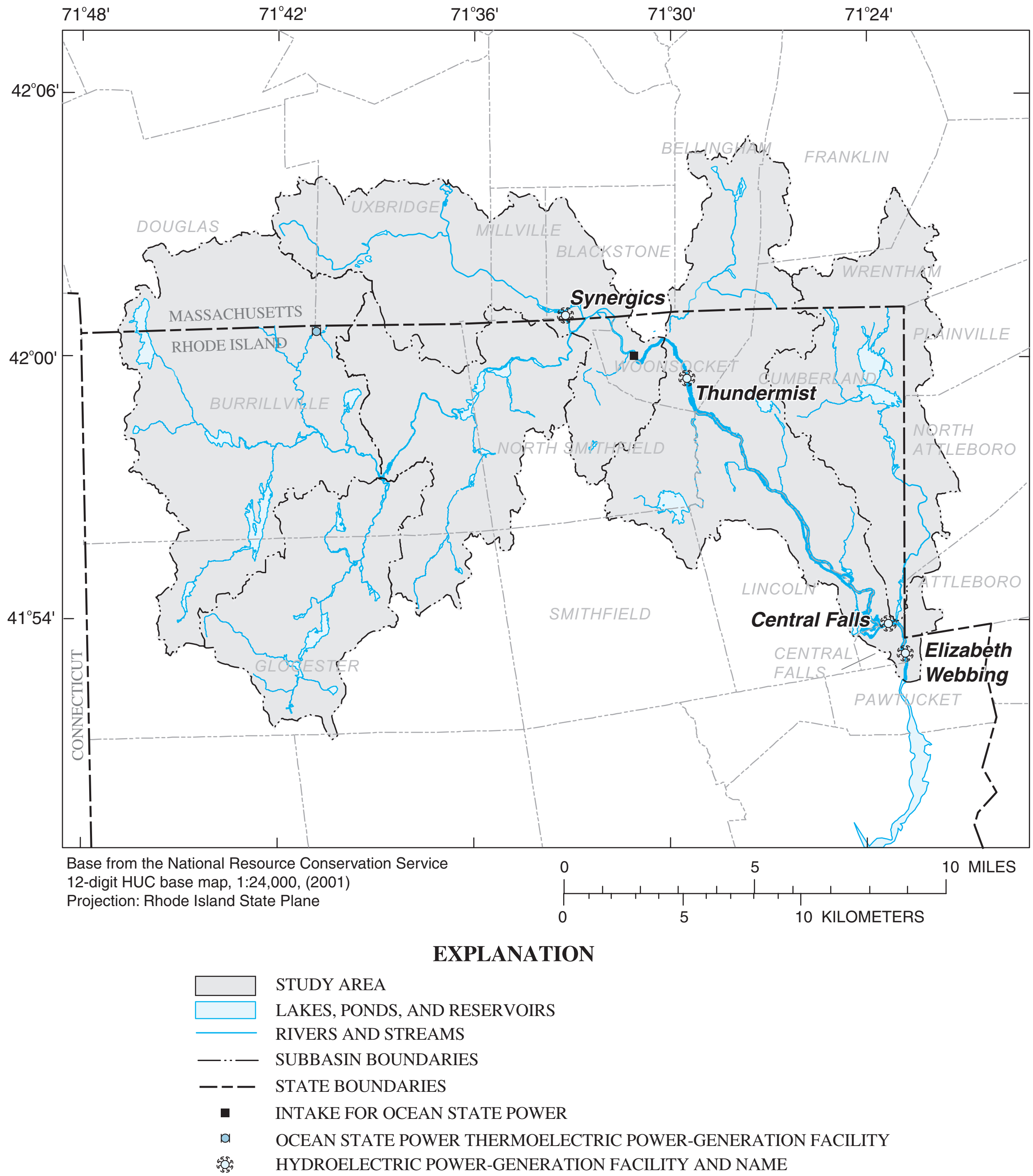

Figure 8. Power-generation facilities within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts

Table 9. Average return flow for wastewater-treatment facilities serving communities of the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[NPDES, National Pollution Discharge Elimination System; WWTF, wastewater-treatment facility; Mgal/d, million gallons per day; --, data not collected for this study]

Wastewater-treatment facility	Municipalities served	NPDES permit number	Receiving water	Average return flow (Mgal/d)
Municipal WWTFs within the Lower Blackstone River basin				
Clear River subbasin				
Burrillville WWTF	Burrillville, RI	RI0100455	Clear River	0.812
Peters River subbasin				
Woonsocket WWTF	Bellingham, MA[1]	RI0100111	Blackstone River	.049
	Blackstone, MA			.149
	North Smithfield, RI			.585
	Woonsocket, RI			8.081
Total discharge for facility				8.86
West River subbasin				
Uxbridge WWTF	Uxbridge, MA	MA0102440	Blackstone River	0.723
Total discharge of the municipal WWTFs within the lower Blackstone River basin				10.395
Municipal WWTFs Outside the Lower Blackstone River basin				
Douglas WWTF	Douglas, MA	MA0101095	Mumford River	[2]0.188
Narragansett Bay Commission–Bucklin Point	Central Falls, RI	RI0100072	Seekonk River	2.284
	Cumberland, RI			2.543
	East Providence, RI			--
	Lincoln, RI			2.327
	Pawtucket, RI			15.064
	Smithfield, RI[3]			.047
Total discharge for facility				23.916
Smithfield Sewer Authority WWTF	Smithfield, RI	RI010025	Woonasquatucket River	1.723
Attleboro WWTF	Attleboro, MA	MA0100595	Ten Mile River	4.416
North Attleboro WWTF	North Attleboro, MA	MA0101036	Ten Mile River	3.017
	Plainville, MA			.354
Total discharge for facility				3.371
Charles River Pollution Control Facility	Bellingham, MA[2]	MA0102598	Charles River[4]	.194
	Franklin, MA			3.231
	Medway, MA			--
	Millis, MA			--
Total discharge for facility				4.354
Total discharge of the municipal WWTFs outside the lower Blackstone River basin				37.965
Total discharge for all facilities				48.363

[1]Bellingham is sewered by both the Woonsocket WWTF and the Charles River Pollution Control Facility.
[2]1995 wastewater return flows for Douglas are currently unavailable; for this reason, average return flow only includes 1996–99.
[3]A small portion of the town of Smithfield is sewered by the Narragansett Bay Commission-Bucklin Point facility.
[4]NPDES discharge location is downstream of Populatic Pond.

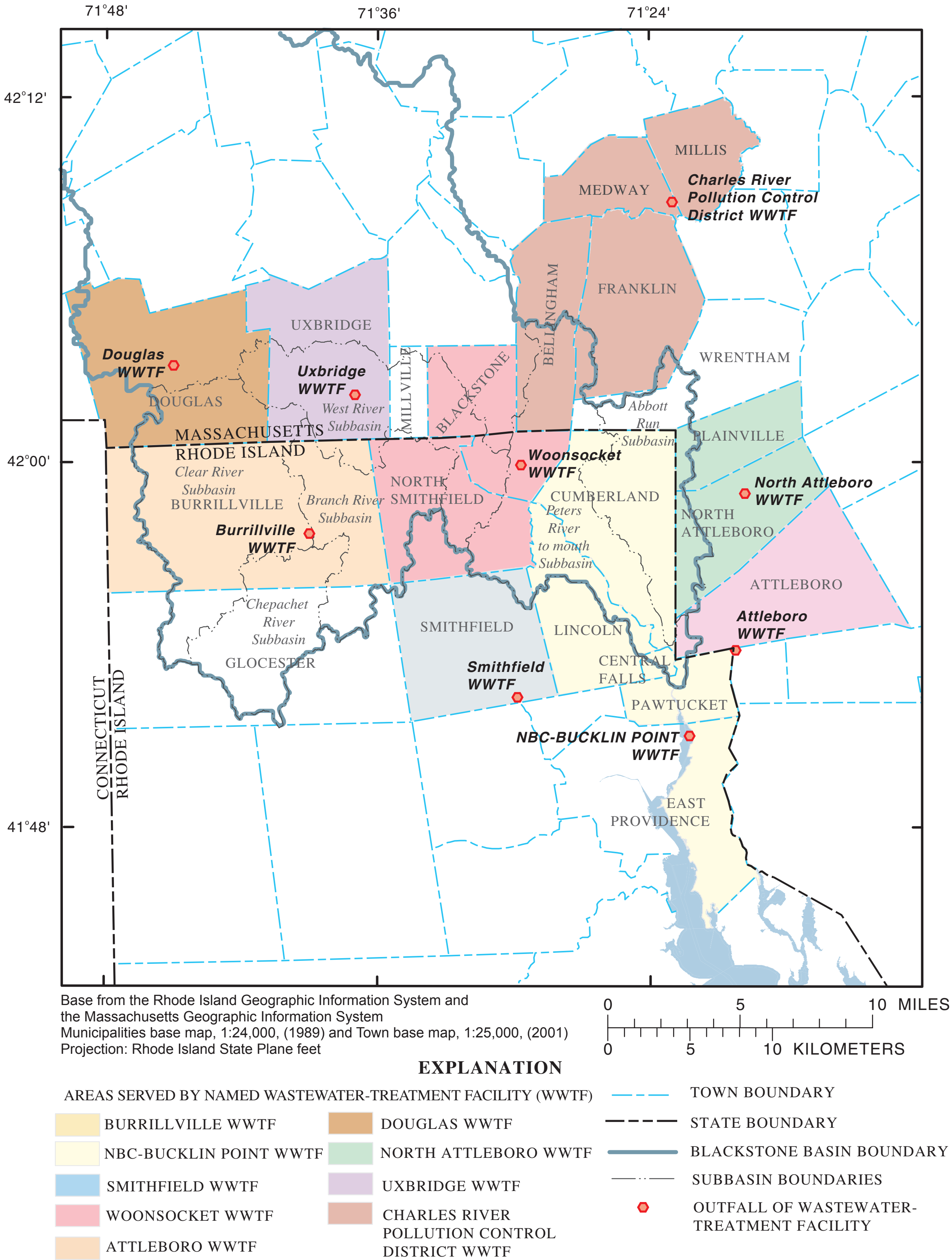

Figure 9. Outfall locations for wastewater-treatment facilities serving towns within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

Average annual return flow for the nine wastewater-treatment facilities serving communities within the lower Blackstone River basin ranged from 0.188 Mgal/d to 23.916 Mgal/d for 1995 through 1999 (table 9). Total average return flows for this period were 48.363 Mgal/d (table 9). Most of the wastewater flows received at these facilities are collected from outside the lower Blackstone River basin (fig. 9). Total average return flows for the three municipal wastewater-treatment facilities within the lower Blackstone River basin were 10.395 Mgal/d. In addition, 1.164 Mgal/d was discharged via NPDES sites to the lower Blackstone River basin by commercial and industrial facilities (table 10 and fig. 10).

Table 10. Average return flow for National Pollution Discharge Elimination System outfall locations for the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[ID, identifier; NPDES, National Pollution Discharge Elimination System; WWTF, wastewater-treatment facility; Mgal/d, million gallons per day]

Commercial/industrial facility	Map ID	Town/city	NPDES permit number	Average return flow (Mgal/d)
Lower Blackstone River basin				
Clear River subbasin				
Eleanor Slater Hospital/ Zambarano Unit	1	Burrillville, RI	RI0100129	0.105
Subtotal				0.105
Branch River subbasin				
Turex, Incorporated	2	Burrillville, RI	RI0000116	.006
Atlantic Thermoplastics	3	North Smithfield, RI	RI0000566	.001
Phillips Components	4	North Smithfield, RI	RI0000019	.003
Subtotal				0.010
Peters River subbasin				
Osram Sylvania	5	Central Falls, RI	RI0001180	.247
Air Products and Chemicals	6	Cumberland, RI	RI0021865	.157
A.T. Cross	7	Lincoln, RI	RI0000124	.006
Blackstone Valley Electric Company	8	Lincoln, RI	RI0023132	.008
Fleet National Bank	9	Lincoln, RI	RI0021865	0
Okonite Company	10	Lincoln, RI	RI0020141	.159
Deblois Oil Company	11	North Smithfield, RI	RI0021971	.013
ACS Industries, Incorporated	12	Woonsocket, RI	RI0021393	.186
Subtotal				0.776
West River subbasin				
Blackstone Smithfield Corporation	13	North Smithfield, RI	RI0000485	.004
Subtotal				0.004
Abbott Run subbasin				
Pawtucket WSB potable treatment plant	14	Cumberland, RI	RI0001589	.269
Subtotal				0.269
Total of the lower Blackstone River basin				1.164

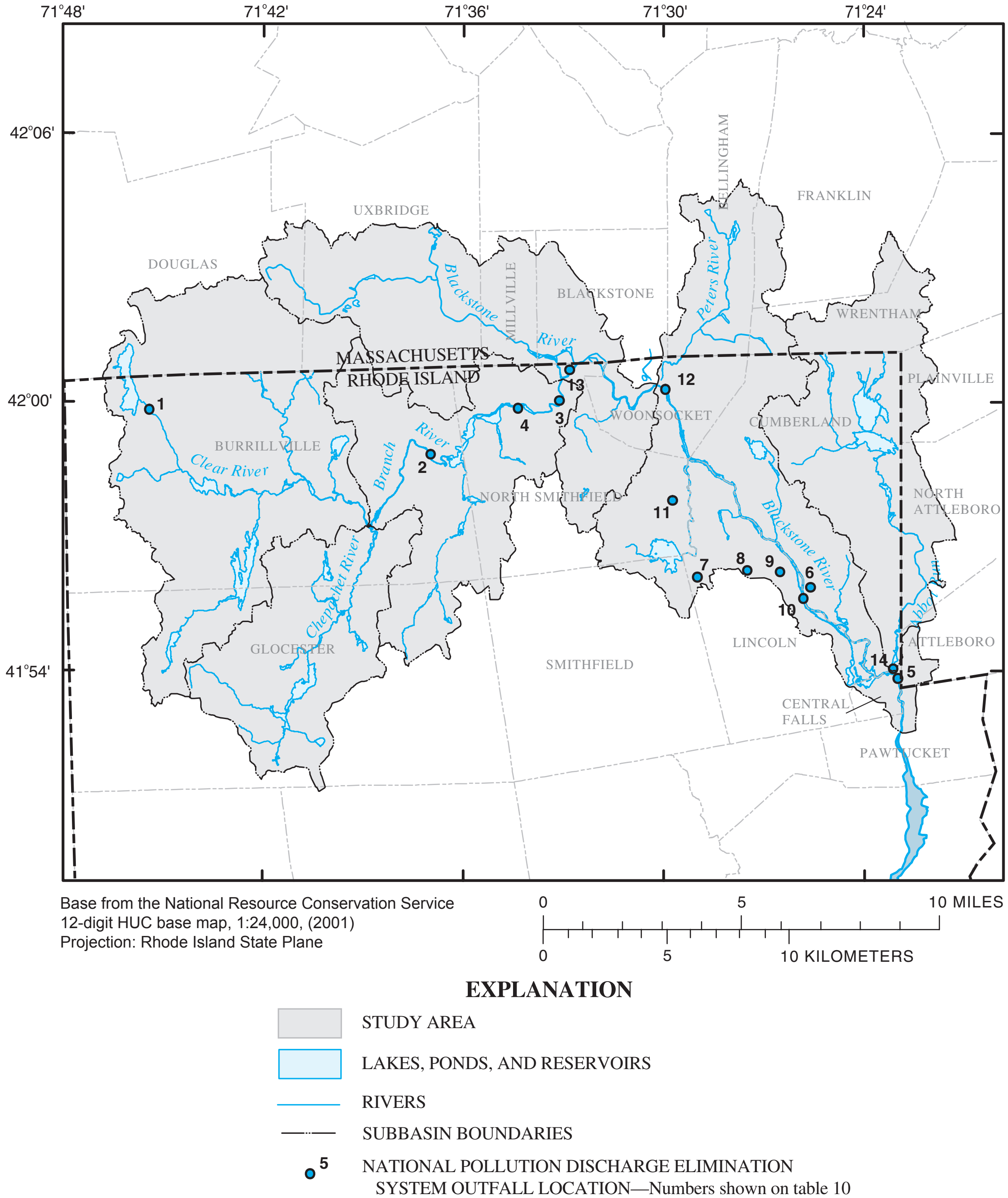

Figure 10. National Pollution Discharge Elimination System outfalls for commercial and industrial facilities within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

Public-disposal of domestic wastewater was calculated for the lower Blackstone River basin from estimated populations on public disposal for each town (Medalie, 1995) adjusted for population changes from 1995 through 1999, multiplied by water use per capita minus consumptive use (eq. 1). Public disposal of commercial wastewater was calculated from the total commercial-use rates for the town minus the estimated consumptive-use rates and NPDES return flows for commercial facilities (eq. 2). Public disposal of industrial wastewater was calculated in the same manner as public disposal of commercial wastewater (eq. 3). Infiltration and inflow was estimated by subtracting the sum of all public-disposal wastewater estimates from the reported discharge rates at the municipal wastewater-treatment facilities (eq. 4).:

$$PDWW_{Dom} = PD_{pop} * (WU_{per\ capita} - (0.15 WU_{per\ capita})), \quad (1)$$

$$PDWW_{Com} = WU_{Com} - 0.10 WU_{Com} - NPDES_{Com}, \quad (2)$$

$$PDWW_{Ind} = WU_{Ind} - 0.10 WU_{Ind} - NPDES_{Ind}, \quad (3)$$

and

$$I/I = NPDES_{Mun} - (PDWW_{Dom} + PDWW_{Com} + PDWW_{Ind}), \quad (4)$$

where

$PDWW_{Com}$ = public-disposal wastewater commercial,
$PDWW_{Dom}$ = public-disposal wastewater domestic,
$PDWW_{Ind}$ = public-disposal wastewater industrial,
PD_{pop} = population on public-disposal,
$WU_{per\ capita}$ = water use per capita (per person),
WU_{Com} = commercial water use,
WU_{Ind} = industrial water use,
$NPDES_{Com}$ = metered National Pollution Discharge Elimination System return flows for commercial sites,
$NPDES_{Ind}$ = metered National Pollution Discharge Elimination System return flows for industrial sites,
$NPDES_{Mun}$ = metered National Pollution Discharge Elimination System return flows for municipal wastewater-treatment facilities, and
I/I = infiltration and inflow.

Wastewater Imports and Exports

The estimated amount of public wastewater collected from the lower Blackstone River basin was 10.121 Mgal/d (table 11). When a municipal wastewater-treatment facility collects wastewater from outside of the subbasin, this wastewater is considered imported. Average wastewater imports ranged from 0.000 Mgal/d in the Chepachet, Branch, and Abbott Run subbasins to 4.734 Mgal/d in the Peters River subbasin. Average wastewater imports for the lower Blackstone River basin were estimated at 1.818 Mgal/d (table 11).

When a municipal wastewater-treatment facility discharges wastewater outside of a subbasin but serves sections of town(s) within that subbasin, these discharges are considered wastewater exports. That is, they will be exported from the subbasin and treated at a wastewater-treatment facility outside the subbasin. Average wastewater exports ranged from 0.038 Mgal/d in the Clear River subbasin to 3.467 Mgal/d in the Peters River subbasin. Average total wastewater exports for the lower Blackstone River basin were 4.086 Mgal/d.

Infiltration and Inflow Estimates

Infiltration and Inflow (*I/I*) is water that enters the sewer system through indirect and direct means. Infiltration is extraneous water that enters the sewer system through leaking joints, cracks and breaks, or porous walls. Inflow is stormwater that enters the sewer system from storm-drain connections (catch basins), roof leaders, foundation and basement drains, or through manhole covers (Metcalf and Eddy, 1991).

The Burrillville WWTF in the Clear River subbasin provided wastewater-flow data by use type (John E. Martin, III, Superintendent, Burrillville WWTF, written commun., 2000) and was estimated to receive 0.000 Mgal/d of infiltration and inflow. The Uxbridge WWTF in the West River subbasin was estimated to receive 0.268 Mgal/d of infiltration and inflow, which was about 37 percent of total metered NPDES discharge from the municipal wastewater-treatment facility. The Woonsocket WWTF in the Peters River subbasin was estimated to receive 2.639 Mgal/d of infiltration and inflow, which is about 30 percent of the total metered NPDES discharged from the municipal wastewater-treatment plant (table 11).

Table 11. Public disposal (estimated and metered) of wastewater, including imports, exports, and infiltration and inflow, self-disposal (on-site septic estimates and metered), and total return flows for the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[Numbers may not sum correctly due to rounding errors. All values in million gallons per day. Italicized values indicate an import or export out of the study area. **Wastewater collected within subbasin:** Public-disposal estimates were made by equations 1-3 in the “Public disposal” section of this report. **Infiltration/Inflow:** Infiltration and inflow was estimated by equation 4 in the “Public disposal” section of this report. **Total wastewater return flow:** Wastewater return flow is the sum of self-disposal (onsite septic and NPDES commercial and industrial sites) and NPDES metered discharge for municipal WWTFs. COM, commercial; IND, industrial; NPDES, National Pollution Discharge Elimination System; WWTF, wastewater-treatment facility; <, actual value is less than value shown; --, not applicable]

Minor civil division	Estimated Public-disposal				Metered NPDES municipal WWTF discharge	Self-disposal		Total wastewater return flow
	Wastewater collected within subbasin	Imports	Exports	Infiltration/ Inflow		Onsite septic	Metered NPDES (COM and IND)	
Lower Blackstone River basin								
Chepachet River subbasin								
Burrillville	0.076	--	0.076	--	--	0.067	0	0.067
Glocester	--	--	--	--	--	.198	0	.198
Subtotal	0.076	--	0.076	--	--	.266	0	.266
Clear River subbasin								
Burrillville	.656	0.231	0	0	0.812	.224	.105	1.141
Glocester	--	--	--	--	--	.049	0	.049
Douglas	.031	--	.031	--	--	.067	0	.067
Uxbridge	.007	--	.007	--	--	.014	0	.014
Subtotal	0.694	0.231	.038	0	0.812	0.354	0.105	1.271
Branch River subbasin								
Burrillville	.063	--	.063	--	--	.201	.006	.207
Glocester	--	--	--	--	--	.206	0	.026
North Smithfield	.182	--	.182	--	--	.204	.004	.208
Smithfield	.001	--	.001	--	--	.002	0	.002
Millville	--	--	--	--	--	.006	0	.006
Uxbridge	.004	--	.004	--	--	.004	0	.004
Subtotal	0.249	--	0.249	--	--	0.443	0.01	0.453
West River subbasin								
Burrillville	.002	--	.002	--	--	.027	0	.027
North Smithfield	.16	--	.16	--	--	.114	.004	.114
Woonsocket	3.1935	--	3.1935	--	--	.145	0	.145
Blackstone	.077	--	.077	--	--	.152	0	.152
Douglas	.009	--	.009	--	--	.014	0	.014
Millville	--	--	--	--	--	.128	0	.128
Uxbridge	.108	[1].347	--	.268	.723	.116	0	.839
Subtotal	3.55	0.347	3.442	0.268	0.723	0.696	0.004	1.419
Peters River subbasin								
Central Falls	.771	--	.771	--	--	.022	.247	.269
Cumberland	1.084	--	1.084	--	--	.279	.157	.436
Lincoln	.795	--	.795	--	--	.168	.173	.341
North Smithfield	.028	.353	--	.204	.585	.06	.013	[2].073
Pawtucket	.55	--	.55	--	--	0	0	0
Smithfield	.061	--	.061	--	--	.023	0	.023
Woonsocket	1.417	[3,4,5]4.229	--	2.435	8.081	.046	.186	9.096
Attleboro	.127	--	.127	--	--	.155	0	.155
Bellingham	.054	0	--	0	.049	.296	0	[2].296

Table 11. Public disposal (estimated and metered) of wastewater, including imports, exports, and infiltration and inflow, self-disposal (onsite septic estimates and metered), and total return flows for the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99—Continued

Minor civil division	Estimated Public-disposal				Metered NPDES municipal WWTF discharge	Self-disposal		Total wastewater return flow
	Wastewater collected within subbasin	Imports	Exports	Infiltration/ Inflow		Onsite septic	Metered NPDES (COM and IND)	
Peters River subbasin—*Continued*								
Blackstone	0.006	0.152	--	0	0.149	0.003	0	[2]0.003
Franklin	.073	--	0.073	--	--	.032	0	.032
Wrentham	--	--	--	--	--	.031	0	.031
Subtotal	4.968	4.734	3.467	2.639	8.86	1.114	0.776	10.782
Abbott Run subbasin								
Cumberland	.407	--	.407	--	--	.439	.269	.439
Attleboro	.026	--	.026	--	--	.016	0	.016
Franklin	.027	--	.027	--	--	.016	0	.016
North Attleboro	.093	--	.093	--	--	.156	0	.156
Plainville	.03	--	.03	--	--	.025	0	.025
Wrentham	--	--	--	--	--	.135	0	.135
Subtotal	0.583	--	0.583	--	--	0.787	0.269	1.429
Total of the lower Blackstone River basin	10.121	1.818	4.086	2.907	10.395	3.66	1.164	15.219

[1]0.336 Mgal/d of the 0.347 Mgal/d imported for public-disposal is from outside the study area.

[2]Wastewater is conveyed to the Woonsocket WWTF therefore, publicly collected wastewater return flow is reported on the Woonsocket line under wastewater return flow.

[3]Includes an estimated 1.854 Mgal/d of wastewater collected from the Seville/Dorado Company, textile mill (Adel Banoub, Woonsocket WWTF, written commun., 2003).

[4]Includes an estimated 0.294 Mgal/d of wastewater imported to the subbasin from the dewatering process of a sludge merchant, Synagro, (Adel Banoub, Woonsocket WWTF, written commun., 2003).

[5]1.036 Mgal/d of the 4.229 Mgal/d imported for public-disposal is from outside the study area.

Wastewater discharge from municipal wastewater-treatment facilities in the lower Blackstone River basin ranged from 0.723 Mgal/d in the West River subbasin to 8.860 Mgal/d in the Peters River subbasin. There are no municipal wastewater-treatment facilities in the Chepachet, Branch, and Abbott Run subbasins (table 11).

Self-Disposal

Of the 19 municipalities included in this study, only Glocester, RI, and Wrentham and Millville, MA, entirely self-dispose of their wastewater. The 5-year average rate of self-disposal for the lower Blackstone River basin, including disposal from commercial and industrial NPDES discharge sites was 4.824 Mgal/d. An estimated 3.660 Mgal/d, or 76 percent, was self-disposed through on-site septic and the remaining 1.164 Mgal/d, or 24 percent, was discharged by commercial and industrial NPDES facilities (tables 10 and 11).

Total Return Flows

Wastewater-return flows by subbasin, including self-disposal and public disposal, indicate that the Clear River and Peters River subbasins have a net gain of wastewater. The remaining subbasins in the lower Blackstone River basin have a net loss of wastewater (imports minus exports). Total return flow of wastewater (public and self-disposal) ranged from 0.266 Mgal/d in the Chepachet River subbasin to 10.782 Mgal/d in the Peters River subbasin (table 11).

Water-Use Summary

Total withdrawals for the lower Blackstone River basin for the period 1995-99 were 29.869 Mgal/d (table 12). The 5-year average withdrawal rates ranged from 0.414 Mgal/d in the Chepachet River subbasin to 15.221 Mgal/d in the Abbott Run subbasin. A net export

Table 12. Summary of estimated water withdrawals, imports, exports, use, non-account use, consumptive use, and return flow in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[Numbers may not sum correctly due to rounding. All values in million gallons per day. **Net import or export:** +, imports to subbasin and basin; -, exports from subbasin and basin. AG, agricultural; COM, commercial; DOM, domestic; IND, industrial; Mgal/d, --, million gallons per day; water use not applicable]

Subbasin	Water withdrawals (public and self)	Net import (+) or export (-) of potable water	Water use (public and self)			Return Flow		Net import (+) or export (-) of wastewater
			DOM, COM, IND, AG	Non-account (public use)	Consump-tive use	Surface water	Ground water	
Chepachet River	0.414	0.002	0.409	0.007	0.079	0.000	0.266	-0.086
Clear River	1.093	2.415[1]	3.451	.058	2.557[2]	.917	.354	0.193
Branch River	.864	-.002	.841	.022	.111	.010	.443	-0.249
West River to Peters River	5.049[3]	.042	4.843	.252	.582	.727	.696	-3.095
Peters River to mouth	7.226	.902	7.178	.944	.949	9.636	0.787	-1.267
Abbott Run	15.221	-12.839	1.799	.583	.254	.269	1.160	-0.583
Total of the study area	29.869	-9.475	18.522	1.867	4.532	11.559	3.660	-2.268

[1]Includes 2.379 Mgal/d imported from the West River subbasin for use at the Ocean State Power thermoelectric facility.

[2]Includes 2.379 Mgal/d consumed at the Ocean State Power thermoelectric facility.

[3]Includes 2.379 Mgal/d withdrawn by Ocean State Power and 2.039 Mgal/d withdrawn by Seville/Dorado.

of 9.475 Mgal/d of potable water for the lower Blackstone River basin was calculated. Net exports ranged from 0.002 Mgal/d in the Branch River subbasin to 12.839 Mgal/d in the Abbott Run Subbassin. Net imports of water ranged from 0.002 Mgal/d in the Chepachet River subbasin to 2.415 Mgal/d in the Clear River subbasin (2.379 Mgal/d was imported into the Clear River subbasin for use at the Ocean State Power thermoelectric facility).

Water use, including public and self-supply, for the lower Blackstone River basin was estimated at 18.522 Mgal/d (not including non-account use). Water use ranged from 0.409 Mgal/d in the Chepachet River subbasin to 7.178 in the Peters River subbasin. Non-account water use totaled 1.867 Mgal/d for the lower Blackstone River basin and ranged from 0.007 Mgal/d in the Chepachet River subbasin to 0.944 Mgal/d in the Peters River subbasin. Consumptive use for the lower Blackstone River basin was estimated at 4.532 Mgal/d and ranged from 0.079 Mgal/d in the Chepachet River subbasin to 2.557 Mgal/d in the Clear River subbasin (2.379 Mgal/d was consumed at the Ocean State Power thermoelectric facility).

Surface-water return flow consisted of wastewater discharged at NPDES outfall locations. The total for the lower Blackstone River basin was 11.559 Mgal/d and ranged from 0.000 Mgal/d in the Chepachet River subbasin to 9.636 Mgal/d in the Peters River subbasin. Ground-water return flow for the lower Blackstone River basin was estimated at 3.660 Mgal/d and ranged from 0.266 Mgal/d in the Chepachet River subbasin to 1.160 Mgal/d in the Abbott Run subbasin. Overall, wastewater was exported from the lower Blackstone River basin. Net exports of wastewater for the lower Blackstone River basin were estimated at 2.268 Mgal/d and ranged from 0.086 Mgal/d in the Chepachet River subbasin to 3.095 Mgal/d in the West River subbasin. The Clear River subbasin had a net import of wastewater at 0.193 Mgal/d. Withdrawals, use, and return flows for the lower Blackstone River basin are shown in figure 11.

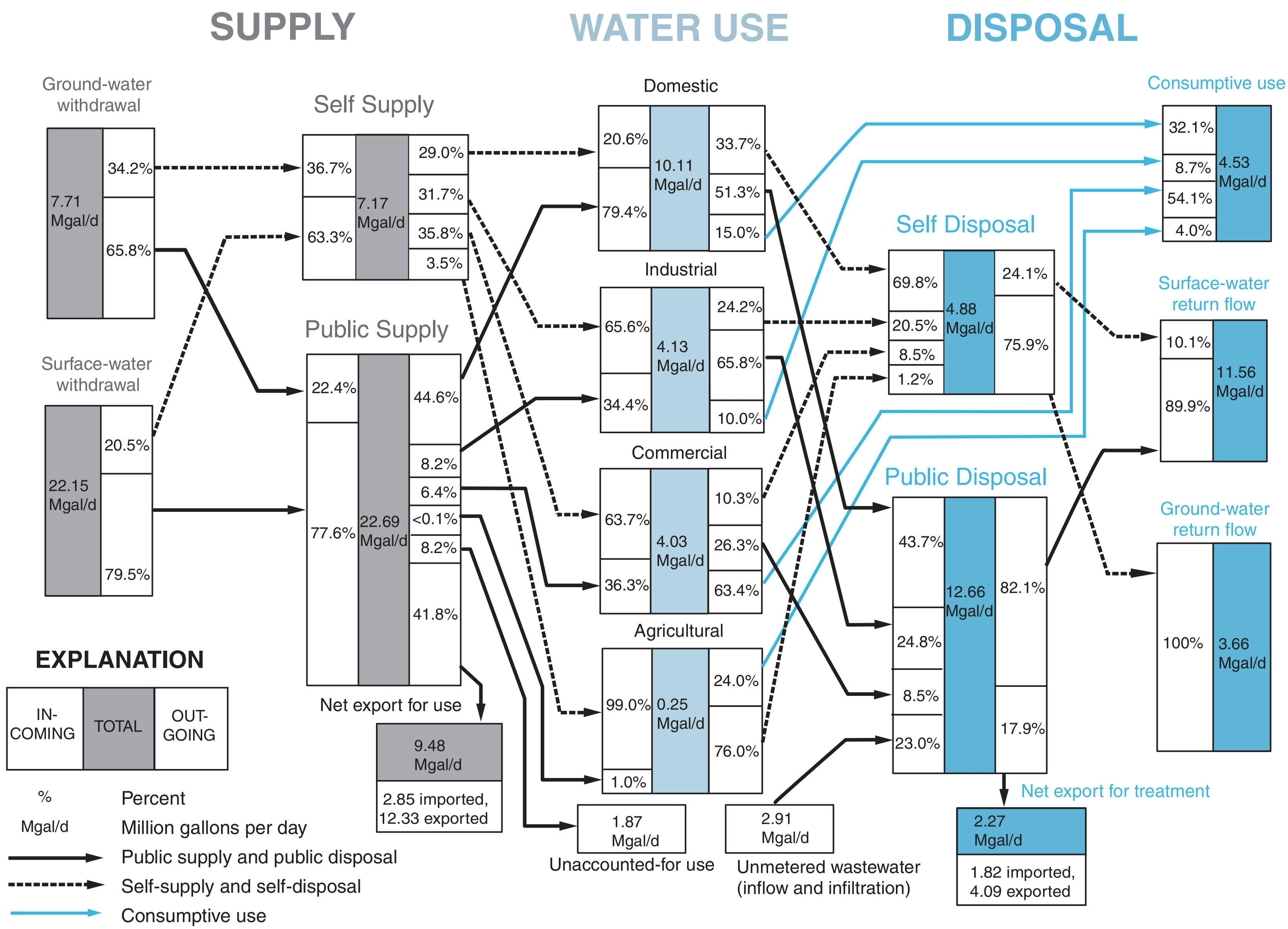

Figure 11. Water withdrawals (supply), use, and return flow (disposal) for the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

WATER AVAILABILITY

This section describes the methods used to estimate water availability within the lower Blackstone River basin. The availability of ground-water discharge (base flow) for the lower Blackstone River basin was determined for four months: June, July, August, and September (referred to as the low-flow period). This determination was made from U.S. Geological Survey long-term streamflow-gaging stations.

Base flow during the low-flow period was estimated for a reference site by the PART program developed by Rutledge (1998, 2000). Water-availability determinations described in this report include base-flow volumes determined by PART and safe-yield estimates for public-supply reservoirs within the lower Blackstone River basin. The safe-yield estimates for the Cumberland WD's Sneech Pond, the Pawtucket Water Supply Board's reservoir system, and the Woonsocket Water Division's Crookfall Brook Reservoirs no. 1 and no. 3 and Harris Pond were obtained from the respective municipal water departments' Water Supply Management Plans (Pare Engineering, 2000; Pawtucket Water Supply Board, 2000; and Camp, Dresser, and McKee, 1994). Harris Pond is outside the lower Blackstone River basin but supplies water to communities within the lower Blackstone River basin.

In addition, water availability was evaluated relative to withdrawals. Public- and self-supply withdrawals were divided by water-availability determinations for ground and surface water. The ratio of withdrawals to availability gives an indication of relative subbasin stress within the lower Blackstone River basin.

Streamflow depletions by ground-water withdrawals for six supply wells within the lower Blackstone River basin were analyzed with STRMDEPL, a program developed by Barlow (2000). These wells are in aquifers with different properties and are at different distances from nearby streams.

Streamflow-Gaging Stations Used in Analysis

The USGS has collected data for decades at three streamflow-gaging stations in the Blackstone River basin in Rhode Island (Socolow and others, 2000). These stations include the Nipmuc River near Harrisville, RI (01111300); the Branch River at Forestdale, RI (01111500); and the Blackstone River at Woonsocket, RI (01112500) (fig. 3, table 13). Each station was examined for possible use as a reference gaging station to estimate base flow for each of the six subbasins within the lower Blackstone River basin. From this group of stations, the Branch River at Forestdale, RI (01111500), was selected as the best reference station for the base-flow calculations. The overall saturated thickness of sand and gravel deposits within the drainage area associated with this station is representative of the other deposits in the lower Blackstone River basin. In addition, discharge records at this site are rated as fair. Currently, flows at the Forestdale station have occasional minor regulation from an upstream pond. Prior to 1957, there was greater regulation (Socolow and others, 2000); for this reason, only discharge records from the calendar years 1957–99 were used for analysis.

To normalize flows between the different subbasins in the lower Blackstone River basin, the areal extent of sand and gravel deposits upstream of the Forestdale station was determined with the MassGIS basin tools and a coverage of sand and gravel deposits.

Table 13. U.S. Geological Survey streamflow-gaging stations in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts

[**Latitude and longitude**: In degrees, minutes, and seconds. No., number; USGS, U.S. Geological Survey; mi^2, square mile]

USGS station No.	Name	Latitude ° ′ ″	Longitude ° ′ ″	Period of record (years)	Drainage area (mi^2)
1111300	Nipmuc River near Harrisville, RI	41 58 52	71 41 11	33	16
1111500	Branch River at Forestdale, RI	41 59 47	71 33 47	59	91.2
1112500	Blackstone River at Woonsocket, RI	42 00 22	71 30 13	70	416

Method Used to Estimate Base-Flow Volumes

This section describes the method (Rutledge, 1998 and 2000) used to calculate base flow in the lower Blackstone River basin. On the basis of this method and two minimum streamflow criteria (the 7-day, 10-year low flow [7Q10, Socolow and others, (2000)] and Aquatic Base Flow [ABF, U.S. Fish and Wildlife Service, (1981)], available base-flow volumes for the low-flow period were calculated.

The computer programs RECESS and PART (Rutledge, 1998) were used to estimate ground-water discharge (base flow) for the Branch River at Forestdale during the low-flow period. RECESS uses input data generated from long-term streamflow-gaging records stored in the USGS Automated Data Processing System (ADAPS) to calculate the master recession constant (K). The K value calculated by the RECESS program at the Branch River at Forestdale was 30.9 days per log cycle for calendar years 1957–99.

The K value is input into the PART program, which calculates base flow. Output from PART is given as daily, monthly, and quarterly streamflow and base flow in inches. Base flow from PART was then converted to a flow rate by using the drainage area for the Forestdale station. To estimate available base flow, the 7Q10 and ABF were subtracted from the monthly base-flow volumes calculated for the period 1957-99. The 7Q10 is 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 (Socolow and others, 2000). The 7Q10 is commonly used to assess the capacity of a river to carry pollutants (Kliever, 1996). The 7Q10 calculated for the Forestdale streamflow-gaging station was 11.9 ft^3/s (7.9 Mgal/d), which corresponds to the 99.5-percent flow duration. Aquatic Base Flow, an alternative minimum streamflow criterion, is often set at 0.5 $ft^3/s/mi^2$ of drainage area when no discharge records are available; however, when discharge records are available, it can be calculated as the median of the August daily means or the median of the August monthly means (Ries, 1997). The ABF is considered the minimum streamflow necessary to protect indigenous aquatic fauna throughout the year (U.S. Fish and Wildlife, 1981). The ABF for the Forestdale station was calculated as the median of the August monthly means for 1957 through 1999. The ABF was 38.8 ft^3/s (25.1 Mgal/d), which corresponds to the 83.6-percent flow duration.

All values of available base flow for the 42 years of interest were plotted by month and minimum streamflow criterion (fig. 12). On the basis of the ABF criterion, the base flow at the Branch River at Forestdale was below the ABF about 66 percent of the time in August, 55 percent of the time in September, 46 percent of the time in July, and 6 percent of the time in June for the period 1957–99 (fig. 12). Water-availability estimates made from base-flow calculations are conservative estimates because actual streamflows are generally greater than base flow except for periods of no recharge.

Available base-flow volumes at the Branch River at Forestdale station decrease from June to August and then increase slightly in September (fig. 12). In addition, the range in available base-flow volumes decreases as the summer progresses. This may be due to the larger variability in precipitation volumes in June compared to the other months of the low-flow period. Available base-flow volumes calculated at the 50th percentile with the 7Q10 criterion ranged from 1,180 Mgal (about 39.3 Mgal/d) in June to 428 Mgal (about 13.8 Mgal/d) in August. The available base-flow volume calculated with the ABF criterion ranged from 658 Mgal (about 21.9 Mgal/d) in June to 0 Mgal in August and September. This means that base flow at the 50th percentile was below the ABF in August and September (table 14).

Safe-Yield Analysis for Public-Supply Reservoirs

Safe-yield analyses for the surface-water reservoirs within the lower Blackstone River basin have been done by consulting firms and reported in the municipal water departments' Water Supply Management Plans (Pare Engineering Corporation, 2000; Pawtucket Water Supply Board, 2000; Camp, Dresser, and McKee, 1994). Safe-yield analyses for the Pawtucket WSB and the Woonsocket WD were based on the drought of record for Rhode Island during 1964–66. The drought used to calculate the Cumberland WD safe-yield estimate for Sneech Pond was not identified in the Water Supply Management Plan (Pare Engineering Corporation, 2000); however, safe-yield determinations are often based on the routing of streamflows for the selected period through the water-supply system (Camp, Dresser, and McKee, 1994).

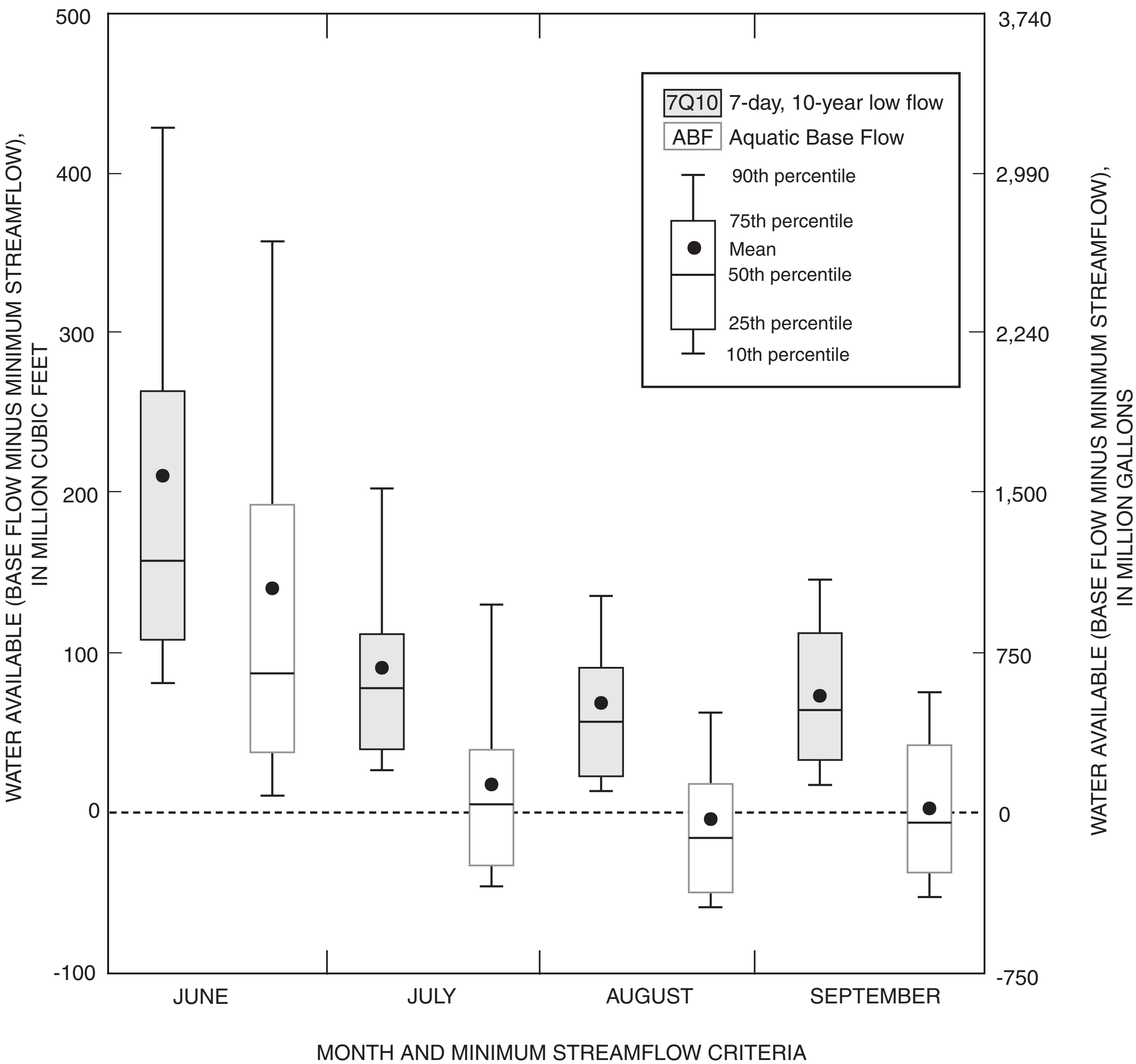

Figure 12. Available base flow calculated as base flow minus minimum streamflow determined by two criteria, the 7-day, 10-year low flow (7Q10) and Aquatic Base Flow (ABF), for June, July, August, and September for the period 1957–99 at the streamflow-gaging station at the Branch River at Forestdale, Rhode Island (U.S. Geological Survey station number 01111500).

Table 14. Available base-flow volumes calculated at the 50th percentile by the PART program minus minimum streamflows determined by two criteria, the 7-day 10-year low flow and the Aquatic Base Flow, for the Branch River at Forestdale (01111500) for June, July, August, and September for the period 1957–99

[7Q10, 7-day 10-year low flow; ABF, Aquatic Base Flow; Mgal, million gallons; Mft^3, million cubic feet]

Minimum flow criteria	Available base flow in Mgal (Mft^3)				Minimum flow criteria	Available base flow in Mgal (Mft^3)			
	June	July	August	September		June	July	August	September
7Q10	1,180 (158)	586 (78)	428 (57)	483 (65)	ABF	658 (88)	47 (6)	0 (0)	0 (0)

Safe-yield estimates for the three municipal water suppliers with surface-water reservoirs range from 0.75 to 16 Mgal/d (table 15). The safe yield of the Cumberland WD's Sneech Pond was estimated at 0.75 Mgal/d. The combined safe yield of the Woonsocket WD's Crookfall Brook Reservoirs was estimated at 3.5 Mgal/d, and the Harris Pond Reservoir safe yield was estimated at 4.4 Mgal/d. The largest surface-water safe yield was within the Pawtucket WSB's reservoir system and was estimated at 16 Mgal/d. These safe-yield estimates were compared to the 5-year average demand. The results show that 5-year average withdrawals from Sneech Pond and the Crookfall Brook Reservoirs are greater than the safe-yield estimates. In contrast, withdrawals from the Pawtucket WSB's reservoir system and the Woonsocket WD's Harris Pond are 75.1 and 6.7 percent of their safe-yield estimates, respectively (table 15).

Table 15. Safe-yield estimates and 5-year average demand for surface-water reservoirs of three municipal water suppliers in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[WD, water department; WDIV, water division; WSB, water supply board; Mgal/d, million gallons per day]

Municipal water supplier	Source	Safe yield (Mgal/d)	5-year average demand (Mgal/d)	Percent of safe yield
Lower Blackstone River Basin				
Peters River subbasin				
Cumberland WD	Sneech Pond	0.75	0.837	111.6
Woonsocket WDIV	Crookfall Brook Reservoirs No. 1 and 3	3.5	4.759	136
Abbott Run subbasin				
Pawtucket WSB	Diamond Hill, Arnolds Mills, Robin Hollow Pond, and Happy Hollow Reservoirs	16	12.017	75.1
Outside the lower Blackstone River basin				
Mill River subbasin				
Woonsocket WDIV	Harris Pond	4.4	0.293	6.7

Evaluation of Water Availability and Basin Stress

Water availability in the six subbasins of the lower Blackstone River basin was evaluated for the low-flow period. Water availability as described in this report is the sum of available base-flow and safe-yield estimates.

A regression equation relating the percent area of sand and gravel deposits to the percent contribution of base flow from sand and gravel was developed for six streamflow-gaging stations in the Pawcatuck River basin in Rhode Island (P.J. Zarriello, U.S. Geological Survey, written commun., 2003). Based on this equation, 60 percent of base flow at the Forestdale station in Rhode Island would be from sand and gravel deposits and the remaining 40 percent would be from till deposits. Johnston and Dickerman (1974a) reported that, on average, about 78 percent of the base flow in the Branch River subbasin was assumed to be from sand and gravel deposits and the remaining 22 percent from till. Based on these two sources of information, the median base flow during the low-flow period ranges from 0.958 to 1.242 $ft^3/s/mi^2$ (0.619 to 0.803 $Mgal/d/mi^2$) for sand and gravel deposits and 0.163 to 0.293 $ft^3/s/mi^2$ (0.105 to 0.189 $Mgal/d/mi^2$) for till deposits.

The analysis presented in this report is based on the results of the regression equation and estimates that 60 percent of base flow is from sand and gravel (0.619 $Mgal/d/mi^2$) and 40 percent is from till (0.189 $Mgal/d/mi^2$). Although the Johnston and Dickerman (1974a) results may be attributable to the thinner till deposits in the Branch River basin as compared to those in the Pawcatuck River basin, methods for estimating flow from till have evolved over the years and therefore the regression equation developed for the streamflow-gaging stations in the Pawcatuck River basin was used to estimate the contribution from each aquifer type.

To estimate available base flow by subbasin, the available base flow calculated at the Forestdale streamflow-gaging station per square mile of sand and gravel deposits and till deposits was multiplied by the area of the respective deposits in each subbasin (table 16). The drainage area for the Forestdale station is composed of about 28.7 mi^2 of sand and gravel deposits and about 62.5 mi^2 of till deposits. Upstream subbasins were not considered in the available base-flow calculations used in the relative-stress ratios, because withdrawal data were not available for all upstream areas.

Water withdrawals and return flows for the Chepachet, Clear, and Branch River subbasins, which compose about 98 percent of the drainage area to the Branch River station at Forestdale, were evaluated for any

Table 16. Area of sand and gravel and till deposits and percent of sand and gravel deposits within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts

[SGD, sand and gravel deposits; mi^2, square miles]

Subbasin	Area (mi^2)			
	Subbasin	SGD in subbasin	Till in subbasin	Percent of sand and gravel deposits in subbasin
Chepachet	21.3	8.6	12.7	40.4
Clear	45.5	10.4	35.1	22.8
Branch	26.3	10.2	16.2	38.8
West River to Peters River	34.6	12.5	22.1	36.1
Peters River to mouth	43.1	15.5	27.6	36
Abbott Run	27.3	7	20.3	25.6
Study area	198.1	64.2	133.9	32.4

anthropogenic factors that might influence base flow at the station. During the study period 2.371 Mgal/d of water was withdrawn (table 5) and 1.990 Mgal/d returned through on-site septic and the municipal wastewater-treatment facilities (table 11) during 1995–99; these values represent a net loss of 0.381 Mgal/d. This net loss is less than 3 percent of the median base flow at the station for August. For this reason, anthropogenic factors were considered to have a negligible affect on base flow.

Median water availability for each subbasin was calculated for the low-flow period by subtracting the 7Q10 and ABF from base-flow estimates and adding safe-yield estimates for public-supply reservoirs (table 17 and fig. 13). These estimates indicate that Abbott Run subbasin has the largest volume of available water and the Chepachet River subbasin had the smallest volume of available water (table 17). Water-availability estimates were calculated at the 14-digit HUC level; interpolation of this data to smaller areas may overestimate or underestimate availability.

The medians of the available water volumes estimated for June were larger than for any other summer month: 106.8 Mgal/d (7Q10) and 68.5 Mgal/d (ABF). The median based on the ABF criterion was about 64 percent of the available volume based on the 7Q10 criterion. The medians based on the 7Q10 criterion for July, August, and September were about 58, 47, and 52 percent of the corresponding volume estimated for June. The median based on the ABF criterion for July was about 34 percent of the volume estimated in June. In August and September, median base flow calculated by PART was less than the ABF; however, estimates indicated that water was available from surface-water safe yield.

In addition to the medians of available water estimates, the 75th and 25th percentiles for available water estimates for each subbasin and the lower Blackstone River basin were calculated (table 17) to provide a range of values over the low-flow period to aid in management of water resources within the basin. Because the month of August has the lowest base flow, median results for August are highlighted to illustrate the stresses that the basin is likely to undergo in a typical year. Due to the fact that the ABF criterion is higher than the calculated base flow at the 50th percentile in August, results presented use the 7Q10 as the minimum streamflow criterion.

Overall, water availability for the lower Blackstone River basin ranges from 42.4 Mgal/d to 181.8 Mgal/d in June, 20.2 Mgal/d to 96.7 Mgal/d in July, 20.2 Mgal/d to 85.5 Mgal/d in August, and 20.2 Mgal/d to 97.5 Mgal/d in September (table 17). Estimated yields from sand and gravel deposits and till deposits are presented in table 18.

To evaluate basin stress by subbasin, the average monthly withdrawal volumes from surface- and ground-water by subbasin for the period 1995–99 (table 19) were divided by estimates of available water (table 17):

$$R = \frac{W(G+S)}{BF + \Sigma S}, \qquad (5)$$

where

R = basin-stress ratio (when ratio equals 1, withdrawals equal available water),

$W(G+S)$ = the sum of the 5-year average monthly withdrawals (W) from ground (G) and surface (S) water for the low-flow period within the subbasin,

BF = base-flow estimates based on the Branch River at Forestdale streamflow-gaging station, and

ΣS = the sum of safe-yield estimates for all the surface-water systems in the subbasin.

Table 17. Summary of water availability, defined as base flow plus safe-yield estimates, for June through September in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1957–99

[All values in million gallons per day. 7Q10, 7-day 10-year low flow; ABF, Aquatic Base Flow; Mgal/d, million gallons per day]

Subbasin	Percentile of base flow			Percentile of base flow minus the 7Q10			Percentile of base flow minus the ABF		
	75th	50th	25th	75th	50th	25th	75th	50th	25th
June									
Chepachet River	19.2	12.3	9.2	17.2	10.3	7.2	12.6	5.7	2.6
Clear River	32.4	20.8	15.57	29	17.4	12.1	21.3	9.7	4.4
Branch River	23.3	14.9	11.1	20.8	12.5	8.7	15.3	6.9	3.2
West River	29.7	19	14.2	26.6	15.9	11.1	19.5	8.9	4.1
Peters River	36.7	23.5	17.6	32.9	19.7	13.7	24.2	11	5
Abbott Run	20.3	13	9.7	18.2	10.9	7.6	13.3	6.1	2.8
Basin total[1]	181.8	123.7	97.5	164.9	106.8	80.6	126.6	68.5	42.4
July									
Chepachet River	9.1	6.9	4.5	7.1	4.9	2.5	2.5	0.4	0
Clear River	15.3	11.7	7.7	12	8.3	4.3	4.3	0.7	0
Branch River	11	8.4	5.5	8.6	6	3.1	3.1	0.5	0
West River	14	10.7	7	10.9	7.6	3.9	3.9	0.6	0
Peters River	17.4	13.3	8.7	13.6	9.5	4.9	4.8	0.8	0
Abbott Run	9.6	7.3	4.8	7.5	5.2	2.7	2.7	0.4	0
Basin total[1]	96.7	78.7	58.5	79.8	61.8	41.6	41.6	23.6	20.2
August									
Chepachet River	7.7	5.6	3.5	5.7	3.6	1.5	1.2	0	0
Clear River	13.1	9.5	5.9	9.7	6.1	2.5	2	0	0
Branch River	9.4	6.8	4.2	7	4.4	1.8	1.4	0	0
West River	12	8.7	5.4	8.9	5.6	2.3	1.8	0	0
Peters River	14.8	10.7	6.7	11	6.9	2.8	2.3	0	0
Abbott Run	8.2	5.9	3.7	6.1	3.8	1.5	1.3	0	0
Basin total[1]	85.5	67.5	49.5	68.6	50.6	32.6	30.3	20.2	20.2
September									
Chepachet River	9.2	6.2	4.2	7.2	4.2	2.2	2.6	0	0
Clear River	15.5	10.5	7.1	12.1	7.1	3.7	4.4	0	0
Branch River	11.1	7.5	5.1	8.7	5.1	2.7	3.2	0	0
West River	14.2	9.6	6.5	11.1	6.5	3.4	4.1	0	0
Peters River	17.6	11.9	8.1	13.7	8.1	4.2	5	0	0
Abbott Run	9.7	6.6	4.4	7.6	4.4	2.3	2.8	0	0
Basin total[1]	97.5	72.6	55.7	80.6	55.7	38.8	42.4	20.2	20.2

[1]Water-availability estimates for the basin include safe-yield estimates of 4.2 Mgal/d in the Peters River subbasin and 16.0 Mgal/d in the Abbott Run subbasin.

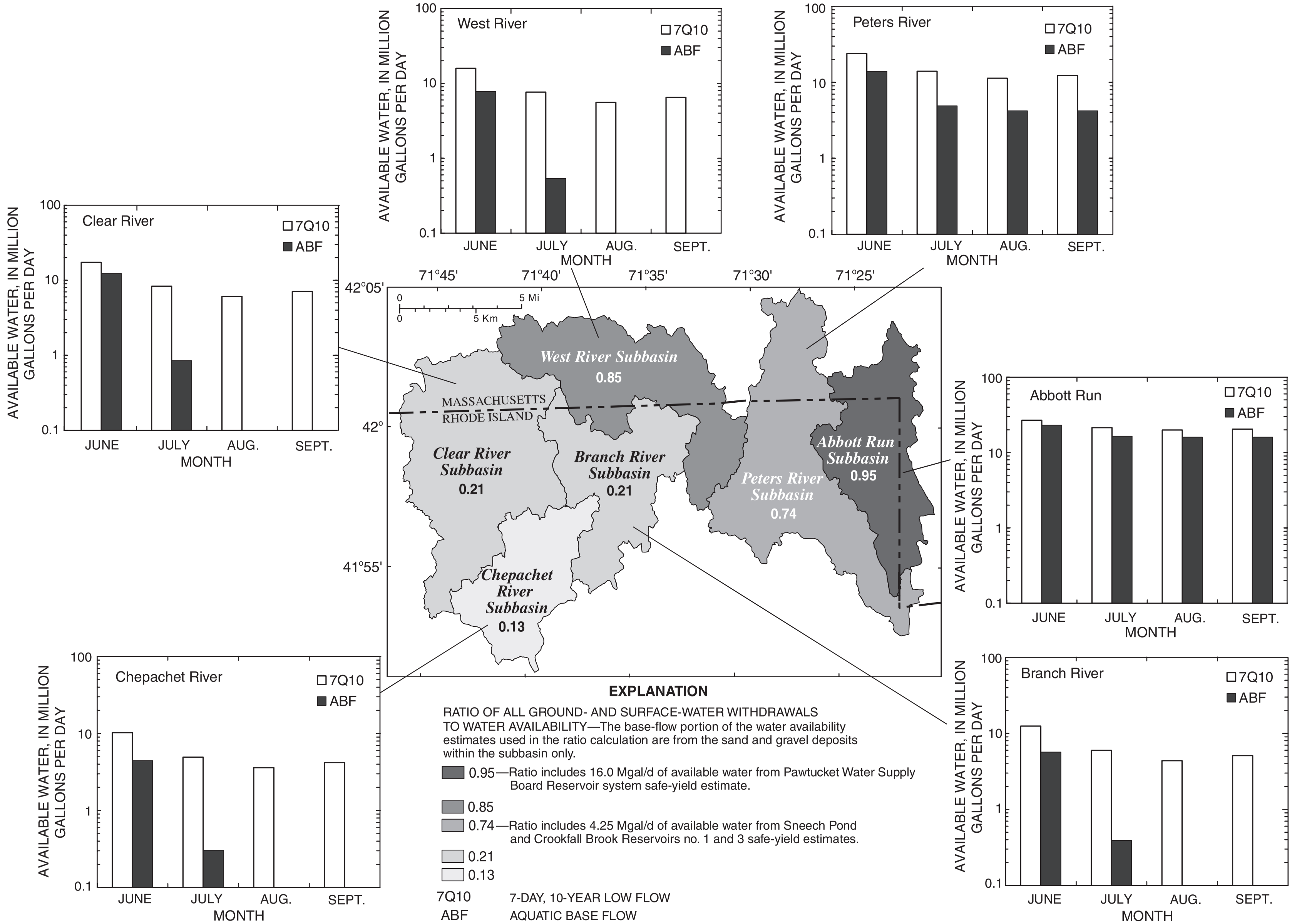

Figure 13. Subbasin stress indicated by the ratio of water withdrawals, 1995–99, to estimated water availability, 1957–99, during August; and graphs of water availability for June, July, August, and September for the six subbasins within the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts.

Table 18. Summary of water availability, defined as base flow by aquifer type plus safe yield, for June through September in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1957–99

[All values in million gallons per day. 7Q10, 7-day 10-year low flow; ABF, Aquatic Base Flow; Mgal/d, million gallons per day]

Subbasin	Percentile of base flow			Percentile of base flow minus the 7Q10			Percentile of base flow minus the ABF		
	75th	50th	25th	75th	50th	25th	75th	50th	25th
June									
Estimated Yields from Sand and Gravel Deposits									
Chepachet River	13.2	8.5	6.3	11.9	7.1	4.9	8.7	4	1.8
Clear River	15.9	10.2	7.6	14.3	8.5	6	10.5	4.8	2.2
Branch River	15.7	10	7.5	14	8.4	5.9	10.3	4.7	2.1
West River	19.3	12.3	9.2	17.3	10.3	7.2	12.7	5.8	2.6
Peters River	23.8	15.2	11.4	21.3	12.7	8.9	15.7	7.1	3.3
Abbott Run	10.7	6.9	5.1	9.6	5.8	4	7.1	3.2	1.5
Subtotal	98.6	63.2	47.2	88.3	52.8	36.9	64.9	29.5	13.5
Estimated Yields from Till Deposits									
Chepachet River	6	3.8	2.8	5.3	3.2	2.2	3.9	1.8	.8
Clear River	16.5	10.6	7.9	14.8	8.8	6.2	10.9	4.9	2.3
Branch River	7.6	4.9	3.6	6.8	4.1	2.8	5	2.3	1
West River	10.4	6.7	5	9.3	5.6	3.9	6.8	3.1	1.4
Peters River	13	8.3	6.2	11.6	6.9	4.8	8.5	3.9	1.8
Abbott Run	9.5	6.1	4.6	8.5	5.1	3.6	6.3	2.8	1.3
Subtotal	62.9	40.3	30.1	56.3	33.7	23.5	41.4	18.8	8.6
Basin total[1]	181.7	123.7	97.5	164.8	106.7	80.6	126.5	68.5	42.3
July									
Estimated Yields from Sand and Gravel Deposits									
Chepachet River	6.3	4.8	3.1	4.9	3.4	1.7	1.7	0.3	0
Clear River	7.5	5.8	3.8	5.9	4.1	2.1	2.1	.3	0
Branch River	7.4	5.7	3.7	5.8	4	2.1	2.1	.3	0
West River	9.1	7	4.6	7.1	5	2.5	2.5	.4	0
Peters River	11.3	8.6	5.6	8.8	6.1	3.1	3.1	.5	0
Abbott Run	5.1	3.9	2.5	4	2.8	1.4	1.4	.2	0
Subtotal	46.7	35.7	23.3	36.4	25.4	13	13	2	0
Estimated Yields from Till Deposits									
Chepachet River	2.8	2.2	1.4	2.2	1.5	.8	.8	.1	0
Clear River	7.8	6	3.9	6.1	4.2	2.2	2.2	.3	0
Branch River	3.6	2.8	1.8	2.8	2	1	1	.2	0
West River	4.9	3.8	2.5	3.8	2.7	1.4	1.4	.2	0
Peters River	6.1	4.7	3.1	4.8	3.3	1.7	1.7	.3	0
Abbott Run	4.5	3.4	2.3	3.5	2.5	1.3	1.3	.2	0
Subtotal	29.8	22.8	14.9	23.2	16.2	8.3	8.3	1.3	0
Basin total[1]	96.7	78.7	58.4	79.8	61.8	41.5	41.5	23.5	20.2

Table 18. Summary of water availability, defined as base flow by aquifer type plus safe-yield, for June through September in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1957–99—*Continued*

Subbasin	Percentile of base flow			Percentile of base flow minus the 7Q10			Percentile of base flow minus the ABF		
	75th	50th	25th	75th	50th	25th	75th	50th	25th
August									
Estimated Yields from Sand and Gravel Deposits									
Chepachet River	5.3	3.9	2.4	4	2.5	1	0.8	0	0
Clear River	6.4	4.7	2.9	4.8	3	1.2	1	0	0
Branch River	6.3	4.6	2.8	4.7	2.9	1.2	1	0	0
West River	7.8	5.6	3.5	5.8	3.6	1.5	1.2	0	0
Peters River	9.6	7	4.3	7.1	4.5	1.8	1.5	0	0
Abbott Run	4.3	3.1	1.9	3.2	2	.8	.7	0	0
Subtotal	39.8	28.8	17.9	29.5	18.5	7.5	6.1	0	0
Estimated Yields from Till Deposits									
Chepachet River	2.4	1.7	1.1	1.8	1.1	.5	.4	0	0
Clear River	6.7	4.8	3	4.9	3.1	1.3	1	0	0
Branch River	3.1	2.2	1.4	2.3	1.4	.6	.5	0	0
West River	4.2	3	1.9	3.1	2	.8	.6	0	0
Peters River	5.2	3.8	2.3	3.9	2.4	1	.8	0	0
Abbott Run	3.8	2.8	1.7	2.8	1.8	.7	.6	0	0
Subtotal	25.4	18.4	11.4	18.8	11.8	4.8	3.9	0	0
Basin total[1]	85.4	67.4	49.5	68.5	50.5	32.5	30.2	20.2	20.2
September									
Estimated Yields from Sand and Gravel Deposits									
Chepachet River	6.3	4.3	2.9	4.9	2.9	1.5	1.8	0	0
Clear River	7.6	5.2	3.5	6	3.5	1.8	2.2	0	0
Branch River	7.5	5.1	3.4	5.9	3.4	1.8	2.1	0	0
West River	9.2	6.2	4.2	7.2	4.2	2.2	2.6	0	0
Peters River	11.4	7.7	5.2	8.9	5.2	2.7	3.3	0	0
Abbott Run	5.1	3.5	2.4	4	2.4	1.2	1.5	0	0
Subtotal	47.2	31.9	21.6	36.9	21.6	11.3	13.5	0	0
Estimated Yields from Till Deposits									
Chepachet River	2.8	1.9	1.3	2.2	1.3	.7	.8	0	0
Clear River	7.9	5.3	3.6	6.2	3.6	1.9	2.3	0	0
Branch River	3.6	2.5	1.7	2.8	1.7	.9	1	0	0
West River	5	3.4	2.3	3.9	2.3	1.2	1.4	0	0
Peters River	6.2	4.2	2.8	4.8	2.8	1.5	1.8	0	0
Abbott Run	4.6	3.1	2.1	3.6	2.1	1.1	1.3	0	0
Subtotal	30.1	20.4	13.8	23.5	13.8	7.2	8.6	0	0
Basin total[1]	97.5	72.5	55.6	80.6	55.6	38.7	42.3	20.2	20.2

[1]Water-availability estimates for the basin include safe-yield estimates of 4.2 Mgal/d in the Peters River subbasin and 16.0 Mgal/d in the Abbott Run subbasin.

Table 19. Average water-withdrawal rates for the low-flow period in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1995–99

[All values in million gallons per day]

Subbasin	5-year average withdrawal rates for low-flow period			
	June	July	August	September
Chepachet River	0.487	0.508	0.462	0.372
Clear River	1.344	1.402	1.289	1.379
Branch River	.952	.981	.916	.817
West River	5.303	4.435	4.758	4.577
Peters River	8.638	8.763	8.245	7.349
Abbott Run	18.305	19.211	18.89	15.622
Basin total	35.029	35.3	34.56	30.116

The basin-stress ratio gives an indication of how much of a water resource is currently utilized in relation to its long-term availability. This ratio, calculated for the month of August at the 50th percentile minus the 7Q10 minimum flow, ranged from 0.13 in the Chepachet River subbasin to 0.95 in the Abbott Run subbasin (table 20 and fig. 13). Water-availability estimates and basin-stress ratios were calculated from subbasin to subbasin, which does not reflect the cumulative demand from upstream subbasins. Overall availability and basin stress for the lower Blackstone River basin as a whole is presented in tables 18 and 20. The Abbott Run subbasin had the highest level of subbasin stress. Water withdrawals in this subbasin provide water to two major suppliers: the Pawtucket WSB in Rhode Island and the North Attleboro WD in Massachusetts. The basin-stress ratio calculated for August for the entire lower Blackstone River basin at the 50th percentile minus the 7Q10 minimum flow was 0.68. That is, 68 percent of the available water calculated for a typical year is withdrawn from the lower Blackstone River basin in August, while the 7Q10 streamflow is maintained.

Overall, the basin-stress ratio for the lower Blackstone River basin ranges from 0.19 to 0.83 in June, 0.36 to 1.50 in July, 0.40 to 1.14 in August, and 0.31 to 0.78 in September (table 20). Basin-stress ratios based on the ABF minimum flow could not be calculated at the 25th percentile from July to September and at the 50th and 25th percentiles in August and September because base flow at these percentiles is less than the ABF minimum flow.

Streamflow Depletion by Ground-Water Withdrawals

The computer program STRMDEPL developed by Barlow (2000) was used to evaluate the effects of ground-water withdrawals on streamflow depletion. STRMDEPL calculates streamflow depletion caused by time-varying pumping at a well. The program is based on analytical solutions to the ground-water-flow equations developed by Jenkins (1968) and Hantush (1965). The solution of Jenkins (1968) assumes unimpeded connection between the stream and the aquifer, whereas that of Hantush (1965) accounts for resistance to flow at the boundary between the stream and aquifer caused by semipervious streambed and streambank materials. The following simplifying assumptions must be made in the application of the analytical solutions (Barlow, 2000):

1. The aquifer is isotropic, homogeneous, and semi-infinite in areal extent;
2. The transmissivity of the aquifer does not change with time. Thus, for a water-table aquifer, drawdown is considered to be negligible when compared to the initial saturated thickness of the aquifer;
3. The stream that forms a boundary to the aquifer is straight, fully penetrates the aquifer, and is in direct hydraulic connection with the aquifer;
4. The stage of the stream (and the ground-water head at the stream boundary) remains constant with time;
5. Water is released instantaneously from storage;
6. The well is open to the full saturated thickness of the aquifer; and
7. The pumping rate is steady during any period of pumping.

Two separate analyses were done for public-supply wells in the lower Blackstone River basin. In the first analysis, specified daily pumping rates were used to calculate streamflow depletion caused by the Cumberland WD's Manville well no. 1 during the 5-year period of study, 1995–99, on the basis of the Jenkins equation. In the second analysis, streamflow depletion caused by a constant pumping rate was calculated at six public-supply wells during 10-, 20-, and 30-day periods (table 21). The second analysis was done to simulate relative streamflow depletions during one month at wells in aquifers with different properties and at different distances to a nearby stream. Streamflow depletion caused by pumping at the six public-supply wells was calculated on the basis of the Jenkins equation for two of the wells and the Hantush equation for four of the wells.

Table 20. Summary of basin-stress ratios for June through September in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1957–99

[7Q10, 7-day 10-year low flow; ABF, Aquatic Base Flow; --, not applicable]

Subbasin	Percentile of available water			Percentile of available water minus the 7Q10			Percentile of available water minus the ABF		
	75th	50th	25th	75th	50th	25th	75th	50th	25th
June									
Chepachet River	0.03	0.04	0.05	0.03	0.05	0.07	0.04	0.08	0.19
Clear River	.04	.06	.09	.05	.08	.11	.06	.14	.3
Branch River	.04	.06	.09	.05	.08	.11	.06	.14	.3
West River	.18	.28	.37	.2	.33	.48	.27	.6	1.31
Peters River	.21	.31	.4	.23	.36	.48	.3	.57	.93
Abbott Run	.51	.63	.71	.54	.68	.78	.62	.83	.97
Basin total	0.19	0.28	0.36	0.21	0.33	0.43	0.28	0.51	0.83
July									
Chepachet River	.06	.07	.11	.07	.1	.2	.2	1.29	--
Clear River	.09	.12	.18	.12	.17	.33	.33	2.11	--
Branch River	.09	.12	.18	.11	.16	.32	.32	2.05	--
West River	.32	.41	.63	.41	.58	1.13	1.13	7.28	--
Peters River	.4	.5	.68	.49	.64	.96	.96	1.75	--
Abbott Run	.75	.82	.92	.82	.91	1.03	1.03	1.17	--
Basin total	0.36	0.45	0.6	0.44	0.57	0.85	0.85	1.5	--
August									
Chepachet River	.06	.08	.13	.08	.13	.31	.39	--	--
Clear River	.1	.14	.22	.13	.21	.52	.64	--	--
Branch River	.1	.13	.22	.13	.21	.52	.63	--	--
West River	.4	.55	.89	.54	.85	2.1	2.57	--	--
Peters River	.43	.55	.76	.54	.74	1.17	1.26	--	--
Abbott Run	.78	.86	.96	.86	.95	1.08	1.09	--	--
Basin total	0.4	0.51	0.7	0.5	0.68	1.06	1.14	--	--
September									
Chepachet River	.04	.06	.09	.05	.09	.17	.14	--	--
Clear River	.09	.13	.19	.11	.19	.37	.31	--	--
Branch River	.07	.11	.16	.09	.16	.31	.26	--	--
West River	.32	.48	.7	.41	.7	1.34	1.13	--	--
Peters River	.34	.46	.6	.41	.6	.87	.79	--	--
Abbott Run	.61	.69	.76	.66	.76	.85	.83	--	--
Basin total	0.31	0.42	0.54	0.37	0.54	0.78	0.71	--	--

Depletion in the Blackstone River caused by pumping at the Cumberland WD's Manville well no. 1 was analyzed with STRMDEPL on the basis of specified daily pumping rates for the period 1995-99 (1,826 days). The well is about 200 ft from the Blackstone River. The diffusivity of the aquifer is determined by dividing the transmissivity of the aquifer by the storativity or specific yield. The transmissivity of the aquifer near the Manville well was estimated as 12,000 ft^2/d and the specific yield was set at 0.28. The diffusivity (T/S) of the aquifer near the well was estimated to be 42,850 ft^2/d (0.50 ft^2/s) on the basis of the hydraulic properties of the aquifer in the lower Blackstone River basin given in Johnston and Dickerman (1974b). The streambed materials are coarse in the vicinity of the well (D.C. Dickerman, U.S. Geological Survey, oral commun., 2000); therefore, it was assumed that there would be no resistance to flow at the streambank caused by semipervious materials. As a result, the Jenkins equation was used to calculate streamflow depletion at the well.

Table 21. Selected public-supply wells, parameters used to calculate streamflow depletion with the program STRMDEPL, and streamflow depletion as a percentage of the well pumping rate at 10, 20, and 30 days after the start of pumping

[CWD, Cumberland Water Department; LWC, Lincoln Water Commission; WSB, Water Supply Board; ft, foot; ft^2/s, square feet per second]

Well name	Distance of supply well to stream (ft)	Diffusivity (ft^2/s)	Semipervious streambank material	Streambank leakance term (ft)	Streamflow depletion as a percentage of pumping rate		
					10 days	20 days	30 days
Not simulated							
CWD Manville well No.1	200	0.5	0	--	83	88	90
CWD Manville well No. 2	180	.5	0	--	85	89	91
Simulated							
LWC Lonsdale well No. 4	250	.87	1	225	70	79	82
Pawtucket WSB well No. 2	250	.54	1	557	47	59	65
Pawtucket WSB well No. 3	100	.54	1	557	56	66	71
Pawtucket WSB well No. 4	400	.54	1	557	39	52	59

The analytical solution presented in Jenkins (1968) is

$$Q_s = Q_w \mathrm{erfc}\,(U), \qquad (6)$$

where

erfc is the complementary error function,

$$U = \sqrt{d^2 S / 4Tt}\,, \qquad (7)$$

and

Q_s is the rate of streamflow depletion (ft^3/s),
Q_w is the pumping rate of the well (ft^3/s),
d is the perpendicular distance from the well to the stream (ft),
S is the storativity (or specific yield) of the aquifer (dimensionless),
T is the transmissivity of the aquifer (ft^2/s), and
t is time (s).

As noted in Barlow (2000), immediately after withdrawals begin, the source of water to the supply well is ground water released from storage in the aquifer, and there is little or no streamflow depletion. As time increases, the proportion of water released from storage that contributes to the discharge from the well decreases, whereas the amount of streamflow depletion that contributes to the discharge from the well increases. Streamflow depletion consists of two components: captured ground-water discharge and induced infiltration. Ultimately, as steady-state conditions are reached, all of the discharge from the well will consist of streamflow depletion. STRMDEPL, which does not differentiate between captured ground-water discharge and induced infiltration, provides a calculation of total streamflow depletion (Barlow, 2000).

Manville well no. 1 was pumped intermittently during January 1995. The first day of pumping was January 4, 1995, at a rate of 0.06 ft^3/s. For this reason, an initial pumping rate of 0.06 ft^3/s (0.04 Mgal/d) was specified in the input file. This initial rate was used for 10,000 days prior to the beginning of the simulation to obtain an initial streamflow depletion that accounts for the effects of pumping prior to the start of the analysis. This rate caused an initial streamflow depletion of 0.0597 ft^3/s.

Specified daily pumping rates at the well and calculated streamflow depletions in the river for the period 1995–99 are shown in figure 14. As seen in the figure, daily pumping rates indicate that the well was used intermittently throughout the period of analysis and that there were large variations in the rates of withdrawal, ranging from 0.00 to 1.03 ft^3/s (0.00 to 0.67 Mgal/d). There were 483 days during the period of analysis during which the well was inactive. The well was inactive in April, May, June, and July of 1995. In addition, pumping at the well showed a trend of decreasing use in the second half of 1996. The years 1997, 1998, and 1999 include days during which the well was inactive; however, these periods were usually less than a week.

Average daily pumping rates at Manville well no. 1 for each year of the 5-year period, 1995–99, were 0.05, 0.20, 0.37, 0.38, and 0.40 ft^3/s, respectively. Streamflow depletions for Manville well no. 1 were about 97 percent of average daily pumping rates for 1995 through 1999.

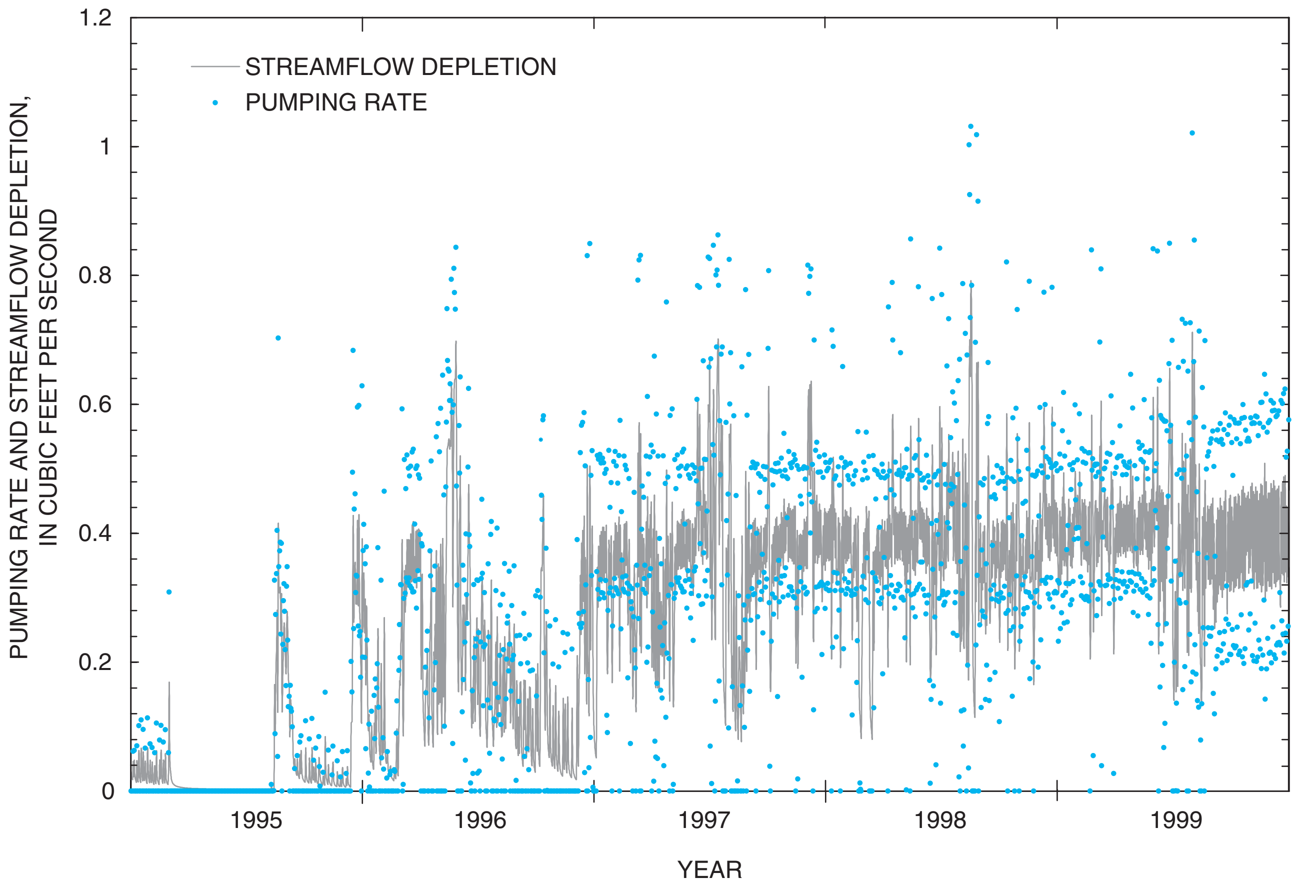

Figure 14. Specified daily pumping rates at Cumberland Water Department Manville well no.1, Rhode Island, 1995-99, and calculated streamflow depletion in the nearby Blackstone River.

The range and variability of calculated streamflow depletions, however, is much less than the range and variability of the daily pumping rates. Variability of the daily pumping rates is effectively damped by the diffusivity of the aquifer and distance of the well to the stream. The streamflow depletions exhibit the same general trend as the withdrawals during the period of analysis.

In addition to calculating streamflow depletion for the Cumberland WD Manville well no. 1, relative streamflow depletions (Q_s/Q_w) were calculated for Manville well no. 1 and five other public-supply wells in the lower Blackstone River basin (table 21). A constant pumping rate of 0.4 ft^3/s was simulated for a period of 180 days at the six supply wells to illustrate the effects that different aquifer properties and various well distances to streams have on relative streamflow depletion.

The Cumberland WD wells, Manville well no. 1 and no. 2, were determined to be in direct hydraulic connection with the stream (Johnston and Dickerman, 1974b, D.C. Dickerman, oral commun., 2000). Therefore, the Jenkins (1968) equation was used in the STRMDEPL program. However, the Pawtucket and Lincoln supply wells selected for analysis are near ponded areas where the Abbott Run and Blackstone Rivers were determined to have fine-grained semipervious streambed and streambank materials (Johnston and Dickerman, 1974b; and D. C. Dickerman, oral communication, September, 2000). For this reason, the Hantush (1965) equation was used in the STREMDEPL program for these four wells and the streambank-leakance term was estimated for each well. The analytical solution presented by Hantush is

$$Q_s = Q_w \{\mathrm{erfc}(U) - \exp[-U^2 + (U + w)^2]\mathrm{erfc}(U + w)\}, \quad (8)$$

where Exp is = the exponential function, $w = \frac{Tt/S}{a}$, where a is the streambank leakance term (ft), and is defined by $a = Kb'/K'$, where K is the hydraulic conductivity of the aquifer (ft/d), K' is the hydraulic conductivity of the streambank (ft/d), and b' is the thickness of the streambank (ft).

The hydraulic conductivity of the aquifer (K) is determined by dividing the transmissivity of the aquifer by its saturated thickness. Hydraulic conductivities of the aquifer estimated for the six wells range from 131 to 325 ft/d.

The hydraulic conductivity of the streambank (K') is unknown at the Lincoln Water Commission and Pawtucket WSB sites along the Blackstone River. Field measurements of the vertical hydraulic conductivity of streambed sediments at 11 sites in the Hunt River basin by Rosenshein and others (1968) ranged from 0.1 ft/d for organically rich, fine sand and silt to 15.2 ft/d for medium to coarse sand. Hunt River streambed sediments on average are 2 ft thick, but can be as much as 10 ft locally (Rosenshein and others, 1968). Hydraulic properties of the Blackstone River basin stream-aquifer system in South Grafton, MA, were estimated using analytical modeling techniques by Desimone and Barlow (1998). Because vertical hydraulic conductivities and streambank thicknesses were not available for the four wells simulated by the Hantush equation, the calibrated values from the Grafton site were used (K' = 1.4 ft/d and b' = 2.4 ft) (DeSimone and Barlow, 1998). Based on a combination of these calibrated values and the hydraulic conductivities at the well locations, the streambank leakance term was 225 ft for the Lincoln Lonsdale well no. 4 and 557 ft for the Pawtucket WSB wells 2, 3, and 4 (table 21).

The STRMDEPL simulation results for the six public-supply wells (table 21, fig. 15) show that the greatest relative streamflow depletion occurred at the Cumberland WD Manville well no. 2, which is about 180 ft from the streambank. This well likely has unimpeded connection with the stream. As well distances increase, relative streamflow depletions decrease. However, Pawtucket well no. 3, which is closer to the stream (100 ft) and at whose location the aquifer has a higher diffusivity than the aquifer at Manville well no. 2, has lower relative streamflow depletions due to impedance from streambed and streambank materials. Relative streamflow depletions at 10, 20, and 30 days after simulation were tabulated to show the variation in relative streamflow depletion over a one-month period due to varying aquifer properties and distances to a nearby stream (table 21). Changes in the relative streamflow depletion after the 30-day period have a smaller rate of increase than those occurring within the first 30 days (fig. 15).

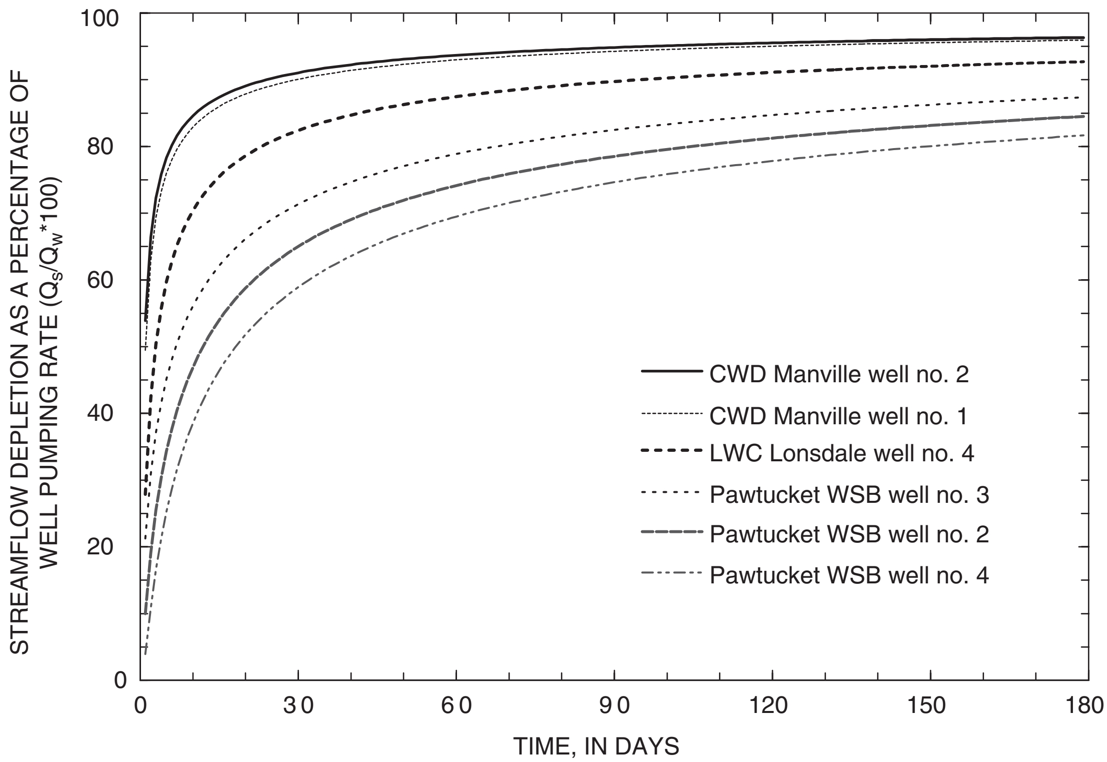

Figure 15. Streamflow depletion as a percentage of well pumping rate (Q_S/Q_W * 100) for six public-supply wells with different aquifer properties and distances to the stream in the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts. Q_S is the rate of streamflow depletion (cubic feet per second) and Q_W is the pumping rate of the well (cubic feet per second).

WATER BUDGET

A long-term water budget was developed for the lower Blackstone River basin and for each of the six subbasins within the lower Blackstone River basin. The 14-digit HUC subbasins used to report withdrawals, use, and return flow in this report served as units for the budget calculation. A simple water budget can be stated as the mass-balance equation: inflow minus outflow equals change in storage. A long-term average annual water budget was used. Therefore, change in storage could be assumed to be zero and inflow equals outflow. The components of inflow and outflow are defined separately in the long-term budget equation:

$$P_T + SF_I + GW_I + WWRF_I = ET + SF_O + W + GW_U, \quad (9)$$

where

P_T = average annual precipitation over the subbasin or basin,
SF_I = streamflow from upstream subbasins,
GW_I = ground-water inflow,
$WWRF_I$ = wastewater-return flow from septic and NPDES (commercial, industrial, and municipal wastewater facilities),
ET = estimated evapotranspiration,
SF_O = streamflow out of the subbasin or basin,
W = withdrawals (public-supply and self-supply), and
GW_U = ground-water underflow.

Inflow

Three terms in the water-budget equation were used to quantify the inflow to each subbasin and to the whole lower Blackstone River basin: precipitation (P_T), streamflow entering the basin boundary from upstream (SF_I), and wastewater-return flow ($WWRF_I$) (table 22). A fourth term, ground-water inflow (GW_I), was not estimated for the lower Blackstone River basin hydrologic budget because the information was unavailable.

Table 22. Long-term average annual hydrologic budget by subbasin for the lower Blackstone River basin, northern Rhode Island and south-central Massachusetts, 1957–99

[NPDES, National Pollution Discharge Elimination System; Mgal/d, million gallons per day; Mgal/d/mi^2, million gallons per day per square mile; mi^2, square miles; --, not applicable]

Water-budget component	Areal extent						
	Chepachet River subbasin	Clear River subbasin	Branch River subbasin	West River subbasin	Peters River subbasin	Abbott Run subbasin	Lower Blackstone River basin
Total drainage area at outlet (mi^2)	21.3	45.5	93.1	242.3	447.2	27.3	474.5
Estimated inflow (Mgal/d)							
Precipitation (P_T)	48.55	103.72	60.13	79.06	98.38	62.33	452.17
Streamflow from upstream (SF_I)	0	0	85.54	261.57	509.07	0	348.04
Ground-water inflow (GW_I)	--	--	--	--	--	--	--
Return flow ($WWRF_I$)	0.27	1.27	0.45	1.42	10.78	1.43	15.62
Total inflow	48.82	104.99	146.12	342.05	618.23	63.76	815.83
Estimated outflow (Mgal/d)							
Evapotranspiration (ET)	21.28	45.45	26.35	35.38	44.03	27.32	199.8
Streamflow (SF_O)	27.13	58.45	118.91	301.62	566.97	21.22	586.16
Water withdrawals (W)	0.41	1.09	0.86	5.05	7.23	15.22	29.87
Ground-water underflow (GW_U)	--	--	--	--	--	--	--
Total outflow	48.82	104.99	146.12	342.05	618.23	63.76	815.83
Streamflow (SF_O) in (Mgal/d/mi^2)	1.27	1.28	1.28	1.25	1.27	0.78	1.24

Total monthly precipitation (P_T) values in inches for the National Weather Service rain gage in Woonsocket, RI, were obtained from the Woonsocket WDIV for the period 1957–99 (Carol LaRiviere, Assistant Superintendent for the Woonsocket Water Division, written commun., 2002). Monthly precipitation for the rain gage averaged 47.9 in/yr. Total monthly precipitation accounts only for the precipitation over the subbasin; any precipitation in upstream subbasins is included in estimates of streamflow from upstream subbasins. Average monthly precipitation in Mgal/d ranged from 48.55 Mgal/d in the Chepachet River subbasin to 103.72 Mgal/d in the Clear River subbasin. Average precipitation for the lower Blackstone River basin was 452.17 Mgal/d (table 22).

Streamflow from upstream subbasins (SF_I) was calculated for each subbasin and the lower Blackstone River basin on the basis of streamflow at one of two USGS streamflow-gaging stations. Streamflow into the Branch River subbasin was estimated from mean monthly discharge records at the Branch River at Forestdale streamflow-gaging station (01111500) for the period 1957–99. The long-term mean flow for the period 1957–99 at the Forestdale station was 180.8 ft^3/s (1.98 ft^3/s/mi^2, 1.28 Mgal/d/mi^2). Streamflows into the West River and Peters River subbasins were estimated from mean monthly discharge records at the Blackstone River at Woonsocket streamflow-gaging station (01112500) for the period 1957–99. The long-term mean flow for the period 1957–99 at the Woonsocket station was 810.9 ft^3/s (1.95 ft^3/s/mi^2, 1.26 Mgal/d/mi^2). The Chepachet, Clear, and Abbott Run subbasins have zero inflow due to streamflow from upstream subbasins. The largest inflow from upstream flow was in the Peters River subbasin, 509.07 Mgal/d. Long-term average inflows to the lower Blackstone River basin for the period 1957–99 totaled 348.04 Mgal/d (table 22).

Outflow

Three terms in the water budget equation are used to quantify outflows: evapotranspiration (ET), streamflow out of the subbasin (SF_O), and water withdrawals (W) (table 22). A fourth term, ground-water underflow (GW_U), was not estimated for the hydrologic budget because the information was unavailable.

Evapotranspiration (*ET*) was estimated by subtracting estimated long-term streamflow within each subbasin from long-term average annual precipitation for the period 1957–99. Evapotranspiration was estimated at 21.3 in/yr for the lower Blackstone River basin, which agrees with evapotranspiration estimates made for the area by Randall (1996). Estimated evapotranspiration rates ranged from 21.28 Mgal/d in the Chepachet River subbasin to 45.45 Mgal/d in the Clear River subbasin. Evapotranspiration for the entire lower Blackstone River basin was estimated at 199.8 Mgal/d.

Streamflow out of the subbasin (SF_O) was estimated from the water-budget equation and equals the difference between the sum of inflows and the sum of evapotranspiration and withdrawals. Average streamflow out of the six subbasins ranged from 21.22 Mgal/d in the Abbott Run subbasin to 566.97 Mgal/d in the Peters River subbasin. Long-term outflow from the lower Blackstone River basin was estimated to be 586.16 Mgal/d (table 22).

SUMMARY AND CONCLUSIONS

This report discusses water use, availability, streamflow depletion at six public-supply wells and a long-term hydrologic budget for the lower Blackstone River basin in Rhode Island. This study was conducted by the U.S. Geological Survey, in cooperation with the Rhode Island Water Resources Board (RIWRB), to examine the pattern of water use within the basin and its effect on water availability.

Water-use data, including withdrawals, uses, and return flows, were collected for six subbasins of the Blackstone River basin for the period 1995–99. Total withdrawals for the lower Blackstone River basin were 29.869 Mgal/d; public-supply withdrawals were 22.694 Mgal/d, and self-supply withdrawals were 7.170 Mgal/d. Total withdrawals by subbasin ranged from 0.414 Mgal/d in the Chepachet River subbasin to 15.221 Mgal/d in the Abbott Run subbasin. Total water use for the lower Blackstone River basin was estimated at 20.388 Mgal/d; public-supply use was estimated at 13.215 Mgal/d and self-supply use was estimated at 7.170 Mgal/d. Water use ranged from 0.416 Mgal/d in the Chepachet River subbasin to 8.122 Mgal/d in the Peters River subbasin. The largest aggregate users in the lower Blackstone River basin were the domestic water users (10.113 Mgal/d, 50 percent), followed by industrial water users (4.127 Mgal/d, 20 percent), commercial water users (4.026 Mgal/d, 20 percent), non-account water use (1.866 Mgal/d, 9 percent), and agricultural water users (0.252 Mgal/d, 1 percent). Public-supply imports and exports for the basin totaled 2.852 and 12.327 Mgal/d, respectively.

Total wastewater disposal to the lower Blackstone River basin was 15.219 Mgal/d. Public-disposal of wastewater at National Pollution Discharge Elimination System (NPDES) outfalls was 10.395 Mgal/d, including imports from outside the lower Blackstone River basin, and self-disposal of wastewater was estimated at 4.824 Mgal/d. Of this amount, 3.660 Mgal/d was disposed through on-site septic and 1.164 Mgal/d was disposed through commercial and industrial NPDES surface-water discharge sites. Public-disposal wastewater imports and exports for the basin totaled 1.818 and 4.086 Mgal/d, respectively.

The computer program PART was used to estimate base flow at the Branch River at Forestdale, Rhode Island. Two minimum streamflows, the 7-day, 10-year low flow (7Q10) (11.9 ft^3/s) and the Aquatic Base Flow (ABF) (38.8 ft^3/s), were subtracted from the base-flow values calculated from PART for the low-flow period, which included June, July, August, and September.

Available base flows estimated by PART at the 50th percentile minus the 7Q10 minimum flow were 180, 586, 428, and 483 Mgal for the Branch River at Forestdale streamflow-gaging station drainage area, in June, July, August, and September, respectively. Available base flows estimated by PART at the 50th percentile minus the ABF minimum flow were about 658 Mgal in June and 47 Mgal in July for the station's drainage area. Base flows estimated by PART at the 50th percentile for August and September, however, were less than the ABF minimum flow.

Water availability (base-flow estimates plus safe-yield estimates) was 50.5 Mgal/d for the lower Blackstone River basin in August at the 50th percentile minus the 7Q10. Water availability with and without taking minimum streamflow into account was calculated at the 75th, 50th, and 25th percentiles for all four months of the low-flow period. These values ranged from 42.3 to 181.7 Mgal/d in June, 20.2 to 96.7 Mgal/d in July, 20.2 to 85.4 Mgal/d in August, and 20.2 to 97.5 Mgal/d in September. Water-availability estimates were done at the 14-digit HUC level; therefore, interpolation of this data to smaller areas may overestimate or underestimate availability. In addition, water-availability estimates calculated from base flow are conservative estimates because actual streamflows are generally greater than base flow except for periods of no recharge.

A basin-stress ratio for the six subbasins of the lower Blackstone River basin was calculated by dividing total withdrawals by water availability for the low-flow period during 1995–99. The lowest base-flow rate was in August. The basin-stress ratio for August at the 50th percentile minus the 7Q10 minimum flow ranged from 0.13 in the Chepachet River subbasin to 0.95 in the Abbott Run subbasin. The ratios for other subbasins in the lower Blackstone River basin were 0.21, 0.21, 0.74, and 0.85 for the Branch River, Clear River, Peters River, and West River subbasins, respectively. The ratio for the lower Blackstone River basin was 0.68. Basin-stress ratios with and without taking minimum streamflow into account were calculated at the 75th, 50th, and 25th percentiles for all four months of the low-flow period. These values ranged from 0.19 to 0.83 in June, 0.36 to 1.50 in July, 0.40 to 1.14 in August, and 0.31 to 0.78 in September. Ratios calculated on the basis of the ABF criterion could not be calculated at the 25th percentile from July through September and at the 50th percentile in August and September because the estimated base flow at these percentiles was less than the ABF. Water availability estimates and basin-stress ratios were calculated from subbasin to subbasin, which does not reflect the cumulative demand from upstream subbasins.

Streamflow depletions resulting from ground-water withdrawals at six public-supply wells within the lower Blackstone River basin were quantified based on calculations from the program STRMDEPL developed by Barlow (2000). Streamflow depletions were about 97 percent of average daily pumping rates for 1995 through 1999 for the Cumberland Water District (WD) Manville well no. 1. In addition, relative streamflow depletions resulting from a simulated constant pumping rate were calculated for the Cumberland WD Manville wells no. 1 and no. 2, Pawtucket wells no. 2, 3, and 4, and Lincoln Lonsdale well no. 4. The aquifers at these wells had different properties and the wells were at different distances from the streambank. Simulated relative streamflow depletions for these wells were 90, 91, 65, 71, 59, and 82 percent, respectively.

A long-term hydrologic budget was calculated for the period 1957 through 1999. Water-withdrawal and wastewater-return-flow data were used in the hydrologic budget. Precipitation, surface-water inflow, and wastewater-return flow in the six subbasins ranged from 48.82 Mgal/d in the Chepachet River subbasin to 618.23 Mgal/d in the Peters River subbasin. Inflow volumes were 104.99 Mgal/d, 146.12 Mgal/d, 342.05 Mgal/d, and 63.76 Mgal/d for the Clear River, Branch River, West River, and the Abbott Run subbasins, respectively. Outflow volumes, which consisted of evapotranspiration, streamflow out of the basin, and withdrawals, were set equal to inflows.

Inflow to the lower Blackstone River basin was 815.83 Mgal/d. Inflows from precipitation, streamflow from upstream subbasins, and wastewater-return flow were 55, 43, and 2 percent of total inflows, respectively. Outflows from evapotranspiration, streamflow out of the basin, and withdrawals were 24, 72, and 4 percent of total outflows, respectively.

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GLOSSARY

7-day, 10-year low flow: 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). The 7-day, 10-year low flow is commonly used to assess the capacity of a river to carry pollutants.

Aggregate water use: Water used within a defined area (town, basin, or water district).

Aquatic Base Flow: Median flow during the month of August considered adequate flow to protect indigenous aquatic fauna throughout the year established by the U.S. Fish and Wildlife Service. Can be calculated as long as there is U.S. Geological Survey streamflow-gaging data for at least 25 years of unregulated flow, and the drainage area at the streamflow-gaging station is at least 50 square miles.

Base Flow: is flow in a channel sustained by ground-water discharge in the absence of direct runoff.

Base flow in inches (in.): shows the depth to which the drainage area would be covered if all the base flow for a given time period were uniformly distributed on it.

Commercial water use: Water used for motels, restaurants, office buildings, ski resorts, water parks, and other commercial facilities and institutions, including fish hatcheries. The water may be obtained from a public water supply or may be self-supplied. See also institutional water use.

Consumptive use: That part of withdrawn water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment.

Conveyance: The systematic and intentional flow or transfer of water from one point to another. Conveyance types include water distribution and wastewater collection.

Distribution: The process of conveying water from a water supplier's point of withdrawal or treatment through the distribution system to the user or another water supplier.

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 public-supply or may be self-supplied.

Exfiltration: Leakage from a conveyance system or storage area into the surrounding and underlying materials.

Flow duration: is a cumulative frequency curve that shows the percent of time specified discharges were equaled or exceeded during a given period.

Industrial water use: Water used for industrial purposes, such as fabrication, processing, washing, and cooling, and includes such industries as steel, chemicals, paper, and petroleum refining. The water may be obtained from a public water supply or may be self-supplied.

Infiltration: water entering a sewer system, including sewer service connections, from the ground through such means as defective pipes, pipe joints, connections, or manhole walls.

Inflow: consists of two types, steady inflow and direct inflow. *Steady inflow* is water discharged from cellar and foundation drains, cooling water discharges, and drains from springs and swampy areas. This type of inflow is steady and is identified and measured along with infiltration. *Direct inflow* is composed of those types of inflow that have a direct stormwater-runoff connection to the sanitary sewer and cause an almost immediate increase in wastewater flows. Possible sources are roof leaders, yard and areaway drains, manhole covers, cross connections from storm drains and catch basins, and combined sewers (Metcalf and Eddy, 1991).

Instream use: Water that is used, but not withdrawn, from a surface-water source, or a ground-water source, for hydroelectric-power generation, navigation, water-quality improvement or waste assimilation, fish propagation, wildlife preservation, recreation, and ecosystem maintenance, which includes freshwater circulation to the estuaries and maintenance of riparian vegetation and floodplain wetlands. Also referred to as non-withdrawal use or in-channel use.

Intake: Point of withdrawal from a surface water body such as a reservoir or a stream.

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

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

Local wastewater collection: collection of wastewater from domestic, industrial, and commercial users within a city or town (minor civil division) to be processed at a local wastewater-treatment facility.

Minor water supplier: a supplier who withdraws, distributes, or uses water for a public population, such as in nursing homes, condominium complexes, and mobile home parks.

Major water supplier: a supplier who withdraws, distributes, or uses more than 50 Mgal/yr as defined by the Rhode Island Water Resources Board.

Million gallons per day per square mile [(Mgal/d)/mi^2]: is the average number of million gallons of water flowing per day from each square mile of area drained, the flow is assumed to be distributed uniformly in time and area.

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

Non-account water use: Water within a public-water supply system that is unaccounted for in the suppliers' billing records because it was lost through firefighting, inaccurate meters, flushing, major breaks, recreation, illegal connections, street washing and leakage (exfiltration).

NPDES discharge site: A National Pollution Discharge Elimination System (NPDES) discharge location at which effluent is released after use into a receiving stream. In Rhode Island these sites are named Rhode Island Pollution Discharge Elimination System (RIPDES) discharge sites. Also referred to as an outfall.

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

Per capita water use: The average volume of water used per person (or other unit) during a standard time period, generally per day. (Other units may include various types of livestock, hospital beds, etc.).

Public-disposal wastewater: Wastewater collected through the public wastewater-collection system.

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

Public water-supply system: Water withdrawn by public and private water systems and delivered to users or groups of users. Public water systems provide water for a variety of uses, such as domestic, commercial, industrial, and thermoelectric power.

Public-supply use: Water supplied from a public water system and used for domestic, commercial, industrial, and agricultural purposes.

Regional wastewater collection: Collection of wastewater from several cities and/or towns to be processed at a regional wastewater-treatment facility.

Return Flow: Water that is returned to surface or ground water after use or wastewater treatment.

Self-disposal wastewater: Wastewater that is returned to the ground through septic systems or returned to surface water through NPDES discharge sites by a user or group of users that are not on a public wastewater-collection system.

Self-supply water: Water withdrawn from a ground- or surface-water source by a user or group of users that are not on a public 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.

Streamflow-gaging station: is a particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

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

Wastewater treatment: The processing of wastewater to remove or reduce solids or other undesirable constituents.

Water supply: All of the processes involved in obtaining and distributing water prior to use. Includes withdrawal, treatment, and distribution.

Water treatment: The processing of potable water to meet safe drinking water standards. The processing may include: coagulation, flocculation, sedimentation, filtration, and disinfection.

Water use: Water that is used for public supply, industry, commercial, domestic, irrigation, livestock, and hydroelectric and thermoelectric power generation.

Withdrawal: The removal of surface water or ground water from the natural hydrologic system for use by humans.

Appendix 1:
SIC Code Estimates by Minor Civil Division

Appendix 1. SIC code estimates by minor civil division

[**Water-use coefficient:** Units are in gallons per employee per day. Mgal/d, million gallons per day; --, not applicable]

Category and two digit SIC code	Water-use coefficient	Attleboro (Mgal/d)	Bellingham (Mgal/d)	Blackstone (Mgal/d)	Burrillville (Mgal/d)	Central Falls (Mgal/d)	Cumberland (Mgal/d)	Douglas (Mgal/d)	Franklin (Mgal/d)	Glocester (Mgal/d)	Lincoln (Mgal/d)
Construction	35	0.0188	0.0075	0.0016	--	--	0.0001	0.0020	0.0112	--	0.0042
Industrial [20-39]	116	--	--	--	--	--	--	--	--	--	--
Food [20]	469	--	--	--	0.0328	--	--	--	--	--	.0469
Tobacco [21]	217	--	--	--	--	--	--	--	--	--	--
Textile mill products [22]	315	--	--	--	.0473	0.2914	.1575	--	--	--	.0296
Finished apparel [23]	13	--	--	--	--	--	.0000	--	--	--	.0004
Wood, lumber [24]	78	.0019	--	--	--	--	.0098	--	.0015	--	--
Furniture [25]	30	--	--	--	--	--	--	--	--	--	--
Paper products [26]	863	--	--	--	--	.1752	--	--	--	--	--
Printing, publishing [27]	42	.0096	--	--	--	--	.0013	--	.0027	--	.0006
Chemical products [28]	289	.0629	--	--	--	.0038	--	--	.0083	--	.0260
Petroleum [29]	1,045	--	--	--	--	--	--	--	--	--	--
Rubber [30]	119	--	--	--	.0075	--	.0167	--	.0101	--	.0035
Leather [31]	148	--	--	--	--	--	--	--	--	--	--
Stone, clay, glass, and concrete [32]	202	--	--	--	--	.1010	--	--	--	--	--
Primary metals [33]	178	.1101	--	--	--	--	.0134	--	.0485	--	.0890
Fabricated metals [34]	95	.0947	.014497	--	.0114	.0128	.0193	--	.0154	--	.0670
Machinery [35]	58	.0289	.0068556	--	--	.0024	--	.0041	.0164	0.0001	.0102
Electronic equipment [36]	71	--	--	--	--	--	.0001	--	.0166	--	.0045
Transportation equipment [37]	63	--	--	--	--	--	.0006	--	--	--	--
Instruments [38]	66	.0074	--	--	--	--	.0009	--	.0314	--	.0070
Jewelry, precious metals [39]	36	.0991	--	--	--	.0104	.0030	--	--	--	.0511
Miscellaneous industrial		--	--	--	--	--	--	--	--	--	--
Total industrial		.433	.029	.002	.099	.597	.222	.006	.162	.000	.340
Commercial [40-97]	94	--	--	--	--	--	--	--	--	--	--
Transportation, communication, utilities [40-49]	51	.0066	.0009	--	--	--	.0103	.0005	.0172	--	.0189
Wholesale trade [50-51]	58	.0316	.0159	.0014	.0070	--			.0560	--	--
Retail trade [52-59]	58	.2257	.0670	.0093	.0067	--	.0450	.0026	.1394	--	.0073
Finance, insurance, and real estate [60-67]	71	.0194	.0042	--	--	--	--	.0016	.0181	--	.0391
Services [70-89]	106	.5347	.0362	.0077	.0377	.0339	.1514	.0024	.1528	.0307	.2663
Public administration (Government) [91-97]	71	.0242	--	--	--	--	--	.0008	.0000	--	--
Total commercial		.842	.124	.018	.051	.034	.207	.008	.383	.031	.331
Domestic	71	--	--	--	--	--	--	--	--	--	--

Appendix 1. SIC code estimates by minor civil division—*Continued*

Category and two digit SIC code	Water-use coefficient	Millville (Mgal/d)	North Attleboro (Mgal/d)	Plainville (Mgal/d)	North Smithfield (Mgal/d)	Pawtucket (Mgal/d)	Smithfield (Mgal/d)	Uxbridge (Mgal/d)	Woonsocket (Mgal/d)	Wrentham (Mgal/d)
Construction	35	0.0008	0.0065	0.0103		0.0053	0.0044	0.0034		0.0058
Industrial [20-39]	116									
Food [20]	469					.2101	.0774			
Tobacco [21]	217									
Textile mill products [22]	315					.6426			0.3963	
Finished apparel [23]	13					.0003			.0016	
Wood, lumber [24]	78		.0012						.0016	
Furniture [25]	30					.0224	.0030			
Paper products [26]	863					.5264			.0155	
Printing, publishing [27]	42		.0030		0.0001	.0252		.0003	.0061	
Chemical products [28]	289				.0072	.0188			.0127	
Petroleum [29]	1,045									
Rubber [30]	119		.0029		.0155	.1939			.0129	
Leather [31]	148									
Stone, clay, glass, and concrete [32]	202				.1414	.0026	.0061		.1010	
Primary metals [33]	178		.0466			.1899	.0107		.1139	
Fabricated metals [34]	95		.0473	.0061		.0486	.0010		.0863	.0237
Machinery [35]	58		.0073	.0044		.0135	.0048	.0044	.0046	.0028
Electronic equipment [36]	71		.0060		.0089	.0256	.0026		.0163	
Transportation equipment [37]	63						.0025			
Instruments [38]	66		.0044	.0192	.0015	.0983	.0497		.0122	
Jewelry, precious metals [39]	36		.0424	.0024		.1075	.0186		.0050	
Miscellaneous industrial										
Total industrial		.0008	.168	.042	.175	2.131	.181	.008	.786	.032
Commercial [40-97]	94									
Transportation, communication, utilities [40-49]	51		.0020		.0003	.0158		.0030		.006833
Wholesale trade [50-51]	58		.0300	.0065	.0096	.0029		.0084		.0041412
Retail trade [52-59]	58		.2902	.0280	.0162	.0484	.0305	.0293	.2437	.03132
Finance, insurance, and real estate [60-67]	71		.0127	.0004		.0359	.0763	.0027	.0071	.0035784
Services [70-89]	106	.0001	.1496	.0366	.0519	.5060	.1514	.0117	.2780	.0689424
Public administration (Government) [91-97]	71		.0023					.0087		
Total commercial		.0001	.487	.071	.078	.609	.258	.064	.529	0.115
Domestic	71									

Appendix 2:
Water-Use Case Study—Cumberland, Rhode Island

CONTENTS

FIGURES

TABLES

WATER-USE CASE STUDY—CUMBERLAND, RHODE ISLAND

In this appendix, a case study for the town of Cumberland is presented to illustrate the types of retrievals that can be made from the New England Water Use Database System [NEWUDS; Tessler (2002) and Horn (2002)]. Two water suppliers withdraw water for public supply within Cumberland: the Cumberland Water Department (WD) and Pawtucket Water Supply Board (WSB). The Cumberland WD received about 55 percent of its water supply from the Pawtucket WSB during the 5-year period of study (1995-99). In addition, the southern portion of Cumberland known as Valley Falls receives its public-supply water directly from the Pawtucket WSB; therefore, water use for the Valley Falls section of Cumberland is presented separately from water use for the section of Cumberland that is supplied by the Cumberland WD.

RETRIEVALS

To retrieve the information described within this section from the NEWUDS database, a parameter query was created (table 2.1). A parameter query requires input from the user. In this example, the user is prompted to enter a system name. The query links together four tables in the database: tdxSystem, tblSite, tblConveyance, and tblTransaction. An explanation of naming conventions for tables in the NEWUDS database can be found in Tessler (2002). To retrieve the 5-year average, the summary option "average" was chosen. In addition, the minimum and maximum rates were selected within the summary option.

The tasSystemSite table ties each site within the database to a particular system. The withdrawals, use, and return-flow sites for the town of Cumberland were attached to five different systems within the tasSystemSite table. For the town of Cumberland these systems included: the Cumberland WD, the Pawtucket WSB, Cumberland Aggregate, Cumberland Site Specific, and the Narragansett Bay Commission-Bucklin Point. These five system names were entered to retrieve data.

Because the Pawtucket WSB system serves the Valley Falls section of Cumberland, Pawtucket, and Central Falls, two statements were specified within the SiteName field to restrict the query to wells and intakes and the Valley Falls section of Cumberland (for example, "*Wells*", "*Intakes"; and "*Valley Falls"). An asterisk before or after the specified site name will retrieve all records that include those characters without the user having to specify the entire site name.

The Cumberland Aggregate system includes all public-supply, self-supply, public-disposal, and self-disposal uses for the town of Cumberland including the Valley Falls section. Because public supply for northern Cumberland is contained within the Cumberland WD system and public supply for Valley Falls is contained within the Pawtucket WSB system, a statement was used to restrict the retrieval to self-supply aggregate use (for example, "*self-supply"). Public-supply aggregate uses are within the public-supply system (for example, the Cumberland Water Department) and also within the Aggregate system because the user may want to compile the data in either system.

Because the system Cumberland Site Specific includes only two National Pollution Discharge Elimination System (NPDES) outfall locations, a statement was not needed to restrict the query. The Narraganset Bay Commission-Bucklin Point system includes the towns of Central Falls, Cumberland, East Providence, Lincoln, and Pawtucket. Because only the flow information for the town of Cumberland was needed, a statement was used to restrict the query (for example, "*Cumberland").

Table 2.1. New England Water Use Database System (NEWUDS) retrievals for the town of Cumberland, Rhode Island

[**Query restriction:** *, an asterisk before or after the specified site name will retrieve all records that include those characters without the user having to specify the entire site name. No., number; Mgal/d, million gallons per day; --, information not available]

System name	Query restriction	Conveyance name	Rate (Mgal/d)		
			Average	Minimum	Maximum
Cumberland WD	None	Sneech Pond intake to Cumberland Treatment Plant	0.837	0.237	1.016
		Manville well No. 1 to Cumberland Treatment Plant	.179	0	.293
		Manville well No. 2 to Cumberland Treatment Plant	.16	0	.263
		Abbott Run well No. 2 to Cumberland Treatment Plant	0	0	0
		Abbott Run well No. 3 to Cumberland Treatment Plant	0	0	0
		Backwash discharge to Sneech Pond	--	--	--
		Pawtucket/Cumberland Interconnection to Cumberland local distribution	1.43	.198	3.725
		Lincoln/Cumberland Interconnection to Cumberland local distribution (emergency use only)	0	0	0
		Cumberland Treatment Plant to local distribution	1.176	.255	1.53
		Cumberland local distribution to public-supply agricultural water use	0	0	0
		Cumberland local distribution to public-supply commercial water use	.253	.143	.472
		Cumberland local distribution to public-supply industrial water use	.248	.081	.634
		Cumberland local distribution to public-supply domestic water use	1.431	.921	2.798
		Cumberland local distribution to non-account water use	.682	.46	1.352
Pawtucket WSB	"*well" or "*intake"	Happy Hollow intake to Pawtucket Treatment Plant	12.017	7.097	16.334
		Pawtucket well No. 2 to Pawtucket Treatment Plant	.156	0	.52
		Pawtucket well No. 3 to Pawtucket Treatment Plant	.273	0	.803
		Pawtucket well No. 4 to Pawtucket Treatment Plant	.065	0	.736
		Pawtucket well No. 5 to Pawtucket Water Supply Board regional distribution	0	0	0
		Pawtucket well No. 6 to Pawtucket Water Supply Board regional distribution	.129	0	.595
		Pawtucket well No. 7 to Pawtucket Treatment Plant	.169	0	.595
		Pawtucket well No. 8 to Pawtucket Treatment Plant	.179	0	.595
		Pawtucket well No. 9 to Pawtucket Treatment Plant	.183	0	.595
	"*Valley Falls"	Pawtucket Water Supply Board regional distribution to Valley Falls local distribution	.832	.681	1.117
		Valley Falls local distribution to public-supply agricultural water use	0	0	0
		Valley Falls local distribution to public-supply commercial water use	.081	.066	.097
		Valley Falls local distribution to public-supply industrial water use	.089	.071	.107
		Valley Falls local distribution to public-supply domestic water use	.603	.6	.61
		Valley Falls local distribution to public-supply non-account water use	.025	.025	.025

Table 2.1. New England Water Use Database System (NEWUDS) retrievals for the town of Cumberland, Rhode Island—*Continued*

System name	Query restriction	Conveyance name	Rate (Mgal/d)		
			Average	Minimum	Maximum
Cumberland Aggregate	"*self-supplied"	Cumberland self-supplied agricultural water use	0.038	0.011	0.157
		Cumberland self-supplied commercial water use	0	0	0
		Cumberland self-supplied industrial water use	0	0	0
		Cumberland self-supplied domestic water use	.081	.081	.081
Cumberland Site Specific	none	Cumberland industrial water use to NPDES surface water discharge for Okonite, Company	.159	.067	.246
		Cumberland public-supply industrial use to NPDES surface water discharge for Air Products and Chemicals	.157	.019	.33
NBC-–Bucklin Point	"*Cumberland"	Cumberland public-disposal agricultural water use to local wastewater collection	0	0	0
		Cumberland public-disposal commercial water use to local wastewater collection	.223	.223	.223
		Cumberland public-disposal domestic water use to local wastewater collection	.586	.586	.586
		Cumberland local wastewater collection to Narragansett Bay Commission regional collection- Bucklin Point	2.543	.064	5.608
		Valley Falls public-disposal agricultural water use to local wastewater collection	0	0	0
		Valley Falls public-disposal domestic water use to local wastewater collection	.497	.495	503
		Valley Falls public-disposal commercial water use to local wastewater collection	.088	.088	.088
		Valley Falls public-disposal industrial water use to local wastewater collection	.096	.096	.096
Cumberland Aggregate	"*self-disposal"	Cumberland self-disposal of domestic water use to ground water return flow	.7	.7	.7
		Cumberland self-disposal of commercial water use to ground water return flow	0	0	0
		Cumberland self-disposal of industrial water use to ground water return flow	.232	.232	.232

WITHDRAWALS

Average monthly withdrawals for the town of Cumberland, which include self-supply withdrawals and public-supply withdrawals, for both the Cumberland WD and the Pawtucket WSB, ranged from about 11.7 Mgal/d in March 1996 to about 20.4 Mgal/d in June 1999, averaging 14.5 Mgal/d for the period 1995-99 (fig. 2.1). Of the 14.5 Mgal/d withdrawn, an average of 3.5 Mgal/d (24 percent) is used in the town of Cumberland (northern and southern Cumberland), an additional 0.3 Mgal/d is filter backwash at the Pawtucket WSB potable-water treatment facility, and the remaining 10.7 Mgal/d is exported out of Cumberland for use in Pawtucket (8.6 Mgal/d), Central Falls (2.0 Mgal/d), and Seekonk (< 0.1 Mgal/d). Withdrawals within the town of Cumberland follow a cyclical pattern; the largest volumes of water were withdrawn during the summer and the smallest in the winter and spring.

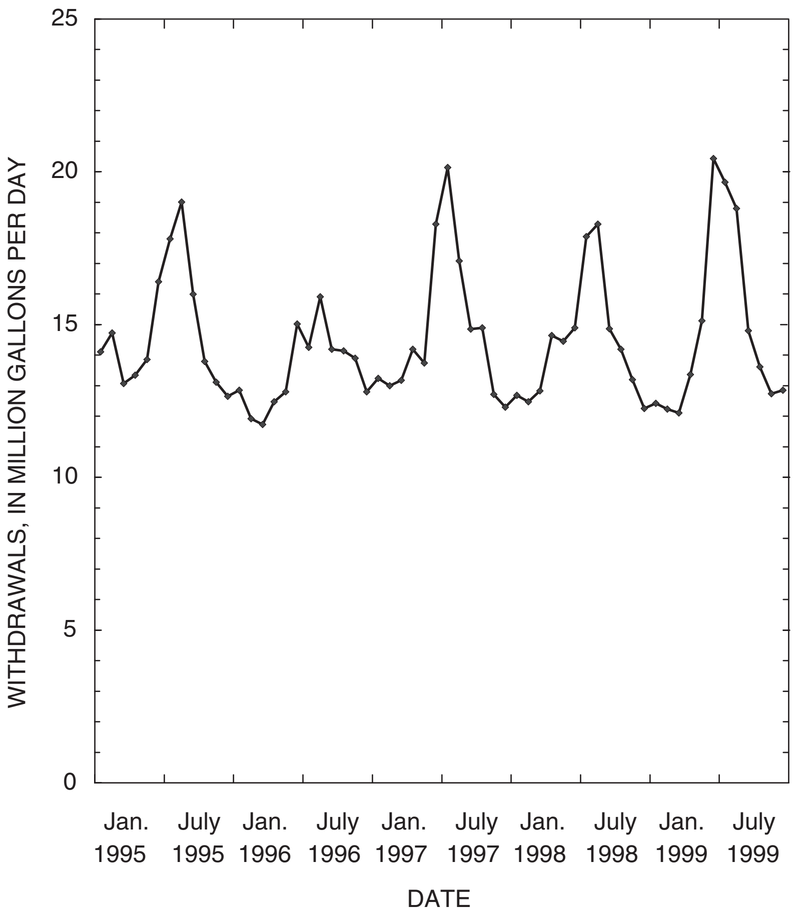

Figure 2.1. Total withdrawals in million gallons per day within the town of Cumberland, Rhode Island, 1995–99.

Cumberland Water Department

The Cumberland WD withdrew water from three separate sources during the study period: Sneech Pond and Manville wells no. 1 and no. 2. (figs. 2.2 and 2.3) These withdrawals averaged 0.837 Mgal/d, 0.179 Mgal/d, and 0.160 Mgal/d from 1995–99 (table 2.1 and fig. 2.3). Two Cumberland WD wells were inactive during the study period: Abbot Run wells no. 2 and no. 3 (fig. 2.2, table 2.1). In addition to the 1.176 Mgal/d supplied from the Cumberland WD's own sources, an average of 1.430 Mgal/d (Cumberland Water Department, written commun., 2002) was purchased from Pawtucket WSB.

Pawtucket Water Supply Board

The Pawtucket WSB withdrew water from eight separate sources within the town of Cumberland during the study period, including the Happy Hollow Pond intake and Pawtucket wells no. 2, 3, 4, 6, 7, 8, and 9 (fig. 2.2). These withdrawals averaged 12.017, 0.156, 0.273, 0.065, 0.129, 0.169, 0.179, and 0.183 Mgal/d, respectively (table 2.1). Three Pawtucket WSB wells (nos. 5, 10, and 11) were inactive during the study period (fig. 2.2). The Pawtucket WSB withdrew an average of 13.171 Mgal/d during 1995–99. Of this amount, 91 percent came from the Happy Hollow Pond intake. The remaining 9 percent

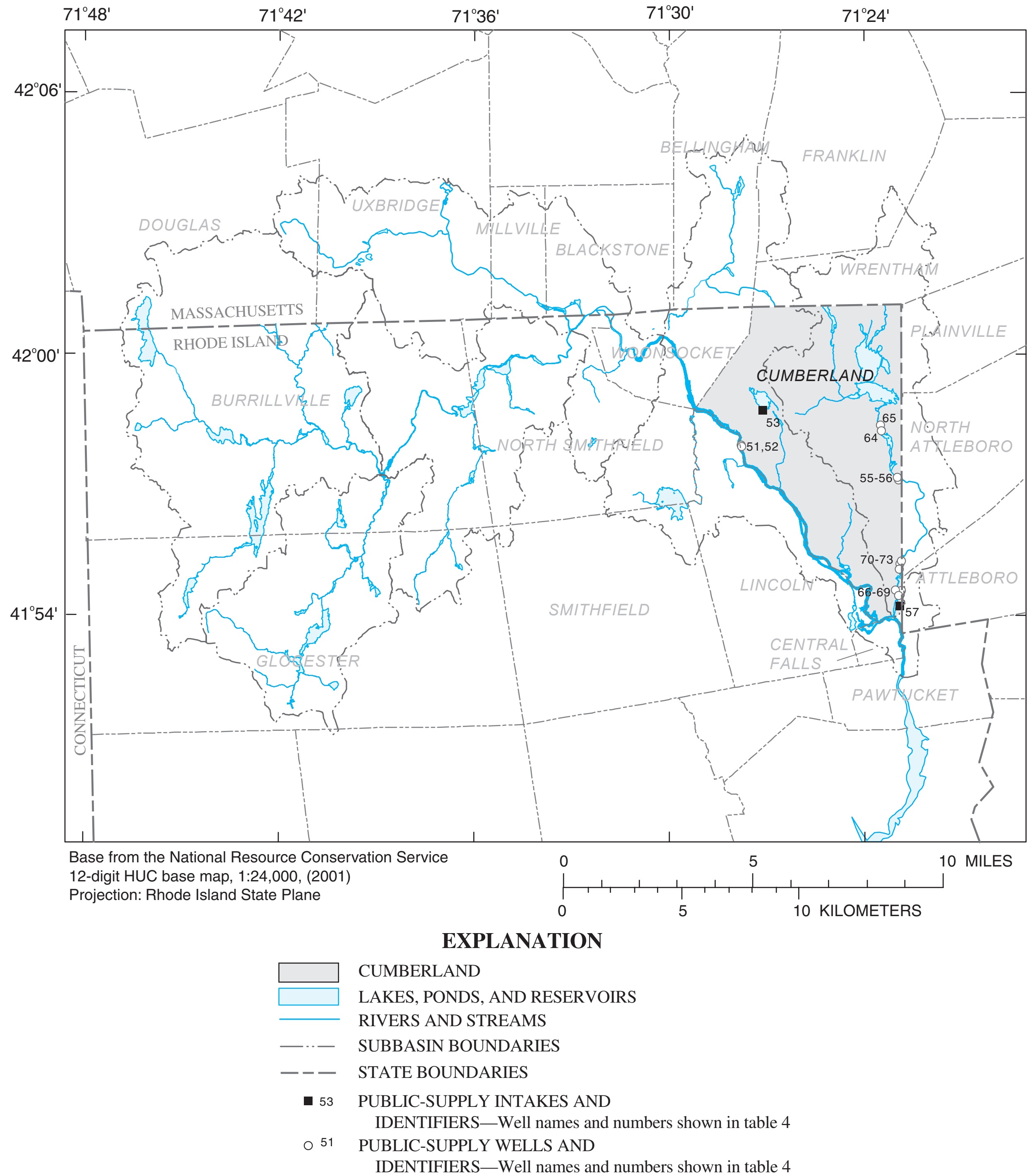

Figure 2.2. Public-supply withdrawal locations in the town of Cumberland, Rhode Island.

came from the Pawtucket wells. The wells were used primarily in the summer months for all five years, with use extending into the spring or fall in 1996, 1998, and 1999.

The maximum volume withdrawn from Happy Hollow Pond was 490 million gallons in June 1999, at an average rate of about 16.3 Mgal/d.

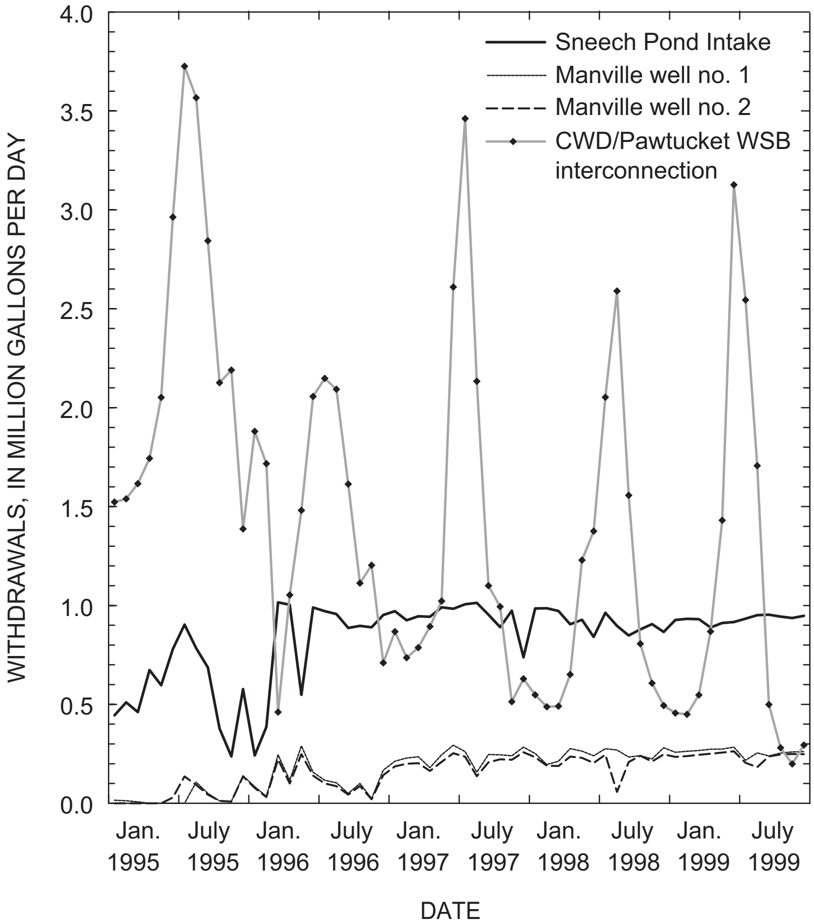

Figure 2.3. Cumberland Water Department monthly withdrawal volumes and wholesale purchases by source, 1995–99.

WATER USE

The 5-year average water use for the town of Cumberland was 3.574 Mgal/d (table 2.2). Non-account water use for the Cumberland WD was reported as 26.1 percent of distribution, and the Pawtucket WSB reported non-account water use at 3.0 percent. The Cumberland WD supplied 73.3 percent of the town's water (including wholesale purchases from the Pawtucket WSB) and the Pawtucket WSB supplied 23.3 percent of the town's water to the Valley Falls section of Cumberland. Averaging these percentages of non-account use relative to distribution for use in the town of Cumberland gives an estimated non-account use for the entire town of 19.8 percent. Self-supply use accounted for about 3.3 percent of the total water use in Cumberland. Monthly water-use values for public-supply users in the Cumberland WD service area were based on yearly percentage values reported in the water-supply-management plan (Water Works Engineering and Associates, 1994). Only 1-year and 5-year estimates of water-use values were available for the Valley Falls section of Cumberland.

Table 2.2. Water-use summary by category for the town of Cumberland, Rhode Island

[All values in million gallons per day. na, not applicable; --, none known]

Source	Water-use rate					
	Agricultural	Commercial	Industrial	Domestic	Non-account	Total
Self-supply	0.038	--	--	0.082	na	0.12
Cumberland Water Department	0	0.255	0.251	1.432	0.683	2.621
Pawtucket Water Supply Board[1]	0	.098	.107	.603	.025	.833
Total	0.038	0.353	0.358	2.117	0.708	3.574

[1]The Pawtucket Water Supply Board service area includes the southern portion of Cumberland known as Valley Falls. Water use values reported here are for Valley Falls only. The Pawtucket Water Supply Board also serves Pawtucket and Central Falls.

WASTEWATER RETURN FLOWS

The Narragansett Bay Commission's Bucklin Point Facility in East Providence, Rhode Island received an estimated 2.543 Mgal/d of wastewater from the town of Cumberland. Public disposal of wastewater for Cumberland was estimated at about 1.490 Mgal/d, of which 1.083 Mgal/d was from domestic, 0.311 Mgal/d from commercial, and 0.096 Mgal/d from industrial wastewater. These estimates indicate that 1.053 Mgal/d or about 41.4 percent of the flow received at the Bucklin Point facility from the town of Cumberland may be attributed to infiltration and inflow. Self-disposal of wastewater for the town of Cumberland was estimated at about 0.932 Mgal/d, of which 0.700 Mgal/d was from domestic and 0.232 Mgal/d from industrial wastewater.

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