Part 1. Water Resources in the Pawcatuck River Basin

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Characterizing ground- and surface-water resources in the Pawcatuck River Basin of southwestern Rhode Island and southeastern Connecticut requires an understanding of how precipitation enters, flows through, and leaves the aquifers and streams in the basin. Data to support this understanding include climatological, hydrogeologic, groundwater, pond-level, streamflow, and water-use data. These data also are needed to develop and calibrate surface-water- and groundwater-flow models that characterize and simulate these flow processes.

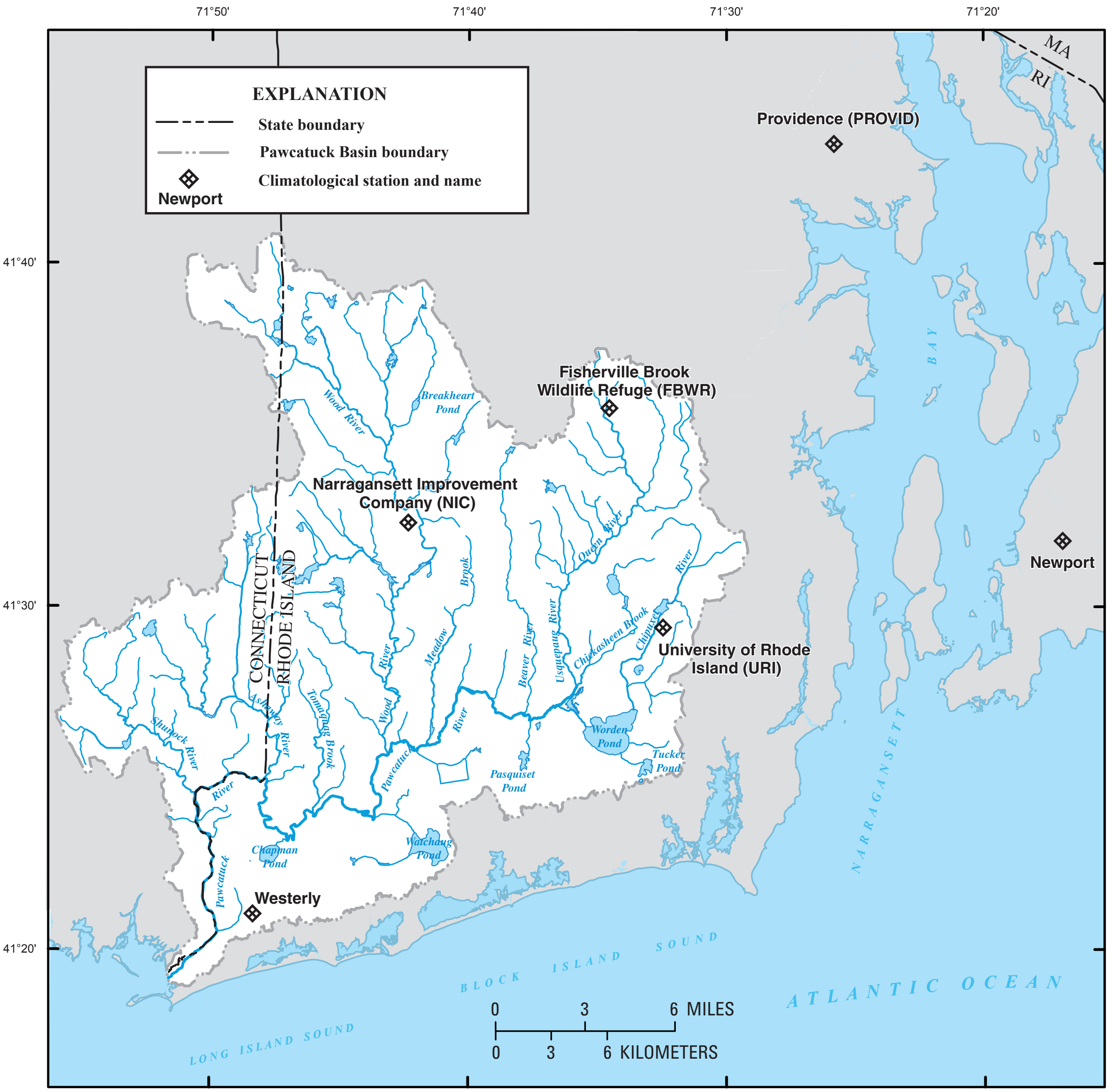
Climate

Climatological data were available for the Pawcatuck River Basin from several National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) stations in and near the basin and from two new stations established by USGS for the present study. Data included precipitation, air temperature, dew-point temperature, wind speed, and solar radiation (table 1–1). Long-term data were available from the NWS stations at Providence T.F. Green Airport in Warwick, R.I. (PROVID; hourly data) and at the University of Rhode Island in Kingston, R.I. (URI; hourly data since 1998). NWS weather stations at the Newport and Westerly Airports have collected data since the late 1990s. The PROVID and NEWPORT stations are about 10 miles (mi) to the northeast and about 11 mi to the east of the basin, respectively, and the WESTERLY station is in the southwestern part of the basin (fig. 1–1). The USGS stations at the Fisherville Brook Wildlife Refuge (FBWR) and the Narragansett Improvement Company (NIC) were established in the northeastern and central parts of the basin, respectively (fig. 1–1), to provide local climatological data for model calibration. Data from the FBWR station were available from November 22, 1999, through November 15, 2001, and October 1, 2002, through December 15, 2004. Data from the NIC station were available for the period December 15, 2002, through December 15, 2004.

Table 1–1. Types of climatological data collected at U.S. Geological Survey stations and compiled from National Oceanic and Atmospheric Administration National Weather Service (NOAA-NWS) stations in and near the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[Locations shown in figure 1–1. USGS, U.S. Geological Survey; NWS, National Weather Service; IDLOC, identification attribute in the Watershed Data Management (WDM) database for the Hydrologic Simulation Program-FORTRAN (HSPF) model; FBWR, Fisherville Brook Wildlife Refuge; NIC, Narragansett Improvement Company; URI, University of Rhode Island; PROVID, Providence; Y, yes; N, no]

	USGS station	USGS station	NWS University of Rhode Island	NWS T.F. Green Airport	NWS Newport Airport	NWS Westerly Airport
IDLOCN	FBWR	NIC	URI	PROVID	NEWPORT	WESTERLY
Time step	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly
Begin date	11/22/1999	12/4/2002	9/30/1998	1/1/1960	7/1/1996	7/28/1999
End date	12/31/2004	12/31/2004	12/31/2004	12/31/2004	12/31/2004	12/31/2004
Precipitation	Y	Y	Y	Y	Y	Y
Air temperature	Y	Y	Y	Y	Y	Y
Dew-point temperature	Y	Y	Y	Y	Y	Y
Wind speed	Y	Y	Y	Y	Y	Y
Solar radiation	Y	Y	Y	Y	N	N
Potential evapotranspiration computed	Y	N	N	Y	N	N



Base from U.S. Geological Survey digital data
North American Datum of 1983
Rhode Island state plane projection, 1:24,000

Figure 1–1. Location of climatological stations in and near the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

Mean annual precipitation was 46.45 in. at the PROVID station and 51.82 in. at the URI station for the 30-year period 1971 through 2000 (National Oceanic and Atmospheric Administration, 2002a). Differences in total precipitation at the two stations may reflect local weather patterns given that mean annual precipitation ranged from 39.79 to 53.17 in. for the same period at six NWS stations (including the PROVID and URI stations) across the State. Mean monthly precipitation is fairly uniform throughout the year, with the mean monthly low of 3.17 in. at PROVID (3.31 in. at URI) in July and the high of 4.43 in. at PROVID (5.11 in. at URI) in March for the 30-year period. Snowfall generally occurs during the months of November through April, but on occasion has occurred in late October and early May (National Oceanic and Atmospheric Administration, 2002b). The 30-year mean annual snowfall at PROVID was 32.9 in., with 19.6 in. in the months of January and February together. The mean annual temperature was 51.1°F at the PROVID station (49.7°F at URI) with the mean monthly low of 28.7°F (28.6°F at URI) in January and the high of 73.3°F (70.7°F at URI) in July for the 30-year period (National Oceanic and Atmospheric Administration, 2002a).

During the study period 2000–04, mean annual precipitation at the URI station was 52.08 in. (National Oceanic and Atmospheric Administration, 2007), which is very close to the long-term mean of 51.82 in/yr. March 2001 was the wettest month, with 12.29 in. of precipitation, and October 2000 was the driest month, with 0.69 in. of precipitation (fig. 1–2A). A 13-month dry spell occurred from August 2001 through 2002 (fig. 1–2A) with only 38.93 in. of precipitation, which represented a deficit of about 17.3 in. based on the 1971–2000 normals. Mean annual snowfall was 33.1 in. at the URI station during 2000–04; this value is very similar to the long-term mean of 32.9 in/yr at the PROVID station. Mean annual temperature at the URI station for 2000–04 was 51.0°F, with January having the lowest mean temperature of 28.1°F and August having the highest mean temperature of 71.9°F. Monthly temperatures were similar to the 1971–2000 normals (fig. 1–2B).

Geologic Setting

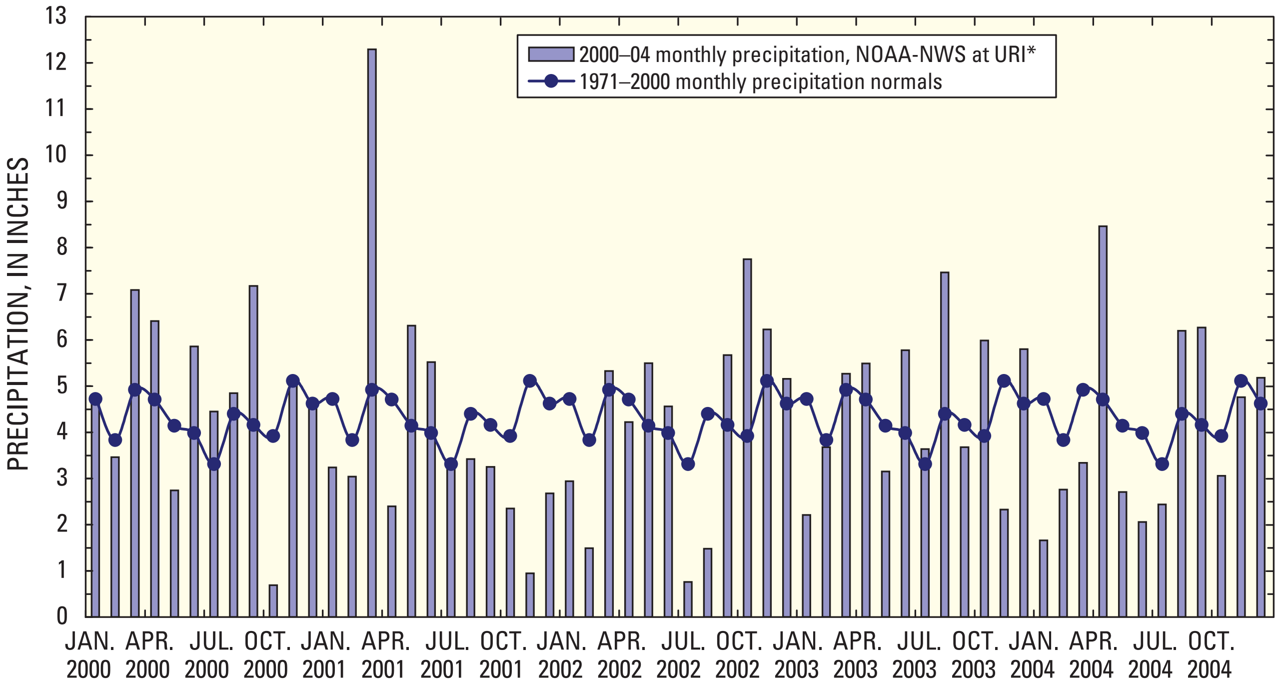
The geology of the Pawcatuck River Basin is characterized by glacial deposits of variable thickness overlying crystalline bedrock. Stratified sand, gravel, silt, and clay (stratified glacial deposits), glacial till, and the Charlestown Moraine compose the glacial deposits (fig. I–2). Most of these materials are deposits from the last two continental ice sheets that covered New England during the middle and late Pleistocene. Most were laid down during the advance and retreat of the last (late Wisconsinan) ice sheet, which reached its maximum extent about 21,000 years ago and was retreating northward through southern Rhode Island by about 19,500 years ago (Stone and Borns, 1986; Boothroyd and others, 1998). Postglacial Holocene deposits, consisting of flood-plain alluvium along rivers and streams, organic peat, and muck (swamp deposits), are present in some areas. Bedrock beneath the basin is predominantly granite and granite gneiss of Late Proterozoic and Paleozoic age (Hermes and others, 1994). The bedrock surface is irregular and is characterized by preglacial, seaward-sloping, north-south-trending valleys (Masterson and others, 2007).

Glacial till was deposited directly by glacier ice and is characterized as an unsorted, unstratified, relatively compact mixture of sand, silt, and clay with variable amounts of stones, cobbles, and large boulders. Till blankets the bedrock surface in most places, and underlies most upland areas and extends beneath stratified glacial deposits in valleys. The thickness of the till layer is variable geographically, but is reported to average around 20 to 25 feet (ft) in the uplands and less than 10 ft beneath stratified glacial deposits (Johnston and Dickerman, 1985; Dickerman and others, 1990, 1997; Dickerman and Bell, 1993; Masterson and others, 2007). Local accumulations of till in drumlins and along some bedrock hills may reach thicknesses of 80 ft (Johnston and Dickerman, 1985, Dickerman and others, 1990, 1997; Dickerman and Bell, 1993). In upland areas where till is absent, bedrock is exposed at the land surface.

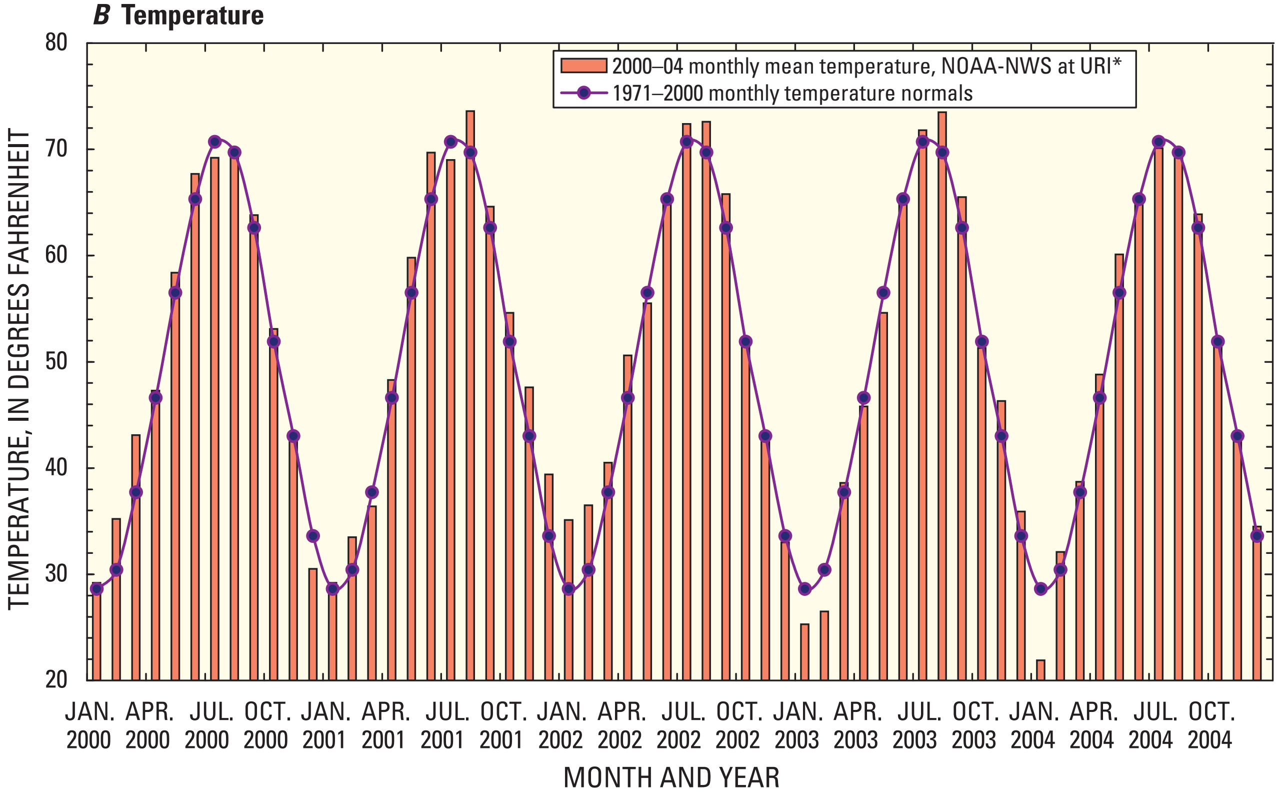
The Charlestown Moraine is a WSW–ENE trending, hummocky linear ridge that forms the southern boundary or surface-water divide between the Pawcatuck River Basin and the South Coastal Basin (fig. I–2). The moraine represents a long-term recessional position of the retreating glacier (Schafer, 1965). The deposition of the moraine across the valleys of preglacial south-flowing rivers diverted drainage in the area and resulted in the southwesterly course of the present-day Pawcatuck River (Masterson and others, 2007). The moraine is a thick and complex mixture of sediments, including sandy ablation till and intermixed sands and gravel. The few lithologic logs available from the moraine indicate that the western part of the moraine consists of material that is more stratified and permeable than the material in the eastern part (Friesz, 2004). Masterson and others (2007) report that the glacial deposits are as much as 300 ft thick where the moraine crosses the deepest bedrock valleys.

The stratified glacial deposits are glaciofluvial and glaciolacustrine sands, gravel, silt, and clay. Stratified glacial deposits in valleys and lowlands cover about 35 percent of the basin (fig. I–2). The deposits were transported by meltwater streams that drained from the ice margin and commonly flowed directly or indirectly into glacial lakes (Dickerman and others, 1997). The deposits consist of multiple, sequentially deposited packages of proximal, coarse-grained (gravel, sand and gravel, and sand) sediments that grade into distal or lacustrine, fine-grained sediments (very fine sand, silt, and clay). These packages represent the systematic northward retreat of the ice sheet through the basin (Dickerman and others, 1997). Proximal deposits commonly consist of ice-marginal deltaic sequences. Lateral migration of depositional environments and collapse at the ice margin resulted in vertical gradations in grain size, such as sand and gravel overlying sand, or very

A **Precipitation**



B **Temperature**



*Data from National Oceanographic and Atmostpheric Administration, National Weather Service station at Univerisy of Rhode Island (NOAA-NWS at URI)

Figure 1–2. Monthly *(A)* precipitation and *(B)* mean temperature at the National Oceanic and Atmospheric Administration National Weather Service (NOAA-NWS) University of Rhode Island (URI) climate station in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

fine sand and silt overlying poorly sorted sand and gravel. The stratified glacial deposits range in thickness from a few feet at deposit margins to more than 100 ft, with typical ranges of about 60 to 80 ft; thicknesses are generally greatest along the axes of preglacial stream valleys (Dickerman and Ozbilgin, 1985; Johnston and Dickerman, 1985; Dickerman and others, 1990, 1997; Dickerman and Bell, 1993).

Groundwater

Aquifers in the Pawcatuck River Basin typically are unconfined. Recharge occurs from precipitation in till and bedrock uplands and in areas of stratified glacial deposits; surface runoff from uplands also may recharge stratified glacial deposits at their upland boundaries. Groundwater generally flows from topographic highs in the uplands toward upland stream channels and the stratified glacial deposits in valleys and lowlands. The water table mimics topography; surface-water and groundwater divides typically coincide, especially in uplands. Groundwater levels and flow directions, especially in the sand and gravel deposits, are strongly influenced by the locations and elevations of streams, ponds, and wetlands that are the discharge points for the groundwater-flow system (Winter and others, 1998; Randall, 2001).

The geologic materials in the Pawcatuck River Basin differ substantially with respect to their hydraulic properties, which determine rates of groundwater flow and well yield. The primary porosity of crystalline bedrock is extremely low, and groundwater in bedrock flows through fractures and joints. Thus, bedrock permeabilitites are low except in some highly fractured zones, and supply wells in bedrock are usually small and low-yielding. The permeability of glacial till also is low, and it varies with till composition, structure, and process of deposition. Because of its low permeability and small saturated thickness, till is not a major aquifer, but it is an important component of the groundwater-flow system in the basin because it affects recharge to and discharge from underlying aquifers (Dickerman and others, 1997). Stratified glacial deposits with relatively high permeability and hydraulic conductivity form the major aquifers in the basin.

Detailed descriptions of the groundwater-flow systems in the Pawcatuck River Basin and its subbasins are in Allen and others (1963, 1966); Gonthier and others (1974); Johnston and Dickerman (1985); Dickerman and Ozbilgin (1985); Dickerman and others (1990); Dickerman and Bell (1993); Dickerman and others (1997); Friesz (2004); and Masterson and others (2007). These studies provide hydrogeologic information for the major glacial deposits in the basin and include geologic cross sections, water-table maps, saturated-thickness maps, transmissivity maps, aquifer tests, and other information. The present study did not develop new water-table, saturated-thickness, or transmissivity maps for the model areas or the entire basin.

Recharge

Groundwater recharge is the amount of precipitation that infiltrates through the land surface and reaches the water table. Generally, groundwater in the study area is recharged from October through April when evapotranspiration is low. From May through September, evapotranspiration generally exceeds precipitation, resulting in little to no groundwater recharge. During droughts, aquifers might not receive recharge for an extended time period. Annual recharge rates can vary substantially with annual precipitation. Groundwater recharge in the Pawcatuck River Basin was estimated from streamflow data by using the computer programs RECESS and RORA (Rutledge, 1998). These programs use the recession-curve-displacement method to estimate groundwater recharge for each peak in streamflow during the period of record. Streamflow records from 1942 through 2004 (63 years) for three streamflow-gaging stations—the Pawcatuck River at Wood River Junction (01117500), Wood River at Hope Valley (01118000), and Pawcatuck River at Westerly (01118500)—were used (fig. 1–3). The estimated average annual recharge rates of 25.9, 27.6, and 25.8 in/yr for the three stations, respectively, were similar. The recharge rates estimated from streamflow also were similar to recharge rates estimated as about 25 to 28 in/yr for sand and gravel deposits in southern Rhode Island in other studies (Dickerman and others, 1997; Barlow and Dickerman, 2001; Granato and others, 2003; Friesz, 2004; Zarriello and Bent, 2004; Masterson and others, 2007). Therefore, on average, about 50 percent of the mean annual precipitation in the Pawcatuck River Basin (51.82 in/yr measured at the URI station) is lost through either evaporation or plant transpiration. These estimated RECESS and RORA recharge rates are basin-wide estimates that averaged different recharge rates for areas of stratified glacial deposits, glacial till, wetlands and ponds, and various land uses.

Water Levels

Groundwater levels in the Pawcatuck River Basin are affected by many factors, including the amount of recharge; surficial geology in the area of the well; lithology at the well, particularly around the well screen; location of the well on a hilltop, hill slope, or in a valley; thickness of the unsaturated zone; and proximity of the well to surface-water bodies (such as a stream, pond, or wetland). Currently (2009), the USGS measures water levels in 19 wells (17 in Rhode Island and 2 in Connecticut) in the basin (table 1–2 and fig. 1–4). Four of the 19 wells have continuous recorders and the remaining 15 wells are measured monthly between the 20th day and the last day of each month. During the study period (2000–04), water levels in 4 of the 15 monthly wells also were measured continuously from fall (October and November) 2002 through the end of 2004. Seven of the 8 continuously monitored wells during the study period were completed in sand and gravel deposits, and the other well (NSN–77) was completed in till deposits (fig. 1–5). Water levels in the monthly measured wells in sand

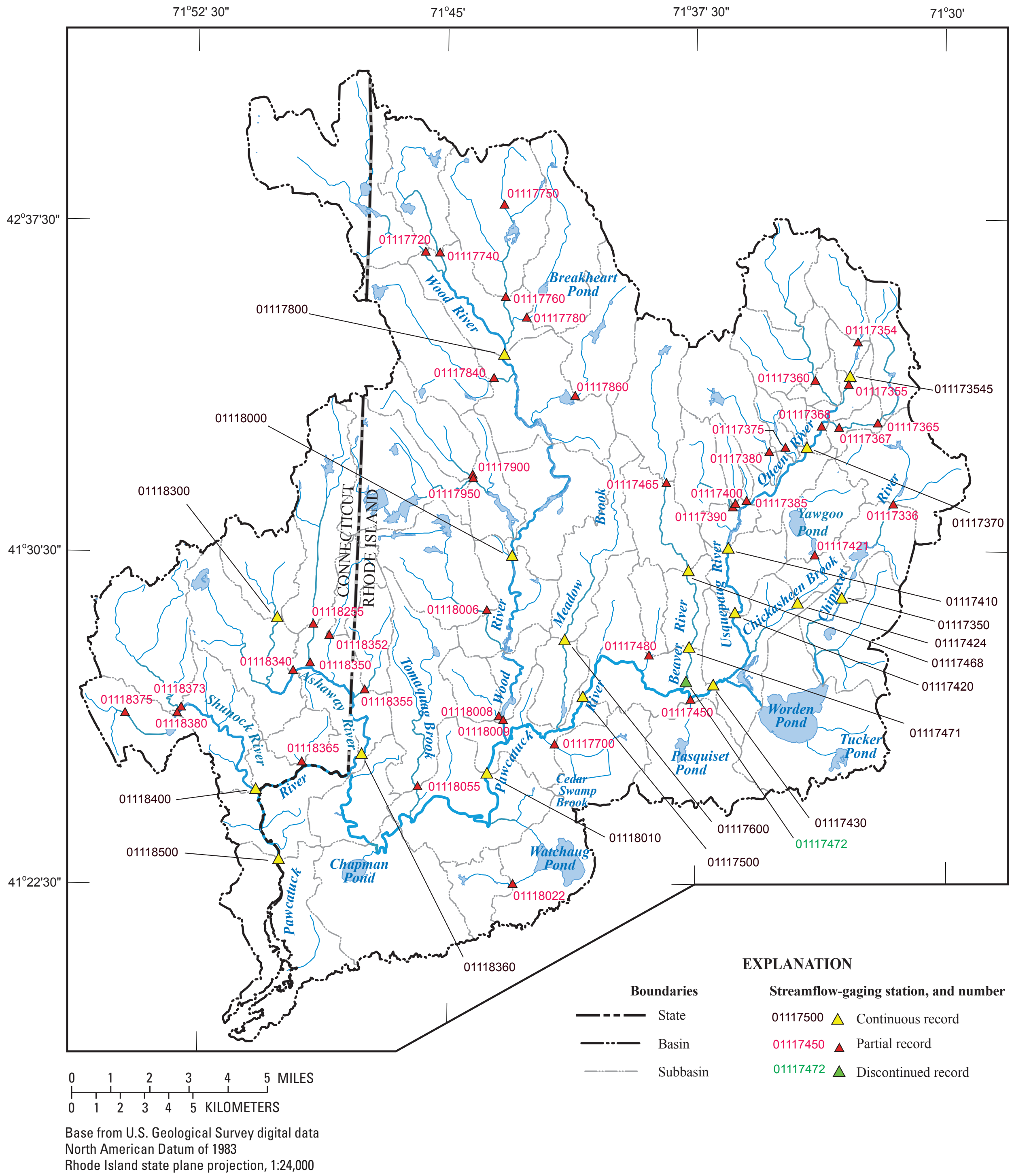
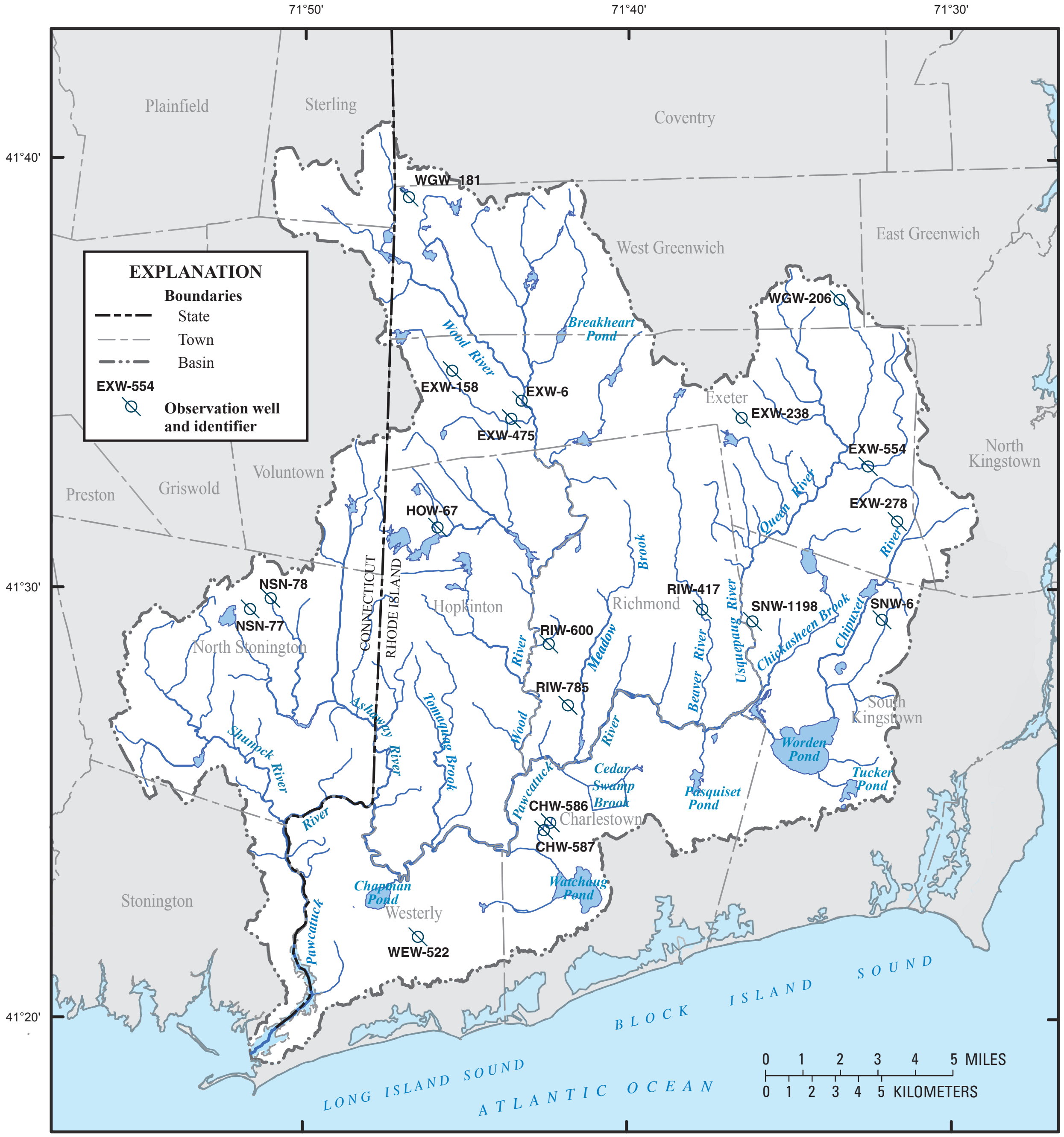


Figure 1–3. Location of U.S. Geological Survey continuous streamflow-gaging stations and partial-record stations in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

Table 1–2. U.S. Geological Survey observation wells in which groundwater levels were measured in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–2004.

[Locations shown in figure 1–4. USGS, U.S. Geological Survey; no., number; NGVD 29, National Geodetic Vertical Datum of 1929]

USGS station no.	Station name	Latitude (decimal degree)	Longitude (decimal degree)	Approximate altitude (feet above NGVD 29)	Aquifer material	Measurement frequency
			Rhode Island			
412154071462901	WEW–522	41.3651	-71.7742	45	Sand and gravel	Monthly 2000–fall 2002 and continuous fall 2002–2004.
412424071423601	CHW–587	41.4068	-71.7095	90	Till	Monthly.
412434071422401	CHW–586	41.4095	-71.7062	125	Till	Monthly.
412718071415201	RIW–785	41.4551	-71.6973	85	Sand and gravel	Monthly 2000–fall 2002 and continuous fall 2002–2004.
412844071422802	RIW–600	41.4790	-71.7073	100	Sand and gravel	Continuous.
412918071321001	SNW–6	41.4884	-71.5356	112	Sand and gravel	Continuous.
412932071374302	RIW–417	41.4923	-71.6281	116	Sand and gravel	Continuous.
412935071355701	SNW–1198	41.4932	-71.5987	112	Sand and gravel	Monthly.
413126071455501	HOW–67	41.5240	-71.7648	335	Till	Monthly.
413135071314201	EXW–278	41.5265	-71.5278	231	Till	Monthly.
413252071323601	EXW–554	41.5479	-71.5428	155	Sand and gravel	Monthly 2000–fall 2002 and continuous fall 2002–2004.
413358071433801	EXW–475	41.5662	-71.7267	143	Sand and gravel	Continuous.
413400071363101	EXW–238	41.5668	-71.6081	334	Till	Monthly.
413423071431901	EXW–6	41.5732	-71.7215	133	Sand and gravel	Monthly.
413505071452801	EXW–158	41.5848	-71.7573	315	Till	Monthly.
413645071332901	WGW–206	41.6126	-71.5576	374	Till	Monthly.
413907071465001	WGW–181	41.6520	-71.7801	380	Sand and gravel	Monthly.
			Connecticut			
412931071514201	NSN–77	41.4920	-71.8612	520	Till	Monthly 2000–fall 2002 and continuous fall 2002–2004.
412746071510601	NSN–78	41.4964	-71.8506	325	Till	Monthly.



Base from U.S. Geological Survey digital data
North American Datum of 1983
Rhode Island state plane projection, 1:24,000

Figure 1–4. Location of U.S. Geological Survey groundwater observation wells in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

and gravel deposits typically fluctuated only a few feet to 7 ft (Socolow and others, 2001, 2002, 2003, 2004, 2005). Water levels in the continuously monitored wells in sand and gravel deposits fluctuated up to about 5 ft (fig. 1–5). Wells measured monthly in till deposits have more variable water-level fluctuations from a few feet up to 23 ft (Socolow and others, 2001, 2002, 2003, 2004, 2005). The water levels in the continuously monitored till-deposit well (NSN–77) fluctuated up to about 11 ft (fig. 1–5).

Surface Water

The Pawcatuck River originates at the outflow of Worden Pond in the southeastern part of the basin (fig. I–1). The drainage area at the outflow point is about 25.8 mi^2 and comprises the drainage areas of the Chipuxet River, which is the main tributary into Worden Pond, a few small brooks that flow into the pond, and the pond itself. The Pawcatuck River is a low-slope river, dropping only about 90 ft in altitude from its origin at Worden Pond to its outlet to the Atlantic Ocean; the entire drainage area of the river is 303 mi^2. It generally flows east to west along the southern part of the basin. Several tributaries that flow from north to south include (from east to west) the Chipuxet River, Chickasheen Brook, Usquepaug-Queen River, Beaver River, Meadow Brook, Wood River, Tomaquag Brook, Ashaway River, and Shunock River (fig. I–1). Of the eight dams on the main stem of the Pawcatuck River, seven are less than or equal to 10 ft in height. The only dam higher than 10 ft is the Horseshoe Falls Dam in the village of Shannock in Richmond, R.I. Within the entire Pawcatuck River Basin in Rhode Island are about 100 dams on tributaries and the main stem of the river.

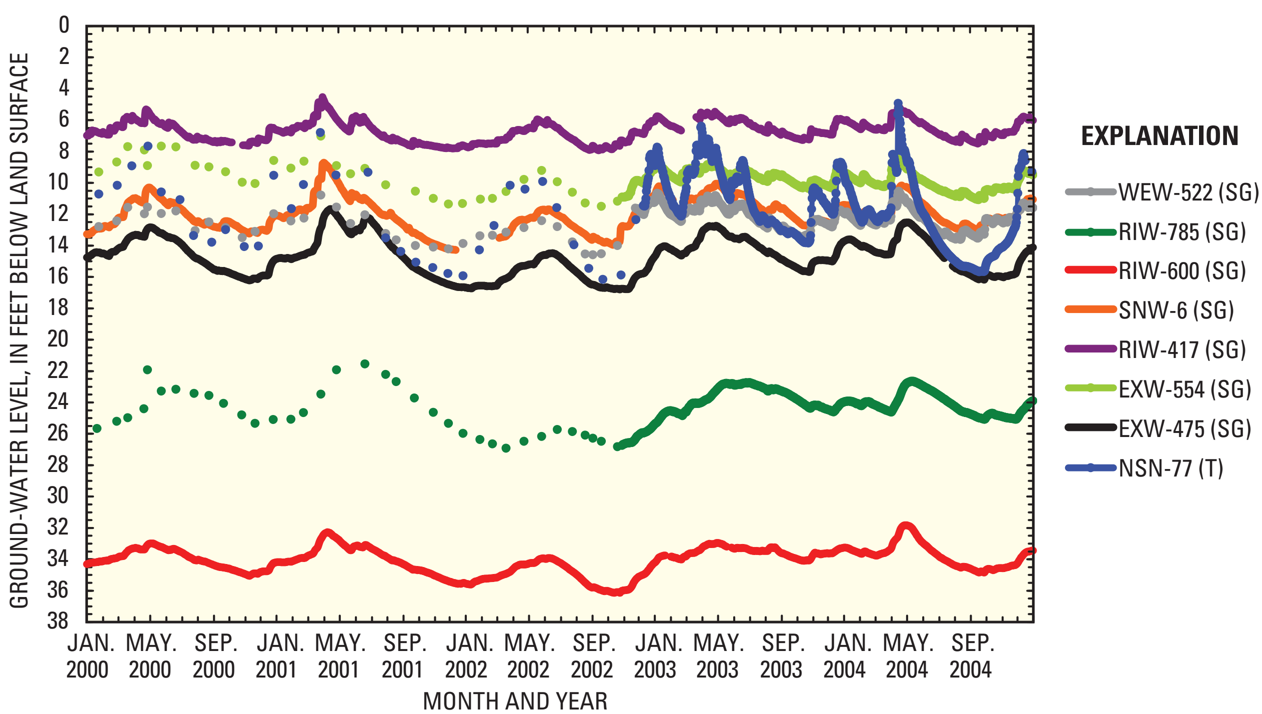


Figure 1–5. Groundwater levels in selected U.S. Geological Survey observation wells in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04 (SG, sand and gravel; T, till).

Streamflow

Streamflow data were collected at 18 of the 19 continuous streamflow-gaging stations and 38 of the 40 partial-record stations in the Pawcatuck River Basin during the study period (tables 1–3 and 1–4, fig. 1–3). One continuous streamflow-gaging station and 2 partial-record stations were not operated and measured, respectively, during the study period. The streamflow data at 18 of the 19 continuous streamflow-gaging stations were needed to provide data for calibration of the precipitation-runoff and groundwater models and for the evaluation of their performance. The streamflow data from 35 of the 40 partial-record stations provided supplemental information for evaluating the performance of the models across the respective areal extents of the models.

Three of the continuous streamflow-gaging stations in the Pawcatuck River Basin (table 1–3 and fig. 1–3) have been operated since the early 1940s as part of the USGS surface-water network for Rhode Island. The Pawcatuck River at Wood River Junction (01117500), Pawcatuck River at Westerly (01118500), and Wood River at Hope Valley (01118000) stations have been operated since from October 1940, November 1940, and March 1941, respectively. Mean annual streamflow from the Pawcatuck River Basin was about 577 ft^3/s (1.96 $ft^3/s/mi^2$) from 1942 through 2004 on the basis of records for the Pawcatuck River at Westerly (01118500) station (table 1–5).

During the study period (2000–04), mean annual streamflow was about 571 ft^3/s (1.94 $ft^3/s/mi^2$) at the Pawcatuck River at Westerly (table 1–5). Streamflow across the basin was fairly uniform; streamflow at the Pawcatuck River at Wood River Junction (01117500) and Wood River at Hope Valley (01118000) stations averaged about 1.98 and 2.07 $ft^3/s/mi^2$, respectively, during the 2000–04 study period and about 1.96 and 2.15 $ft^3/s/mi^2$ from 1942 through 2004. During the study period of 2000–04, average annual streamflow was close to the long-term average annual during the period 1942–2004. During the individual calendar years 2000, 2001, and 2004, annual streamflow was close to normal, but in calendar year 2002, the annual streamflow was about 30 to 32 percent below normal, and in calendar year 2003, annual streamflow was about 23 to 26 percent above normal. From September 2001 through October 2002, monthly streamflows at all three stations were below the long-term (1942–2004) mean monthly streamflow, except for May and June 2002 (fig. 1–6A–C). This period of below-normal streamflow nearly coincided with the 13-month dry spell from August 2001 through 2002 in which precipitation was 17.3 in. below normal (fig. 1–2A).

Continuous Stations

Nine of the 19 continuous streamflow-gaging stations are part of the USGS surface-water network for Rhode Island and Connecticut (long-term stations) and were operated during the entire study period (table 1–3 and fig. 1–3). Nine of the remaining 10 stations (short-term stations) were installed and operated for at least 2 years of the study period, generally during the period 2002–04. Streamflow data for these stations are published annually in the Massachusetts-Rhode Island Data Report (Socolow and others, 2001, 2002, 2003, 2004, 2005) and all streamflow data are available online at http://waterdata.usgs.gov/ri/nwis/sw or http://waterdata.usgs.gov/ct/nwis/sw through the USGS National Water Information System (NWIS). At the nine short-term stations operated for part of the study period, streamflow records (daily mean discharge) were estimated by use of record-extension techniques for the periods when the stations were not operating. Streamflow records for each of the nine short-term stations were related to concurrent daily mean streamflows for at least one nearby index station. The list of index stations used and the correlation coefficients describing the relations between the short-term stations and the index stations are listed in table 1–6.

Table 1–3. U.S. Geological Survey continuous streamflow-gaging stations operated in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[USGS station no.: Locations shown in figure 1–3. USGS, U.S. Geological Survey; no., number; mi², square miles; IDLOCN, identification attribute in the Watershed Data Management (WDM) database for the Hydrologic Simulation Program-FORTRAN model; RCHRES, river or reservoir reach for the Hydrologic Simulation Program-FORTRAN model; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; St., Street; p, present; ft, feet; mi, miles; --, not applicable]

USGS station no.	Station name	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi^2)	Period of record	Remarks	Station IDLOCN	Stream reach No. (RCHRES)	Sub-basin IDLOCN
011173545	Queen River, 1,400 ft upstream Williams Reynolds Rd. at Exeter, RI	41.5658	-71.5475	3.69	2000–05	Occasional upstream withdrawals for irrigation at golf course from April through November.	QRPB	2	QUEN2
01117350	Chipuxet River, State Rte. 138 at West Kingston, RI	41.4823	-71.5512	9.99	1958–60, 1973–p	Occasional upstream withdrawals for irrigation at turf farms from May through October and by supply wells year round.	CRWK	32	CHIP2
01117370	Queen River, Liberty Rd. at Liberty, RI	41.5390	-71.5687	19.1	1999–p		QRLY	9	QUEN4
01117410	Usquepaug River, State Rte. 138 at Usquepaug, RI	41.5026	-71.6078	32.8	1999–2005	Occasional upstream withdrawals for irrigation at turf farms from May through October.	URUS	19	QUEN6
01117420	Usquepaug River, State Rte. 2 near Usquepaug, RI	41.4768	-71.6048	36.1	1974–p	Occasional upstream withdrawals for irrigation at turf farms and golf courses from April through November.	USQU	20	QUEN7
01117424	Chickasheen Brook, Liberty Lane at West Kingston, RI	41.4804	-71.5734	4.82	2002–05	Occasional upstream withdrawals for irrigation at turf farms from May through October.	CBLL	36	CHIC2
01117430	Pawcatuck River, State Rte. 2 at Kenyon, RI	41.4462	-71.6212	72.7	1958–60, 2002–05, 2007–p		PRBC	37	PAWC2
01117468	Beaver River, State Rte. 138 near Usquepaug, RI	41.4926	-71.6281	8.87	1974–p		BRUS	42	BEAV2
01117471	Beaver River, Shannock Hill Rd. near Shannock, RI	41.4643	-71.6278	11.2	2002–05	Occasional upstream withdrawals for irrigation at turf farms from May through October.	BRSH	43	BEAV3
01117472	Beaver River, 1 mi downstream Shannock Hill Rd. at Kenyon, RI	41.4523	-71.6281	11.7	1975–78	Not operated during the study period. Occasional upstream withdrawals for irrigation at turf farms from May through October.	--	--	--
01117500	Pawcatuck River, State Rte. 91 at Wood River Junction, RI	41.4451	-71.6809	100	1940–p	Occasional upstream withdrawals for irrigation at turf farms from May through October.	PRWR	46	PAWC3
01117600	Meadow Brook, Pine Hill Rd. near Carolina, RI	41.4665	-71.6901	5.53	1965–74, 2002–05		MBCA	47	MEAD1
01117800	Wood River, State Rte. 165 near Arcadia, RI	41.5740	-71.7206	35.2	1964–81, 1983–p		WRAR	53	WOOD2
01118000	Wood River, 0.2 mi upstream Interstate 95 at Hope Valley, RI	41.4982	-71.7165	72.4	1941–p		WRHV	63	WOOD5
01118010	Pawcatuck River, Burdickville Rd. at Burdickville, RI	41.4162	-71.7290	205	2002–05		PRBV	50	PAWC4
01118300	Pendleton Hill Brook, Grindstone Hill Rd. near Clarks Falls, CT	41.4748	-71.8342	4.02	1959–p		PHBK	74	PEND1
01118360	Ashaway River, Laurel St. at Ashaway, RI	41.4234	-71.7917	28.6	2002–05		ASHA	77	ASHA1
01118400	Shunock River, State Rte. 49 near North Stonington, CT	41.4101	-71.8448	17.2	2002–05		SRNS	83	SHUN2
01118500	Pawcatuck River, 500 ft downstream Arch St. at Westerly, RI	41.3837	-71.8331	295	1940–p	Upstream withdrawals by supply wells year round.	PRWS	84	PAWC9

Table 1–4. U.S. Geological Survey partial-record stations measured in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[USGS station no.: Locations shown in figure 1–3. USGS, U.S. Geological Survey; no., number; mi^2, square miles; IDLOCN, identification attribute in the Watershed Data Management (WDM) database for the Hydrologic Simulation Program-FORTRAN model; RCHRES, river or reservoir reach for the Hydrologic Simulation Program-FORTRAN model; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; --, not applicable]

USGS station no.	Station name	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi^2)	Period of record	Number of measurements	Remarks	Station IDLOCN	Stream reach No. (RCHRES)	Sub-basin IDLOCN
01117336	Chipuxet River, Yawgoo Valley Rd. near West Kingston, RI	41.5176	-71.5253	6.34	1959–60, 1972, 1980, 2002–04	19	Occasional upstream withdrawals for irrigation at turf farms from May through October.	CRWK-p	31	CHIP1
01117354	Queen River, State Rte. 102 at Exeter, RI	41.5787	-71.5431	2.8	1993, 2000–04	29		QECC-p	1	QUEN1
01117355	Queen River, William Reynolds Rd. near Exeter, RI	41.5626	-71.5478	3.69	1959–60, 1988–93, 1999–2002	63	Occasional upstream withdrawals for irrigation at golf course from April through November.	QREX-p	3	QUEN3
01117360	Fisherville Brook, Liberty Church Rd. near Exeter, RI	41.5643	-71.5645	8.14	1959–60, 1988–93, 2000–04	65		FBEX-p	5	FISH2
01117365	Queens Fort Brook, Slocumville Rd. near Exeter, RI	41.5482	-71.5331	3.22	1988–91, 1996–97	46	Not measured during study period and not used in study.	--	--	--
01117367	Queens Fort Brook, intersection of Dawley Rd. and School Lands Rd. near Liberty, RI	41.5465	-71.5526	4.09	2000–03	29	Occasional upstream withdrawals for irrigation at turf farms from May through October.	QFBK-p	8	QUFB2
01117368	Queen River, Dawley Rd. near Liberty, RI	41.5487	-71.5603	18.4	1993, 2000–02	23	Not used in study.	--	--	--
01117375	Unnamed Tributary to Queen River, Mail Rd. at Liberty, RI	41.5390	-71.5795	0.82	1988–91, 1999–2004	48		UTLY-p	11	TRIB1
01117380	Locke Brook, Mail Rd. at Liberty, RI	41.5373	-71.5876	4.37	1959–60, 1988–91, 1993, 2000–04	61		LBLY-p	14	LOCK1
01117385	Rake Factory Brook, Glen Rock Rd. at Glen Rock, RI	41.5190	-71.5990	0.25	1988–91, 1999–2004	51		RFBK-p	16	RAKE
01117390	Glen Rock Brook, Glen Rock Rd. at Glen Rock, RI	41.5165	-71.6059	2.83	1988–91, 1993, 2000–04	59		GRGR-p	18	GLEN1
01117400	Sherman Brook, Glen Rock Rd. at Glen Rock, RI	41.5179	-71.6045	1.04	1966–74, 1989–91, 1993, 2000–04	58	Occasional upstream withdrawals for irrigation at vegetable farms from May through October.	SBGR-p	17	SHER1
01117421	Chickasheen Brook, State Rte. 2 at West Kingston, RI	41.4984	-71.5648	3.26	2002–04	14	Occasional upstream withdrawals for irrigation at turf farms from May through October.	CBLL-p	35	CHIC1
01117450	Pasquiset Brook, State Rte. 2 at Kenyon, RI	41.4440	-71.6270	6.32	1966–67, 1974, 1976, 1980, 2002–04	20		PBWY-p	44	PASQ1
01117465	Beaver River, Hillsdale Rd. near Wyoming, RI	41.5257	-71.6392	5.53	1966–67, 1974, 1976, 1991, 2002–04	22		BRWY-p	41	BEAV1
01117480	Taney Brook, Shannock Hill Rd. at Carolina, RI	41.4607	-71.6478	1.67	1966–67, 2002–04	18		TBCA-p	45	TANE1

Table 1–4. U.S. Geological Survey partial-record stations measured in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.—Continued

[USGS station no.: Locations shown in figure 1–3. USGS, U.S. Geological Survey; no., number; mi², square miles; IDLOCN, identification attribute in the Watershed Data Management (WDM) database for the Hydrologic Simulation Program-FORTRAN model; RCHRES, river or reservoir reach for the Hydrologic Simulation Program-FORTRAN model; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; --, not applicable]

USGS station no.	Station name	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi^2)	Period of record	Number of measurements	Remarks	Station IDLOCN	Stream reach No. (RCHRES)	Sub-basin IDLOCN
01117700	Cedar Swamp Brook, Kings Factory Rd. at Wood River Junction, RI	41.4270	-71.6951	5.1	1966–67, 2002–04	18		CSBK-p	49	CEDA1
01117720	Wood River, Falls River Rd. at Escoheag, RI	41.6126	-71.7603	11.4	1966–67, 1991, 2002–04	20		WREH-p	51	WOOD1
01117740	Kelley Brook, Falls River Rd. at Escoheag, RI	41.6123	-71.7531	4.2	1966–67, 1991, 2002–04	20		KBEH-p	52	KELL1
01117750	Factory Brook, Plain Meetinghouse Rd. near Summit, RI	41.6332	-71.7223	1.31	1966, 2002–04	15	Not used in study.	--	--	--
01117760	Flat River, Plain Rd. near Arcadia, RI	41.5957	-71.7201	8.38	1978, 1982, 2002–04	15		FRAR-p	54	FLAT1
01117780	Breakheart Brook, Frosty Hollow Rd. near Arcadia, RI	41.5879	-71.7095	6.68	1966–67, 1979, 1982, 1991–92, 2002–04	22		BBAR-p	55	BREA1
01117840	Parris Brook, Blitzkrieg Trail near Arcadia, RI	41.5651	-71.7259	7.18	1966–67, 1979, 1991, 2002–04	22		PBAR-p	56	PARR1
01117860	Roaring Brook, Arcadia Rd. at Arcadia, RI	41.5584	-71.6851	5.01	1966–67, 1991, 2002–04	21		RBAR-p	58	ROAR1
01117900	Brushy Brook, Sawmill Rd. near Hope Valley, RI	41.5287	-71.7365	3.71	1966–67, 1977, 1979, 1991, 2002–04	21		BBHV-p	60	BRUS1
01117950	Moscow Brook, Sawmill Rd. near Hope Valley, RI	41.5273	-71.7362	6.37	1966–67, 1977, 1979, 1991, 2002–04	22		MBHV-p	61	MOSC1
01118006	Canonchet Brook, Woodville-Alton Rd. near Hope Valley, RI	41.4776	-71.7292	5.89	1977, 1979–80, 1991, 2002–04	19	Occasional upstream withdrawals for irrigation at golf course from April through November.	CBHV-p	64	CANO1
01118008	Wood River Tributary, Woodville-Alton Rd. at Alton, RI	41.4376	-71.7231	2.05	1977, 2002–04	15		CHAL-p	66	COON1
01118009	Wood River, State Rte. 91 near Alton, RI	41.4362	-71.7209	85.7	1977, 1979–81, 1991, 2002–04	18	Occasional upstream withdrawals for irrigation at turf farms from May through October.	WRAL-p	65	WOOD6
01118022	Perry-Healy Brook, Klondike Rd. near Bradford, RI	41.3745	-71.7159	2.36	2002–04	13		PHBB-p	67	PERR1
01118055	Tomaquag Brook, State Rte. 216 at Bradford, RI	41.4111	-71.7642	6.67	1991, 2002–04	16		TBBF-p	70	TOMA1
01118255	Green Fall River, Putker Rd. at Laurel Glen, CT	41.4723	-71.8162	7.42	1963–67, 2002–04	24		GRLG-p	73	GREE1
01118340	Wyassup Brook, State Rte. 216 at Clarks Falls, CT	41.4547	-71.8267	11.5	2002–04	14		WBCF-p	75	WYAS1

Table 1–4. U.S. Geological Survey partial-record stations measured in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.—Continued

[USGS station no.: Locations shown in figure 1–3. USGS, U.S. Geological Survey; no., number; mi^2, square miles; IDLOCN, identification attribute in the Watershed Data Management (WDM) database for the Hydrologic Simulation Program-FORTRAN model; RCHRES, river or reservoir reach for the Hydrologic Simulation Program-FORTRAN model; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; --, not applicable]

USGS station no.	Station name	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi^2)	Period of record	Number of measurements	Remarks	Station IDLOCN	Stream reach No. (RCHRES)	Sub-basin IDLOCN
01118350	Green Fall River, State Rte. 216 at Clarks Falls, CT	41.4548	-71.8140	19.8	1961–73	25	Not measured during study period and not used in study.	--	--	--
01118352	Glade Brook, Pine Woods Rd. near Laurel Glen, CT	41.4682	-71.8081	1.92	1965–67, 2002–04	18		GBLG-p	76	GLAD1
01118355	Parmenter Brook, Extension 184 near Hopkinton, RI	41.4476	-71.7903	2.54	1966–67, 2002–04	17		PBHK-p	78	PARM1
01118365	Lewis Pond Outlet, Boom Bridge Rd. near Potter Hill, RI	41.4204	-71.8217	1.59	1966–67, 2002–04	18		LPPH-p	79	LWPD1
01118373	Shunock River, Main St. at North Stonington, CT	41.4409	-71.8823	7.79	1965, 2002–04	15		SRPH-p	81	SHUN1
01118375	Assekonk Brook, Jeremy Hill Rd. near North Stonington, CT	41.4387	-71.9104	1.63	1963–65, 2002–04	26		--	--	--
01118380	Assekonk Brook, State Rte. 2 at North Stonington, CT	41.4387	-71.8842	4.54	1963–65, 2002–04	22		ABNS-p	82	ASSE1

Table 1–5. Streamflow and estimated baseflow for selected U.S. Geological Survey streamflow-gaging stations in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04 and 1942–2004.

[Locations shown in figure 1–5. ft^3/s, cubic feet per second; RI, Rhode Island]

		Streamflow (ft^3/s)			Estimated baseflow (ft^3/s)[1]			Estimated percentage of baseflow to streamflow		
	Period	Pawcatuck River at Wood River Junction, RI (01117500)	Wood River at Hope Valley, RI (01118000)	Pawcatuck River at Westerly, RI (01118500)	Pawcatuck River at Wood River Junction, RI (01117500)	Wood River at Hope Valley, RI (01118000)	Pawcatuck River at Westerly, RI (01118500)	Pawcatuck River at Wood River Junction, RI (01117500)	Wood River at Hope Valley, RI (01118000)	Pawcatuck River at Westerly, RI (01118500)
	2000	201	145	570	176	122	481	87.5	84.1	84.4
	2001	209	165	595	184	137	506	88.4	83.0	85.0
	2002	135	103	397	118	87	330	87.3	84.6	83.1
	2003	247	185	721	221	157	615	89.5	84.5	85.3
	2004	199	151	573	176	129	488	88.6	85.2	85.3
Study period										
Mean	2000–04	198	150	571	175	126	484	88.4	84.2	84.8
Long-term period										
Mean	1942–2004	196	156	577	176	132	501	89.9	85.0	86.8
Minimum	1942–2004	99	85	296	89	74	258	89.4	86.8	87.4
Maximum	1942–2004	322	254	914	287	204	789	89.3	80.3	86.3

[1] Baseflow estimated using the computer program PART (Rutledge, 1998).

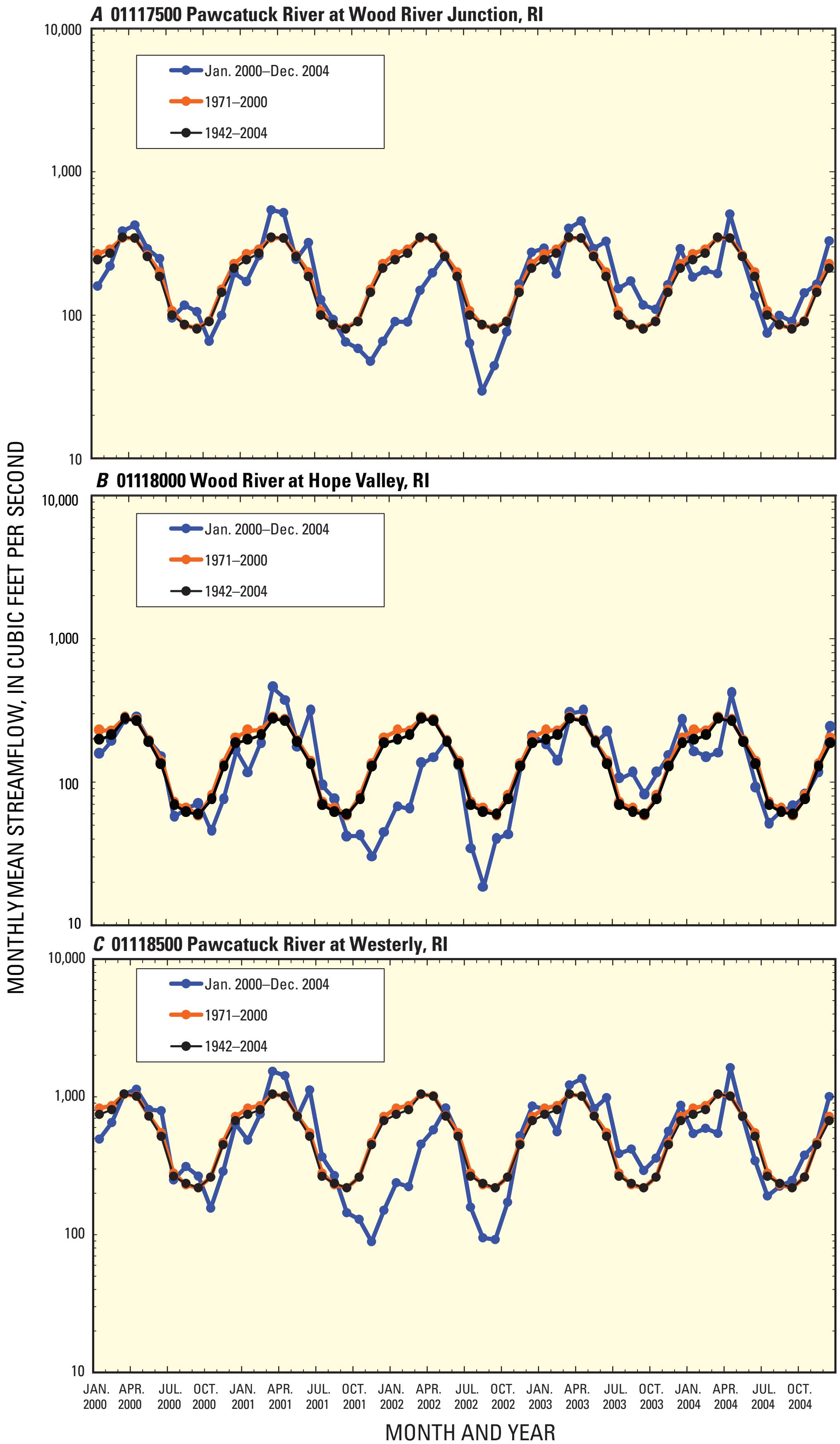


Figure 1–6. Mean monthly streamflows for selected long-term U.S. Geological Survey streamflow-gaging stations in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

Table 1–6. Relation of U.S. Geological Survey short-term streamflow-gaging stations and partial-record stations to nearby long-term index streamflow-gaging stations used to estimate streamflow records in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[USGS station no.: Locations shown in figure 1–3 and described in table 1–3 for streamflow-gaging stations and in table 1–4 for partial-record stations. USGS, U.S. Geological Survey; no., number; ft, feet; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; --, not applicable]

USGS station no.	Station name	Number of measurements used in relation to index gages	Correlation coefficient — Long-term index streamflow-gaging stations[1]: Queen River at Liberty Rd. at Liberty, RI (01117370)	Usquepaug River near Usquepaug, RI (01117420)	Beaver River near Usquepaug, RI (01117468)	Pawcatuck River at Wood River Junction, RI (01117500)	Wood River near Arcadia, RI (01117800)	Wood River at Hope Valley, RI (01118000)	Pendleton Hill Brook near Clarks Falls, CT (01118300)	Remarks
	Short-term streamflow-gaging stations[2]									
011173545	Queen River 1,400 ft upstream Williams Reynolds Rd. at Exeter, RI	--	--	--	--	--	--	--	--	No analysis was done.
01117410	Usquepaug River at Rte. 138 at Usquepaug, RI	1,605	--	0.99	--	--	--	--	--	
01117424	Chickasheen Brook at West Kingston, RI	731	0.92	--	0.94	--	--	--	--	
01117430	Pawcatuck River at Rte. 2 at Kenyon, RI	1,752	--	--	--	0.98	--	0.92	--	
01117471	Beaver River at Shannock Hill Rd. near Shannock, RI	731	--	--	0.98	--	--	--	--	
01117600	Meadow Brook near Carolina, RI	791	0.93	--	0.96	--	--	--	0.91	
01118010	Pawcatuck River at Burdickville, RI	787	--	--	--	0.99	0.97	0.98	--	
01118360	Ashaway River at Ashaway, RI	777	--	--	0.91	--	0.94	--	--	
01118400	Shunock River at North Stonington, CT	731	--	--	0.92	--	0.95	--	--	
	Partial-record stations									
01117336	Chipuxet River, Yawgoo Valley Rd. near West Kingston, RI	15	--	--	0.90	--	0.88	--	0.88	
01117354	Queen River, State Rte. 102 at Exeter, RI	27	--	--	0.96	--	0.96	--	0.86	
01117355	Queen River, William Reynolds Rd. near Exeter, RI	--	--	--	--	--	--	--	--	No analysis was done.
01117360	Fisherville Brook, Liberty Church Rd. near Exeter, RI	61	--	--	0.98	--	0.95	--	0.91	
01117365	Queens Fort Brook, Slocumville Rd. near Exeter, RI	12	--	--	0.94	--	0.94	--	0.97	Correlation was based on arithmetic relation (streamflows were not transformed to logarithmic units).
01117367	Queens Fort Brook, intersection of Dawley Rd. and School Lands Rd. near Liberty, RI	27	--	--	0.95	--	0.91	--	0.87	
01117368	Queen River, Dawley Rd. near Liberty, RI	--	--	--	--	--	--	--	--	No analysis was done.
01117375	Unnamed Tributary to Queen River, Mail Rd. at Liberty, RI	40	--	--	0.97	--	0.95	--	0.96	Correlation was based on arithmetic relation (streamflows were not transformed to logarithmic units).

Table 1–6. Relation of U.S. Geological Survey short-term streamflow-gaging stations and partial-record stations to nearby long-term index streamflow-gaging stations used to estimate streamflow records in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.—Continued

[USGS station no.: Locations shown in figure 1–3 and described in table 1–3 for streamflow-gaging stations and in table 1–4 for partial-record stations. USGS, U.S. Geological Survey; no., number; ft, feet; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; --, not applicable]

USGS station no.	Station name	Number of measurements used in relation to index gages	Correlation coefficient							Remarks
			Long-term index streamflow-gaging stations[1]							
			Queen River at Liberty Rd. at Liberty, RI (01117370)	Usquepaug River near Usquepaug, RI (01117420)	Beaver River near Usquepaug, RI (01117468)	Pawcatuck River at Wood River Junction, RI (01117500)	Wood River near Arcadia, RI (01117800)	Wood River at Hope Valley, RI (01118000)	Pendleton Hill Brook near Clarks Falls, CT (01118300)	
Partial-record stations—Continued										
01117380	Locke Brook, Mail Rd. at Liberty, RI	56	--	--	0.97	--	0.97	--	0.93	
01117385	Rake Factory Brook, Glen Rock Rd. at Glen Rock, RI	47	--	--	0.92	--	0.95	--	0.97	Correlation was based on arithmetic relation (streamflows were not transformed to logarithmic units).
01117390	Glen Rock Brook, Glen Rock Rd. at Glen Rock, RI	58	--	--	0.96	--	0.94	--	0.95	
01117400	Sherman Brook, Glen Rock Rd. at Glen Rock, RI	53	--	--	0.94	--	0.93	--	0.95	
01117421	Chickasheen Brook, State Rte. 2 at West Kingston, RI	12	--	--	0.91	--	0.89	--	0.84	
01117450	Pasquiset Brook, State Rte. 2 at Kenyon, RI	15	--	--	0.92	--	0.90	--	0.89	
01117465	Beaver River, Hillsdale Rd. near Wyoming, RI	16	--	--	0.94	--	0.96	--	0.97	
01117480	Taney Brook, Shannock Hill Rd. at Carolina, RI	14	--	--	0.94	--	0.92	--	0.90	
01117700	Cedar Swamp Brook, Kings Factory Rd. at Wood River Junction, RI	13	--	--	0.95	--	0.93	--	0.94	
01117720	Wood River, Falls River Rd. at Escoheag, RI	15	--	--	0.87	--	0.95	--	0.98	
01117740	Kelley Brook, Falls River Rd. at Escoheag, RI	15	--	--	0.88	--	0.95	--	0.94	
01117750	Factory Brook, Plain Meetinghouse Rd. near Summit, RI	14	--	--	0.92	--	0.93	--	0.96	
01117760	Flat River, Plain Rd. near Arcadia, RI	14	--	--	0.97	--	0.97	--	0.90	
01117780	Breakheart Brook, Frosty Hollow Rd. near Arcadia, RI	17	--	--	0.95	--	0.97	--	0.93	
01117840	Parris Brook, Blitzkrieg Trail near Arcadia, RI	17	--	--	0.92	--	0.96	--	0.98	
01117860	Roaring Brook, Arcadia Rd. at Arcadia, RI	16	--	--	0.92	--	0.94	--	0.91	
01117900	Brushy Brook, Sawmill Rd. near Hope Valley, RI	17	--	--	0.93	--	0.97	--	0.98	

Table 1–6. Relation of U.S. Geological Survey short-term streamflow-gaging stations and partial-record stations to nearby long-term index streamflow-gaging stations used to estimate streamflow records in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.—Continued

[USGS station no.: Locations shown in figure 1–3 and described in table 1–3 for streamflow-gaging stations and in table 1–4 for partial-record stations. USGS, U.S. Geological Survey; no., number; ft, feet; RI, Rhode Island; CT, Connecticut; Rte., Route; Rd., Road; --, not applicable]

USGS station no.	Station name	Number of measurements used in relation to index gages	Correlation coefficient: Long-term index streamflow-gaging stations[1]							Remarks
			Queen River at Liberty Rd. at Liberty, RI (01117370)	Usquepaug River near Usquepaug, RI (01117420)	Beaver River near Usquepaug, RI (01117468)	Pawcatuck River at Wood River Junction, RI (01117500)	Wood River near Arcadia, RI (01117800)	Wood River at Hope Valley, RI (01118000)	Pendleton Hill Brook near Clarks Falls, CT (01118300)	
Partial-record stations—Continued										
01117950	Moscow Brook, Sawmill Rd. near Hope Valley, RI	18	--	--	0.92	--	0.96	--	0.96	
01118006	Canonchet Brook, Woodville-Alton Rd. near Hope Valley, RI	19	--	--	0.99	--	0.97	--	0.91	
01118008	Wood River Tributary, Woodville-Alton Rd. at Alton, RI	15	--	--	0.99	--	0.98	--	0.91	
01118009	Wood River, State Rte. 91 near Alton, RI	18	--	--	--	0.96	0.96	0.99	--	
01118022	Perry-Healy Brook, Klondike Rd. near Bradford, RI	12	--	--	0.98	--	0.96	--	0.96	
01118055	Tomaquag Brook, State Rte. 216 at Bradford, RI	16	--	--	0.97	--	0.96	--	0.94	
01118255	Green Fall River, Putker Rd. at Laurel Glen, CT	11	--	--	0.96	--	0.97	--	0.99	
01118340	Wyassup Brook, State Rte. 216 at Clarks Falls, CT	14	--	--	0.97	--	0.97	--	0.96	
01118350	Green Fall River, State Rte. 216 at Clarks Falls, CT	--	--	--	--	--	--	--	--	No analysis was done.
01118352	Glade Brook, Pine Woods Rd. near Laurel Glen, CT	14	--	--	0.96	--	0.96	--	0.98	Correlation was based on arithmetic relation (streamflows were not transformed to logarithmic units).
01118355	Parmenter Brook, Extension 184 near Hopkinton, RI	14	--	--	0.95	--	0.95	--	0.99	
01118365	Lewis Pond Outlet, Boom Bridge Rd. near Potter Hill, RI	14	--	--	0.96	--	0.96	--	0.92	
01118373	Shunock River, Main St. at North Stonington, CT	14	--	--	0.97	--	0.97	--	0.93	
01118375	Assekonk Brook, Jeremy Hill Rd. near North Stonington, CT	13	--	--	0.95	--	0.99	--	0.99	Correlation was based on arithmetic relation (streamflows were not transformed to logarithmic units).
01118380	Assekonk Brook, State Rte. 2 at North Stonington, CT	14	--	--	0.92	--	0.93	--	0.99	

[1] Long-term index streamflow-gaging stations are generally naturally flowing sites that are part of the long-term network of streamflow-gaging stations in Rhode Island and Connecticut.
[2] Short-term streamflow-gaging stations were installed and operated during part of the study.

Partial-Record Stations

To augment the data from the continuous streamflow-gaging stations, miscellaneous streamflow data were collected at 40 partial-record stations (table 1–4 and fig. 1–3), mostly located on tributary streams to the major rivers within the Pawcatuck River Basin. Periodic streamflow measurements made at these stations, generally during base-flow conditions (about 2 to 5 days after a precipitation event), were mainly correlated with concurrent daily mean discharges representing natural-flow conditions at three nearby long-term index stations—Beaver River at Usquepaug (01117468), Wood River near Arcadia (01117800), and Pendleton Hill Brook near Clarks Falls, Conn. (01118300)—to obtain a continuous discharge record (table 1–6). Streamflows at each partial-record station were measured 11 to 61 times during this study and in past studies. Streamflow measurements at partial-record stations are published in the Annual Water Resources Data Reports for Massachusetts and Rhode Island (Socolow and others, 2001, 2002, 2003, 2004, 2005) for the water years (October 1 to September 30) in which the measurements were made. The number of correlated streamflow measurements depended on the availability of concurrent streamflow records at the index station (table 1–6). For example, the Beaver River at Usquepaug (0117468) station did not begin operation until December 1974, so streamflow measurements made prior to 1974 at partial-record stations were not included in this analysis. Correlations were generally made for a wide range of discharges (low flows through at least medium flows) at each partial-record station.

A mathematical procedure developed by Hirsch (1982) known as Maintenance of Variance Extension (MOVE.1) was applied to logarithms of the measured streamflow at each partial-record station and the same-day daily mean discharge at the index stations. Scatter plots indicated which relations between the log-transformed measured streamflow at each partial-record station and the same-day log-transformed daily mean discharges at each of the index stations were linear. Estimated daily mean discharges for water years 2000–04 were computed for each partial-record station from the streamflow records for the selected index stations (based on a linear relation, a high correlation coefficient, and general drainage-area size) (table 1–6) by the MOVE.1 procedure. The final daily mean discharge at each partial-record station for water years 2000–04 was then computed by a weighted average of the mean daily discharges for each index station. Each index-station discharge was weighted on the basis of the mean square error between the computed discharge and the measured discharge at the partial-record station.

The retransformation of the computed logs of discharges into arithmetic units for each equation can create a bias. This bias was evaluated by Duan's smearing method (Duan, 1983); however, a bias-correction factor was not applied to the retransformed log discharges because the overall bias among index stations was generally small (less than a few percent).

The accuracy of this record-extension technique is determined by the goodness-of-fit between the instantaneous discharge measurements at the partial-record station and the same-day daily mean discharge records at continuous streamflow-gaging stations, the accuracy of the instantaneous discharge measurements, the accuracy of the continuous-discharge record, and the range of the flows measured at the partial-record station. Because each of these factors can introduce error, the extrapolated records for the partial-record stations are considered estimates. Because most measurements at the partial-record stations were made during low to moderate flows, the estimates of daily discharge during high flows could be poor.

Baseflow

Baseflow (groundwater discharge) is that part of streamflow that discharges from an aquifer to the stream channel upstream from the measuring point. Groundwater discharges to streams and is typically the principal component of streamflow 3 to 7 days after a peak in streamflow caused by periods of precipitation or snowmelt. During most years, groundwater levels and baseflow decrease during the growing season. Annual baseflow can vary significantly with annual precipitation and long-term variations in groundwater storage.

Baseflow was estimated from streamflow by the computer program PART (Rutledge, 1998), which uses an automated hydrograph-separation technique. Mean annual baseflow from the Pawcatuck River Basin is estimated to be about 501 ft^3/s (about 87 percent of mean annual streamflow) on the basis of analysis of streamflow records for the Pawcatuck River at Westerly (01118500) station from 1942 through 2004 (table 1–5). Baseflow also was estimated for the Pawcatuck River at Wood River Junction (01117500) and the Wood River at Hope Valley (01118000) stations. The long-term mean annual baseflows for these two stations were about 176 and 132 ft^3/s (about 90 and 85 percent of the respective mean annual streamflows) for 1942–2004. During the study period (2000–04), mean annual baseflows for the stations Pawcatuck River at Wood River Junction, Wood River at Hope Valley, and Pawcatuck River at Westerly were 175, 126, and 484 ft^3/s (about 88, 84, and 85 percent of the respective mean annual streamflows during 2000–04); these values are fairly close to the long-term means for 1942–2004. During 2002, however, baseflows were about 32 to 34 percent lower than the long-term means, and in 2003, baseflows were 19 to 26 percent higher than the long-term means.

Ponds and Wetlands

Numerous ponds throughout the Pawcatuck River Basin make up about 2.7 percent of the area in the basin (fig. I–3). During the period 2003–04, water levels were measured 1 to 2 times per month at 22 of the larger ponds across the basin (table 1–7 and fig. 1–7). Water-level measurements were made during 2000–02 for one pond (Glen Rock Reservoir). Water levels for ponds in the basin generally fluctuated about 0.3 to 2.1 ft during the 1.5 years of miscellaneous measurements. Several of the ponds were affected by water withdrawals for irrigation and other regulations, specifically Yawgoo Mill Pond, Hundred Acre Pond, Thirty Acre Pond, Barber Pond, and Glen Rock Reservoir (table 1–7 and fig. 1–7). Water levels in these ponds could be affected by these regulations, especially during the summer (June through August) and early fall (September and October). Additionally, several unidentified ponds may be affected by lowering of water levels in the fall to kill weeds over the winter and then refilling of the pond in the spring.

Wetlands make up a significant portion of the Pawcatuck River Basin. Nonforested wetlands occupy about 2.3 percent and forested wetlands about 12.5 percent of the basin. Wetlands are mainly in the southern part of the basin along the Pawcatuck River, with extensive areas upstream of the Pawcatuck River at Kenyon (station 01117430) to Worden Pond; around the north side of Worden Pond at the mouths of the Chipuxet River, Chickasheen Brook, and the Usquepaug River; and around Cedar Swamp Brook (south side of the Pawcatuck River in Charlestown), Watchaug Pond, and Chapman Pond (figs. I–3 and 1–7).

Water Withdrawals

Municipal groundwater withdrawals and irrigation were the primary water uses in the basin during the study period (2000–04). Municipal withdrawals averaged 7.18 Mgal/d during the study period. Irrigation in the basin is mainly for turf farms (4.40 mi^2) and golf courses (0.76 mi^2); irrigation for vegetable farms (0.41 mi^2) and tree nurseries (0.005 mi^2) was minor. Estimated agricultural (turf, vegetables, and tree nurseries) and golf course irrigation withdrawals totaled 8.44 and 0.88 Mgal/d, respectively, on an average day of irrigation in the basin during the study period. Unlike domestic water use, irrigation can vary widely from day to day, season to season, and among farms. Irrigation water use may be estimated from climatic factors, but estimation may also be complicated by limited data from turf farms and golf courses. It was estimated that agricultural irrigation withdrawals occurred on average about 68 days per year from May 1 through October 30, and golf course irrigation occurred on average about 140 days per year from April 16 through November 15 during the study period. If measured withdrawal data were available, they were incorporated into the HSPF and MODFLOW models for calibration. Irrigation withdrawals were estimated for unmetered sites and unmetered periods from 1960 through 2004. The irrigation data were estimated by using logistic regression to predict the probability of irrigation on a specific day, an average 24-hr rate of irrigation, and an average rate per unit area on the basis of data collected during 2000–04 (see below).

Municipal Withdrawals

During the study period, five major water suppliers in the basin operated a total of 16 wells (fig. 1–8). The five water suppliers' total average withdrawals for 2000–04 were about 7.18 Mgal/d (table 1–8). Wild and Nimiroski (2004) reported a total average withdrawal rate for these same suppliers of about 6.77 Mgal/d for 1995–99; this value is about 6 percent lower than the value during the study period. During the study period, municipal withdrawals did not vary much from year to year (table 1–8), but during all years, withdrawals were generally greater during May through September and especially during July and August (fig. 1–9). These higher withdrawals during the summer months may be a result of outdoor water use and increases in summer population for communities near the ocean. This pattern of greater municipal withdrawals during the summer months than during the rest of the year was also documented in Rhode Island by Granato and Barlow (2005, p. 32). The only major supplier whose summer withdrawals decreased was the WSCB Well #1; this well supplied a school, and the majority of students were not at the school during most of May through August.

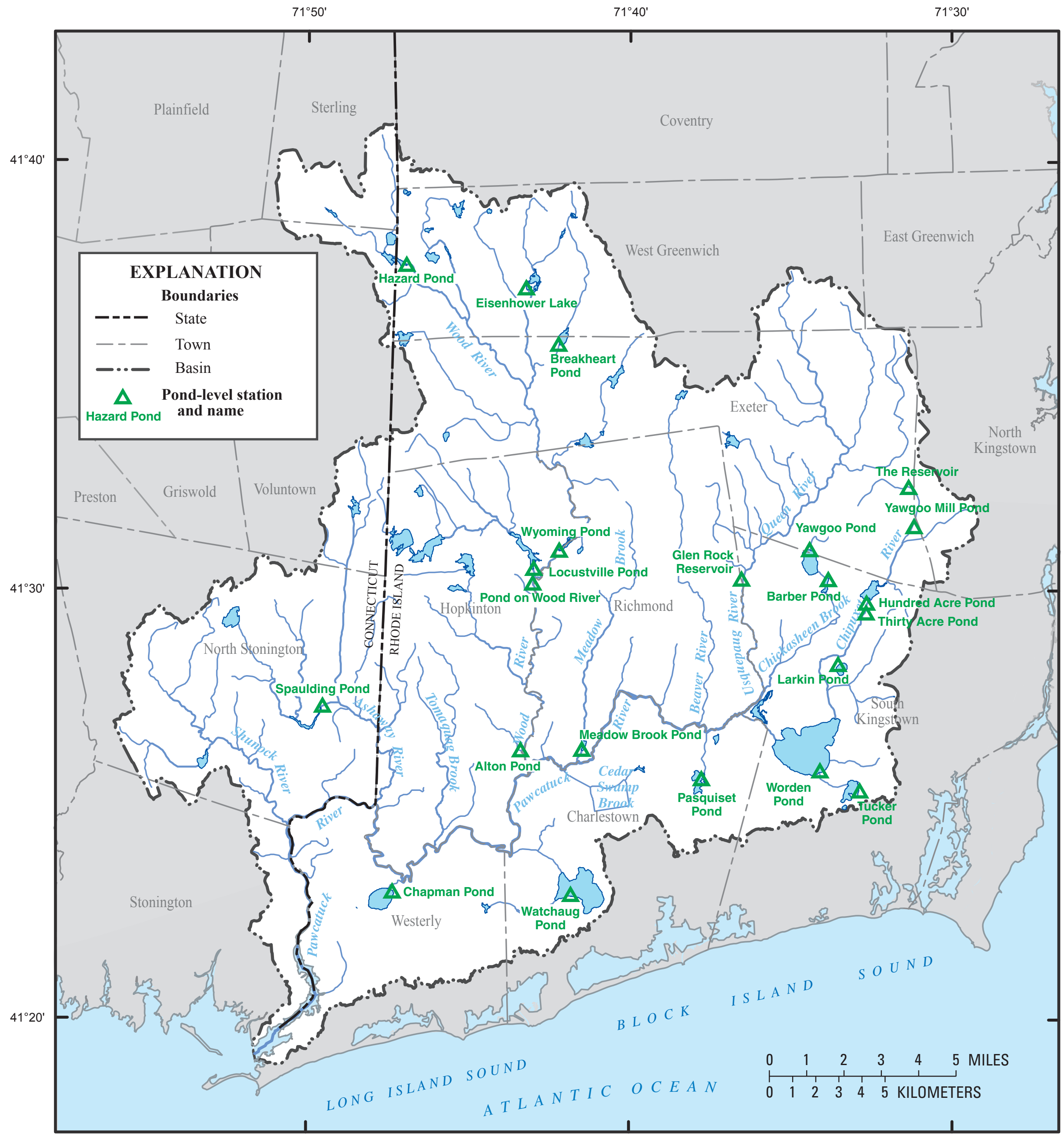
Nonmunicipal Withdrawals

Thirteen minor nonmunicipal suppliers were reported in the basin in 1999 by Wild and Nimiroski (2004, p. 10, 22); these wells withdrew an average of about 0.1 Mgal/d and serviced only about 60 to 200 people each. These minor nonmunicipal suppliers withdraw water from wells registered with the Rhode Island Department of Environmental Management (RIDEM) as serving 25 or more people for a minimum of 60 days. Wild and Nimiroski (2004) estimated that self-supply withdrawals for domestic, commercial, industrial, and agricultural use averaged about 2.3, 0.2, 0.5, and 1.4 Mgal/d during 1995–99 in the Pawcatuck River Basin.

Table 1–7. U.S. Geological Survey pond-level stations in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

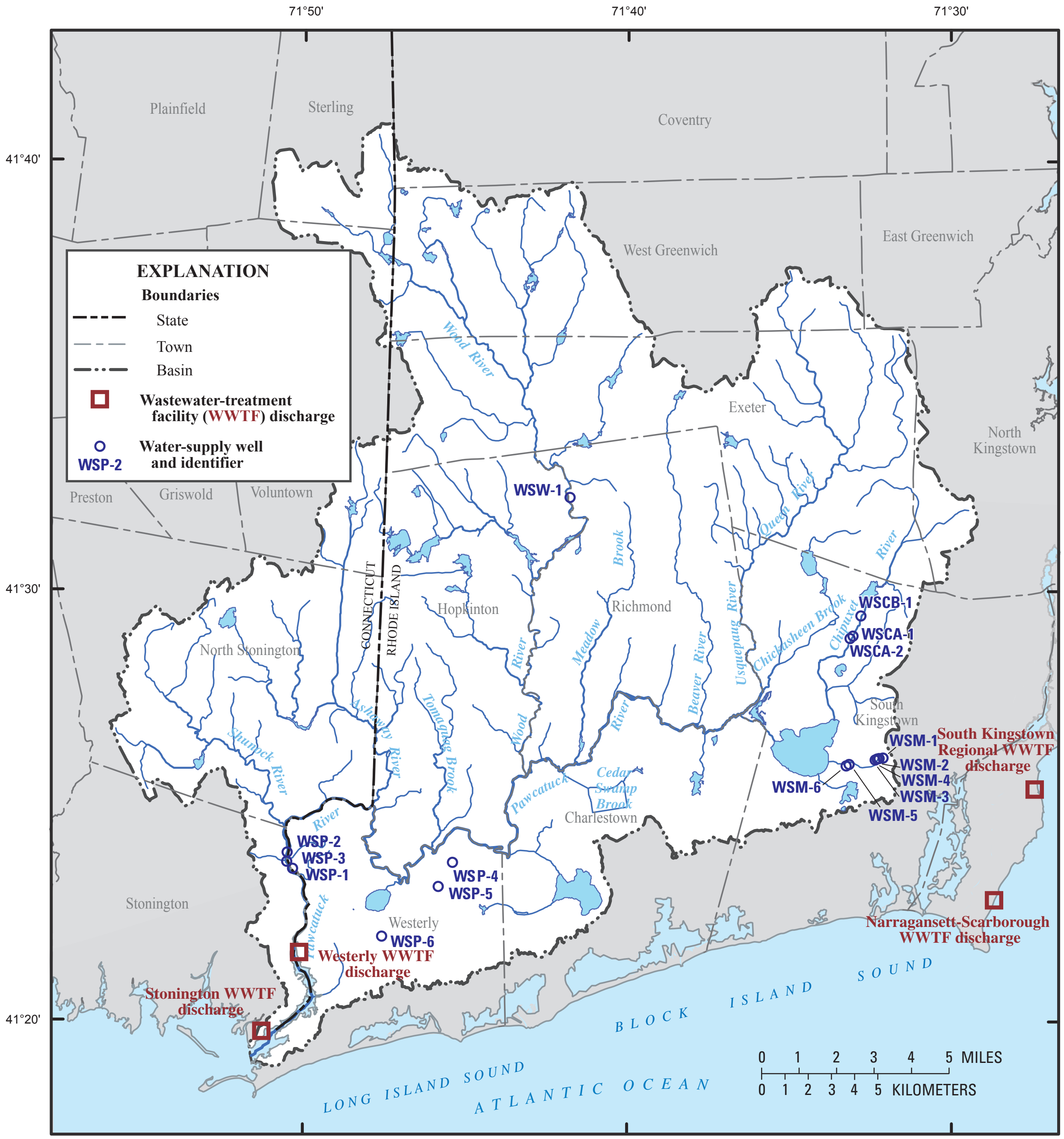
[USGS station no.: Locations shown in figure 1–7. USGS, U.S. Geological Survey; no., number; NAVD 88, North American Vertical Datum 1988; RI, Rhode Island; CT, Connecticut; URI, University of Rhode Island]

USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Period of record	Number of measurements	Water level (feet above NAVD 88)					Remarks
						Average	Median	Minimum	Maximum	Range	
412254071414701	Watchaug Pond, Burlingame State Park, Charlestown, RI	41.3817	-71.6965	04/2003–09/2004	27	36.84	36.83	36.31	37.41	1.10	
412258071471901	Chapman Pond, at Moose Lodge, State Route 91, Westerly, RI	41.3828	-71.7887	04/2003–09/2004	26	30.24	30.20	29.75	31.07	1.32	
412520071325009	Tucker Pond, off a gravel road, South Kingstown, RI	41.4221	-71.5472	04/2003–09/2004	26	92.97	92.96	92.58	93.29	0.71	
412537071374401	Pasquiset Pond, Old Coach Road, Charlestown, RI	41.4269	-71.6290	04/2003–09/2004	26	87.39	87.38	87.14	87.64	0.50	
412548071340401	Worden Pond, Wordens Pond Road, South Kingstown, RI	41.4299	-71.5677	04/2003–09/2004	26	89.38	89.52	88.08	89.98	1.90	
412616071432101	Alton Pond, State Route 91, Hopkinton, RI	41.4378	-71.7225	04/2003–09/2004	30	48.55	48.49	48.27	48.96	0.69	
412617071412701	Meadow Brook Pond, State Route 91, Richmond, RI	41.4382	-71.6909	04/2003–09/2004	28	53.57	53.59	52.94	53.82	0.88	
412718071493001	Spaulding Pond, State Route 216, North Stonington, CT	41.4550	-71.8250	04/2003–09/2004	26	80.19	80.13	79.91	80.67	0.76	
412817071333101	Larkin Pond, at Camp Hoffman, South Kingstown, RI	41.4713	-71.5586	04/2003–09/2004	26	93.41	93.37	93.14	93.73	0.59	
412928071323901	Thirty Acre Pond, Thirty Acre Pond Road, South Kingstown, RI	41.4912	-71.5441	04/2003–09/2004	26	94.83	94.91	93.61	95.70	2.09	Occasional withdrawals for irrigation at turf farms from May through October and manipulation of pond levels.
412943071323801	Hundred Acre Pond, East Hundred Acre Pond Road, South Kingstown, RI	41.4952	-71.5438	04/2003–09/2004	26	95.82	95.90	94.88	96.48	1.60	Occasional withdrawals for irrigation at turf farms from May through October and manipulation of pond levels.
413010071425901	Pond on Wood River, Mechanic Street, Hopkinton, RI	41.5028	-71.7163	04/2003–09/2004	27	76.10	76.06	75.72	76.58	0.86	
413015071334801	Barber Pond, Barber Pond Road, South Kingstown, RI	41.5042	-71.5634	04/2003–09/2004	26	114.79	114.73	114.28	115.37	1.09	Occasional withdrawals for irrigation at turf farms from May through October.
413016071363001	Glen Rock Reservoir, Kenyon Corn Meal Company, South Kingstown, RI	41.5045	-71.6085	03/2000–12/2002 and 05/2003–09/2004	83	111.35	111.30	110.67	112.64	1.97	Occasional withdrawals for irrigation at turf farms from May through October.
413030071425701	Locustville Pond, Locustville Rd., Hopkinton, RI	41.5084	-71.7159	04/2003–09/2004	27	93.74	93.70	93.56	93.98	0.42	
413056071421001	Wyoming Pond, Arcadia Road, Richmond, RI	41.5154	-71.7027	04/2003–09/2004	27	96.83	96.80	96.61	97.10	0.49	
413057071342301	Yawgoo Pond, at Camp Miskiania, Exeter, RI	41.5159	-71.5732	04/2003–09/2004	26	118.88	118.90	118.31	119.63	1.32	
413130071310901	Yawgoo Mill Pond, at dock near pump house, Exeter, RI	41.5249	-71.5193	05/2003–09/2004	30	119.84	119.90	118.77	120.08	1.31	Occasional withdrawals for irrigation at turf farms from May through October.
413224071311901	The Reservoir, Canonicus Camp, Exeter, RI	41.5401	-71.5221	05/2003–09/2004	26	133.86	133.85	133.67	134.23	0.56	
413544071421201	Breakheart Pond, Plain Road, Exeter, RI	41.5955	-71.7034	05/2003–09/2004	27	234.27	234.28	233.91	234.47	0.56	
413703071431301	Eisenhower Lake, on URI dock, West Greenwich, RI	41.6174	-71.7202	04/2003–09/2004	26	206.50	206.51	206.40	206.69	0.29	
413735071465601	Hazard Pond, Hazard Road, West Greenwich, RI	41.6265	-71.7821	04/2003–09/2004	25	326.56	326.57	325.80	327.29	1.49	



Base from U.S. Geological Survey digital data
North American Datum of 1983
Rhode Island state plane projection, 1:24,000

Figure 1–7. Location of U.S. Geological Survey pond-level stations in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.



Base from U.S. Geological Survey digital data
North American Datum of 1983
Rhode Island state plane projection, 1:24,000

Figure 1–8. Location of major water-supply wells and wastewater treatment facilities in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

Table 1–8. Water withdrawals for major water suppliers in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[Locations shown in figure 1–8. Mgal/d, million gallons per day; Jan., January; Sept., September; Dec., December]

Well	Average withdrawals (Mgal/d)					Average withdrawals (Mgal/d)	
	2000	2001	2002	2003	2004	Jan. 2000–Sept. 2004	Jan. 2000–Dec. 2004 (study period)
WSCA							
Well #1	0.168	0.149	0.092	0.191	0.095	0.139	0.139
Well #2	0.219	0.252	0.312	0.198	0.192	0.241	0.235
Subtotal	0.387	0.401	0.404	0.389	0.286	0.380	0.374
WSCB							
Well #1	0.457	0.432	0.404	0.410	0.428	0.424	0.426
WSM							
Well #1	0.044	0.085	0.058	0.056	0.060	0.064	0.061
Well #2	0.344	0.353	0.347	0.346	0.377	0.358	0.354
Well #3	0.057	0.096	0.067	0.065	0.069	0.075	0.071
Well #4	0.450	0.458	0.421	0.431	0.507	0.451	0.453
Well #5	0.759	0.830	0.886	0.969	0.966	0.882	0.882
Well #6	1.084	1.063	1.082	1.191	1.167	1.121	1.118
Subtotal	2.739	2.885	2.860	3.059	3.147	2.950	2.938
WSW							
Well #1	0.052	0.056	0.063	0.057	0.053	0.057	0.056
WSP							
Well #1	0.807	0.882	0.764	0.788	0.629	0.781	0.774
Well #2	1.168	1.300	1.456	1.219	1.379	1.310	1.304
Well #3	0.433	0.502	0.475	0.520	0.460	0.479	0.478
Well #4	0.198	0.138	0.217	0.185	0.212	0.192	0.190
Well #5	0.316	0.369	0.285	0.225	0.273	0.299	0.293
Well #6	0.346	0.427	0.365	0.303	0.309	0.356	0.350
Subtotal	3.267	3.617	3.561	3.240	3.263	3.417	3.390
TOTAL	6.902	7.391	7.292	7.156	7.177	7.228	7.184

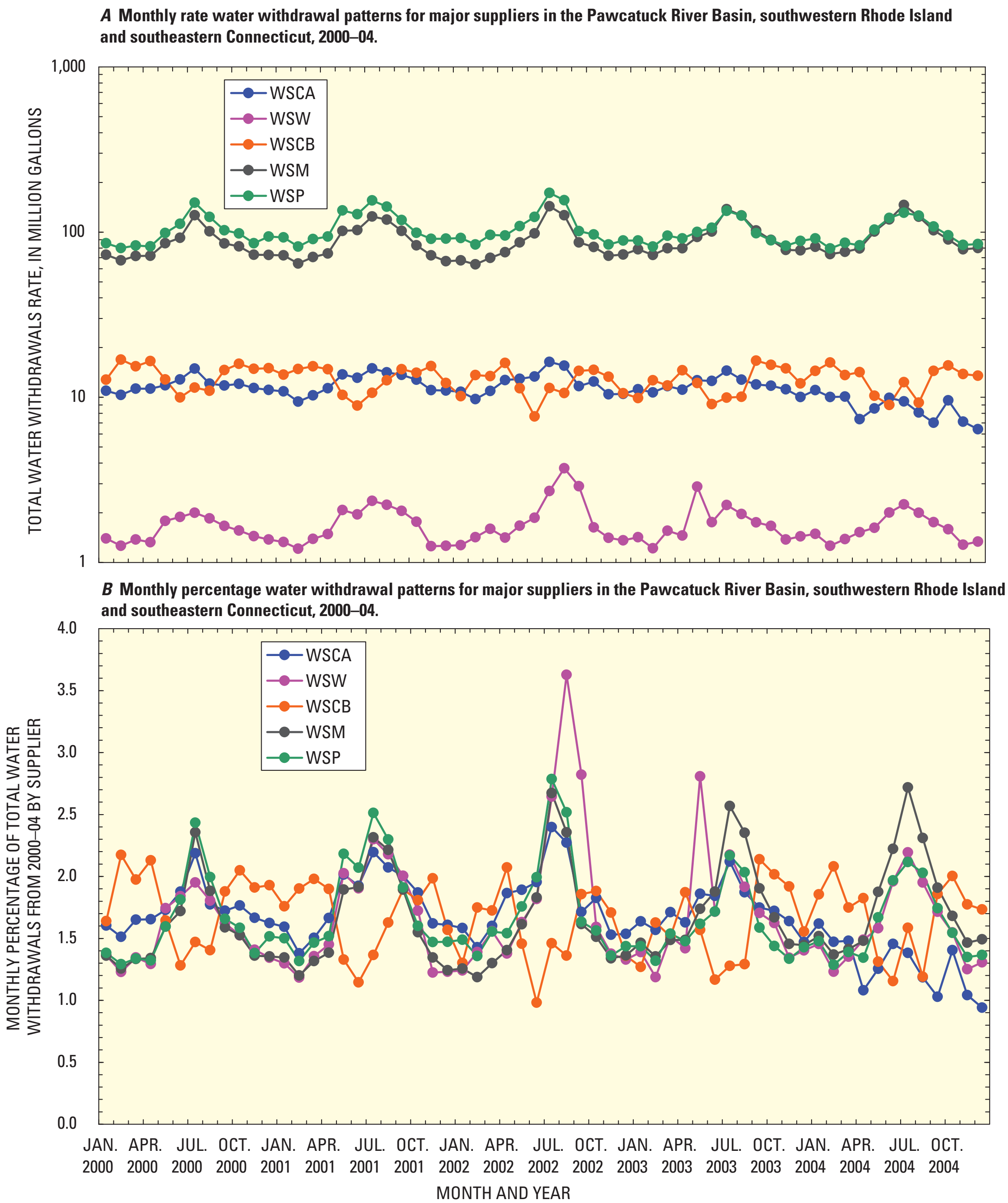


Figure 1–9. Monthly water withdrawal patterns for major suppliers in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

Agricultural Withdrawals

The Pawcatuck River Basin is estimated from GIS data layers (1995) and aerial photographs (2002) to include about 4.82 mi^2 (3,082 acres) of irrigated agricultural land (turf farms, vegetable farms, and tree nurseries). Turf farms are estimated to account for about 4.40 mi^2 (2,815 acres) of the irrigated agricultural land in the basin. Withdrawals from streams or instream ponds are the sources of irrigation water for about 3.31 mi^2 (2,115 acres) of the turf farms; about 1.09 mi^2 (700 acres) are irrigated from wells or ponds not directly connected to streams. Vegetable farms were estimated to account for about 0.41 mi^2 (264 acres) of the irrigated agricultural land in the basin. Nearly all the vegetable farms, about 0.35 mi^2 (227 acres), were irrigated from water withdrawals on streams or instream ponds, and only about 0.06 mi^2 (37 acres) was irrigated from wells or ponds not directly connected to streams. Tree nurseries were estimated to account for about 0.005 mi^2 (3.0 acres) of the irrigated agricultural land, and all were irrigated from instream ponds.

During each year, an estimated 40 to 50 percent of the turf-farm area is kept fallow (Vicky Drew, U.S. Department of Agriculture, Natural Resources Conservation Service, oral commun., 2005). Most turf farms irrigate the remaining active areas of turf. Irrigation-withdrawal data were collected by direct measurement at 11 turf-farm sites, at 2 of which groundwater was withdrawn and at 9 of which surface water was withdrawn from the basin (table 1–9). At two turf farms, irrigation-withdrawal data from two measured withdrawal points had to be combined into one data set, because the areas irrigated by withdrawal at the two points could not be determined individually. As a result of the two combined sites, data were available only for 9 separate turf-farm sites in the basin. Data were collected for either three or five irrigation seasons (May through October) during 2000–04. These withdrawals were measured continuously and totaled hourly by an impeller flowmeter installed between the pump and the irrigation nozzles.

The turf farms where irrigation data were collected covered a total area of about 2.08 mi^2 (1,329 acres) or about 47 percent of the turf-farm land in the basin. The total area of turf farms where irrigation data were collected includes the areas that were fallow during part of the study, because the fallow areas were changed during the year and from year to year. When they were irrigated, the metered turf farms applied an average of 3,399 gal/d/acre (table 1–9). On an average day, withdrawal rates at the turf farms tended to increase from about 0800 hours and continue to about 1300 hours, after which withdrawal rates decreased steadily through the remainder of the day (fig. 1–10). A wide range of withdrawal rates per unit area was measured among the turf farms over the average 24-hour period. Site AUQ8A was generally operated differently than the other turf farms; withdrawals increased during the early evening hours, remained steady through the early morning hours, and then decreased during the day (fig. 1–10). This unusual pattern may be a result of the fact that an electric pump was used to withdraw groundwater at this site, probably because electric pumps are quieter than the diesel engine pumps used at most other sites. Operation of the electric pump during the nighttime also may be preferred because of lower electricity rates. The nine turf-farm sites averaged about 31 days of irrigation during the May-through-October irrigation seasons for 2000–04, but the number of days of irrigation varied among sites and years from 0 days (one farm in 2003) to 75 days (one farm in 2001) per year. The number of days of irrigation in any season was likely dependent on climatic factors, such as precipitation and temperature, and on other factors, such as soil moisture, grass type, and planned harvest time. During some years, turf farms left fields fallow; during summer 2003, when conditions were wetter, a few turf farms did not irrigate at all.

Golf-Course Withdrawals

Eleven golf courses are currently (2009) in the Pawcatuck River Basin, of which 10 are completely in the basin and 1 is partially in the basin. The total in-basin area of greens and fairways for the 11 golf courses was about 0.89 mi^2 (572 acres). All 11 golf courses irrigate their greens, and 9 of the 11 golf courses irrigate their fairways, for a total of 0.76 mi^2 (487 acres) of irrigated area. Withdrawals for irrigation at the golf courses come from surface-water (streams or instream ponds) or groundwater sources; groundwater withdrawals may be directly from wells or from ponds that have been filled with water from wells.

The two golf courses in the basin where irrigation data were collected covered a total area of about 0.19 mi^2 (124 acres), or about 25 percent of the irrigated golf-course area in the basin. Irrigation data were collected at one course that used direct stream withdrawals (GUQ2A and GUQ2B) and at another course that filled a pond from groundwater withdrawals (GMB2A) (table 1–9). Groundwater-withdrawal data were also collected at a third golf course (GP2A), of which only a few fairways and green were in the basin. Average withdrawals at the three metered golf courses were 1,756 gal/d/acre during the irrigation period of April 16 through November 15 for the 4 years of the study (table 1–9). Water-withdrawal rates per unit area for all three golf courses were similar. Although the withdrawal rates per unit area for these three metered golf courses were similar, they may not represent the general withdrawal rates or patterns at the other golf courses in the basin.

On an average day, metered withdrawal rates at the two golf courses dependent on groundwater sources (GMB2A and GP2A) were generally at their highest from about 2200 hours until about 0600 hours and at their lowest from about 0700 hours through about 2100 hours (fig. 1–11). The golf course dependent on surface-water sources (GUQ2A and GUQ2B—two metered withdrawal sites at the same course) had a distinctly different average daily water-withdrawal rate than the two courses dependent on groundwater sources; the highest withdrawal rates occurred from 0400 through 0900 hours.

Table 1–9. Summary of irrigation withdrawals for metered turf farms and golf courses in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[USGS, U.S. Geological Survey; gal, gallons; SW, surface water; GW, groundwater; yr, year; ac, acre; d, day; ft, feet; °, degrees; ′, minutes; ″, seconds]

USGS station name	With-drawal type	Irrigated area (acres)	Pe-riod of record	Remarks	Number of days of measured water with-drawals during period of record	Average num-ber of days of measured wa-ter withdrawals per year	Total measured withdrawals during period of record (gal)	Average measured withdrawals (gal/yr)	Average measured withdrawals per unit area (gal/yr/ac)	Average measured withdrawals (gal/d)	Average measured withdrawals per unit area (gal/d/ac)
Turf farms											
AC1A and AC1B	SW	504.80	2002–04	Two withdrawal points metered, but withdrawals combined into one system because individual irrigated acres were unknown.	129	43	87,515,611	29,171,870	57,789	678,416	1,344
AUQ10A	SW	83.52	2000–04		165	33	48,541,025	9,708,205	116,238	294,362	3,525
AUQ10B	SW	48.31	2000–04		81	16	7,438,463	1,487,693	30,795	91,833	1,901
AUQ10C	SW	47.50	2000–04		73	15	10,885,400	2,177,080	45,833	149,115	3,139
AP1A and AW2A	SW	351.86	2000–04	Several days of missing data in 2001 and 2002. Two withdrawal points metered, but withdrawals combined into one system because individual irrigated acres were unknown.	318	64	230,073,537	46,014,707	130,776	725,191	2,061
AUQ8A	GW	95.22	2002–04		112	37	31,091,912	10,363,971	108,842	272,736	2,864
AC5A	GW	61.89	2002–04		102	34	27,410,730	9,136,910	147,631	268,733	4,342
AB4A	SW	33.82	2002–04		48	16	9,825,879	3,275,293	96,845	204,706	6,053
AW1A	SW	101.80	2002–04	Several days of missing data in 2004.	57	19	31,121,926	10,373,975	101,905	545,999	5,364
All metered turf farms	**Total**	1,328.72		**Average**	--	31	--	13,523,300	92,962	359,010	3,399
Golf courses											
GUQ2A and GUQ2B	SW	62.30	2000–04	Two withdrawal points metered, but withdrawals combined into one system because individual irrigated acres were unknown.	374	75	39,912,585	7,982,517	128,130	106,718	1,713
GP2A	GW	64.19	2002–04	Only partially (a few fairways and greens) in the basin.	389	130	42,310,384	14,103,461	219,714	108,740	1,694
GMB2A	GW	62.02	2002–04	Several days of missing data in 2002 and 2004.	397	132	45,364,524	15,121,508	243,817	115,358	1,860
All metered golf courses	**Total**	188.51		**Average**	--	105	--	12,402,495	197,220	110,272	1,756
GUQ1A	SW	71.50	2000–04	Estimated withdrawals based on streamflow fluctuations at USGS station 011173545 about 3,300 ft downstream of withdrawal point. No streamflow data recorded during irrigation period of April through mid-July 2002.	323	65	28,592,045	5,718,409	79,978	88,520	1,238

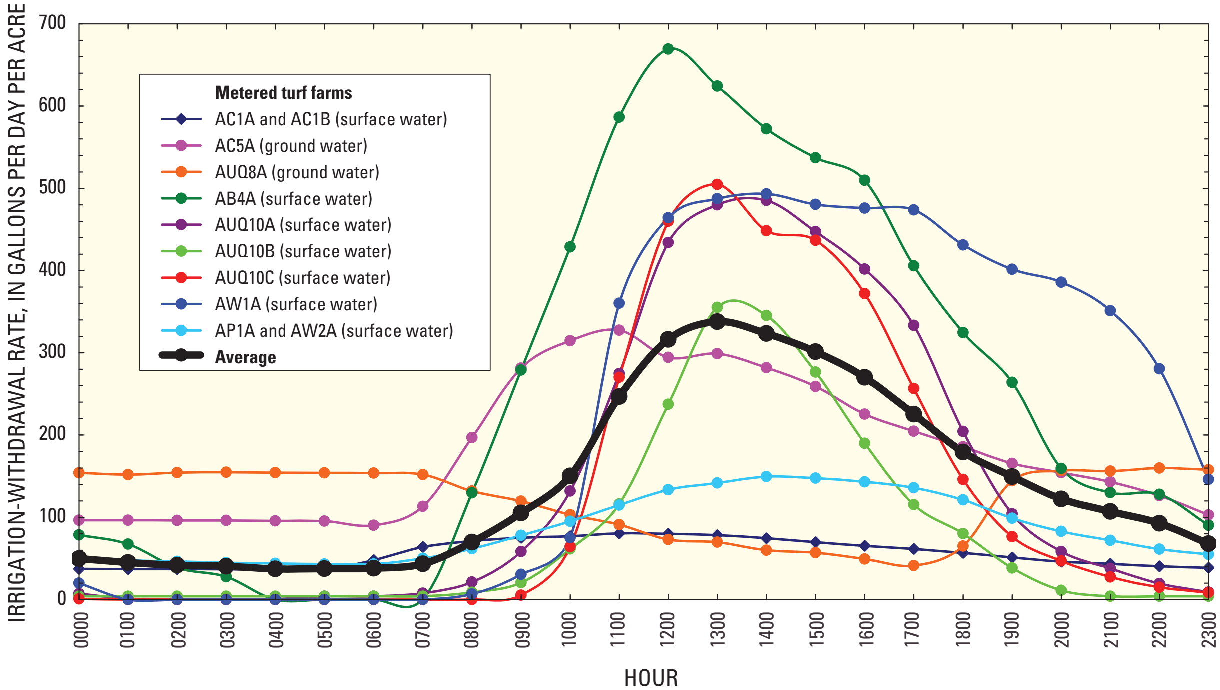


Figure 1–10. Average 24-hour irrigation-withdrawal rates for metered turf farms in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

The different patterns for the groundwater and surface-water withdrawals may be a result of the fact that the electric pumps at the groundwater-withdrawal sites were outfitted with timers. Nighttime pumping may be preferred for the groundwater withdrawal golf courses because of lower electricity rates. The surface-water site is dependent on diesel-engine pumps that can be loud and have to be turned on manually. Golf courses were irrigated 62 days (one course in 2004) to 208 days (one course in 2002) per year during 2000–04.

At a fourth golf course (GUQ1A), surface-water withdrawals were estimated by linear interpolation between abrupt drops and rises in the observed streamflow hydrograph for a USGS station about 3,300 ft downstream of the withdrawal point. The difference between the interpolated and observed hydrograph during these periods was assumed to represent withdrawals. The estimated average water withdrawal at this site, 1,238 gallons per day per acre (gal/d/acre), was about 29 percent lower than the average water withdrawal measured at the other three golf courses (1,756 gal/d/acre) during either 2000–04 or 2002–04 (table 1–9). This difference in average water withdrawals per day per acre may be a result of the estimation method used, which did not include time periods during which abrupt drops and rises in the hydrograph were not noticeable. During these periods, which may have coincided with the irrigation of greens only, withdrawals may have been low enough not to have noticeably affected the hydrograph at the downstream USGS streamflow-gaging station. Additionally, from April 16 through July 16, 2002, the downstream USGS streamflow-gaging station was not operating. During this period, water withdrawals likely would have occurred, because at the other surface-water-withdrawal golf course (GUQ2A and GUQ2B—two metered withdrawal sites at the same course), 39 days of withdrawals were measured from May 7 through July 16, 2002. Even though water withdrawals could be estimated for the period of April 16 through July 16, 2002 at site GUQ1A, withdrawals were estimated for 323 other days during 2000–04 (table 1–9). This number of days of surface-water withdrawals compared well with the 337 days of measured surface-water withdrawals at golf course site GUQ2A and GUQ2B for the same time period excluding April 16 through July 16, 2002.

Groundwater-withdrawal data measured at golf-course site GP2A averaged a little more than 247,000 gallons per year per acre (gal/yr/acre) for the period 1994–2004 (table 1–10). This 11-year average water-withdrawal rate compares reasonably well to the average groundwater-withdrawal rates per year per acre for the two groundwater sites (GMB2A and GP2A) during 2002–04 (table 1–9). During the 11 years, yearly groundwater withdrawals rates per year per acre ranged from 39 percent less to 36 percent more than the 11-year-average withdrawal rate. This wide range of yearly groundwater withdrawals likely is the result of climatic factors during each of the years (table 1–10).

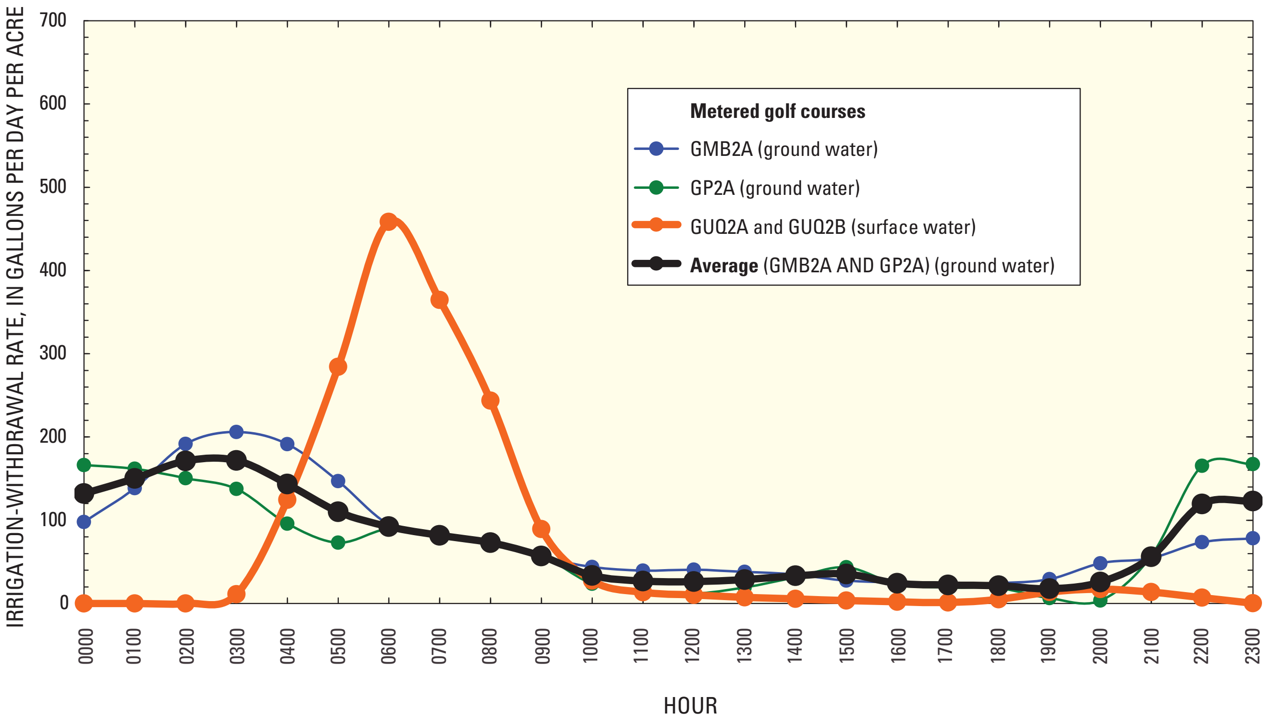


Figure 1–11. Average 24-hour irrigation-withdrawal rates for metered golf courses in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

Table 1–10. Annual groundwater withdrawals at golf course GP2A partially located in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 1994–2004.

[NOAA-NWS, National Oceanic and Atmospheric Administration National Weather Service; URI, University of Rhode Island; gal, gallons; yr, year; ac, acres; yd, yards; in., inches; --, not applicable; /, per]

Year	Total groundwater withdrawals (gal/yr)	Groundwater withdrawals (gal/yr/ac)	Groundwater withdrawals (gal/yr/yd)	Rank of yearly groundwater withdrawals from highest to lowest	Total precipitation from April 16 through November 15 at the NOAA-NWS-URI station (in.)	Rank of yearly precipitation from lowest to highest
1994	21,583,000	336,236	3,473	2	18.94	1
1995	15,577,000	242,670	2,507	7	27.09	5
1996	9,640,000	150,179	1,551	11	34.82	10
1997	14,164,000	220,657	2,279	8	27.61	6
1998	16,874,000	262,876	2,715	5	36.33	11
1999	17,851,000	278,096	2,873	3	26.59	3
2000	11,419,000	177,894	1,838	10	34.27	8
2001	21,618,000	336,781	3,479	1	24.76	2
2002	17,471,000	272,176	2,812	4	31.04	7
2003	12,158,707	189,417	1,957	9	34.47	9
2004	16,141,046	251,457	2,598	6	26.90	4
Minimum	9,640,000	150,179	1,551	--	18.94	--
Maximum	21,618,000	336,781	3,479	--	36.33	--
Average	15,863,341	247,131	2,553	--	29.35	--
Median	16,141,046	251,457	2,598	--	27.61	--

Predicting Turf-Farm and Golf-Course Irrigation

Logistic-regression equations were developed to predict the probability of irrigation on a specific day at turf farms and golf courses from 1960 through 2004, so water withdrawal estimates were available for long-term model analyses. Separate equations were developed for turf farms (includes vegetable farms and tree nurseries), golf courses with surface-water withdrawals, and golf courses with groundwater withdrawals. The three separate equations for predicting water withdrawals were needed because of differences in the number of days of withdrawals per year (table 1–9), withdrawal rates per day per acre (table 1–9), and 24-hour irrigation patterns at the nine turf farms (fig. 1–10) and three golf courses (fig. 1–11). The approach of developing separate equations for turf farms and golf courses with surface-water and groundwater withdrawals differed from that of a previous study for the Usquepaug-Queen River Basin (Zarriello and Bent, 2004), because the additional data collected in this study revealed different and more detailed patterns.

The equations were developed from irrigation-withdrawal data measured during 2000–04 or 2002–04 and antecedent precipitation and potential evapotranspiration rates that served as potential explanatory variables for these time periods. The rates were determined from climatic data collected at the FBWR station. The equations were developed with the stepwise-logistic regression procedure in SAS (SAS Institute, Inc., 1989, 1995). Explanatory climatic variables tested included total rainfall and potential evapotranspiration rates during the previous 2, 5, 10, 15, and 20 days. Correlated explanatory variables were not used during the stepwise-regression analysis because colinearity between independent variables can result in erroneous results (Helsel and Hirsch, 1992). Explanatory variables for sequences of data collected during closely overlapping time intervals—for example, rainfall in the previous 2 days and in the previous 5 days—tended to be correlated and were not used together in the analysis. Other climatic variables were dropped from the stepwise regression or only marginally added to the goodness-of-fit as indicated by the chi-squared values and Akaike Information Criterion (AIC) values.

Irrigation withdrawals at turf farms were made only from May 1 through October 31 in any year; for this reason, data from November 1 through April 30 were omitted from the analysis. Irrigation data were available for three turf-farm sites for 2000–04 and for eight other turf-farm sites for 2002–04. Several days of data were missing for the three turf-farm sites for which data were collected in 2000 and 2001. Turf-farm irrigation occurred on 373 of the 920 days used in the analysis during the 5-year period (table 1–11). Irrigation at turf farms differed with respect to the number of days of withdrawals and the amount withdrawn in any one year. The logistic-regression analysis determined that the best equation for estimating the probability of turf-farm irrigation on any day from May 1 through October 31 (P) was based on total potential evapotranspiration during the previous 5 days ($PET5$) and total precipitation during the previous 2 days ($PREC2$) and the previous 20 days ($PREC20$). The probability (P) of irrigation occurring on a specific day at turf farms is given by

$$P = \frac{\left(exp\left(-2.1149 + 5.1917\left(PET5\right) - 0.7777\left(PREC2\right) - 0.5877\left(PREC20\right)\right)\right)}{1 + \left(exp\left(-2.1149 + 5.1917\left(PET5\right) - 0.7777\left(PREC2\right) - 0.5877\left(PREC20\right)\right)\right)} \quad (1)$$

Results of the analysis of maximum likelihood estimates for equation (1) are presented in table 1–11.

Irrigation withdrawals at golf courses were made only from April 16 through November 15 in any year; for this reason, data from November 16 through April 15 were omitted from the analysis. Irrigation data were available for one golf course with surface-water withdrawals for 2000–04 and for two golf courses with groundwater withdrawals for 2002–04. Separate logistic-regression equations for estimating the probability of irrigation on any day were developed for golf courses with surface-water withdrawals and golf courses with groundwater withdrawals. Two separate equations were developed because the golf course with surface-water withdrawals irrigated on only 374 of the 1,075 days between April 16 and November 15 during the 5-year period, whereas the golf courses with groundwater withdrawals irrigated on 472 of 568 days during 2002–04.

For golf courses irrigated with surface-water withdrawals, the logistic-regression analysis determined that the best equation for estimating the probability of irrigation on any day from April 16 through November 15 (P) was based on total potential evapotranspiration during the previous 5 days ($PET5$) and total precipitation during the previous 5 days ($PREC5$) and the previous 20 days ($PREC20$). The probability (P) of irrigation occurring on a specific day at golf courses with surface-water withdrawals is given by

$$P = \frac{\left(exp\left(-2.1590 + 4.3063\left(PET5\right) - 1.4975\left(PREC5\right) - 0.1506\left(PREC20\right)\right)\right)}{1 + \left(exp\left(-2.1590 + 4.3063\left(PET5\right) - 1.4975\left(PREC5\right) - 0.1506\left(PREC20\right)\right)\right)} \quad (2)$$

Results of the analysis of maximum likelihood estimates for equation (2) are presented in table 1–11.

For golf courses irrigated with groundwater withdrawals, the logistic-regression analysis determined that the best equation for estimating the probability of irrigation on any day from April 16 through November 15 (P) was based on total potential evapotranspiration during the previous 20 days ($PET20$) and total precipitation during the previous 5 days ($PREC5$). The probability (P) of irrigation occurring on a specific day at golf courses with groundwater withdrawals is given by

$$P = \frac{\left(exp\left(-0.9898 + 1.9531\left(PET20\right) - 0.6466\left(PREC5\right)\right)\right)}{1 + \left(exp\left(-0.9898 + 1.9531\left(PET20\right) - 0.6466\left(PREC5\right)\right)\right)} \quad (3)$$

Results of the analysis of maximum likelihood estimates for equation (3) are presented in table 1–11.

Table 1–11. Summary statistics for logistic-regression analyses of the equations for estimating the probability of irrigation on a specific day at a *(A)* turf farm, *(B)* golf course with surface-water withdrawals, and *(C)* golf course with groundwater withdrawals in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, 2000–04.

[Helsel and Hirsch, 1992, p. 393–402; SAS Institute, Inc., 1995; *PET*-[*x*], [*x*]-day potential evapotranspiration; *PREC*-[*x*], [*x*]-day precipitation; AIC, Akaike Information Criterion; C, rank correlation coefficient of predicted probabilities and observed responses; <, actual value is less than value shown]

	***(A)* Turf-farm irrigation - equation 1**				***(B)* Golf-course irrigation with surface-water withdrawals - equation 2**				***(C)* Golf-course irrigation with ground-water withdrawals - equation 3**		
	Intercept	***PET5***	***PREC2***	***PREC20***	**Intercept**	***PET5***	***PREC5***	***PREC20***	**Intercept**	***PET20***	***PREC5***
Analysis of maximum likelihood estimates:											
Degrees of freedom	1	1	1	1	1	1	1	1	1	1	1
Estimate	-2.1149	5.1917	-0.7777	-0.5877	-2.159	4.3063	-1.4975	-0.1506	-0.9898	1.9531	-0.6466
Standard error	0.2678	0.3958	0.2818	0.0634	0.2355	0.3237	0.1972	0.0544	0.3135	0.2166	0.1696
Chi-square	62.3687	172.0721	7.6188	86.0436	84.0518	177.0236	57.6486	7.6612	9.9695	81.3048	14.539
p-value	<0.0001	<0.0001	0.0058	<0.0001	<0.0001	<0.0001	<0.0001	0.0056	0.0016	<0.0001	0.0001
Likelihood ratio:											
Number of data points (total number of days)	920				1,075				568		
Number of days with irrigation	373				374				472		
Number of days with no irrigation	547				701				96		
AIC	841.092				956.162				343.168		
C	0.861				0.861				0.886		
-2 Log likelihood	833.092				948.162				337.168		
Chi-square	409.1914				441.0414				178.9394		
Degrees of freedom	3				3				2		
p-value	<0.0001				<0.0001				<0.0001		
Score:											
Chi-square	333.9262				344.9402				139.8057		
Degrees of freedom	3				3				2		
p-value	<0.0001				<0.0001				<0.0001		

Equation 1 for turf farms and equations 2 and 3 for golf courses yield the probability of irrigation on a specific day at turf farms for May 1 through October 31 and at golf courses for April 16 through November 15 as a value between 0 and 1.0; the closer the value is to 1.0, the greater the likelihood of irrigation. For turf farms, a probability of 0.40 provided the best cutoff value for estimating observed irrigation: if the estimated probability of turf-farm irrigation on a day is equal to or greater than 0.40, then irrigation was assumed to have occurred, but if the probability is less than 0.40, then irrigation was assumed not to have occurred. At the 40-percent probability, the equation correctly estimated turf-farm irrigation about 78 percent of the time and balanced the sensitivity[1] and specificity[2] of the equation more closely than at the other probabilities (appendix 1, table A1–1). For golf courses with surface-water withdrawals, a probability of 0.36 provided the best cutoff value for estimating observed irrigation. At the 36-percent probability, the equation correctly estimated golf-course surface-water irrigation about 79 percent of the time and balanced the sensitivity and specificity of the equation more closely than at the other probabilities (appendix 1, table A1–2). For golf courses with groundwater withdrawals, a probability of 0.80 provided the best cutoff value for estimating observed irrigation. At the 80-percent probability, the equation correctly estimated golf-course groundwater irrigation about 80 percent of the time and balanced the sensitivity and specificity of the equation more closely than at the other probabilities (appendix 1, table A1–3).

Each of the individual logistic-regression equations was used to estimate the specific days of irrigation for turf farms, surface-water-supplied golf courses, and groundwater-supplied golf courses. The turf-farm equation was used to estimate the specific dates of irrigation for unmetered withdrawal sites (29 turf farms, 8 vegetable farms, and 1 tree nursery). The groundwater-supplied golf-course equation was used to estimate the specific days of irrigation for six unmetered groundwater golf courses, with a total of nine different withdrawal sites. The surface-water-supplied golf-course equation was used to estimate the specific days of irrigation for one unmetered surface-water golf course, and the specific days of irrigation at golf course GUQ1A from April 16 through July 16, 2002, when no streamflow data were available for the downstream streamflow-gaging station. After the specific days of irrigation were estimated for the study period (2000–04) by each equation, the appropriate average hourly water-withdrawal rate per acre was multiplied by the number of acres to be irrigated to estimate the hourly withdrawal rate for each unmetered site.

[1] Sensitivity: The ratio of correctly classified events (days of irrigation) to the total number of events (days of irrigation).

[2] Specificity: The ratio of correctly classified nonevents (days of no irrigation) to the total number of nonevents (days of no irrigation).

Water-withdrawal data were also estimated for all turf farms, vegetable farms, tree nurseries, and golf courses using the appropriate logistic regression equations in the Pawcatuck River Basin for the period of 1960–99, so that water-withdrawal estimates were available for model analyses during 1960–2004. It was assumed that the irrigation rate, irrigated acres, type of withdrawal (surface- or groundwater), and locations of withdrawals for the period of 1960–99 were the same as those used 2000–04 because metered water use data were not available during the earlier period. To estimate the water withdrawals during this period using the logistic-regression equations, precipitation and potential evapotranspiration data from the PROVID climate station were adjusted by the differences between data from the FBWR and PROVID climate stations for the 2000–04 study period, because climatic data were not available for FBWR for 1960–99. During 2000–04, daily precipitation and potential evapotranspiration data at the FBWR climate station were 9.9 percent higher and 8.5 percent lower, respectively, than at the PROVID climate station. Thus, PROVID daily precipitation data were multiplied by 1.099 and PROVID daily potential evapotranspiration data were multiplied by 0.915 to adjust for climatic conditions in the Pawcatuck River Basin. The adjusted antecedent-precipitation and potential-evapotranspiration explanatory variables were then used in the appropriate logistic-regression equations to estimate the days of irrigation for 1960–99. On the basis of the appropriate hourly water withdrawal rate per acre and the acreage of each turf farm, vegetable farm, tree nursery, and golf course, the hourly withdrawal rate for each withdrawal point was estimated during the irrigation seasons for the period of 1960–99.

Wastewater Discharge and Return Flow

The withdrawals of most major and minor production wells are returned to the basin through onsite septic systems. Withdrawals from domestic self-supply wells are also mostly returned to the basin through onsite septic systems. Wild and Nimiroski (2004, p. 40) reported 11 Rhode Island National Pollutant Discharge Elimination System (NPDES) sites discharging an average return flow of about 1.7 Mgal/d in the Pawcatuck River Basin during 1995–99. Wild and Nimiroski (2004, p. 42) also reported average return flows of about 2.8 Mgal/d from two wastewater-treatment facilities in the southwestern part of the basin during 1995–99 (fig. 1–8). The wastewater from these two facilities discharges near the mouth of the Pawcatuck River below the Pawcatuck River at Westerly (01118500) streamflow-gaging station. The wastewater-treatment facility in the southeastern part of the basin, which services parts of one town and a university, discharges return flow into the Atlantic Ocean.

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