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People and Water in the Assabet River Basin, Eastern Massachusetts

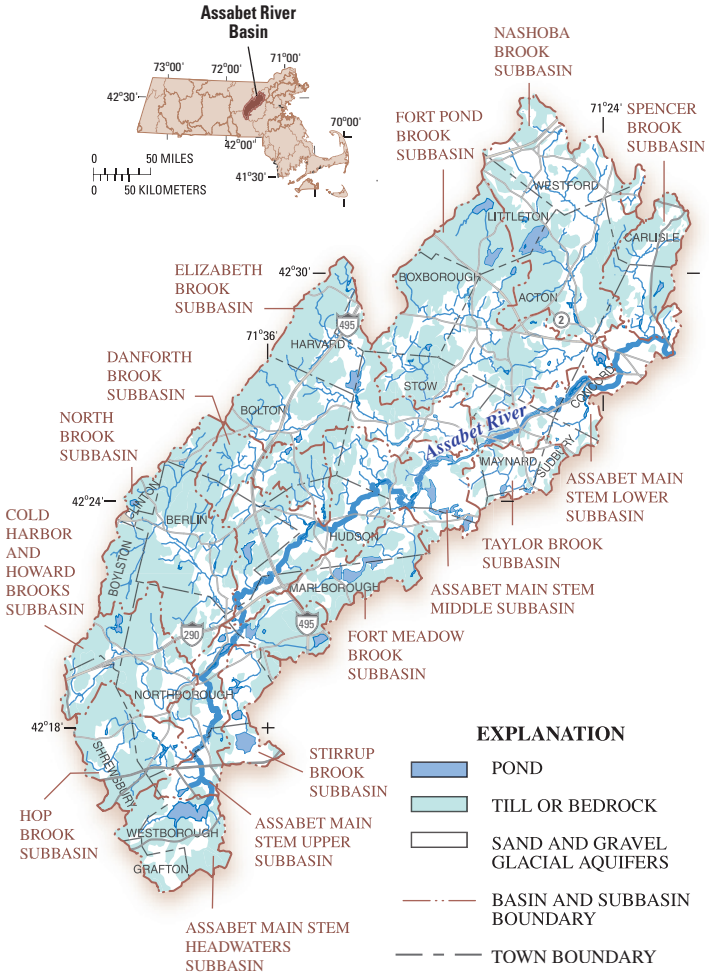
An accounting of the inflows, outflows, and uses of water in the rapidly developing Assabet River Basin, along Interstate 495 in eastern Massachusetts, was done to quantify how people's activities alter the hydrologic system. The study identified subbasins and seasons in which outflows resulting from people's activities were relatively large percentages of total flows, and quantified the fraction of streamflow in the Assabet River that is treated wastewater. Computer models of ground-water flow were also used to test how the components of the hydrologic system, particularly streamflow, would change with future development and increased water use. Computer simulations showed that, when water use was increased to currently permitted levels, streamflows in tributaries would decrease, particularly during the low-flow period. In the Assabet River, increased wastewater discharges resulted in a slight increase in total streamflow and an increase in the fraction of streamflow in the river that is wastewater, relative to existing conditions.

INTRODUCTION

Withdrawals from public-supply wells and reservoirs, wastewater discharges to streams, ground water leaking into sewer pipes, and septic-system leachate percolating to the water table—these are some of the ways in which people alter the hydrologic system in a river basin. Ultimately, the effects of these activities are seen in streams, as changes in the quantity and quality of streamflow. In the Assabet River Basin, water use and population density vary greatly, and people's activities have altered streamflow in the Assabet River and its tributaries to varying degrees. The basin is in a rapidly growing area along Interstate 495 in eastern Massachusetts (fig. 1), where demands for water supply and wastewater disposal are increasing. Between 1990 and 2000, population in the 20 towns in the basin (table 1) increased by 15 percent—nearly three times the statewide average—and by more than 30 percent in some towns.

Ground water supplies much of the water used in the basin. Most public-supply wells are in the sand and gravel glacial aquifers along the Assabet River and its tributary streams (fig. 1). The aquifers drain to the streams, so that, between storms, most of the water in the streams consists of ground-water discharge (base flow). After use, much of the publicly supplied water is transferred to downstream treatment facilities, where it is discharged to the Assabet River. Currently (2004), the Assabet River is eutrophic during the summer and fails to meet most applicable water-quality standards (Massachusetts Department of Environmental Protection, 2003). Ground-water withdrawals contribute to this problem by reducing the amount of high-quality base flow that would dilute wastewater in the river. In many tributaries, reductions in streamflow result in the loss of habitat for fish and other aquatic organisms. Less ground water available for discharge also may alter wetlands.

To better understand the effects of current and future water withdrawals and wastewater discharges on streamflows in the Assabet River and its tributaries, the U.S. Geological Survey (USGS), in cooperation with the Massachusetts Department of Conservation and Recreation (MADCR), recently



From USGS and MassGIS data sources, Massachusetts State Plane Coordinate System, Mainland Zone.

Figure 1. The Assabet River Basin, subbasins, and surficial geology, eastern Massachusetts.

completed a study of the basin's water resources (DeSimone, 2004). Representatives from Federal and State agencies, towns, a watershed association, and other organizations provided guidance to the study through a Technical Advisory Committee. The water-use and management issues of concern in the Assabet River Basin are common to many other basins in eastern Massachusetts and adjacent States, where communities are striving to balance growth and the available water resources. This Fact Sheet summarizes some of the important findings of the cooperative study.

Table 1. Population on public water and sewer in towns in the Assabet River Basin. Yellow shading indicates towns with public-water supply and wastewater disposal (sewers); green shading indicates towns with public-water supply and private-wastewater disposal (septic systems); and brown shading indicates towns with private-water supply and wastewater disposal.

[**Total population**: From U.S. Census Bureau, 2003. **Population on public water and sewer**: From U.S. Census Bureau, 2003, and town water departments]

Town	Proportion of town area in basin (percent)	Total population	Population on public water and sewer (percent), 2003	
			Water	Sewer
Acton	100	20,331	94	0
Berlin	100	2,380	0	0
Bolton	72	4,148	0	0
Boxborough	66	4,868	0	0
Boylston	24	4,008	[1]0	0
Carlisle	29	4,717	0	0
Clinton	15	13,435	100	100
Concord	36	15,537	95	38
Grafton	7	14,894	[1]0	[1]0
Harvard	22	5,981	[1]0	0
Hudson	94	18,113	94	82
Littleton	42	8,184	80	0
Marlborough	43	36,255	99	92
Maynard	100	10,433	100	95
Northborough	94	14,013	85	20
Shrewsbury	37	31,640	97	85
Stow	100	5,902	0	0
Sudbury	9	16,841	[1]100	0
Westborough	41	17,997	95	85
Westford	24	20,754	75	0

[1] Value applies to area of town in basin.

WATER USE AND THE MANAGED HYDROLOGIC SYSTEM, 1997–2001

Through infrastructure such as wells, water-distribution and sewer systems, and treatment facilities, water use and management moves water around in the Assabet River Basin and changes water quality (fig. 2). Water used in the basin is provided by public-supply and private wells, a few surface-water reservoirs, and water imported from outside the basin. Public-water systems supply most of the water that is used in the basin, serving about 80 percent of the basin population and about half of its area (table 1 and fig. 3). Water withdrawals for public supply and large nonmunicipal users, 9.9 Mgal/d in 1997–2001, are mostly (74 percent) from ground water. Nonmunicipal users include industrial, agricultural, and golf-course users. Nearly half of the ground water withdrawn for public supply is discharged to the Assabet River after treatment (3.6 Mgal/d) and nearly half is returned to the ground-water-flow system through on-site septic systems (3.5 Mgal/d; fig. 2). Septic-system return flow occurs in areas that are supplied by public water but are not served by public sewers (fig. 3). Water use and disposal, therefore, redistribute water from supply-well locations to areas served by public-water systems, and they accelerate the natural flow of ground water to the main stem of the Assabet River.

Water is imported into the basin for public supply (1.7 Mgal/d), and as wastewater (3.7 Mgal/d) for treatment at a regional facility near the basin headwaters (fig. 3). Imported

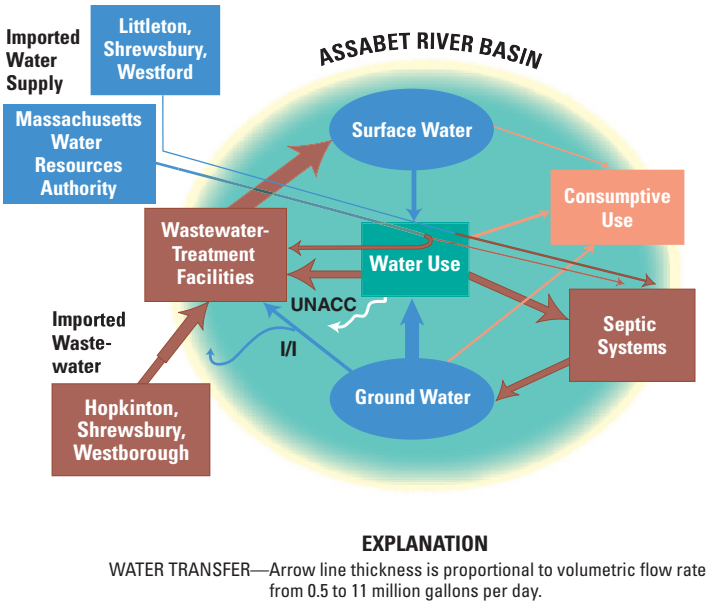


Figure 2. Schematic diagram showing water use, transfer, and disposal in the Assabet River Basin, 1997-2001. Blue lines indicate withdrawal or import of water for use; brown lines indicate discharge, disposal, or import of wastewater; and orange lines indicate consumptive use. (UNACC, unaccounted-for water; I/I, infiltration to sewers)

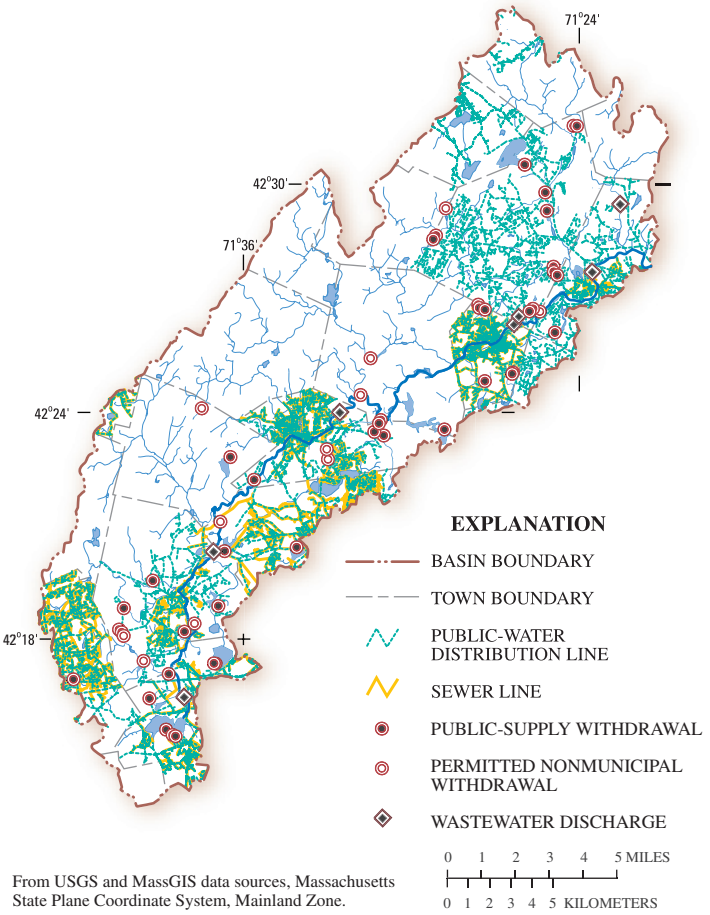


Figure 3. Public-water and sewer systems and locations of permitted water withdrawals and wastewater discharges in the Assabet River Basin, 2001.

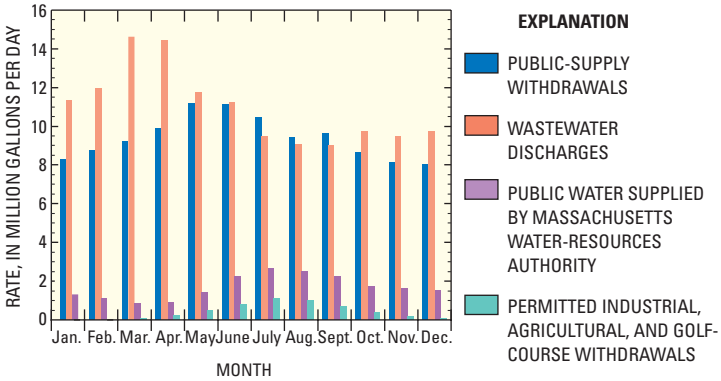


Figure 4. Monthly average permitted withdrawals, wastewater discharges, and imported water for public supply, 1997–2001, in the Assabet River Basin.

wastewater accounted for about one-third of the total wastewater discharged to the Assabet River, which was 11.0 Mgal/d in 1997–2001. About one-quarter of the discharged wastewater (2.6 Mgal/d) originated as ground water leaking into sewers (ground-water infiltration). Ground-water infiltration and wastewater discharges are greatest in the spring (fig. 4), when ground-water levels are high. Sewer systems and wastewater-treatment facilities (fig. 3) serve about 50 percent of the basin population.

Water withdrawals were greatest in May, June, and July in 1997–2001 (fig. 4). Per capita water-use rates averaged 30 percent greater in these months (82 gallons per person per day) than in November through March (61 gallons per person per day; annual average is 73 gallons per person per day). Greater withdrawals in the late spring and summer probably supply outdoor water use, which is partly or wholly consumptive. Consumptive use is water that is evaporated, transpired by plants, incorporated into products or crops, consumed by people or animals, or otherwise removed from the immediate environment (Hutson, 2004). Consumptive use by publicly and privately supplied residential users was estimated at 1.4 Mgal/d in 1997–2001, and averaged about 15 percent of total residential use annually; agriculture and golf courses consumptively used an estimated additional 0.6 Mgal/d. In basin areas where private wells supply water use, consumptive use is the only component of the water withdrawals that is a net outflow of water from the ground-water-flow system; water withdrawn from private wells that is not used consumptively (85 percent of total withdrawals) is returned to the aquifer after use, although degraded in quality, through septic systems.

BASIN WATER BUDGETS

Water budgets provide the framework for understanding how much water is available in a basin and how much of that water is being used or manipulated by people's activities. Knowing water budgets for the basin and its subbasins allows water-resource managers to identify areas of greatest concern in the basin and make more informed decisions about permitting, conservation, and remediation. The water-use information described above was used in conjunction with computer models of ground-water flow to calculate water budgets for the Assabet River Basin and its tributary subbasins. The calibrated models represent average annual and monthly conditions during 1997–2001. The models simulate water flow, and account for processes that affect flow in the saturated zones (that is, below the water table) of the sand and gravel glacial aquifers, glacial till, and underlying bedrock, in the basin. Flow in streams also is simulated, except for the component of streamflow that results from storms (direct runoff). The streamflows calculated with the models are average nonstorm streamflows, which are equal to base flow plus any wastewater discharges to the streams. More information about the models can be found in the report by DeSimone (2004).

Basinwide Budget

Annually, total nonstorm water flow through the study area averaged 195 Mgal/d. Recharge from precipitation (180 Mgal/d) and ground-water discharge to streams (129 Mgal/d) were the major inflow and outflow components of the hydrologic system, respectively (fig. 5). Evapotranspiration of ground water from wetlands (29 Mgal/d) and nonwetland areas (13 Mgal/d) also were important losses (outflows) from the hydrologic system. Basinwide, water-supply withdrawals (9.9 Mgal/d) were 5 percent of total annual outflows; septic-system return flows (4.3 Mgal/d, which includes septic-system return flow from imported public supply) accounted for 2 percent of total annual inflows.

Seasonally, inflows and outflows to the hydrologic system varied substantially. In March, the highest flow month, total nonstorm water flow averaged 592 Mgal/d. Precipitation recharge (578 Mgal/d) was still the major inflow. Much of the recharge was stored in the aquifer, as the water table rose (261 Mgal/d, fig. 5; flow to aquifer storage is shown as an outflow, although it remains within the hydrologic system). Most of the remaining outflow was to ground-water discharge to streams (297 Mgal/d). Water-supply withdrawals were a smaller fraction of total outflows (1.6 percent, or 9.3 Mgal/d), as was infiltration to sewers (less than 1 percent of total flows, or 4.2 Mgal/d), although infiltration is larger in March than annually.

In September, the lowest flow month, total nonstorm water flow averaged 112 Mgal/d. The source of nearly all of the water flowing through the hydrologic system was aquifer storage, as the water table declined and water was released from storage (93 Mgal/d, fig. 5; flow from aquifer storage is shown as an inflow). Outflows were about equal for ground-water discharge to streams (49 Mgal/d) and evapotranspiration of ground water from wetlands, ponds, and nonwetland areas (49 Mgal/d; fig. 5).

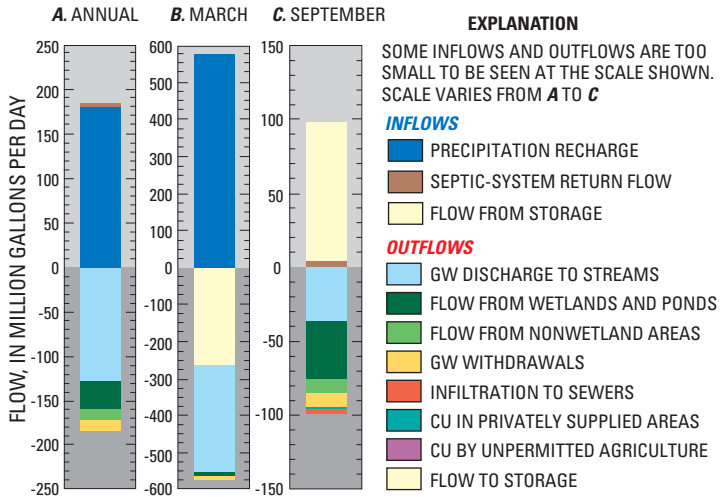


Figure 5. Model-calculated water budgets for the ground-water-flow system in the Assabet River Basin. The budgets represent average annual, high-flow (March), and low-flow (September) conditions during 1997–2001. (GW, ground water; CU, consumptive use)

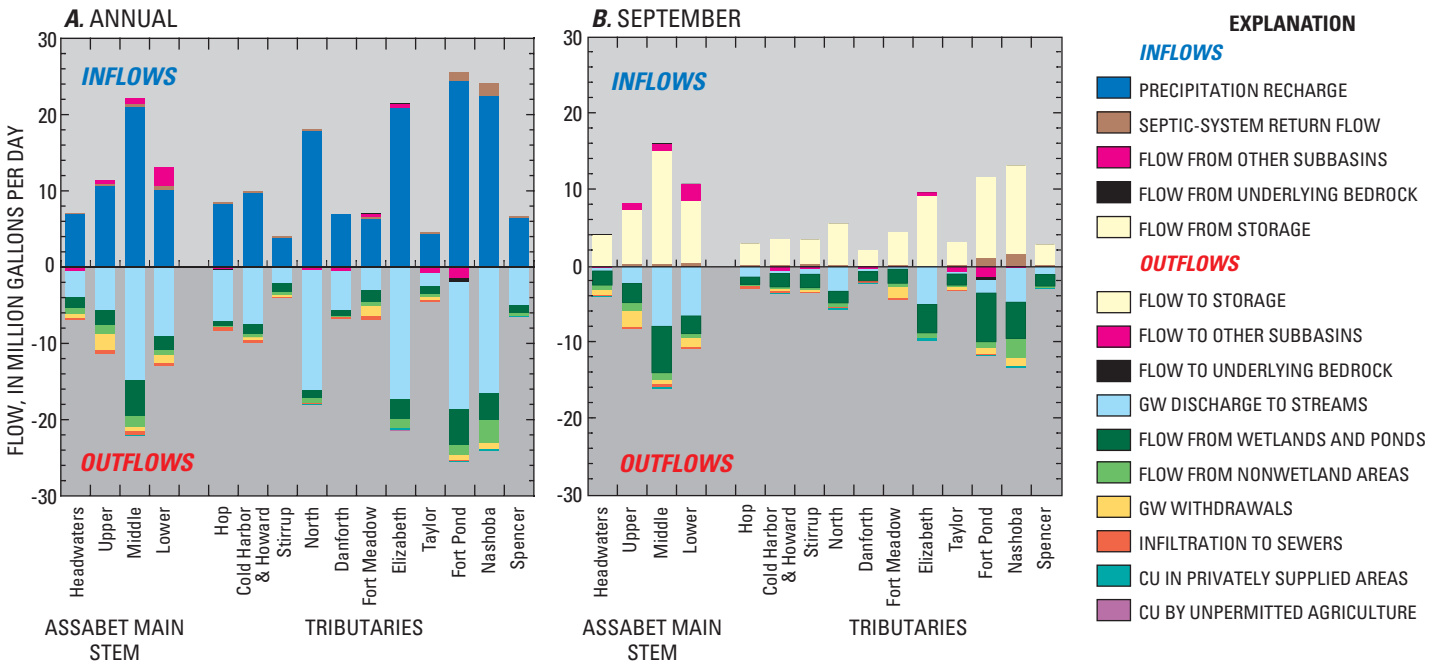


Figure 6. Model-calculated water budgets for the ground-water-flow system in subbasins of the Assabet River Basin, for average annual and average low-flow (September) conditions during 1997–2001 (gw, ground water; cu, consumptive use).

Inflows and outflows from people's activities were higher percentages of total flows in September than in March or annually, averaging 4 percent of total inflows for septic-system return flow (4.3 Mgal/d) and 9 percent of total outflows for water-supply withdrawals (10.5 Mgal/d).

Subbasin Budgets

Major inflows and outflows of water in subbasins of the Assabet River Basin were similar to those for the basin as a whole. However, water withdrawals, septic-system return flow, and other flows caused by people's activity varied among subbasins, from nearly zero in the Elizabeth Brook subbasin in Stow, to relatively large fractions of total flows, as in the Assabet Main Stem Upper and Fort Meadow subbasins in Westborough, Marlborough, and Hudson (fig. 6). Septic-system return flow was largest in subbasins where much of the population was served by public water and private disposal, such as the Fort Pond and Nashoba Brook subbasins in Acton (figs. 1 and 3). Evapotranspiration of ground water also varied among subbasins, depending to a large extent on the areal distribution of wetlands.

By comparing total outflows from people's activities (ground-water withdrawals, surface-water withdrawals, and ground-water infiltration to sewers) to total water flows through the subbasin, the degree of alteration to the hydrologic system in a subbasin can be characterized. On an annual average basis, outflows from people's activities were more than 10 percent of total flows through four subbasins: Taylor Brook, Fort Meadow Brook, Stirrup Brook, and the Assabet Main Stem Upper subbasin (fig. 7). Outflows from people's activities also were relatively large percentages (5 to 10 percent) of total flows in the Assabet Main Stem Headwaters and Lower subbasins. In September, flows from people's activities accounted for more than 20 percent of total flows in the Fort Meadow and Assabet Main Stem Upper subbasins and for more than 10 percent of total flows in seven basins (fig. 7).

Wastewater in the Assabet River

Treated wastewater was discharged to the Assabet River from four municipal treatment facilities and one nonmunicipal facility in 2001, which are distributed along the length of the river (fig. 1). Thus, wastewater accounted for a variable percentage of total nonstorm streamflow in the Assabet River from its headwaters downstream. At its maximum, immediately downstream of the wastewater-treatment facility that is closest to the headwaters of the river (facility in Westborough, figs. 1 and 3), wastewater accounted for 60 percent of average annual streamflow in the Assabet River, and for 93 percent of average September streamflow (figs. 8*A* and *B*). In March, when overall nonstorm streamflows were much higher, wastewater accounted for smaller fractions of flow. Surface-water withdrawals were insignificant fractions of total nonstorm streamflow in the main stem Assabet River in all seasons.

UNDERSTANDING THE PRESENT AND SIMULATING THE FUTURE

One way to understand how people's activities affect conditions in the Assabet River Basin is to simulate the removal of all the water-management activities in the hydrologic system. Streamflows that result from this scenario approximate streamflows that might have occurred before water-resource development in the basin (that is, predevelopment conditions). A way to understand how people's activities may further change hydrologic conditions is to simulate future water-use activities. The computer flow models were used to simulate these two conditions. In the first scenario (S1), water withdrawals, wastewater discharges, infiltration to sewers, septic-system return flows, and consumptive uses were set to zero, to simulate predevelopment conditions. In the second scenario (S2), water withdrawals and wastewater discharges were increased to levels currently

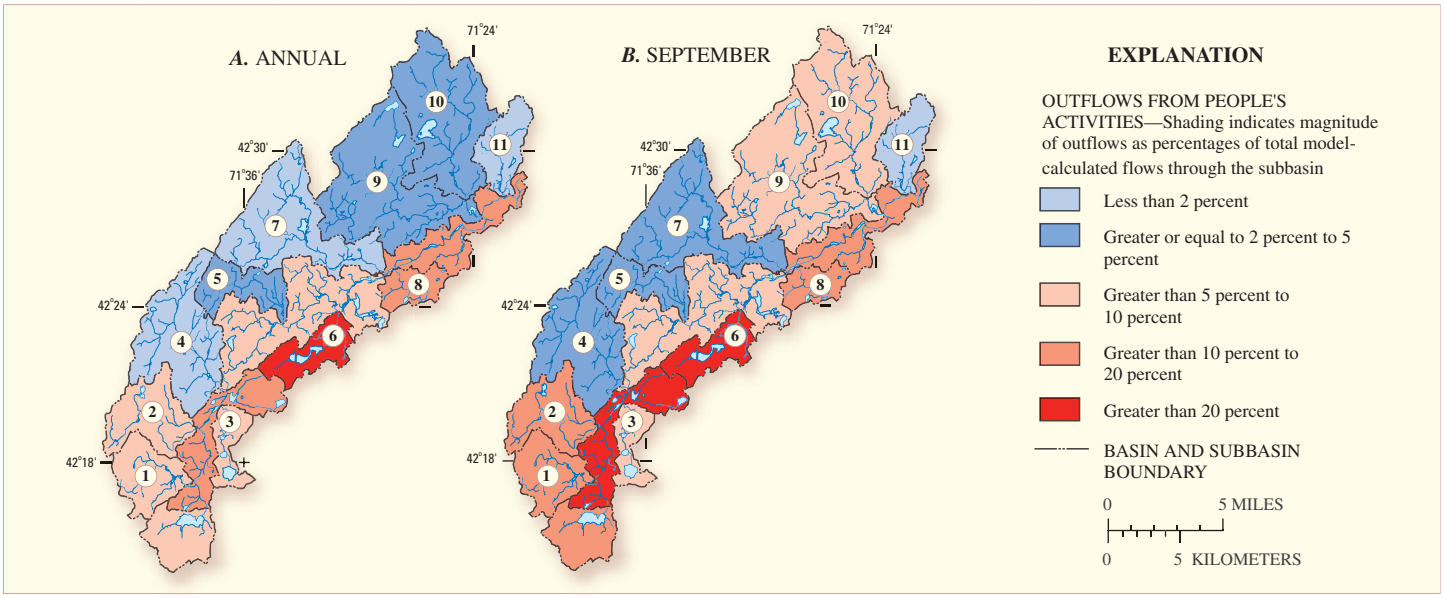


Figure 7. Outflows from people's activities (ground-water withdrawals, surface-water withdrawals, and ground-water infiltration to sewers) relative to total model-calculated outflows from the ground-water-flow system in subbasins of the Assabet River Basin, for average annual and average low-flow (September) conditions during 1997–2001. Subbasin numbers refer to subbasin names as listed in table 2.

permitted under the Massachusetts Water Management Act and the National Pollution Discharge Elimination System; the effects of new sewers also were simulated in the second scenario. Other scenarios simulated in the study are described by DeSimone (2004).

Predevelopment Conditions

In scenario S1, elimination of withdrawals, discharges, and other flows associated with people's activities resulted in more streamflow in tributaries and less streamflow in the Assabet River. Increased average annual streamflows in tributaries ranged from 2 percent, in the Elizabeth Brook subbasin, to 44 percent, in the Fort Meadow Brook subbasin. In most subbasins, streamflow increases resulted from a variable combination of decreased withdrawals and decreased ground-water infiltration to sewers (table 2). Decreased withdrawals contributed most to the streamflow increases in the Assabet Main Stem Headwaters (not shown in table 2), Cold Harbor and Howard Brooks, Stirrup Brook, Fort Meadow Brook, and Taylor Brook subbasins. In the Hop Brook and Danforth Brook subbasins, decreased infiltration to sewers contributed most to increases in streamflow (table 2). In many subbasins, decreases in withdrawals and infiltration to sewers were offset by decreases in septic-system return flow, which was an inflow to the aquifer and augmented streamflow under simulated existing conditions. This happened in the Fort Pond Brook and Nashoba Brook subbasins, which have primarily public-water supply and private disposal. In the Elizabeth Brook subbasin, where private-water supply and disposal serve most of the population, the small streamflow increase resulted mostly from decreased consumptive use (table 2). A small decrease in streamflow in the Spencer Brook subbasin resulted from the elimination of a wastewater discharge.

Changes in average monthly flows in scenario S1 relative to existing conditions varied during the annual cycle and among subbasins, depending on the variable monthly rates of

Table 2. Changes in average annual inflows and outflows from people's activities and the resulting model-calculated streamflow in tributary subbasins of the Assabet River Basin in simulated scenarios of (1) predevelopment conditions and (2) future conditions, in which withdrawals and discharges are increased to maximum permitted levels. Changes are relative to existing (1997–2001) conditions.

Tributary subbasin (Number refers to label on figure 7)	Change in inflows and outflows from people's activities (cubic feet per second)				Change in streamflow, in cubic feet per second (change in percent)	
	Inflows	Outflows				
	Septic-system return flow	Water-supply withdrawals	Ground-water infiltration to sewers	Consumptive use		
Scenario 1: Predevelopment Conditions						
Hop Brook (1)	-0.17	-0.14	-0.45	0	+0.36	(+5)
Cold Harbor & Howard Brooks (2)	-.13	-.45	-.20	-.05	+.65	(+9)
Stirrup Brook (3)	-.14	-.28	-.06	0	+.22	(+12)
North Brook (4)	-.14	0	-.05	-.13	+.10	(+.6)
Danforth Brook (5)	0	-.01	-.12	-.05	+.20	(+4)
Fort Meadow Brook (6)	-.11	-1.45	-.33	0	+1.3	(+44)
Elizabeth Brook (7)	0	-.08	0	-.24	+.29	(+2)
Taylor Brook (8)	-.11	-.50	-.08	0	+.37	(+23)
Fort Pond Brook (9)	-1.04	-.71	-.06	-.14	-.03	(-.1)
Nashoba Brook (10)	-1.53	-.93	0	-.10	-.35	(-2)
Spencer Brook (11)	-.12	0	0	-.05	-.08	(-2)
Scenario 2: Future Conditions–Maximum Permitted Withdrawals and Discharges						
Hop Brook (1)	-.17	+.28	+.05	0	-.67	(-10)
Cold Harbor & Howard Brooks (2)	-.13	0	+.05	0	-.20	(-3)
Stirrup Brook (3)	-.11	0	+.03	0	-.15	(-8)
North Brook (4)	-.14	0	+.03	0	-.17	(-1)
Danforth Brook (5)	0	-.03	0	0	-.03	(-.05)
Fort Meadow Brook (6)	-.09	+.21	+.02	0	-.34	(-11)
Elizabeth Brook (7)	0	0	0	0	0	(0)
Taylor Brook (8)	0	+.07	0	0	-.04	(-3)
Fort Pond Brook (9)	-.32	-.01	+.05	0	-.37	(-1)
Nashoba Brook (10)	-.01	+.03	0	0	-.04	(-.3)
Spencer Brook (11)	0	0	0	0	+.03	(+.7)

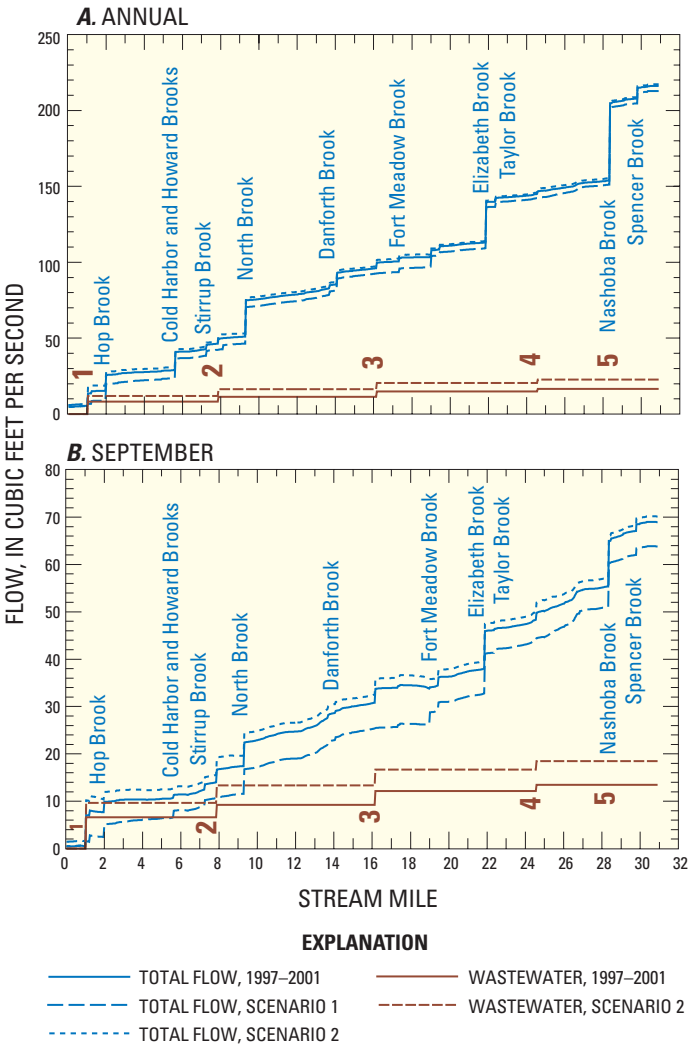


Figure 8. Model-calculated nonstorm streamflow in the Assabet River and the component of flow that originated as wastewater for existing conditions (1997–2001) and for two hypothetical scenarios. Scenario 1 represents predevelopment conditions, in which flows caused by people's activities are eliminated. Scenario 2 represents conditions in which water withdrawals and wastewater discharges are increased to the maximum currently permitted levels. Average annual and average low-flow (September) conditions are shown. Numbers indicate the locations of municipal (1-4) and nonmunicipal wastewater (5) discharges to the river.

withdrawals, infiltration to sewers, and other flows and on the response time of streamflow to these changes. Generally, changes were smaller fractions of total model-calculated streamflow during March, when overall flows were high, and changes were larger fractions of total streamflow during September, during the low-flow period. In March, increases in tributary streamflows ranged from less than 1 to about 20 percent. In September, increases ranged from 4 to more than 100 percent.

Along the main stem Assabet River downstream of the Headwaters subbasin (and downstream of the wastewater-treatment facility near the basin headwaters), model-calculated annual streamflows were slightly less (2 to 3 percent) in S1 than under existing conditions (fig. 8*A*). These streamflows were reduced because wastewater discharges, which augment streamflow under existing conditions, were eliminated in S1. In September, decreases in streamflow in the Assabet River ranged from more than 60 percent, downstream of the headwaters wastewater-treatment facility, to about 7 percent, at the confluence with the Sudbury River (fig. 8*B*).

Increased Withdrawals and Discharges

In scenario S2, water withdrawals were increased from existing sources and a new source (supply well) was added in Westborough so that total withdrawals increased from 9.9 Mgal/d to maximum permitted levels of 12.2 Mgal/d. Wastewater discharges at existing treatment facilities were increased to the maximum permitted levels, and a new facility was added in Acton to increase total discharges from 11.0 Mgal/d to permitted levels of 15.0 Mgal/d. The effects of new sewers, mostly in Acton and Northborough, also were simulated, by decreasing septic-system return flow and increasing ground-water infiltration to sewers in these areas. Basinwide, septic-system return flow decreased from 4.3 Mgal/d to 3.0 Mgal/d, and infiltration to sewers increased from 2.6 Mgal/d to 2.9 Mgal/d. In this scenario, streamflow decreased in nearly all tributaries and increased in the Assabet River, relative to existing conditions (table 2 and figs. 8*A* and 8*B*). Decreases relative to existing conditions ranged from less than 1 percent, in the Danforth and Nashoba Brook subbasins, to about 10 percent, in the Hop and Fort Meadow Brook subbasins. In Hop, Fort Meadow, and Taylor Brook subbasins, increased withdrawals accounted for most of the decrease in streamflow; decreased septic-system return flow accounted for most of the decreased streamflow in other subbasins (table 2). As in scenario S1, changes in monthly model-calculated streamflows were largest relative to 1997–2001 flows in September, when decreases in model-calculated streamflows ranged from about 1 to 98 percent.

In the Assabet River, other than in the main stem Headwaters subbasin (fig. 1), model-calculated streamflows for the S2 scenario increased to relative existing conditions (figs. 8*A* and B), because of increased wastewater discharges. In this scenario, the wastewater fraction of streamflow ranged from 69 to 10 percent annually (decreasing downstream from the headwaters wastewater-treatment facility, number 1 in fig. 8), and from 94 to 26 percent in September, both of which are increases of several percentage points relative to existing conditions.

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For more information about this or other USGS investigations in Massachusetts, contact the USGS Massachusetts-Rhode Island Water Science Center 1-508-490-5000 or visit our Web site at http://ma.water.usgs.gov/.

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