Method for Estimating Water Use and Interbasin Transfers of Freshwater and Wastewater in an Urbanized Basin

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Abstract

Techniques for management of drainage basins that use water budgets to balance available water resources with actual or anticipated water use require accurate and precise estimates of basin withdrawals, interbasin transfers of freshwater, unaccounted-for use, water use, consumptive use, inflow and infiltration, basin return flow, and interbasin transfers of wastewater. Frequently, interbasin transfers of freshwater and wastewater are not included in basin water budgets because they occur within public water-delivery and wastewater-collection systems. A new 10-step method was developed to improve estimates of inflow and infiltration and interbasin transfers using readily available statewide data. The accuracy and precision of water-use estimates determined by this method are improved through careful application of coefficients for small users and the use of metered values for large users. The method was developed and tested with data for the Ten Mile River Basin in southeastern Massachusetts. This report uses examples from the basin to illustrate each step of the method.

INTRODUCTION

Effective management of a watershed, or drainage-basin (basin) requires use of a water budget to balance available water resources with current or anticipated water use (demand) and its associated consumptive use. Water use in the broadest sense pertains to the interaction of human activity with and its influence on the hydrologic cycle (fig. 1). Water use begins when water is diverted or withdrawn from surface- or ground-water sources and is conveyed to the place of use. The withdrawal may be (1) by the user or (2) by a public water system, in which case the water may be treated and is conveyed to the user through a distribution system. Water use *by a user or group of users* refers to water that is actually used for a specific purpose, such as for domestic activities (drinking or bathing), irrigation, or industrial processing. After use, wastewater either is conveyed to a wastewater-treatment facility for treatment and return flow or is returned directly to the hydrologic system through septic systems. Consumptive use is water that evaporates or is incorporated into a product during use.

Basin water budgets are often based upon the assumption that water withdrawals equal water use by a user or group of users and, in turn, equal consumptive use plus return flow. In some areas, however, particularly urban areas, interbasin transfers of water or wastewater could cause the water resources in the basin to be overestimated or underestimated. Interbasin transfers may be difficult to identify, particularly if they occur within a Minor Civil Division (MCD) or town. For this reason, the Massachusetts Department of Environmental Management (MADEM) and the Massachusetts Department of Environmental Protection (MADEP) requested the assistance of the U.S. Geological Survey (USGS) in developing an efficient and accurate method to estimate interbasin transfer and water use. The Ten Mile River Basin in southeastern Massachusetts was selected as the basin for which to develop the method because the basin is small and highly urbanized.

The major requirements for the new method for determining water use and interbasin transfer was that it (1) use readily available statewide data and (2) efficiently estimate accurate and precise water-use values. Initially, data were collected and analyzed from the Attleboro and North Attleborough Water Departments following the methods described in Horn and others (1994) for estimating MCD water use. This approach, however, which incorporated the review of hundreds of meter readings, proved too time consuming and inaccurate to estimate basin water use efficiently.

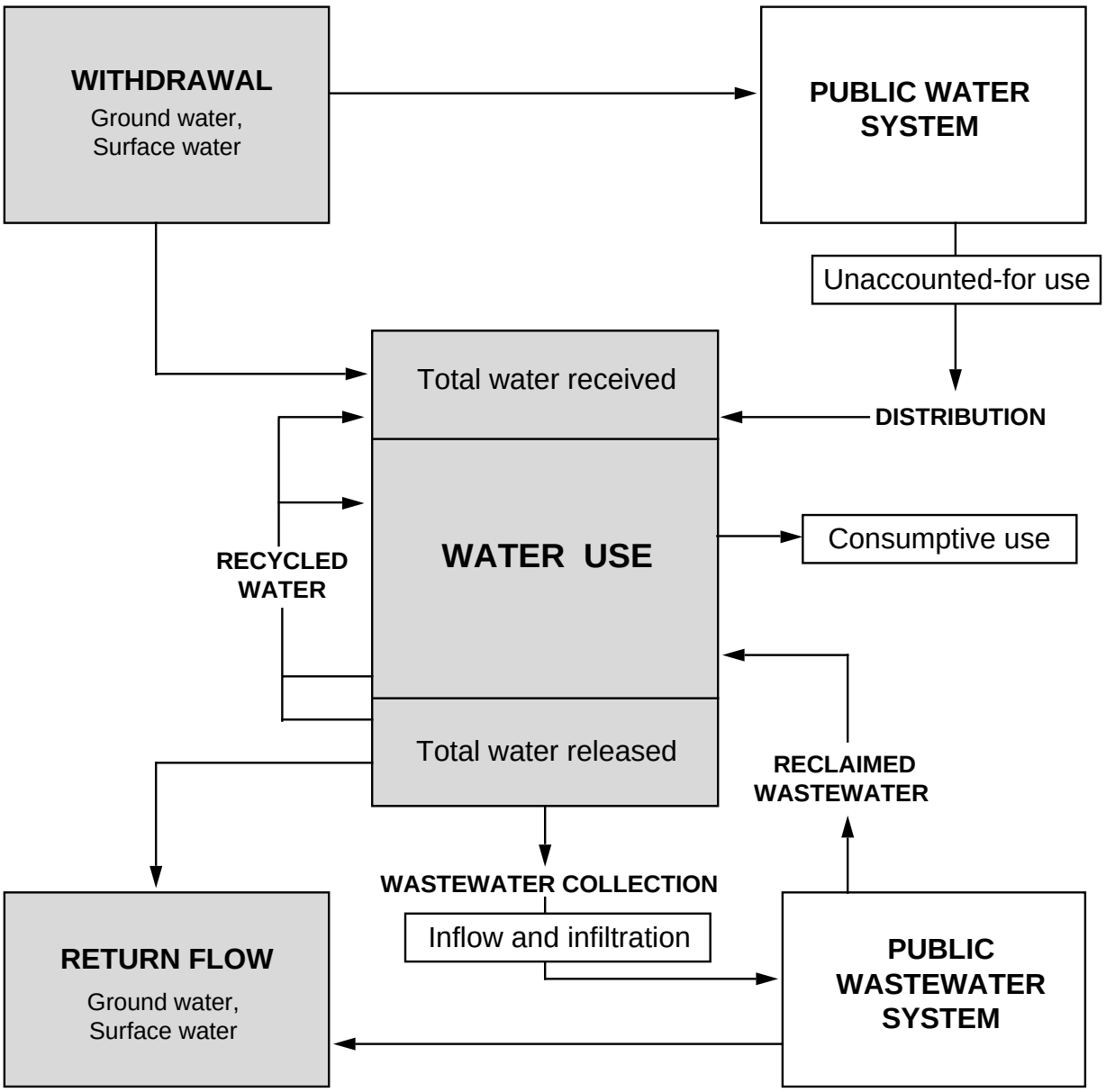


Figure 1. Relations among water-use processes. [Consumptive use occurs as evapotranspiration or product incorporation, primarily during use and storage in open systems. Conveyance is represented in this diagram as an arrow (⟶).]

The new approach integrated computerized maps of population, land use, basin divides, public water-system distribution, and wastewater-system collection with tabular data for withdrawals, return flow, and employee statistics. Most of the data were obtained from sources that are available for any area in the State.

Purpose and Scope

The purpose of this report is to describe an efficient and accurate method for estimating basin withdrawals, interbasin transfers of freshwater and wastewater, unaccounted-for uses, water use, consumptive use, inflow and infiltration, and basin return flow by using readily available statewide data. The method was developed and tested with data from the five subbasins of the Ten Mile River Basin in southeastern Massachusetts, hereafter called the study area. The data are used in this report to illustrate how to apply the methods. The report briefly describes the political, hydrologic, and water-use characteristics of the Ten Mile River Basin from about 1992 through 1995, but focuses on the method developed for analyzing water-use data and the net gains or losses to the water resources in the basin and subbasins.

Acknowledgments

Most of the data used in developing and testing the water-use and interbasin transfer method were obtained from the Attleboro Department of Public Works, the North Attleborough Department of Public Works, and the Water Departments of Seekonk, Plainville, and Mansfield. The cooperation of the personnel from these utilities is gratefully acknowledged.

DESCRIPTION OF STUDY AREA

The study area in southeastern Massachusetts includes 46 mi^2 of the 54-square-mile Ten Mile River Basin in Massachusetts and Rhode Island (fig. 2). In 1990, the population in the basin was about 61,751. The basin is densely populated (1,351 people per square mile) and industrialized. Area and population by MCD and subbasin are given in table 1. A land-use map of the study area, where domestic, industrial, and commercial uses predominate, is shown in figure 3.

Minor Civil Division

The political subdivisions in the basin provide the basic unit by which data initially are collected and analyzed. The smallest level at which data are available is the MCD, which is a term used by the U.S. Bureau of the Census that, in New England, is generally equivalent to a town or city. Three towns are in Norfolk County (Foxborough, Plainville, and Wrentham), and the remaining five towns are in Bristol County (Attleboro, Mansfield, North Attleborough, Rehoboth, and Seekonk). Each MCD has a "water-use" setting composed of its population density, population/household, employment characteristics, and public water and wastewater systems.

The city of Attleboro covers 27.5 mi^2 with a population of 38,383, of which 18.0 mi^2 and 30,757 people (U.S. Department of Commerce, 1991) are in the Ten Mile River Basin. Of the 22,170 people (Dun and Bradstreet Business Information database, 1995) working in Attleboro, 10,900 people (49 percent; Dun and Bradstreet Business Information database, 1995) work in the established jewelry industry and the newer metal-fabrication industries, which use water for fabrication, processing, washing, and cooling. The remaining 51 percent are employed by commercial facilities such as office buildings, institutions, motels, and restaurants. About 52 percent of the housing units are single-family, with an average of 2.66 persons per household (Massachusetts State Data Center, 1992). The Attleboro Water Department provides water to about 36,000 people in Attleboro; North Attleborough Water Department and Pawtucket Water Supply Board (R.I.) provide water to small areas in the town. The Attleboro Sewage Treatment Plant collects wastewater from about 27,000 people.

The town of North Attleborough covers 18.7 mi^2 with a population of 25,038 (U.S. Department of Commerce, 1991), of which 15.3 mi^2 and 22,886 people are in the Ten Mile River Basin. Industries, primarily metal fabrication, employ 4,216 people (36 percent; Dun and Bradstreet Business Information database, 1995) of the 11,555 people working in North Attleborough. About 59 percent of housing units are single-family, with 2.69 persons per household (Massachusetts State Data Center, 1992). The North Attleborough Water Department serves about 23,000 (MADEP, written commun., 1992) people in North Attleborough, and the Attleboro Water Department and Kings Grant Water Company serve small areas in the town. The North Attleborough Sewage Treatment Plant serves about 17,000 people (Massachusetts State Data Center, 1992).

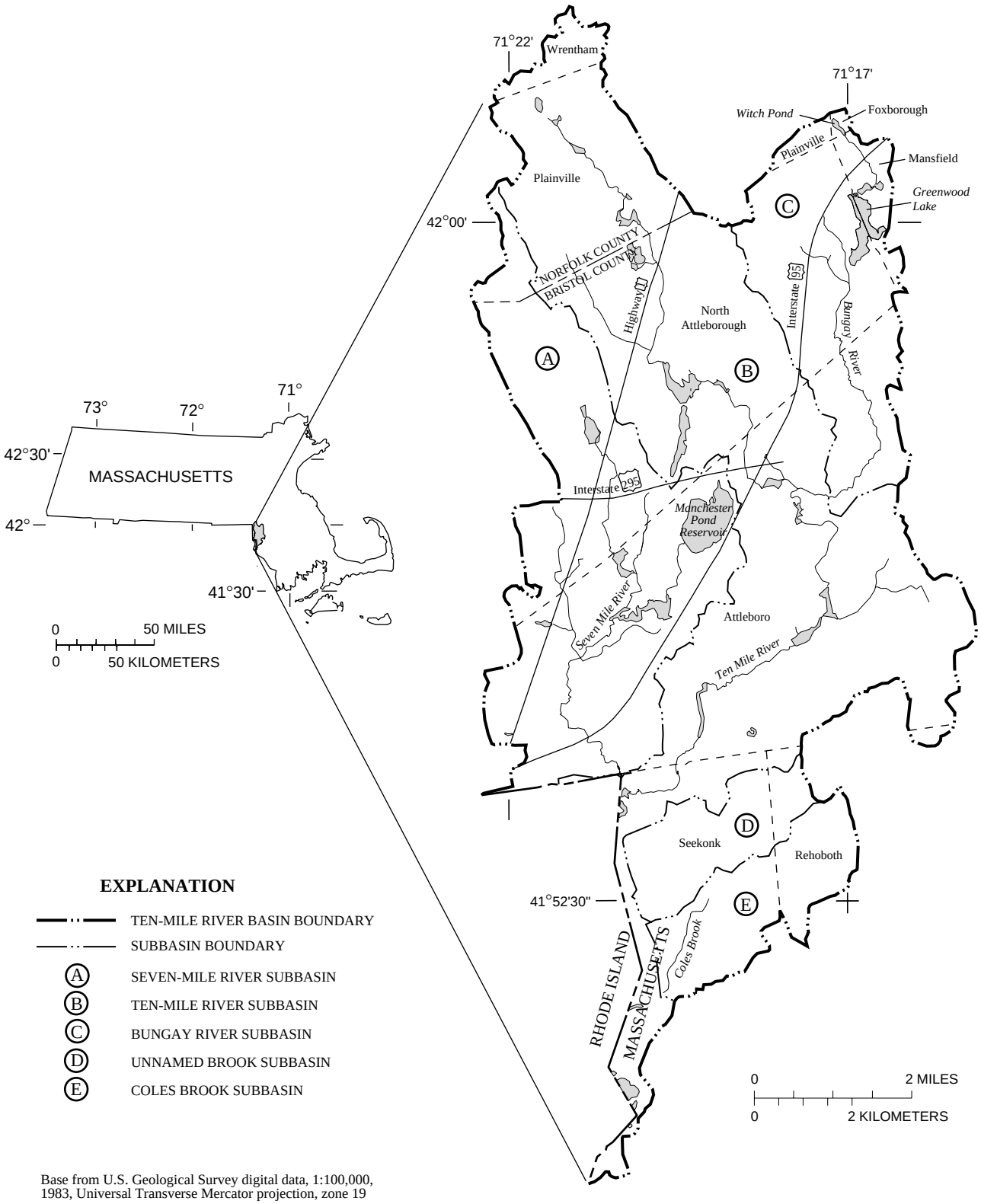


Figure 2. Location of the five subbasins of the Ten Mile River Basin, southeastern Massachusetts.

Table 1. Area and population in the five subbasins of the Ten Mile River Basin and adjacent areas, southeastern Massachusetts, 1990

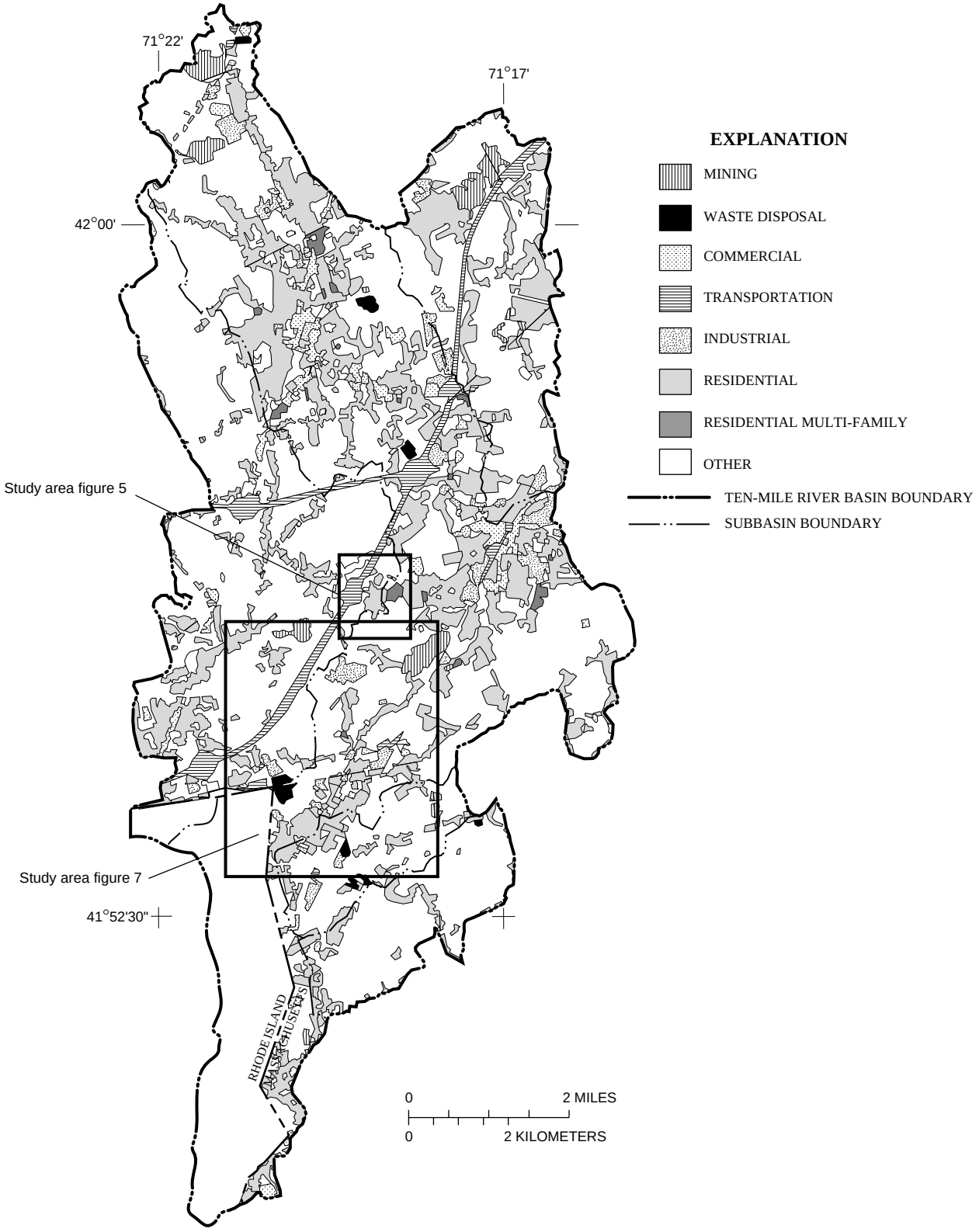
[mi^2, square mile]

Minor Civil Division	Total	
	Land area (mi^2)	Population 1990
Ten Mile River subbasin		
Attleboro	10.0	22,723
North Attleborough	6.4	16,483
Plainville	3.7	3,426
Rehoboth	.2	65
Seekonk	.7	955
Wrentham	.6	56
Total	21.6	43,708
Seven Mile River subbasin		
Attleboro	6.1	6,014
North Attleborough	5.4	2,361
Plainville	.6	22
Total	12.1	8,397
Bungay River subbasin		
Attleboro	1.9	2,020
Foxborough	.1	0
Mansfield	.8	469
North Attleborough	3.5	4,042
Plainville	.2	458
Total	6.5	6,989
Coles Brook subbasin		
Rehoboth	1.2	193
Seekonk	1.9	960
Total	3.1	1,153
Unnamed Brook subbasin		
Rehoboth	0.3	71
Seekonk	2.1	1,433
Total	2.4	1,504
Total Inside Ten Mile River Basin		
Attleboro	18.0	30,757
Foxborough	.1	0
Mansfield	.8	469
North Attleborough	15.3	22,886
Plainville	4.5	3,906
Rehoboth	1.7	329
Seekonk	4.7	3,348
Wrentham	.6	56
Total	45.7	61,751
Outside Ten Mile River Basin		
Attleboro	9.5	7,626
Foxborough	20.0	14,419
Mansfield	19.7	16,099
North Attleborough	3.4	2,152
Plainville	6.6	2,965
Rehoboth	44.8	8,327
Seekonk	13.6	9,698
Wrentham	21.6	8,950
Total	139.2	70,236
Total for each Minor Civil Division		
Attleboro	27.5	[1]38,383
Foxborough	20.1	[1]14,419
Mansfield	20.5	[1]16,568
North Attleborough	18.7	[1]25,038
Plainville	11.1	[1]6,871
Rehoboth	46.5	[1]8,656
Seekonk	18.3	[1]13,046
Wrentham	22.2	[1]9,006
Total	184.9	[1]131,987

[1]Numbers are from the U.S. Bureau of Census.

The town of Plainville covers 11.1 mi^2 with a population of 6,871 (U.S. Department of Commerce, 1991), of which 4.5 mi^2 and 3,906 people are in the Ten Mile River Basin. Industries employ 813 people (33 percent; Dun and Bradstreet Business Information database, 1995) of the 2,447 people working in Plainville. About 55 percent of the housing units are single-family, with an average of 2.57 persons per household (Massachusetts State Data Center, 1992). The Plainville Water Department serves about 6,500 people (MADEP, written commun., 1992). There is a small wastewater-collection system in Plainville.

The town of Seekonk covers 18.3 mi^2 with a population of 13,046 (U.S. Department of Commerce, 1991), of which 4.7 mi^2 and 3,348 people live in the Ten Mile Basin. Industries employ 411 people (5 percent; Dun and Bradstreet Business Information database, 1995) of the 7,703 people working in Seekonk. About 90 percent of the housing units are single-family, with an average of 2.91 persons per household (Massachusetts State Data Center, 1992). The Seekonk Water Department serves about 12,615 people (MADEP, written commun., 1992). There is no wastewater collection system in Seekonk.



Base from U.S. Geological Survey digital data, 1:100,000, 1983, Universal Transverse Mercator projection, zone 19

Figure 3. Land use in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts. (Data from MassGIS and U.S. Geological Survey, Massachusetts-Rhode Island District.)

The town of Mansfield covers 20.5 mi^2 with a population of 16,568 (U.S. Department of Commerce, 1991), of which only 0.8 mi^2 and 469 people are in the Ten Mile River Basin. The Mansfield Water Department serves about 16,600 (MADEP, written commun., 1992) people in the town and the Attleboro Water Department serves a small area. The Mansfield Water Treatment Plant serves about 10,000 people (Massachusetts State Data Center, 1992).

The town of Rehoboth covers 46.5 mi^2 with a population of 8,656 (U.S. Department of Commerce, 1991), of which 1.7 mi^2 and 329 people live in the Ten Mile River Basin. Rehoboth has no public water or wastewater systems. The town of Wrentham covers 22.2 mi^2 with a population of 9,006 (U.S. Department of Commerce, 1991), of which 0.6 mi^2 and 56 people live in the Ten Mile River Basin. Foxborough has only an unpopulated area of about 0.1 mi^2 in the Ten Mile River Basin and will not be included in the remainder of this report.

Subbasins

The Ten Mile River Basin is mostly flat; some rounded hills in northern parts of the basin reach a maximum altitude of about 430 ft above sea level. The basin contains 50 lakes and ponds, many of which are along the main channel of the Ten Mile River. Twenty-seven of the lakes in the basin have areas of 10 acres or more. The principal aquifers in the Ten Mile River Basin are stratified-drift deposits in valleys and lowlands. These aquifers are hydraulically connected to surface-water bodies and underlie about one-half of the basin. The thickest deposits of stratified drift are along river valleys and lowlands. Land use differs substantially among the five subbasins (fig. 3).

The Ten Mile River begins in a pond (altitude about 230 ft above sea level) in Plainville and flows about 61 mi in a southerly direction through the urbanized areas of North Attleborough, Attleboro, and Seekonk before crossing into Rhode Island at an altitude of 75 ft above sea level. Many dams were built along the river, and, for much of its length, the river flows through impoundments or is confined by concrete or masonry retaining walls (Simcox, 1992). The river altitude in the basin decreases mostly at the dams. The Ten Mile River subbasin of the Ten Mile River Basin includes about 47 percent of the land area in the basin. The subbasin includes 71 percent of the basin population with a density of 2,124 people/mi^2, 73 percent of the land used for industry, and 48 percent of the land used for commercial purposes.

The Bungay River begins in Witch Pond in Foxborough (altitude about 157 ft above sea level), flows through Greenwood Lake, and after 15 mi, enters the Ten Mile River in Attleboro. The Bungay River subbasin composes about 14 percent of the land area in the Ten Mile River Basin. Eleven percent of the basin population resides within the Bungay River subbasin, with a population density of 1,075 people/mi^2. The subbasin includes 16 percent of the land used for industry in the basin and 15 percent of the land used for commercial purposes in the basin.

The Seven Mile River subbasin extends from Plainville through North Attleborough and enters the Ten Mile River near the Rhode Island-Massachusetts border. The largest lake in the Ten Mile River Basin, the Manchester Pond Reservoir in Attleboro (218 acres; Massachusetts Department of Environmental Quality Engineering, 1976, p. 7, 114–116) at altitude of 145 ft above sea level, is in the Seven Mile River subbasin. The Seven Mile River subbasin composes about 27 percent of the land area in the Ten Mile River Basin. Fourteen percent of the basin population resides in the subbasin, which has a population density of 694 people/mi^2. The subbasin includes 5 percent of the land used for industry in the basin, and 36 percent of the land used for commercial purposes in the basin.

The remaining two subbasins in Rehoboth and Seekonk, subbasins D and E in figure 2, drain 5 percent of the total basin land area to an unnamed stream and 7 percent to Coles Brook, respectively; each subbasin contains about 2 percent of the basin population.

METHOD OF ESTIMATING WATER USE AND INTERBASIN TRANSFER

The recommended method for estimating basin water use and interbasin transfer of freshwater and wastewater incorporate readily available State data in the form of computerized maps and tables. Interbasin transfers are determined by means of a water budget, in which all components of water withdrawal, use, and return flow (public and self supply, industrial, commercial, and domestic use, and public and self disposal) are included. Ten steps are followed in constructing this budget (fig. 4).

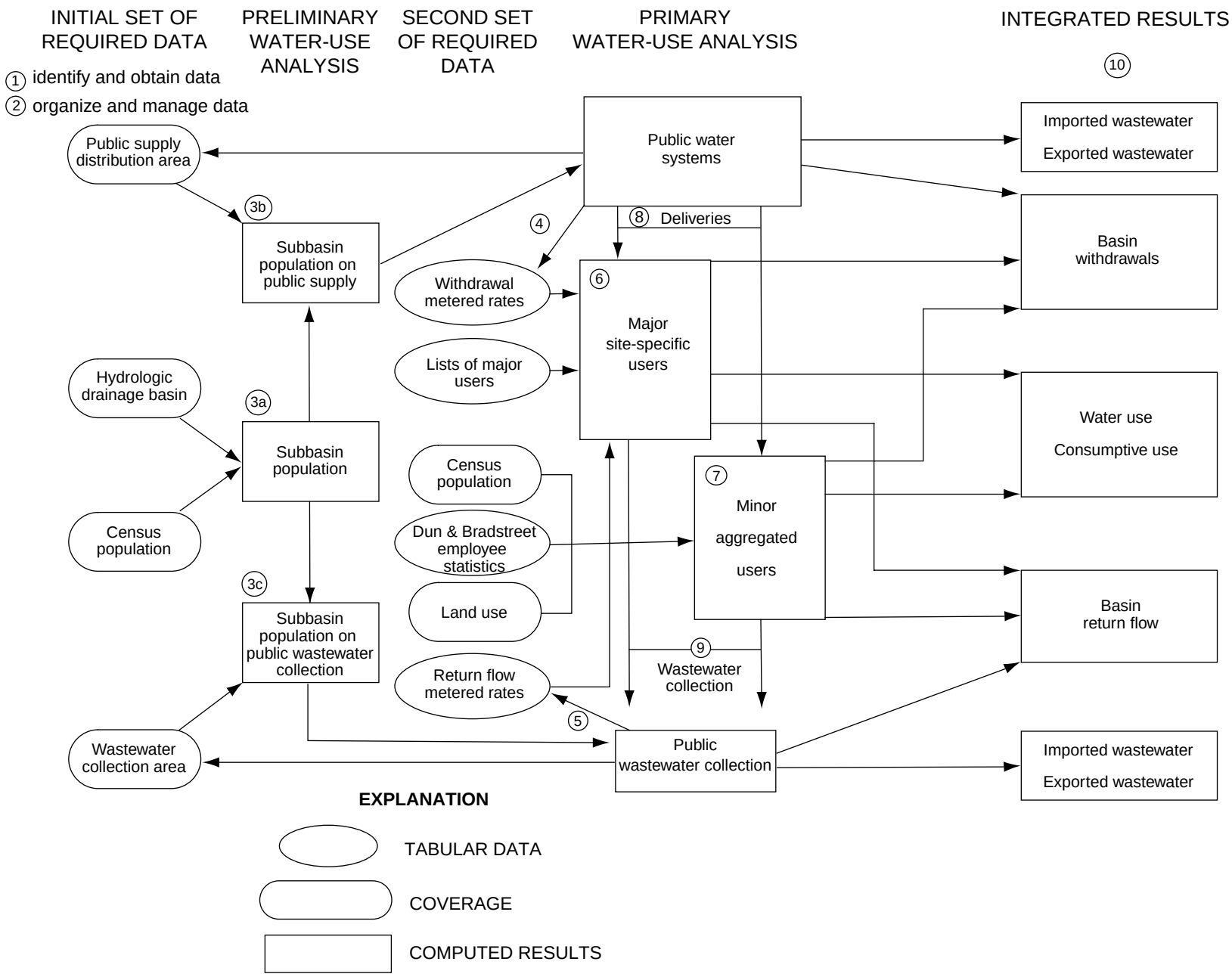


Figure 4. General approach for estimating basin water use and interbasin transfers.

Required data must be (1) identified and obtained and (2) organized by MCD and managed through spreadsheets, data bases, and a geographic information system (GIS). Basin divides are superimposed on population maps to estimate the total population in each subbasin (3a), on distribution-service area maps to estimate subbasin population served by public water systems (3b), and on wastewater-collection service area maps to estimate subbasin population served by public wastewater systems (3c). Metered-withdrawal rates for public water systems are used to determine rates of withdrawal from water resources (4). Metered-return-flow rates from public wastewater systems are used to determine rates of return flow for wastewater-treatment plants and outfalls to water resources (5). Lists of major users are combined with metered withdrawal and return-flow rates to identify locations and determine rates of use for major users (6). Bureau of the Census population maps and Dun and Bradstreet Business Information database data are combined with data on major users and land-use coverages to estimate areal extent and rates of use for aggregated minor users (7). Data on major and minor users are combined with public water-system data to estimate areal extent and rates for public water-system deliveries and self-supplied withdrawals (8). Data on major and minor users are combined with public wastewater-system data to estimate areal extent and rates for public wastewater-system collection and self-disposed return flow (9). The final step is to combine all of this information and calculate basin water use, interbasin transfers, and net gain/loss to the resources for the basin and subbasin (10).

Identify and Obtain Required Data

The first major step involves (1) identifying (a) what data are needed, (b) which organizations collect the data, and (c) how and where the data are stored; and (2) requesting and receiving the data.

Data required to estimate water use and interbasin transfers fall into four areas: hydrology, land use, population, and water use. Table 2 provides a general guide for obtaining the required data and a specific description of where the data were obtained for this study. Hydrologic data are required to define boundaries and areal extents of subbasins. MADEM provided drainage-basin maps which incorporated modifications to existing USGS maps that defined drainage areas upstream of USGS gaging stations. The new drainage maps were digitized to become part of the USGS Massachusetts–Rhode Island District GIS library.

Land-use information provides the location and areal extent of residential, commercial, industrial, and agricultural activities. Topographic maps provide land-use data on population centers, hydrography (rivers, lakes, and wetlands), roads, land cover, and some individual sites of water-use activities, such as treatment plants, large industries, and mining operations. Spatial data sets (coverages) of land use were obtained from the Massachusetts Geographic Information Services (MassGIS). Coverages of political boundaries, roads, and hydrography were obtained from the USGS Massachusetts–Rhode Island District GIS library.

Population data identify (1) the number and location of people and type of housing units in the subbasin; (2) the proportion of households on public supply and public disposal systems; and (3) the number of people employed by the industrial and commercial facilities in each MCD. The proportion, not the number of households on public supply, is needed because we are using household values of supply and disposal to estimate population on public supply and disposal. Tabular data on population, type of housing, and proportion of households on public supply and disposal systems were obtained from the U.S. Bureau of the Census and from the Massachusetts State Data Center. Spatial population data sets originating from the U.S. Bureau of the Census as TIGER (Topographical Integrated Geographic Encoding and Referencing) files and processed by MassGIS were obtained for all the MCDs in the Ten Mile River Basin area. TIGER files are not meant to portray the geography of the area accurately, but provide a street-related (census-block) population distribution. Judgment must be used in combining TIGER files with other coverages.

The numbers of industrial, commercial, agricultural, and mining employees classified by two-digit Standard Industrial Classification (SIC) code for each town (not MCD) during the 1992–95 period were obtained from the Business Information data base maintained by Dun and Bradstreet. The data for each town were summarized by MCD and stored in the New England water-use database (NEWUDS). Community Profiles, which consist of a brief description of the social, political, and economic characteristics of each MCD, were obtained from the Massachusetts Executive Office of Communities and Development.

Table 2. Summary of data and data sources

[MADEP, Massachusetts Department of Environmental Protection; MADEM, Massachusetts Department of Environmental Management; MCD, Minor Civil Division; GIS, geographic information system]

Data	Generic data sources	Data sources used in Ten Mile River Basin	Type of data
HYDROLOGY			
Drainage basin boundaries Streams	U.S. Geological Survey State agency responsible for water-resource management	U.S. Geological Survey	GIS coverage
Water bodies Wetlands	U.S. Geological Survey topographic maps	U.S. Geological Survey	GIS coverage, paper maps
LAND USE			
Land use including residential, commercial, industrial, agricultural, and open land use types	State Geographic Information Center U.S. Geological Survey (Digital Line Graph National Land Use coverage)	Massachusetts Geographic Information Service	GIS coverage
POPULATION			
Residential population and type of housing unit by MCD	U.S. Bureau of Census; State agency that works with census data	U.S. Bureau of Census; Massachusetts State Data Center	tabular
Mapped residential population within MCD	U.S. Bureau of Census; State agency that works with census data or State Geographic Information Center	Massachusetts Geographic Information Service	GIS coverage
Residential population on public water and public disposal systems	U.S. Bureau of Census; State agency that works with census data	Massachusetts State Data Center	tabular
Population employed by industrial and commercial facilities by MCD	Dun and Bradstreet; State agency that works with employment data or community development	Dun and Bradstreet; Massachusetts Executive Office of Communities and Development	tabular
WATER USE			
Water Supply			
Supply source and treatment plant location Population served Withdrawal rates Distribution area Major user rates	Individual Water Suppliers; State Agency that implements Safe Drinking Water Regulations State agency that implements water allocation or water management program U.S. Geological Survey water-use program	Town water departments; MADEP, Division of Water Supply U.S. Geological Survey water-use program	tabular
Wastewater Disposal			
Treatment plant and outfall location Population served Wastewater collection area Discharge rates Major user rates	Individual wastewater-treatment plants, State agency that implements the National Pollutant Discharge Elimination Program, U.S. Geological Survey water-use program	Town wastewater-treatment plants; MADEP, Division of Pollution Control, U.S. Geological Survey water-use program	tabular
Major Users			
Number of employees Location SIC code Water withdrawal and disposal rates	Dun and Bradstreet; State agency that works with employment data or community development; Individual water suppliers and wastewater-treatment plants; State agency that implements the National Pollutant Discharge Elimination Program, U.S. Geological Survey water-use program	Dun and Bradstreet; Massachusetts Executive Office of Communities and Development; Town water supplies and treatment plants; MADEP, Division of Water Supply; MADEM, Division of Water Resources; U.S. Geological Survey water-use program	tabular

Water-use data were divided into water supply, wastewater disposal, and major users. Data on individual large users and summary data on small and medium users are needed to account accurately for the occurrence and distribution of water use in each subbasin. Data on water supply were obtained from individual water suppliers in the Ten Mile River Basin, namely the water departments in Attleboro, North Attleborough, Plainville, and Seekonk. These data included (1) location of wells and surface-water intakes, water-treatment plants, and major users; (2) population served; (3) metered rates for source withdrawals, unaccounted-for use, and deliveries to major users; and (4) distribution areas. Data on population served, total withdrawals, and sales of water to other water suppliers also were obtained from the MADEP, Division of Water Supply, and from data collected and analyzed through the U.S. Geological Survey's water-use program.

Data on wastewater collection and return flow were obtained from individual wastewater systems in the Ten Mile River Basin, namely the sewer departments in Attleboro and North Attleborough. These data included (1) location of wastewater-treatment plants; (2) population served; (3) metered rates for collection from major users, plant influent, and plant effluent; and (4) wastewater collection areas. Data on wastewater discharges also were obtained from the Division of Pollution Control of the MADEP in support of the National Pollutant Discharge Elimination System (NPDES) Program.

The definition for a major user initially included anyone who withdrew, used, or discharged in excess of 10,000 gal/d. It was determined that a threshold of 50,000 gal/d (0.05 Mgal/d) for defining a major user, however, was more appropriate in terms of the overall water budget in the basin. This new threshold of 0.05 Mgal/d equals 0.5 to 1.0 percent of total withdrawals in the study area (7.63 Mgal/d), 1.0 percent of the water use in the largest MCD (5.0 Mgal/d), and about 1.0 percent of water use in the largest subbasin (4.85 Mgal/d). These general criteria provide a tentative threshold for identifying major users. The availability of time, money, and data will determine whether to raise or lower the precision to which site-specific water-use data on major users can be pursued. Data on major users in addition to the sources discussed above also were obtained from the Division of Water Resources of the MADEM in support of the water-resources management program requiring permits for all withdrawals in excess of 100,000 gal/d (0.1 Mgal/d).

Organize and Manage Data

The data described in the previous section were combined into a series of GIS coverages and automated tabular and paper files. Separate GIS point coverages for public water supply and wastewater disposal were created from location information on wells, surface-water intakes, discharge outfalls, treatment plants, and connections to other public water and wastewater systems. A GIS line coverage was created from areal-extent maps of water-distribution and wastewater-collection lines. GIS polygon coverages for land use, population, hydrography, political boundaries, and roads were created for each MCD.

The automated data from the Dun and Bradstreet Business Information database on major users were combined with data from other sources described in the previous sections and entered into NEWUDS. The metered data collected from the public suppliers were entered into spreadsheets, but data from only the largest users were entered into NEWUDS. Data on public supply wells and NPDES discharges already in NEWUDS were supplemented with the new data from MADEP.

Paper records and retrievals from NEWUDS were organized by MCD for reference and archiving along with paper copies of the coverages and topographic maps.

Estimate Subbasin Populations

Digital population data and basin boundaries were combined (overlain) to determine the population in each subbasin as summarized in table 1. These data sets can be combined with the areal extent of public water and wastewater systems to estimate the population served by public water and wastewater systems in each subbasin.

Subbasin populations were determined first. The population values for all census polygons wholly within each subbasin (in table 3 and fig. 5, see polygons 280, 334, 350, 363, and 364 in the Seven Mile River subbasin, and 332 in the Ten Mile River subbasin) were summed. About 5 percent of the polygons in the Ten Mile River Basin include areas from more than one subbasin (for example, polygon 333); this requires disaggregating the population in the polygon to each subbasin. The first step was to create a data table containing census polygon ID, total polygon area and population, and the polygon area in each subbasin

Table 3. Population of subbasins in the Ten Mile River Basin estimated by direct areal proportion and by use of housing-unit density

[No., number; mi^2, square mile; --, does not apply; <, actual value is less than value shown]

Census polygon identification No.	Total Census polygon		Census polygon for Seven Mile River subbasin			Census polygon for Ten Mile River subbasin		
	Area (mi^2)	Population	Area (mi^2)	Estimated population using percentage of land area	Population estimated using housing-unit density	Area (mi^2)	Estimated population using percentage of land area	Population estimated using housing-unit density
280	<0.01	13	<0.01	13	13	0	--	--
334	.01	38	.01	38	38	0	--	--
350	.01	25	.01	25	25	0	--	--
363	<.01	10	<.01	10	10	0	--	--
364	.01	20	.01	20	20	0	--	--
332	.01	168	0	--	--	.01	168	168
228	.11	50	.06	27	27	.05	23	23
266	.07	246	.05	176	80	.02	70	166
327	.57	482	.15	127	155	.42	355	327
333	.01	69	.01	69	37	<.01	0	32
Total	0.81	1,121	0.31	305	405	0.50	616	716

(table 3). The population in each subbasin could be determined in most cases (as in polygon 228) by multiplying the percent of area included in the subbasin (0.06/0.11) with the total population (50). An evaluation of population distribution was required, however, when the polygon area was large (greater than 0.5 mi^2, as in polygon 327), the population was large (greater than 100 people, as in polygons 327 and 266), or the distribution of multi-family housing units was heterogeneous (as in polygon 266).

When the distribution of population in the polygon required evaluation, the areas on the topographic map that correspond to these polygons were reviewed to determine the uniformity in housing-unit density across the subbasin divide. The land-use coverage indicates areas of multi-family households (fig. 5). The heterogeneous distribution of housing units is represented in table 3 by apportioning the distribution and type of housing units in each polygon according to their representation as solid boxes on the topographic map. The assumption was made that the distribution of additional housing built since the date on the topographic map was in the same proportion as on the topographic map except in areas that can not be developed for housing, such as along a freeway, or in a swamp, lake, or landfill. If the subbasin populations for large areas and populations had not been adjusted in this manner, the accuracy of the population distribution in the subbasin would be unacceptably low. For example, locating one large apartment complex incorrectly could result in reporting 500 people in the wrong subbasin. For polygon 266, the difference in total population is greater than 100 percent when the figures for housing-unit density are compared to the figures for percentage of land area.

Although the Bureau of Census estimates the population on the public water and wastewater systems for MCDs with a population in excess of 500, the percentage of population served varies within the MCD depending on areal extent of the distribution system and on population density. Therefore, the population served by public water and wastewater systems (table 4) in each subbasin in the MCDs was determined by combining the line coverages of the areal extents of the water distribution (fig. 5) and wastewater-collection systems with polygon coverages for population, land use, and subbasin boundaries. Because the TIGER files do not portray accurately the geography of the area, the distribution lines and population polygons in figure 5 do not coincide exactly.

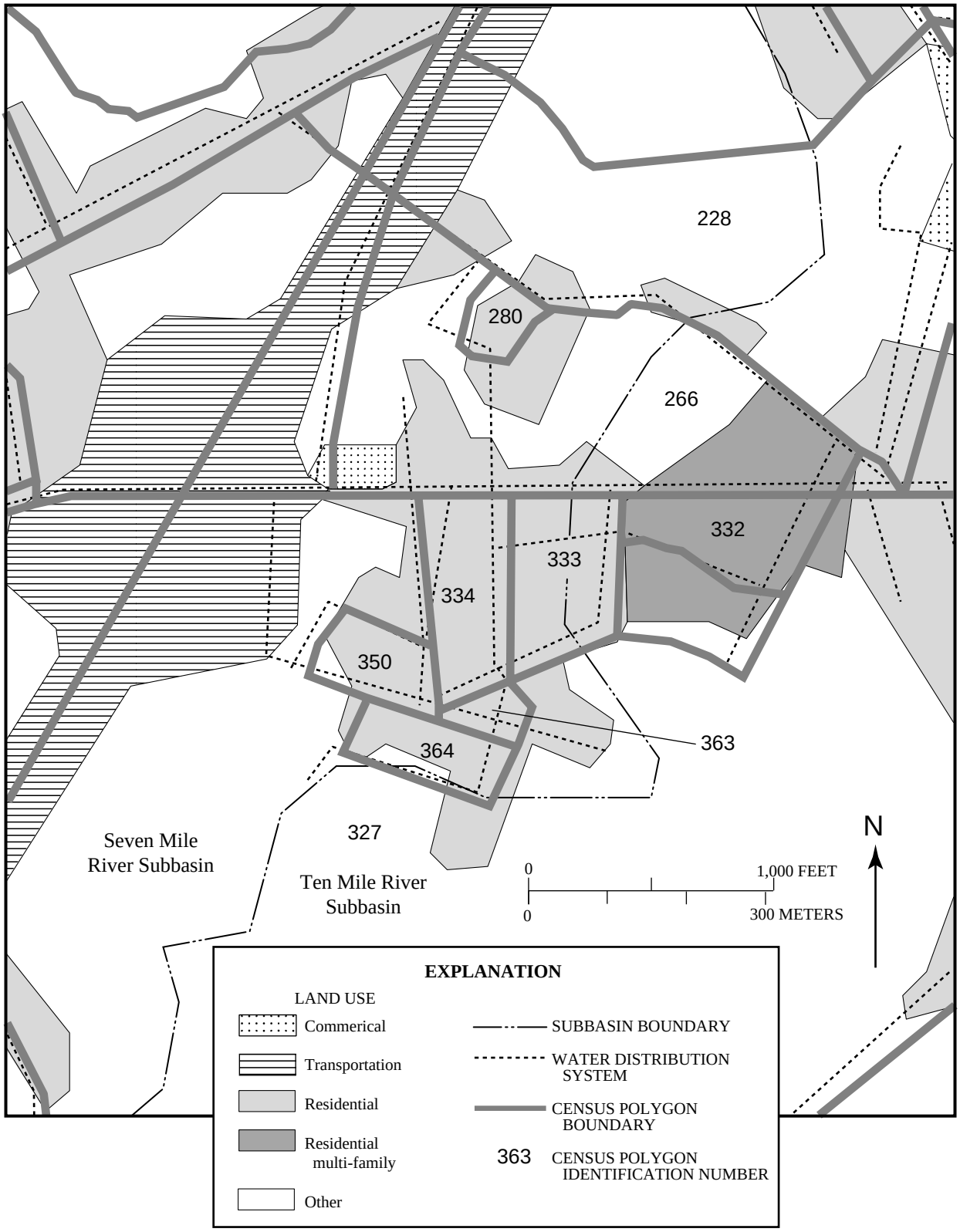


Figure 5. Diagram illustrating combined coverages for areal extent of public water-system distribution, population, land use, and subbasin boundaries in two subbasins of the Ten Mile River Basin, southeastern Massachusetts.

Table 4. Total population and population served by public water systems and public wastewater systems by Minor Civil Divisions in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts, 1990

[Population served by water and wastewater systems determined by methods described on p. 33–37. --, not applicable]

Minor Civil Division	Population		
	Total	Public supply	Wastewater collection
Ten Mile River subbasin			
Attleboro	22,723	21,588	16,029
Mansfield	--	--	--
North Attleborough	16,483	16,232	15,418
Plainville	3,426	2,878	1,984
Rehoboth	65	0	0
Seekonk	955	925	0
Wrentham	56	56	0
Total	43,708	41,679	33,431
Seven Mile River subbasin			
Attleboro	6,014	5,623	4,098
Mansfield	--	--	--
North Attleborough	2,361	2,196	713
Plainville	22	0	0
Rehoboth	--	--	--
Seekonk	--	--	--
Wrentham	--	--	--
Total	8,397	7,819	4,811
Bungay River subbasin			
Attleboro	2,020	2,020	1,348
Mansfield	469	469	469
North Attleborough	4,042	3,882	556
Plainville	458	385	352
Rehoboth	--	--	--
Seekonk	--	--	--
Wrentham	--	--	--
Total	6,989	6,756	2,725
Coles Brook subbasin			
Attleboro	--	--	--
Mansfield	--	--	--
North Attleborough	--	--	--
Plainville	--	--	--
Rehoboth	193	0	0
Seekonk	960	832	0
Wrentham	--	--	--
Total	1,153	832	0
Unnamed Brook subbasin			
Attleboro	--	--	--
Mansfield	--	--	--
North Attleborough	--	--	--
Plainville	--	--	--
Rehoboth	71	0	0
Seekonk	1,433	1,190	0
Wrentham	--	--	--
Total	1,504	1,190	0

The population served by public water systems is related to the polygon coverages to the extent that the distribution system coincides with the streets within each population polygon. If distribution lines extended beneath every street in a population polygon, as in polygons 332 and 333 in figure 5, then the entire population in the polygon was considered to be served by the public water system. If one-half of the streets had distribution lines, then one-half the population in the polygon was considered served by public water systems. The calculated results, like those for subbasin population, must be adjusted for large populations and heterogeneous population distribution. The estimated populations served by public supply and wastewater systems are summarized in table 4.

Analyze Data on Public Water System Withdrawals

The GIS point coverage for wells, surface-water intakes, treatment plants, and connections to other public water systems, the line coverage of distribution lines, and the polygon coverage for subbasins were combined to determine interbasin transfers. An interbasin transfer occurs if a distribution line crosses a subbasin divide. For example (fig. 6), the Attleboro Water Department has two wells (Wading River wells 1 and 2) outside the Ten Mile River Basin that withdraw and release water into the distribution system for users in the Bungay, Ten Mile, and Seven Mile River subbasins as well as users outside the Ten Mile River Basin. The Attleboro Water Department also withdraws water from wells around Orrs Pond in the Seven Mile River subbasin. This water is released into the same distribution system. In these cases, water is imported into the Ten Mile River Basin, and exported and imported among the subbasins. Table 5 summarizes public water-system rates of withdrawal by MCD and general areas of distribution into subbasins by the MCDs.

Analyze Data on Public Wastewater System Return Flow

The point coverage for wastewater-treatment plants, outfalls, and interconnections to other wastewater-collection systems, the line coverage of wastewater-collection lines, and the polygon coverage for subbasin divides were combined (overlain) to determine wastewater interbasin transfers.

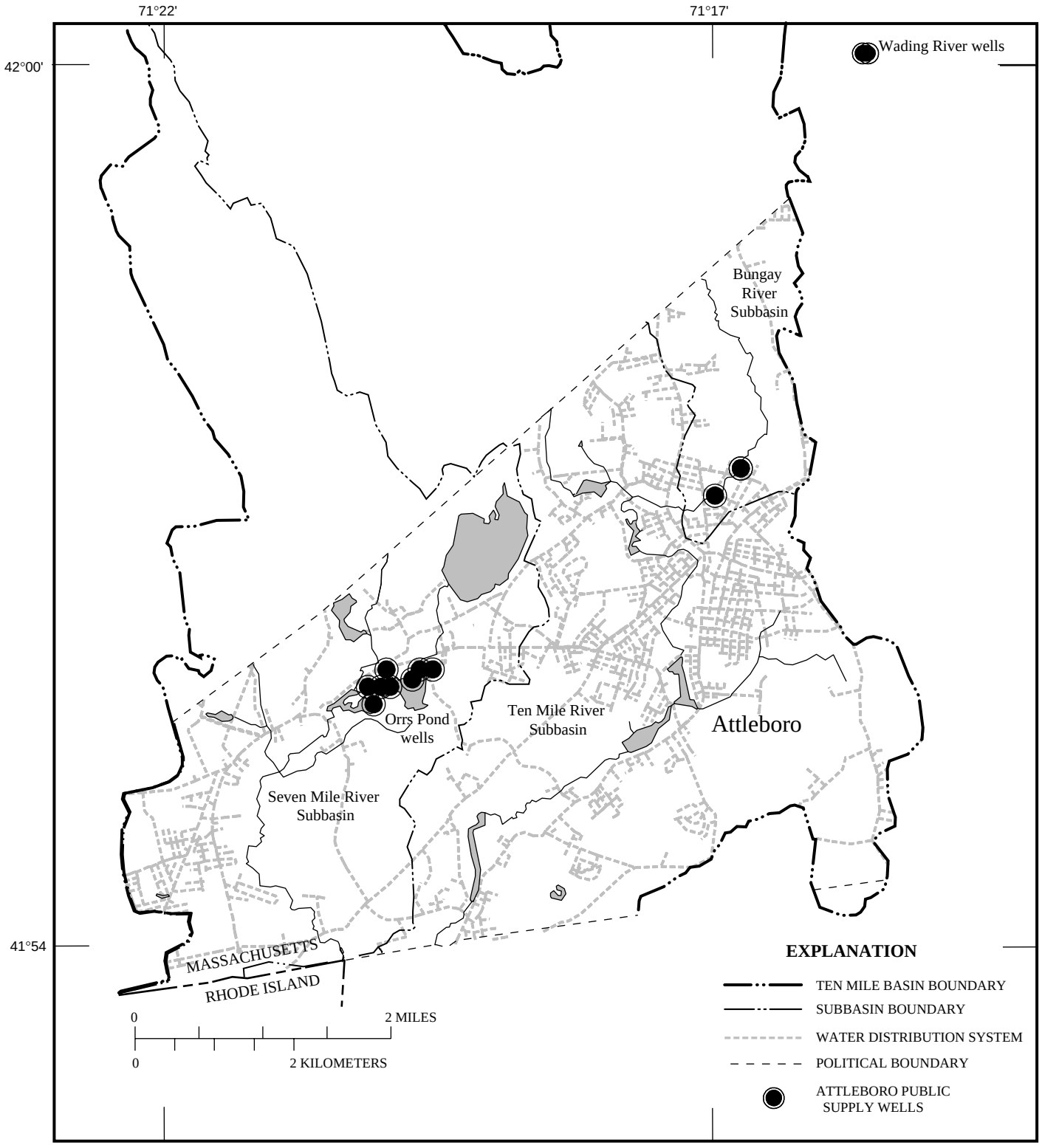


Figure 6. Diagram illustrating public water-system wells, distribution lines, and subbasin boundaries in the Attleboro portion of the Seven Mile River, Ten Mile River and Bungay River subbasins of the Ten Mile River Basin, southeastern Massachusetts. This information was used to determine the potential for interbasin transfer of freshwater.

Table 5. Distribution systems and withdrawals by public water systems in the five subbasins of the Ten Mile River Basin and adjacent areas, southeastern Massachusetts, 1992

[Mgal/d, millions of gallons per day; --, no withdrawals]

Public water system	Withdrawals (Mgal/d)	Water is distributed to users in subbasin
Ten Mile River subbasin		
Attleboro Water Department	--	yes
Mansfield Water Department	--	no
North Attleborough Water Department	1.05	yes
Plainville Water Department	--	yes
Seekonk Water District	1.17	yes
Wrentham Water System	--	yes
Total	2.22	
Seven Mile River subbasin		
Attleboro Water Department	4.00	yes
Mansfield Water Department	--	no
North Attleborough Water Department	--	yes
Plainville Water Department	--	yes
Seekonk Water District	--	no
Wrentham Water System	--	no
Total	4.00	
Bungay River subbasin		
Attleboro Water Department	--	yes
Mansfield Water Department	0.81	yes
North Attleborough Water Department	--	yes
Plainville Water Department	--	yes
Seekonk Water District	--	no
Wrentham Water System	--	no
Total	0.81	
Coles Brook subbasin		
Attleboro Water Department	--	no
Mansfield Water Department	--	no
North Attleborough Water Department	--	no
Plainville Water Department	--	no
Seekonk Water District	0.23	yes
Wrentham Water System	--	no
Total	0.23	
Unnamed Brook subbasin		
Attleboro Water Department	--	no
Mansfield Water Department	--	no
North Attleborough Water Department	--	no
Plainville Water Department	--	no
Seekonk Water District	--	yes
Wrentham Water System	--	no
Total	--	
Outside Ten Mile River Basin		
Attleboro Water Department	1.40	yes
Mansfield Water Department	1.37	yes
North Attleborough Water Department	.76	yes
Plainville Water Department	.53	yes
Seekonk Water District	--	yes
Wrentham Water System	1.07	yes
Total	5.13	

Wastewater interbasin transfer occurs between basins or subbasins if the wastewater-collection line crosses a subbasin divide. For example (fig. 7), wastewater from Attleboro users in the Seven Mile River subbasin and from users farther west that are outside the Ten Mile River Basin (A) is combined with wastewater from Attleboro users in the Ten Mile River subbasin and the Bungay River subbasin (farther east) (B) and is conveyed across the political boundary (C) into the wastewater-treatment plant in Seekonk. The treated water is discharged from an outfall into the Ten Mile River. In this case, wastewater is discharged inside the Ten Mile River subbasin and both exported and imported among the subbasins. Table 6 summarizes public wastewater-treatment plant rates of return flow by MCD and general areas of collection within subbasins by the MCDs.

Identify Major Water Users and Determine Rates of Water Use

A major user withdraws, uses, or returns a volume of water that is significant relative to the local water budget. In the Ten Mile River Basin, a major user meets or exceeds a threshold of about 0.05 Mgal/d. Major users can be identified by comparing the list of large customers obtained from the public water and wastewater systems with data from the MADEP NPDES permit program, MADEP withdrawal permit program, Community Profiles, and the Dun and Bradstreet Business Information database (table 7). Data from these sources were combined to develop a complete set of data on large users, including the name, location, SIC code, number of employees, all sources of water for each user, how the water is used, and disposal of all wastewater.

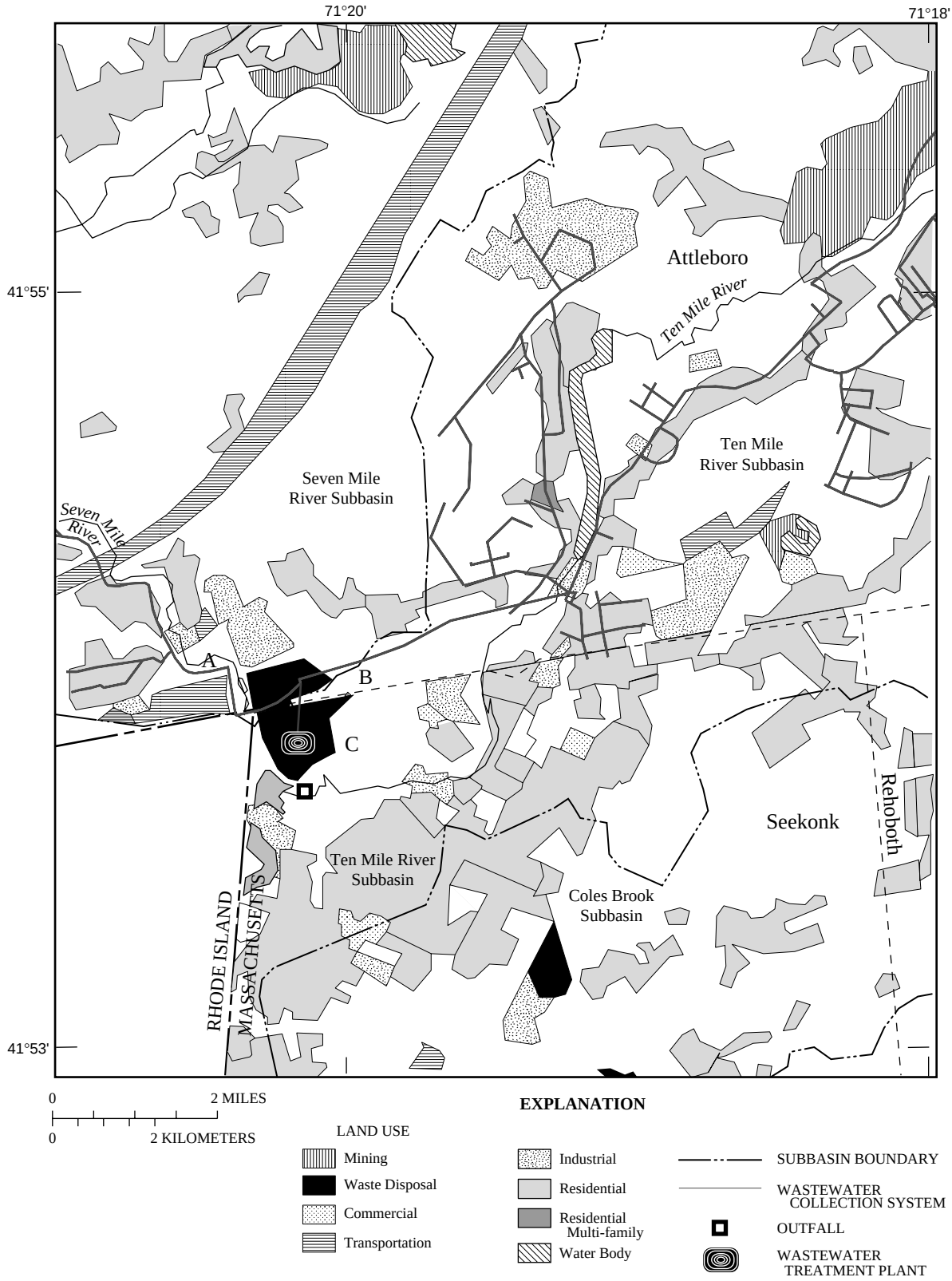


Figure 7. Diagram illustrating public wastewater-system treatment plants, outfalls, collection lines, and subbasin boundaries in the Attleboro and Seekonk portion of the Seven Mile River and Ten Mile River subbasins of the Ten Mile River Basin, southeastern Massachusetts.

Table 6. Collection systems and return flow from public wastewater systems in the five subbasins of the Ten Mile River Basin and adjacent areas, southeastern Massachusetts, 1992

[Mgal/d, million gallons per day; --, no return flow]

Public wastewater system name	Return flow (Mgal/d)	Wastewater is collected from users in subbasin
Ten Mile River subbasin		
Attleboro Sewer Department	5.79	yes
Mansfield Water Treatment Plant	--	no
North Attleborough Sewage Plant	3.37	yes
Total	9.16	
Seven Mile River subbasin		
Attleboro Sewer Department	--	yes
Mansfield Water Treatment Plant	--	no
North Attleborough Sewage Plant	--	yes
Total	--	
Bungay River subbasin		
Attleboro Sewer Department	--	yes
Mansfield Water Treatment Plant	--	yes
North Attleborough Sewage Plant	--	yes
Total	--	
Coles Brook subbasin		
Attleboro Sewer Department	--	no
Mansfield Water Treatment Plant	--	no
North Attleborough Sewage Plant	--	no
Total	--	
Unnamed Brook subbasin		
Attleboro Sewer Department	--	no
Mansfield Water Treatment Plant	--	no
North Attleborough Sewage Plant	--	no
Total	--	
Outside Ten Mile River Basin		
Attleboro Sewer Department	--	yes
Mansfield Water Treatment Plant	1.80	yes
North Attleborough Sewage Plant	--	yes
Total	1.80	

Data on potential major users were requested from the Dun and Bradstreet Business Information database by SIC code and employee number. The minimum number of employees per SIC code required for the facility to use at least 0.05 Mgal/d was determined by using the median coefficient for water use per employee per day (table 8) (Planning and Management Consultants, Ltd., 1995, Appendix D, p. D10–D24). These coefficients were originally determined from a census report (U.S. Department of Commerce, 1986) and subsequently have been updated through application of the U.S. Army Corps of Engineers' Institute for Water Resources Municipal and Industrial Needs Model (IWR-MAIN model). This model is used for forecasting changes in domestic, commercial, and industrial use that take into account economic factors (Davis and others, 1991, p. II40–II52). Public-supplied domestic, commercial, and industrial water use is estimated by the application of coefficients for water use per employee for large and average-sized establishments to SIC codes, number of employees, and an adjustment for price change of water; however, water use by specific industries may range widely due to factors such as age and conditions of plants, processes at each plant, amount of recycled use, and quality of cooling water (James and others, 1980, p. 5). Therefore, extreme care needs to be exercised when using SIC code/employee coefficients to ensure that estimates are within acceptable limits. It is not recommended that coefficients be used to determine site-specific water use of major industries, but coefficients can be used to categorize industries into small, medium, or large water users or to estimate total water use for a large number of small industries in a specific area. The water-use rates for major users can be obtained from a State withdrawal or discharge permitting agency (MADEP), metered records collected by a wastewater-treatment plant for determining sewer bills, or by direct contact.

Estimate Areal Extent and Rates of Use for Minor Water Users

In the Ten Mile River Basin, a minor user withdraws, uses, or discharges less than 0.05 Mgal/d for industrial, commercial, or domestic use. Table 9 shows the number of employees in each two-digit SIC code category along with (in bold) the number of employees of the major users as listed in the Dun and Bradstreet Business Information database for the 1992–95 period. Also, at the bottom of table 9, is the population in each MCD. These counts include water users in the entire MCD and thus include users inside and outside of the Ten Mile River Basin.

The number of employees of companies that are minor users in each SIC code category for each MCD was calculated by subtracting the number of employees of companies that are major water user

Table 7. Availability of types of data on major water users

[MADEP, Massachusetts Department of Environmental Protection; NPDES, National Pollutant Discharge Elimination System; --, no data available]

Data source	Major user name	Location	Standard Industrial Classification code	Number of employees	Type of water use for which rates are given
Dun and Bradstreet Business Information database	yes	yes	yes	yes	--
MADEP NPDES discharge permits	yes	yes	yes	--	discharge
MADEP withdrawal permits	yes	yes	--	--	withdrawal
Public water system—customers	yes	yes	--	--	delivery/withdrawal
Public wastewater system—customers	yes	yes	--	--	delivery/withdrawal/ release
Community profiles	yes	--	--	yes	--

from the totals in table 9. The median coefficients (table 8) were applied to the number of employees of minor users and added to the reported withdrawal/deliveries for the major users to estimate water use for each MCD (table 10). The number of agricultural and mining employees was not used to generate water-use values because there is not a strong correlation between water use and employee number for these use categories. A non-zero number of agriculture and mining employees, however, did indicate the presence of these types of activities in a given MCD. Mining sites were visited to evaluate how water was used at the site, and mining withdrawals were included with industrial values. Agriculture is important in Rehoboth; however, irrigation is minimal within the Ten Mile River Basin.

The rate for domestic use was estimated to be 65 gal/d per person, on the basis of a combination of locally derived data. A value of 66 gal/d per person was calculated from Attleboro Water Department metered delivery data for a portion of Attleboro (District 5). Deliveries to mobile home parks were calculated at 60 gal/d per person. Horn and others (1994) derived 68 gal/d per person from two public water systems in Rhode Island.

Water use by minor users per MCD was apportioned by subbasin according to the proportions of commercial and industrial land use in each subbasin. Table 11 summarizes commercial and industrial land use by subbasin expressed as a percentage of the total land area within each MCD for that use category. The percentages were determined by overlaying the subbasin and the land-use coverages.

Total water use in each subbasin was estimated as the sum of commercial, industrial, and domestic use. Each use value was estimated from MCD water use and the percentage of land area for that use type in the subbasin. For example, commercial use in table 12 in the Ten Mile River subbasin in Attleboro (0.23 Mgal/d) was estimated by multiplying Attleboro commercial water use (0.90 Mgal/d) from table 10 by the percentage of Attleboro commercial-use land in the Ten Mile River subbasin (25 percent) from table 11. Subbasin industrial use in the Ten Mile River subbasin in Attleboro (1.11 Mgal/d) was estimated by (1) multiplying Attleboro industrial use by minor users (1.61 Mgal/d - 1.28 Mgal/d = 0.33 Mgal/d) from table 10 by the percentage of Attleboro industrial-use land in the Ten Mile River subbasin (49 percent) from table 11 and (2) adding the site-specific use for the major industrial users in the Ten Mile River subbasin (0.95 Mgal) from table 10. Domestic use in each subbasin was not estimated this way because domestic use is areally heterogeneous as described previously. Subbasin domestic use in the Ten Mile River subbasin in Attleboro (1.48 Mgal/d) was estimated by multiplying the population in the Ten Mile River subbasin in Attleboro (22,723) from table 1 by the domestic per capita use coefficient of 65 gal/d per person.

Table 8. Coefficients for estimating commercial and industrial water use from two-digit Standard Industrial Classification categories and number of employees

[**Nonresidential employee water-use coefficients** are from Planning and Management Consultants, Ltd., 1995, IWR-MAIN Water Demand Analysis Software, User's Manual and System Description, Version 6.1, Appendix D. --, no data available]

Two-digit Standard Industrial Classification category and code	Nonresidential employee water-use coefficient (gallons/employee/day)		
	Range	Median	Mean
Mining [14]	([1])	([1])	([1])
Construction [15–17]	15–113	35	42
Industrial [20–39]	21–2,160	116	297
Food [20]	96–677	469	419
Tobacco [21]	--	--	217
Textile mill products [22]	246–1,076	315	521
Apparel [23]	6–43	13	21
Lumber and wood [24]	32–109	78	72
Furniture [25]	25–65	30	37
Paper [26]	114–8,304	863	2,160
Printing [27]	15–66	42	40
Chemicals [28]	128–653	289	363
Petroleum [29]	278–1,437	1,045	920
Rubber [30]	73–170	119	119
Leather [31]	--	--	148
Stone, clay, glass, and concrete [32]	13–224	202	147
Primary metal [33]	87–424	178	186
Fabricated metal [34]	48–585	95	189
Machinery [35]	28–153	58	70
Electrical equipment [36]	30–169	71	112
Transportation equipment [37]	14–143	63	78
Instruments [38]	40–141	66	72
Jewelry, precious metals [39]	27–61	36	39
Commercial [40–97]	58–172	94	100
Transportation [40–49]	26–353	51	95
Wholesale trade [50–51]	29–87	58	58
Retail trade [52–59]	35–156	58	78
Finance, insurance, and real estate [60–67]	59–156	71	92
Services [70–89]	58–462	106	172
Public administration [91–97]	--	--	106

[1] Too variable.

Estimate Areal Extent and Rates of Public Water-System Deliveries and Self-Supplied Withdrawals

Total water used in each subbasin portion of the MCD (table 12) needs to be apportioned between water distributed by public water systems (termed public water-system deliveries) and water withdrawn by the user (termed self-supplied withdrawals). These calculations were made by multiplying domestic, minor commercial, and minor industrial water use in each subbasin of each MCD (table 12) by the percentage of the total population in each subbasin in each MCD served by public water systems (described earlier, table 4). The source (public or self supply) of water used by major commercial and industrial users was determined individually by using public water-system data.

Public water systems generally withdraw more water than can be accounted for through billed deliveries. In the study area, reported "unaccounted-for" use (unmetered use) ranges from 7 percent of withdrawals (Attleboro) to 37 percent of withdrawals (North Attleborough) and needs to be added to the public water-system deliveries in order to equal the total for public water system withdrawals. Reported values for unaccounted-for water use cannot be accepted without further analysis because each public water system may include only some of a variety of components contributing to unaccounted-for water use. The components include leakage; treatment-plant filter backwash; hydrant flushing; fire fighting; street cleaning; water use in municipal and public buildings, pools, fountains, and lawns; unauthorized use; and inaccurate meter readings. In the study area, unaccounted-for use was initially represented by a flat 10 percent (table 13).

The public water-system deliveries and unaccounted-for use estimated according to the methods described here were compared with public water-system withdrawals reported to the MADEP (after adjustments were made for purchase or sale of water between water companies, table 14). The values for the estimated and reported public water-system withdrawals were within 15 percent of each other, and for those public water systems (Attleboro and North Attleborough) that had been contacted for information on the major users, the values were within 6 percent of each other.

Table 9. Number of employees per two-digit Standard Industrial Classification code category and number employed by major users for seven Minor Civil Divisions in southeastern Massachusetts, 1992–95

[**Number of employees:** Numbers in bold indicate number of employees of major users that are included in the unbold number; --, no employees in this category; numbers in parentheses indicate number of major facilities in category.]

Two-digit Standard Industrial Classification category and code	Number of employees						
	Attleboro	Mansfield	North Attleboro	Plainville	Rehoboth	Seekonk	Wrentham
Agriculture [01]	74	55	53	9	153	125	24
Mining [10–14]	--	5	--	40	--	5	50
Construction [15–17]	591	287	504	247	317	469	316
Food [20]	2	170	--	--	--	6	--
Textile mills [22]	62	65	--	--	--	--	--
Finished apparel [23]	212	5	6	--	3	4	--
Wood, lumber [24]	39	3	12	--	8	1	3
Furniture [25]	3	5	9	--	2	1	--
Paper products [26]	100	565	161	--	--	--	--
	100(1)	**565(2)**					
Printing, publishing [27]	266	101	105	12	4	150	10
Chemical products [28]	105	75	--	11	20	8	--
	105(1)						
Petroleum refining [29]	--	--	5	53	--	--	--
Rubber [30]	149	68	67	60	--	10	--
Leather [31]	500	--	130	4	--	--	--
	500(1)		**100(1)**				
Stone, clay, glass, and concrete [32]	12	--	6	80	92	7	--
Primary metals [33]	1,102	--	701	--	30	--	48
	825(2)		**400(1)**				
Fabricated metals [34]	909	111	321	41	9	57	371
	110(1)		**110(1)**				**371(1)**
Machinery [35]	121	412	319	116	3	96	145
		300(1)					
Electronic equipment [36]	4,863	1,862	344	2	--	--	2
	3,929(2)	**1,200(1)**					
Transportation equipment [37]	--	12	--	--	--	--	1
Instruments [38]	290	1,460	39	295	--	44	--
		1,100(1)		**150(1)**			
Miscellaneous manufacturing [39]	2,165	5	1,991	139	6	27	2
	1,300(2)						
Total Industrial	10,900	4,907	4,216	813	177	411	582
	6,869(10)	**3,165(5)**	**610(3)**	**150(1)**			**371(1)**
Transportation, communication, utilities[40–49]	260	559	144	100	75	722	62
Wholesale trade [50–51]	593	1,452	556	136	95	353	77
Retail trade [52–59]	3,105	777	2,618	413	203	4,000	255
Finance, insurance, real estate [60–67]	436	336	457	253	58	139	83
Services [70–89]	6,008	1,635	2,154	405	977	1,183	2,778
Government [91–97]	203	100	853	32	152	296	315
Total commercial	10,605	4,859	6,792	1,339	1,560	6,693	3,570
Total employees	22,170	10,125	11,555	2,447	2,207	7,703	4,542
	6,689	**3,165**	**610**	**150**			**371**
Population	38,383	16,568	25,038	6,871	8,656	13,046	9,006

Table 10. Water use per two-digit Standard Industrial Classification code category and by major users for seven Minor Civil Divisions in southeastern Massachusetts, 1992

[**IWR-MAIN coefficient:** Shown in gallons per day per employee. **Water use**: Numbers in bold indicate water use by major users that is part of the total water use for the Standard Industrial Classification code and Minor Civil Divisions. Numbers in parentheses indicate number of major facilities in category. Numbers in brackets are the two-digit Standard Industrial Classification Codes. --, water use less than 0.01 Mgal/d or not applicable]

Two-digit Standard Industrial Classification category and code	IWR-MAIN coefficient	Water use, in million gallons per day						
		Attleboro	Mansfield	North Attleboro	Plainville	Rehoboth	Seekonk	Wrentham
Construction [15–17]	35	0.02	0.01	0.02	0.01	0.01	0.02	0.01
Food [20]	469	--	.08	--	--	--	--	--
Textile mills [22]	315	.02	.02	--	--	--	--	--
Finished apparel [23]	13	--	--	--	--	--	--	--
Wood, lumber [24]	78	--	--	--	--	--	--	--
Furniture [25]	30	--	--	--	--	--	--	--
Paper products [26]	863	.02	.49	.14	--	--	--	--
		[1].02(1)	**[2].49(2)**					
Printing, publishing [27]	42	.01	--	--	--	--	.01	--
Chemical products [28]	289	.04	.02	--	--	--	--	--
		[2].04(1)						
Petroleum refining [29]	1,045	--	--	--	.05	--	--	--
Rubber [30]	119	.02	.01	.01	.01	--	--	--
Leather [31]	148	.08	--	.02	--	--	--	--
		[3].08(1)		**[3].02(1)**				
Stone, clay, glass, and concrete [32]	202	--	--	--	.02	.02	--	--
Primary metals [33]	178	.15	--	.08	--	.01	--	.01
		[3].06(1)		**[1].03(1)**				
		[2].04(1)						
Fabricated metals [34]	95	.10	.01	.10	--	--	.01	.04
		[3].02(1)		**[3].08(1)**				**[2].04(1)**
Machinery [35]	58	.01	.03	.02	.01	--	.01	.01
			[2].02(1)					
Electronic equipment [36]	71	1.02	.13	.02	--	--	--	--
		[2,4].23(1)	**[2].09(1)**					
		[3,4].65(1)						
Transportation equipment [37]	63	--	--	--	--	--	--	--
Instruments [38]	66	.02	.10	--	.02	--	--	--
			[2].07(1)		**[3].01(1)**			
Miscellaneous manufacturing [39]	36	.10	--	.07	.01	--	--	--
		[3].07(2)						
Total industrial	--	1.61	.90	.48	.13	.04	.05	.07
		1.28(10)	**.67(5)**	**.13(3)**	**.01(1)**			**.04(1)**
Transportation, communication, utilities [40–49]	51	.01	.03	.01	.01	--	.04	--
Wholesale trade [50–51]	58	.03	.08	.03	.01	.01	.02	--
Retail trade [52–59]	58	.18	.05	.15	.02	.01	.23	.02
Finance, insurance, real estate [60–67]	71	.03	.02	.03	.02	--	.01	.01
Services [70–89]	106	.64	.17	.23	.04	.10	.13	.29
Government [91–92]	71	.01	.01	.06	--	.01	.02	.02
Total commercial	--	.90	.36	.51	.10	.13	.45	.34
Total domestic	65	2.49	1.08	1.63	.45	.56	.85	.59
Total water use	--	5.00	2.34	2.62	.68	.73	1.35	1.00
		1.28	**.67**	**.13**	**.01**	--	--	**.04**

[1] Located in Bungay River subbasin.
[2] Located outside Ten Mile River Basin.
[3] Located in Ten Mile River subbasin.
[4] One factory that straddles the subbasin divides.

A few large users can substantially affect total water use as shown in tables 10 and 14. In Attleboro, the 10 major industrial users accounted for 80 percent of industrial water use and 20 percent of total public water-system deliveries. In Mansfield, five users accounted for 74 percent of industrial water use and 29 percent of total public water-system deliveries. Mansfield had the largest difference between estimated and reported use, which could be explained if one or more major users were self-supplied (major users outside the Ten Mile River Basin were not analyzed for source of supply). North Attleborough had three users which accounted for 27 percent of industrial water use, but only 5 percent of total public water-system deliveries.

The importance of collecting and using site-specific information on large users also is demonstrated in Attleboro. If industrial water use had been calculated solely on the basis of the two-digit SIC code coefficient, Attleboro industrial water use would have been 0.99 Mgal/d instead of 1.61 Mgal/d. Working with too much site-specific information, however, can be extremely time-consuming with few benefits because (1) SIC codes and the employee population for the water user usually are not available with the metered account descriptions; (2) the accuracy of meter readings may be highly variable; (3) the relationship between meter readings for multiple-metered customers may be too intricate for timely analysis; and (4) any name changes would require careful tracing of customers through meter records. Therefore, it is important to determine the threshold level for major users to maximize accuracy and minimize time.

Table 11. Commercial and industrial land-use area as a percentage of total land area per Minor Civil Division for that use category in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts

[--, percentage of land use less than 1]

Minor Civil Division	Percentage of land use area of each Minor Civil Division within subbasin	
	Commercial	Industrial
Ten Mile River subbasin		
Attleboro	25	49
Mansfield	--	--
North Attleborough	43	49
Plainville	25	76
Rehoboth	--	--
Seekonk	2	9
Wrentham	7	--
Seven Mile River subbasin		
Attleboro	25	5
Mansfield	--	--
North Attleborough	28	2
Plainville	2	--
Rehoboth	--	--
Seekonk	--	--
Wrentham	--	--
Bungay River subbasin		
Attleboro	3	5
Mansfield	8	--
North Attleborough	23	49
Plainville	--	--
Rehoboth	--	--
Seekonk	--	--
Wrentham	--	--

Minor Civil Division	Percentage of land use area of each Minor Civil Division within subbasin	
	Commercial	Industrial
Cole Brook subbasin		
Attleboro	--	--
Mansfield	--	--
North Attleborough	--	--
Plainville	--	--
Rehoboth	--	--
Seekonk	1	--
Wrentham	--	--
Unnamed Brook subbasin		
Attleboro	--	--
Mansfield	--	--
North Attleborough	--	--
Plainville	--	--
Rehoboth	--	--
Seekonk	2	26
Wrentham	--	--
Outside Ten Mile River Basin		
Attleboro	47	41
Mansfield	92	100
North Attleborough	6	0
Plainville	73	24
Rehoboth	100	100
Seekonk	95	64
Wrentham	93	100

Table 12. Water use by major and aggregated minor users in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts, 1992

[--, water use less than 0.01 million gallons per day; numbers in bold face represent the volume of total water use that is accounted for by major users]

Minor Civil Division	Water use in million gallons per day		
	Domestic	Commercial	Industrial
Ten Mile River subbasin			
Attleboro	1.48	0.23	1.11
			.95
Mansfield	--	--	--
North Attleborough	1.07	.22	.27
			.10
Plainville	.22	.03	.10
			.01
Rehoboth	.01	--	--
Seekonk	.06	.01	.01
Wrentham	.01	.02	--
Total	2.85	0.51	1.49
Seven Mile River subbasin			
Attleboro	0.39	0.23	0.02
Mansfield	--	--	--
North Attleborough	.16	.14	.01
Plainville	--	--	--
Rehoboth	--	--	--
Seekonk	--	--	--
Wrentham	--	--	--
Total	0.55	0.37	0.03
Bungay River subbasin			
Attleboro	0.13	0.03	0.04
			.02
Mansfield	.03	.03	--
North Attleborough	.26	.12	.20
			.03
Plainville	.03	--	--
Rehoboth	--	--	--
Seekonk	--	--	--
Wrentham	--	--	--
Total	0.45	0.18	0.24
Cole Brook subbasin			
Attleboro	--	--	--
Mansfield	--	--	--
North Attleborough	--	--	--
Plainville	--	--	--
Rehoboth	0.01	--	--
Seekonk	.06	--	--
Wrentham	--	--	--
Total	0.07	--	--
Unnamed Brook subbasin			
Attleboro	--	--	--
Mansfield	--	--	--
North Attleborough	--	--	--
Plainville	--	--	--
Rehoboth	0.01	--	--
Seekonk	.10	0.01	0.01
Wrentham	--	--	.--
Total	0.11	0.01	0.01
Outside Ten Mile River Basin			
Attleboro	0.49	0.41	0.44
			.31
Mansfield	1.05	.33	.90
North Attleborough	.14	.03	--
Plainville	.20	.07	.03
Rehoboth	.53	.13	.04
Seekonk	.63	.43	.03
Wrentham	.58	.32	.07
Total	3.62	1.72	1.51

Estimate Areal Extent and Rate of Public Wastewater-System Collection and Self-Disposed Return Flow

Rates for public wastewater-system collection and self-disposed return flow need to incorporate estimates of consumptive use, inflow (from surface runoff) and infiltration (from ground water). Consumptive use was estimated as 15 percent for domestic use, and 10 percent for commercial and industrial use, which are consistent with traditional consumptive-use rates in New England (Solley and others, 1993; table 15). Local studies on the rates of consumptive use that would refine these values are rare, and, in New England, consumptive use rates are generally smaller than rates of inflow and infiltration, so more time is spent estimating inflow and infiltration. In New England, the water table is frequently at or above the wastewater collection lines so that infiltration by ground water into the lines is common. Rainfall contributes inflow through manhole covers and other breaches in the wastewater-collection lines. Consumptive-use calculations are also hampered because meters that are capable of reliably reading

Table 13. Summary of water use as supplied by public water-system deliveries and self-supplied withdrawals in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts, 1992

[All values are in million gallons per day. --, water use less than 0.01 million gallons per day or not applicable]

Minor Civil Division	Domestic Supply		Percentage of population on public supply	Commercial supply		Industrial supply		Public supply unaccounted-for use	Total public supply
	Public	Self		Public	Self	Public	Self		
Ten Mile River subbasin									
Attleboro	1.40	0.08	95	0.22	0.01	1.05	0.06	0.27	2.94
North Attleborough	1.06	.01	98	.22	--	.27	--	.15	1.70
Plainville	.19	.03	84	.02	.01	.08	.02	.03	.32
Rehoboth	--	.01	--	--	--	--	--	--	--
Seekonk	.06	--	97	.01	--	.01	--	.01	.09
Wrentham	.01	--	100	.02	--	--	--	--	.03
Total	2.72	0.13	--	0.49	0.02	1.41	0.08	0.46	5.08
Seven Mile River subbasin									
Attleboro	0.37	0.02	93	0.22	0.01	0.02	--	0.06	0.67
North Attleborough	.15	.01	93	.13	.01	.01	--	.03	.32
Total	0.52	0.03	--	0.35	0.02	0.03	--	0.09	0.99
Bungay River subbasin									
Attleboro	0.13	--	100	0.03	--	0.04	--	0.02	0.22
Mansfield	.03	--	100	.03	--	--	--	.01	.07
North Attleborough	.25	.01	96	.11	.01	.19	.01	.06	.61
Plainville	.02	.01	84	--	--	--	--	--	.02
Total	0.43	0.02	--	0.17	0.01	0.23	0.01	0.09	0.92
Coles Brook subbasin									
Rehoboth	--	0.01	--	--	--	--	--	--	--
Seekonk	0.05	.01	87	--	--	--	--	0.01	0.06
Total	0.05	0.02	--	--	--	--	--	0.01	0.06
Unnamed Brook subbasin									
Rehoboth	--	0.01	--	--	--	--	--	--	--
Seekonk	0.08	.02	83	0.01	--	0.01	--	0.01	0.11
Total	0.08	0.03	--	0.01	--	0.01	--	0.01	0.11
Ten-Mile River Basin Study area total	3.80	0.23	--	1.02	0.05	1.68	0.09	0.66	7.16

wastewater-discharge rates for individual users in a gravity-flow system, where the rates range from 0 to full pipe under pressure, are too expensive for many users.

Rates for public wastewater-system collection for each MCD were calculated from water-use data (table 12) after subtraction of consumptive use and apportioning the remaining water use between self-disposed and public wastewater-collection systems (table 15). Total water use was apportioned using the relative percentages of total population served by public wastewater-collection systems (sewers) in each subbasin for each MCD (table 4). This procedure was also used to apportion rates of wastewater release by commercial and industrial users.

Inflow and infiltration rates were estimated for the Attleboro and North Attleborough wastewater-collection systems (table 16) by applying the U.S. Bureau of the Census values for households on sewers (U.S. Department of Commerce, 1991) to the entire MCD rather than to the portion of the MCD within the study area (table 4). Inflow and infiltration (2.73 Mgal/d in Attleboro) were estimated as the difference between the treatment plant discharge (5.79 Mgal/d in Attleboro) and the estimated rate of

Table 14. Comparison between public water-system deliveries estimated through methods described in report with those reported to the Massachusetts Department of Environmental Protection for seven Minor Civil Divisions in southeastern Massachusetts, 1992

[MADEP, Massachusetts Department of Environmental Protection; --, water use less than 0.01 million gallons per day or not applicable]

	Water use, in millions of gallons per day						
	Attleboro	Mansfield	North Attleborough	Plainville	Rehoboth	Seekonk	Wrentham
Estimated total water use (table 10)	5.00	2.34	2.62	0.68	0.73	1.35	1.00
Major industrial self-supply use	.37	--	--	--	--	--	--
Percentage of population on public supply[1]	99	99	96	84	0	86	85
Estimated public water-system use	4.58	2.32	2.52	.57	--	1.16	.85
Estimated public water-system use plus 10 percent unaccounted-for use	5.09	2.57	2.80	.63	--	1.29	.94
Public water-system use reported to MADEP	5.39	2.19	2.76	.56	--	1.23	1.07
Percentage of difference between estimated and reported use	-6	+15	+1	+11	--	+5	-14
Percentage of total use by major users	20	29	5	2	--	0	4
Site-specific data analyzed for major user	yes	no	yes	no	--	no	no
Percentage of unaccounted-for use if used to account for difference between estimated and reported public water-system use	15	0	9	0	--	6	21

[1]Data from U.S. Bureau of the Census.

wastewater discharged into the sewers by users (3.06 Mgal/d in Attleboro). The estimated inflow and infiltration rate is 47 percent for Attleboro and 54 percent for North Attleborough. The area average of 50 percent was used for Mansfield and Plainville wastewater-collection systems.

A total of 3.92 Mgal/d were discharged by domestic, commercial, and industrial users into wastewater-collection systems within the Ten Mile River Basin (table 15). Approximately 3.91 Mgal/d of runoff and ground water entered the wastewater-collection system in the Ten Mile River Basin as inflow and infiltration. Consumptive use was about 0.86 Mgal/d. About 2.08 Mgal/d was returned to the ground water through septic systems.

Integrate Estimated Water-Use Data into Subbasin Summaries

The water-use data in each of the five subbasins of the Ten Mile River Basin that are presented in table 5 (public water-system withdrawals), table 6 (public wastewater-system return flow), table 13 (water use by category and source of supply), and table 15 (water use by category and disposal method) are summarized by process and subbasin in table 17. For example, use in table 17 for the Ten Mile River subbasin part of Attleboro (2.82 Mgal/d) is the sum of domestic, commercial, and industrial public and self supply (table 13). Unaccounted-for use is from table 13 and consumptive use, as well as inflow and infiltration, is from table 15. Self-supplied withdrawal in table 17 is the sum of domestic, commercial, and industrial self supply (table 13). Self-disposed return flow is the sum of domestic, commercial, and industrial self-disposal values (table 15). Public water-system withdrawal is from table 5 and public wastewater-system return flow is from table 6.

Water use, interbasin transfers of freshwater and wastewater, and net gain or loss to the resources in each subbasin for the Ten Mile River Basin can be estimated as shown in figure 8. A total of 7.63 Mgal/d of ground water was withdrawn in the Ten Mile River Basin. Public water systems withdrew 95 percent of the total, over one-half of which came from the Seven Mile River subbasin. The North Attleborough, Plainville, and Wrentham public-water systems imported 1.95 Mgal/d and the Attleboro, Mansfield, and Seekonk public-water systems exported 2.05 Mgal/d. The difference between these two figures gives a net export of 0.10 Mgal/d of freshwater from the Ten Mile River Basin.

Table 15. Summary of public wastewater-system collection and self-disposed return flow in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts, 1992

[All values are in million gallons per day. --, water use less than 0.01 million gallons per day or not applicable]

Minor Civil Division	Domestic disposal (85 percent of total water use)		Percentage of population on public wastewater collection	Commercial disposal (90 percent of total water use)		Industrial disposal (90 percent of total water use)		Consumptive use	Inflow and infiltration
	Public	Self		Public	Self	Public	Self		
Ten Mile River subbasin									
Attleboro	0.89	0.37	71	0.15	0.06	0.71	0.29	0.35	1.56
North Attleborough	.86	.05	94	.19	.01	.23	.01	.21	1.48
Plainville	.11	.08	49	.02	.01	.05	.04	.04	.18
Rehoboth	--	.01	--	--	--	--	--	--	--
Seekonk	--	.05	--	--	.01	--	.01	.01	--
Wrentham	--	.01	--	--	.02	--	--	--	--
Total	1.86	0.57	--	0.36	0.11	0.99	0.35	0.61	3.22
Seven Mile River subbasin									
Attleboro	0.22	0.11	68	0.14	0.07	0.02	--	0.08	0.34
North Attleborough	.04	.10	30	.04	.09	--	0.01	.03	.09
Total	0.26	0.21	--	0.18	0.16	0.02	0.01	0.11	0.43
Bungay River subbasin									
Attleboro	0.07	0.04	67	0.02	0.01	0.02	0.01	0.03	0.10
Mansfield	.02	--	100	.03	--	--	--	.01	.05
North Attleborough	.03	.19	14	.02	.09	.03	.15	.07	.09
Plainville	.02	.01	49	--	--	--	--	--	.02
Total	0.14	0.24	--	0.07	0.10	0.05	0.16	0.12	0.26
Coles Brook subbasin									
Rehoboth	--	0.01	--	--	--	--	--	--	--
Seekonk	--	0.05	--	--	--	--	--	0.01	--
Total	--	0.06	--	--	--	--	--	0.01	--
Unnamed Brook subbasin									
Rehoboth	--	0.01	--	--	--	--	--	--	--
Seekonk	--	.08	--	--	0.01	--	0.01	0.02	--
Total	--	0.09	--	--	0.01	--	0.01	0.02	--
Ten-Mile River Basin study area total	2.26	1.17	--	0.61	0.38	1.06	0.53	0.86	3.91

About 6.87 Mgal/d was used in the Ten Mile River Basin by domestic (59 percent), commercial (16 percent), and industrial (26 percent) users, mostly in the Ten Mile River subbasin (4.85 Mgal/d). About 0.66 Mgal/d was unaccounted for by public suppliers. This figure is based on an assumed average of 10 percent that may have been (1) leaked; (2) used for filter backwash; hydrant flushing; fire fighting; street cleaning; municipal and other public pools, fountains, buildings, and lawn watering; (3) diverted by unauthorized users; or (4) due to inaccurate meter readings, which can contribute a substantial proportion of unaccounted-for use. Consumptive use was estimated as 0.86 Mgal/d on the basis of an average 15 percent domestic consumptive use, and 10 percent commercial and industrial consumptive use.

A total of 11.24 Mgal/d of wastewater was returned to ground and surface water in the Ten Mile River Basin. The Attleboro and North Attleborough public wastewater-treatment plants discharged 9.16 Mgal/d (81 percent) into the Ten Mile River. About 4.62 Mgal/d (table 16) was disposed into these two wastewater-collection systems by users—3.68 Mgal/d (table 15) from inside and 0.94 from outside the Ten Mile River Basin (table 18).

Table 16. Method for estimating inflow and infiltration in Attleboro and North Attleborough in the Ten Mile River Basin, southeastern Massachusetts

[Mgal/d, million gallons per day]

	Attleboro				North Attleborough			
	Domestic	Commercial	Industrial	Total	Domestic	Commercial	Industrial	Total
Water use (Mgal/d)	2.49	0.90	1.61	5.00	1.63	0.51	0.48	2.62
Consumptive use (Mgal/d)	.37	.09	.16	.62	.24	.05	.05	.34
Self disposal (Mgal/d)	.66	.26	.40	1.32	.36	.19	.17	.72
Public disposal (Mgal/d)[1]	1.46	.55	1.05	3.06	1.03	.27	.26	1.56
Treatment plant discharge (Mgal/d)				5.79				3.37
Discharge coefficient				.892				1.16
Estimated inflow and infiltration (Mgal/d)[2]				2.73				1.81
Estimated inflow and infiltration as a percent are of total treatment plant discharge				47				54

[1]Percentage of population on public disposal: 68 percent for Attleboro, 65 percent for North Attleborough.

[2]Discharge coefficient is multiplied by volume of water released by users into wastewater-collection system to calculate inflow and infiltration.

Table 17. Summary of withdrawals, use, inflow and infiltration, wastewater returns, and resource gains or losses in the five subbasins of the Ten Mile River Basin, southeastern Massachusetts, 1992

[All values given in million gallons per day. **Net gain or loss to resource:** G, net gain, L, net loss]

Minor Civil Division	Withdrawal		Use			Inflow and infiltration	Returns		Net gain or loss to resource
	Public water system	Self supplied	Use	Unaccounted for	Consumptive		Public wastewater system	Self disposed	
Ten Mile River subbasin									
Attleboro	--	0.15	2.82	0.27	0.35	1.56	5.79	0.72	
North Attleborough	1.05	.01	1.56	.15	.21	1.48	3.37	.07	
Plainville	--	.06	.35	.03	.04	.18	--	.13	
Rehoboth	--	.01	.01	--	--	--	--	.01	
Seekonk	1.17	--	.08	.01	.01	--	--	.07	
Wrentham	--	--	.03	--	--	--	--	.03	
Total	2.22	0.23	4.85	0.46	0.61	3.22	9.16	1.03	4.37G
Seven Mile River subbasin									
Attleboro	4.00	0.03	0.64	0.06	0.08	0.34	--	0.18	
North Attleborough	--	.02	.31	.03	.03	.09	--	.20	
Total	4.00	0.05	0.95	0.09	0.11	0.43	--	0.38	4.12L
Bungay River subbasin									
Attleboro	--	--	0.20	0.02	0.03	0.10	--	0.06	
Mansfield	0.81	0	.06	.01	.01	.05	--	--	
North Attleborough	--	.03	.58	.06	.07	.09	--	.43	
Plainville	--	.01	.03	--	--	.02	--	.01	
Total	0.81	0.04	0.87	0.09	0.11	0.26	--	0.50	0.63L
Coles Brook subbasin									
Rehoboth	--	0.01	0.01	--	--	--	--	0.01	
Seekonk	0.23	.01	.06	0.01	0.01	--	--	.05	
Total	0.23	0.02	0.07	0.01	0.01	--	--	0.06	0.19L
Unnamed Brook subbasin									
Rehoboth	--	0.01	0.01	--	--	--	--	0.01	
Seekonk	--	.02	.12	0.01	0.02	--	--	.10	
Total	--	0.03	0.13	0.01	0.02	--	--	0.11	0.07G
Ten-Mile River Basin Total	7.26	0.37	6.87	0.66	0.86	3.91	9.16	2.08	0.50L

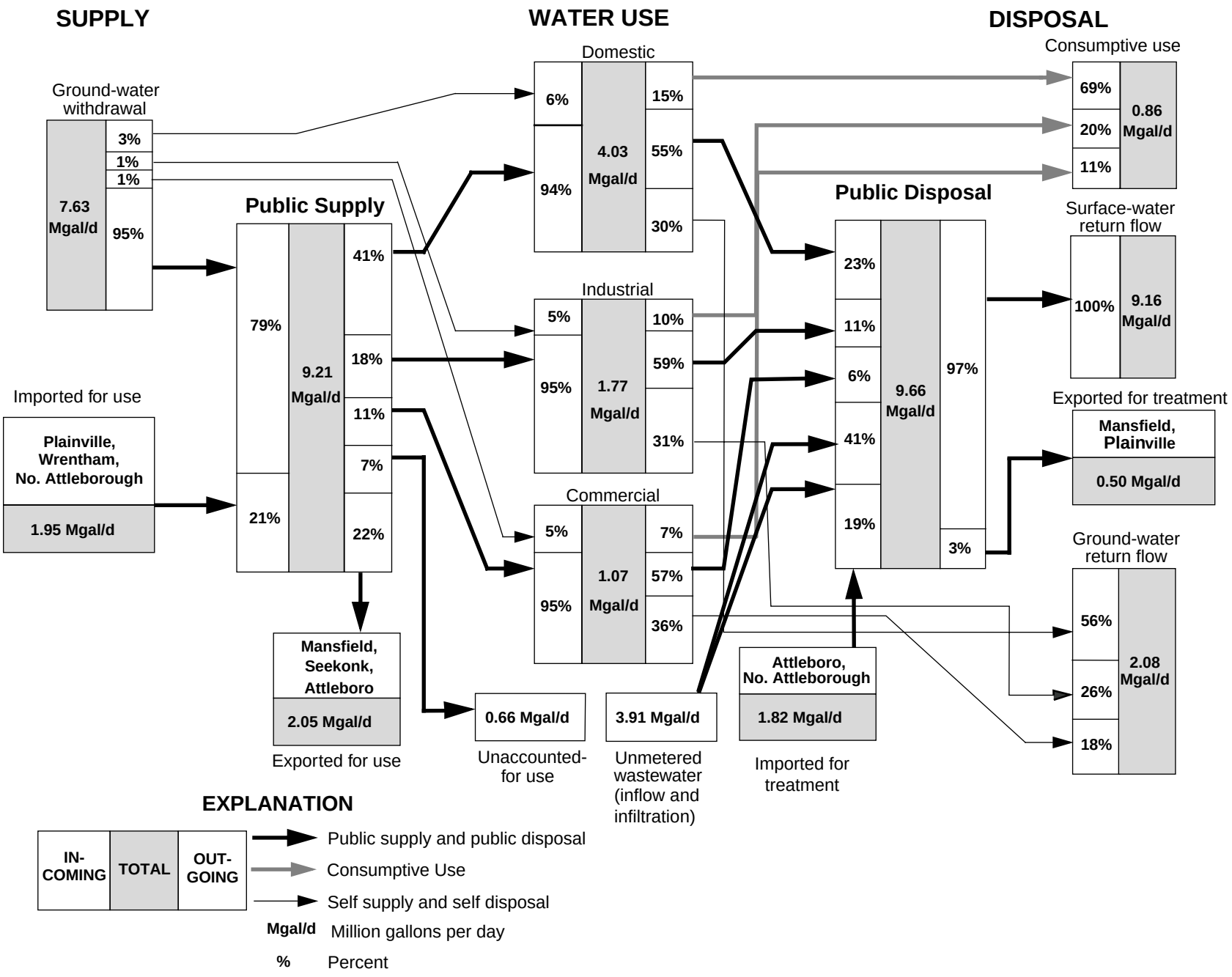


Figure 8. Basin water-use and interbasin transfer of freshwater and wastewater in the Ten Mile River Basin, southeastern Massachusetts, 1992. (Percentages have been rounded.)

Table 18. Interbasin transfer of wastewater and inflow and infiltration in the Ten Mile River Basin, southeastern Massachusetts, 1992

[All values given in million gallons per day]

Interbasin transfer	Waste-water	Inflow and infiltration	Total
From study area to study area	3.68	3.66	7.34
From outside study area to study area	.94	.88	1.82
From study area to outside study area	.25	.25	.50

The remaining 4.54 Mgal/d that was discharged through these two treatment plants entered the wastewater-collection system as inflow and infiltration—3.66 Mgal/d from inside and 0.88 Mgal/d from outside the Ten Mile River Basin. Mansfield and Plainville users discharged 0.25 Mgal/d into wastewater-collection systems within the Ten Mile River Basin (table 15). This discharge was combined with about 0.25 Mgal/d inflow and infiltration and the total of 50 Mgal/d was exported for treatment outside the basin. About 3.91 Mgal/d entered into wastewater-collection systems within the Ten Mile River Basin as inflow and infiltration, 1.82 Mgal/d in wastewater, inflow, and infiltration was imported for treatment, and 0.50 Mgal/d in wastewater, inflow, and infiltration was exported for treatment. Return flow to ground water through septic systems accounted for 2.08 Mgal/d.

Net gain or loss of water to the resources in the basin and to individual subbasins can be determined from data in table 17 and the equation:

$$Net_{G/L} = (SWRF + GWRF + UFW) - (SWW + GWW + CU + I/I), \quad (1)$$

where

$Net_{G/L}$ = Net gain or loss of water to resource in the basin or subbasin;
SWRF = Surface-water return flow;
GWRF = Ground-water return flow;
UFW = Unaccounted-for water;
SWW = Surface-water withdrawal;
GWW = Ground-water withdrawal;
CU = Consumptive use; and
I/I = Inflow and infiltration.

A positive value indicates a net gain, whereas a negative value indicates a net loss of water to resources to the basin or subbasin. For example, using data in table 18:

$$Net_{G/L} = (9.16 + 2.08 + 0.66) - (0 + 7.63 + 0.86 + 3.91) = -0.50. \quad (2)$$

There is a net loss to the resources in the basin of 0.50 Mgal/d.

SUMMARY AND CONCLUSIONS

Watershed management techniques that use water budgets to balance available water resources with actual or anticipated water use require accurate and precise estimates of basin withdrawals, interbasin transfer of freshwater, unaccounted-for use, water use, consumptive use, inflow and infiltration, basin return flow, interbasin transfer of wastewater, and ultimately, net gain or loss of water to the resources of the basin. Frequently, estimates of inflow and infiltration are missing and estimates of interbasin transfers of freshwater and wastewater are not integrated into water budgets because they occur within public water-delivery and wastewater-collection systems. A new 10-step method that uses easily obtained Statewide data was developed to improve estimates of inflow and infiltration and interbasin transfers.

The method was developed and tested with data for the Ten Mile River Basin in southeastern Massachusetts. This report uses examples from the basin to illustrate each step of the method. The Ten Mile River Basin comprises 46 mi^2 in Massachusetts and includes five subbasins. In 1990, approximately 61,751 people lived in the densely populated (1,351 people per square mile) and industrialized basin.

The recommended method for estimating basin water use and interbasin transfer of freshwater and wastewater incorporate readily available State data in the form of computerized maps and tables. Tabular data from MADEP, MADEM, Bureau of the Census, Massachusetts Executive Office of Communities and Development, Dun and Bradstreet, the USGS, public water systems and public wastewater systems were combined with land use, drainage, and population maps.

A 10-step method was developed for estimating basin water use and interbasin transfers. Required data must be (1) identified and obtained (2) organized by

MCD and managed though spreadsheets, databases, and a GIS. Basin divides are superimposed on population maps to estimate the total population (3a) in each subbasin, then are superimposed on distribution service-area maps to estimate (3b) subbasin population served by public water systems, and on wastewater-collection service-area maps to estimate (3c) subbasin population served by public wastewater systems. Public water-system metered-withdrawal rates are used to determine (4) rates of withdrawal from water resources. Metered-return-flow rates from public wastewater-systems are used to determine (5) rates of return flow for wastewater-treatment plants and outfalls to water resources. Lists of major users are combined with metered withdrawal and return-flow rates to identify (6) locations and rates of use for major users. Bureau of the Census population maps and the Dun and Bradstreet Business Information database are combined with data on major users and land-use coverages to estimate (7) areal extent and rates of use for aggregated minor users. Data on major and minor users are combined with public water-system data to estimate (8) areal extent and rates for public water-system deliveries and self-supplied withdrawals. Data on major and minor users are combined with public wastewater-system data to estimate (9) areal extent and rates for public wastewater-system collection and self-disposed return flow. The final step (10) is to integrate all of this information in order to summarize basin water use, calculate interbasin transfers, and determine the net gain or loss of water to the resources of the basin. The accuracy and precision of the water-use estimates determined by these methods are increased through careful application of coefficients for small users and the use of metered values for large users.

The 10-step method provided a variety of water use data for the Ten Mile River Basin. A total of 7.63 Mgal/d of ground water was withdrawn in the Ten Mile River Basin. Public water systems withdrew 95 percent of the water, over half of which came from the Seven Mile River subbasin. The North Attleborough, Plainville, and Wrentham public water systems imported 1.95 Mgal/d into the Ten Mile River Basin, while the Attleboro, Mansfield, and Seekonk public water systems exported 2.05 Mgal/d. The differences between these two figures gives a net export of 0.10 Mgal/d from the Ten Mile River Basin. About 6.87 Mgal/d was used in the Ten Mile River Basin by domestic (59 percent), commercial (16 percent), and industrial (26 percent) users, mostly in the Ten Mile River subbasin (4.85 Mgal/d). Approximately 0.66 Mgal/d was unaccounted for by public suppliers. Consumptive use was estimated as 0.86 Mgal/d. A total of 11.24 Mgal/d was returned to ground and surface water in the Ten Mile River Basin. Public wastewater-treatment plants discharged 9.16 Mgal/d (81 percent) into the Ten Mile River. About 3.93 Mgal/d was released by users into the wastewater-collection system in the Ten Mile River Basin. About 3.91 Mgal/d entered into the systems as inflow and infiltration. About 1.82 Mgal/d in wastewater, inflow, and infiltration was imported for treatment, and 0.50 Mgal/d in wastewater, inflow, and infiltration was exported for treatment. Return flow to ground water through septic systems accounted for 2.08 Mgal/d. Net loss to the water resources of the basin was 0.50 Mgal/d, with a maximum net gain of 4.37 Mgal/d in the Ten Mile River subbasin, and a maximum net loss of 4.12 Mgal/d in the Seven Mile River subbasin.

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GLOSSARY

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

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

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

Delivery: The amount of water delivered to a point of use.

Discharge point: A location at which effluent is released after use into a receiving stream or infiltration bed. Also referred to as an outfall.

Distribution: The process of conveying water from a water supplier's points of withdrawal or treatment through the distribution system to the user or another water supplier. Water is "**released**" from the public water supplier into the distribution system and "**delivered**" to users. See also delivery and release.

Diversion: Point of withdrawal from surface water.

Domestic water use: Water for household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. Households include single and multi-family dwellings. Also called residential water use. The water may be obtained from a public water supply or may be self supplied.

Exfiltration: Leakage from a conveyance system or storage area into the surrounding and underlying materials. This process will occur if the ambient ground-water pressure is less than the internal pressure of the conveyance system or storage area at a breach.

Ground-water disposal: Refers to wastewater that is disposed of through the ground either by seepage or injection. This includes the following discharge methods, injection well, drain fields, percolation ponds, and spray fields (land application/spreading). Reuse systems and land disposal systems are considered a ground-water disposal method, such as the wastewater used to irrigate turf or crops is generally intended to filter through the soil.

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

Institutional water use: Water used in the maintenance and operation of institutions such as large schools, universities, hospitals, rest homes, or similar installations. Owners of institutions may be individuals, corporations, churches, or government units. Subset of commercial water use.

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

Instream conveyance: Flow of water from one water body to another without using the water.

Intake: (1) Point of diversion of stream flow into a conduit or irrigation system conveyance. (2) Water infiltration into the soil.

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

Irrigation water use: The artificial application of water on lands to assist in the growth of crops or pasture including in greenhouses. Irrigation water use may also include application of water to maintain vegetative

growth in recreational lands such as parks and golf courses, including water used for frost and freeze protection of crops.

Major user: A user who withdraws, distributes, or uses water, or collects or returns wastewater at a rate averaging more than 50,000 gallons per day 0.050 million gallons per day (Mgal/d).

Measuring point: Specific point where data are collected. It is usually marked and has some specific criteria that assure consistent data collection.

Mining water use: Water used for the extraction of naturally occurring minerals including coal, ores, petroleum, and natural gas. Includes water associated with quarrying, dewatering, milling, and other on site activities done as part of mining. Excludes water used for processing, such as smelting and refining, or slurry pipeline (industrial water use). These activities are included in SIC codes 10–14.

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

Offstream use: Water withdrawn or diverted from a ground- or surface-water source for use.

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

Point of diversion: The location at which water is diverted or withdrawn from a source.

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

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

Public water-system delivery: Water delivered to a user or group of users through public water-system distribution lines.

Public use: Water supplied from a public water system and used for firefighting, street washing, and municipal parks and swimming pools.

Raw water: Untreated water.

Reclaimed wastewater: Public or industrial treatment-plant effluent that has been diverted or intercepted for use before it reaches a natural waterway or aquifer.

Recycled water: Water that is used more than one time before it passes back into the natural hydrologic system, generally by the same user, or for similar purposes.

Release: Water discharged by a user or group of users into a wastewater-collection system.

Resident population: The number of persons who live in a State who consider it their primary place of residence. College students, military personnel, and inmates of penal institutions are counted as residents. Tourists and seasonal or part-time residents are considered nonresident population.

Return flow: (1) Water that is returned to surface or ground water after use or wastewater treatment, and thus becomes available for reuse. Return flow can go directly to surface water, directly to ground water through an injection well or infiltration bed, or indirectly to ground water through septic systems. (2) That proportion of the water diverted from a stream that returns to the stream channel either as surface or underground flow (U.S. Department of Agriculture).

Reuse: Use of water that has undergone wastewater treatment and is delivered to a user as reclaimed wastewater.

Self-supplied water: Water withdrawn from a ground- or surface-water source by a user and not obtained from a public water supply.

Septic system: Refers to a buried tank for the separation in the absence of oxygen of solids, grease, and liquid components of wastewater. The liquid fraction from the septic tank is discharged to a drain field for disposal.

Service area: (franchise area) A customer, group of customers, entity of group of activities which are served with water through a single delivery and or measuring/metering device from a main distribution system.

Standard Industrial Classification (SIC) code: Four-digit codes established by the U.S. Office of Management and Budget and used in the classification of establishments by type of activity in which they are engaged.

Surface-water disposal: Refers to wastewater that is disposed of directly into a surface-water body or wetland. This does not include water discharged into ponds for holding or percolation purposes.

Unaccounted-for water: Water supplied from a public water supply that has not been accounted for as being distributed to domestic, commercial, industrial, or thermoelectric uses. It includes public water use (fire fighting, street washing, and municipal parks and swimming pools), leakage (conveyance loss), and meter-errors.

Wastewater: Water that carries wastes from homes, businesses, and industries; a mixture of water and dissolved or suspended solids.

Wastewater collection: The process of conveying wastewater from users through a wastewater-collection system (sewer system) to a wastewater-treatment facility. May also include storm runoff. Wastewater is released by the user into the collection system and

received by the treatment facility. Wastewater can also be released from a local collection system into a regional collection system.

Wastewater treatment: The processing of wastewater for the removal or reduction of contained solids or other undesirable constituents.

Wastewater-treatment return flow: Water returned to the hydrologic system by wastewater-treatment facilities. Also referred to as effluent water.

Water demand: (1) Relation between water use and price, when all other factors are held constant that is, increased prices results in decreased water use. (2) Demand is a general concept used by economists to denote the willingness of consumers or users to purchase goods, services, or inputs to production processes, since the willingness varies with the price of the thing being purchased. (3) Refers to the schedule of quantities that consumers would use per unit of time at a particular price per unit of water used.

Water supply: All of the processes that are involved in obtaining water for the user before use. Includes withdrawal, water treatment, and distribution.

Water transfer: Artificial conveyance of water from one area to another.

Water treatment: The processes that withdrawn water may undergo prior to use, including chlorination, fluoridation, and filtration.

Water use: (1) In a restrictive sense, the term refers to water that is actually used for a specific purpose, such as for domestic use, irrigation, or industrial processing. (2) More broadly, water use pertains to human interaction with and influence on the hydrologic cycle, and includes elements such as water withdrawal, distribution, consumptive use, wastewater collection, and return flow.

Withdrawal: The removal of surface water or ground water from the natural hydrologic system for use, including public-water supply, industry, commercial, domestic, irrigation, livestock, thermoelectric power generation, water uses.