Source-Water Protection and Water-Quality Investigations in the Cambridge, Massachusetts, Drinking-Water Supply System

Ongoing investigations of the quality of source water in the Cambridge, Massachusetts, drinking-water supply system will help the Cambridge Water Department (CWD) deliver high-quality drinking water at a reasonable cost. When completed, the investigations will provide the CWD with a better understanding of the sources and quantities of contaminants entering the water supply. This information will help the CWD implement cost-effective watershed-management and water-quality-monitoring procedures as part of the Department's Source Water Protection Plan.

Introduction

The Cambridge Water Department (CWD) supplies about 15 million gallons of water each day to more than 95,000 customers in the City of Cambridge, Massachusetts. Most of this water is obtained from a system of reservoirs located in Cambridge and in parts of five other suburban-Boston communities. The drainage basin that contributes water to these reservoirs includes several potential sources of drinking-water contaminants, including major highways, secondary roads, areas of commercial and industrial development, and suburban residential tracts. The CWD is implementing a comprehensive Source-Water Protection Plan to ensure that the highest quality water is delivered to the treatment plant. A key element of this plan is a program that combines systematic monitoring of the drainage basin with detailed investigations of the effects of nonpoint-source contaminants, such as highway-deicing chemicals, nutrients, oxygen-demanding organic compounds, bacteria, and trace metals arising from stormwater runoff. The U.S. Geological Survey (USGS) is working with the CWD and the Massachusetts Highway Department (MassHighway) to develop a better understanding of the sources, transport, and fate of many of these contaminants (fig. 1). This Fact Sheet describes source-water protection and water-quality investigations currently underway in the Cambridge drinking-water supply system. The investigations are designed to complement a national effort by the USGS to provide water suppliers and regulatory agencies with information on the vulnerability of water supplies and the movement and fate of source-water contaminants (Patterson, 1997).

Figure 1. U.S. Geological Survey and Cambridge Water Department staff collect water-quality information at a continuous-record streamflow and water-quality monitoring station located on a tributary to Hobbs Brook Reservoir near Waltham, Massachusetts.

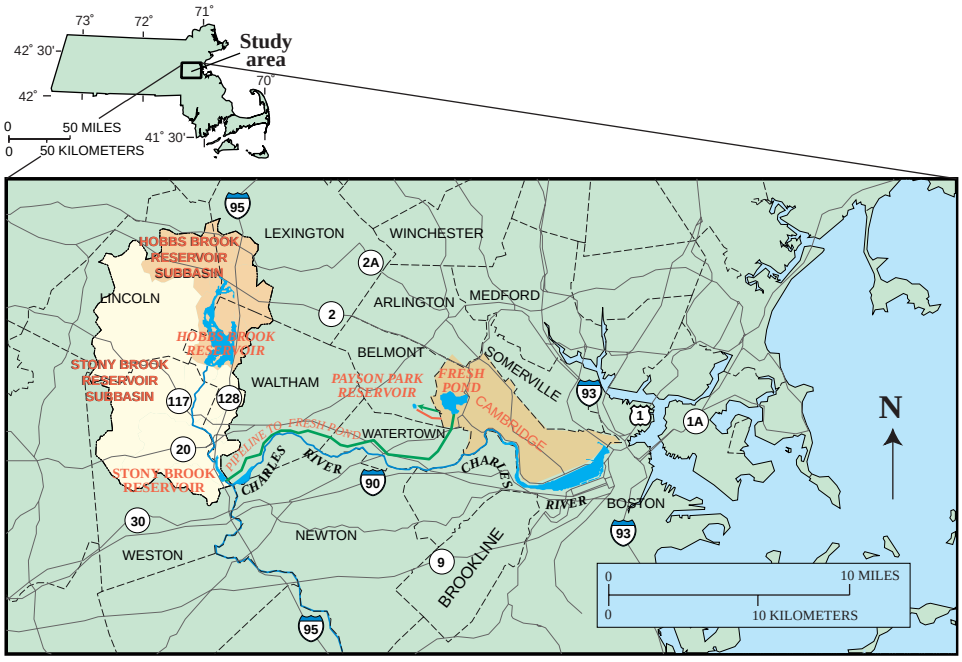
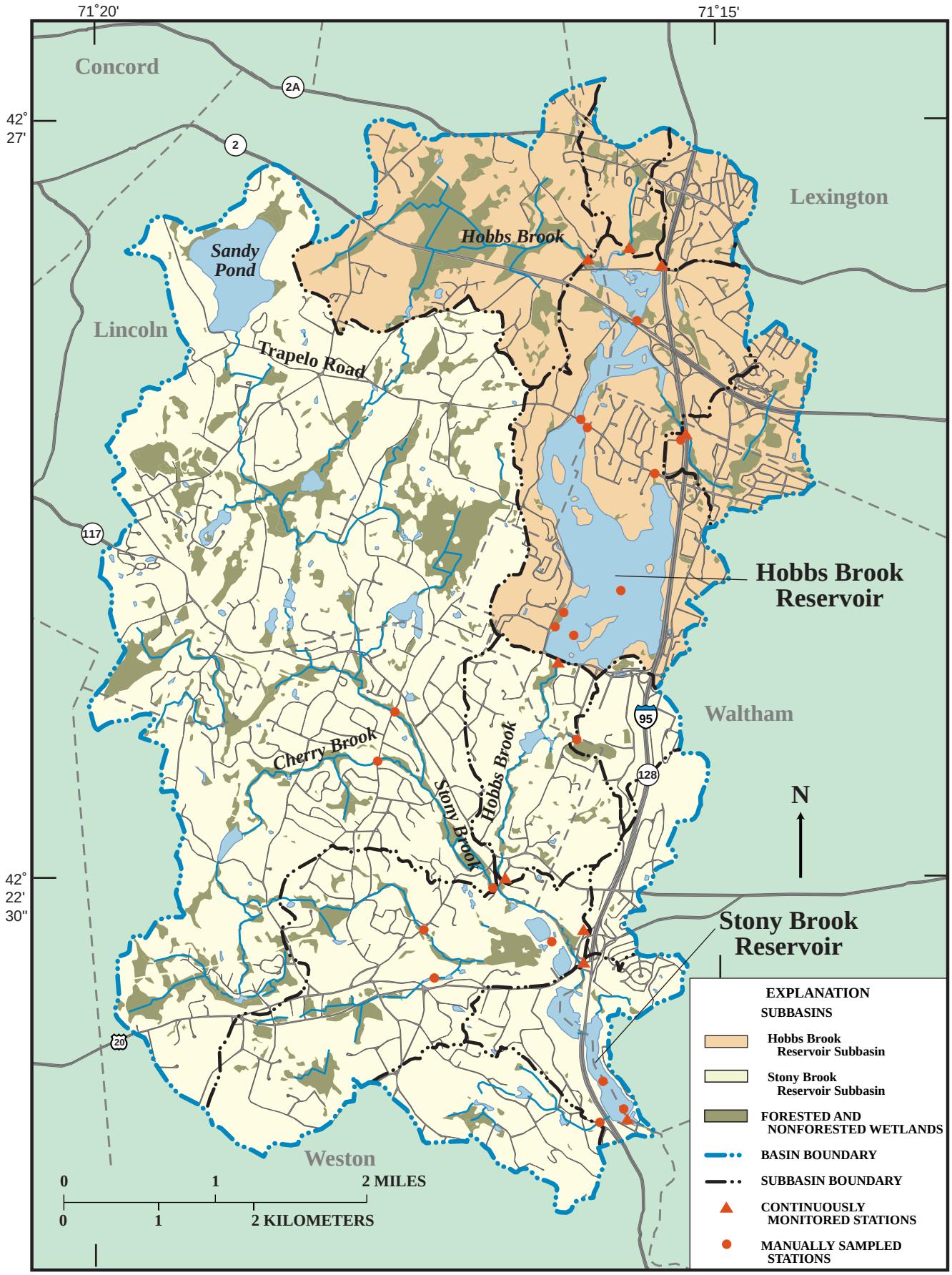


Figure 2. Map showing the location, extent, and components of the City of Cambridge drinking-water supply system, eastern Massachusetts.

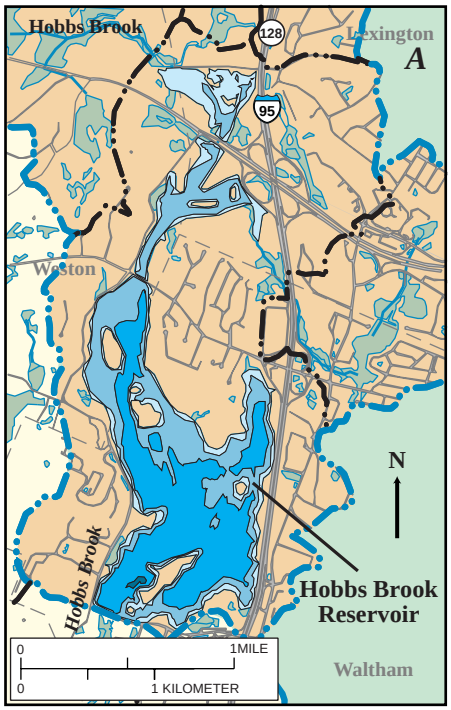
The Cambridge Drinking-Water Supply System

The Cambridge, Massachusetts drinking-water supply system consists of Hobbs Brook and Stony Brook Reservoirs, which drain a 15,200-acre (6,200-hectare) basin in Lexington, Lincoln, Waltham, and Weston,



Base from U.S. Geological Survey NMD, MassGIS, Cambridge Water Department, Harvard Design and Mapping, and Boston Edison. This map built by USGS-WRD personnel in Marlborough, MA, April 1998.

Figure 3. Hydrography, subbasin boundaries, streamflow and water-quality monitoring stations, wetlands, major highways, and secondary roads in the Cambridge, Massachusetts, drinking-water source area.



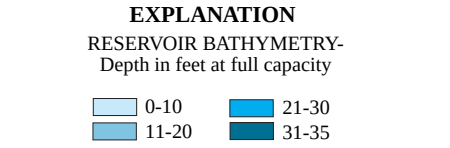


Figure 4. Bathymetric maps of (A) Hobbs Brook Reservoir, located in Lexington, Lincoln, Waltham, and Weston, Massachusetts, and (B) Stony Brook Reservoir, located in Waltham and Weston, Massachusetts.

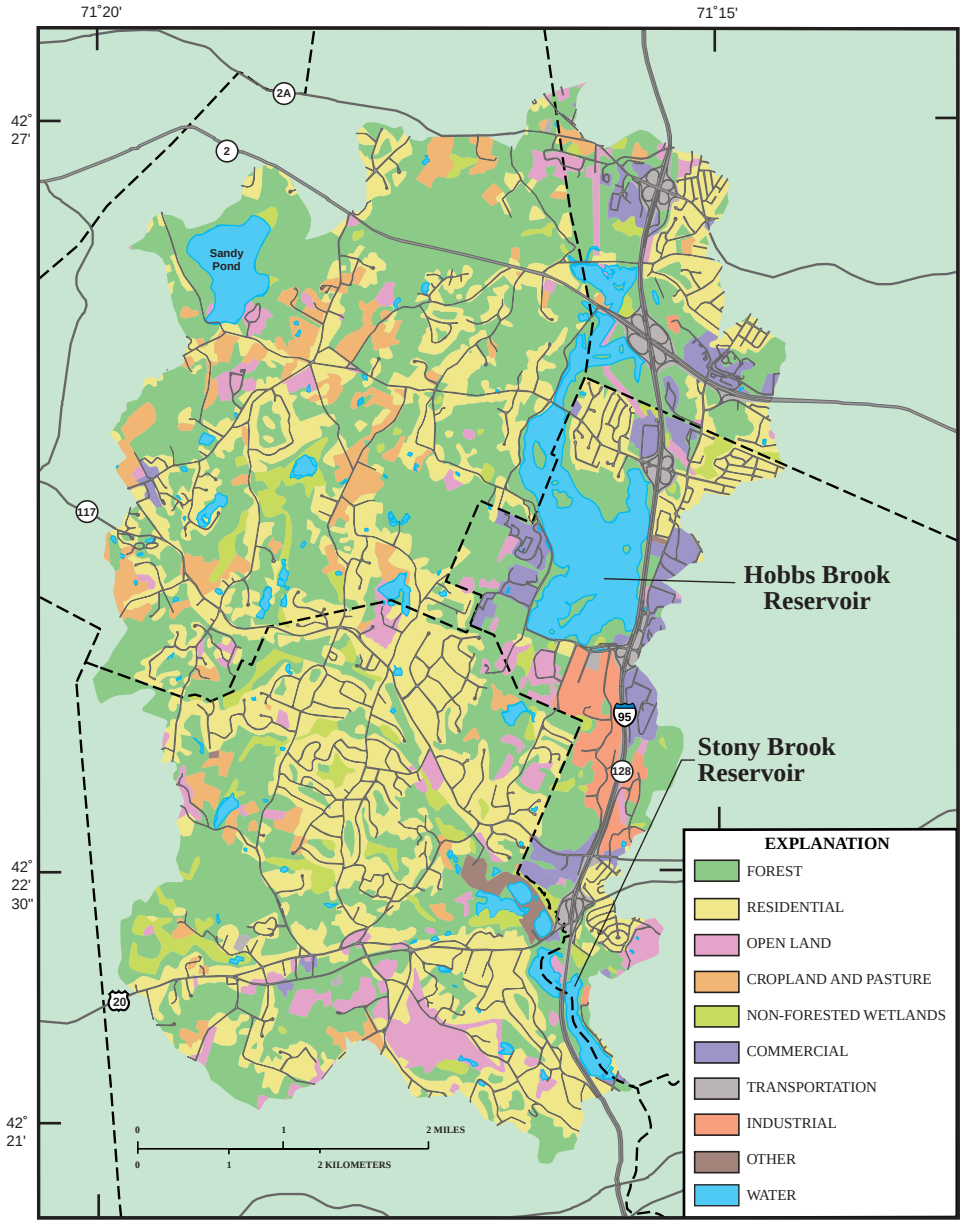


Figure 5. Land use and land cover in the Cambridge, Massachusetts, drinking-water source area.

Massachusetts, and Fresh Pond, a 155-acre (63-hectare) kettle lake located in Cambridge (fig. 2). Hobbs Brook Reservoir is fed by several tributaries and by storm drains associated with State Routes 128 and 2, secondary roads, and commercial and industrial parking lots. Stony Brook Reservoir is fed by drainage from the Stony Brook subbasin, by the outflow from Hobbs Brook Reservoir, and by other small tributaries. The CWD pipes water from Stony Brook Reservoir to Fresh Pond, where it is stored prior to treatment. After treatment, the finished water is pumped to the Payson Park Reservoir in Belmont, Massachusetts, from which it flows by gravity through a 190-mile distribution system. Overflow from Stony Brook Reservoir flows into the Charles River near Waltham, Massachusetts.

The primary source area for the Cambridge water supply varies seasonally. The larger Stony Brook subbasin (fig. 3) provides most of the water that is piped to Fresh Pond during periods of high flow (mainly winter and spring). During low-flow periods (summer and autumn), most of the supply comes from Hobbs Brook Reservoir. Thus differences in contaminant loading to streams in the two subbasins could result in seasonal differences in source-water quality.

Recent bathymetric surveys (Fugro East, Inc., 1996) of the two main reservoirs (fig. 4) indicate that the surface area of Hobbs Brook Reservoir, when filled to capacity, is 580 acres (235 hectares) and that the average depth of the reservoir is 12.6 feet (3.8 meters). The reservoir's storage capacity is about 317 million cubic feet (9 million cubic meters)

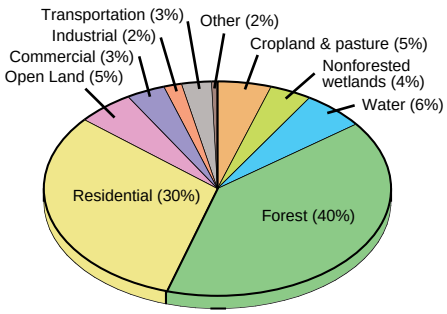


Figure 6. Distribution of land use and land cover in the Cambridge, Massachusetts, drinking-water source area.

(Fugro East, Inc., 1996). Stony Brook Reservoir has a maximum surface area of 66 acres (27 hectares), an average depth of 14.3 feet (4.4 meters), and a storage capacity of about 41 million cubic feet (1.2 million cubic meters). The average time required for a complete exchange of the water in Hobbs Brook Reservoir is about two years. In contrast, the average exchange time in Stony Brook Reservoir is only 17 to 21 days (Fugro East, Inc., 1996). The longer storage period in Hobbs Brook Reservoir may improve source-water quality by effectively trapping particle-bound contaminants within the reservoir and by providing more time for chemical and biological processes to remove dissolved contaminants from the water.

The drainage basin for the Cambridge drinking-water supply is located in moderately to heavily developed suburban areas (fig. 5). About 40 percent of the basin is forested (including forested wetlands) and 30 percent is residential (fig. 6). The residential areas consist of about 85 percent low-density housing (lots larger than one-half acre), 10 percent medium-density housing (lots one-fourth to one-half acre), and five percent high-density and multi-family housing (lots smaller than one-fourth acre). About three percent of the basin is used for commercial activities and two percent is considered industrial. Most of the industrial and commercial land, and all of the high-density housing, are concentrated in the eastern half of the drainage basin close to Hobbs Brook and Stony Brook Reservoirs (fig. 5).

Parts of four major State highways (Routes 128, 2, 2A, and 20) and four interchanges, comprising 90 lane miles, pass through the basin. (One lane mile is a paved road surface one mile long and 12 feet wide.) In addition, about 43 lane miles of secondary roads are maintained by municipalities within the basin. About three percent of the drainage basin is devoted to transportation, including highway maintenance facilities and interchanges. Five percent of the basin is cropland and pasture, six percent is water, including the two drinking-water supply reservoirs and numerous other lakes and ponds, and five percent is open land, including public parks, fields, and powerline right-of-ways. More than 6,500 acres (2,600 hectares) of nonforested wetlands cover about four percent of the total basin area. The largest concentration of wetlands is in the western half of the drainage basin (fig. 3), which also includes most of the low-density residential areas. Other land uses, such as mining operations and landfills, occupy one percent or less of the total basin area.

Source-Water Protection Activities

Because the CWD owns less than five percent of the drainage basin that contributes water to Hobbs Brook and Stony Brook Reservoirs, protection of the Cambridge water supply presents a difficult challenge. Lack of land ownership and regulatory authority limit the range of watershed-management alternatives, and the high cost of land in the basin precludes future land acquisitions. In addition, Fresh Pond Reservation, the City-owned area surrounding Fresh Pond, is the largest and most heavily used recreational open space in Cambridge. The CWD is implementing an innovative Source Water Protection Plan to meet these management challenges. The plan includes monitoring streamflow and water quality in the drainage basin (fig. 7), tracking development and construction activities, advocating for stormwater-management improvements, and maintaining a hazardous-materials response program.

Figure 7. Cambridge Water Department staff member measuring streamflow in an ungaged tributary to Stony Brook Reservoir near Weston, Massachusetts.

A significant part of CWD's Protection Plan is an effort to build positive working relationships with communities, government agencies, and other parties with interests in the drainage basin. The CWD sponsors the Cambridge Watershed Advisory Committee, which includes representatives from communities in the basin, and has developed active partnerships with businesses such as GTE Laboratories and Polaroid Corporation, State and Federal agencies such as MassHighway and the USGS, and local municipal services such as the City of Waltham Fire Department.

The CWD and the USGS have established partnerships with the Minuteman Science-Technology High School and Adult Career Center (Minuteman Tech) located within the basin in Lexington, Massachusetts. The Environmental Technology Program at Minuteman Tech prepares high school students for careers and advanced training in environmental science and technology, and is the first such program approved by the Massachusetts Department of Education. With support from the CWD, the Environmental Technology Program received a grant from the Massachusetts Environmental Trust to develop teaching capabilities in hydrology, water-quality monitoring, and

Figure 8. U.S. Geological Survey continuous-record streamflow and water-quality monitoring station located on a tributary to Hobbs Brook Reservoir near Waltham, Massachusetts.

geographic information systems (GIS), and to collect environmental data in the upper part of the drainage basin. USGS scientists regularly conduct workshops designed to supplement the curriculum with presentations and hands-on training in data-collection methods.

Ongoing Water-Quality Investigations

The CWD's source-water protection activities have been augmented by several technical projects and water-resources investigations. The CWD has developed an extensive GIS data base for the drainage basin, conducted bathymetric surveys of the reservoirs (fig. 4), and implemented a new water-quality monitoring network based on results of a limnological investigation of the reservoir system (Fugro East, Inc., 1996). The USGS is assisting the CWD in reviewing and updating the water-quality monitoring network and is conducting two large-scale investigations of factors that may affect source-water quality.

Sources and Loads of Sodium, Chloride, and Calcium to the Water Supply

In February 1997, the USGS began a multi-year investigation designed to identify sources of sodium, chloride, and calcium entering Hobbs Brook and Stony Brook Reservoirs. Sodium, which is a component of road-deicing salt, is of concern because it persists in treated water and may contribute sodium to consumers' diets. Since 1986, MassHighway has reduced by 50 to 70 percent the amount of sodium chloride added annually to State highways in the drainage basin. After more than 10 years of such reductions, however, sodium concentrations in the reservoirs remain unchanged from pre-1986 levels, indicating that additional sources and transport pathways may exist for sodium in the drainage basin.

To identify sources of the sodium, the USGS, in cooperation with MassHighway, established continuously monitored stations on all major tributary streams and at the outlets of Hobbs Brook Reservoir and Stony Brook Reservoir (fig. 3). Stream and reservoir stage, water temperature, and specific conductance of the water are measured continuously at the monitoring stations (fig. 8), and the continuous records are correlated with periodic measurements of streamflow and concentrations of sodium, chloride, and calcium. The data will be used to determine annual loads and subbasin budgets for these constituents. The results of these analyses will help MassHighway and the CWD prioritize watershed-management activities and target specific subbasins for remediation.

Nutrient, Manganese, and Organic-Carbon Budgets for the Water-Supply Reservoirs

In September 1997, the USGS and CWD began an investigation of seasonal and annual loads of total nitrogen, total phosphorus, dissolved manganese, and dissolved organic carbon (DOC) to the reservoirs. Nitrogen and phosphorus, which may enter the water supply from nonpoint sources such as precipitation, bank erosion, fertilizer, and stormwater runoff, can stimulate excessive growth of algae, causing increased turbidity, depletion of dissolved oxygen, and mobilization of contaminants from reservoir sediments (Cooke and others, 1986). Manganese and DOC, derived mainly from natural sources in the drainage basin, may have additional adverse effects on the water supply. Dissolved manganese can stain laundry and ceramic plumbing fixtures; DOC can react with chlorine during disinfection to produce toxic organic by-products (Aiken and Cotsaris, 1995; Reckhow and others, 1990).

Water samples for analysis of nutrients, dissolved manganese, and DOC are collected at each of the continuous-record streamflow and water-quality monitoring stations and at additional ungaged stream and reservoir sites in the drainage basin (fig. 9). Constituent concentrations measured in samples from these sites will be combined with the extensive hydrologic data already being collected at the monitoring stations to determine annual and seasonal loads of total nitrogen, total phosphorus, dissolved manganese, and DOC entering the reservoirs. The loads will then be related to conditions in the reservoirs and to changing land-use activities in the drainage basin. This information will be used to design more effective operating strategies and long-term monitoring protocols for the reservoirs.

Benefits and Transferability

The ongoing USGS investigations of source-water quality in the Cambridge drinking-water supply system will help the CWD continue to deliver high-quality drinking water at a reasonable cost. When completed, the investigations will provide the CWD with a better understanding of the sources and quantities of contaminants entering the drinking-water supply. Contaminant loads will be determined for each contributing subbasin and related to land use, land cover, and other subbasin features to identify contaminant sources. Information on contaminant sources will enable the CWD and MassHighway to direct costly management and remediation activities to appropriate subbasins. Cost-effective source-water protection efforts applied in this way ultimately will lower the long-term costs of water treatment and treatment-plant maintenance. Results of the ongoing investigations also will provide a scientific basis for evaluating the effectiveness of watershed-management practices and water-quality monitoring procedures.

Data on the spatial and seasonal variability of contaminant loads will be useful to other water-suppliers, both in the region and nationally. Spatial and seasonal differences in the types and amounts of DOC, for example, may be used to help New England water suppliers design operating procedures and reservoir-withdrawal strategies that minimize the formation of undesirable by-products of the water-treatment process. A better understanding of the relations between land use, land cover, and contaminant loads in the Cambridge drinking-water supply system will aid current efforts by State and Federal regulatory agencies to determine the vulnerability of the Nation's source water to contamination.

Figure 9. U.S. Geological Survey hydrologist collects water samples from Stony Brook Reservoir near Waltham, Massachusetts, and prepares the samples for chemical analysis.

Literature Cited

Aiken, George, and Cotsaris, Evangelo, 1995, Soil and hydrology--their effect on NOM: Journal of the American Water Works Association, vol. 87, p. 36-45.

Cooke, G.D., Welch, E.B., Peterson, S.A., and Newroth, P.R., 1986, Lake and reservoir restoration: Butterworths, Boston, Mass., 392 p.

Fugro East, Inc., 1996, Limnological investigations of the Cambridge Reservoir system: impacts of watershed inputs and alum sludge discharge: Cambridge Water Department, Cambridge, Mass., 75 p. + 4 appendices.

Patterson, Glenn, 1997, The U.S. Geological Survey Drinking Water Initiative: U.S. Geological Survey Fact Sheet 047-97, 2 p.

Reckhow, D.A., Singer, P.C., and Malcolm, R.L., 1990, Chlorination of humic materials--by-product formation and chemical interpretations: Environmental Science and Technology, vol. 24, p. 1655-1664.

For more information:

District Chief
U.S. Geological Survey
28 Lord Road, Suite 280
Marlborough, Massachusetts
01752

Internet: http://mass1.er.usgs.gov

Watershed Manager
City of Cambridge
Water Department
250 Fresh Pond Parkway
Cambridge,
Massachusetts 02138

Internet: http://www.ci.cambridge.ma.us/~Water

—Report by:
Marcus C. Waldron, USGS, with contributions from Chip Norton and Timothy W. D. MacDonald, Cambridge Water Department.

—Layout, text and graphic design by:
Mary S. Ashman, Mark V. Bonito, Christine T. Mendelsohn, and Peter A. Steeves, USGS.