

Detailed Description of Water Resources Monitoring Program

Monitoring Objectives

The process of designing a water resources monitoring program begins with a clear definition of program goals and objectives (Reinelt and others, 1988). The goals then guide the entire process of program design and implementation. Ideally, the data obtained through monitoring provide an objective source of information needed to support management decisions. Specifically, an effective water-quality monitoring program will provide quantitative answers to the following questions (Intergovernmental Task Force on Monitoring Water Quality, 1995):

- What is the condition of the source water?
- Where, how, and why are water-quality conditions changing over time?
- What problems are related to source-water quality? Where are the problems occurring and what is causing them?
- Are programs to prevent or remediate problems working effectively?
- Are water-quality goals and standards being met?

The primary goal of the Cambridge drinking water source-area monitoring program is to ensure that water withdrawn from Fresh Pond for treatment is as free as possible from contaminants, thereby minimizing the costs of treatment. Specific objectives of the program are to:

- Monitor the condition of source waters in the Cambridge drinking water supply system;
- Determine where, when, and how water-quality conditions are changing over time;
- Identify actual and potential problems related to source-water quality;
- Evaluate effectiveness of programs to prevent or remediate problems;
- Ensure that all applicable water-quality goals, standards, and guidelines are being met; and
- Provide for rapid response to emerging problems.

Monitoring-Program Elements

The Cambridge source-area monitoring program consists of four major elements: (1) routine monitoring of reservoirs and tributary streams during dry weather, (2) event-based monitoring of streams, storm drains, and other outfalls during wet weather, (3) continuous recording of stage and selected water-quality characteristics at critical sites within the drainage basin, and (4) periodic monitoring of ground water in the vicinity of Fresh Pond.

Routine (Dry Weather) Surface-Water Monitoring

Dry-weather sampling is conducted at 3 primary and 6 secondary reservoir-monitoring stations, and at 11 primary and 5 secondary tributary-monitoring stations. The distinction between primary and secondary monitoring stations is based on the frequency of sampling and on the number of analyses performed on the samples.

The reservoir sampling schedule for this study (table A1) is based on the results of a USGS study which determined that monthly sampling was sufficient to characterize changes in reservoir water quality during the spring, summer, and early autumn months and that sampling every other month was sufficient during winter. At regular intervals (once each month from May through October and every other month from December through April), CWD staff measure Secchi disk transparency and depth profiles of specific conductance, pH, water temperature, turbidity, and dissolved oxygen concentration at both the primary and the secondary reservoir-monitoring stations.

Secchi disk transparency is a measure of the depth of penetration of sunlight in a reservoir. It is measured by lowering a small horizontal disk on a calibrated line and noting the depth at which it is no longer visible from the surface (Lind, 1974). In the Cambridge drinking-water source area, the Secchi disk transparency is related mainly to the abundance of phytoplankton algae in the upper mixed layers of the reservoirs which proliferate relative to nutrient abundance. Thus, Secchi depth readings provide a quick and inexpensive indicator of eutrophication problems. Water temperature, specific conductance, pH, turbidity, and dissolved oxygen concentration were measured *in-situ* with an electronic multiparameter water-quality monitoring system lowered on a cable. Depth profiles of these characteristics provide essential information on physical, chemical, and biological conditions in the reservoirs.

Reservoir Sampling Process Overview

At the three primary reservoir-monitoring stations only, water samples were pumped with a peristaltic pump through pre-cleaned Tygon tubing from three depths—6 ft below the surface, the depth of the thermocline (the point of maximum rate of change in water temperature with depth), and 2 to 6 ft above the bottom—when the water column was thermally stratified. Samples were dipped from below the surface of the pond when limnological conditions were isothermal. Water from each sampling depth was

collected in accordance with clean-sampling protocols (Wilde and others, 1999) into Teflon bottles. The samples were returned to the CWD laboratory and analyzed for color, alkalinity, and concentrations of major ions (sodium, calcium, chloride, and sulfate), nutrients (ammonia nitrogen, total Kjeldahl nitrogen, nitrate nitrogen, total phosphorus, and orthophosphate phosphorus), selected metals (aluminum, iron, and manganese), and phytoplankton chlorophyll-*a*, using standard methods (American Public Health Association and others, 1995). Studies conducted by the USGS have shown that under most conditions, water-quality data collected in depth profiles at these stations are indicative of conditions throughout the reservoirs.

Color was measured spectrophotometrically on each sample and is primarily an indicator of the concentration of dissolved organic matter, which is abundant in source-area streams and reservoirs, and must be removed during treatment to prevent formation of organochlorine by-products. Alkalinity is a measure of the acid-neutralizing capacity of a water sample and is mainly dependent on the quantities of carbonate and bicarbonate ions. The most accurate indicator of the abundance of phytoplankton algae is the amount of particulate chlorophyll-*a* in the upper mixed layer of the reservoir. Changes in chlorophyll concentrations are indicative of changes in reservoir trophic state – the extent to which a water body is enriched with plant nutrients.

Nitrogen and phosphorus are plant nutrients that can, in sufficient quantities, cause algal blooms in the reservoirs and excessive growth of algae and higher plants in the streams. Ecologically significant forms of nitrogen include ammonia and nitrate nitrogen in runoff from areas that receive fertilizer applications and in wastewater discharges, and organic nitrogen produced by microbial processes. The concentration of organic nitrogen is determined by subtracting the concentration of ammonia nitrogen from that of total Kjeldahl nitrogen (TKN), therefore ammonia and TKN were analyzed in source water samples.

During each round of reservoir sampling, concentrations of fecal coliform bacteria were measured at the withdrawal points in all three reservoirs. The presence of fecal coliform bacteria in a water sample indicates that the water may have been contaminated with feces from humans or other warm-blooded animals. Such contamination can introduce disease-causing viruses and other potential pathogens.

Routine Tributary Monitoring Process Overview

Water entering the reservoirs is monitored at 11 primary and 5 secondary tributary-stream-monitoring stations. These stations represent streams that contribute water directly to the reservoirs and major tributaries, or integrate large areas of the drainage basin. Thus, the stations are important primary indicators of the condition of water likely to enter the reservoirs. Every 2 months, the CWD uses USGS methods (Rantz and others, 1982; Wilde and others, 1999) to measure stage and discharge and to assess water quality at each primary stream-monitoring station. The sampling frequency (table A1), in conjunction with continuous monitoring in each of the three reservoirs, is sufficient to capture changes in water quality in time to prevent contamination problems at the water-treatment plant intake.

Specific conductance, pH, water temperature, turbidity, and dissolved oxygen concentration are measured on site and water samples are collected in accordance with clean-sampling protocols (Wilde and others, 1999) into 1-liter Teflon isokinetic samplers. Discharge-weighted, representative samples are collected from multiple vertical profiles distributed at equal distances along stream cross sections (Edwards and Glysson, 1999). The samples are then returned to the CWD laboratory for analysis of color, fecal coliform bacteria, alkalinity, total suspended solids, and concentrations of major ions, nutrients, and selected metals (table A1).

The five secondary stream-monitoring stations are monitored twice a year, usually during base flow and high flow. These stations are located higher up in the drainage basin on smaller tributaries or at points that discharge to the reservoirs predominantly during wet weather. The secondary stations are sampled biannually for the same constituents as the primary stations to provide indicators of potential changes in water quality or of base-flow conditions.

As with all samples collected during this study, each round of periodic sampling included quality-assurance samples (field and instrument blanks, duplicates, and sample splits) that represent about 10 percent of the total number of samples analyzed. Results from these analyses are out of the scope of this report, but were monitored throughout the field work component to insure that USGS quality control standards were consistently met.

Event-Based (Wet Weather) Surface-Water Monitoring

Storm-event sampling was conducted several times during this study at several sites, some of which are primary and secondary stream-monitoring stations and some of which are pipes and culverts that discharge to the reservoirs. The goal of the storm-event sampling is to collect samples of the first flush of runoff from storms producing 0.5 inches or more of rain after a period of at least 3 days of dry weather. For this study, this goal was accomplished by manually collecting the first flush from, open tributaries, pipes, or culverts. The samples were analyzed for color, fecal coliform bacteria, alkalinity, total suspended solids, and concentrations of major ions, nutrients, and selected metals. These data were compared to results from routine, dry-weather monitoring in order to assess the effects of storms on introducing sediment and associated constituent loads to the reservoirs. A detailed, multi-year stormwater study is proposed beginning in 2002 which will provide an in-depth understanding of water quality during storm events that pass through the Cambridge Watershed.

Special Water Quality Investigations

The water resources monitoring program includes the investigation of specific point-source locations that contribute contaminants to the water supply. These locations are not tributary sampling stations, rather outfalls, or elicited discharges that enter tributaries, whose sources were detected by routine or stormwater sampling in the tributaries and traced back upstream to their specific location.

Continuous-Record Surface-Water Monitoring

Continuous (15 minute interval) monitoring is conducted at three primary tributary-monitoring stations and two secondary reservoir-monitoring stations. These stations are operated and maintained by the USGS and CWD for continuous measurement of stream and reservoir stage and temperature-corrected specific conductance. Precipitation also is monitored at two of the stations. Specific conductance, a measure of the ability of the water to conduct an electrical current, is an indicator of the concentrations of dissolved electrolytes in the water. The station at Hobbs Brook Reservoir and Stony Brook Reservoir also monitor stage and specific conductance of the discharges from the reservoirs. This information is uploaded on a real-time basis to the USGS internet site. The continuous stream-stage data are converted to discharge by the use of stage-discharge relations (Rantz and others, 1982) and the specific conductance records are converted to concentrations of sodium, calcium, and chloride in a similar fashion (Granato and Smith, 1999). Late in 2001, a more elaborate water quality monitoring system was installed at Stony Brook which measures pH, specific conductance, turbidity, temperature, and dissolved oxygen. Data from several additional continuous monitoring stations is anticipated to be accessible on the Internet by late 2002.

Data Management, Interpretation, Reporting, and Review

The monitoring and quality-assurance data were entered into a database, maintained by the CWD as part of this study, that enables the CWD analyze, track, and report changes in water quality efficiently. Monitoring was conducted by CWD staff with technical support from the USGS. USGS methods and protocols were used in the program so that results may be compared to baseline data collected by the USGS during water year 1998. This report was reviewed by a Technical Advisory Committee that includes members from the Cambridge academic community and a Watershed Advisory Committee composed of representatives from Cambridge, Waltham, Weston, Lexington, and Lincoln.

The CWD also conducts special investigations of water-quality-related problems and situations within the source area. Such investigations may include intensive monitoring at present water-quality-monitoring stations where increasing trends in contaminant loading have been noted, monitoring at locations where a known disturbance is taking place, and monitoring to assess the effectiveness of new management practices or infrastructure. These investigations frequently require analysis of a variety of constituents and water- quality related properties.

