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CONVERSION FACTORS AND WATER-QUALITY INFORMATION

CONVERSION FACTORS

Multiply	By	To obtain
acres	0.4047	hectares
feet (ft)	0.3048	meters
miles (mi)	1.609	kilometers
square miles (mi^2)	12.590	square kilometers
Temperature is given in degrees Fahrenheit (^oF), which can be converted to degrees Celsius (^oC) by the following equation: $^oC = (^oF-32)/1.8$		

WATER-QUALITY INFORMATION

Concentrations of chemical constituents are given in milligrams per liter (mg/L). Milligrams per liter are units expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, milligrams per liter is equivalent to “parts per million.”

Statewide Water-Quality Network for Massachusetts

EXECUTIVE SUMMARY

Problem

Public agencies tasked with protecting and managing water resources need information from water-quality monitoring for many purposes. Information is needed to assess the current "health" of water bodies with respect to water-quality standards, to design and evaluate remediation programs, to document compliance with regulations, to detect trends in water quality, to identify emerging problems, and to increase community awareness of water-resource protection. In Massachusetts, several State and Federal agencies and many volunteer groups conduct water-quality monitoring, but their programs do not always provide data at the spatial or temporal scales necessary to meet these information needs. For example, only 18 percent of total stream miles and 48 percent of lake acres were reported as assessed in the State's 1998 Summary of Water Quality [305(b)] report, and statewide trends cannot be determined from the existing data (Commonwealth of Massachusetts, 1997, 1998). Previous statewide data-collection programs have been biased towards larger rivers, known problem areas, and point pollution sources; in this way, the programs have provided limited spatial coverage and have not adequately depicted water-quality conditions throughout the State. A statewide strategy for water-quality monitoring is needed to provide consistent and comprehensive water-quality data on waters throughout the Commonwealth.

Overview

The U.S. Geological Survey worked with the Massachusetts Department of Environmental Protection, Division of Watershed Management (DEP/DWM) to design a water-quality monitoring program for Massachusetts. The program design was guided by the information needs of the DEP/DWM, which include mandates of the Clean Water Act (CWA) and activities of the Massachusetts Watershed Initiative (MWI), and by input from many organizations involved in water-quality monitoring in the State. To be effective, a monitoring program must be designed to fulfill the purposes for which the data will be used. Thus, the proposed program for Massachusetts' multiple information needs has several components or tiers, that are defined by specific monitoring objectives:

- *Tier I—Basin-Based, Statewide Water-Quality Assessment*: To provide a periodic assessment of the water-quality status of the State's surface waters, as required by section 305(b) of the CWA; implemented on a 5-year, rotating-basin basis with the MWI basin assessments;
- *Tier II—Contaminant Loads*: To determine loads of contaminants carried by major rivers in Massachusetts at strategic locations, such as at the mouths of major rivers and at State boundaries;
- *Tier III —Targeted Monitoring*, *Spatially or by Issue*: To identify impaired water bodies required by section 303(d) of the CWA, to determine causes and sources of impairments for purposes of 303(d) and 305(b) requirements, to identify pollution sources or "hot-spots," and other site-specific objectives;
- *Tier IV—TMDLs*: To develop Total Maximum Daily Loads for specific water bodies.
- *Tier V—Compliance monitoring:* To meet regulatory requirements and permits.

The program as described in this report is most fully developed for Tiers I and II, which are statewide in scale, and resource requirements for implementing these tiers are discussed. Strategies for Tier III "hot-spot monitoring," an objective of the MWI teams, also are investigated. Strategies for Tier IV, TMDL development and monitoring in Massachusetts, are being developed separately and are not discussed in this report. Finally, a network is investigated that would use compliance monitoring under the National Pollutant Discharge Elimination System as a possible fifth Tier in the program.

Design Considerations

To guide the monitoring program design, a review was conducted of general principles of network design, including monitoring objectives and approaches, and of ongoing monitoring activities of Massachusetts State agencies. A clear definition of objectives for the monitoring program is a first and necessary step in network design. Monitoring approaches, which comprise the details of how water-quality measurements will be made, are chosen to answer the water-quality questions posed by the program objectives. Monitoring approaches can be defined in terms of the time period of the measurements (short-term, long-term, or rotating), the method of site selection (targeted or probabilistic), the types of measurements made (for example, physical, chemical, or biological), the type of water resource being monitored (for example, stream, lake, or ground water), and the use of the monitoring results. Monitoring methods include fixed-station monitoring, which is a type of monitoring in which the same sites are repeatedly sampled at regular intervals, for a long period of time. Fixed-station monitoring and flow data typically are needed to estimate mass fluxes or constituent loads, as in Tier II of the proposed monitoring program; this is not the best approach for a large-scale assessment of water-resource conditions, as is needed for Tier I of the proposed program. Short-term (synoptic) surveys that incorporate probabilistic designs are more appropriate for large-scale assessments.

Ongoing monitoring programs by State agencies include (1) lake sampling, fish-toxics monitoring, benthic macroinvertebrate measurements, and some water-chemistry monitoring by DEP/DWM, (2) lake monitoring by DEM in State parks, (3) reservoir, reservoir tributary, and coastal river sampling for bacteria and water-chemistry by the Metropolitan District Commission and the Massachusetts Water Resources Authority, (4) bacteria and physical monitoring in coastal waters by the Division of Marine Fisheries and fish community surveys by the Division of Fisheries and Wildlife of the Department of Fisheries, Wildlife, and Environmental Law Enforcement, (5) groundwater monitoring for highway-runoff contaminants by the Massachusetts Highway Department, and (6) diverse monitoring activities of many local volunteer groups. Many of these activities would provide useful data for components of the statewide monitoring program, but none has the monitoring approach, geographic coverage, sampling density, or sampling parameters that would provide information to meet all the information needs of DEP/DWM, the MWI teams, and the U.S. Environmental Protection Agency. The review of ongoing monitoring programs demonstrates the need for the development of a statewide monitoring program.

Statewide Water-Quality Network Design

Tier I—Basin-Based, Statewide Water-Quality Assessment

The proposed monitoring program developed for Tier I objectives consists of a basin-based assessment of existing surface-water-quality conditions with respect to State water-quality standards and the designated uses of water bodies. Requirements for a Tier I program, reflecting CWA mandates, are that it be statewide in scale, comprehensive (all water bodies in the Commonwealth are assessed), and repeated at regular intervals. Another goal is that the program lead to improvements in the 305(b) assessment, by increasing the number of stream miles and lake acres assessed and reducing the historical bias toward problem areas. Monitoring for Tier I objectives would be implemented on a 5-year, rotating basin basis, reflecting the State's strong commitment to the watershed approach. Several approaches for this tier were investigated by use of information collected in the Neponset Basin in eastern Massachusetts. This basin was also used as a pilot area for the MWI in the early 1990s. The Neponset Basin is a 117-square-mile watershed with urban (19 percent), residential (35 percent), and forested or undeveloped (48 percent) land uses that drains to Boston Harbor.

Geographic Information System (GIS) procedures were developed to inventory streams and lakes in the Neponset Basin for a comprehensive assessment using the 1:25,000-scale centerline hydrography and Watershed Tools of the Massachusetts Office of Geographic and Environmental Information (MassGIS). The basin contains 152 miles of perennial streams and 46 lakes larger than 5 acres for inclusion in the assessment. About 50 percent of stream miles were first-order, or small headwater, streams; about 35 percent were second- or third-order streams, many of which drain major tributary subbasins; and about 15 percent were fourth- and fifth-order streams, primarily parts of the mainstem Neponset and East Branch Neponset Rivers.

In order to investigate an exhaustive approach to assessment, stream miles in the basin were segmented on the basis of physical features (confluences with tributaries, lakes, and point discharges) that could potentially alter water quality. Lakes were assessed as discrete water bodies. Resources required for an exhaustive approach, in which all stream segments and lakes in the Neponset Basin are assessed and data are collected to evaluate nearly all applicable water-quality standards, were estimated to be about 2,660 personnel-days or 12 full-time equivalents (FTEs) for field sample collection and processing and about 4,700 laboratory analyses. The Neponset Basin, areally less than one-half of the Boston Harbor Watersheds Basin, is small compared to the 27 major basins in Massachusetts, which average about 300 mi^2 in area (about 400 mi^2 when basins are combined for MWI teams). Thus, the resource estimates for the Neponset Basin probably represent at best about one-half of the resources needed for an exhaustive assessment of a typical major basin. For statewide implementation with the MWI, in which five major basins are assessed per year, perhaps 10 times the Neponset estimates would be needed, or about 120 FTEs for sample collection and processing and about 47,000 analyses; in all likelihood, more than double the personnel resources would be needed when project planning, field preparation, data management and analysis are included. Thus, resource requirements for a comprehensive assessment of all water bodies using this exhaustive approach are much greater than could be realistically expended.

The monitoring program and results of the 1994 Neponset assessment were reviewed for comparison with the goals and requirements of a comprehensive assessment, such as the exhaustive approach described above. The 1994 study was an in-depth assessment of water resources in the Neponset River Basin, with multiple objectives in addition to that of a basin-wide (though not comprehensive) use-support assessment for the CWA. During that study, about one-half of the total stream miles in the basin were assessed for their designated uses, with a sampling density that was considerably less than that proposed for a systematic, exhaustive assessment of streams and lakes in the basin. All fourth- and fifth-order streams were assessed for most designated uses; the fraction of third-order streams assessed varied from 15 to 85 percent, by use; and less than one-half of second-order streams and less than one-third of first-order streams were assessed for any use. About one- to three-fourths of significant (larger than 5 acres in area) lakes in the basin were assessed for designated uses; lake assessments were based on limited data that resulted in only impairment being assessed for important uses of aquatic life and primary contact recreation.

Analysis of the Neponset Basin hydrography and 1994 study demonstrated that resource-limitation problems will always be posed by the large number of sites needed in order for all the small streams in a basin to be sampled and the need for repeated site visits to assess some uses. Thus, a monitoring program is proposed in which (a) probabilistic monitoring of small streams is combined with the deterministic or targeted monitoring of large streams and (b) deterministic or probabilistic monitoring of lakes may be supplemented with more intensive sampling in lakes of special interest. Small streams, including first-, second-, and third-order streams, are assessed probabilistically for the aquatic life and recreational uses with biomonitoring and bacteria sampling. This approach is proposed to meet the CWA requirement of 100 percent coverage for small streams. Estimates of use support would be provided for all small streams as a group, rather than definitive information for individual streams, and causes or sources of impairments could not be identified. Depending on the resources expended, comprehensive estimates of these uses for small streams could be made on a statewide basis only or for individual basins. For large streams, including fourth-, fifth, and some third-order streams, nearly all designated uses would be assessed, with biomonitoring and sampling for water chemistry, bacteria, sediment, and fish tissue. All large streams in a basin would be assessed using a fixed sampling distance of about 5 miles per sample. This approach is proposed to meet DEP/DWM's need for information on water-quality conditions on specific reaches of these streams. Lakes greater than 10 acres are assessed for aquatic life use and trophic status, with field parameters, macrophytes, Secchi-disk, nutrients, and chlorophyll-a sampling.

The combined probabilistic-deterministic program would provide information to meet CWA requirements and provide data for other information needs of Massachusetts regulatory agencies and MWI teams. It would be implemented on schedule with the 5-year rotating-basin cycle of the MWI, probably in the MWI's research and assessment years. Management-level decisions would be needed with respect to program objectives and sampling density for the probabilistic component of the program, about whether estimates of use support are needed for small streams on the statewide scale only or for individual basins

also. These decisions would affect resource requirements, but with the statewide estimate for small streams only, about 30 FTEs for field sample collection and processing and about 10,500 laboratory analyses would be needed; this assumes that five basins, each of which requires about twice the effort as the Neponset, are assessed per year. Additional time for field preparation and data management could double these requirements to about 60 FTEs, with several additional FTEs needed for program administration, planning, site selection, and obtaining permissions. Although they are much less than the requirements for the exhaustive approach, these resource requirements are substantial. They could be reduced by eliminating or reducing assessment of some designated uses that require intensive sampling, such as the recreational use for small streams or frequent sampling of lakes for trophic status, or by using a probabilistic approach for lakes.

Volunteer monitoring could be used in several ways to enhance the proposed program for Tier I monitoring or to offset the resource requirements for field data collection. Volunteer monitoring, coordinated through the MWI teams, could be used to conduct biomonitoring or collect bacteria samples at additional sites in basins where individual status estimates for small streams are needed; these estimates could be less rigorous if less sophisticated biomonitoring protocols were followed by the volunteer groups than by agency personnel. Volunteer monitoring of additional sites on large streams could be used to increase the number of third-order streams that are deterministically monitored, or to increase the sampling density on mainstem reaches, most likely for aquatic life (water chemistry sampling) or recreational (bacteria sampling) uses. For lakes, volunteer monitoring could be used to increase or maintain the measurement frequency for trophic-status indicators, to conduct more intensive assessments for some lakes, or to sample lakes of special interest deterministically if a probabilistic approach for lakes generally is taken.

Tier II—Contaminant Loads in Major Rivers

Tier II is a fixed-station sampling network to determine contaminant loads carried by major rivers. Nineteen sampling sites, in 17 of the 27 major basins in Massachusetts, are proposed. Because continuous streamflow records are needed for accurate loads calculations, the sites are located primarily at or near existing streamflow gages. The proposed sampling sites are: near the mouths of the Merrimack, Aberjona, Charles, Ipswich, Neponset, and Taunton Rivers, which collectively drain to Boston Harbor, the Gulf of Maine, and Narrangansett Bay; at the mouths of the Millers, Deerfield, Chicopee, and Westfield Rivers, which discharge to the Connecticut River; at the mouths of the Concord and Nashua Rivers, which discharge to the Merrimack River; and at locations on the Quinebaug, French, Blackstone, West Branch Farmington, Housatonic, and Connecticut Rivers near where they enter and(or) leave the State. Sampling at these sites would provide information on contaminant loads from 67 percent of the total land area of the State. The remaining unsampled areas of the State would be primarily coastal areas, which are drained by numerous small streams. Resource limitations would preclude including all these streams in a loads network. A limited number of sites in small coastal watersheds also could be sampled for a sufficient time (several years) to characterize loads from the watersheds, however, and then discontinued and re-located elsewhere in the coastal area. Loads from some areas, between the coast and the inland limit of tidal influence, will not be determinable without developing site-specific, non-standard methods for flow measurement (through dams, for example), or modelling. Sampling parameters for Tier II monitoring, proposed to provide information on the water-quality issues of concern for receiving waters or specific site locations, include field parameters, bacteria, nutrients, suspended sediment, and possibly metals at some sites. Sampling frequency is determined by the need to characterize adequately the range of hydrologic and seasonal conditions for loads calculations. Thus, about 15 samples per year are proposed, at about monthly intervals but also during high and low flows. The sampling frequency could be enhanced by the use of volunteers or paid observers. Volunteer monitoring would be particularly useful for sediment and sediment-borne contaminants, because frequent sampling is needed to adequately quantify sediment loads. Resource requirements for Tier II of the network were estimated at about 2 FTEs for water-quality sample collection, with additional time needed for field preparation, data analysis and management, and resources for the installation, operation, and maintenance of any new streamflow gages.

Tier III—Targeted Monitoring Programs

Targeted programs of Tier III of the proposed network are described primarily in terms of strategies for hot-spot monitoring, that is, monitoring to identify pollution sources. These strategies are investigated using an analysis of the bacteria sampling program of the 1994 Neponset Basin assessment. In that study, data from 41 sites were used to identify leaking sewer lines and failed septic systems, as well as stormwater runoff, as general sources of bacteria contamination in the basin and to confirm that bacteria were a basin-wide problem. The bacteria source for a specific impaired reach was identified in only one instance out of 29 impairments, using infrastructure investigation by a town rather than by additional water-quality sampling. An analysis of watershed areas of the sampling sites found little relation between bacteria concentrations and land uses expected to be bacteria sources. These analyses illustrate the difficulties that can arise when a single monitoring design is used to address multiple, sometimes partly conflicting, monitoring objectives. They also demonstrated that effective programs for hot-spot monitoring are based on substantial knowledge of suspected problem areas and on site and contaminant characteristics, information that commonly is compiled by MWI teams and also could be provided to some extent by Tier I of the monitoring program. Monitoring data at all quality levels and the local knowledge of volunteer groups also could be very effective for site selection or source identification. Once known or suspected hot spots are identified, site-specific sampling programs in terms of sampling parameters and density can be designed. Because these programs are issue-, site-, and basin-specific, resource requirements for an effective program for this component of Tier III of the network cannot be defined in advance.

Tier V—Strategies for Compliance-Based Ambient Monitoring

The distribution of major National Pollutant Discharge Elimination System (NPDES) sites in Massachusetts was evaluated to determine the usefulness of these sites for the collection of ambient water-quality data. Locations of 155 sites were reviewed. The sites were well distributed geographically among basins, but were located primarily on large rivers, with two-thirds or more on fourth- or higher order streams. Use of these sites for a statewide assessment of stream-water quality, such as needed for Tier I of the monitoring program, would yield estimates of use support that were biased towards large streams. The targeted approach to site selection also would mean that monitoring could not be extrapolated to unsampled streams. Thus, with assumptions of 3 miles of assessed stream per site for first- through third-order streams and 5 miles per site for fourth- and higher order streams, a total of 553 miles, or less than 10 percent of the perennial stream miles in the State, would be assessed by sampling major NPDES sites. NPDES sites might be more suited to sampling for loads or Tier II objectives than for a statewide status assessment. Watersheds of major NPDES sites, where they could be determined, account for about 70 percent of the total land area of Massachusetts. These sites may not be optimally located in terms of the loads objectives, however, and would require review; the isokinetic depth- and flow-integrated sampling needed for loads calculations also generally is best implemented by experienced water-quality personnel. Moreover, it might be difficult to adequately design and implement protocols for sample collection, handling, and analysis by multiple private entities to ensure data of sufficient comparability and quality to meet statewide information needs.

Summary

The water-quality monitoring program described in this report contains several components that would provide information to meet many of the water-quality information needs of the Massachusetts state agencies and others concerned about water resources in the State. The components are complementary in many ways but are not interchangeable, and each component requires a substantial investment of personnel time, laboratory analyses, and other resources. Several components must be developed on site-specific bases, and available resources will place important constraints on all aspects of the program. The water-quality information needs to which components of the proposed program are addressed must be carefully evaluated and prioritized, so that monitoring resources are efficiently and effectively deployed in accordance with the critical tasks of protecting and managing the water resources of Massachusetts.