The Charles River, Eastern Massachusetts: Scientific Information in Support of Environmental Restoration

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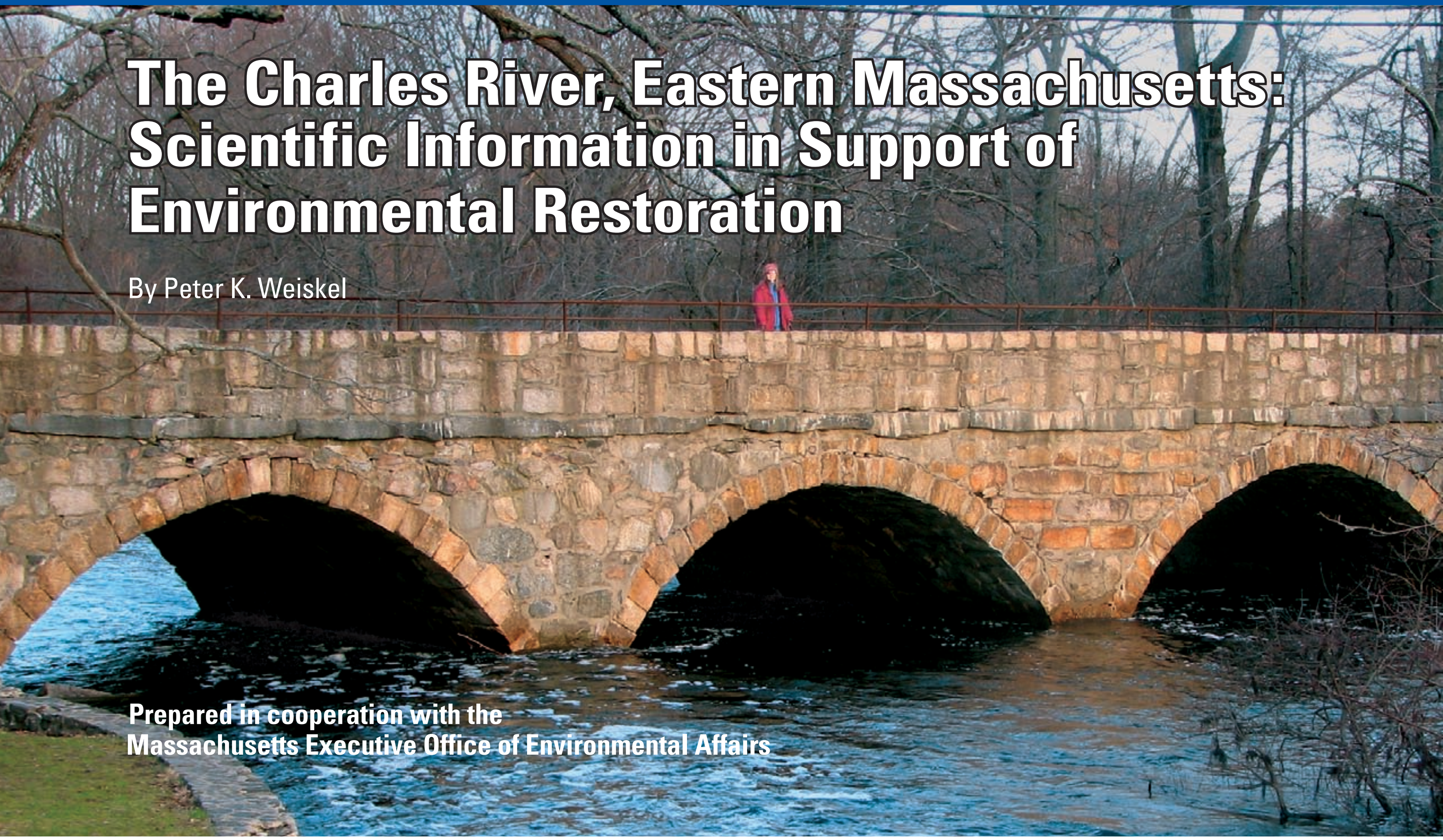
Prepared in cooperation with the
Massachusetts Executive Office of Environmental Affairs



The Charles River at South Natick, Massachusetts.

Human activity has profoundly altered the Charles River and its watershed over the past 375 years. Restoration of environmental quality in the watershed has become a high priority for private- and public-sector organizations across the region. The U.S. Environmental Protection Agency and the Massachusetts Executive Office of Environmental Affairs worked together to coordinate the efforts of the various organizations. One result of this initiative has been a series of scientific studies that provide critical information concerning some of the major hydrologic and ecological concerns in the watershed. These studies have focused upon:

- ***Streamflows—***Limited aquifer storage, growing water demands, and the spread of impervious surfaces are some of the factors exacerbating low summer streamflows in headwater areas of the watershed. Coordinated management of withdrawals, wastewater returns, and stormwater runoff could substantially increase low streamflows in the summer. Innovative approaches to flood control, including preservation of upstream wetland storage capacity and construction of a specially designed dam at the river mouth, have greatly reduced flooding in the lower part of the watershed in recent decades.

- ***Water quality—***Since the mid-1990s, the bacterial quality of the Charles River has improved markedly, because discharges from combined sewer overflows and the number of illicit sewer connections to municipal storm drains have been reduced. Improved management of stormwater runoff will likely be required, however, for full attainment of State and Federal water-quality standards. Phosphorus inputs from a variety of sources remain an important water-quality problem.

- ***Fish communities and habitat quality—***The Charles River watershed supports a varied fish community of about 20 resident and migratory species. Habitat conditions for fish and other aquatic species have improved in many parts of the river system in recent years. However, serious challenges remain, including the control of nutrients, algae, and invasive plants, mitigation of dam impacts, addressing remaining sources of bacteria to the river, and remediation of contaminated bottom habitat and the nontidal salt wedge in the lower river.

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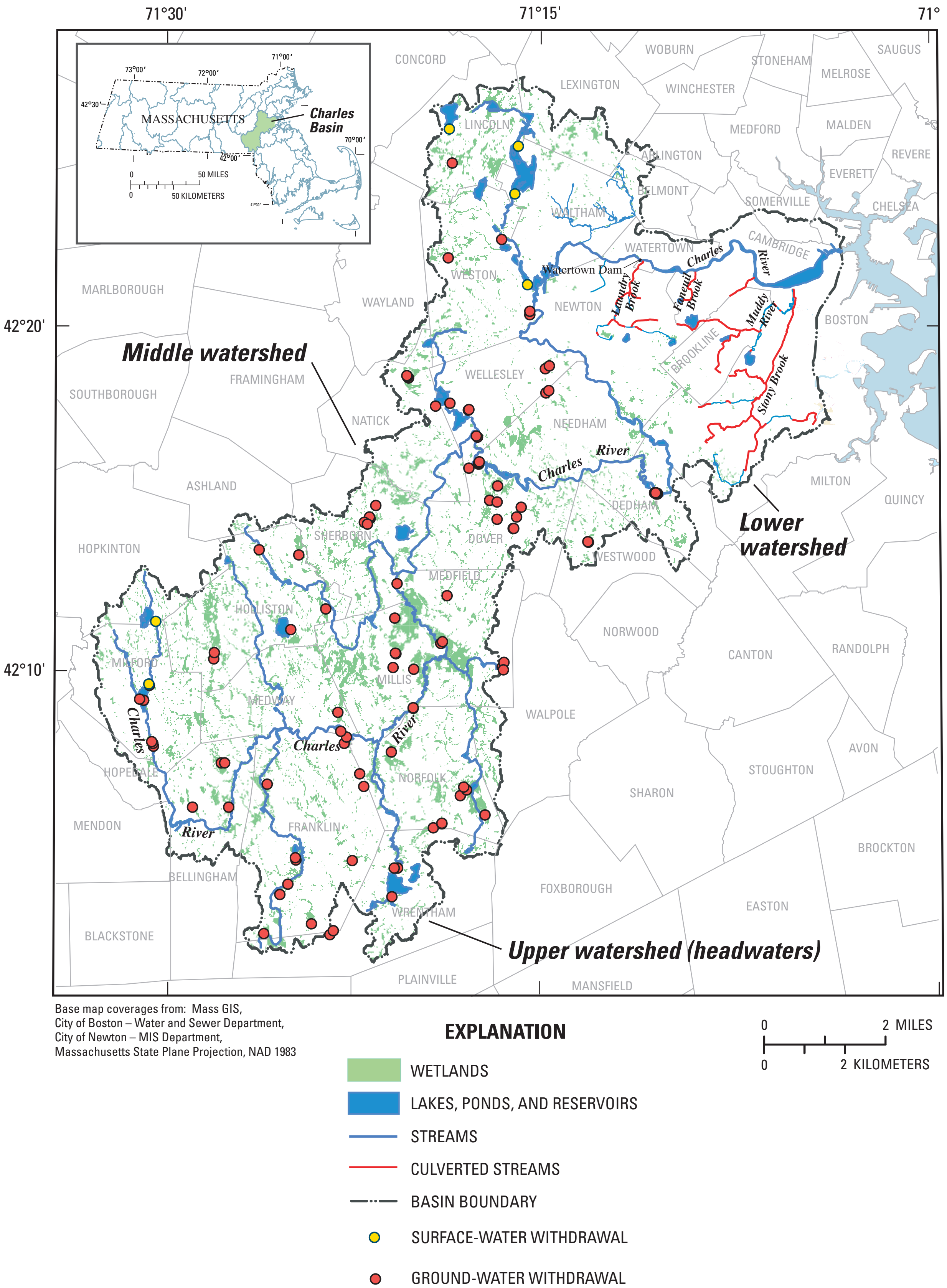


Figure 1. The Charles River watershed, eastern Massachusetts.

Introduction

The Charles River flows for 83 miles from its source in Hopkinton, Massachusetts to its mouth at Boston Harbor (fig. 1). The longest stream entirely within the Commonwealth of Massachusetts, the Charles River drains a watershed of 308 square miles populated by about 1 million people in the heart of the Boston metropolitan region. About 20,000 people a day use the lower river for recreation in the warm season, and the Charles River is known internationally for its fall rowing regatta and spring canoe-and-kayak race. In addition to recreation, the streams, aquifers, lakes, and wetlands of the watershed provide many other human and ecological benefits, including aquatic habitat, water supply, and wastewater assimilation.

In the upper and middle portions of the watershed, changes in land- and water-use patterns have begun to affect streamflow and aquatic habitat (DeSimone and others, 2002; Parker and others, 2004). The lower watershed, by contrast, has a long history of water-quality and aquatic-habitat impairment linked to over 375 years of modern human settlement in Boston and adjacent urban communities (Seasholes, 2003; Weiskel and others, 2005). In response to both the recent and historic environmental challenges facing the residents of the watershed, efforts have been initiated in recent years by citizens' groups, the private sector, and government agencies to restore the environmental quality of the Charles River and its tributaries.

In conjunction with these efforts, scientific studies have been conducted in recent years to better define the streamflow, water-quality, fish communities, and habitats in the river system, and the potential benefits of restoration alternatives. This report summarizes the principal findings of these studies, and the major scientific questions that remain to be answered. The studies described here were conducted by several organizations and agencies, including the Charles River Watershed Association (CRWA), the U.S. Environmental Protection Agency (USEPA), the Massachusetts Executive Office of Environmental Affairs (EOEA), the Massachusetts Department of Environmental Protection (MDEP), the Massachusetts Water Resources Authority (MWRA), the Massachusetts Department of Fish & Game (MDFG), and the U.S. Geological Survey (USGS).

Streamflow

Low flows in the upper watershed. Streamflow in the watershed is affected by human land- and water-use patterns, and the effects differ in different portions of the watershed. The upper watershed, which includes a major portion of the Interstate 495 corridor, underwent rapid development during the 1990s, with population increases of over 30 percent in some towns. Annual water withdrawals grew by similar amounts (DeSimone and others, 2002). Most of these withdrawals are taken from production wells screened in thin valley aquifers closely connected to the streams, ponds, and wetlands of the watershed (fig. 2). Ground-water discharge from these aquifers, plus wastewater return flow, provides sustained flow or baseflow for the mainstem Charles River and its tributaries during the summer months.

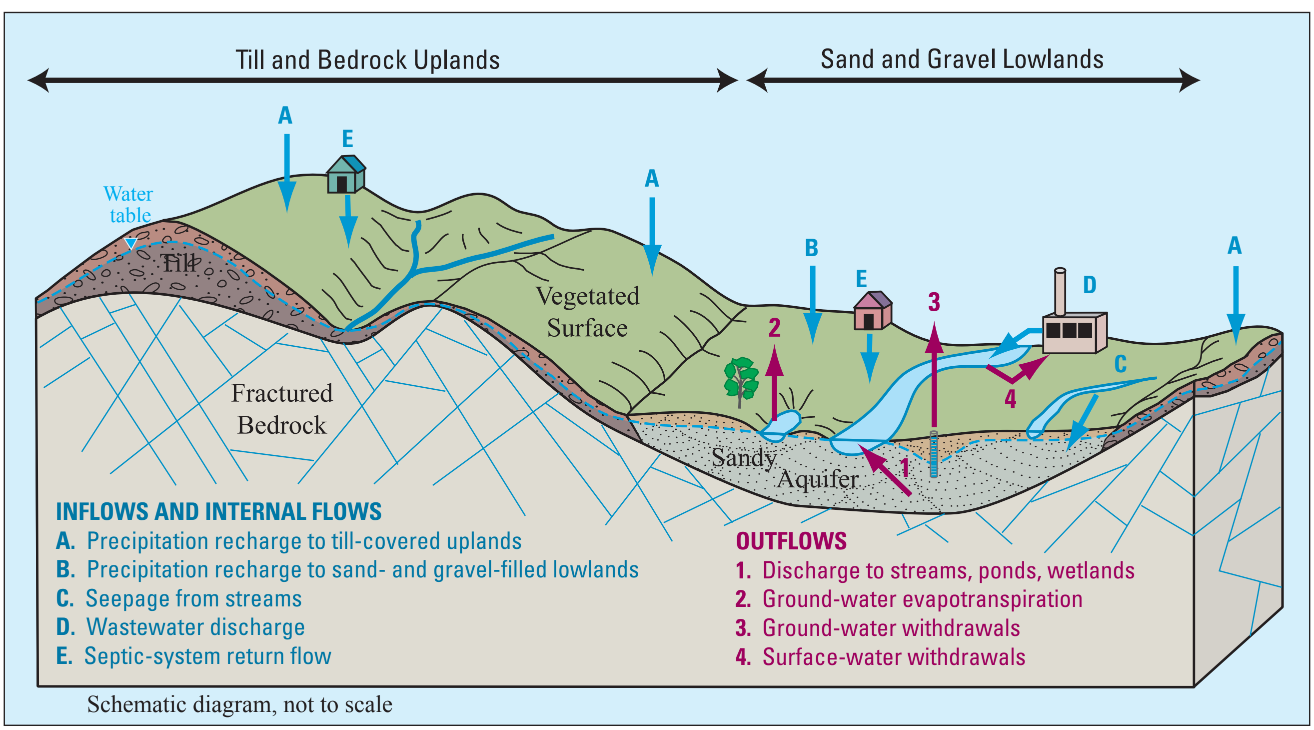


Figure 2. The water cycle of the upper Charles River watershed (modified from DeSimone and others, 2002 and Randall and others, 1988).

In the upper watershed, more water is withdrawn in the summer than during any other season (fig. 3), in part, to supply water for lawn irrigation and other outdoor uses. From 1989 to 1998, summer withdrawals in the upper watershed increased by about 35 percent (DeSimone and others, 2002).

This increase in summer withdrawals is having a disproportionate effect on streamflows, because (1) streamflows are naturally at their lowest in the summer, and (2) the portion of withdrawn water that is lost to the watershed (consumptive use) is highest in the summer because outdoor uses are more subject to evapotranspiration losses.

Recent modeling studies by the USGS in the upper watershed have shown that certain water management strategies could substantially increase summer low flows (DeSimone and others, 2002; Eggleston, 2004). Such management actions include returning treated municipal wastewater flows and stormwater runoff to watershed aquifers, minimizing summer withdrawals from production wells near streams, regional sharing of water supplies, reducing ground-water infiltration to sewer networks, and improved water-conservation practices. Increased operational flexibility and regional sharing of water supplies, in particular, have the potential to increase summer streamflows in the mainstem Charles River substantially while preserving additional supply capacity for future increases in demand (Eggleston, 2004). Such approaches take advantage of the fact that wells distant from streams generally have less short-term impact on streamflow than wells near streams.

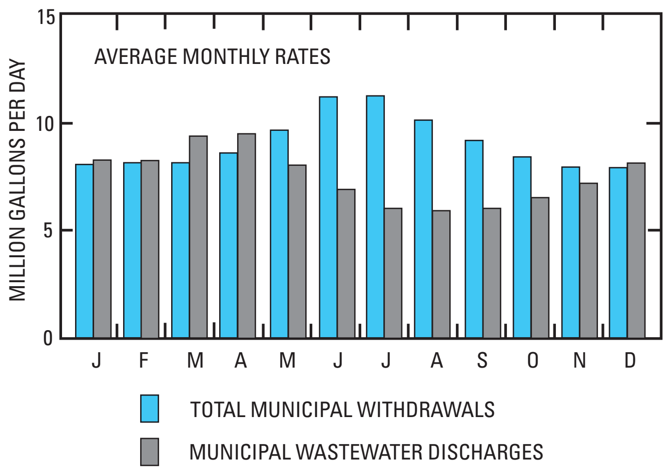


Figure 3. Average monthly municipal withdrawals and wastewater discharges in the upper Charles River watershed, eastern Massachusetts, 1989-98 (modified from DeSimone and others, 2002).

Flooding in the lower watershed. In contrast to the rapidly developing upper watershed, the lower watershed downstream of the Watertown Dam has long been heavily urbanized. From about 1870 to 1950, the percentage of impervious area in the lower watershed increased greatly, and extensive storm-drain networks were constructed to convey runoff from streets, roofs, and other impervious areas to the lower Charles River and its tributaries (Weiskel and others, 2005). At the same time, the flood-storage capacity of the lower watershed was reduced, as wetlands and ponds were filled and natural stream networks were culverted (figs. 1, 4A). As a result, flooding adjacent to the lower reaches of Stony Brook and Muddy River became more common. An example of this type of urban flooding is shown in figure 4B. Although Boston park designer Frederick Law Olmsted made allowance for the storage of Muddy River and Stony Brook flood waters in his 1879 design for the Back Bay Fens (Seasholes, 2003), he apparently did not anticipate the tremendous growth in impervious watershed area—and the loss of available channel storage—in these tributary watersheds during the next century. In October 1996, a 5.5-inch rainstorm severely flooded the Muddy River and lower Stony Brook corridor, causing over $70 million in damage and disabling a portion of the regional transit system for several weeks. In response, the City of Boston and the Town of Brookline have recently developed a flood-mitigation strategy to remove undersized culverts and accumulated bottom sediment in this corridor (City of Boston/Town of Brookline, 2003).

The other major flood hazard in the lower watershed is associated with the Charles River itself. In August 1955, Hurricane Diane dropped over 12 inches of rain on the lower watershed and flooded about 1,700 acres in Boston, Cambridge, and Watertown (U.S. Army Corps of Engineers, 1968). An innovative, twofold approach to this flood hazard was designed jointly by CRWA, the U.S. Army Corps of Engineers, and the Commonwealth of Massachusetts in the 1960s. First, 8,500 acres of nearstream or riparian wetland area in the middle and upper watershed were acquired and protected as natural valley storage for flood waters (Spirn, 1984). Second, a new dam was planned for the mouth of the Charles River. Large-capacity pumps in the dam were designed to maintain a constant water level in the freshwater basin behind the dam, even under extreme flood and tide conditions. This combination of structural and nonstructural approaches proved highly effective in preventing flood damage by the Charles River during the October 1996 storm, and during other large storms over the past 25 years.

A

B

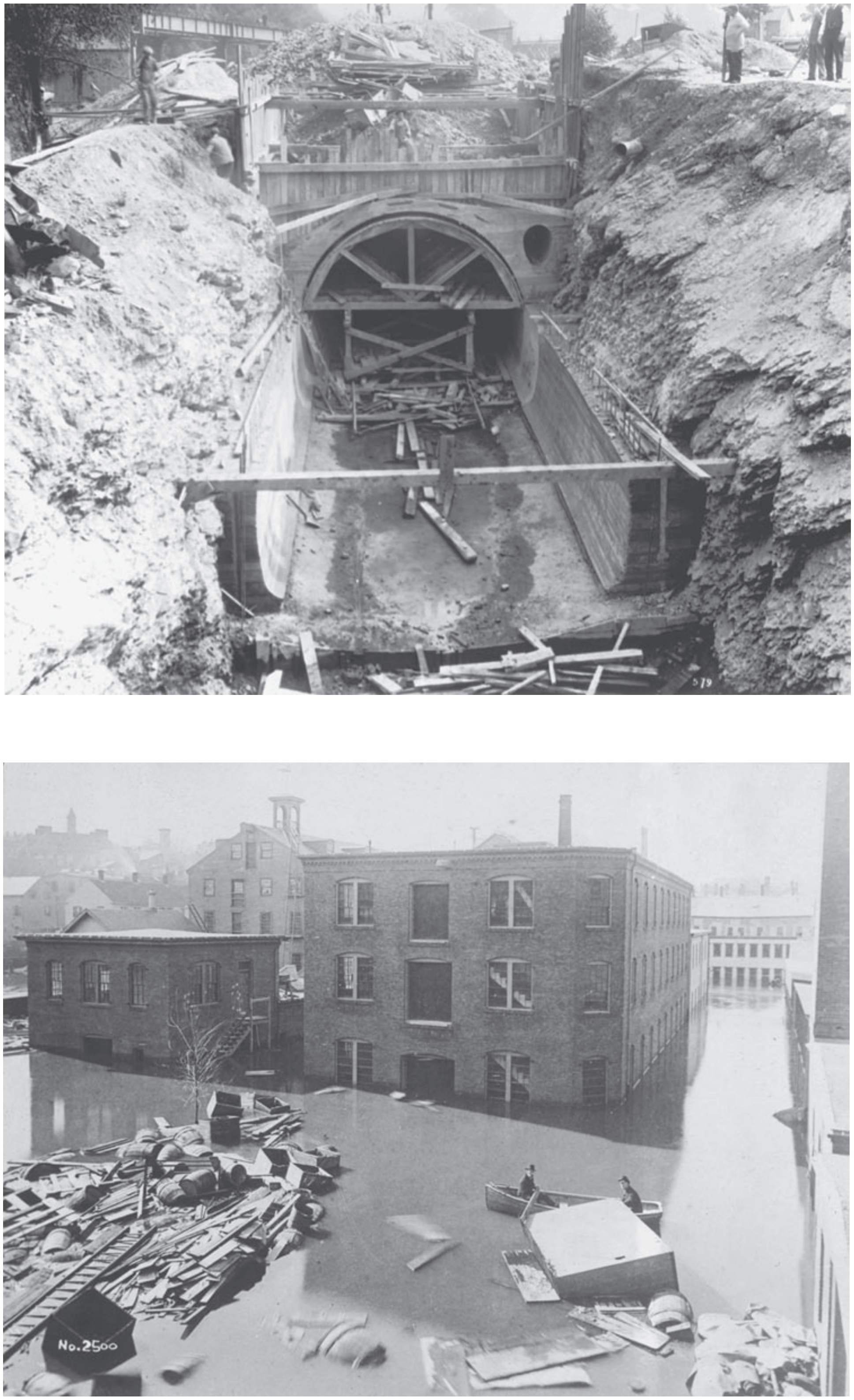


Figure 4. (*A*) The culverting of Stony Brook at Forest Hills, about 1900. (*B*) Urban flooding, lower Stony Brook watershed, Boston, about 1900 (Photographs courtesy of the Boston Water & Sewer Commission).

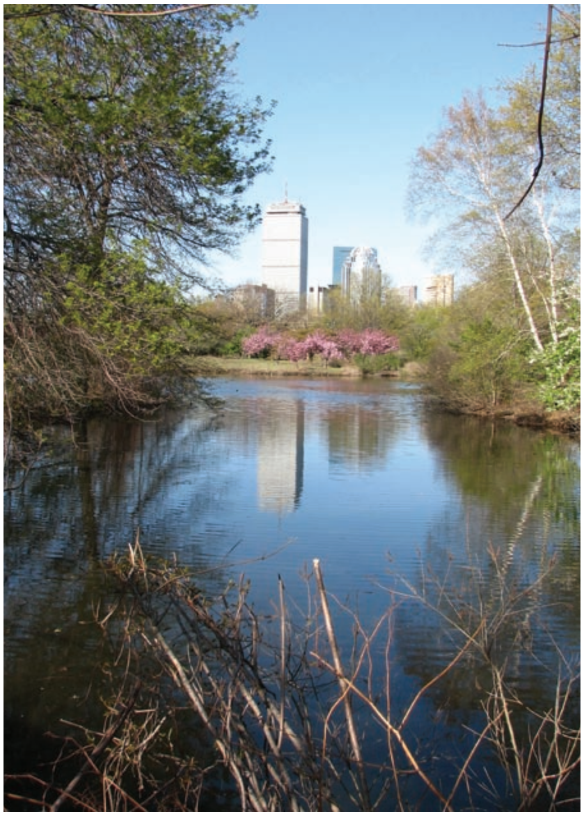
Remaining scientific information needs—low flows and flooding. More research is needed to assess the capacity of structural and nonstructural approaches to increase infiltration of rainfall, increase low flows, and reduce flooding in all parts of the watershed. Such approaches include low-impact development (LID) practices that preserve natural areas, use pervious paving materials, and recharge stormwater runoff through rain gardens and other infiltration methods. Because irrigation of residential lawns and golf courses accounts for a large fraction of consumptive water use in the upper watershed, the potential benefits of natural landscaping and high-efficiency irrigation practices must also be carefully evaluated. Finally, the benefits, costs, and feasibility of regional water-supply sharing in the upper watershed need further evaluation.

Water Quality

The water quality of the Charles River has been a matter of public concern for at least the last 125 years. In 1878, the Boston Board of Health gave a vivid description of the sewage-contaminated tidal flats where the Stony Brook and the Muddy River join the Charles:

> *Large areas have been at once, and frequently, enveloped in an atmosphere of stench so strong as to arouse the sleeping, terrify the weak, and nauseate and exasperate nearly everybody… (City of Boston, 1878).*

Construction of a dam at the mouth of the river converted the estuary into a freshwater basin and improved conditions substantially (Haglund, 2003). However, the lower Charles still experienced Combined Sewer Overflows (CSOs), or discharges of sewage combined with stormwater. They occur when stormwater and wastewater are conveyed through the same pipe and the pipe capacity is exceeded. By the 1960s, CSOs discharges had become quite frequent because of large increases in sewage flows over the course of the 20th century.



Muddy River, Back Bay Fens, Boston, Massachusetts.

Laundry Brook, Newton Center, Massachusetts

The resulting public concern led, in part, to the founding of the CRWA in 1965. Since the mid 1990s, sewer-system upgrades by local communities and the MWRA have greatly reduced CSO discharges to the lower river and thus have enhanced recreational values. In addition, many illicit sewage connections to the storm-drain networks of the lower watershed have been eliminated by the river communities. These efforts, coordinated by the USEPA and EOEA agencies, have measurably improved water quality over the past decade (fig. 5). Nevertheless, regular monitoring by the CRWA, USEPA, and MWRA has shown that all reaches of the river continue to be affected by bacteria concentrations in excess of State swimming and boating standards, especially after major rain storms.

To help answer some of the remaining water-quality questions on the lower river, USGS recently quantified the relative amounts or loads of contaminants entering the river from upstream and from tributary streams and storm drains downstream of the Watertown Dam (Breault and others, 2002; Zarriello and Barlow, 2002). On an annual basis, bacterial loads to the lower river were found to be dominated by wet-weather inputs from Stony Brook and Muddy River, with substantial additional bacterial inputs from areas of the watershed upstream of the Watertown Dam (fig. 6A). Improvements of sewage infrastructure now underway in the Stony Brook and Muddy River sub-watersheds, improved stormwater management in the middle- and lower watershed communities, and treatment of the remaining large CSO discharges to the lower river are expected to further reduce wet-weather bacterial loads (Massachusetts Water Resources Authority, 2004; Zarriello and others, 2003).

Phosphorus loading to the Charles River is also a

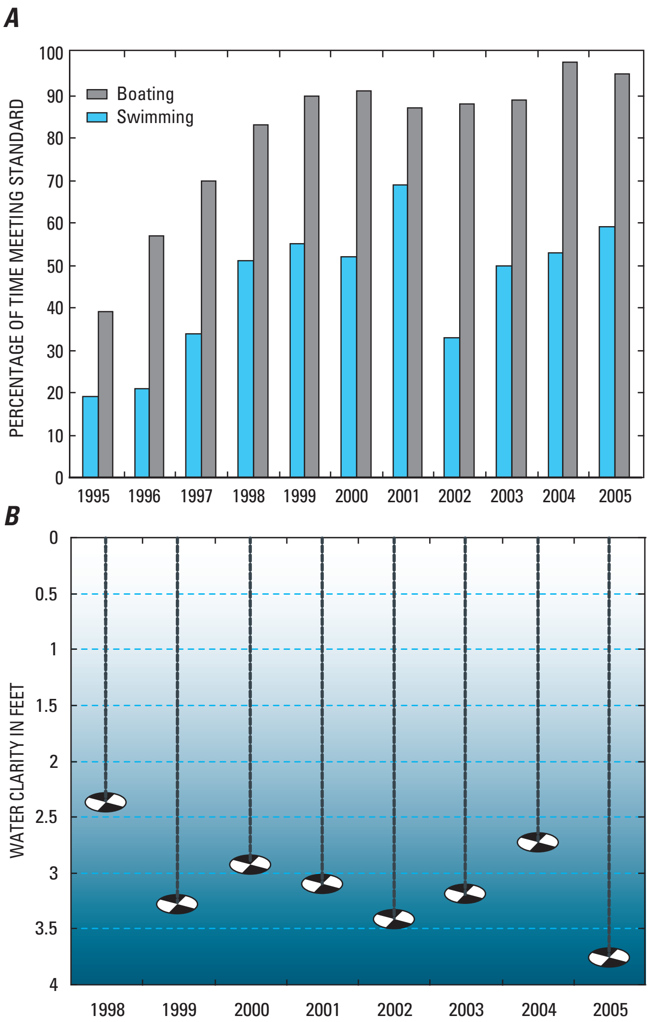


Figure 5. (*A*) Percentage of time that the lower Charles River meets Massachusetts swimming and boating standards for bacteria, 1995-2005 (Charles River Watershed Association, 2004b). (*B*) Average summer clarity of water in the lower Charles River at Boston University Bridge, as measured by the maximum depth at which a black-and-white patterned disk (Secchi disk) remains visible (U.S. Environmental Protection Agency, 2003).

major concern because it stimulates excessive growth of phytoplankton and other types of algae (eutrophication). Phosphorus loads to the lower river are dominated by dry-weather inputs from upstream, although wet-weather inputs are also substantial (fig. 6B). The upstream dry-weather loads likely originate from municipal wastewater treatment plants in the middle and upper watershed (Charles River Watershed Association, 2004a), and non-point sources such as residential lawn fertilizer. In addition, internal loading of phosphorus from the sediments and stagnant bottom waters of the lower river is thought to be large and is just beginning to be quantified (Breault and others, 2000b).

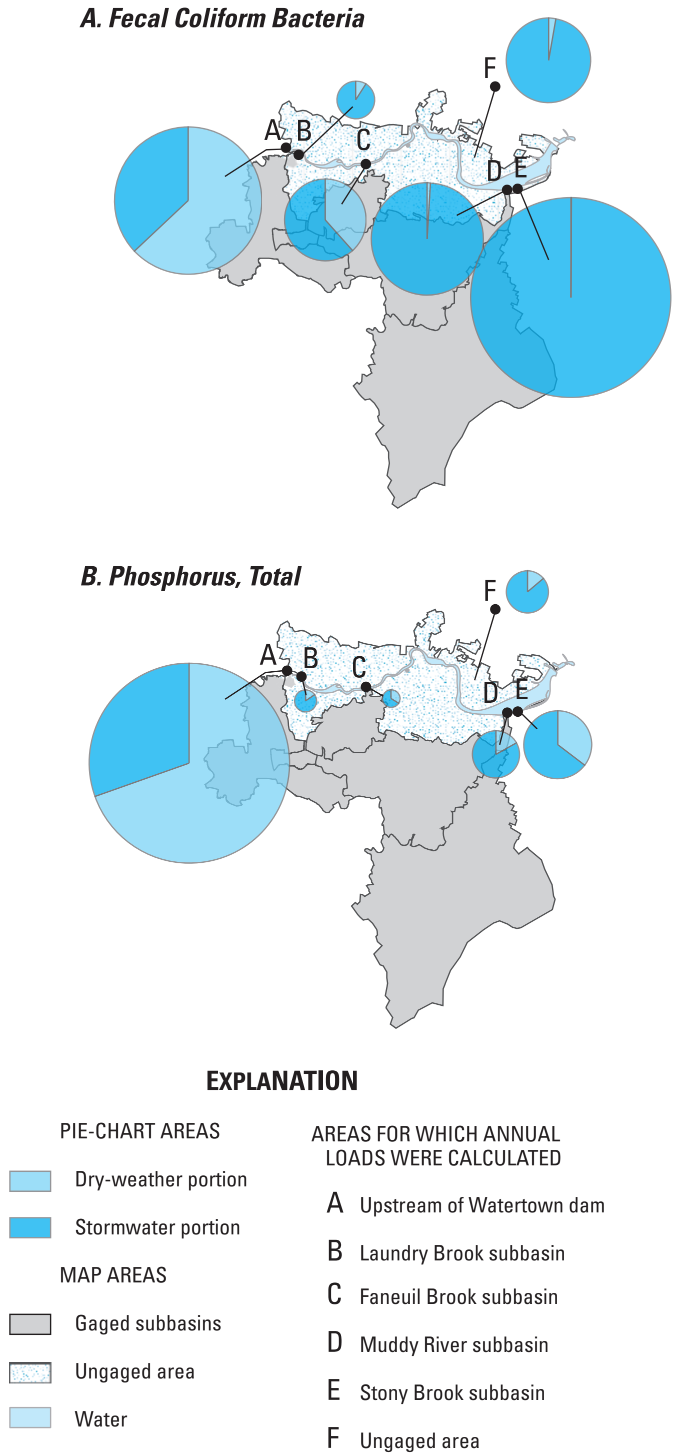


Figure 6. Relative size of the (*A*) fecal coliform bacteria, and (*B*) phosphorus loads to the lower Charles River from upstream sources and from tributary subbasins downstream of Watertown Dam. The total bacterial load from the largest source, Stony Brook, was 4,200 trillion colony forming units per year during the 2000 study period. The total phosphorus load from the largest source, upstream inputs, was 9,900 kilograms per year (Breault and others, 2002).

Other contaminants affecting water quality in the Charles River include trace metals and organic compounds. Dissolved trace-metal concentrations in the water column are generally below both Acute and Chronic Ambient Water Quality Criteria for aquatic life (U.S. Environmental Protection Agency, 2003). Through reconnaissance sampling in the lower watershed, the USGS found detectable concentrations of many trace-organic contaminants, including wastewater-derived human pharmaceuticals and personal-care products. Such compounds are common in urban streams affected by treated or untreated sewage effluent (Barnes and others, 2002; Kolpin and others, 2002).

Remaining scientific information needs—water quality. More refined techniques of bacterial source tracking are needed so that the remaining sources of bacteria to the river, including sewage, wildlife, and domestic pets, can be better differentiated, quantified, and mitigated. In order to reduce eutrophication in the river, the CRWA and USEPA are presently quantifying the maximum amount or Total Maximum Daily Load (TMDL) of phosphorus that can be absorbed by the river without violating water quality standards in the upper and lower portions of the river, respectively (Charles River Watershed Association, 2004a). Finally, the effects of the highly contaminated bottom sediments of the river (see next section) upon the quality and ecological health of the overlying water column need further investigation.

Fish Communities and Habitat Quality

The Charles River supports a rich aquatic community, including about 20 species of resident and migratory fish (Charles River Watershed Association, 2003). Because the main-stem river is a low-slope stream with many dams and impounded reaches, most of the resident fish are considered macrohabitat generalists (Armstrong and others, 2004) adapted to both ponded and flowing-water conditions (fig. 7). Recent sampling by MDFG and CRWA at several sites from Medway to Newton indicates that macrohabitat generalists such as bluegill, redfin pickerel, American eel, and largemouth bass dominate the fish community (Charles River Watershed Association, 2003). Important migratory species in the Charles River include alewife and blueback herring; historically, eel and smelt populations were also important. The Charles River main stem has 20 dams along its length; the 7 most downstream dams have fish ladders or have been breached to promote fish migration, although the actual success of fish passage varies at these structures.

The quality of aquatic habitat in the upper and middle watershed was recently found by CRWA to be suboptimal to marginal with respect to physical and hydrologic characteristics (Charles River Watershed Association, 2003). Habitat quality is governed by many factors, including summer streamflows, water quality, dams, invasive species, and bottom-sediment quality. Low summer streamflows restrict available cover and fish habitat, raise water temperatures,

Impounded freshwater basin, lower Charles River, Boston and Cambridge, Massachusetts.

and reduce both dissolved oxygen (DO) concentrations and the capacity of the river to assimilate wastewater-effluent discharges (Parker and others, 2004; Charles River Watershed Association, 2003). Extreme low flows are most common in the tributaries and headwater reaches of the main-stem river (DeSimone and others, 2002). Water-quality impairments from wastewater-treatment-plant discharges, stormwater runoff, and other sources tend to affect the more sensitive fluvial-specialist species more than the more tolerant, generalist fish species. Such impairments may contribute to the low numbers of fluvial-specialist fish in the river. In the lower river, water quality is further impaired by a bottom layer of salt water (a salt wedge) which is associated, especially during the summer, with boat-lock operations at the New Charles River Dam at Boston Harbor (Breault and others, 2000a). The salt wedge, which extends as far as 4 miles upstream during summer low-flow periods, depresses DO and elevates dissolved sulfide concentrations in the bottom water; these chemical conditions degrade the habitat for bottom-dwelling (or benthic) biota, including fish.

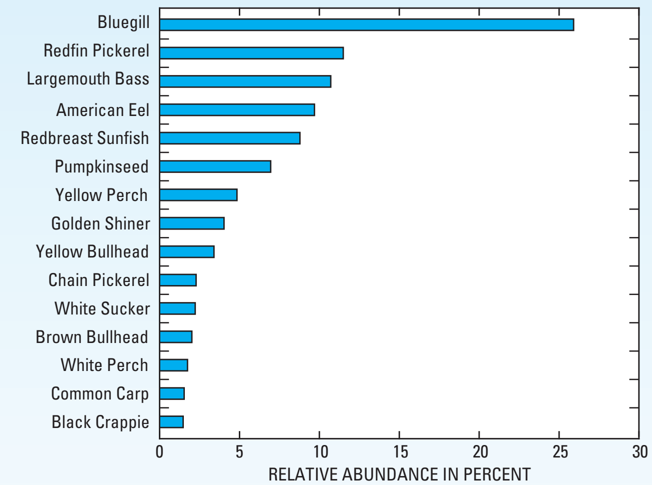


Figure 7. The 15 most common fish species in the mainstem Charles River and tributaries, on the basis of a sample of 3,320 fish collected in the summer of 2002 by CRWA and MDFG (written commun., 2005, Charles River Watershed Association and Massachusetts Department of Fish & Game).

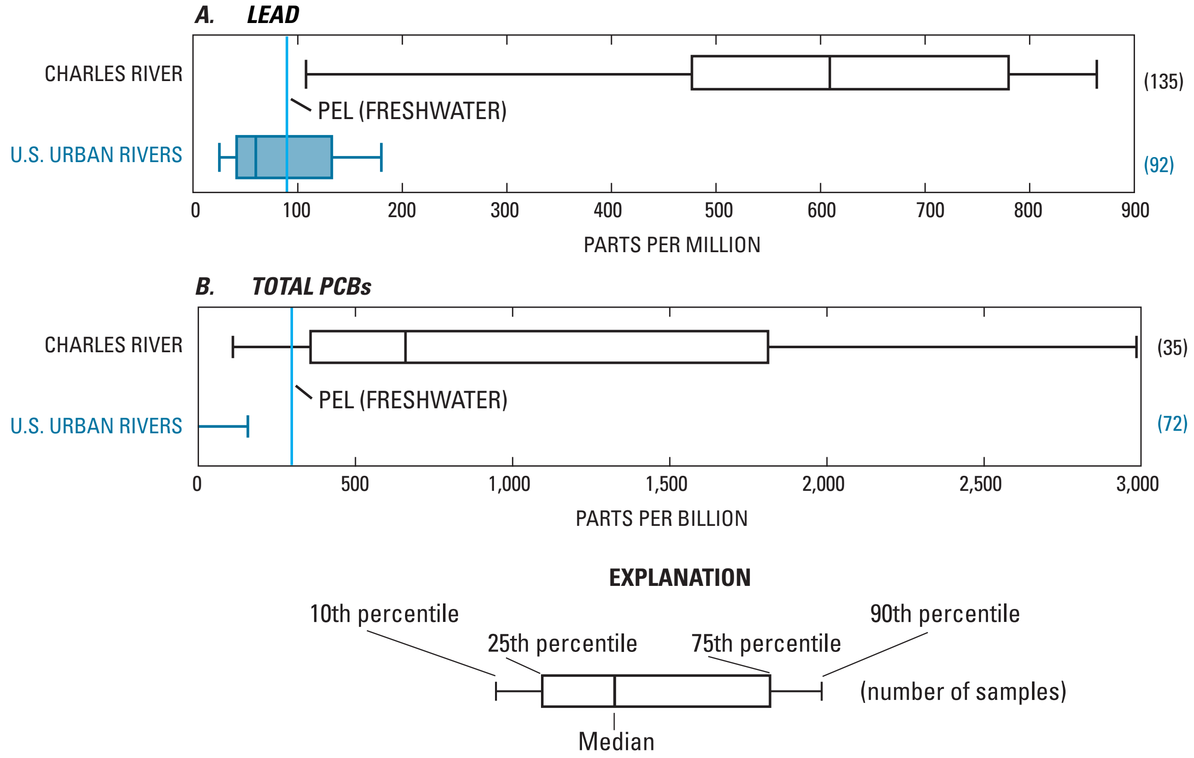


Figure 8. (*A*) Lead and (*B*) total PCB concentrations in bottom sediments of the lower Charles River, in comparison to other U.S. urban rivers. Probable Effects Levels (PELs) for each contaminant are also shown. At least 75% of the U.S. urban river samples used for comparison purposes had total PCB concentrations below detection. Data from Breault and others (2000b).

Although dams on the Charles River have reduced migratory fish populations from their historic numbers, dam-breaching and fish-ladder installations on the most downstream dams have likely increased migratory fish numbers in recent decades. Invasive plant species, such as water chestnut, affect habitat and recreational quality by displacing native species, shading the water column, and impeding navigation. Water chestnut is particularly widespread in the impounded Lakes District section of the river in Newton and Waltham, and in Watertown near a yacht club and boathouse. Finally, the benthic habitat of the lower river is contaminated by a suite of inorganic and organic constituents which have accumulated since the 1908 construction of the Old Dam, located about 0.5 miles upstream of the New Dam at Boston Harbor (Breault and others, 2000b). Median concentrations of bottom-sediment lead and total polychlorinated biphenyls (PCBs) substantially exceed median concentrations found in a recent national USGS survey of urban river sediment (fig. 8), and also exceed Probable Effects Levels (PELs) for adverse effects on benthic organisms.

The effects of bottom-sediment and water-column contamination are evident in a recent USEPA survey of fish contaminants in the lower Charles River (U.S. Environmental Protection Agency, 2001). More than 100 fish were sampled for trace metals, PCBs, organochlorine pesticides, and dioxins. Although contaminants were commonly detected in the fish, contaminant concentrations in the target species (largemouth bass, yellow perch, and carp) were generally below the Human Consumption Action Levels of the U.S. Food and Drug Administration (FDA). PCB concentrations in carp, however, were found to exceed the FDA Action Level of 2 parts per million at two sampling sites. This finding is consistent with the high PCB concentrations in lower-river bottom sediments, the bottom-feeding habits of carp, and the tendency of PCBs to accumulate in the fatty tissue of carp and other high-lipid fish species. In addition, USEPA investigators found internal abnormalities in some of the carp, and noted that fish health may be compromised at tissue PCB levels considerably below the FDA Action Level for human consumption (U.S. Environmental Protection Agency, 2001).

Remaining scientific information needs—fish communities and habitat quality. In order to guide ecosystem restoration efforts in the Charles River, several scientific questions need to be addressed. These include the assessment of (1) the target communities of both resident and migratory fish that are sought for the river; (2) the ecological and human-health risks of wastewater-derived, trace-organic contaminants; (3) the relative benefits of dam removal compared to fish ladder construction to extend fish passage farther upstream and improve passage at the lower dams; (4) the vertical extent of bottom-sediment contaminants in the lower river, their uptake by benthic organisms, and their potential for transfer to the water column and uptake by aquatic organisms; (5) the potential benefits of bottom-sediment removal or capping; (6) the role played by native and invasive macrophytes (large plants) in the phosphorus cycle of the river; and (7) alternatives for reducing or eliminating salt-water intrusion through the New Dam and improving fish passage through this dam.

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Unnumbered Photo (Charles002): Laundry Brook, Newton Center, Massachusetts

Charles River, Wellesley, Massachusetts

Photographs by P. Weiskel

For more information about the Charles River, consult the following Web sites:

Charles River Watershed Association: http://charlesriver.org

Charles River Conservancy: http://www.charlesriverconservancy.org/

Massachusetts Department of Conservation and Recreation: http://www.mass.gov/dcr/parks/metroboston/charlesR.htm

U.S. Geological Survey: http://ma.water.usgs.gov

U.S. Environmental Protection Agency: http://www.epa.gov/NE/charles/index.html

For more information about USGS programs in Massachusetts, contact:

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