Prepared in cooperation with the
Massachusetts Department of Fish and Game, Division of Ecological Restoration

Estimated Sediment Thickness, Quality, and Toxicity to Benthic Organisms in Selected Impoundments in Massachusetts

Scientific Investigations Report 2012–5191

U.S. Department of the Interior
U.S. Geological Survey

Cover. Upper Left—The Ballardville impoundment on the Shawsheen River, Andover, Massachusetts.
Lower Right—Rice City impoundment on the Blackstone River, Uxbridge, Massachusetts. Photographs by Robert F. Breault.

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KEN SALAZAR, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:
Breault, R.F., Sorenson, J.R., and Weiskel, P.K., 2013, Estimated sediment thickness, quality, and toxicity to benthic organisms in selected impoundments in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2012–5191, 42 p., at http://pubs.usgs.gov/sir/2012/5191/.

Acknowledgments

The authors wish to express their gratitude to the Massachusetts Department of Fish and Game, Division of Ecological Restoration (DFG/DER) for their support of this study. We would particularly like to thank Tim Purinton, Eileen Goldberg, Beth Lambert, Alex Hackman, and Chris Leuchtenburg for their assistance throughout. The cooperation of public and private landowners who granted permission to access the impoundments also is appreciated.

The authors thank Leslie DeSimone and Jonathan Morrison of the U.S. Geological Survey (USGS), and Alex Hackman of the DFG/DER for their technical reviews of the report and Andrew Massey and Dave Armstrong of the USGS for their field and modeling assistance. The authors also thank Lance Ostiguy and Pete Steeves of the USGS for their geographic information systems assistance, Anna Glover of the USGS for editorial review, and Susan Bergin, Ann Marie Squillacci, and others in the USGS Pembroke Publishing Service Center for their work on the figures, tables, and layout of the report.

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Conversion Factors, Datum, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentrations of chemical constituents (inorganic elements and organic compounds) in bottom sediment are given in parts per million (ppm) and parts per billion (ppb).

Abbreviations

AVS	acid-volatile sulfides
CIT	commercial, industrial, and transportation
DDE	dichlorodiphenyl-dichloroethylene
DDT	dichlorodiphenyl-trichloroethane
DO	dissolved oxygen
ODS	Office of Dam Safety
HRGC/LRMS	high-resolution gas chromatography/low-resolution mass spectrometry
ICP–MS	inductively coupled mass spectrometry
MDFG	Massachusetts Department of Fish and Game
MDER	Massachusetts Division of Ecological Restoration
NID	U.S. Army Corps of Engineers National Inventory of Dams
NIST	National Institute of Standards and Technology
NWQL	National Water Quality Laboratory
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PEC	probable effects concentration
PECQ	probable effects quotient for an individual contaminant in a sample
$PECQ_x$	average probable effects quotient for a sample
QA/QC	quality assurance/quality control
RPD	relative percent difference
SOD	sediment-oxygen demand
TEC	threshold effects concentration
USGS	U.S. Geological Survey

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Estimated Sediment Thickness, Quality, and Toxicity to Benthic Organisms in Selected Impoundments in Massachusetts

By Robert F. Breault, Jason R. Sorenson, and Peter K. Weiskel

Abstract

There are presently more than 3,000 dams in Massachusetts. Many of these dams are no longer used for their original purpose, and some are in disrepair. Contaminants bound to sediment trapped behind dams have the potential to affect the downstream environment in the event of a sudden release or dam failure. These sediments may also be an ongoing source of contaminants to overlying water and to organisms living on or in bottom sediment. In addition, dams do not entirely retain impounded sediment and associated contaminants. Such sediments are subject to scour, resuspension, and downstream redistribution during storm events.

The U.S. Geological Survey and the Massachusetts Department of Fish and Game, Division of Ecological Restoration, collaborated to collect baseline information on the quantity and quality of sediment impounded behind selected dams in Massachusetts, including sediment thickness and the occurrence of contaminants potentially toxic to benthic organisms. The thicknesses of impounded sediments were measured, and cores of sediment were collected from 32 impoundments in 2004 and 2005. Cores were chemically analyzed, and concentrations of 32 inorganic elements and 108 organic compounds were quantified. Sediment thicknesses varied considerably among the 32 impoundments, with an average thickness of 3.7 feet. Estimated volumes also varied greatly, ranging from 100,000 cubic feet to 81 million cubic feet. Concentrations of toxic contaminants as well as the number of contaminants detected above analytical quantification levels (also known as laboratory reporting levels) varied greatly among sampling locations. Based on measured contaminant concentrations and comparison to published screening thresholds, bottom sediments were predicted to be toxic to bottom-dwelling (benthic) organisms in slightly under 30 percent of the impoundments sampled. Statistically significant relations were found between several of the contaminants and individual indicators of urban land use and industrial activity in the upstream drainage areas of the impoundments. However, models developed to estimate contaminant concentrations at unsampled sites from upstream landscape characteristics had low predictive power, consistent with the long and complex land-use history that is typical of many drainage areas in Massachusetts.

Introduction

More than 3,000 dams presently impound the streams of Massachusetts, according to the Division of Ecological Restoration of the Massachusetts Department of Fish and Game (MDER, written commun., 2013). Nearly 1,500 of these dams are also listed in the National Inventory of Dams (U.S. Army Corps of Engineers, 1996). Worcester County, in central Massachusetts, has more dams than any other county in the United States (425; Graf, 1999). Because many Massachusetts dams no longer serve their original purposes, may present safety risks, and have the potential to impair ecological conditions, public interest in removing unused dams has grown substantially in recent years. Dams not only restrict the recreational use of rivers for boaters, they also limit or block the free passage of fish and other biota, slow water velocities, cause sediment and organic matter to settle out, and commonly raise water temperatures. This combination of factors affects water quality, impairs in-stream habitat, alters food web dynamics, and limits access to different habitats for resident and migratory fish (Wang and others, 2010; Armstrong and others, 2011). Dam removal can increase the amount of suitable aquatic habitat in a stream system, both upstream and downstream of the original structure, as well as restore ecological processes (for example, the natural movement of water, sediment, and organic matter) that form and maintain downstream habitat and food web dynamics over time (Poff and Hart, 2002; Gardner and others, 2011).

The purposeful breaching and removal of dams can have unintended effects on the downstream environment if not thoughtfully planned and implemented. One potential negative effect is the release of toxic contaminants by mobilization, transport, and downstream redeposition of impounded sediment. Many contaminants discharged to rivers and streams in the form of industrial wastes, accidental spills, or urban runoff

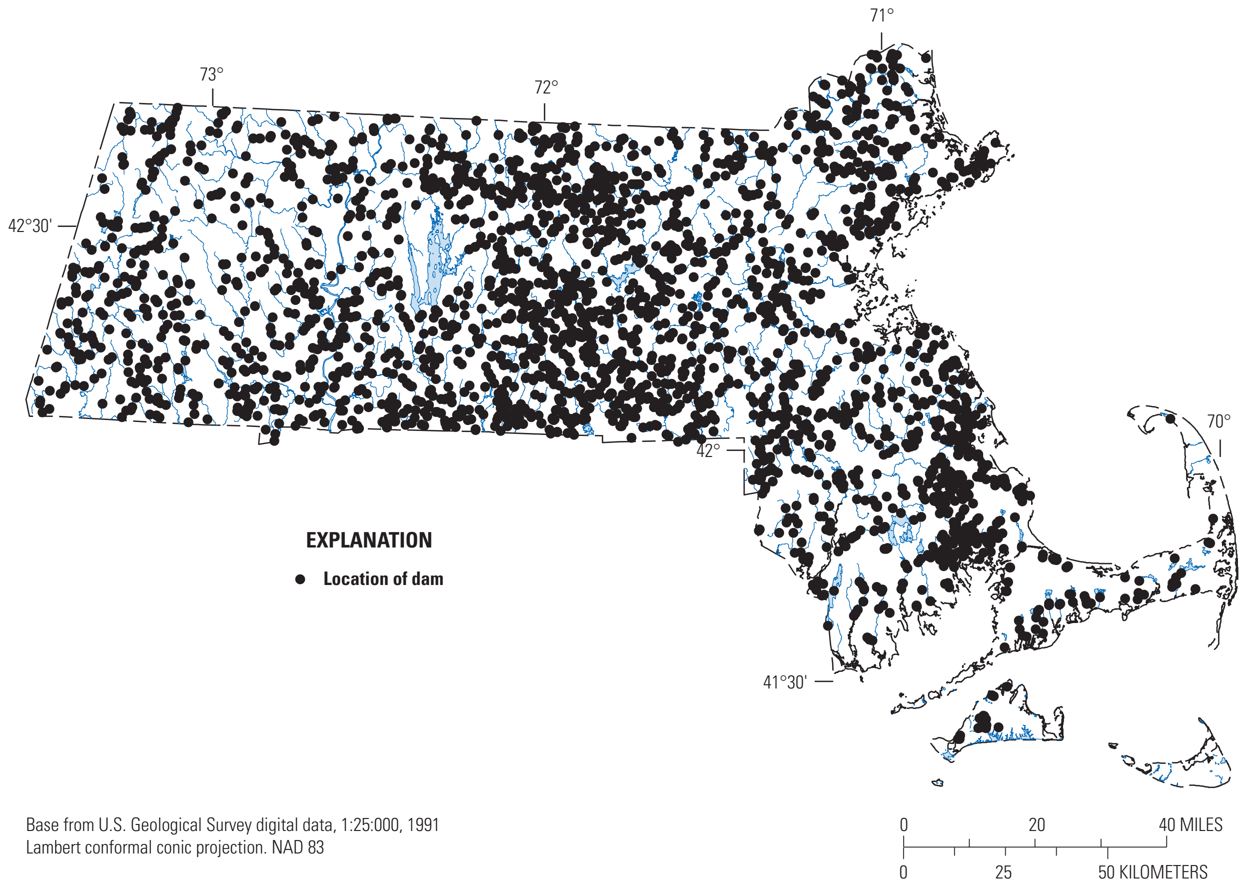


Figure 1. The locations of dams in Massachusetts. Data are from the U.S. Army Corps of Engineers (1996).

commonly adhere to solids suspended in the water column of a stream and ultimately accumulate in slack water environments, such as impoundments behind dams. The accumulation of contaminated sediments behind dams in Massachusetts began principally after 1810, in the early years of the industrial revolution in the Commonwealth (Brown and Tager, 2000, p. 121). Urbanization in the latter part of the 19th century and throughout the 20th century further increased the load of contaminants from urban watershed sources to stream impoundments (see, for example, Breault and others, 2000, 2004, 2005).

Although contaminants trapped in sediment behind dams are often considered buried, it is incorrect to assume that these contaminants are immobile. For example, some contaminants are easily exchanged between bottom sediment and the overlying water column, allowing these contaminants to become biologically available under certain environmental conditions. Moreover, sediment-bound contaminants can be scoured, resuspended, transported downstream and redeposited during storm events, potentially affecting aquatic organisms, including fish, a long distance from the original source. Benthic organisms, which live on or within the bottom sediment, may be directly exposed to hazardous levels of these contaminants and, in turn, indirectly expose fish and other wildlife to the contaminants through food-web magnification. Humans may be exposed through ingestion of affected wildlife or by direct physical contact.

The Massachusetts Office of Dam Safety (ODS) requires regular safety inspections at dams under ODS jurisdiction. However, such inspections do not presently (2012) include estimates of the volume of impounded bottom sediment nor do they include the occurrence of potentially toxic contaminants trapped behind these dams. Hence, this aspect of the overall hazard associated with accidental dam failures or purposeful dam breaches is not fully known. Impounded sediment volumes and chemical data, together with information regarding the structural integrity of each dam, are necessary to inform decisions regarding potential dam removal projects in the Commonwealth. Accordingly, the U.S. Geological

Survey (USGS), in cooperation with the MDER, collected baseline information concerning the thickness and volume of impounded bottom sediment and the occurrence of potentially toxic contaminants trapped behind 32 selected dams in Massachusetts. These data may be used to help prioritize dams that pose the greatest risk to the environment in case of either dam failure or purposeful dam breach, as well as identify sediment that may be acting as a present day source of toxic contaminants to the environment.

Purpose and Scope

This report describes the methods used to measure the thickness, estimate the volume, and collect cores of bottom sediment impounded behind selected dams in Massachusetts. The report also characterizes the chemical quality of the impounded sediment, including sediment-associated inorganic elements and organic compounds. The potential toxicity of the impounded sediment to benthic organisms is assessed by comparing observed concentrations of contaminants to consensus-based sediment quality guidelines. Finally, the report describes and interprets relations among contaminant concentrations in sediment, present day land use, and available indicators of past industrial history in the watersheds of the study impoundments.

Field, Laboratory, and Statistical Methods

The USGS assessed soft-sediment thicknesses and chemistry in 32 impoundments in Massachusetts by probing with a steel rod and collecting and chemically analyzing sediment cores. Chemical analysis of sediment cores (one homogenized sample per impoundment) included 32 inorganic elements and 108 organic compounds; the organic compounds included polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dichlorodiphenyl-trichloroethane (DDT) pesticide compounds. Potential toxicity was estimated using predictive relations between sediment contaminant concentrations and the probable effects on bottom-dwelling (benthic) organisms (Ingersoll and others, 2000; MacDonald and others, 2000). Relations between present day land use and sediment quality were evaluated by means of statistical correlation analysis.

Site Selection and Sampling Techniques

Dams were selected in consultation with the MDER using several criteria, including the likelihood that the dam might be removed, land use in the upstream drainage basin (ranging from undeveloped to drainage basins with long industrial histories), local interest, and geographical location (fig. 2; table 1).

Soft-sediment thicknesses were measured manually with a steel rod at an average of 20 locations in each of the 32 impoundments; the number of measurements made in the study ranged from 8 to 30 per impoundment. The steel rod was pushed into the soft sediment from a boat or, in cases where impoundments were drained or dams breached, by standing on the sediment surface (fig. 3). Changes in the ease of penetration and the sound emitted from the rod as it was slowly pushed through the soft sediment were interpreted as changes in sediment character. In general, the interface between soft sediment and the original stream channel or flood plain material was felt as an abrupt change in the amount of force necessary to advance the probe. On occasion, this change was accompanied by an audible noise, as the tip of the rod encountered gravel or cobbles that were likely part of the historical flood plain or stream channel. The distance the rod was pushed (minus the measured water depth) was measured and recorded as the soft-sediment thickness. Sediment cores were visually inspected and their length was measured, to verify that soft-sediment thicknesses inferred from probing with the steel rod corresponded to changes in the sediment texture observed in cores from each impoundment in question. The average sediment thickness for an impoundment was calculated by summing the recorded depths and dividing by the number of measurements made in the impoundment.

At least one core was collected from each impoundment. The number and locations of cores collected was determined based on the size of each impoundment and the distribution of the estimated bottom-sediment thicknesses within each impoundment. Each core extended from the sediment water interface to the soft sediment bottom (to a maximum depth of about 8 ft). Cores were collected from a small boat, a custom-built pontoon boat and platform, or a solid platform placed directly on the sediment surface (fig. 4). Sediment was collected with a coring device comprising a polyethylene piston, a slide hammer, and a disposable polycarbonate core barrel. The core barrel was pushed by hand or hammered into the sediment. Before driving the core barrel into the sediment, the piston was suspended in the core barrel and secured with a steel cable to either the boat gunwale or the platform to keep the piston from moving as the core barrel was pushed into the sediment. Suction produced by the piston minimizes core compaction as the core barrel is pushed forward and helps to retain sediment in the barrel as it is pulled out of the sediment. Sediment cores were retrieved by hand or with a battery-powered winch.

In most cases, the core barrel was pushed past the soft-sediment bottom into the underlying material; however, in a few cases the soft-sediment thickness was greater than the core barrel length (8 ft). In these cases, the maximum core length was 8 ft. After retrieval, the bottom of each core was checked for evidence suggesting that the barrel was pushed deep enough to collect samples representative of the entire soft-sediment thickness. The end of the core barrel was frequently plugged with either fine gray clay, which was deposited long before the dam was built, or the remains of vegetation that

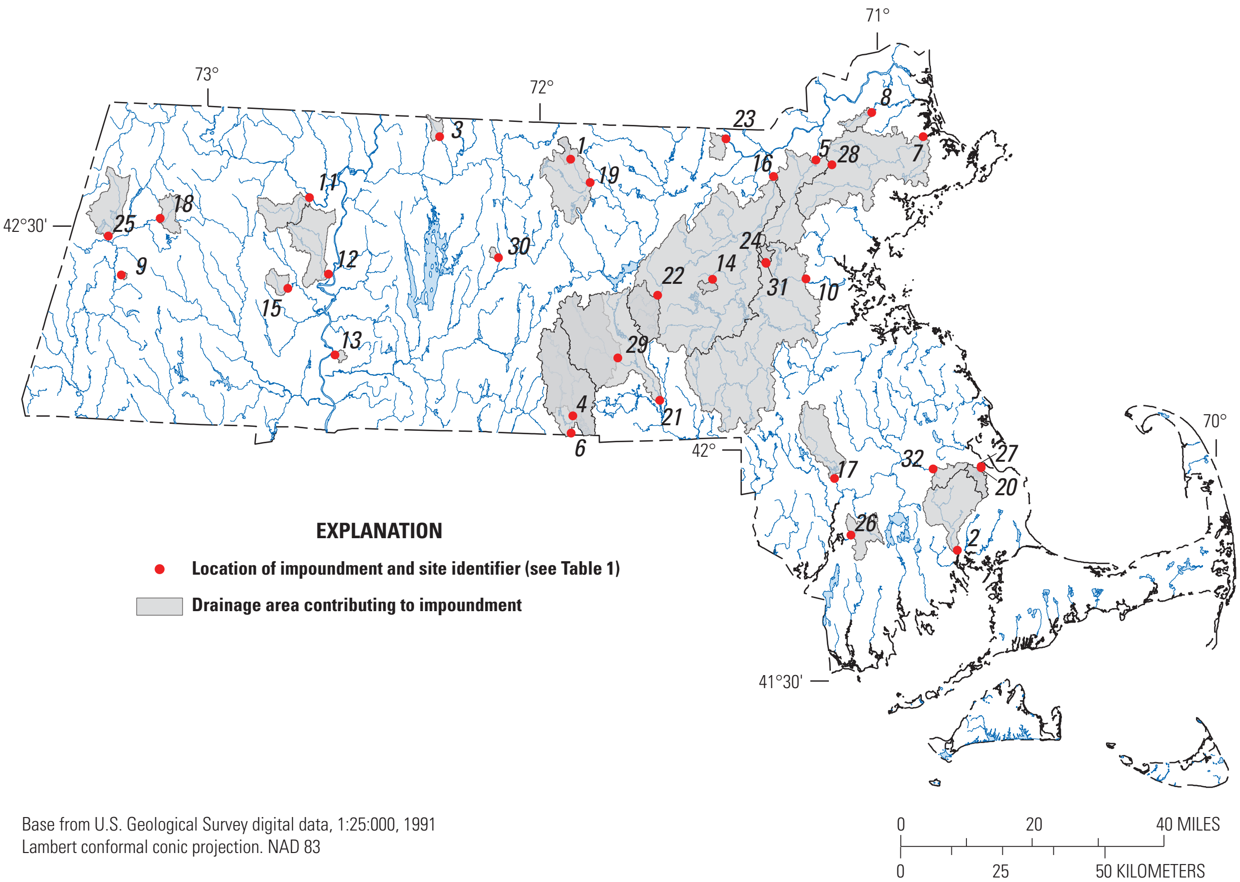


Figure 2. Locations of impoundments in Massachusetts assessed in this study and the drainage areas to the dams that form the impoundments. Sites 24 and 31 are located less than 0.2 mile (mi) apart, and sites 20 and 27 are located less than 0.70 mi apart. Both pairs of sites are shown by a single red symbol. Location data are from the U.S. Army Corps of Engineers (1996).

presumably grew in the flood plain before inundation (fig. 5). If the core barrel appeared not to extend through the entire soft-sediment thickness and the total sediment thickness was less than 8 ft, the sample was discarded, the core barrel rinsed with ambient water, and another core was collected. It is important to note that core samples collected from individual impoundments may or may not represent the entire history of sediment deposition, given the limited number of core samples collected and the fact that only one composite sample was submitted for laboratory analyses. As stated above, the dynamic nature of sediment transport in river systems also means that some historically impounded sediment has likely been resuspended and transported downstream by large storms or dam breach or both. In some cases, sediment may have also been previously dredged and disposed of elsewhere during the history of the impoundment.

In the laboratory, cores from each impoundment were homogenized in a precleaned Teflon bag to produce one composite sample for each impoundment. Prior to filling, the Teflon bags were cleaned first with 5-percent hydrochloric acid, then with methanol, and finally with deionized water. Subsamples were collected and placed in precleaned plastic (inorganic elements) or glass (organic compounds) containers for delivery to appropriate analytical laboratories. Samples were shipped on ice in sealed plastic coolers along with accompanying documentation.

Chemical Analysis of Sediment

Chemical analysis of 32 inorganic elements was done at SGS Laboratory, Lakefield, Ontario, Canada, by means of inductively coupled plasma mass spectrometry (ICP–MS). Chemical analysis of 108 organic compounds was done at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, by means of high-resolution gas chromatography/low-resolution mass spectrometry (HRGC/LRMS).

Table 1. Characteristics of selected dams in Massachusetts and sampling information for 2004 and 2005.

[The State ID comprises [district number]-[county number]-[town number]-[dam number]. Dam latitude and longitude obtained from U.S. Army Corps of Engineers (2006), except for sites 31 and 32, which were determined in the field. Other dam data were obtained from the Massachusetts Office of Dam Safety database. no., number; NATID; national identification number; State ID, State identification number; USGS, U.S. Geological Survey; --, unknown]

Site no.	NATID	State ID	USGS station no.	Latitude/longitude, in decimal degrees		Dam name	Year built[1]	Structural height, in feet	Town name	County	Stream name	Major basin	Sample date
1	MA00006	3-14-11-25	423744071532401	42.628747	-71.889712	Factory Village Pond	1924	20	Ashburnham	Worcester	Phillips Brook	Nashua	06/21/05
2	MA00026	7-12-310-1	414554070445101	41.764962	-70.747216	Horseshoe Pond	1920	16	Wareham	Plymouth	Weweantic River	Buzzards Bay	08/02/05
3	MA00057	2-6-312-7	424037072165001	42.676413	-72.280499	Sheomet Lake	1924	17	Warwick	Franklin	West Branch Tully River	Millers	07/14/05
4	MA00108	3-14-80-4	01125005	42.063413	-71.880131	North Webster Village Pond	1906	20	Dudley	Worcester	French River	French	11/10/05
5	MA00154	5-5-9-8	423736071093001	42.627113	-71.157547	Ballardvale	1838	18	Andover	Essex	Shawsheen River	Shawsheen	07/08/05
6	MA00216	3-14-80-1	420130071530501	42.024780	-71.884312	Perryville Pond	1874	18	Dudley	Worcester	French River	French	05/17/04
7	MA00231	5-5-144-4	424037070501701	42.677648	-70.837756	Ipswich Mills	1900	9	Ipswich	Essex	Ipswich River	Ipswich	09/08/05
8	MA00261	5-5-105-1	424403070594701	42.731749	-70.990537	Pentucket Pond Outlet	1850	8	Georgetown	Essex	Parker River	Parker	07/13/05
9	MA00315	1-2-313-6	422142073132401	42.361564	-73.223409	Felton Lake	1937	15	Washington	Berkshire	Housatonic River	Housatonic	11/08/05
10	MA00456	4-9-314-1	011046115	42.365362	-71.189229	Watertown	1900	8	Watertown	Middlesex	Charles River	Charles	11/11/05
11	MA00463	2-6-68-1	423221072400201	42.538763	-72.667110	Conway Electric	1898	77	Conway	Franklin	South River	Deerfield	09/01/05
12	MA00493	2-8-127-2	422208072362801	42.371453	-72.608327	D.F. Rile Grist Mill	1900	16	Hatfield	Hampshire	Mill River	Connecticut	05/27/04
13	MA00530	2-7-61-1	421135072350601	42.192920	-72.584950	Mountain Lake Dam	1923	36	Chicopee	Hampden	Willimansett Brook	Connecticut	11/01/05
14	MA00742	4-9-288-3	01098730	42.364608	-71.465922	Carding Mill Pond	1930	15	Sudbury	Middlesex	Hop Brook	Sudbury	06/30/05
15	MA00760	2-8-214-15	01171470	42.338019	-72.727849	Robert Meadow Upper Reservoir	1883	35	Northhampton	Hampshire	Roberts Meadow Brook	Connecticut	11/01/05
16	MA00774	4-9-31-1	01098980	42.591832	-71.283919	Talbot Mills	1850	12.5	Billerica	Middlesex	Concord River	Concord	11/03/05
17	MA00813	6-3-293-5	415528071062401	41.924374	-71.106524	Mill River	1832	12	Taunton	Bristol	Mill River	Taunton	11/15/05
18	MA00841	1-2-345-2	422919073063901	42.488376	-73.109927	Windsor Reservoir	1865	51	Windsor	Berkshire	Waconah Falls Brook	Housatonic	11/08/05
19	MA00877	3-14-97-11	423441071495601	42.578111	-71.830495	Mill Pond	1900	14	Fitchburg	Worcester	North Nashua River	Nashua	06/17/04
20	MA00909	7-12-239-8	011058739	41.946569	-70.673699	Mill Pond #1	1900	16	Plymouth	Plymouth	Town Brook	South Coastal	11/15/05
21	MA00935	3-14-304-4	420610071372201	42.098145	-71.623096	Rice City Pond	1880	21	Uxbridge	Worcester	Blackstone River	Blackstone	06/09/04
22	MA00995	3-14-215-4	421944071374801	42.329712	-71.630020	Assabet River	1900	12	Northborough	Worcester	Assabet River	Concord	05/20/04
23	MA01001	4-9-301-5	424030071253401	42.674801	-71.426043	Upper Flints Pond	1900	10	Tyngsborough	Middlesex	Unnamed tributary to Merrimack River	Merrimack	07/07/05
24	MA01572	4-9-157-4	422406071182801	42.401599	-71.307854	Stony Brook	1900	10	Lincoln	Middlesex	Stony Brook	Charles	06/16/04
25	MA01970	1-2-236-11	422651073155001	42.446875	-73.263670	Tel Electric Pond	1920	20	Pittsfield	Berkshire	West Branch Housatonic	Housatonic	05/26/04
26	MA02116	6-3-102-2	01109088	41.798038	-71.063516	Monument Pond #2	1900	--	Freetown	Bristol	Assonet River	Taunton	11/17/05
27	MA02458	7-12-239-7	415656070402701	41.949048	-70.673844	Town Brook #1	1900	11	Plymouth	Plymouth	Town Brook	South Coastal	07/21/05
28	MA02512	5-5-9-17	423704071063701	42.616993	-71.110105	Deleano Pond	1930	14	North Andover	Essex	Unnamed tributary to Skug	Ipswich	05/19/04
29	MA02828	3-14-186-1	421127071445202	42.190776	-71.747510	Worcester Consolidated Station	1900	6	Millbury	Worcester	Blackstone River	Blackstone	06/22/05
30	MA03175	3-14-21-21b	422440072061201	42.411263	-72.102398	Cooks Canyon Lower Pond	1900	15	Barre	Worcester	Galloway Brook	Chicopee	06/10/04
31	--	--	422358071182601	42.399460	-71.307113	Unnamed, Stony Brook	1900	--	Weston	Middlesex	Stony Brook	Charles	06/16/04
32	--	--	415638070485101	41.944083	-70.815004	Unnamed, Winnetuxet River	1900	--	Plympton	Plymouth	Winnetuxet River	Taunton	06/21/04

[1]The year 1900 is typically assigned to dams for which the actual year of construction is unknown (Brian Graber, Massachusetts Riverways Program, oral commun., 2005).

A

B

Figure 3. Measurement of soft-sediment thickness where *A,* dam has been breached and the impoundment has been drained and *B,* impoundment is present at the time of sampling.

Analysis of Inorganic Elements

Before chemical analysis, SGS collected from each sample an unsieved aliquot (about 1 gram). Next, the sample was digested with 2 milliliters (mL) of nitric acid (HNO_3) and heated at 80 to 90 degrees Celsius for ½ hour. After the sample had cooled slightly, the digestates were spiked with 4 mL of hydrochloric acid (HCl) and heated for 2 hours in a water bath. Next, the digestates were allowed to cool to room temperature and diluted with distilled water to a final volume of 20 mL. About 5 mL of this solution was poured into a test tube for ICP–MS analysis (U.S. Environmental Protection Agency, 1996).

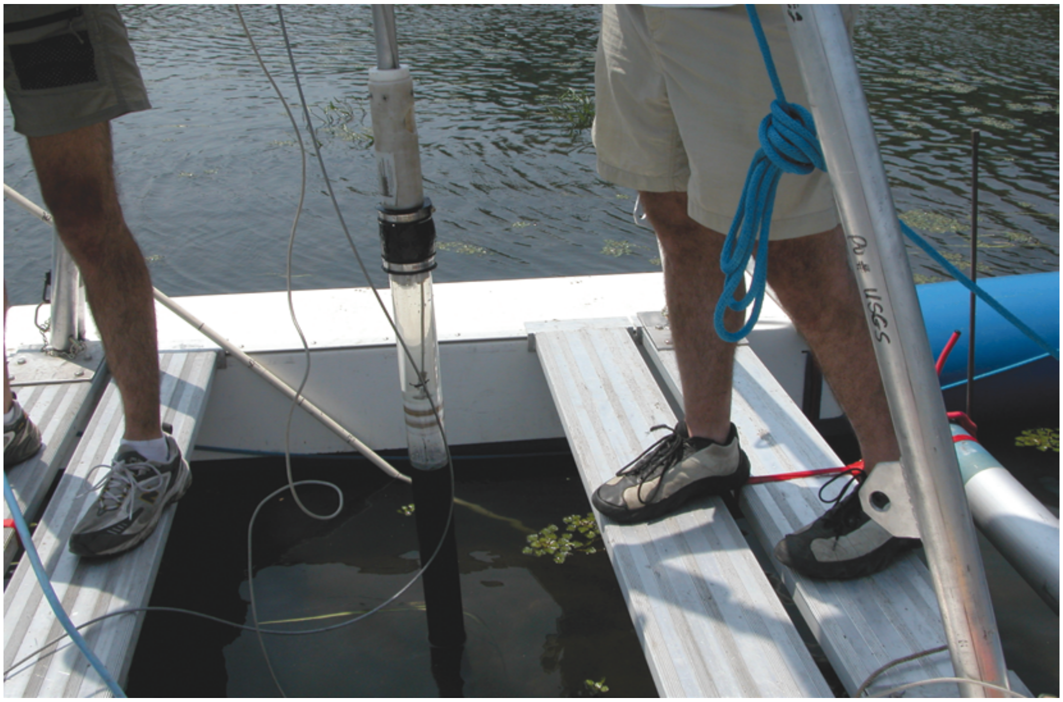
Environmental samples were analyzed by SGS in batches of up to 40 samples. Each batch was accompanied by quality assurance/quality control (QA/QC) samples—including procedural blanks, laboratory duplicates, matrix-spike samples, and recovery standards—to test laboratory bias and variability. Before analytical results were accepted, QA/QC samples had to meet the following methodology criteria: inorganic element concentrations measured in procedural blanks were required to be less than quantification limits; relative percentage differences (RPDs) between laboratory duplicate and matrix-spike samples were no more than 10 percent; and percent recoveries were within the 50 to 100 percent range. Laboratory instruments were calibrated in accordance with the standard operating procedures of SGS and were required to meet method specifications (SGS Laboratory, written commun., 2006).

Organic Analysis

The day before the chemical analysis, the USGS laboratory extracted unsieved sediment overnight with dichloromethane in a Soxhlet apparatus and split into two aliquots (Foreman and others, 1995; Furlong and others, 1996). The first aliquot was analyzed for PAHs and alkyl-PAHs by capillary column gas chromatography with detection by mass spectrometry (Furlong and others, 1996). The second aliquot was analyzed for chlorinated hydrocarbons by dual capillary column gas chromatography with electron capture detection (Noriega and others, 2004).

Environmental samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in batches of up to 12 samples. Each batch was accompanied by QA/QC samples—including procedural blanks, laboratory duplicates, matrix-spike samples, and recovery standards—to test laboratory bias and variability (Noriega and others, 2004). Before analytical results were accepted, QA/QC samples had to meet the following methodology criteria: chemical concentrations measured in procedural blanks were less than quantification limits; RPDs between laboratory duplicate and matrix-spike samples were no more than 10 percent; and percent recovery ranges were within 50 to 120 percent. Laboratory instruments were calibrated in accordance with the standard operating procedures of the USGS and were required to meet method specifications.

A



B

Figure 4. Methods used to obtain cores from impoundments. Cores were collected *A,* from floating pontoon or *B,* at the sediment surface where the impoundment has been drained.

A

B

Figure 5. Examples of core penetration through the full thickness of impounded sediment into preimpoundment material. Core samples contain *A,* floodplain vegetation, and *B,* inorganic clay.

Bias and Variability in Field and Laboratory Analyses

Environmental samples were collected and analyzed along with field duplicates (or split samples) and blind reference samples. These QA/QC samples were collected, processed, and analyzed in exactly the same way as the environmental samples. Therefore, the field QA/QC samples can be used to assess bias and variability associated with environmental conditions, sample collection, and sample processing as well as with laboratory processing. Field duplicates were collected at 3 of 32 locations and consisted of two representative aliquots of sediment that were taken from the homogenized sample and were analyzed separately. RPDs for detectable inorganic element concentrations between field duplicate samples averaged 2.9 percent, with one exception. The RPD for detectable molybdenum concentration measured in the Mountain Lake impoundment field duplicate sample (site 13) was 66 percent. Blind reference samples for the inorganic elements, consisting of National Institute of Standards and Technology (NIST) standard reference material (SRM) 2711 Montana Soil, were submitted to SGS for analysis. RPDs between the SGS-reported inorganic element concentrations and the NIST-certified values for the blind samples were all less than 15 percent, with the exception of that for titanium, which had an RPD of about 28 percent. Field duplicate samples were not analyzed for organic compounds.

Quality assurance for organic constituents was conducted at the NWQL. No blind reference samples were submitted to NWQL. However, percent recovery of laboratory surrogate organic constituents ranged between 30 and 95 percent, and RPDs between sample and replicate results were less than 25 percent for 103 of the 115 constituents investigated for two of the replicate sample pairs and less than 25 percent for 88 of the constituents for the third replicate sample pair. Average and median RPDs between all replicate sample pairs were 18 and 6 percent, respectively.

Concentrations of inorganic elements and organic compounds greater than the detection limit indicate that the compound concentration is greater than the laboratory reporting level (LRL) for a given analytical technique. Nondetection may indicate either that the compound is not present in the sample or that the concentration of the compound in the sample is less than the LRL for the analytical technique used. The LRL is generally equal to twice the long-term method detection limit (LT–MDL) for a given analyte and laboratory method (Childress and others, 1999).

Estimated Toxicity of Sediment

The consensus-based sediment quality guidelines (Ingersoll and others, 2000; MacDonald and others, 2000) were used in this study to compare impounded-sediment chemistry results to predicted impacts on benthic dwelling organisms. It is important to note that these guidelines are empirical, effects-based thresholds derived from laboratory toxicology tests on a limited range of organisms. As such, the thresholds do not account for chronic toxicity that results from prolonged exposure, toxicity caused by mixtures of chemicals, nor to biological availability of contaminants or other mortality drivers that may be governed by environmental conditions. For example, high sediment-oxygen demand (SOD) may result in low dissolved oxygen (DO) concentrations that can be lethal to some aquatic organisms; by contrast, acid-volatile sulfides (AVS) may chemically bind some toxic chemicals making them biologically immobile.

Nevertheless, estimation of sediment toxicity from concentrations of common contaminants and known threshold effect concentrations (TECs) and probable effect concentrations (PECs) has been shown to be a reasonable predictor of toxicity in a laboratory setting for a limited range of organisms (Ingersoll and others, 2000; MacDonald and others, 2000). The TEC for a given contaminant is defined as the concentration below which harmful effects are unlikely to be observed, and the PEC is defined as the concentration above which effects are likely to be observed (MacDonald and others, 2000).

Understanding of potential sediment toxicity is facilitated by determination of PEC quotients (PECQs) for individual contaminants within a sample (MacDonald and others, 2000). The PECQ is defined as the ratio of the concentration of a contaminant in a sample to the contaminant PEC. To obtain an estimate of the overall toxicity of a sediment sample *x*, the PECQs for the individual contaminants (and contaminant groups) in a sample are averaged to obtain the overall sample PECQ, also known as the $PECQ_x$, as follows:

$$PECQ_x = \frac{\sum \frac{C_{x,y}}{PEC_y}}{n_x}, \quad (1)$$

where

$PECQ_x$ is the average PECQ for sediment sample *x*,
$C_{x,y}$ is the concentration of contaminant *y* or contaminant group *y* in sample *x*,
PEC_y is the PEC for chemical *y* (MacDonald and others (2000), and
n_x is the number of contaminants or contaminant groups used in sample *x*.

Before calculating the $PECQ_x$, the contaminant concentrations are first adjusted for censored data (data below the laboratory reporting level). In accordance with the practice of Breault and others (2005, p. 10), censored data were set equal to zero in the calculation of the PECQ and $PECQ_x$ values. Consequently, our approach to the calculation of $PECQ_x$ for a sample does not include any toxicity associated with undetected constituents.

In the current study, 10 PECQs (for arsenic, cadmium, chromium, copper, lead, nickel, and zinc, total PAHs, total PCBs, and total DDTs) were averaged to determine a $PECQ_x$ for each sample. For the purposes of this report, total PAHs equal the sum of anthracene, benzo(a)anthracene, benzo(a)pyrene, chrysene, 9H-fluorene, fluoranthene, naphthalene, phenanthrene, and pyrene; total PCBs equal the sum of all polychlorinated biphenyl congeners; and total DDTs equal the sum of ortho,para'-DDE, para,para'-DDE, ortho,para'-DDD, para,para'-DDD, ortho,para'-DDT, and para,para'-DDT.

The probability of observing sediment toxicity in a sample may be estimated from the $PECQ_x$ using the following equation (MacDonald and others, 2000):

$$Y = 101.48 \times \left(1 - 0.36^{x}\right) \quad (2)$$

where

Y is the estimated probability of toxicity, in percent; and

x is the average probable effects quotient for a sample ($PECQ_x$); as calculated in equation 1.

Sediment Thickness, Chemical Quality, and Estimated Toxicity

The thickness, chemical quality, and estimated toxicity of bottom sediment were assessed at each of the 32 impoundments selected for this study. Major results are presented in the following sections.

Measured Sediment Thicknesses and Estimated Volumes

Average sediment thicknesses ranged from 0.5 to 6.7 ft among the impoundments, with an overall average of 3.7 ft (table 2). Minimum sediment thicknesses ranged from 0 to 2.6 ft. The maximum measured sediment thickness was about 15 ft (D.F. Rile Grist Mill Dam, site 12). At the Conway Electric Dam on the South River in Conway (site 11), sediment thicknesses were found to be greater than what could be feasibly measured with a steel rod (greater than 20 ft). At the Pentucket Pond Outlet and Carding Mill Dams (sites 8 and 14), local field conditions precluded collection of thickness data. For these reasons, estimates of sediment volume could not be calculated for these three sites. At all other sites, surface areas reported in the NID for each impoundment (U.S. Army Corps of Engineers, 1996) were multiplied by average thicknesses to give planning-level estimates of sediment volumes (table 2). Sediment volumes estimated in this manner ranged from 110,000 ft^3 (Deleano Pond Dam on an unnamed tributary of the Skug River in North Andover, site 28) to 81 million cubic feet (Mft^3; Talbot Mills Dam on the Concord River in Billerica, site 16). It is important to note that sediment may not accumulate in a uniform manner behind a dam; commonly it forms a wedge shape based upon the gradual settling of different grain sizes in response to reduced water velocities within an impoundment. Therefore, actual volumes of impoundment sediment may be greater or less than the estimated volumes presented here.

Concentrations of Inorganic Elements

Contaminant concentrations in the sediment cores (inorganic elements and organic compounds) varied substantially among impoundments. Many of these contaminants are on the U.S. Environmental Protection Agency list of 126 priority pollutants (U.S. Environmental Protection Agency, undated). The priority pollutant elements arsenic, chromium, copper, lead, nickel, and zinc were detected at all 32 impoundment sites. The priority pollutant element cadmium was detected at 14 of the 32 sites.

The highest concentrations of the inorganic elements copper, nickel, and zinc were measured at the Worcester Consolidated Station Dam (site 29) on the Blackstone River in Millbury (fig. 6; table 3). This finding is consistent with the long industrial history of the Blackstone River and its watershed, which, together with the Charles River, is considered the birthplace of the industrial revolution in Massachusetts (Brown and Tager, 2000, p. 121). Among the 32 impoundment sites, the highest concentrations of the inorganic elements arsenic, cadmium, chromium, and lead were measured at the Mill Pond Dam #1 on the Town Brook in Plymouth (site 20), the Mill Pond Dam on the North Nashua River in Fitchburg (site 19), the Perryville Pond Dam on the French River in Dudley (site 6), and the Tel Electric Pond Dam on the West Branch Housatonic in Pittsfield (site 25), respectively. The Rice City Pond Dam on the Blackstone River in Uxbridge (site 21) also had relatively higher concentrations of the priority pollutant elements than most other sites, with the second highest concentrations of cadmium, chromium, copper, and nickel and the third highest concentrations of lead and zinc among the 32 sites (fig. 6).

Table 2. Bottom-sediment thicknesses and estimated volumes of sampled impoundments in Massachusetts in 2004 and 2005.

[Estimated sediment volumes are rounded values. no., number; ft, feet; ft^2, square feet; ft^3, cubic feet; --, not sampled]

Site no.	Dam	Estimated surface area, in ft^2	Average water depth, in ft	Average sediment thickness, in ft	Minimum sediment thickness, in ft	Maximum sediment thickness, in ft	Number of measurements	Estimated sediment volume, in ft^3	Number of sediment cores collected
1	Factory Village Pond	220,000	6.2	3.4	1.1	7.0	29	750,000	4
2	Horseshoe Pond	2,600,000	1.6	4.4	1.9	6.1	16	12,000,000	2
3	Sheomet Lake	1,300,000	6.9	2.5	0.0	4.2	24	3,200,000	2
4	North Webster Village Pond	3,700,000	4.4	4.5	0.0	7.8	15	17,000,000	5
5	Ballardvale	1,600,000	2.3	3.3	0.0	5.1	23	5,200,000	5
6	Perryville Pond[1]	1,100,000	3.0	4.5	2.5	9.5	50	1,917,000	3
7	Ipswich Mills	1,300,000	4.1	3.3	0.0	8.5	27	4,300,000	2
8	Pentucket Pond Outlet[2]	4,000,000	--	--	--	--	--	--	4
9	Felton Lake	540,000	7.0	2.8	0.1	5.5	15	1,500,000	1
10	Watertown	630,000	5.0	1.5	0.0	5.2	17	950,000	3
11	Conway Electric[3]	98,700	--	--	--	--	--	--	2
12	D.F. Rile Grist Mill	770,000	8.5	5.0	0.0	15.0	18	3,900,000	7
13	Mountain Lake	460,000	(4)	6.4	1.5	9.3	21	2,900,000	2
14	Carding Mill Pond[2]	1,800,000	--	--	--	--	--	--	3
15	Robert Meadow Upper Reservoir	240,000	8.6	6.7	1.4	10.6	19	1,600,000	2
16	Talbot Mills	22,000,000	9.3	3.7	0.0	8.0	12	81,000,000	3
17	Mill River	870,000	2.5	4.8	2.6	7.2	11	4,200,000	2
18	Windsor Reservoir	3,200,000	(4)	4.0	0.3	8.0	26	13,000,000	2
19	Mill Pond	200,000	3.1	3.3	0.0	9.6	26	660,000	2
20	Mill Pond #1	40,800	2.5	4.8	2.6	7.2	11	200,000	1
21	Rice City Pond	940,000	1.3	5.4	0.3	8.1	8	5,000,000	6
22	Assabet River[5]	210,000	1.5	4.5	0.3	11.0	140	1,483,200	3
23	Upper Flints Pond	3,100,000	4.9	1.7	0.6	4.0	21	5,400,000	3
24	Stony Brook	59,800	2.5	2.0	0.6	3.8	23	120,000	3
25	Tel Electric Pond	610,000	4.3	3.4	0.0	6.5	21	2,000,000	3
26	Monument Pond #2	320,000	4.7	2.4	1.4	4.4	18	770,000	3
27	Town Brook #1	50,500	1.8	3.4	0.8	4.9	16	170,000	3
28	Deleano Pond	220,000	4.0	0.5	0.0	1.8	27	110,000	7
29	Worcester Consolidated Station	2,400,000	3.2	4.0	1.0	6.7	30	9,600,000	4
30	Cooks Canyon Lower Pond	30,800	2.5	5.1	0.3	11.4	25	160,000	2
31	Unnamed, Stony Brook	120,000	2.5	2.0	0.6	3.8	23	240,000	3
32	Unnamed, Winnetuxet River	17,200	2.3	3.2	0.2	5.7	25	55,000	2

[1]Data from Zimmerman and Breault (2003).

[2]Field conditions precluded measurement.

[3]Thickness greater than 20 ft probe length.

[4]Impoundment was dry at time of measurement.

[5]Data from Zimmerman and Sorenson (2005).

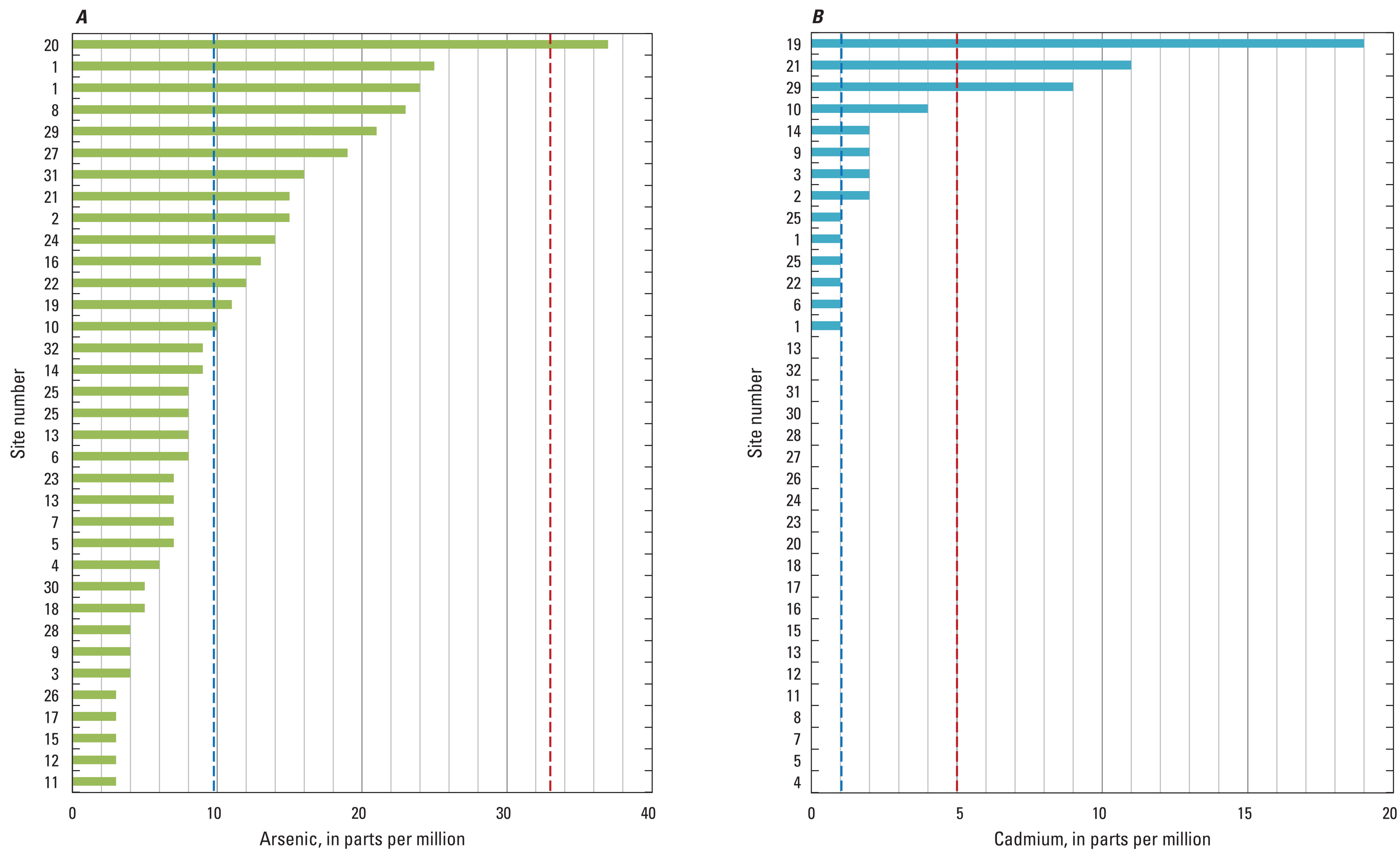


Figure 6. Concentrations of *A,* arsenic, *B,* cadmium, *C,* chromium, *D,* copper, *E,* lead, *F,* nickel, and *G,* zinc in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration (TEC), and the red dashed line shows probable effects concentration (PEC; MacDonald and others, 2000). The laboratory reporting level (LRL) for cadmium coincides with the threshold effects concentration (1 ppm) on part B. LRLs are not shown for the remaining elements, because all other elements were found above the respective LRLs at all sites. Concentrations of field duplicate samples (table 3) are plotted for sites 1, 13, and 25. Site locations are listed in table 1.

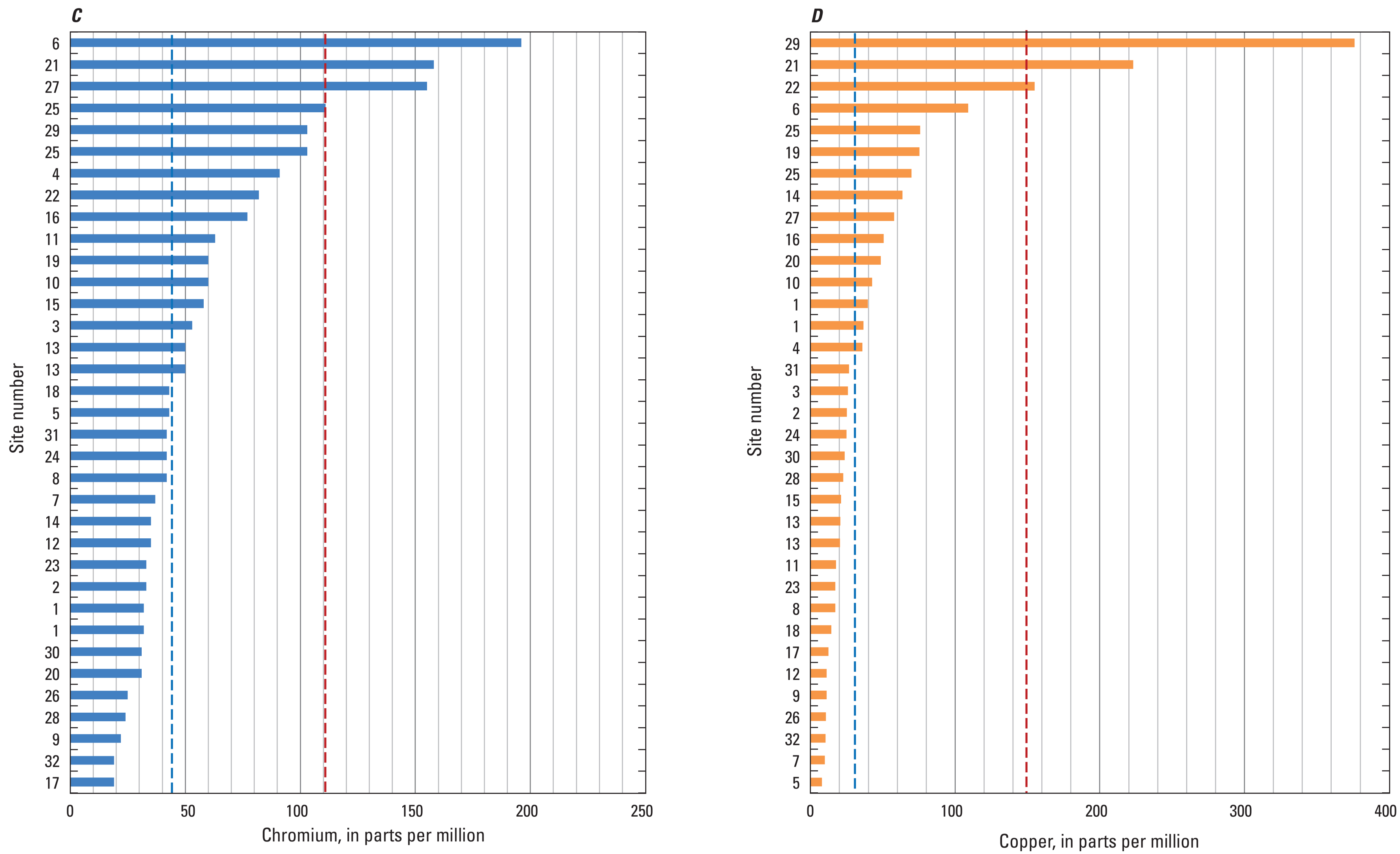


Figure 6. Concentrations of *A,* arsenic, *B,* cadmium, *C,* chromium, *D,* copper, *E,* lead, *F,* nickel, and *G,* zinc in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration (TEC), and the red dashed line shows probable effects concentration (PEC; MacDonald and others, 2000). The laboratory reporting level (LRL) for cadmium coincides with the threshold effects concentration (1 ppm) on part B. LRLs are not shown for the remaining elements, because all other elements were found above the respective LRLs at all sites. Concentrations of field duplicate samples (table 3) are plotted for sites 1, 13, and 25. Site locations are listed in table 1.—Continued

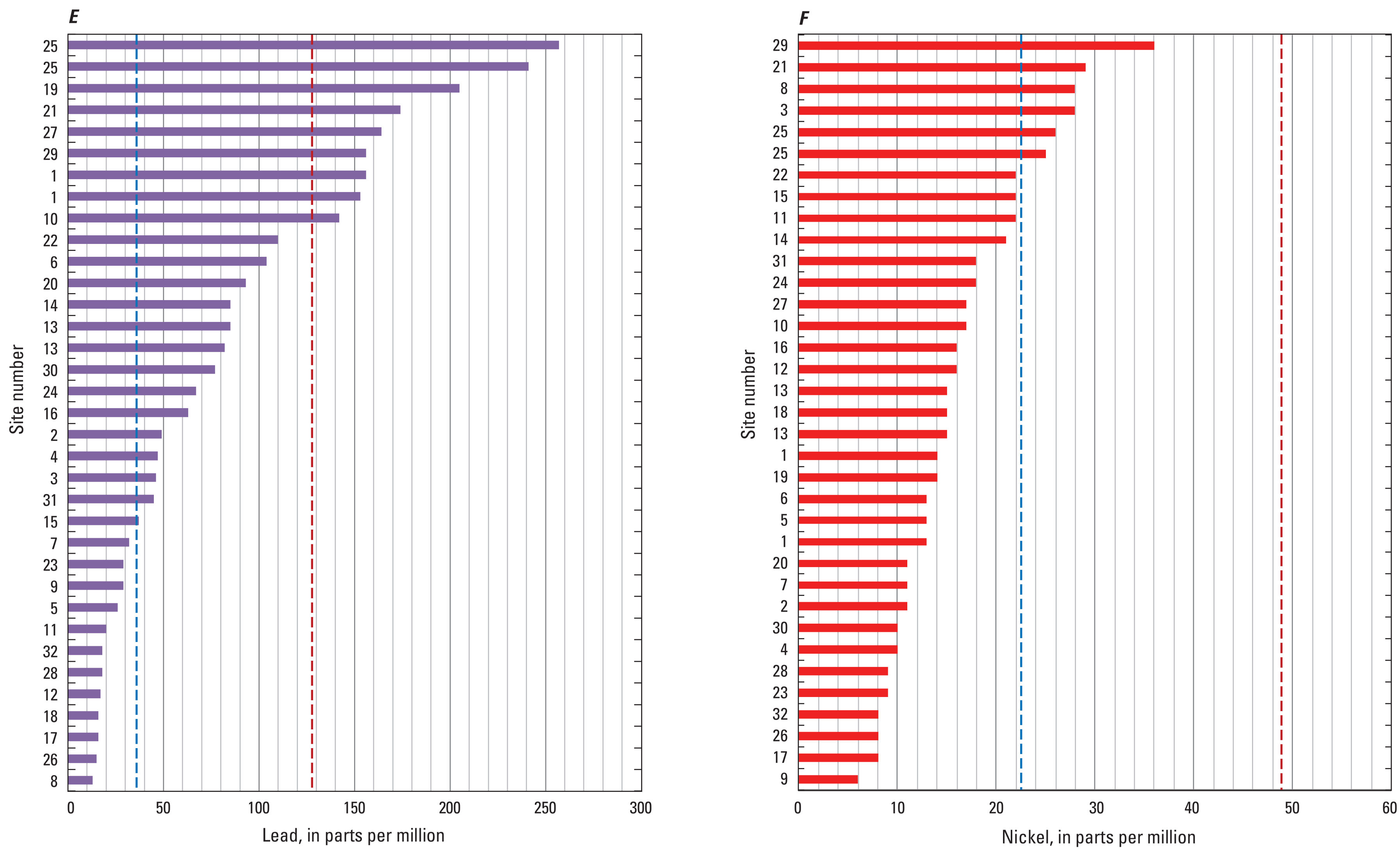


Figure 6. Concentrations of *A*, arsenic, *B*, cadmium, *C*, chromium, *D*, copper, *E*, lead, *F*, nickel, and *G*, zinc in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration (TEC), and the red dashed line shows probable effects concentration (PEC; MacDonald and others, 2000). The laboratory reporting level (LRL) for cadmium coincides with the threshold effects concentration (1 ppm) on part B. LRLs are not shown for the remaining elements, because all other elements were found above the respective LRLs at all sites. Concentrations of field duplicate samples (table 3) are plotted for sites 1, 13, and 25. Site locations are listed in table 1.—Continued

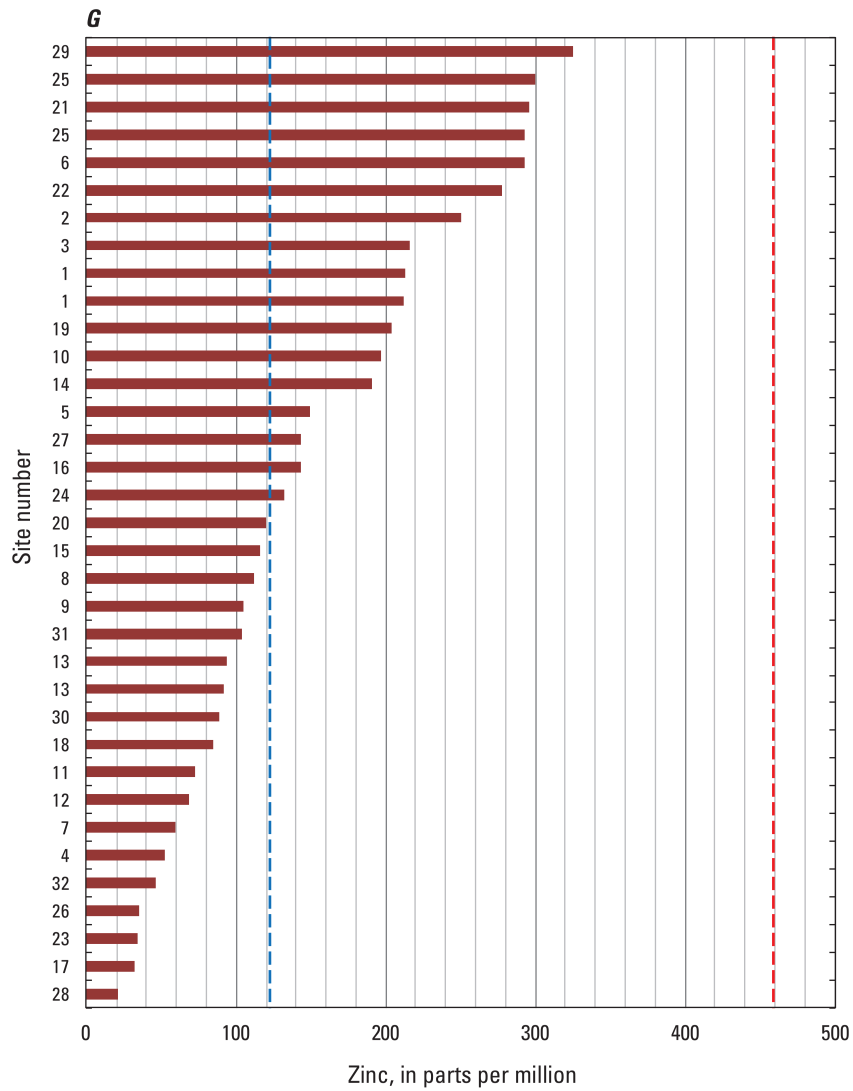


Figure 6. Concentrations of *A,* arsenic, *B,* cadmium, *C,* chromium, *D,* copper, *E,* lead, *F,* nickel, and *G,* zinc in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration (TEC), and the red dashed line shows probable effects concentration (PEC; MacDonald and others, 2000). The laboratory reporting level (LRL) for cadmium coincides with the threshold effects concentration (1 ppm) on part B. LRLs are not shown for the remaining elements, because all other elements were found above the respective LRLs at all sites. Concentrations of field duplicate samples (table 3) are plotted for sites 1, 13, and 25. Site locations are listed in table 1.—Continued

Table 3. Concentrations of inorganic elements measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.

[Concentrations were determined on unmilled samples using method 3050b digestion from U.S. Environmental Protection Agency (1996). DUP, field duplicate sample; no., number; ppm, parts per million; %, percent; <, less than value shown]

Site no.	Dam name	Beryllium, in ppm	Sodium, in %	Magnesium, in %	Aluminum, in %	Phosphorus, in %	Potassium, in %	Calcium, in %	Scandium, in ppm	Titanium, in %	Vanadium, in ppm
1	Factory Village Pond	4.2	1.08	0.28	5.91	0.15	2.19	0.6	5.3	0.2	46
2	Horseshoe Pond	1.5	0.89	0.2	3.73	0.1	1.06	0.56	4.3	0.19	54
3	Sheomet Lake	1.9	0.8	0.58	5.46	0.12	0.85	0.87	10	0.29	94
4	North Webster Village Pond	2.1	1.12	0.3	4.75	0.04	1.48	0.99	3.9	0.16	27
5	Ballardvale	2.4	1.11	0.36	4.73	0.05	1.51	1.01	4.6	0.18	36
6	Perryville Pond	2.2	1.1	0.31	4.57	0.07	1.5	0.93	4.2	0.16	33
7	Ipswich Mills	1.7	1.36	0.39	4.82	0.03	1.73	0.76	4	0.12	36
8	Pentucket Pond Outlet	1.2	0.44	0.33	2.4	0.05	0.52	1.18	3.3	0.08	31
9	Felton Lake	1.7	0.99	0.28	4.54	0.23	0.86	1.22	9.2	0.51	37
10	Watertown	1.8	1.36	0.68	5.47	0.09	1.66	1.26	7.8	0.33	78
11	Conway Electric	1.9	1	1	6.15	0.06	1.22	1.42	15.3	0.3	93
12	D.F. Rile Grist Mill	1.6	1.43	0.67	5.62	0.05	1.22	1.27	9.8	0.28	70
13	Mountain Lake	2.1	1.53	0.55	6.39	0.1	1.66	1.32	8	0.3	68
14	Carding Mill Pond	2.4	0.78	0.26	3.73	0.25	0.88	1.32	4.7	0.16	36
15	Robert Meadow Upper Reservoir	2.9	1.12	0.56	6.45	0.09	1.52	1.12	9.8	0.31	83
16	Talbot Mills	1.9	0.97	0.25	4.02	0.1	1.3	0.98	3.6	0.1	30
17	Mill River	1.5	1.45	0.25	4.57	0.03	1.6	0.83	4.3	0.21	36
18	Windsor Reservoir	1.5	0.87	0.64	5.48	0.07	2.17	0.84	7.3	0.28	61
19	Mill Pond	2.7	1.05	0.24	7.07	0.07	1.58	0.67	5.4	0.45	50
20	Mill Pond #1	1.5	0.6	0.22	2.84	0.07	0.88	0.41	3.3	0.14	42
21	Rice City Pond	1.9	1.08	0.36	4.71	0.18	1.54	0.8	4.9	0.21	43
22	Assabet River	2.1	1.19	0.62	5.53	0.14	1.27	1.22	8	0.25	63
23	Upper Flints Pond	2.2	1.14	0.21	4.18	0.06	1.47	0.87	3.3	0.14	21
24	Stony Brook	1.6	0.81	0.48	4.05	0.11	0.89	1.31	5.7	0.2	61
25	Tel Electric Pond	1.5	0.56	1.66	5.18	0.08	1.71	2.52	7.9	0.18	66
26	Monument Pond #2	1.4	0.85	0.25	3.58	0.03	1.12	0.43	3.4	0.15	34
27	Town Brook #1	2.1	0.61	0.2	3.67	0.06	0.97	0.38	5.3	0.18	54
28	Deleano Pond	1.9	0.17	0.16	1.41	0.15	0.15	1.05	5.5	0.05	14
29	Worcester Consolidated Station	1.9	1.05	0.42	5.25	0.12	1.77	0.84	5.6	0.23	49
30	Cooks Canyon Lower Pond	2.8	1.65	0.33	6.12	0.18	1.67	1.67	5.3	0.35	46
31	Unnamed, Stony Brook	1.3	0.79	0.37	3.64	0.1	0.79	1.11	4.5	0.17	49
32	Unnamed, Winnetuxet	0.9	0.7	0.15	2.61	0.03	0.96	0.32	2.3	0.14	25
1	DUP-Factory Village Pond	4	1.09	0.28	5.95	0.15	2.21	0.61	5.2	0.2	47
13	DUP-Mountain Lake	2.2	1.51	0.56	6.37	0.1	1.65	1.34	8.1	0.3	70
25	DUP-Tel Electric Pond	1.5	0.57	1.63	5.21	0.08	1.71	2.46	8	0.18	68

Table 3. Concentrations of inorganic elements measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Concentrations were determined on unmilled samples using method 3050b digestion from U.S. Environmental Protection Agency (1996). DUP, field duplicate sample; no., number; ppm, parts per million; %, percent; <, less than value shown]

Site no.	Dam name	Chromium, in ppm	Manganese, in ppm	Iron, in %	Cobalt, in ppm	Nickel, in ppm	Copper, in ppm	Zinc, in ppm	Arsenic, in ppm	Strontium, in ppm	Yttrium, in ppm	Zirconium, in ppm
1	Factory Village Pond	32	472	2.25	9	13	36.5	213	24	111	10.9	35.7
2	Horseshoe Pond	33	546	2.97	8	11	25.1	250	15	95.2	17.1	57.1
3	Sheomet Lake	53	602	3.64	17	28	26	216	4	80.9	17.3	37
4	North Webster Village Pond	91	297	1.23	3	10	35.9	51.8	6	137	10.5	38
5	Ballardvale	43	379	1.55	6	13	7.9	149	7	121	11.9	47.7
6	Perryville Pond	196	377	1.69	5	13	109	293	8	130	10.4	43.7
7	Ipswich Mills	37	372	2.08	5	11	9.9	59.2	7	120	7.4	32
8	Pentucket Pond Outlet	42	702	3.24	12	28	17.2	112	23	67.3	13	21.4
9	Felton Lake	22	285	1.89	4	6	11.2	105	4	96.1	54.7	28.4
10	Watertown	60	581	3.23	8	17	42.5	197	10	162	15.7	56.2
11	Conway Electric	63	1,310	4.27	8	22	17.6	72.2	3	150	23.7	30.8
12	D.F. Rile Grist Mill	35	681	2.86	8	16	11.2	68.2	3	149	19.1	28.2
13	Mountain Lake	50	577	3.67	7	15	20.7	91.4	8	238	16.5	32.7
14	Carding Mill Pond	35	469	2	10	21	63.6	191	9	125	21.5	34.6
15	Robert Meadow Upper Reservoir	58	789	3.32	8	22	21.2	116	3	152	18.1	50.1
16	Talbot Mills	77	451	1.74	12	16	50.6	143	13	123	10.7	22.6
17	Mill River	19	430	1.63	3	8	12.5	32	3	146	11.9	39.4
18	Windsor Reservoir	43	539	3.24	9	15	14.5	85.1	5	128	15.2	59.8
19	Mill Pond	60	360	1.79	7	14	75.3	204	11	160	10.4	41.7
20	Mill Pond #1	31	447	2.06	5	11	48.7	120	37	64.3	11.5	37.3
21	Rice City Pond	158	561	2.8	5	29	223	296	15	138	11.5	66.2
22	Assabet River	82	557	2.5	11	22	155	278	12	163	14.4	45.6
23	Upper Flints Pond	33	419	1.26	3	9	17.2	34.1	7	133	9.2	27.3
24	Stony Brook	42	650	2.68	11	18	25	132	14	113	11.7	40.3
25	Tel Electric Pond	103	805	3.69	11	25	69.8	293	8	79.3	12.3	56.8
26	Monument Pond #2	25	271	1.61	4	8	10.7	35.1	3	82.8	8.2	44.4
27	Town Brook #1	155	266	1.99	7	17	57.9	143	19	96.5	13.6	52.5
28	Deleano Pond	24	154	0.61	2	9	22.7	21	4	71.7	17.8	10.3
29	Worcester Consolidated Station	103	537	3.78	6	36	376	325	21	155	12.4	57.6
30	Cooks Canyon Lower Pond	31	468	1.83	6	10	23.6	88.4	5	454	17.4	24.7
31	Unnamed, Stony Brook	42	907	2.97	12	18	26.6	104	16	96.5	11.4	37.1
32	Unnamed, Winnetuxet	19	347	1.84	6	8	10.4	46.7	9	71.5	6.8	33.1
1	DUP-Factory Village Pond	32	470	2.27	9	14	39.5	212	25	111	11.5	36
13	DUP-Mountain Lake	50	573	3.81	7	15	20.5	94.1	7	236	16.4	32.9
25	DUP-Tel Electric Pond	111	792	3.69	11	26	75.7	300	8	79.9	13.1	59.2

Table 3. Concentrations of inorganic elements measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Concentrations were determined on unmilled samples using method 3050b digestion from U.S. Environmental Protection Agency (1996). DUP, field duplicate sample; no., number; ppm, parts per million; %, percent; <, less than value shown]

Site no.	Dam name	Molybdenum, in ppm	Silver, in ppm	Cadmium, in ppm	Tin, in ppm	Antimony, in ppm	Barium, in ppm	Lanthanum, in ppm	Tungsten, in ppm	Lead, in ppm	Bismuth, in ppm	Lithium, in ppm
1	Factory Village Pond	<1	<2	1	10	<5	479	27.4	<10	153	<5	32
2	Horseshoe Pond	2	<2	2	<10	<5	321	25.6	<10	49	<5	11
3	Sheomet Lake	2	<2	2	<10	<5	336	24.6	<10	46	<5	24
4	North Webster Village Pond	<1	<2	<1	40	<5	336	21.6	<10	47	<5	17
5	Ballardvale	<1	<2	<1	<10	<5	343	19.8	<10	26	<5	19
6	Perryville Pond	<1	<2	1	20	<5	323	20.3	<10	104	<5	18
7	Ipswich Mills	<1	<2	<1	<10	<5	346	14.6	<10	32	<5	18
8	Pentucket Pond Outlet	2	<2	<1	<10	<5	143	17.2	<10	13	<5	13
9	Felton Lake	1	<2	2	<10	<5	327	60.8	<10	29	<5	16
10	Watertown	2	<2	4	<10	7	440	24.7	<10	142	<5	16
11	Conway Electric	<1	<2	<1	<10	<5	363	24.8	<10	20	<5	40
12	D.F. Rile Grist Mill	<1	<2	<1	<10	<5	381	24.9	<10	17	<5	23
13	Mountain Lake	1	5	<1	<10	6	582	43.7	<10	82	<5	14
14	Carding Mill Pond	3	<2	2	<10	<5	291	34.5	<10	85	<5	17
15	Robert Meadow Upper Reservoir	1	<2	<1	<10	<5	404	35.3	<10	37	<5	59
16	Talbot Mills	1	<2	<1	<10	<5	329	16.8	<10	63	<5	13
17	Mill River	<1	<2	<1	<10	<5	466	18.2	<10	16	<5	9
18	Windsor Reservoir	<1	<2	<1	<10	<5	501	31.1	<10	16	<5	19
19	Mill Pond	2	<2	19	20	20	531	26	<10	205	<5	30
20	Mill Pond #1	2	<2	<1	<10	<5	304	18.7	<10	93	<5	10
21	Rice City Pond	2	2	11	60	<5	451	25.4	30	174	<5	20
22	Assabet River	2	2	1	20	<5	438	27.6	<10	110	<5	25
23	Upper Flints Pond	1	<2	<1	<10	<5	383	16.7	<10	29	<5	13
24	Stony Brook	2	<2	<1	<10	<5	318	21.1	<10	67	<5	23
25	Tel Electric Pond	1	<2	1	<10	<5	420	25.9	<10	241	<5	36
26	Monument Pond #2	<1	<2	<1	<10	<5	329	14.1	<10	15	<5	13
27	Town Brook #1	2	<2	<1	40	<5	344	21.6	<10	164	<5	23
28	Deleano Pond	4	<2	<1	<10	<5	77	23.2	<10	18	<5	5
29	Worcester Consolidated Station	1	<2	9	60	7	468	29.5	<10	156	<5	27
30	Cooks Canyon Lower Pond	<1	<2	<1	<10	<5	862	45.3	<10	77	<5	10
31	Unnamed, Stony Brook	2	<2	<1	<10	<5	296	21.6	<10	45	<5	21
32	Unnamed, Winnetuxet	2	<2	<1	<10	<5	307	13.2	<10	18	<5	9
1	DUP-Factory Village Pond	<1	<2	1	10	<5	442	29.5	<10	156	<5	32
13	DUP-Mountain Lake	2	5	<1	<10	<5	568	39.8	<10	85	<5	14
25	DUP-Tel Electric Pond	1	<2	1	<10	<5	398	26.3	<10	257	<5	37

Concentrations of Organic Compounds

High concentrations of organic compounds in bottom sediment are generally the result of human activity, although some PAHs have natural sources (Van Metre and others, 2004). Of the 108 organic compounds tested in this study, 64 were measured in concentrations greater than the laboratory reporting level (table 4, in back of report). In general, the highest concentrations of organic compounds were measured at the Ballardvale Dam (site 5) on the Shawsheen River in Andover (table 4, in back of report). Almost half of the individual compounds detected were found at their highest concentration at this site [number (n) of maximum concentrations = 26]. The site with the second largest number of maximum concentrations (n = 10) was the Deleano Pond Dam (site 28). This result was unexpected. Deleano Pond drains a relatively small drainage area (0.3 square mile) with no commercial, industrial, or transportation land use and is presently within the Harold Parker State Forest in northeastern Massachusetts. The Deleano Pond Dam was built in the 1930s and may have had an industrial history that is not evident by information readily available from a geographic information system (GIS). High concentrations of individual organic compounds were also measured at the Tel Electric Pond Dam (site 25) and the Felton Lake Dam on the Housatonic River in Washington (site 9) compared with measurements at the other sampling locations.

The maximum concentrations for the three major groups of organic compounds considered in this study (total PAHs, total PCBs, and total DDTs) are also of interest (fig. 7; table 4, in back of report). The maximum concentration of total PAHs was found at the Ballardvale Dam (site 5) where individual compounds were also present at elevated concentrations. The maximum concentration of total PCBs was found at the Mill Pond Dam (site 19; estimated value), and the maximum concentration of total DDTs was found at the Stony Brook Dam in Lincoln (site 24).

The major groups of compounds differed in their frequency of detection. Total PAHs were found most frequently, with detections at all 32 sites (100 percent of sites). Total PCBs were the least widespread, with detections at only 10 of the sites (31 percent). Total DDTs were found at 29 of the sites (91 percent), a detection frequency between that of the other two groups. The relatively high rate of detection for total PAHs (69 percent of sites) suggests a potential likelihood of nonpoint sources of total PAHs in the contributing watersheds to the impoundments. The potential role of nonpoint sources of PAHs to impoundments is supported by recent research on sources of PAHs to the lakes and reservoirs of the United States (Van Metre and others, 2010). By contrast, the lower rate of detection for total PCBs (31 percent of sites) suggests that point sources may play an important role at sites where PCBs were detected during the present study. Recent research in Massachusetts (Breault and others, 2004) has provided site-specific information on the role of PCB point sources in the contamination of impounded sediment.

Estimated Toxicity of Sediments

Although concentrations of priority pollutants may be used to help prioritize dam removal projects, contaminant concentrations alone do not indicate the potential risk posed by toxic contaminants. Potential toxicity of sediments to benthic organisms may be estimated by comparing observed contaminant concentrations in sediment to widely accepted criteria such as threshold effects concentrations (TECs) and probable effects concentrations (PECs; MacDonald and others, 2000). The TECs and PECs for each of the contaminants considered in this study (inorganic elements and organic compound groups) are shown on figures 6 and 7.

Among the inorganic elements, lead exceeded the PEC most frequently, with 7 of 32 impoundments (22 percent) having average lead concentrations above the PEC. Cadmium, chromium, and copper each exceeded the PEC at three impoundments (9 percent of sites), and arsenic exceeded the PEC at one impoundment. The remaining inorganic elements (nickel and zinc) did not exceed their PECs at any of the impoundments. Among the organic compound groups, total PAHs, total PCBs, and total DDTs exceeded the PEC at three, two, and zero sites, respectively.

The overall sediment toxicity at each of the impoundments was estimated by calculating the average $PECQ_x$ for a sample (MacDonald and others (2000). The $PECQ_x$ values (table 5) are used to assign an overall likelihood of toxicity (in percent) to each sediment sample (table 6). These likelihood values serve as indicators of the potential risk posed by the sediment to local and downstream receptors.

The likelihood of toxicity ranged from 8 to 70 percent among the sampling locations, and averaged 28 percent. A likelihood value of 28 percent means that 28 out of 100 toxicity tests are likely to show some level of toxicity for a given sample. Values greater than 60 percent were obtained for 3 of the 32 sites: Mill Pond Dam (site 19), Rice City Pond Dam (site 21), and Worcester Consolidated Station Dam (site 2). Cadmium was the largest single contributor to the estimated sediment toxicity at the two sites with the highest overall toxicity (Mill Pond Dam and Rice City Pond Dam; table 5). although total PCBs were also a large contributor to toxicity at the Mill Pond Dam. Copper was the largest contributor to toxicity at the Worcester Consolidated Station Dam, the site with the third highest overall toxicity. The Ballardville Dam (site 5) was the site where toxicity was most strongly dominated by a single contaminant—in this case, total PAHs, which contributed 70 percent of the overall toxicity. Chromium was a widespread contaminant; it contributed the largest single fraction of toxicity at 11 of the 32 sites, including not only sites with relatively low overall toxicity [Mill River Dam on the Mill River in Taunton (site 17) and Monument Pond #2 Dam on the Assonet River in Freetown (site 26)], but also sites with relatively high overall toxicity [Perryville Pond Dam (site 6) and Town Brook #1 Dam on the Town Brook in Plymouth (site 27)].

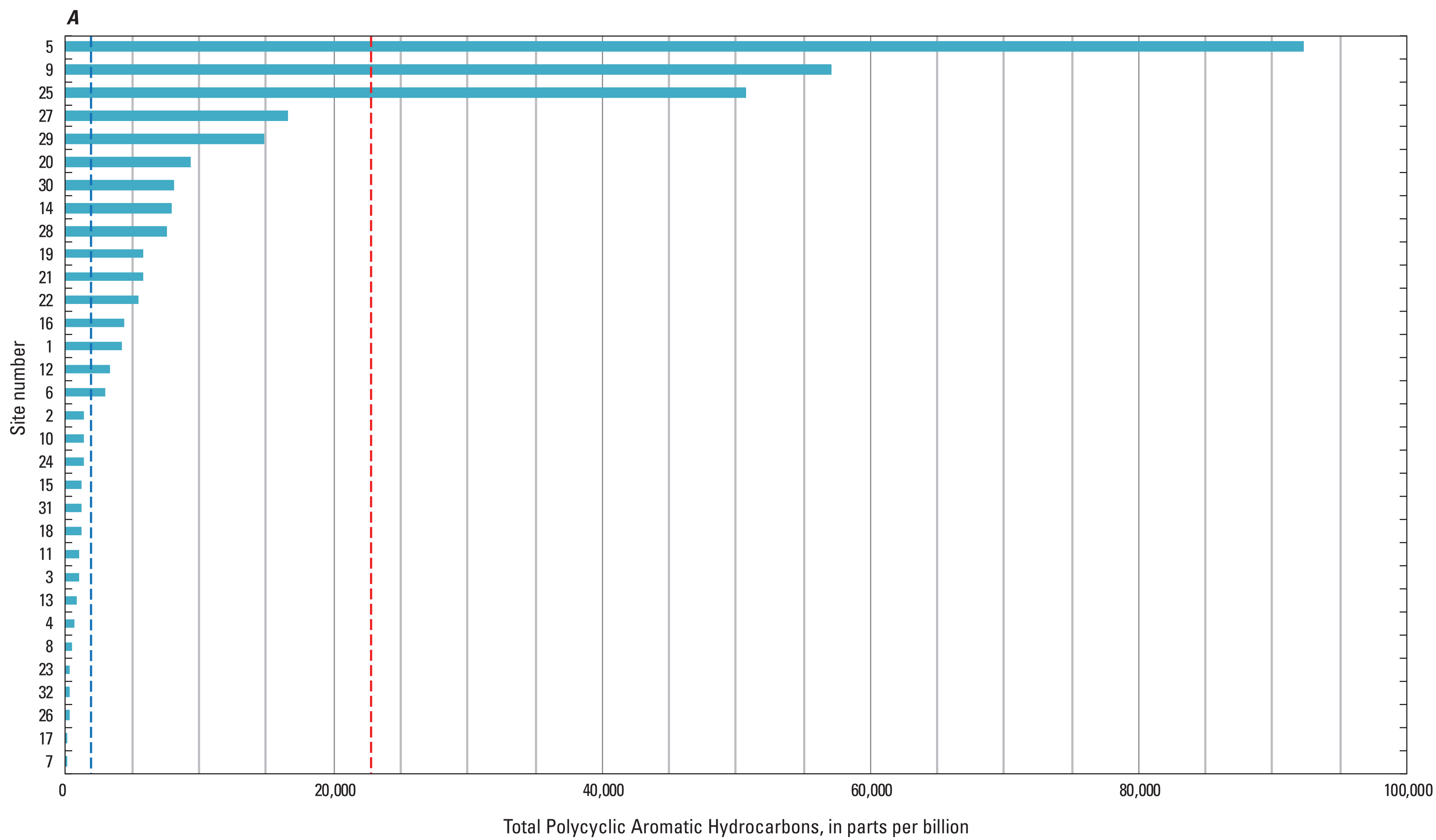


Figure 7. Concentrations for *A,* total polycyclic aromatic hydrocarbons, *B,* total polychlorinated biphenyls, and *C,* total dichlorodiphenyl-trichloroethylene (DDT) compounds in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration, and red dashed line shows the probable effects concentration (PEC) measured in parts per billion (ppb). The graph for DDT compounds does not show the PEC line because the value of the PEC (MacDonald and others, 2000) is more than 20 times greater than the highest DDT concentration from the 32 sampled sites. Sites are listed in table 1.

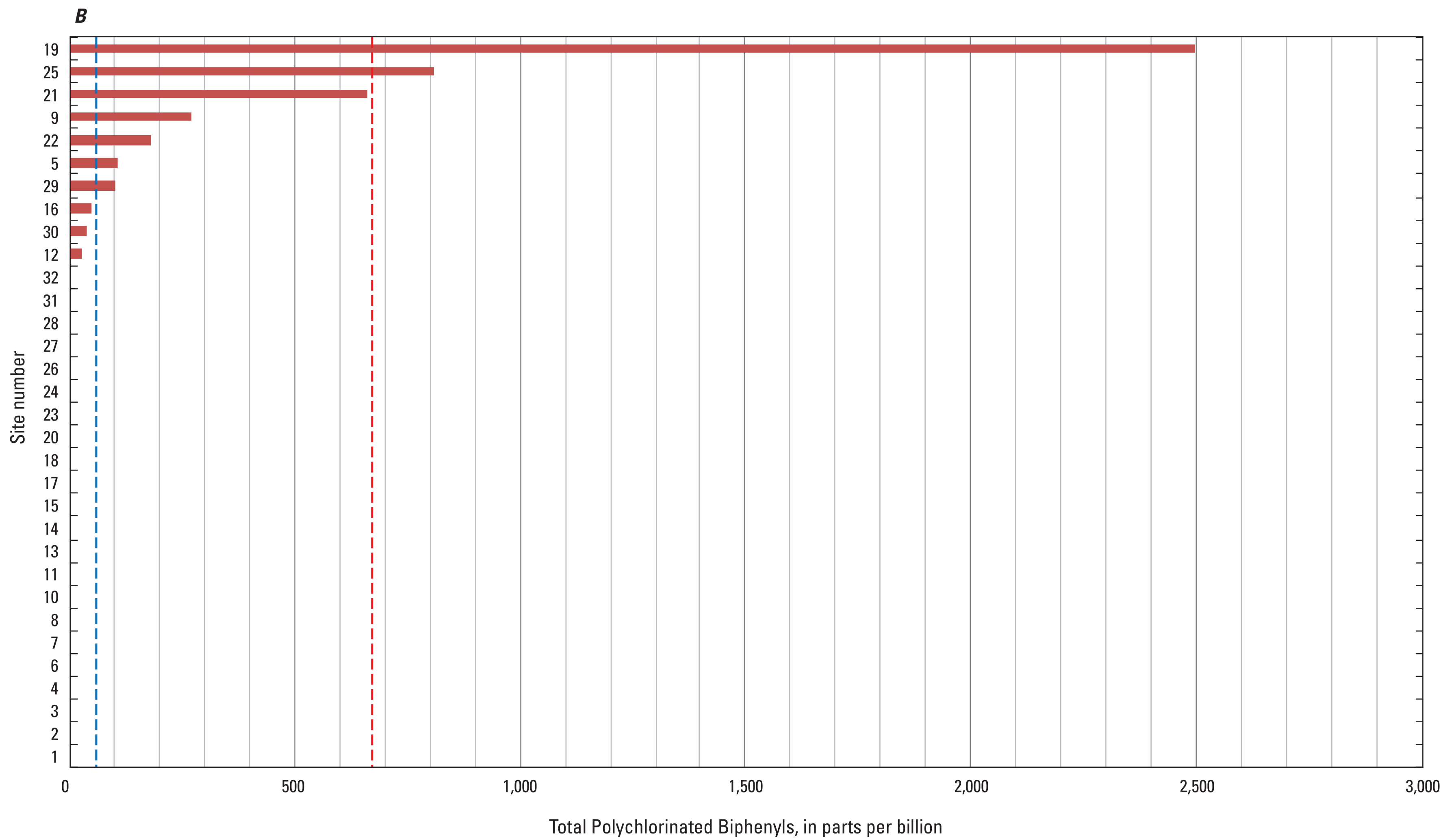


Figure 7. Concentrations for *A,* total polycyclic aromatic hydrocarbons, *B,* total polychlorinated biphenyls, and *C,* total dichlorodiphenyl-trichloroethylene (DDT) compounds in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration, and red dashed line shows the probable effects concentration (PEC) measured in parts per billion (ppb). The graph for DDT compounds does not show the PEC line because the value of the PEC (MacDonald and others, 2000) is more than 20 times greater than the highest DDT concentration from the 32 sampled sites. Sites are listed in table 1.—Continued

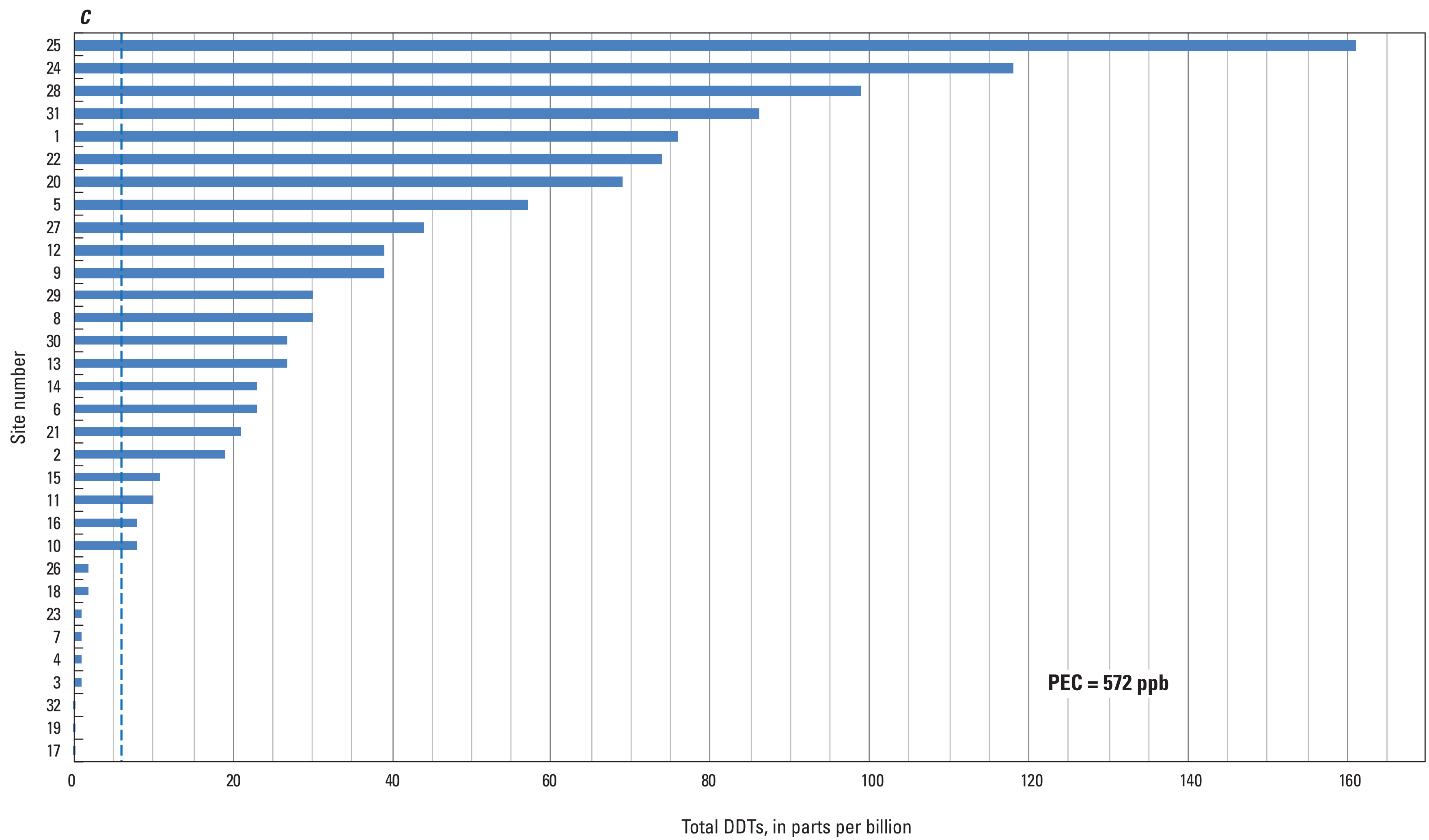


Figure 7. Concentrations for *A*, total polycyclic aromatic hydrocarbons, *B*, total polychlorinated biphenyls, and *C*, total dichlorodiphenyl-trichloroethylene (DDT) compounds in sediment samples from 32 impoundments in Massachusetts. Blue dashed line shows threshold effects concentration, and red dashed line shows the probable effects concentration (PEC) measured in parts per billion (ppb). The graph for DDT compounds does not show the PEC line because the value of the PEC (MacDonald and others, 2000) is more than 20 times greater than the highest DDT concentration from the 32 sampled sites. Sites are listed in table 1.—Continued

Table 5. Average probable effects concentration quotients for bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.

[The probable effects concentration quotient (PECQ, dimensionless) is the ratio of the sample concentration to the probable effects concentration (PEC) for each contaminant at each site. The mean PECQ for a site (*$PECQ_x$*) is the overall average PECQ at a site for arsenic, cadmium, chromium, copper, lead, nickel, zinc, total polycyclic aromatic hydrocarbons (PAHs), total polychlorinated biphenyls (PCBs), and total dichlorodiphenyl-trichloroethane compounds (DDTs). Total PAHs comprise the sum of the concentrations of anthracene, 9-H fluorene, naphthalene, phenanthrene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. Total DDTs comprise the sum of dichlorodiphenyl-trichloroethane (DDT) and dichlorodiphenyl-dichloroethylene (DDE) compounds; no., number]

Site no.	Dam name	Arsenic PECQ	Cad-mium PECQ	Chro-mium PECQ	Copper PECQ	Lead PECQ	Nickel PECQ	Zinc PECQ	Total PAHs PECQ	Total PCBs PECQ	Total DDT PECQ	Mean for sample $PECQ_x$	Maximum single con-tributor to to-tal estimated toxicity	Percent of total toxicity from maxi-mum single contributor
1	Factory Village Pond	0.727	0.201	0.288	0.245	1.195	0.267	0.464	0.175	0.000	0.091	0.365	Lead	33
2	Horseshoe Pond	0.455	0.402	0.297	0.168	0.383	0.226	0.545	0.032	0.000	0.033	0.254	Zinc	21
3	Sheomet Lake	0.121	0.402	0.477	0.174	0.359	0.576	0.471	0.042	0.000	0.000	0.262	Nickel	22
4	North Webster Village Pond	0.182	0.100	0.820	0.241	0.367	0.206	0.113	0.010	0.000	0.000	0.204	Chromium	40
5	Ballardvale	0.212	0.100	0.387	0.053	0.203	0.267	0.325	4.053	0.163	0.065	0.583	Total PAHs	70
6	Perryville Pond	0.242	0.201	1.766	0.732	0.813	0.267	0.638	0.111	0.000	0.038	0.481	Chromium	37
7	Ipswich Mills	0.212	0.100	0.333	0.066	0.250	0.226	0.129	0.000	0.000	0.002	0.132	Chromium	25
8	Pentucket Pond Outlet	0.697	0.100	0.378	0.115	0.102	0.576	0.244	0.000	0.000	0.000	0.221	Arsenic	31
9	Felton Lake	0.121	0.402	0.198	0.075	0.227	0.123	0.229	2.507	0.399	0.000	0.428	Total PAHs	59
10	Watertown	0.303	0.803	0.541	0.285	1.109	0.350	0.429	0.051	0.000	0.014	0.389	Lead	29
11	Conway Electric	0.091	0.100	0.568	0.118	0.156	0.453	0.157	0.037	0.000	0.007	0.169	Chromium	34
12	D.F. Rile Grist Mill	0.091	0.100	0.315	0.075	0.133	0.329	0.149	0.147	0.044	0.056	0.144	Nickel	23
13	Mountain Lake	0.242	0.100	0.450	0.139	0.641	0.309	0.199	0.000	0.000	0.031	0.211	Lead	30
14	Carding Mill Pond	0.273	0.402	0.315	0.427	0.664	0.432	0.416	0.344	0.000	0.000	0.327	Lead	20
15	Robert Meadow Upper Reservoir	0.091	0.100	0.523	0.142	0.289	0.453	0.253	0.047	0.000	0.014	0.191	Chromium	27
16	Talbot Mills	0.394	0.100	0.694	0.340	0.492	0.329	0.312	0.186	0.074	0.000	0.292	Chromium	24
17	Mill River	0.091	0.100	0.171	0.084	0.125	0.165	0.070	0.000	0.000	0.000	0.081	Chromium	21
18	Windsor Reservoir	0.152	0.100	0.387	0.097	0.125	0.309	0.185	0.045	0.000	0.003	0.140	Chromium	28
19	Mill Pond	0.333	3.815	0.541	0.505	1.602	0.288	0.444	0.257	3.698	0.000	1.148	Cadmium	33
20	Mill Pond #1	1.121	0.100	0.279	0.327	0.727	0.226	0.261	0.387	0.000	0.000	0.343	Arsenic	33
21	Rice City Pond	0.455	2.209	1.423	1.497	1.359	0.597	0.645	0.254	0.976	0.003	0.942	Cadmium	23
22	Assabet River	0.364	0.201	0.739	1.040	0.859	0.453	0.606	0.231	0.266	0.065	0.482	Copper	22
23	Upper Flints Pond	0.212	0.100	0.297	0.115	0.227	0.185	0.074	0.000	0.000	0.000	0.121	Chromium	25
24	Stony Brook	0.424	0.100	0.378	0.168	0.523	0.370	0.288	0.015	0.000	0.157	0.242	Lead	22
25	Tel Electric Pond	0.242	0.201	0.928	0.468	1.883	0.514	0.638	2.222	1.198	0.121	0.842	Total PAHs	26
26	Monument Pond #2	0.091	0.100	0.225	0.072	0.117	0.165	0.076	0.004	0.000	0.000	0.085	Chromium	26
27	Town Brook #1	0.576	0.100	1.396	0.389	1.281	0.350	0.312	0.730	0.000	0.000	0.513	Chromium	27
28	Deleano Pond	0.121	0.100	0.216	0.152	0.141	0.185	0.046	0.304	0.000	0.093	0.136	Total PAHs	22
29	Worcester Consolidated Station	0.636	1.807	0.928	2.523	1.219	0.741	0.708	0.653	0.148	0.000	0.936	Copper	27
30	Cooks Canyon Lower Pond	0.152	0.100	0.279	0.158	0.602	0.206	0.193	0.350	0.059	0.019	0.212	Lead	28
31	Unnamed, Stony Brook	0.485	0.100	0.378	0.179	0.352	0.370	0.227	0.000	0.000	0.129	0.222	Arsenic	22
32	Unnamed, Winnetuxet	0.273	0.100	0.171	0.070	0.141	0.165	0.102	0.000	0.000	0.000	0.102	Arsenic	27

Table 6. Likelihood of toxicity of bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.

[Likelihoood of toxicity calculated from equation 2 of this report (MacDonald and others, 2000). The average probable effects concentration quotient for a site ($PECQ_x$) is the average of the PECQs for arsenic, cadmium, chromium, copper, lead, nickel, and zinc, total polycyclic aromatic hydrocarbons (PAHs), total polychlorinated biphenyls (PCBs), and total dichlorodiphenyl-trichloroethylene (DDTs). For the purposes of this report, total DDTs comprise the sum of dichlorodiphenyl-trichloroethane and dichlorodi-phenyl-dichloroethylene compounds. Total PAHs comprise the sum of the concentrations of anthracene, 9H-fluorene, naphthalene, phenanthrene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. no., number]

Site no.	Dam name	Mean PECQ	Estimated likelihood of toxicity of bottom-sediment cores, in percent
1	Factory Village Pond	0.365	32
2	Horseshoe Pond	0.254	23
3	Sheomet Lake	0.262	24
4	North Webster Village Pond	0.204	19
5	Ballardvale	0.583	46
6	Perryville Pond	0.481	39
7	Ipswich Mills	0.132	13
8	Pentucket Pond Outlet	0.221	21
9	Felton Lake	0.428	36
10	Watertown	0.389	33
11	Conway Electric	0.169	16
12	D.F. Rile Grist Mill	0.144	14
13	Mountain Lake	0.211	20
14	Carding Mill Pond	0.327	29
15	Robert Meadow Upper Reservoir	0.191	18
16	Talbot Mills	0.292	26
17	Mill River	0.081	8
18	Windsor Reservoir	0.140	14
19	Mill Pond	1.148	70
20	Mill Pond #1	0.343	30
21	Rice City Pond	0.942	63
22	Assabet River	0.482	39
23	Upper Flints Pond	0.121	12
24	Stony Brook	0.242	22
25	Tel Electric Pond	0.842	59
26	Monument Pond #2	0.085	8
27	Town Brook #1	0.513	41
28	Deleano Pond	0.136	13
29	Worcester Consolidated Station	0.936	62
30	Cooks Canyon Lower Pond	0.212	20
31	Unnamed, Stony Brook	0.222	21
32	Unnamed, Winnetuxet	0.102	10

This evaluation of potential toxicity was intended to distinguish contaminants or contaminant groups that are likely to be associated with adverse biological effects at specific sampling locations. Additionally, these data were calculated for homogenized core samples and may not represent potential toxicity at the present day sediment surface (top 4 inches) where many benthic organisms live and feed. Nevertheless, estimated toxicity values can be used to help evaluate the relative ecological risks present in the studied impoundments.

Relations Among Contaminant Concentrations, Land Use, and Industrial History

Present day land use has been shown to be an accurate predictor of shallow sediment chemistry in certain situations. For example, Chalmers and others (2007, figs. 2 and 3) showed that the percentage of commercial, industrial, and transportation (CIT) land use in a drainage basin can be used to predict concentrations of both individual contaminant concentrations and average PECQs for lake and impoundment sediment accumulated since 1990 in New England. However, predicting potential risk to biota posed by toxic contaminants buried at deeper levels within sediment—representing point- and nonpoint-source contamination from activities in the drainage basin many decades in the past—has not been tested using this approach.

Correlation analysis was conducted to evaluate relations between basin characteristics and sediment contaminant concentrations, following the approach of Chalmers and others (2007). Concentrations of individual inorganic elements and organic compound groups (total PAHs, total PCBs, and total DDTs) were used as response variables. The explanatory variables tested were obtained from publicly available geospatial data layers, and included the drainage basin area upstream of each dam, the number of upstream dams, the percentage of impervious area, the percentage of commercial, industrial, and transportation land use in the basin in 1971 and 2005, and the number of 21E[1] sites (Massachusetts Office of Geographic and Environmental Information, 2009). In addition, the number of factories operating in the 1830s in each drainage basin was obtained from a recent geospatial compilation of historical information (Hall and others, 2002). Information concerning land use in 1971 and the number of factories operating in each drainage basin in the 1830s was included in the analysis (table 7) to represent conditions prior to the effects of the U.S. Clean Water Act, enacted in 1972 (U.S. Environmental Protection Agency, 2011).

[1]Sites noted as 21E sites are oil and (or) hazardous material disposal sites that have been reported and classified under Massachusetts General Laws chapter 21E (General Court of the Commonwealth of Massachusetts, undated) and the Massachusetts Contingency Plan (310 CMR 40.0000; Massachusetts Department of Environmental Protection, undated).

Correlations between several of the response variables and particular explanatory, or landscape, variables were found to be statistically significant (*p* values less than 0.05) or highly significant (*p* less than 0.01; table 8). The landscape variable with the largest number of significant correlations with contaminant concentrations was the number of factories in each drainage area in the 1830s. Concentrations of five of the inorganic elements (chromium, copper, zinc, cadmium, lead) as well as total PAH concentrations were significantly correlated with this variable. Three other landscape variables (number of dams, commercial and industrial land use in 1971, and number of 21E sites) were found to be significantly correlated with inorganic metal concentrations, with each landscape variable showing significant correlations with a different subset of inorganic elements (table 8). One of the inorganic elements (arsenic) and two of the groups of organic compounds (total PCBs and total DDTs) showed no significant correlations with any of the landscape variables.

Other statistical approaches (univariate, multivariate, and logistic regression modeling with and without transformations of variables) were also tested to predict contaminant concentrations and toxicity potential. Numerous individual correlations between chemical concentrations and present day landscape variables were found to be statistically significant (as described above). However, none of the regression models described a sufficient amount of the overall variability to make the models useful for prediction of the depth-averaged, bulk sediment concentration at unsampled impoundments in Massachusetts. These findings suggest that human activities in Massachusetts drainage basins have varied to such an extent during the past 200 years that it may not be feasible to predict the depth-averaged quality of impounded sediment behind most unsampled impoundments, using models based largely on recent land use in the contributing drainage basin. If the objective of a particular investigation is to predict the chemical quality and potential toxicity of recently deposited (post-1990) sediment behind a dam in Massachusetts, existing models relating chemistry and potential toxicity to geospatial indicators of urbanization in New England (for example, Chalmers and others, 2007) may be sufficient for screening purposes. However, if the objective is to characterize average sediment quality and potential toxicity over the entire range of sediment depths, the results of this study suggest that site-specific sampling will likely be required.

The data collected and interpreted for this study could provide a starting point for a statewide database of information concerning Massachusetts impoundments. Such a database could include data on impoundment water depths (bathymetry), impounded sediment thicknesses, sediment chemical quality, and potential toxicity of sediment to benthic organisms. This information could be used to help prioritize sites for dam removal, and to inform impounded sediment management decisions in the Commonwealth.

Table 7. Land use characteristics of selected impoundment drainage areas in Massachusetts.

[Percent industrial, commercial, and transportation land use from the Massachusetts Office of Geographic and Environmental Information (2009). Sites designated as 21E sites are oil and (or) hazardous material disposal sites that have been reported and classified under Massachusetts General Laws chapter 21E (General Court of the Commonwealth of Massachusetts, undated) and the Massachusetts Contingency Plan (310 CMR 40.0000; Massachusetts Department of Environmental Protection, undated). Information on Massachusetts factories in 1830s was obtained from Hall and others (2002). no., number; mi^2, square miles]

Site no.	Dam name	Drainage area, in mi^2	No. of dams in drainage area	Impervious, in percent	1971 Land use		2005 Land use			No. of 21E sites in drainage area	No. of factories in 1830s
					Industrial, in percent	Commercial, in percent	Industrial, in percent	Commercial, in percent	Transportation, in percent		
1	Factory Village Pond	5.2	4	4.8	0.23	0.33	0.23	0.36	0	2	5
2	Horseshoe Pond	57.1	57	9.6	0.01	0.15	0.21	0.50	1.3	5	11
3	Sheomet Lake	5.5	1	1.1	0	0	0	0	0	0	0
4	North Webster Village Pond	83.3	51	8.0	0.20	0.61	0.63	0.90	1.4	22	30
5	Ballardvale	65.7	8	20.1	3.0	1.7	5.9	2.5	3.6	50	4
6	Perryville Pond	93.3	65	8.6	0.35	0.76	0.76	1.1	1.3	40	37
7	Ipswich Mills	150	53	11.2	0.48	0.77	1.2	1.2	0.99	45	22
8	Pentucket Pond Outlet	7.5	1	8.2	0.12	0.29	0.13	0.46	0.09	2	0
9	Felton Lake	0.8	1	0.78	0	0	0	0	0	0	0
10	Watertown	273	86	16.4	1.3	1.4	2.4	1.8	1.5	146	69
11	Conway Electric	26.0	4	2.2	0	0.16	0.01	0.21	0	0	2
12	D.F. Rile Grist Mill	47.5	7	4.3	0.28	0.21	0.96	0.57	1.4	3	10
13	Mountain Lake	2.2	1	37.9	0	5.1	1.3	5.3	5.6	1	0
14	Carding Mill Pond	3.9	3	12.1	0	2.1	0	4.7	0	0	0
15	Robert Meadow Upper Reservoir	8.8	1	1.3	0	0	0	0	0	0	1
16	Talbot Mills	368	135	12.9	0.98	1.6	2.2	2.3	1.4	112	40
17	Mill River	41.1	18	9.5	0.17	0.19	1.2	0.50	1.4	5	8
18	Windsor Reservoir	14.8	1	1.6	0	0.04	0	0.04	0.09	0	1
19	Mill Pond	58.8	38	6.3	0.59	0.20	1.2	0.39	0.95	11	18
20	Mill Pond #1	8.4	5	10.7	0.02	0.39	1.2	0.94	0.50	0	0
21	Rice City Pond	147	107	18.5	2.1	2.4	3.0	2.9	2.5	121	47
22	Assabet River	30.0	25	13.8	0.24	1.0	1.6	2.5	1.4	8	6
23	Upper Flints Pond	7.9	1	9.6	0	0.06	0.91	0.41	2.3	1	0
24	Stony Brook	4.3	5	7.2	0	0.30	0	0.62	0	0	0
25	Tel Electric Pond	36.1	7	5.4	0.26	0.70	0.26	0.81	0.08	5	4
26	Monument Pond #2	20.7	6	6.7	0.02	0.08	0.06	0.14	0.88	0	0
27	Town Brook #1	8.5	6	10.7	0.05	0.39	1.2	0.94	0.49	0	1
28	Deleano Pond	0.3	1	8.5	0	0	0	0	0	0	0
29	Worcester Consolidated Station	83.1	72	20.4	3.0	2.9	3.9	3.3	3.3	98	25
30	Cooks Canyon Lower Pond	1.6	1	4.5	0.67	0.01	0	0.01	0	0	0
31	Unnamed, Stony Brook	4.4	6	7.2	0	0.30	0	0.62	0	0	0
32	Unnamed, Winnetuxet	10.9	14	14.0	0.20	0.14	0.77	0.84	0.34	3	0

Table 8. Relations between sediment-core contaminant concentrations and land use in the drainage areas of selected impoundments in Massachusetts.

[CIT 2005 is the sum of commercial, industrial, and transportation land use for 2005; CI 1971 is the sum of commercial and industrial land use for 1971. Number of 21E sites is the number of oil and (or) hazardous material disposal sites that have been reported and classified under Massachusetts General Laws chapter 21E and the Massachusetts Contingency Plan. *r* is the Pearson's correlation coefficient. *p* value, a measure of statistical significance; *p* values less than 0.05 are considered significant and are in bold type. The number of factories in 1830s was obtained from Hall and others (2002); all other information was obtained from the Massachusetts Office of Geographic and Environmental Information (2009). DDT, dichlorodiphenyl-trichloroethane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl]

Landscape characteristic	Chromium		Nickel		Copper		Zinc		Arsenic	
	r	*p* value	*r*	*p* value	*r*	*p* value	*r*	*p* value	*r*	*p* value
Drainage area, in square miles	0.295	0.101	0.083	0.652	0.206	0.259	0.224	0.218	0.022	0.907
Number of dams	0.489	**0.004**	0.192	0.293	0.491	**0.004**	0.435	**0.013**	0.140	0.443
Impervious cover, in percent	0.168	0.357	0.120	0.515	0.339	0.057	0.168	0.357	0.207	0.256
CIT 2005, in percent	0.273	0.130	0.239	0.187	0.486	**0.005**	0.317	0.077	0.127	0.490
CI 1971, in percent	0.329	0.066	0.417	**0.018**	0.615	**0.000**	0.437	**0.012**	0.155	0.398
Number of 21E sites	0.417	**0.018**	0.317	0.077	0.523	**0.002**	0.416	**0.018**	0.130	0.480
Number of factories in the 1830s	0.500	**0.004**	0.159	0.386	0.398	**0.024**	0.394	**0.026**	0.047	0.800
	Cadmium		**Lead**		**Total PAH**		**Total PCB**		**Total DDT**	
	r	*p* value	*r*	*p* value	*r*	*p* value	*r*	*p* value	*r*	*p* value
Drainage area, in square miles	0.195	0.286	0.189	0.301	0.293	0.104	0.055	0.764	-0.212	0.245
Number of dams	0.398	**0.024**	0.316	0.078	0.316	0.078	0.144	0.431	-0.242	0.182
Impervious cover, in percent	0.122	0.506	0.203	0.266	0.049	0.790	-0.060	0.745	-0.059	0.750
CIT 2005, in percent	0.249	0.170	0.242	0.182	0.058	0.755	0.029	0.874	-0.130	0.478
CI 1971, in percent	0.346	0.052	0.360	**0.043**	0.121	0.511	0.065	0.724	-0.080	0.663
Number of 21E sites	0.377	**0.034**	0.337	0.059	0.340	0.057	0.056	0.760	-0.199	0.276
Number of factories in the 1830s	0.397	**0.024**	0.366	**0.039**	0.508	**0.003**	0.141	0.440	-0.209	0.251

Summary

Contaminants in impounded sediment may be a source of contaminants to the overlying water column, to organisms that live on or in bottom sediment, and to wildlife and humans that come into contact with contaminated sediment. Such sediment may also be an ongoing source for resuspension, downstream transport, and dispersal of contaminants. The U.S. Geological Survey and the Massachusetts Department of Fish and Game, Division of Ecological Restoration collaborated to collect baseline information describing the thickness of impounded sediment and the concentrations of sediment-associated contaminants behind 32 dams throughout Massachusetts. Sediment-core samples were collected, and concentrations of 32 inorganic elements and 108 organic compounds were quantified.

Sediment thicknesses across the 32 impoundments ranged from 0 to more than 20 feet and averaged 3.7 feet. Bottom-sediment volumes—estimated by multiplying the average sediment thickness by impoundment surface area—ranged from about 55,000 cubic feet to 81 million cubic feet. Concentrations of contaminants toxic to benthic organisms, as well as the number detected above laboratory reporting levels, varied greatly among sampling locations. Of the impoundments sampled, the highest concentrations of inorganic elements and organic compounds generally were measured in samples collected from impoundments downstream of present or former urban and industrial areas, including the Blackstone and North Nashua Rivers (elements) and the Shawsheen River (organic compounds). The estimated probability of toxicity of bottom sediment ranged from about 8 to 70 percent among the sampling locations and averaged slightly under 30 percent. Statistically significant correlations (p less than 0.05) were found between concentrations of some of the contaminants and upstream basin characteristics. In particular, significant correlations were found between the number of factories operating in each drainage basin in the 1830s and the concentrations of several inorganic elements (cadmium, chromium, copper, lead, and zinc) as well as total PAH concentrations. However, predictive statistical models developed from the data were found to have a high degree of uncertainty. This result is consistent with the complex industrial history to which impoundments in Massachusetts have typically been subjected over their periods of deposition. This result also indicates that site-specific sampling may likely be required to characterize overall, depth-averaged sediment quality at unsampled impoundments in Massachusetts.

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Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	1,2,4-Trichlorobenzene, in ppb	1,2-Dichlorobenzene, in ppb	1,2-Dimethylnaphthalene, in ppb	1,3-Dichlorobenzene, in ppb	1,4-Dichlorobenzene, in ppb	1,6-Dimethylnaphthalene, in ppb	1-Methyl-9H-fluorene, in ppb	1-Methylphenanthrene, in ppb	1-Methyl pyrene, in ppb	2,2′-Biquinoline, in ppb
1	Factory Village Pond	<180	<180	<180	<180	<180	e43	<180	e110	e130	<180
2	Horseshoe Pond	<320	<320	<320	<320	<320	<320	<320	<320	<320	<320
3	Sheomet Lake	<63	<63	<63	<63	<63	e14	e20	98	e68	<63
4	North Webster Village Pond	<85	<85	<85	<85	<85	e23	e26	<85	e30	<85
5	Ballardvale	e34	e54	870	<70	120	1,700	1,400	3,900	2,800	<70
6	Perryville Pond	<78	e8	e30	<78	<78	e42	e46	94	e64	<78
7	Ipswich Mills	<310	<310	<310	<310	<310	<310	<310	<310	e44	<310
8	Pentucket Pond Outlet	<320	<320	<320	<320	<320	<320	<320	<320	<320	<320
9	Felton Lake	<62	<62	82	<62	<62	140	240	1,000	880	150
10	Watertown	<62	<62	e21	<62	<62	e20	e30	e38	e34	<62
11	Conway Electric	<120	<120	<120	<120	<120	<120	e42	e40	e51	<120
12	D.F. Rile Grist Mill	<64	<64	e18	<64	<64	e27	e30	77	75	<64
13	Mountain Lake	<200	<200	<200	<200	<200	e62	<200	<200	<200	<200
14	Carding Mill Pond	<100	<100	e27	<100	<100	e57	e79	290	190	<100
15	Robert Meadow Upper Reservoir	<130	<130	e20	<130	<130	<130	<130	e54	<130	<130
16	Talbot Mills	<160	<160	<160	<160	<160	e34	e59	e110	e100	<160
17	Mill River	<58	<58	<58	<58	<58	<58	<58	<58	<58	<58
18	Windsor Reservoir	<64	<64	<64	<64	<64	e15	<64	e30	<64	<64
19	Mill Pond	<80	<80	87	<80	<80	360	100	200	170	<80
20	Mill Pond #1	<290	<290	<290	<290	<290	e88	<290	e200	e180	<290
21	Rice City Pond	e27	<70	<70	<70	e16	120	120	170	240	<70
22	Assabet River	<140	<140	<140	<140	<140	e67	e68	e110	e120	<140
23	Upper Flints Pond	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
24	Stony Brook	<330	<330	<330	<330	<330	e47	e50	e38	e64	<330
25	Tel Electric Pond	e39	e61	e77	<85	e71	140	170	850	800	<85
26	Monument Pond #2	<66	<66	<66	<66	<66	e11	<66	e18	e14	<66
27	Town Brook #1	<120	<120	e55	<120	<120	130	160	600	290	<120
28	Deleano Pond	<650	<650	<650	<650	<650	e260	e250	e210	e280	e580
29	Worcester Consolidated Station	e13	e29	160	<65	<65	270	320	700	480	<65
30	Cooks Canyon Lower Pond	<75	<75	e43	<75	e10	e70	e69	200	140	<75
31	Unnamed, Stony Brook	<430	<430	<430	<430	<430	e53	<430	<430	<430	<430
32	Unnamed, Winnetuxet	<300	<300	<300	<300	<300	<300	<300	e43	<300	<300

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	2,3,6-Trimethylnaphthalene, in ppb	2,4,6-Trichlorophenol, in ppb	2,4,6-Trimethylphenol, in ppb	2,4-Dichlorophenol, in ppb	2,4-Dinitrophenol, in ppb	2,4-Dinitrotoluene, in ppb	2,6-Dimethylnaphthalene, in ppb	2,6-Dinitrotoluene, in ppb	2-Chloronaphthalene, in ppb	2-Chlorophenol, in ppb
1	Factory Village Pond	e39	--	--	--	--	<180	e100	<180	<180	<180
2	Horseshoe Pond	<320	--	--	--	--	<320	e180	<320	<320	<320
3	Sheomet Lake	<63	--	--	--	--	<63	e27	<63	<63	<63
4	North Webster Village Pond	<85	--	--	--	--	<85	e50	<85	<85	<85
5	Ballardvale	1,000	--	--	--	--	<70	2,300	<70	<70	<70
6	Perryville Pond	e40	--	--	--	--	<78	e54	<78	<78	<78
7	Ipswich Mills	<310	--	--	--	--	<310	e94	<310	<310	<310
8	Pentucket Pond Outlet	<320	--	--	--	--	<320	e71	<320	<320	<320
9	Felton Lake	180	--	<68	--	--	<68	260	<65	<62	<62
10	Watertown	e25	--	--	--	--	<62	e24	<62	<62	<62
11	Conway Electric	e46	--	--	--	--	<120	e61	690	<120	<120
12	D.F. Rile Grist Mill	e28	--	--	--	--	<64	e53	<64	<64	<64
13	Mountain Lake	<200	--	--	--	--	<200	330	<200	<200	<200
14	Carding Mill Pond	<100	--	--	--	--	<100	110	<100	<100	<100
15	Robert Meadow Upper Reservoir	<130	--	--	--	--	<130	e56	<130	<130	<130
16	Talbot Mills	<160	--	--	--	--	<160	e70	<160	<160	<160
17	Mill River	<58	--	--	--	--	<58	e13	<58	<58	<58
18	Windsor Reservoir	<64	--	--	--	--	<64	e18	<64	<64	<64
19	Mill Pond	160	--	--	--	<98	<80	440	<80	<80	<80
20	Mill Pond #1	<290	--	--	--	--	<290	e290	<290	<290	<290
21	Rice City Pond	120	--	--	--	--	<70	200	<70	<70	<70
22	Assabet River	e69	--	--	--	--	<140	e87	870	<140	<140
23	Upper Flints Pond	<100	--	--	--	--	<100	e44	<100	<100	<100
24	Stony Brook	<330	--	--	--	--	<330	e100	<330	<330	<330
25	Tel Electric Pond	100	--	--	--	--	<85	200	<85	<85	<85
26	Monument Pond #2	e0	--	--	--	--	<66	e16	<66	<66	<66
27	Town Brook #1	e100	--	--	--	--	<120	230	<120	<120	<120
28	Deleano Pond	<650	--	--	--	--	<650	e520	3,800	<650	<650
29	Worcester Consolidated Station	240	--	--	--	--	<65	450	<65	<65	<65
30	Cooks Canyon Lower Pond	83	--	--	--	--	<75	100	440	<75	<75
31	Unnamed, Stony Brook	<430	--	--	--	--	<430	e160	<430	<430	<430
32	Unnamed, Winnetuxet	<300	--	--	--	--	<300	e58	<300	<300	<300

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	2-Ethylnaphthalene, in ppb	2-Methyl-4,6-dinitrophenol, in ppb	2-Methylanthracene, in ppb	2-Nitrophenol, in ppb	3,5-Dimethylphenol, in ppb	3-Nitrophenol, in ppb	4-Bromophenyl phenyl ether, in ppb	4-Chloro-3-methylphenol, in ppb	4-Chlorophenylphenyl ether, in ppb
1	Factory Village Pond	e26	--	<180	--	<180	--	<180	<180	<180
2	Horseshoe Pond	<320	--	<320	--	<320	--	<320	<320	<320
3	Sheomet Lake	e17	--	e40	--	<63	--	<63	<63	<63
4	North Webster Village Pond	e22	--	<85	--	<85	--	<85	<85	<85
5	Ballardvale	2,000	--	3,200	--	<70	--	<70	<70	<70
6	Perryville Pond	e31	--	e66	--	<78	--	<78	<78	<78
7	Ipswich Mills	<310	--	<310	--	<310	--	<310	<310	<310
8	Pentucket Pond Outlet	<320	--	<320	--	<320	--	<320	<320	<320
9	Felton Lake	110	--	800	--	e39	--	<62	<62	<62
10	Watertown	<62	--	e36	--	<62	--	<62	<62	<62
11	Conway Electric	<120	--	e45	--	<120	--	<120	<120	<120
12	D.F. Rile Grist Mill	e24	--	e47	--	<64	--	<64	<64	<64
13	Mountain Lake	<200	--	<200	--	<200	--	<200	<200	<200
14	Carding Mill Pond	e48	--	160	--	<100	--	<100	<100	<100
15	Robert Meadow Upper Reservoir	<130	--	<130	--	<130	--	<130	<130	<130
16	Talbot Mills	<160	--	<160	--	<160	--	<160	<160	<160
17	Mill River	<58	--	<58	--	<58	--	<58	<58	<58
18	Windsor Reservoir	<64	--	e30	--	<64	--	<64	<64	<64
19	Mill Pond	120	--	<80	--	<80	--	<80	<1,200	<80
20	Mill Pond #1	<290	--	<290	--	<290	--	<290	<290	<290
21	Rice City Pond	87	--	120	--	<70	--	<70	<70	<70
22	Assabet River	<140	--	e99	--	<140	--	<140	<140	<140
23	Upper Flints Pond	<100	--	<100	--	<100	--	<100	<100	<100
24	Stony Brook	<330	--	<330	--	<330	--	<330	<330	<330
25	Tel Electric Pond	e80	--	560	--	<85	--	<85	<85	<85
26	Monument Pond #2	e9	--	<66	--	<66	--	<66	<66	<66
27	Town Brook #1	e77	--	360	--	<120	--	<120	<120	<120
28	Deleano Pond	<650	--	e220	--	<650	--	<650	<650	<650
29	Worcester Consolidated Station	340	--	410	--	<65	--	<65	<65	<65
30	Cooks Canyon Lower Pond	e31	--	110	--	<75	--	<75	<75	<75
31	Unnamed, Stony Brook	<430	--	<430	--	<430	--	<430	<430	<430
32	Unnamed, Winnetuxet	<300	--	<300	--	<300	--	<300	<300	<300

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	4H-Cyclopenta[def]phenanthrene, in ppb	9,10-Anthraquinone, in ppb	9H-Fluorene, in ppb	Acenaphthene, in ppb	Acenaphthylene, in ppb	Acridine, in ppb	Aldrin, in ppb	alpha-Endosulfan, in ppb	alpha-HCH, in ppb
1	Factory Village Pond	e140	240	e100	e31	e110	<180	1	<3	<3
2	Horseshoe Pond	<320	e260	<320	<320	e78	<320	<6	<6	<6
3	Sheomet Lake	e39	e62	e22	e10	e38	e26	<1	<1	<1
4	North Webster Village Pond	e20	e59	e34	e26	e38	<85	<2	<2	<2
5	Ballardvale	4,900	<70	4,400	5,800	2,700	<70	2	<1	M
6	Perryville Pond	100	130	e71	e34	100	<78	<1	<1	<1
7	Ipswich Mills	e52	<310	<310	<310	<310	<310	<6	<6	<6
8	Pentucket Pond Outlet	<320	<320	<320	<320	<320	<320	<6	<6	<6
9	Felton Lake	1,700	1,400	940	510	1,400	400	<1	<1	<1
10	Watertown	e58	72	e51	e23	e54	<62	<1	<1	<1
11	Conway Electric	e53	e63	e51	e33	e65	<120	<2	<2	<2
12	D.F. Rile Grist Mill	100	150	74	e28	93	e54	<1	<1	<1
13	Mountain Lake	e34	e130	<200	e22	e60	<200	<4	<4	<4
14	Carding Mill Pond	270	450	170	e71	580	<100	<2	<2	<2
15	Robert Meadow Upper Reservoir	e47	e120	<130	e18	e61	<130	<3	<3	<3
16	Talbot Mills	e160	250	e90	e34	e140	<160	<3	<3	<3
17	Mill River	e11	e38	<58	e5	e15	<58	<1	<1	<1
18	Windsor Reservoir	e43	e62	e40	e13	e33	<64	<1	<1	<1
19	Mill Pond	200	<80	180	96	180	<80	<1	<1	<1
20	Mill Pond #1	e280	500	e190	e88	e150	<290	<6	<6	<6
21	Rice City Pond	160	110	140	89	390	<70	<1	<1	<1
22	Assabet River	160	190	e96	e63	190	<140	<2	<2	<2
23	Upper Flints Pond	e12	e58	e25	<100	e26	<100	<2	<2	<2
24	Stony Brook	e45	e130	e45	<330	e62	<330	<6	<6	<6
25	Tel Electric Pond	1,200	1,700	720	460	1,800	160	<1	<1	<1
26	Monument Pond #2	e8	e46	<66	e5	<66	<66	<1	<1	<1
27	Town Brook #1	640	670	520	460	370	170	<2	<2	<2
28	Deleano Pond	e340	e500	e260	e160	e310	e160	<13	<13	<13
29	Worcester Consolidated Station	590	<65	670	620	620	<65	<1	<4	<1
30	Cooks Canyon Lower Pond	200	220	120	e56	340	<75	<1	<1	<1
31	Unnamed, Stony Brook	<430	<430	<430	<430	e50	<430	<8	<8	<8
32	Unnamed, Winnetuxet	<300	<300	<300	<300	<300	<300	<6	<6	<6

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	Anthracene, in ppb	Azobenzene, in ppb	Benzo[a]anthracene, in ppb	Benzo[a]pyrene, in ppb	Benzo[b]fluoranthene, in ppb	Benzo[c]cinnoline, in ppb	Benzo[ghi]perylene, in ppb	Benzo[k]fluoranthene, in ppb	Benzyl n-butyl phthalate, in ppb	beta-HCH, in ppb
1	Factory Village Pond	220	<180	500	490	780	<180	e160	270	<190	<3
2	Horseshoe Pond	e100	<320	e170	<320	330	<320	e160	e130	<380	<6
3	Sheomet Lake	e47	<63	150	150	e160	<63	e74	e68	<63	<1
4	North Webster Village Pond	e40	<85	e58	e74	88	<85	<85	e36	<100	<2
5	Ballardvale	9,600	<70	9,000	8,000	4,700	<70	1,200	5,200	<70	<1
6	Perryville Pond	120	<78	300	e300	540	<78	e210	200	<78	<1
7	Ipswich Mills	e60	<310	<310	<310	<310	<310	<310	<310	<310	<6
8	Pentucket Pond Outlet	<320	<320	e98	<320	<320	<320	<320	<320	<380	<6
9	Felton Lake	2,400	<1,000	6,200	6,300	7,400	<62	e4,400	3,300	e260	<1
10	Watertown	e61	<62	140	e150	250	<62	e140	120	<62	<1
11	Conway Electric	e70	<120	130	e120	e100	<120	e95	e110	V	<2
12	D.F. Rile Grist Mill	120	<64	300	370	590	<64	e200	230	<100	<1
13	Mountain Lake	e62	<200	e91	e130	e160	<200	<200	e63	<290	<4
14	Carding Mill Pond	390	<100	760	1,100	940	<100	740	890	<170	<2
15	Robert Meadow Upper Reservoir	e66	<130	e120	140	e220	<130	<130	e96	<150	<3
16	Talbot Mills	180	<160	460	480	e740	<160	e230	290	<160	<3
17	Mill River	e17	<58	e25	e35	e45	<58	e34	e23	<58	<1
18	Windsor Reservoir	e61	<64	120	120	150	<64	e85	78	<75	<1
19	Mill Pond	310	<200	510	420	410	<80	260	320	<80	<1
20	Mill Pond #1	e260	<290	920	1,100	1,800	<290	e620	750	<550	<6
21	Rice City Pond	370	<70	560	630	e440	<70	510	e520	V	<1
22	Assabet River	260	<140	590	480	500	<140	340	500	V	<2
23	Upper Flints Pond	e26	<100	e35	e56	e49	<100	<100	e19	<140	<2
24	Stony Brook	e74	<330	e130	e160	e200	<330	e120	e140	420	<6
25	Tel Electric Pond	2,300	<85	4,900	5,600	5,200	<85	3,700	4,800	V	<1
26	Monument Pond #2	e14	<66	e19	e22	e27	<66	e22	e12	<110	<1
27	Town Brook #1	840	<120	1,700	1,600	1,400	<120	1,000	1,400	<210	<2
28	Deleano Pond	e300	<650	720	790	880	<650	e680	800	V	<13
29	Worcester Consolidated Station	860	<65	1,500	1,400	1,100	<65	890	1,000	e160	<1
30	Cooks Canyon Lower Pond	360	<75	890	1,200	1,000	<75	790	920	V	<1
31	Unnamed, Stony Brook	e67	<430	e100	e140	e99	<430	e140	e80	e390	<8
32	Unnamed, Winnetuxet	e36	<300	<300	<300	<300	<300	<300	<300	e290	<6

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	Bis(2-chloroethoxy) methane, in ppb	Bis(2-chloroethyl) ether, in ppb	Bis(2-chloroisopropyl) ether, in ppb	Bis(2-ethylhexyl) phthalate, in ppb	C8-Alkylphenol, in ppb	Carbazole, in ppb	Chloroneb, in ppb	Chrysene, in ppb	cis-Chlordane, in ppb	cis-Nonachlor, in ppb
1	Factory Village Pond	<180	<180	--	<190	<180	e75	8	560	<3	<3
2	Horseshoe Pond	<320	<320	--	e1,000	e95	<320	<30	e200	<6	<6
3	Sheomet Lake	<63	<63	--	e120	<63	<63	<5	170	<1	<1
4	North Webster Village Pond	<85	<85	--	<85	<85	e38	<8	e61	<2	<2
5	Ballardvale	<70	<70	--	2,200	<70	140	<5	8,800	M	<1
6	Perryville Pond	<78	<78	--	<100	<78	e45	<5	390	M	M
7	Ipswich Mills	<310	<310	--	<310	e88	<310	<30	<310	<6	<6
8	Pentucket Pond Outlet	<320	<320	--	<320	<320	<320	<30	e95	<6	<6
9	Felton Lake	<62	<62	--	12,000	e49	560	<5	7,100	<1	e1
10	Watertown	<62	<62	--	<62	<62	e28	<5	150	<1	<1
11	Conway Electric	<120	<120	--	V	<120	e23	<10	130	<2	<2
12	D.F. Rile Grist Mill	<64	<64	--	740	<64	e51	<5	470	10	2
13	Mountain Lake	<200	<200	--	<230	<200	<200	<20	e96	<4	<4
14	Carding Mill Pond	<100	<100	--	e220	<100	160	<10	1,000	<2	<2
15	Robert Meadow Upper Reservoir	<130	<130	--	<130	e53	<130	<15	150	<3	<3
16	Talbot Mills	<160	<160	--	<240	e69	<160	<15	570	<3	<3
17	Mill River	<58	<58	--	<58	<58	<58	<5	e27	<1	<1
18	Windsor Reservoir	<64	<64	--	<.0	e23	e25	<5	120	<1	<1
19	Mill Pond	<80	<80	--	82	<80	e46	<5	680	<1	<2
20	Mill Pond #1	<290	<290	--	<480	e110	e170	<30	1,300	<6	<6
21	Rice City Pond	<70	<70	--	1,600	<70	e28	<5	830	4	M
22	Assabet River	<140	<140	--	1,300	<140	e69	<10	720	3	e1
23	Upper Flints Pond	<100	<100	--	<100	<100	<100	<10	e22	<2	<2
24	Stony Brook	<330	<330	--	e220	<330	<330	<30	e180	<6	<12
25	Tel Electric Pond	<85	<85	--	1,400	<85	760	<5	6,400	4	M
26	Monument Pond #2	<66	<66	--	<66	<66	<66	<5	e18	<1	<1
27	Town Brook #1	<120	<120	--	<170	e68	450	<12	1,800	<2	<2
28	Deleano Pond	<650	<650	--	V	<650	e160	<65	1,000	15	e10
29	Worcester Consolidated Station	<65	<65	--	1,000	<65	140	<5	1,600	e2	<1
30	Cooks Canyon Lower Pond	<75	<75	--	V	<75	95	<5	1,100	M	<1
31	Unnamed, Stony Brook	<430	<430	--	1,400	<430	<430	<40	e130	<8	<16
32	Unnamed, Winnetuxet	<300	<300	--	e88	<300	<300	<30	<300	<6	<12

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	cis-Permethrin, in ppb	DCPA, in ppb	Dibenzo[a,h] anthracene, in ppb	Dibenzothiophene, in ppb	Dieldrin, in ppb	Diethyl phthalate, in ppb	Dimethyl phthalate, in ppb	Di-n-butyl phthalate, in ppb	Di-n-octyl phthalate, in ppb	Endrin, in ppb
1	Factory Village Pond	<15	<15	<180	<180	2	<180	<180	<180	<180	<6
2	Horseshoe Pond	<30	<30	<320	<320	<6	e82	<320	<320	<320	<12
3	Sheomet Lake	<5	<5	e40	<63	<1	<63	<63	<63	<63	<2
4	North Webster Village Pond	<8	<8	<85	<85	<2	<85	<85	<85	<85	<3
5	Ballardvale	<5	<5	770	1,700	20	V	<70	<70	<70	<2
6	Perryville Pond	<5	<5	<78	e54	<1	<78	<78	<78	<78	<2
7	Ipswich Mills	<30	<30	<310	<310	<6	<310	<310	<310	<310	<12
8	Pentucket Pond Outlet	<30	<30	<320	<320	<6	<320	<320	<320	<320	<12
9	Felton Lake	<5	<5	e260	560	<1	<62	<62	e130	e200	<2
10	Watertown	<5	<5	<62	e32	<1	<62	<62	<62	<62	<2
11	Conway Electric	<10	<10	e36	e39	<2	V	<120	V	<120	<4
12	D.F. Rile Grist Mill	<5	<5	e48	e42	e2	<64	<64	<64	<64	<2
13	Mountain Lake	<20	<20	<200	<200	<4	<200	<200	<200	<200	<8
14	Carding Mill Pond	<10	<10	350	110	<2	<100	<100	<100	<100	<4
15	Robert Meadow Upper Reservoir	<15	<15	e79	<130	<3	<130	<130	<130	<130	<6
16	Talbot Mills	<15	<15	<160	<160	e3	<160	<160	<160	<160	<6
17	Mill River	<5	<5	<58	<58	<1	<58	<58	<58	<58	<2
18	Windsor Reservoir	<5	<5	<64	e24	<1	<64	<64	<64	<64	<2
19	Mill Pond	<5	<5	<140	100	<1	<80	<80	<80	<80	<2
20	Mill Pond #1	<30	<30	e100	e120	<6	<290	<290	<290	<290	<12
21	Rice City Pond	<5	<5	180	100	65	V	<70	<70	<70	M
22	Assabet River	<10	<10	e120	e73	<2	V	<140	V	<140	<4
23	Upper Flints Pond	<10	<10	<100	<100	<2	<100	<100	<100	<100	<4
24	Stony Brook	<30	<30	<330	<330	<6	<330	<330	e170	<330	<12
25	Tel Electric Pond	<5	<5	1,200	370	<1	V	<85	V	<85	<2
26	Monument Pond #2	<5	<5	<66	<66	<1	<66	<66	<66	<66	<2
27	Town Brook #1	<12	<12	460	280	<2	<120	<120	<120	<120	<5
28	Deleano Pond	<65	<65	e250	e220	<13	V	<650	V	<650	<26
29	Worcester Consolidated Station	<5	<5	330	290	<1	<65	<65	<65	<65	<2
30	Cooks Canyon Lower Pond	<5	<5	380	84	<1	V	<75	V	<75	<2
31	Unnamed, Stony Brook	<40	<40	<430	<430	<8	<430	<430	e210	<430	<16
32	Unnamed, Winnetuxet	<30	<30	<300	380	<6	<300	<300	e140	<300	<12

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	Fluoranthene, in ppb	Heptachlor epoxide, in ppb	Heptachlor, in ppb	Hexachlorobenzene, in ppb	Hexachlorobutadiene, in ppb	Hexachlorocyclopentadiene, in ppb	Hexachloroethane, in ppb	Indeno[1,2,3-cd]pyrene, in ppb	Isodrin, in ppb	Isophorone, in ppb
1	Factory Village Pond	900	<3	<3	<3	--	--	--	e180	<3	<180
2	Horseshoe Pond	390	<6	<6	<6	--	--	--	<320	<6	<320
3	Sheomet Lake	170	<1	<1	<1	--	--	--	e75	<1	<63
4	North Webster Village Pond	120	<2	<2	<2	--	--	--	e78	<1	<85
5	Ballardvale	14,000	<1	<1	2	--	--	--	3,600	<1	<70
6	Perryville Pond	730	<1	<1	<1	--	--	--	e210	<1	<78
7	Ipswich Mills	e72	<6	<6	3	--	--	--	<310	<6	<310
8	Pentucket Pond Outlet	e160	<6	<6	e12	--	--	--	<320	<6	<320
9	Felton Lake	14,000	<1	<1	<1	--	--	--	4,200	<1	<62
10	Watertown	360	<1	<1	<1	--	--	--	e130	<1	<62
11	Conway Electric	230	<2	<2	<2	--	--	--	e75	<2	<120
12	D.F. Rile Grist Mill	830	<1	<1	<1	--	--	--	210	<1	<64
13	Mountain Lake	e190	<4	<4	<4	--	--	--	e160	<1	<200
14	Carding Mill Pond	1,700	<2	<2	<2	--	--	--	770	<1	<100
15	Robert Meadow Upper Reservoir	320	<3	<3	<3	--	--	--	e120	<3	<130
16	Talbot Mills	1,100	<3	<3	<3	--	--	--	e250	<3	<160
17	Mill River	e55	<1	<1	<1	--	--	--	e39	<1	<58
18	Windsor Reservoir	260	<1	<1	<1	--	--	--	86	<1	<64
19	Mill Pond	1,200	<1	<1	<1	--	--	--	310	<1	<80
20	Mill Pond #1	2,500	<6	<6	<6	--	--	--	e650	<6	<290
21	Rice City Pond	980	<1	<1	<1	--	--	--	640	<1	<70
22	Assabet River	1,400	<2	<2	<2	--	--	--	400	<2	<140
23	Upper Flints Pond	e69	<2	<2	<2	--	--	--	<100	<1	<100
24	Stony Brook	350	<6	<6	<6	--	--	--	e140	<6	<330
25	Tel Electric Pond	12,000	<1	<1	M	--	--	--	4,100	<1	<85
26	Monument Pond #2	e37	<1	<1	<1	--	--	--	e22	<1	<66
27	Town Brook #1	3,800	<2	<2	<2	--	--	--	1,100	<1	<120
28	Deleano Pond	2,000	<13	<13	<13	--	--	--	e560	<13	<650
29	Worcester Consolidated Station	2,400	<1	<1	<1	--	--	--	890	<1	<65
30	Cooks Canyon Lower Pond	1,600	<1	<1	<1	--	--	--	590	<1	<75
31	Unnamed, Stony Brook	e280	<8	<8	<8	--	--	--	<430	<8	<430
32	Unnamed, Winnetuxet	e120	<6	<6	<6	--	--	--	<300	<6	<300

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	Isoquinoline, in ppb	Lindane, in ppb	Mirex, in ppb	Naphthalene, in ppb	Nitrobenzene, in ppb	N-Nitrosodi-n-propylamine, in ppb	N-Nitrosodi-phenylamine, in ppb	o,p′-DDD, in ppb	o,p′-DDE, in ppb
1	Factory Village Pond	<180	<3	<3	e60	<180	<180	<180	8	<3
2	Horseshoe Pond	<320	<6	<6	e22	<320	<320	<320	2	<6
3	Sheomet Lake	<63	<1	<1	<63	<63	<63	<63	<1	<1
4	North Webster Village Pond	<85	<2	<2	e20	<85	<85	<85	<2	<2
5	Ballardvale	76	<1	<1	2,600	<70	<70	<70	10	2
6	Perryville Pond	<78	<1	<1	e64	<78	<78	<78	3	3
7	Ipswich Mills	<310	<6	<6	<310	<310	<310	<310	<6	<6
8	Pentucket Pond Outlet	<320	<6	<6	<320	<320	<320	<320	<6	<6
9	Felton Lake	<62	<1	<1	410	<62	<62	<68	<1	<1
10	Watertown	<62	<1	<1	e14	<62	<62	<62	1	<1
11	Conway Electric	e47	<2	<2	e19	<120	<120	<120	e1	<2
12	D.F. Rile Grist Mill	<64	<1	<1	e57	<64	<64	<64	6	<1
13	Mountain Lake	<200	<4	<4	<200	<200	<200	<200	<4	<4
14	Carding Mill Pond	<100	<2	<2	120	<100	<100	<100	<2	<2
15	Robert Meadow Upper Reservoir	<130	<3	<3	<130	<130	<130	<130	<3	<3
16	Talbot Mills	<160	<3	<3	e53	<160	<160	<160	<3	<3
17	Mill River	<58	<1	<1	<58	<58	<58	<58	<1	<1
18	Windsor Reservoir	<64	<1	<1	<64	<64	<64	<64	<1	<1
19	Mill Pond	<80	<1	<1	260	<80	<80	<80	<1	<1
20	Mill Pond #1	<290	<6	<6	e64	<290	<290	<290	<6	<6
21	Rice City Pond	<70	<1	<1	190	<70	<70	<70	2	<1
22	Assabet River	<140	<2	<2	e56	<140	<140	<140	11	4
23	Upper Flints Pond	<100	<2	<2	<100	<100	<100	<100	<2	<2
24	Stony Brook	<330	<6	<6	<330	<330	<330	<330	28	<6
25	Tel Electric Pond	<85	<1	<1	340	<85	<85	<85	26	<1
26	Monument Pond #2	e35	<1	<1	88	<66	<66	<66	<1	<1
27	Town Brook #1	e79	<2	<2	280	<120	<120	<120	<2	<2
28	Deleano Pond	<650	13	<13	e100	<650	<650	<650	15	<13
29	Worcester Consolidated Station	<65	<1	<1	950	<65	<65	<65	e5	<1
30	Cooks Canyon Lower Pond	<75	<1	<1	e46	<75	<75	<75	7	M
31	Unnamed, Stony Brook	<430	<8	<8	<430	<430	<430	<430	26	<8
32	Unnamed, Winnetuxet	<300	<6	<6	<300	<300	<300	<300	<6	<6

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	o,p′-DDT, in ppb	o,p′-Metho-xychlor, in ppb	Oxychlordane, in ppb	p,p′-DDD, in ppb	p,p′-DDE, in ppb	p,p′-DDT, in ppb	p,p′-Metho-xychlor, in ppb	Total PCBs, in ppb	p-Cresol, in ppb	Pentachloro-anisole, in ppb
1	Factory Village Pond	<6	<15	<3	42	e24	2	<15	<150	e750	<3
2	Horseshoe Pond	<12	<30	<6	10	7	<12	<30	<300	e2,300	<6
3	Sheomet Lake	<2	<5	<1	<1	e1	<2	<5	<50	<63	<1
4	North Webster Village Pond	<3	<8	<2	<2	e1	<3	<8	<80	160	<2
5	Ballardvale	e1	<5	<1	e19	25	M	<5	110	<70	<1
6	Perryville Pond	<2	<5	<1	11	5	e1	<5	<50	e52	<1
7	Ipswich Mills	<12	<30	<6	<6	1	<12	<30	<300	e88	<6
8	Pentucket Pond Outlet	<12	<30	<6	e21	e9	<12	<30	<300	e190	<6
9	Felton Lake	<2	<5	<1	e27	e12	<2	<5	e270	e160	<1
10	Watertown	<2	<5	<1	5	2	<2	<5	<50	e29	<1
11	Conway Electric	<4	<10	<2	e5	4	<4	<10	<100	<120	<2
12	D.F. Rile Grist Mill	<2	<5	<1	26	e5	e2	<5	e30	e31	<1
13	Mountain Lake	<8	<20	<4	e9	18	<8	<20	<200	<200	<4
14	Carding Mill Pond	<4	<10	<2	e13	e6	e4	<10	<100	220	<2
15	Robert Meadow Upper Reservoir	<6	<15	<3	8	e3	<6	<15	<150	<130	<3
16	Talbot Mills	<6	<15	<3	e4	e4	<6	<15	e50	e130	<3
17	Mill River	<2	<5	<1	<1	<1	<2	<5	<50	<58	<1
18	Windsor Reservoir	<2	<5	<1	2	M	<2	<5	<50	e28	<1
19	Mill Pond	<2	<5	<1	<1	<1	<2	<5	e2,500	<80	<1
20	Mill Pond #1	<12	<30	<6	e38	e31	<12	<30	<300	e170	<6
21	Rice City Pond	M	<5	<1	e6	e11	e2	<5	e660	e43	M
22	Assabet River	<4	<10	<2	e37	22	<4	<10	180	<140	<2
23	Upper Flints Pond	<4	<10	<2	e1	M	<4	<10	<100	e91	<1
24	Stony Brook	<12	<30	<6	e28	62	<12	<30	<300	<330	<6
25	Tel Electric Pond	<2	<5	<1	e92	26	17	<5	810	e75	<1
26	Monument Pond #2	<2	<5	<1	<1	<1	<2	<5	<50	120	<1
27	Town Brook #1	<5	<12	<2	e26	e18	<5	<12	<120	300	<2
28	Deleano Pond	<26	<65	<13	e46	38	<26	<65	<650	<650	<13
29	Worcester Consolidated Station	<2	<5	<1	e14	e11	<2	<5	100	330	<1
30	Cooks Canyon Lower Pond	<2	<5	<1	e16	4	<4	<5	e40	<75	<1
31	Unnamed, Stony Brook	<16	<40	<8	e12	48	<16	<40	<400	<430	<8
32	Unnamed, Winnetuxet	<12	<30	<6	<6	<6	<12	<30	<300	<300	<6

Table 4. Concentrations of organic compounds measured in bottom-sediment cores collected from selected impoundments in Massachusetts in 2004 and 2005.—Continued

[Blue headings indicate members of total PAH group; yellow headings indicate members of total DDT group; gray heading indicates total PCB group. DDTs, dichlorodiphenyl-trichloroethane compounds; e, estimated; M, presence verified but not quantified; PAHs, polycyclic aromatic hydrocarbon compounds; PCBs, polychlorinated biphenyl compounds; ppb, parts per billion; V, value likely affected by contamination; --, not analyzed; <, less than value shown; %, percent]

Site no.	Dam name	Pentachloro-nitrobenzene, in ppb	Pentachloro-phenol, in ppb	Phenan-threne, in ppb	Phenan-thridine, in ppb	Phenol, in ppb	Pyrene, in ppb	Quinoline, in ppb	Toxaphene, in ppb	trans-Chlordane, in ppb	trans-Nonachlor, in ppb	trans-Permethr, in ppb
1	Factory Village Pond	<180	--	500	<180	<180	810	<180	<600	<3	<3	<15
2	Horseshoe Pond	<320	--	e250	<320	<320	330	<320	<1,200	<6	<6	<30
3	Sheomet Lake	<63	--	83	<63	<63	230	<63	<200	<1	<1	<5
4	North Webster Village Pond	<85	--	e81	<85	e38	100	<85	<300	<2	<2	<8
5	Ballardvale	<70	--	17,000	<70	<70	19,000	<70	<200	1	M	<5
6	Perryville Pond	<78	--	420	e36	e42	580	<78	<200	M	<1	<5
7	Ipswich Mills	<310	e240	e33	<310	<310	e60	<310	<1,200	<6	<6	<30
8	Pentucket Pond Outlet	<320	--	e85	<320	e120	e140	<320	<1,200	<6	<6	<30
9	Felton Lake	<62	--	7,800	170	80	12,000	e38	<200	<1	<1	<5
10	Watertown	<62	--	230	e27	100	280	<62	<200	<1	<1	<5
11	Conway Electric	<120	--	160	<120	e93	190	<120	<400	<2	<2	<10
12	D.F. Rile Grist Mill	<64	--	440	<64	e34	750	<64	<200	10	6	<5
13	Mountain Lake	<200	--	e100	<200	e68	e160	<200	<800	e2	<4	<20
14	Carding Mill Pond	<100	--	1,000	<100	e67	1,600	<100	<400	<2	<2	<10
15	Robert Meadow Upper Reservoir	<130	--	200	<130	e46	270	<130	<600	<3	<3	<15
16	Talbot Mills	<160	--	470	<160	e56	990	<160	<600	<3	<3	<15
17	Mill River	<58	--	e22	<58	e10	e48	<58	<200	<1	<1	<5
18	Windsor Reservoir	<64	--	200	<64	e26	200	<64	<200	<1	<1	<5
19	Mill Pond	<80	e830	1,200	<80	e52	1,100	<80	<200	<1	<1	<5
20	Mill Pond #1	<290	--	1,100	<290	e110	1,900	<290	<1,200	<6	<6	<30
21	Rice City Pond	<70	--	690	e41	e190	1,400	<70	<200	4	2	<5
22	Assabet River	<140	--	620	<140	e120	1,200	<140	<400	e2	e1	<10
23	Upper Flints Pond	<100	--	e38	<100	e29	e49	<100	<400	<2	<2	<10
24	Stony Brook	<330	--	e170	<330	e190	e290	<330	<1,200	<6	<6	<30
25	Tel Electric Pond	<85	--	7,400	120	e94	11,000	<85	<200	4	3	<5
26	Monument Pond #2	<66	e570	e58	<66	e37	e32	e23	<200	<1	<1	<5
27	Town Brook #1	<120	--	2,900	<120	e69	3,200	e43	<500	<2	<2	<12
28	Deleano Pond	<650	e1,500	730	<650	e460	1,700	<650	<2,600	e8	e8	<65
29	Worcester Consolidated Station	<65	--	2,500	<65	160	3,000	<65	<200	e3	<1	<5
30	Cooks Canyon Lower Pond	<75	--	1,100	<75	e76	1,600	<75	<200	1	M	<5
31	Unnamed, Stony Brook	<430	--	e130	<430	e610	e220	<430	<1,600	<8	<8	<40
32	Unnamed, Winnetuxet	<300	--	e61	<300	e38	e85	<300	<1,200	<6	<6	<30

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