Massachusetts Probabilistic Monitoring and Assessment Program: Assessment of Lakes (2016-2018)

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Watershed Planning Program

The mission of the Watershed Planning Program (WPP) in the Massachusetts Department of Environmental Protection is to protect, enhance, and restore the quality and value of the waters of the Commonwealth. Guided by the federal Clean Water Act, WPP implements this mission statewide through five Sections that each have a different technical focus: (1) Surface Water Quality Standards; (2) Surface Water Quality Monitoring; (3) Data Management and Water Quality Assessment; (4) Total Maximum Daily Load; and (5) Nonpoint Source Management. Together with other MassDEP programs and state environmental agencies, WPP shares in the duty and responsibility to secure the environmental, recreational, and public health benefits of clean water for all people of the Commonwealth.

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Disclaimer

References to trade names, commercial products, manufacturers, or distributors in this report constituted neither endorsement nor recommendation by MassDEP.

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Abbreviations

AU	Assessment Unit
CALM	Consolidated Assessment and Listing Methodology Guidance Manual
CDF	Cumulative Distribution Function
CI	Confidence Interval
CWA	Clean Water Act
DDT	Dichloro-diphenyl-trichloroethane
DWM	Division of Watershed Management
°F	Degrees Fahrenheit
GHCN	Global Historical Climatology Network
GLA	General Lake Assessment
GRTS	Generalized Random Tessellation Stratified
ha	hectares
HAB	Harmful Algal Bloom
LADI	Lakeshore Anthropogenic Disturbance Index
m	meters
MA DPH	Massachusetts Department of Public Health
MAP2	Massachusetts Probabilistic Monitoring & Assessment Program
MassDEP	Massachusetts Department of Environmental Protection
MassGIS	Massachusetts Bureau of Geographic Information
mg/L	milligrams per liter
MMI	Multimetric Index
MWRA	Massachusetts Water Resources Authority
NARS	National Aquatic Resource Survey
NHD	National Hydrography Dataset
NHEERL	National Health and Environmental Effects Research Laboratory
NCEI	National Centers for Environmental Information
NLA	National Lakes Assessment
NOAA	National Oceanic and Atmospheric Administration
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
PCU	Platinum Cobalt Color Unit
PFAS	Per- and polyfluoroalkyl substances
PWS	Public Water Supply
QA	Quality Assurance
QC	Quality Control
SOP	Standard Operating Procedures
SWQS	Massachusetts Surface Water Quality Standards
TSI	Trophic Status Index
USEPA	United States Environmental Protection Agency
WED	Western Ecology Division
WES	William X. Wall Experiment Station
WPP	Watershed Planning Program

Executive Summary

The *Massachusetts Probabilistic Monitoring and Assessment Program*: *Assessment of Lakes (2016-2018)* report presents the results of an overall assessment of the Commonwealth's lakes. The report encompasses a wide range of lake types – from large, deep lakes to small, shallow lakes and provides information on the condition of designated uses (*Aquatic Life Use*, *Recreation Use,* and *Fish Consumption Use*) as established in the Massachusetts Surface Water Quality Standards (314 Code of Massachusetts Regulations [CMR] 4.00), and key stressors. The target lake population for this survey is defined as all permanent freshwater lakes, reservoirs, and ponds greater than two hectares (ha) in surface area and deeper than two meters (m) at the maximum depth within the Commonwealth of Massachusetts. The word "lake" in this document includes lakes, reservoirs, and ponds. A previous effort for wadeable rivers and streams was the first water resource type assessed within the Massachusetts Probabilistic Monitoring and Assessment Program (MAP2). A future effort will focus on *Aquatic Life Use* in coastal water resources.

The overall goal of MAP2 is to provide an unbiased and statistically valid assessment on the condition of selected designated uses in all waters of the state and key stressors. The goals of the lakes assessment were to determine the extent of the lakes target population supporting *Aquatic Life Use, Recreational Use*, and *Fish Consumption Use*, and the extent affected by key important stressors. The term "assessment threshold" is used in the key findings below as a generic term to describe the criteria or thresholds that were derived from multiple sources and used to evaluate MAP2 data. A more detailed summary of the criteria or thresholds used to evaluate MAP2 data are provided in Appendix D.

The key findings of the report are:

- *Aquatic Life Use* was assessed as impaired in an estimated 44.2% of the lakes target population.
- Non-native aquatic macrophyte species assessment thresholds were violated in an estimated 24.6% of the lakes target population.
- The littoral macroinvertebrate community was rated as "Most Disturbed" in an estimated 22.7% of the lakes target population.
- The phytoplankton community was rated as "Poor" in an estimated 34.7% of the lakes target population.
- Dissolved oxygen assessment thresholds were violated in an estimated 37.1% of the lakes target population.
- pH assessment thresholds were violated in an estimated 34.0% of the lakes target population.

- Nutrient enrichment assessment thresholds were violated in an estimated 15.9% of the lakes target population.
- *Cabomba caroliniana* (fanwort) and *Myriophyllum heterophyllum* (variable milfoil) were the most common non-native aquatic macrophyte species with a presence in an estimated 18.4% and 14.4% of the lakes target population, respectively.
- *Recreational Use* was assessed as impaired in an estimated 46.3% of the lakes target population.
- Aesthetics, and more specifically excessive aquatic macrophyte biovolume was the dominant stressor to *Recreational Use*.
- Aquatic macrophyte biovolume assessment thresholds were violated in an estimated 34.6% of the lakes target population.
- Pathogen assessment thresholds were violated in an estimated 5.3% of the lakes target population.
- An estimated 37.3% of the lakes target population has a site-specific fish consumption advisory.
- An estimated 22.8% of the lakes target population do not have a site-specific advisory but have assessment threshold violations for mercury in fish tissue.
- In the absence of the statewide fish consumption advisory, 60.1% of the lakes target population would be assessed as impaired for *Fish Consumption Use* based on site-specific fish consumption advisories and assessment threshold violations for mercury in fish tissue.
- Nearly all the site-specific fish consumption advisories and assessment threshold violations, as well as the statewide freshwater fish consumption advisory (estimated 91.4% of the target population), were due to mercury contamination in fish tissue.

Introduction

The goal of the federal Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. To meet this objective, the CWA requires states to assess the quality of the Nation's water resources and report this information to the United States Environmental Protection Agency (USEPA), the U.S. Congress, and the public. Section 305(b) of the CWA requires states to report biennially on the condition of all waters in their state. The Watershed Planning Program (WPP) in the Massachusetts Department of Environmental Protection (MassDEP) previously conducted monitoring primarily at targeted sites to fulfill this requirement. Targeted monitoring focuses on specific sites by design, which limits water quality assessments to only waterbodies or assessment units included in the monitoring. Typically, this covers a small percentage of the total waters in the state. There are two monitoring strategies that enable reporting on the condition of all waters in the state: a census strategy and a probabilistic strategy. A census strategy requires monitoring all waters or assessment units in the state and consumes significantly more resources than a probabilistic or statistical strategy. In a probabilistic strategy, monitoring a random subset of waters within a target population provides a statistically valid estimate of overall conditions in the target population (USEPA 2002). Unlike census monitoring, probabilistic strategies can be realistically implemented using MassDEP's current resources.

In 2011, the Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) was initiated as a component of the overall monitoring strategy to help fulfil the requirements of CWA Section 305(b) using a probabilistic network design. The overall goal of MAP2 is to provide an unbiased and statistically valid assessment on the condition of selected designated uses in all waters of the state and the potential stressors impacting those uses. Wadeable rivers and streams were the first water resource type monitored by MassDEP using a probabilistic design from 2011 – 2015 (MassDEP 2020). MAP2 shifted to lakes using a probabilistic design from 2016 – 2018 and is the focus of this report. A future MAP2 report will cover probabilistic monitoring for coastal water resources.

Survey Design

The MAP2 utilizes the Generalized Random Tessellation Stratified (GRTS) design strategy developed principally by USEPA's National Health and Environmental Effects Research Laboratory, Western Ecology Division (USEPA-NHEERL-WED) (USEPA 2010a; Stevens and Olsen 2004). The list below provides the basic survey design for MAP2 lakes.

- Lakes are stratified into three basin groups, with a target of 25 lakes per basin group, and rotated through a three-year cycle until approximately 75 lakes are monitored statewide. Each basin group or stratum is comprised of 7-10 watersheds with an equivalent number of lakes (Figure 1).
- The target population is defined as all permanent freshwater lakes, reservoirs, and ponds greater than two hectares (ha) in surface area and deeper than two meters (m) at the maximum depth within the Commonwealth of Massachusetts. The word "lake" in the remainder of this document includes lakes, reservoirs, and ponds. Lakes that are saline are excluded as are those used for aquaculture, disposal-tailings, sewage treatment, evaporation, or other unspecified disposal use.
- Within the target population, unequal selection probabilities are used to create multi-density categories and allocate selected waterbodies equally between two size classes: (1) 2 – 20 ha and (2) greater than 20 ha.
- The sampling frame is based on the National Hydrography Dataset (NHD) waterbody coverage at a resolution of 1:24,000. Waterbodies with a feature code indicating it is not part of the target population (e.g., aquaculture, swamp/marsh) were excluded from the sampling frame.

Based on this design, 75 primary and 300 ordered oversample sites were selected for the 2016 – 2018 MAP2 lakes monitoring effort (25 primary and 100 oversample sites for each of the three basin groups). Oversample sites are extra sites available to replace any rejected primary sites (i.e., access permission denied or not in the target population) in an ordered unbiased manner. The GRTS software package (spsurvey) developed by USEPA for the R statistical software was used to select sites and to calculate population estimates based on the survey data (USEPA 2010b; Dumelle 2021; R Core Team 2024). Additional survey design details are available in the survey design document (Appendix A).

Waterbody Evaluation

Waterbody evaluations using desktop and field reconnaissance were conducted on the 75 primary waterbodies according to WPP standard operating procedures for site evaluation (MassDEP 2015). If a waterbody was not in the target population (e.g., wetland, tidal, or less than 2 m deep) or was inaccessible (either physically or access permission was denied), the waterbody was rejected from the survey and replaced with the next oversample waterbody on the list for that basin group stratum. Extra lakes above the target of 25 sites per stratum were included in the survey to account for any waterbody evaluation errors or new information that would require removing a waterbody during the survey. Waterbody evaluations were conducted on a total of 159 primary and oversample waterbodies during the probabilistic survey (2016 -2018) and 80

waterbodies were rejected as not part of the target population or inaccessible (Appendix B). All 79 lakes determined to be part of the target population and accessible were sampled during the survey (Figure 1). Detailed lake identification and sampling location information for the target sampled lakes are in Appendix C.

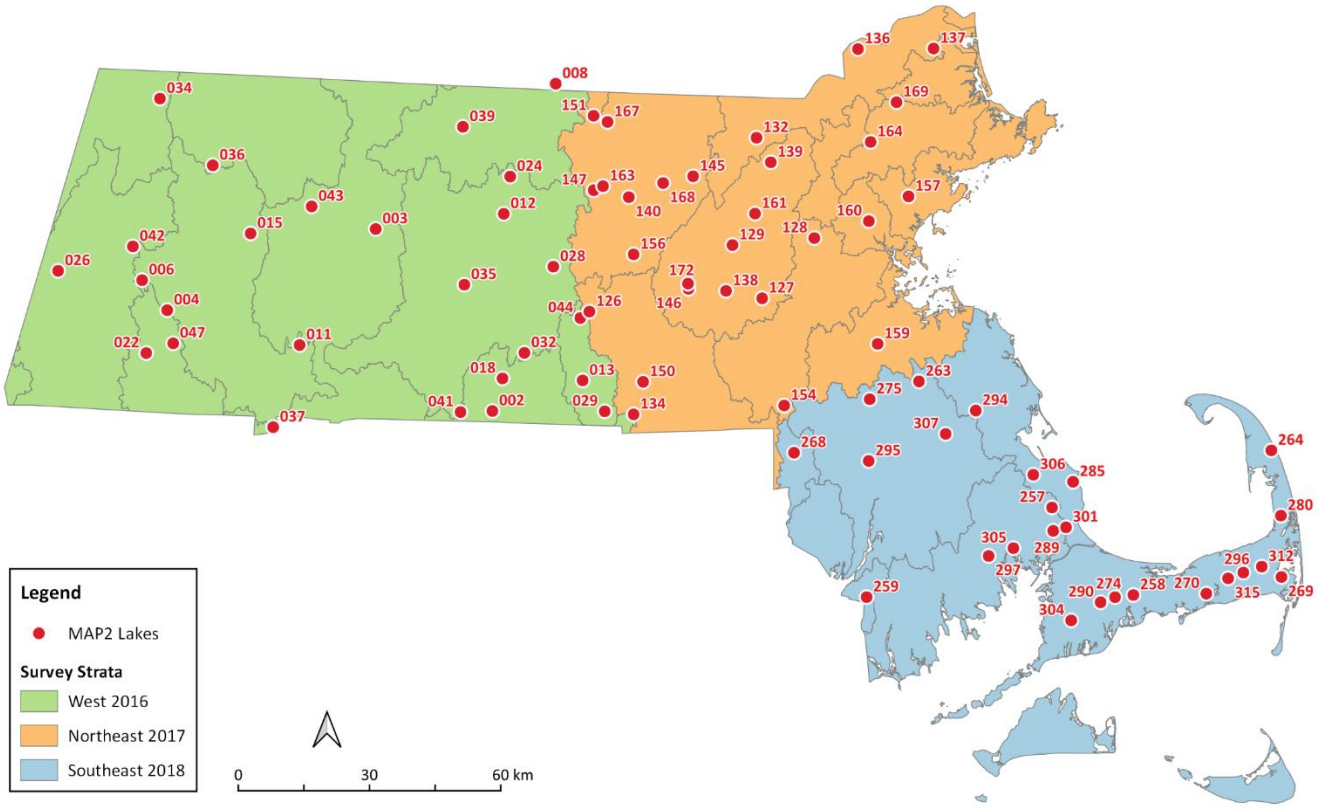

Figure 1. Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) target sampled lakes 2016 – 2018.

Based on the waterbody evaluations, an estimated 45.7% of the sample frame or 1,191 waterbodies were part of the defined target population for the lakes survey. This estimate assumes that inaccessible sites (access permission denied or physically inaccessible) were part of the target population, since confirmation was not possible. The most common non-target categories were map error and wetland (i.e., absent, or poorly defined limnetic zone) at an estimated 17.9% and 12.5% of the sample frame, respectively. Map errors or sampling frame errors cover a variety of situations but were typically the result of an incorrect assignment of a feature code (e.g., Lake/Pond code versus aquaculture code) that prevented the non-target waterbody from being removed prior to finalizing the sample frame.

The extent of the sample frame estimated to be both part of the target population and sampled (referred to as the target population going forward) was 38.1% or 994 lakes. The population estimates of designated use support, biotic integrity, water quality condition, or general characteristics presented in the following sections of this report apply only to this portion of the sample frame. The extent of the sample frame in each waterbody evaluation category is summarized in Figure 2 and Table 1.

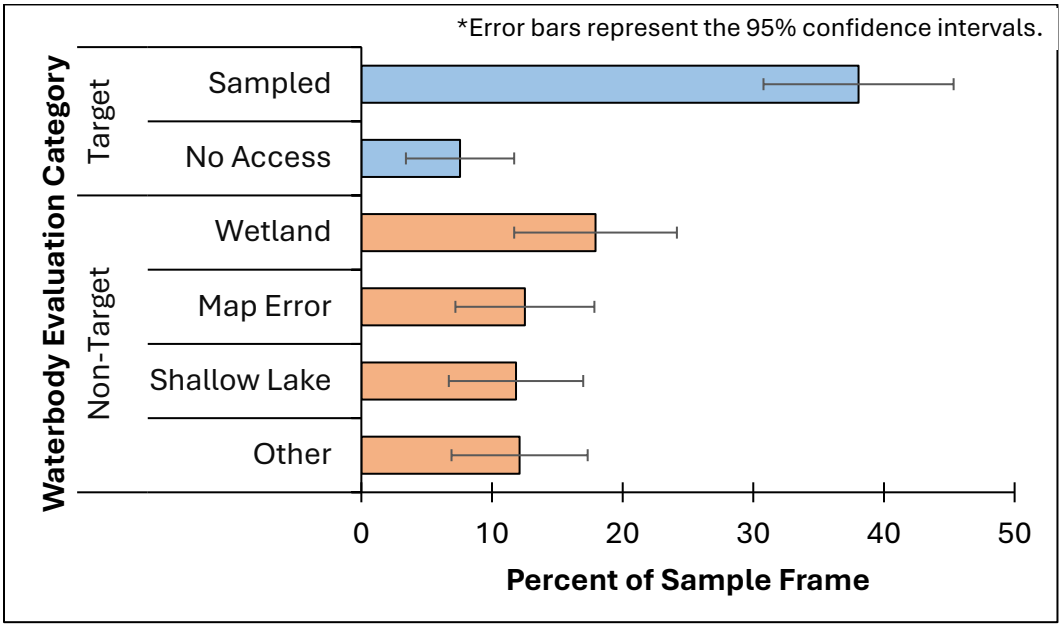

Figure 2. Extent of the sample frame in each waterbody evaluation category.

Table 1. Extent of the sample frame in each waterbody evaluation category.

			Percent of Sample Frame				Number of Waterbodies			
Category		Count	Estimate	MOE[1]	Lower 95% CI[2]	Upper 95% CI[2]	Estimate	MOE[1]	Lower 95% CI[2]	Upper 95% CI[2]
Target	Sampled	79	38.1	7.3	30.8	45.3	994.0	189.6	804.4	1183.6
	No Access[3]	10	7.6	4.1	3.4	11.7	197.3	112.0	85.3	309.3
Non-target	Wetland	18	17.9	6.2	11.7	24.2	468.2	174.2	294.0	642.3
	Map Error	16	12.5	5.3	7.2	17.8	327.0	143.7	183.3	470.7
	Shallow Lake	15	11.8	5.1	6.7	17.0	309.2	136.9	172.3	446.2
	Other[4]	21	12.1	5.2	6.9	17.3	316.3	139.1	177.3	455.4

1 – MOE = Margin of Error
2 – CI = Confidence Interval
3 – Category includes access permission denied, no response to access request, and physically inaccessible, all assumed to be target.
4 – Category includes two minor waterbody rejection categories (tidal and run-of-river impoundment) each constituting approximately 6% of the sample frame.

Monitoring Design

Sampling Plan

The monitoring goal of the MAP2 lakes survey (2016-2018) was to collect sufficient water quality and biological data at each of the 79 probabilistically (randomly) selected lakes located throughout the Commonwealth to assess the status of designated uses (*Aquatic Life Use*, *Recreational Use*, and *Fish Consumption*) and potential stressors to the designated uses at those lakes, thus estimating the status of those designated uses and stressors in the target population as a whole. The list below provides the types of indicator data collected at each lake to reach this goal.

- Vertical profile (dissolved oxygen [DO], temperature, pH, conductivity)
- Secchi disk transparency
- Chemical water quality parameters (total phosphorus, total nitrogen, alkalinity, hardness, dissolved silica, chloride, and dissolved organic carbon).
- Physical water quality parameters (true color and turbidity)
- Chlorophyll-*a*
- Pathogens (*Escherichia coli* [*E. coli*])
- Cyanobacteria cell counts
- Algal toxins (microcystins and anatoxin-a)
- Phytoplankton community
- Littoral macroinvertebrate community
- Fish tissue (mercury, polychlorinated biphenyls (PCBs), organochlorine pesticides, metals)
- Macrophytes (percent cover, biovolume, non-native species)
- Aesthetics observations
- Human disturbance observations
- Bathymetry

Index Site - Water Quality (Chemical, Biological, and Physical)

Water quality samples or measurements (vertical DO/temperature/pH/conductivity profile, Secchi disk transparency, nutrients, dissolved silica, chlorophyll-*a*, phytoplankton, true color, alkalinity, hardness, turbidity, chloride, dissolved organic carbon) were collected approximately once a month between June and September (three sampling events) at the index site of each lake using techniques described in WPP standard operating procedures (SOPs) (MassDEP 2018a). The index site is located at the maximum depth point in each lake. Samples were field preserved, as appropriate, and delivered to the appropriate laboratory for analysis. A minimum of one duplicate and one blank sample per analyte were tested for quality control (QC) biweekly (approximately

10% of the samples). In total, approximately 2,160 samples were analyzed for the listed indicators (MassDEP 2016a; MassDEP 2017a; MassDEP 2018b).

Shoreline Site - Water Quality (Biological and Microbiological)

Water quality samples (*E. coli*, cyanobacteria, and algal toxins) were collected at the designated shoreline site for each lake using techniques described in a WPP SOP document (MassDEP 2018a). The shoreline site was located at a bathing beach if one existed or a shoreline point where the lake is easily accessible by the public (e.g., adjacent road or culvert) for recreation. *E. coli* was sampled once a month between May and September (five sampling events) while cyanobacteria and algal toxins were sampled once a month between July and September (three sampling events). Samples were field preserved, as appropriate, and delivered to the appropriate laboratory for analysis. A minimum of one duplicate and one blank sample per analyte were tested for QC for each sampling week (approximately 10% of the samples). In total, approximately 750 samples were analyzed for the listed indicators (MassDEP 2016a; MassDEP 2017a; MassDEP 2018b).

Macrophyte Community

The macrophyte community (percent cover, biovolume, and species composition) was surveyed once during the summer in each lake using protocols described in a WPP SOP document (MassDEP 2018a). The percent cover and biovolume of macrophytes were estimated using BioBase, which is a cloud-based software package that automates processing of depth finder sonar log files to create aquatic vegetation and bathymetric maps (Navico 2015). Macrophyte species composition was estimated by identifying the macrophyte species present at ten predefined points and other areas of high macrophyte density (e.g., coves) within each lake until no new species were identified by the survey crew. The goal of this method was to determine the dominant macrophyte species in each lake. Macrophyte species that could not be identified by the survey crew were delivered to the WPP biological lab for identification (MassDEP 2016a; MassDEP 2017a; MassDEP 2018b).

Littoral Macroinvertebrate Community

The littoral macroinvertebrate community was sampled at all lakes on one occasion during late summer or early fall, using protocols developed for the 2012 National Lakes Assessment (NLA) and adopted into a WPP SOP document (MassDEP 2018a). The composition of these aquatic communities can integrate environmental conditions (both chemical, including nutrients and toxics, and physical, including shoreline alteration and water level fluctuations) over a long period of time and are an excellent measure of aquatic system health. Specimens were placed into 2L high density polyethylene (HDPE) jars, preserved with denatured 95% ethanol, and transported to the WPP lab for storage. A contractor processed (i.e., subsampled) the macroinvertebrate

samples and completed the necessary taxonomic identifications. In addition, habitat evaluations were completed at all lakes sampled for littoral macroinvertebrates using standard protocols (MassDEP 2016a; MassDEP 2017a; MassDEP 2018a; MassDEP 2018b).

Fish Tissue

Fish tissue samples were collected at all lakes on one occasion during late spring/early summer using a variety of techniques (e.g., electroshocking, gill nets, etc.) (MassDEP 2018a). Composite samples of filets from three individuals of edible and legal size from a species were collected for three to five target species and analyzed by MassDEP's William X. Wall Experiment Station (WES) in Lawrence for mercury, PCBs, organochlorine pesticides (a-BHC, b-BHC, d-BHC, Aldrin, Chlordane, DDT/DDD/DDE, Dieldrin, Endosulfan I, Endosulfan II, Endosulfan Sulfate, Endrin, Endrin Aldehyde, Heptachlor, Heptachlor Epoxide, Hexachlorobenzene, Hexachlorocyclopentadiene, Lindane, Methoxychlor, Toxaphene, and Trifluralin), and other metals (arsenic, cadmium, and selenium). In addition, 10-12 individuals from a top carnivore species (e.g., largemouth bass) were collected and analyzed by WES for mercury (MassDEP 2016a; MassDEP 2017a; MassDEP 2018b).

Aesthetics and Human Disturbance Observations

Aesthetic and human disturbance observations were recorded concurrently on water quality (shoreline and index sites), macroinvertebrate, and macrophyte field sheets multiple times during the summer, using both existing WPP protocols and protocols developed for the 2012 NLA that were adopted by WPP (MassDEP 2018a). These observations were qualitative assessments of the type, extent, and intensity of objectionable aesthetics (e.g., trash, algal scum, foam) and human disturbance (residential, industrial, agricultural) present at the index and shorelines sites, littoral zone, and near shore. The observations from all field sheets were entered into an Excel workbook and summarized for analysis (MassDEP 2016a; MassDEP 2017a; MassDEP 2018b).

Appendix C and Figure 1 provide the locations and other pertinent details pertaining to the MAP2 lakes, including the years when monitoring occurred at those lakes and the locations of the index and shoreline sites. Additional information regarding monitoring plans can be found in *Sampling & Analysis Plan 2016 Monitoring Massachusetts Probabilistic Monitoring and Assessment Program Lakes* (MassDEP 2016b), *Sampling & Analysis Plan 2017 Monitoring Massachusetts Probabilistic Monitoring and Assessment Program Lakes* (MassDEP 2017b), and *Sampling & Analysis Plan 2018 Monitoring Massachusetts Probabilistic Monitoring and Assessment Program Lakes* (MassDEP 2018c).

Field and Analytical Methods

Procedures and protocols used to collect and handle samples or measure chemical, physical, and biological indicators are described in *Massachusetts Probabilistic Monitoring and Assessment Program Field Operations Manual Lakes* (MassDEP 2018a). Procedures used for multiparameter sonde calibration are described in *Water Quality Multiprobe* (MassDEP 2010a). Concurrent with the collection of water quality and biological community data, site characteristics, habitat quality, human disturbance, aesthetics, and sampling conditions were recorded on WPP field sheets using protocols described in the field operations manual (MassDEP 2018a).

Quality Assurance and Quality Control

Quality assurance and quality control procedures used in collecting samples and measurements were consistent with the prevailing WPP protocols that are described in *Massachusetts Probabilistic Monitoring and Assessment Program Field Operations Manual Lakes* (MassDEP 2018a) and *Water Quality Multiprobe* (MassDEP 2010a). Data were validated and finalized per data validation procedures outlined in *DWM Water Quality Data Validation Process (Summary)* (MassDEP 2012a), *Data Validation Decision Table* (MassDEP 2005), *DWM Water Quality Probe File Processing and Validation for Attended Probe Data* (MassDEP 2012b), *File Processing and Data Validation for Unattended Water Quality Probe Data* (MassDEP 2012c), *DWM Water Quality Data Processing and Validation - Laboratory Data* (MassDEP 2012d), *DWM Data Reporting Rules* (MassDEP 2010b), and *DWM Data Validation Processes – Overview* (MassDEP 2013a). All laboratory and discrete/continuous probe data were validated by reviewing QC sample results, analytical holding time compliance, QC sample frequency, QC measurements, and related ancillary data/documentation, as applicable.

Survey Conditions

Precipitation and temperature data from four National Oceanic and Atmospheric Administration (NOAA) Global Historical Climatology Network (GHCN) weather stations in each stratum were analyzed to estimate the general hydrological conditions during the MAP2 monitoring period, 2016 – 2018 (Table 2) (Figure 3) (NOAA 2022). Daily precipitation totals measured at the selected stations during the corresponding monitoring year for each stratum were downloaded from the NOAA, National Centers for Environmental Information (NCEI).

Table 2. Global Historical Climatology Network (GHCN) weather stations in each Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) stratum used in survey condition analysis.

Year Stratum	GHCN Station ID	GHCN Station Name
2016 West	USW00014763	Pittsfield Municipal Airport, MA US
	USW00014775	Westfield Barnes Municipal Airport, MA US
	USW00054756	Orange Municipal Airport, MA US
	USW00054768	North Adams Harriman Airport, MA US
2017 Northeast	USW00004780	Fitchburg Municipal Airport, MA US
	USW00014739	Boston, MA US
	USW00094723	Lawrence Municipal Airport, MA US
	USW00094746	Worcester, MA US
2018 Southeast	USW00054769	Plymouth Municipal Airport, MA US
	USW00054777	Taunton Municipal Airport, MA US
	USW00094720	Hyannis Barnstable Municipal Airport, MA US
	USW00094726	New Bedford Municipal Airport, MA US

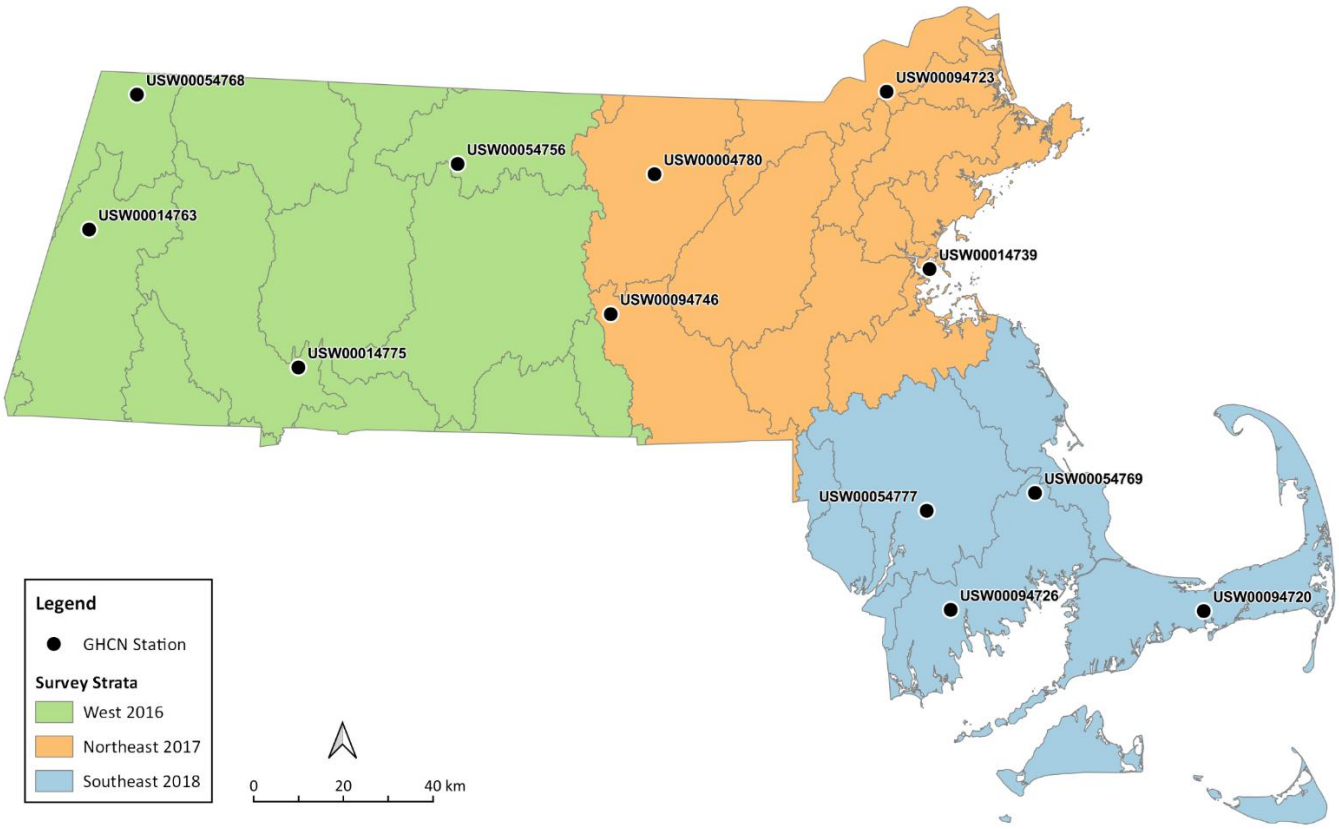

Figure 3. Global Historical Climatology Network (GHCN) weather stations.

The daily precipitation and high temperatures were summarized into monthly precipitation totals and average high temperatures for all selected stations. The monthly precipitation totals and average high temperatures for the four stations in each stratum were averaged by month to estimate the general hydrological and thermal conditions in each stratum during the corresponding monitoring year. In addition, the 20-year monthly normal precipitation totals and average high temperature for the selected stations were downloaded and averaged by month for the four stations in each stratum to compare the observed and normal climate results (Table 3) (Table 4).

Table 3. Average monthly observed and normal precipitation totals (inches) for four selected Global Historical Climatology Network (GHCN) weather stations in each stratum. Area shaded in gray indicates the May - September sampling period.

	2016 West		2017 Northeast		2018 Southeast	
Month	Average Monthly	Average Normal	Average Monthly	Average Normal	Average Monthly	Average Normal
1	1.27	2.89	3.41	3.27	5.03	3.91
2	3.98	2.68	2.37	3.07	5.82	3.59
3	2.55	3.63	3.59	4.26	6.08	5.05
4	2.17	3.85	4.85	3.95	5.15	4.57
5	2.96	4.15	4.96	3.88	1.70	3.62
6	2.13	4.54	4.85	4.05	3.11	3.77
7	3.02	4.26	2.94	3.85	1.38	3.45
8	3.41	4.00	1.70	3.57	3.98	3.89
9	2.78	4.03	4.05	3.68	5.68	3.93
10	2.81	4.50	6.35	4.27	5.92	4.15
11	2.65	3.97	1.59	4.09	9.16	4.57
12	2.98	3.26	2.40	3.61	4.07	4.24
Annual Total	32.71	45.76	43.06	45.55	57.08	48.74
Summer Total	14.30	20.98	18.50	19.03	15.85	18.66

In 2016, annual and summer precipitation totals were below normal for all strata, while high temperatures were above normal in the West stratum. The above normal high temperatures were most evident in July, August, and September where high temperatures were 3-4 degrees Fahrenheit (°F) above normal. The precipitation deficit in 2016 was present and consistent throughout the year. In 2017, both annual and summer precipitation totals and high temperatures were close to normal in the Northeast stratum. However, July and August had below normal precipitation that was obscured by a wetter than normal May and June. In 2018, the annual precipitation was above normal while the summer precipitation was below normal in the

Southeast stratum. The annual and summer high temperatures were only slightly above normal, but July and August were 3-4°F above normal, similar to observations in 2016 (Table 3) (Table 4).

Table 4. Average monthly observed and normal high temperature degrees Fahrenheit (oF) for four selected Global Historical Climatology Network (GHCN) weather stations in each stratum. Area shaded in gray indicates the May - September sampling period.

	2016 West		2017 Northeast		2018 Southeast	
Month	Average Monthly	Average Normal	Average Monthly	Average Normal	Average Monthly	Average Normal
1	35.2	31.2	39.1	33.6	37.6	37.6
2	39.5	34.9	43.3	37.2	47.2	39.9
3	51.5	44.0	40.0	44.9	44.4	46.3
4	56.5	57.0	60.8	56.7	53.5	56.1
5	68.7	68.4	64.4	67.3	70.9	66.4
6	78.0	76.2	78.4	76.3	75.0	75.5
7	84.1	80.8	80.9	81.4	84.2	81.2
8	83.2	79.2	80.1	79.8	84.6	79.8
9	75.4	71.5	75.5	71.9	74.7	72.5
10	61.2	59.7	69.7	60.6	62.8	62.1
11	50.2	48.1	50.9	50.1	50.8	52.7
12	36.7	36.2	34.5	39.0	44.0	42.6
Annual Average	60.0	57.3	59.8	58.2	60.8	59.4
Summer Average	77.9	75.2	75.9	75.3	77.9	75.1

Target Population Characteristics

The data collected during the MAP2 lakes surveys can be categorized into two groups, data used directly for designated use assessments (e.g., macroinvertebrate community, dissolved oxygen, fish tissue concentrations) and ancillary data used to provide context for assessments or describe general characteristics of the lakes (e.g., bathymetry, human disturbance, alkalinity). A portion of the ancillary data collected during the MAP2 lakes surveys are summarized in this section to provide general characteristics of the target population.

General

Massachusetts has one of the highest density of dams (1 dam per 6.7 stream miles) compared to other U.S. states, and Worcester County, MA, has the highest dam density of any U.S. County (Weiskel 2010). As a result of the high dam density in Massachusetts, an estimated 60.7% of the target population was formed or enhanced by impoundments (Figure 4). An estimated 19.4% of

the target population is classified as a Public Water Supply (PWS) (Figure 4). Waterbodies designated as public water supplies were more common in northeastern communities of Massachusetts and often used as a backup or to supplement Massachusetts Water Resources Authority (MWRA) water supplies.

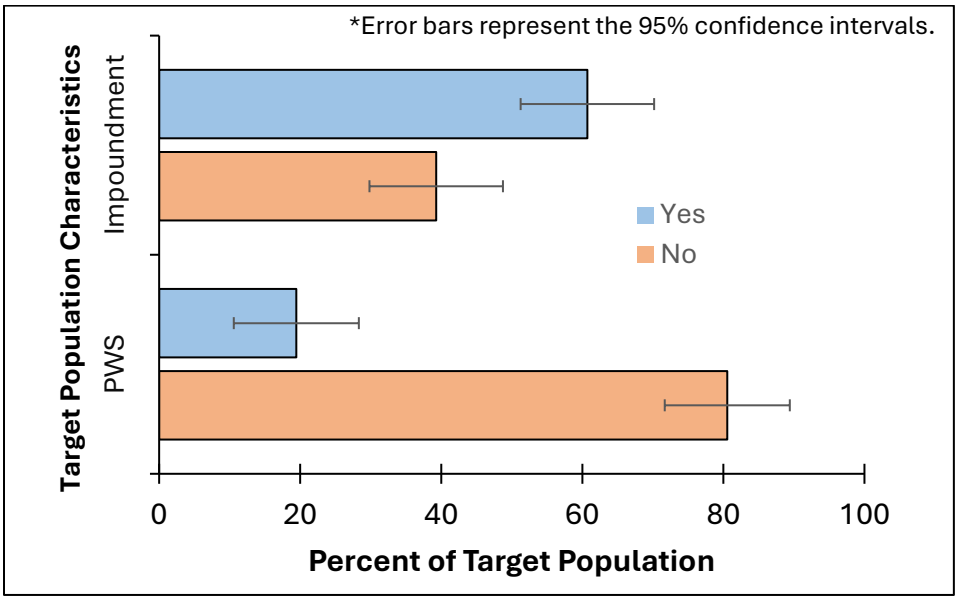

Figure 4. Extent of the target population formed or enhanced by impoundments and classified as a Public Water Supply (PWS).

In addition to population estimates on categorical data, population estimates can be calculated for numerical data (e.g., lake surface area and depth, analyte concentrations) with cumulative distribution function (CDF) curves and percentiles. Figures 5 and 6 are CDF curves with 95% confidence intervals for lake area and maximum depth of the target population. The 25th, 50th, and 75th percentiles are also marked and labeled in the figures. In the target population, the estimated median (50th percentile) lake surface area is 8.8 ha (Figure 5), and the estimated median maximum depth is 4.7 m (Figure 6). These median values indicate that the majority of the target population has a relatively small surface area (<10 ha) and shallow maximum depth (<5 m). Generally, shallow lakes will either have a polymictic stratification pattern (i.e., mix to the bottom intermittently during the heating period) or will not stratify and remain well mixed during the summer. However, multiple factors (e.g., lake fetch, precipitation, macrophyte growth, etc.) can impact stratification and mixing pattens. Stratification and mixing pattens can have a significant impact on chemical and biological processes within the lake.

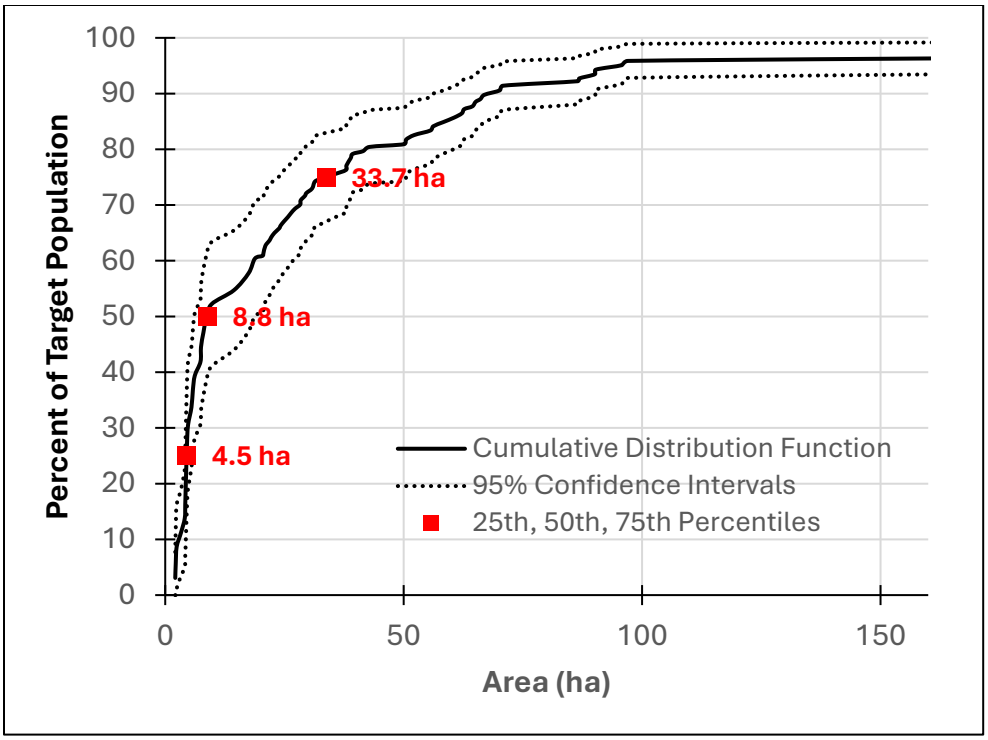

Figure 5. Cumulative distribution frequency curve of lake surface area in the target population with the 25th, 50th, and 75th percentiles marked and labeled.

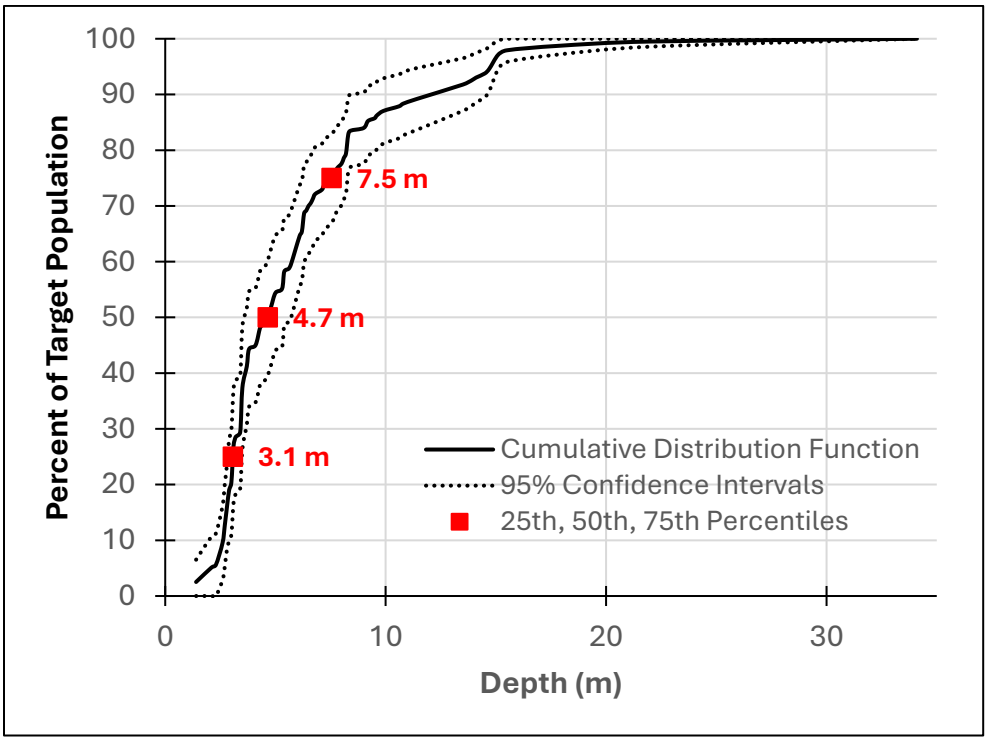

Figure 6. Cumulative distribution frequency curve of lake maximum depth in the target population with the 25th, 50th, and 75th percentiles marked and labeled.

Alkalinity, hardness, and true color are additional lake characteristics that can impact chemical and biological processes within the lake. The majority of the target population has low alkalinity, low hardness (i.e., soft water), and are clear (no color). An estimated 55.8% of the target population has low alkalinity (< 12.5 milligrams per liter as $CaCO_3$ (mg/L)), 80.2% of the target population has soft water (< 60 mg/L as $CaCO_3$), and 57.9% of the target population has clear water (no color) (Figure 7). A significant portion of the target population has medium alkalinity (12 – 50 mg/L) and is moderately colored (20 – 50 platinum cobalt color unit (PCU)) with an estimated 35.2% and 31.3% of the target population, respectively (Figure 7).

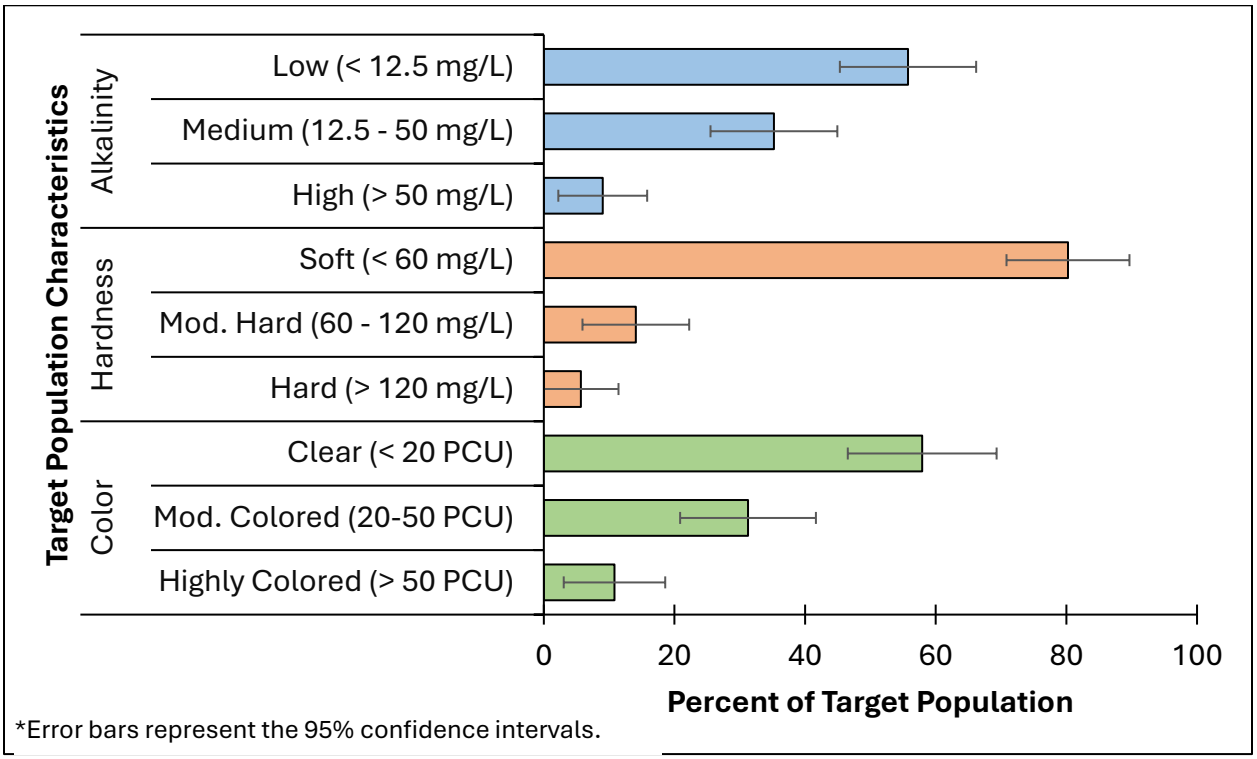

Figure 7. Extent of the target population in three different concentration categories for alkalinity, hardness, and color.

Trophic State

Carlson's Trophic State Index (TSI) is a common method for classifying the biological response (i.e., algal biomass) in waterbodies to nutrients into trophic state categories (e.g., oligotrophic, mesotrophic, and eutrophic) based on a numerical scale (0 – 100). Other factors (e.g., season, mixing regime, grazing, color, etc.) can also impact the biological response. Three independent TSIs can be calculated using three different variables: chlorophyll-*a*, total phosphorus, and Secchi disk. In theory, any of the three independent TSIs can be used to classify the trophic state of a waterbody, but generally the chlorophyll-*a* TSI is a better index for classifying biological

response; therefore, averaging the three independent TSIs would not be appropriate (Carlson, 1996).

Based on the chlorophyll-*a* TSI, an estimated 40.9% of the target population is classified as eutrophic, while 37.3% and 21.8% are classified as mesotrophic and oligotrophic, respectively (Figure 8). The total phosphorus TSI shows a higher estimated percentage (43.9%) of the target population classified as oligotrophic, which could indicate that the algal biomass in a portion of the target population is phosphorus limited. The Secchi disk TSI shows a higher estimated percentage (57.9%) of the target population classified as mesotrophic (Figure 8).

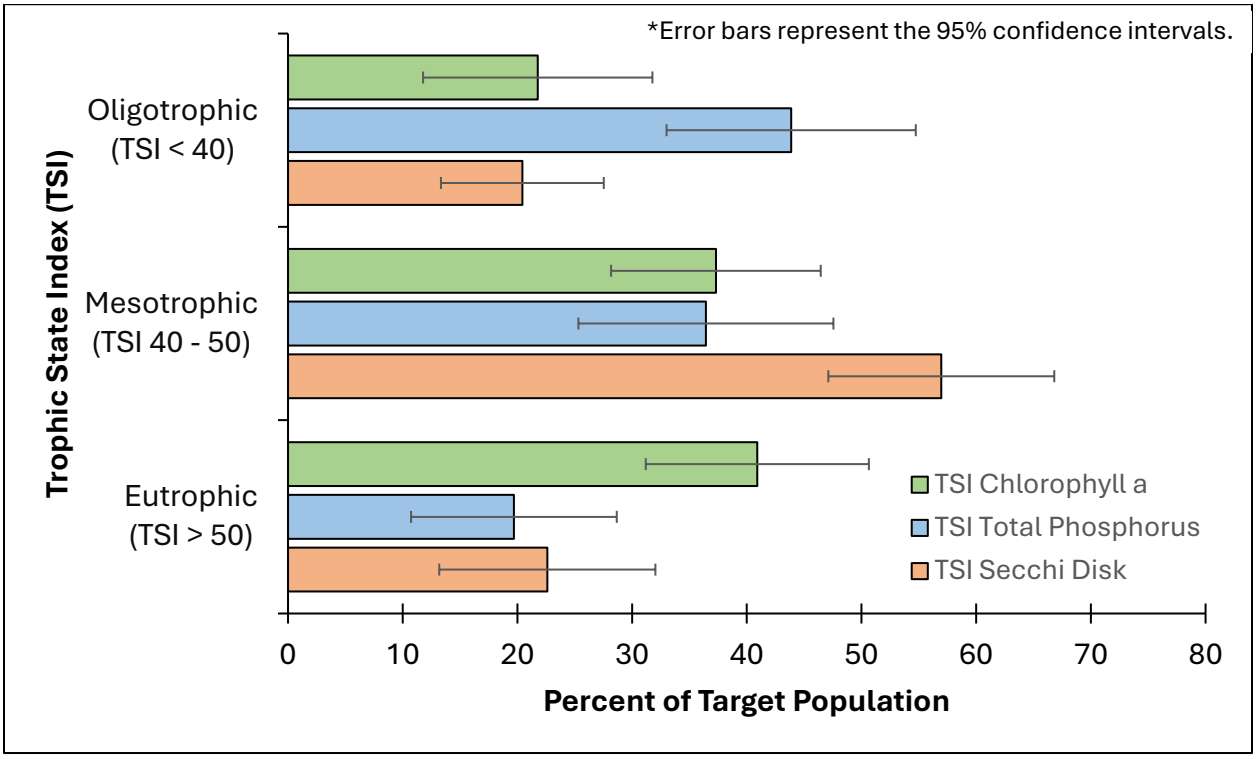

Figure 8. Extent of the target population in each trophic state category of the chlorophyll-a, total phosphorus, and Secchi disk Carlson's Trophic State Index (TSI).

Human Disturbance

The level of human disturbance or stressors impacting the target population were evaluated using the General Lake Assessment (GLA), Lakeshore Anthropogenic Disturbance Index (LADI), and the percent of developed land (urban plus agricultural) in the watershed and within 100 m of the shoreline. The GLA is based on lake activities and disturbances observed while on the lake conducting macrophyte surveys, or while driving or walking through the lake catchments (MassDEP 2018a). The LADI is based on human disturbances observed in or adjacent to the littoral plots while conducting macroinvertebrate surveys (MassDEP 2018a). The GLA and LADI

scores and category thresholds were determined using methodology from the NLA (USEPA 2017). The percentage of developed land within 100 m of the shoreline was calculated using a 100 m shoreline buffer and the 2016 Land Cover/Land Use GIS coverage from the Massachusetts Bureau of Geographic Information (MassGIS). The percentage of developed land in the watershed was calculated from LakeCat data (MassGIS 2019; Hill 2018).

According to the GLA, an estimated 70.7% of the target population is classified as least disturbed while 4.4% is classified as most disturbed (Figure 9). This result was unexpected to some extent but may be explained by a few factors: 1) in western Massachusetts, lakes have less surrounding human disturbance, 2) in eastern Massachusetts, a significant portion of the target population are designated as PWS and are thus protected from adjacent development, and 3) category thresholds could be inappropriate for Massachusetts because the geographic area covered by the NLA is much larger than the state. The LADI indicates that an estimated 34.9% of the target population has low lakeshore disturbance, with 53.9% and 11.2% for medium and high levels, respectively (Figure 9). The LADI is more quantitative than the GLA and likely more representative of lakeshore development.

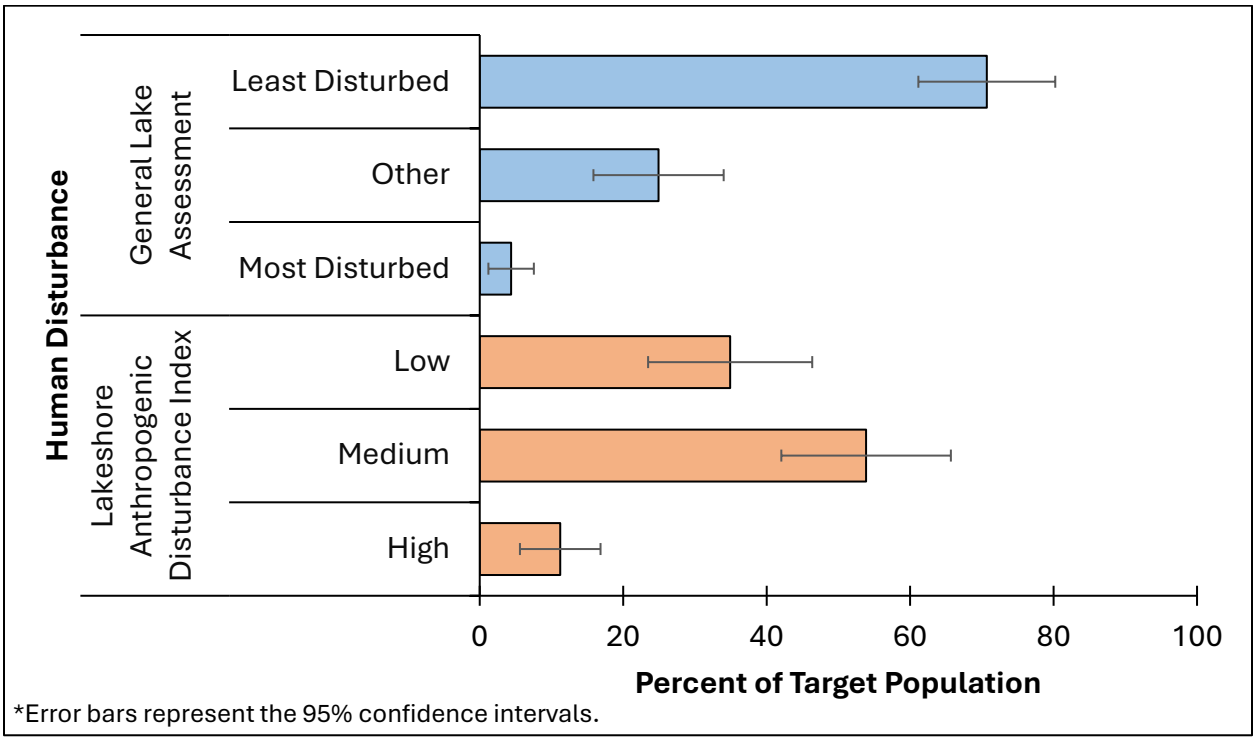

Figure 9. Extent of the target population in each human disturbance category of the General Lake Assessment and Lakeshore Anthropogenic Disturbance Index.

Land cover and land use data at varying spatial scales are another method of evaluating human disturbance in the target population. Figures 10 and 11 are CDF curves with the 95% confidence

intervals for the percent developed land (urban and agricultural) in the watershed and within a 100 m shoreline buffer. The 25th, 50th, and 75th percentiles are also marked and labeled in the figures. In the target population, the estimated median percent developed land in a 100 m shoreline buffer is 25.6% and 20.2% in the watershed. The estimated 75th percentiles for the target population are significantly higher at 54.3% of developed land in the 100 m shoreline buffer and 46.2% in the watershed. The estimated 25th percentiles for the target population are 9.4% of developed land in the 100 m shoreline buffer and 7.3% in the watershed (Figures 10 and 11).

Using land cover and land use data to evaluate human disturbance is a common method but can miss some important details. Land cover and land use data may not accurately portray the intensity of development (due to GIS coverage resolution or land cover classifications), such as the difference between high density and low-density urban development or practices used to reduce the impact of development such as best management practices to control stormwater or agricultural impacts. Land use and land cover data should be used in conjunction with other tools such as the GLA and LADI to accurately evaluate human disturbance.

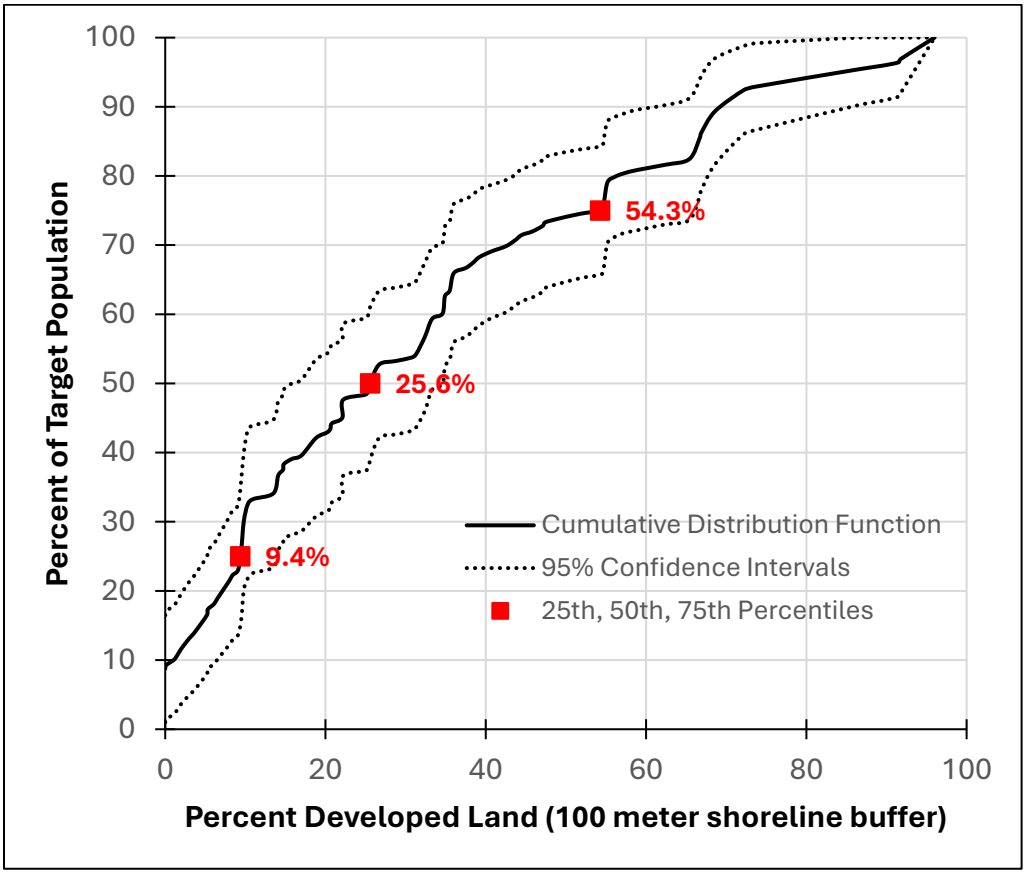

Figure 10. Cumulative distribution frequency curve of the percent developed land (urban and agricultural) within a 100 m shoreline buffer with the 25th, 50th, and 75th percentiles marked and labeled.

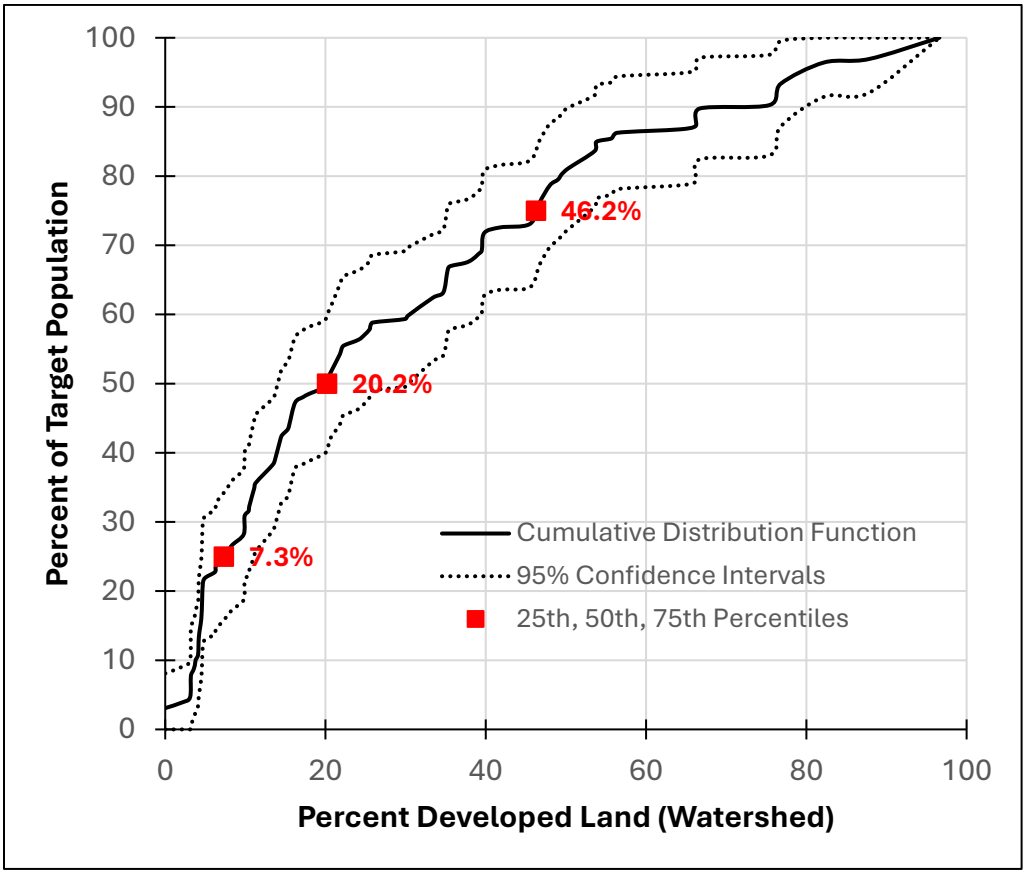

Figure 11. Cumulative distribution frequency curve of the percent developed land (urban and agricultural) in the watershed with the 25th, 50th, and 75th percentiles marked and labeled.

Assessment Methodology

This section outlines the general assessment methodology for the following designated uses: *Aquatic Life Use*, *Recreational Use,* and *Fish Consumption Use*. The primary source for designated uses was the *Massachusetts Surface Water Quality Standards (SWQS)* (MassDEP 2021). For indicator assessment methodologies, the primary sources were the *Massachusetts Consolidated Assessment and Listing Methodology (CALM) Guidance Manual for the 2022 Reporting Cycle* (MassDEP 2022), and the *National Lakes Assessment 2012: Technical Report* (USEPA 2017). The Massachusetts SWQS establishes protective numerical and narrative criteria to support designated uses. The Massachusetts CALM Guidance Manual describes the SWQS criteria, data evaluation methodologies, and assessment thresholds used to assess designated use attainment and surface water quality conditions in the state. The NLA Report (USEPA 2017) describes the data evaluation methodologies and assessment thresholds used to assess water quality and habitat conditions for the NLA surveys. The term "assessment threshold" will be used in the analysis sections of this report as a generic term to describe criteria from the

Massachusetts SWQS, Massachusetts CALM Guidance Manual derived thresholds, NLA derived thresholds, and thresholds specifically derived for this report. A more detailed summary of the assessment methodologies, data evaluation procedures, thresholds, and criteria used to evaluate MAP2 data are provided in Appendix D.

Aquatic Life Use

Waters supporting the *Aquatic Life Use* should be a suitable habitat for sustaining a native, naturally diverse, community of aquatic flora and fauna (MassDEP 2021). The *Aquatic Life Use* includes reproduction, migration, growth, and other critical functions. All available biological and physicochemical data from the MAP2 surveys were considered in assessing the *Aquatic Life Use*. The type, quality, and amount of data generated for each indicator are first evaluated to determine if they are appropriate for use in the assessment decision-making process. Where data are available from multiple indicators and the data are equally usable, such as the MAP2 dataset, the biological community data (macrophytes, macroinvertebrates, phytoplankton), particularly those assessed using calibrated and verified multimetric indices of biotic integrity, usually outweigh all other data types in the decision-making process because they are considered an integration of the effects of pollutants and other conditions over time (MassDEP 2022). However, multimetric indices calibrated and verified for use in Massachusetts lakes do not currently exist for macrophytes, macroinvertebrates, or phytoplankton. Thus, assuming all data are equally usable, the weight-of-evidence approach with both biological and physicochemical data viewed equally was used to assess *Aquatic Life Use*.

Recreational Use

Recreational Use is divided into two types of uses based on the level of contact with the water. Waters supporting the *Primary Contact Recreational Use* are suitable for any recreation or other water use in which there is prolonged and intimate contact with the water, with a significant risk of ingestion of water during the primary contact recreation season (MassDEP 2021). Activities include, but are not limited to, wading, swimming, diving, surfing, and water skiing. The Massachusetts CALM Guidance Manual applies a primary contact recreation period each year from April 1st to October 31st (MassDEP 2022). Waters supporting the *Secondary Contact Recreational Use* are suitable for any recreation or other water use in which contact with the water is either incidental or accidental (MassDEP 2021). These include, but are not limited to, fishing, including human consumption of fish, boating, and limited contact incident to shoreline activities. The secondary contact recreation period applied in the Massachusetts CALM Guidance Manual is year-round (MassDEP 2022).

The assessment of the *Primary and Secondary Contact Recreational Uses* are based on public health (i.e., bacterial indicators of pathogens, harmful algal blooms (HAB) presence), safety (e.g.,

Secchi disk transparency), and/or aesthetic (i.e., desirability) factors. These uses are assessed as supporting when public health, safety, and aesthetic conditions are suitable for the associated contact. The current bacteria criteria for Massachusetts surface waters includes both geometric mean and statistical threshold values (MassDEP 2021). The bacteria assessment decisions are based on samples meeting both these criteria magnitudes for *Primary and Secondary Contact Recreation Uses* (MassDEP 2021; MassDEP 2022).

Fish Consumption Use

Waters supporting the *Secondary Contact Recreational Use* as established in the Massachusetts SWQS are suitable for "[a]ny recreation or other water use in which contact with the water is either incidental or accidental. These include, but are not limited to, fishing, including human consumption of fish, boating and limited contact incident to shoreline activities" (MassDEP 2021). For assessments in this report, however, the status of the *Fish Consumption Use* (human consumption of fish) is reported as its own use rather than part of the *Secondary Contact Recreational Use*. The Massachusetts SWQS, at 314 CMR 4.05(5)(e)2. a. ii., also state that "pollutants shall not result in unacceptable concentrations in edible portions of marketable fish or for the recreational use of fish, shellfish, other aquatic life or wildlife for human consumption" (MassDEP 2021).

The assessment of the *Fish Consumption Use* for this report relies on the July 2022 fish consumption advisory list issued by the Massachusetts Department of Public Health (MA DPH) and the concentrations of toxic pollutants (e.g., mercury, PCBs) in the fish tissue collected during the MAP2 surveys (MA DPH 2022). A statewide consumption advisory, targeting sensitive populations (i.e., women who may become pregnant or are pregnant or nursing, and children under 12 years of age), for fish caught in freshwater lakes and ponds is in effect for Massachusetts. This statewide advisory is in response to mercury contamination and prevents assessing any portion of the target population as supporting *Fish Consumption Use*.

Assessing the status of *Fish Consumption Use* in the target population for this report does not follow the traditional Support/Impaired structure for other designated uses due to the statewide freshwater fish consumption advisory. Instead, *Fish Consumption Use* status was assessed by classifying the target population into three categories based on site-specific fish consumption advisories and mercury concentrations in fish tissue samples: 1) site-specific fish consumption advisory issued, 2) no site-specific fish consumption advisory issued, but Massachusetts SWQS violations for mercury in fish tissue are present, and 3) no site-specific fish consumption advisory issued or Massachusetts SWQS violations for mercury in fish tissue, but the statewide fish consumption advisory is applicable.

Aquatic Life Use

Overall

Aquatic Life Use in the target population was assessed as either support (estimated 55.8%) or impaired (estimated 44.2%), as shown in Figure 12. Additional information regarding the assessment methodology for *Aquatic Life Use* is detailed in Appendix D.

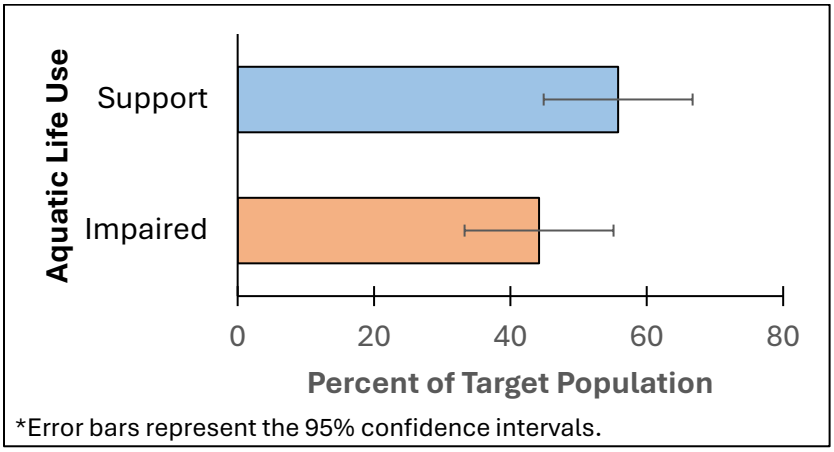

Figure 12. *Aquatic Life Use* attainment status (support or impaired) in the target population.

Indicators

Aquatic Life Use in the target population was assessed by evaluating the following eight indicators: non-native aquatic macrophytes, phytoplankton community, macroinvertebrate community, nutrient enrichment, dissolved oxygen, temperature, pH, and chloride. The assessment thresholds for multiple indicators were violated in comparable (i.e., within the 95% confidence intervals) extents of the target population so there was not a clear dominant stressor to *Aquatic Life Use* (Figure 13). However, the indicators could be organized into three groups based on the extent of the target population where their assessment thresholds were violated.

The assessment thresholds for dissolved oxygen, phytoplankton community, and pH were violated in an estimated 37.1%, 34.7%, and 34.0% of the target population, respectively (Figure 13). Procedures for determining natural background conditions for dissolved oxygen and pH in lakes were not available in any of the sources used for indicator assessment methodologies; therefore a portion of the assessment threshold violations for these two indicators could be a result of natural background conditions (e.g., naturally low dissolved oxygen due to hypolimnetic depletion, naturally low pH due to bedrock geology) (MassDEP 2021; MassDEP 2022; USEPA 2017).

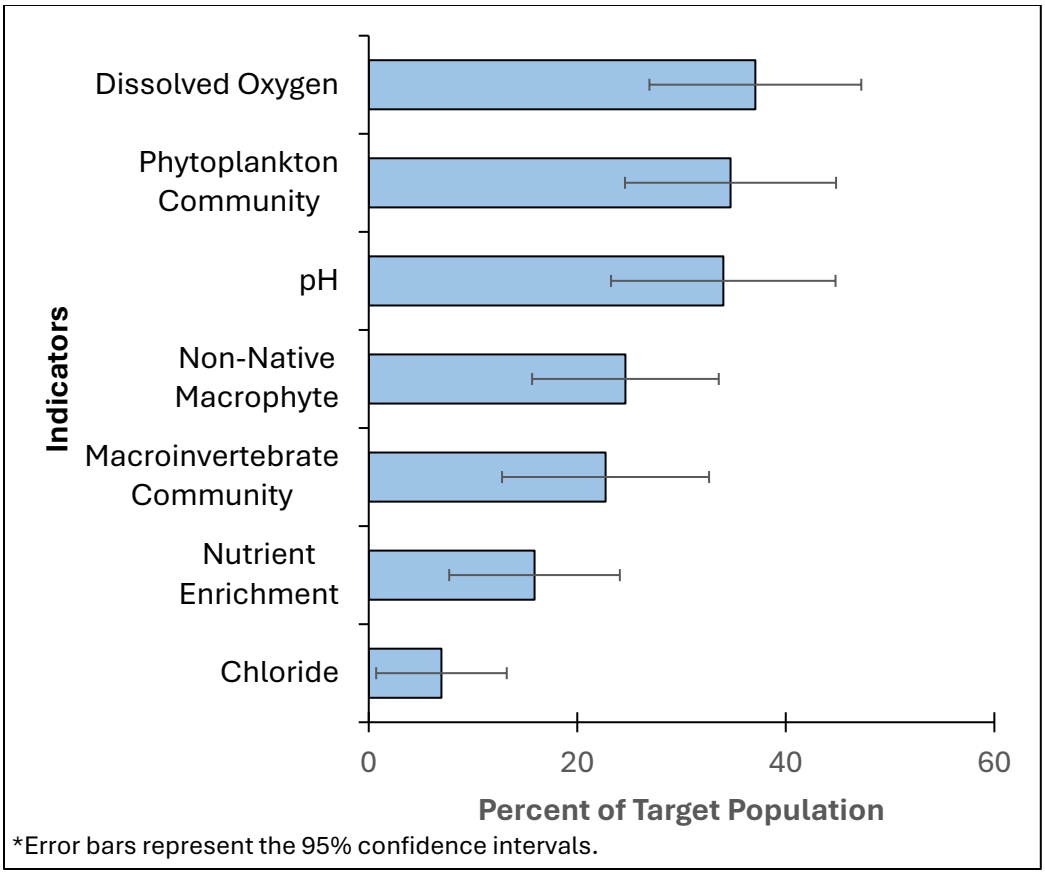

Figure 13. Extent of the target population violating assessment thresholds for the *Aquatic Life Use* indicators.

The assessment thresholds for non-native aquatic macrophytes, macroinvertebrate community, and nutrient enrichment were violated in an estimated 24.6%, 22.7%, and 15.9% of the target population, respectively (Figure 13). If the Massachusetts CALM Guidance Manual assessment threshold for non-native aquatic macrophytes (i.e., any presence) was used instead of the modified assessment threshold (i.e., presence in multiple locations) detailed in Appendix D, the non-native aquatic macrophyte assessment threshold would be violated in an estimated 36.7% of the target population (MassDEP 2022). The assessment thresholds for chloride were violated in an estimated 7.0% of the target population (Figure 13). There were no violations of the temperature assessment threshold in the sampled lakes. There were multiple non-native aquatic macrophyte species present in the target population that could potentially result in an assessment threshold violation, so it is informative to examine the extents of the target population with the presence of individual non-native macrophyte species.

Cabomba caroliniana (fanwort) and *Myriophyllum heterophyllum* (variable milfoil) were the most common non-native aquatic macrophyte species in the target population. *Cabomba caroliniana* (fanwort) was present in an estimated 18.4% of the target population and *Myriophyllum*

heterophyllum (variable milfoil) was present in an estimated 14.4% of the target population (Figure 14). The remaining non-native aquatic macrophytes species presence ranged from an estimated 7.8% to 0.8% of the target population (Figure 14). Any non-native aquatic macrophyte species not listed in Figure 14, were not present in the sampled lakes.

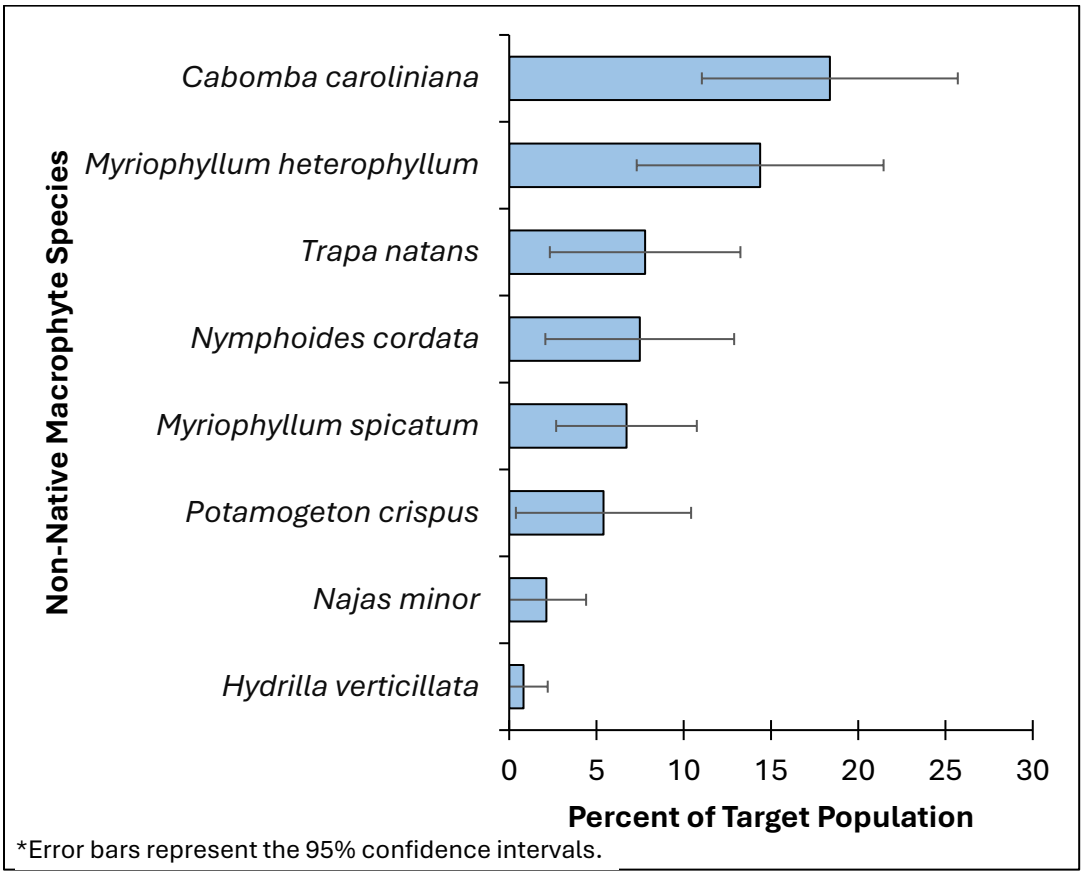

Figure 14. Extent of the target population with individual non-native aquatic macrophyte species.

Assessment thresholds for multiple indicators can be violated in portions of the target population at the same time, so it is informative to examine the extent of the target population with violations of multiple assessment thresholds. An estimated 50.0% of the target population had either one or no indicators violating assessment thresholds (Figure 15). The assessment thresholds of two indicators were violated in an estimated 24.3% of the target population while the assessment thresholds of three or more indicators were violated in an estimated 25.7% of the target population (Figure 15). The number of indicators violating assessment thresholds could indicate the restoration potential for portions of the target population.

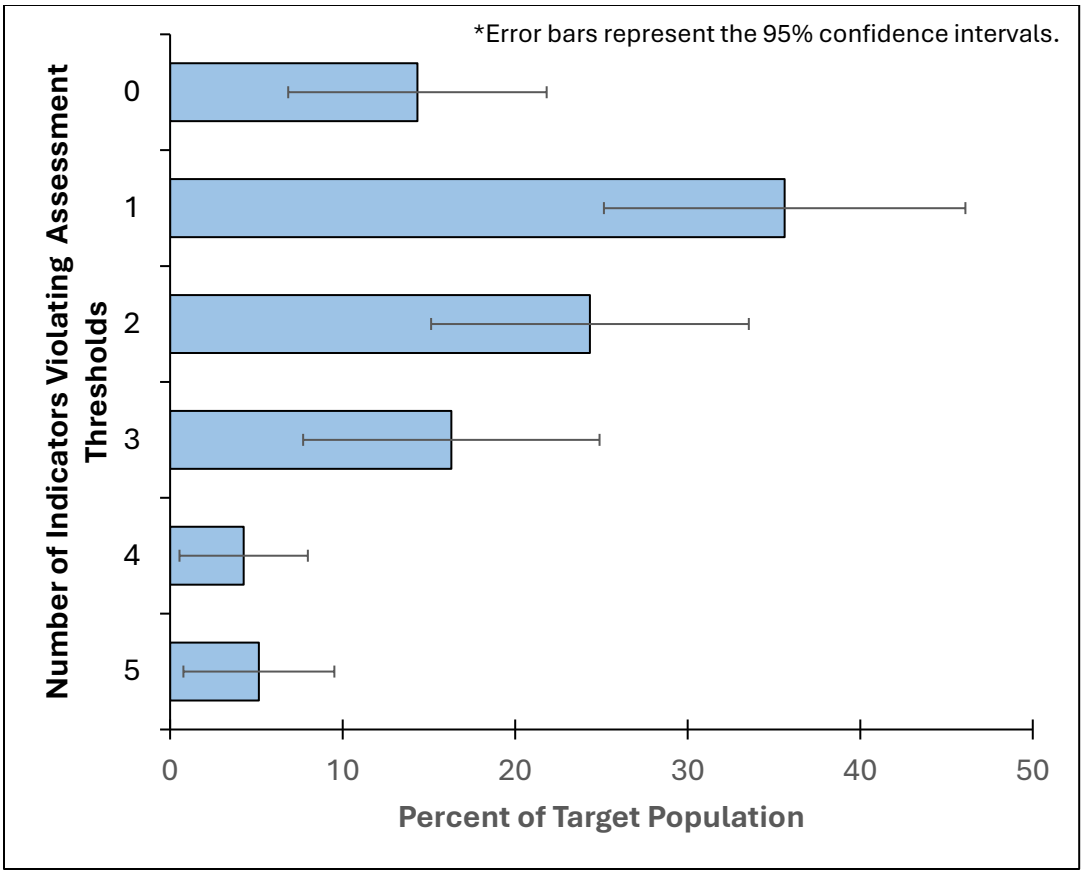

Figure 15. Extent of the target population with multiple indicators violating assessment thresholds.

Recreational Use

Overall

Recreational Use is divided into two categories of use based on the level of contact with the water, primary contact, and secondary contact (MassDEP 2021). These two uses have different assessment thresholds for some indicators and are therefore analyzed separately (Appendix D). *Primary Contact Recreational Use* was assessed as impaired in an estimated 46.3% of the target population while an estimated 42.5% of the target population was assessed as impaired for *Secondary Contact Recreational Use* (Figure 16). The similar impairment percentages for the two uses were due to the type of dominant stressor impacting *Recreational Uses*.

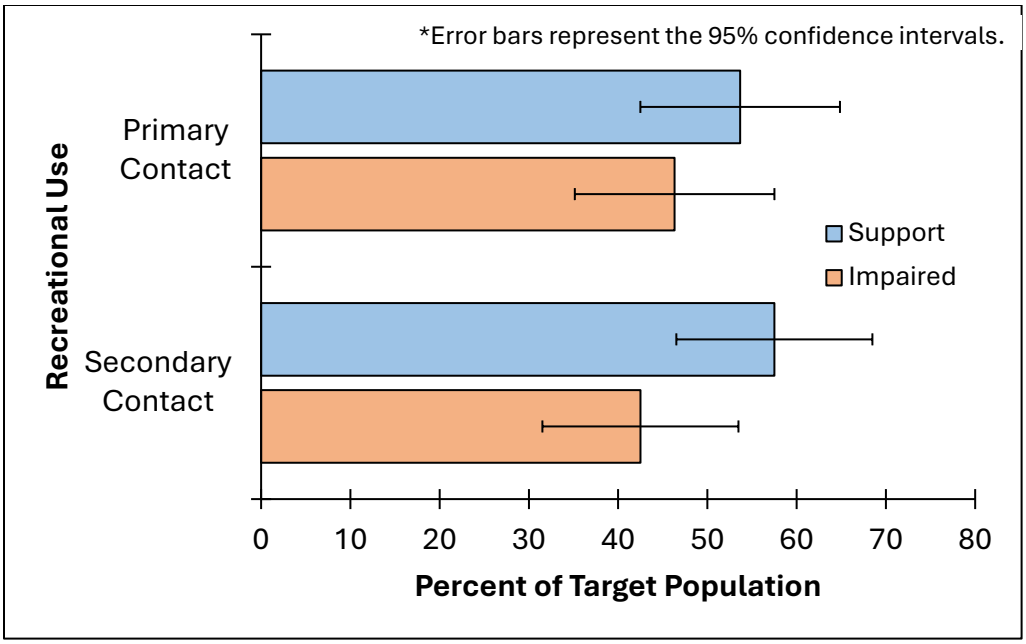

Figure 16. *Recreation Use* attainment status (support or impaired) in the target population.

Indicators

Recreational Use in the target population was assessed by evaluating the following indicators: pathogens (*E. coli* freshwater indicator), cyanobacteria cell counts, algal toxins, Secchi disk transparency, and aesthetics (MassDEP 2022). Aesthetics was clearly the dominate stressor to *Recreational Use* (both primary and secondary contact) in the target population. Aesthetics assessment thresholds were violated in an estimated 39.0% of the target population (Figure 17). Cyanobacteria cell counts, Secchi disk transparency, and pathogen (*E. coli*) assessment thresholds were violated in an estimated 5.3%, 4.1%, and 2.5% of the target population, respectively (Figure 17). The algal toxins assessment thresholds were not violated in the sampled lakes. Assessing aesthetics as a stressor to *Recreation Use* involved evaluating multiple factors from multiple sources (i.e., field sheet observations, BioBase data), so it is informative to look closer at the primary factors that led to the violations of the aesthetics assessment thresholds.

In an estimated 34.6% of the target population, the aesthetics assessment thresholds were violated due to excessive aquatic macrophyte biovolume (quantitatively measured using BioBase or based on visual observations). The other factor that resulted in violations of the aesthetics assessment thresholds was visual observations of excessive algal growth resulting in objectionable conditions (i.e., turbidity, blooms) in an estimated 4.4% of the target population (Figure 17). Based on these results, excessive aquatic macrophyte biovolume was the dominant factor in violations of the aesthetics assessment thresholds thus the dominant stressor to *Recreation Use* in the target population.

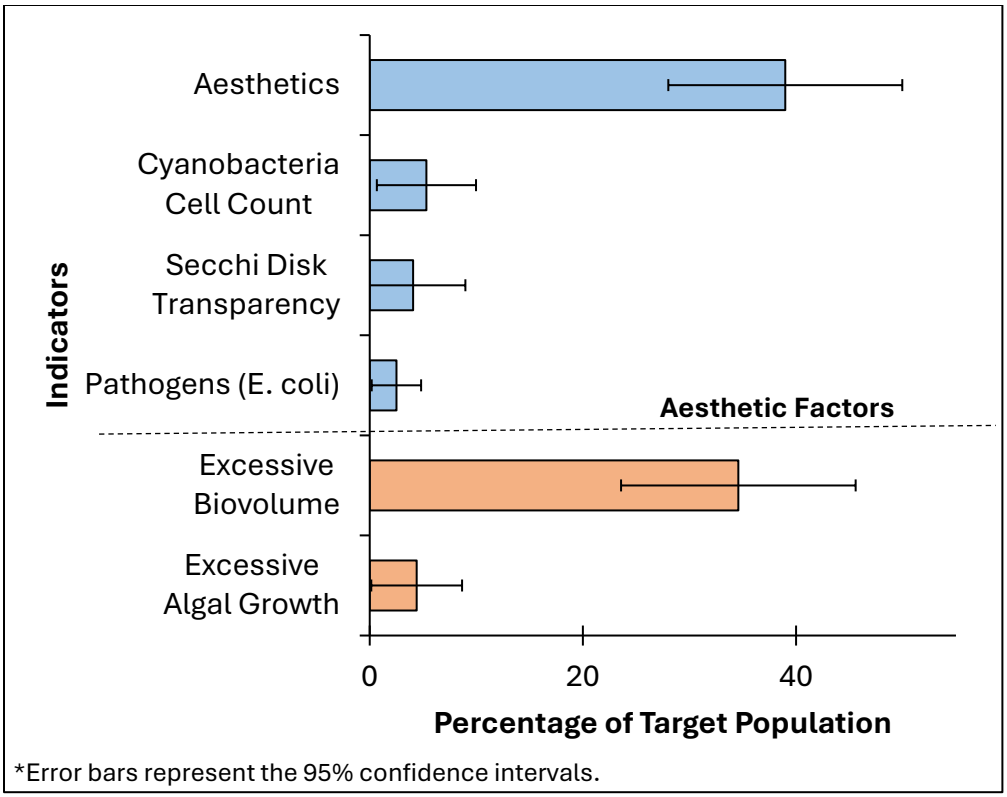

Figure 17. Extent of the target population violating assessment thresholds for the *Recreation Use* indicators.

Fish Consumption Use

Overall

Fish Consumption Use status was evaluated by classifying the target population into three categories based on site-specific fish consumption advisories and mercury concentrations in fish tissue samples. An estimated 37.3% of the target population has a site-specific fish consumption advisory, while an estimated 22.8% of the target population does not have a site-specific advisory but did have Massachusetts SWQS violations for mercury in fish tissue (Figure 18). In the absence of the statewide fish consumption advisory, the sum of these percentages (60.1%) would be the estimated portion of the target population assessed as impaired for *Fish Consumption Use*. An estimated 32.1% of the target population does not have a site-specific fish consumption advisory and did not have Massachusetts SWQS violations for mercury in fish tissue (Figure 18). In the absence of the statewide fish consumption advisory, this portion of the target population would be assessed as supporting *Fish Consumption Use*. Fish tissue data for an estimated 7.8% of the target population was not collected so this portion could not be evaluated for site-specific fish consumption advisory or Massachusetts SWQS violations (Figure 18).

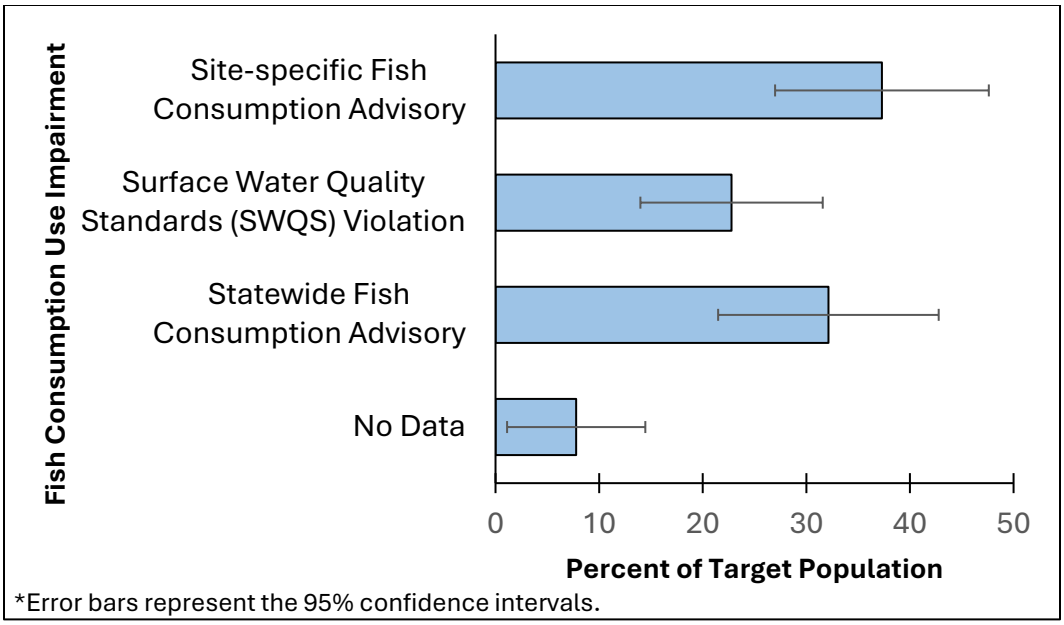

Figure 18. Extent of the target population in each *Fish Consumption Use* class: 1) site-specific fish consumption advisory issued, 2) no site-specific fish consumption advisory issued but Massachusetts SWQS violations for mercury in fish tissue are present, and 3) no site-specific fish consumption advisory issued or Massachusetts SWQS violations for mercury in fish tissue, but the statewide fish consumption advisory is applicable.

Indicators

Nearly all the site-specific fish consumption advisories and Massachusetts SWQS violations as well as the statewide freshwater fish consumption advisory (estimated 91.4% of the target population) were due to mercury contamination in the fish tissue. An estimated 0.8% of the target population has a site-specific fish consumption advisory for dichloro-diphenyl-trichloroethane (DDT) contamination in the fish tissue. There are other toxic pollutants (e.g., per- and polyfluoroalkyl substances [PFAS], polycyclic aromatic hydrocarbons [PAH], and PCBs) cited as hazards (i.e., stressors) in the Massachusetts Freshwater Fish Consumption Advisory List for specific lakes that were not represented in the target population of this probabilistic survey because either: 1) the toxic pollutant concentrations resulted in an advisory to a specific lake in the target population rarely enough not to be captured in the random subset selection from the target population (e.g., PCBs) or 2) the toxic pollutant was not analyzed as part of the probabilistic survey (e.g., PFAS, PAH) (MA DPH 2022).

The dominance of mercury as a potential hazard or stressor to *Fish Consumption Use* in the target population is evident by examining the extent of the target population where each class of toxic pollutant was detected in the fish tissue samples. Mercury was detected in fish tissue samples in an estimated 92.2% of the target population, while pesticides, PCBs, and other metals were detected in only 4.7%, 1.6%, and 0.8% of the target population, respectively (Figure 19). Based on

these results, the fish tissue concentration of mercury in the target population was examined in more detail using CDF curves of the average and maximum mercury concentrations for both the species composite samples (3-5 per lake) and the individual top carnivore fish samples (10-12 per lake) (Figures 20 and 21).

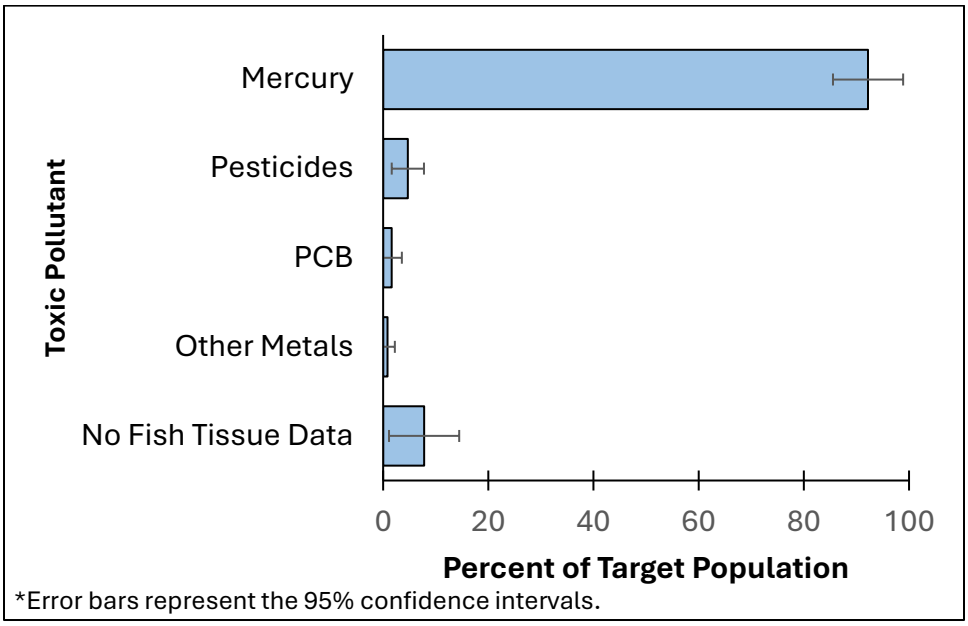

Figure 19. Extent of the target population with detectable levels of different toxic pollutants.

Based on the species composite samples, the estimated 50th percentile of average and maximum mercury concentrations in the target population were 0.26 mg/kg and 0.48 mg/kg, while the 75th percentiles were 0.37 mg/kg and 0.75 mg/kg, respectively (Figure 20). As evident in the CDF curves, a significant portion of the target population have both average and maximum mercury concentrations for the composite samples above the Massachusetts SWQS of 0.3 mg/kg, approximately 40% and 80% of the target population, respectively (Figure 20). Based on the individual top carnivore fish samples, the estimated 50th percentile of average and maximum mercury concentrations in the target population were 0.31 mg/kg and 0.61 mg/kg while the 75th percentiles were 0.44 mg/kg and 0.85 mg/kg, respectively (Figure 21). As evident in the CDF curves, a significant portion of the target population have both average and maximum mercury concentrations for the individual top carnivore fish samples above the human health criterion for methylmercury (0.3 mg/kg) in the Massachusetts SWQS, approximately 55% and 85% of the target population, respectively (Figure 21).

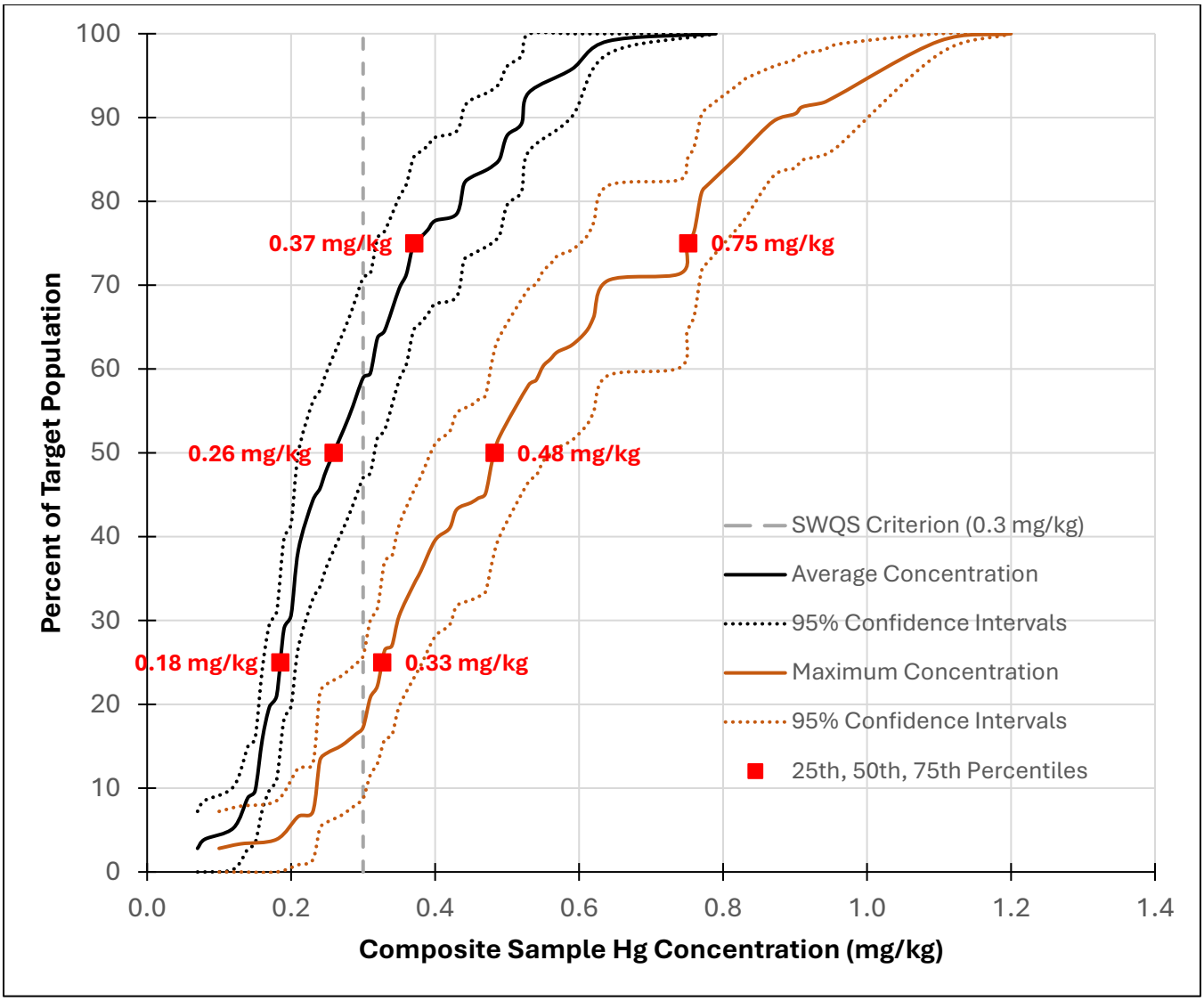

Figure 20. Cumulative distribution frequency curve of the average and maximum mercury concentrations in species composite fish samples in the target population with the human health criterion for methylmercury in the Massachusetts Surface Water Quality Standards (SWQS), and the 25th, 50th, and 75th percentiles marked and labeled.

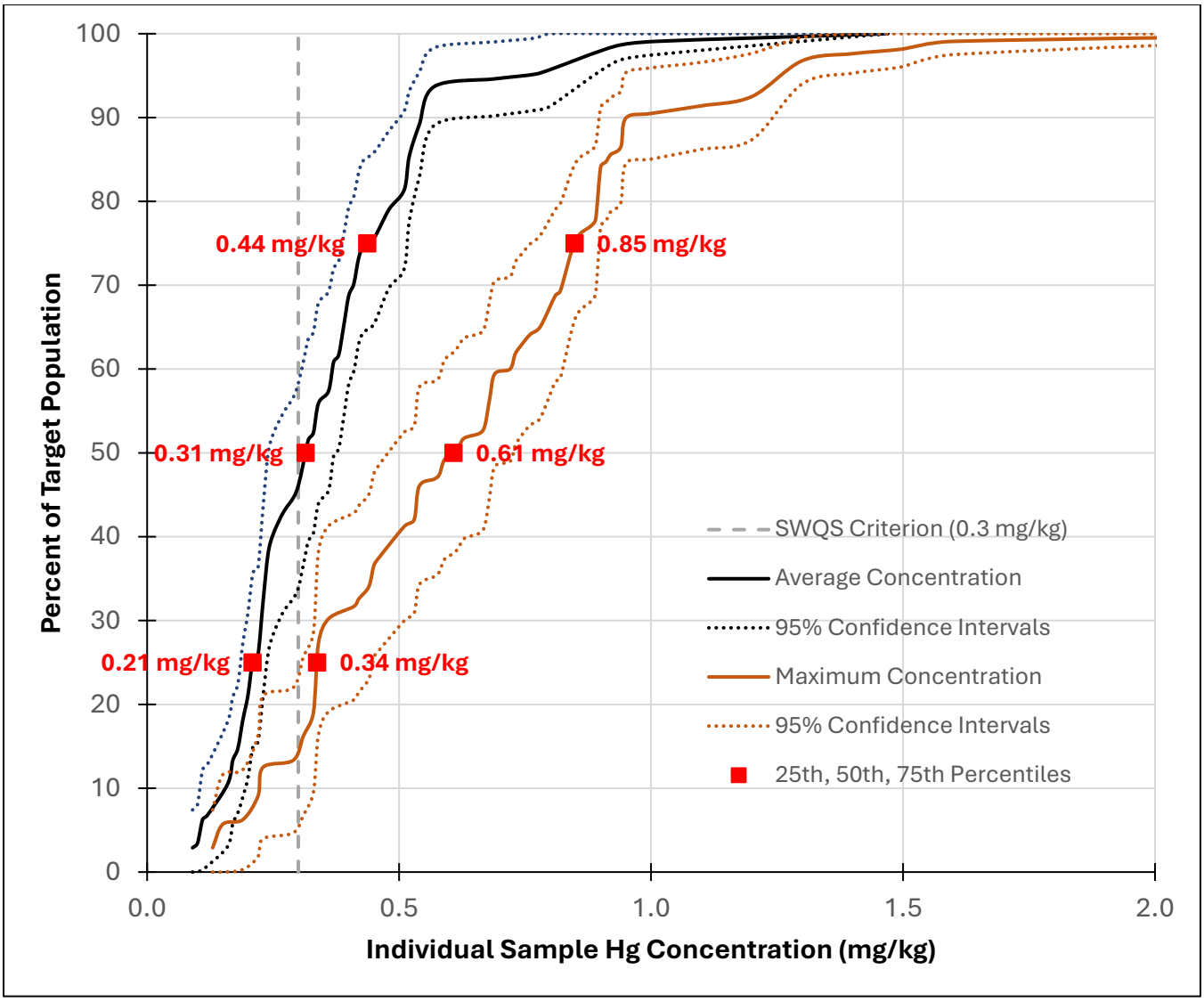

Figure 21. Cumulative distribution frequency curve of the average and maximum mercury concentrations in individual top carnivore fish samples in the target population with the human health criterion for methylmercury in the Massachusetts Surface Water Quality Standards (SWQS), and the 25th, 50th, and 75th percentiles marked and labeled.

Summary and Next Steps

The Watershed Planning Program (WPP) within the Massachusetts Department of Environmental Protection (MassDEP) completed field surveys and coordinated with internal (MassDEP's William X. Wall Experiment Station [WES] and WPP laboratory) and external laboratories to assess the condition of lakes across the Commonwealth. Over three summers, WPP field crews conducted nearly 400 sampling surveys (over 800 individual site visits) to sample or measure multiple indicators at 79 lakes across the Commonwealth's wide-ranging lake types. WPP field crews

yielded over 2,500 water and fish tissue samples (over 22,000 individual analyte results), which were sent to WES, the WPP laboratory, and external laboratories (approximately 20% of the samples) for analysis. Approximately 200 macroinvertebrate and phytoplankton samples were sent to external laboratories for taxonomic identification. In addition, WPP field crews completed over 230 vertical profiles (dissolved oxygen, temperature, pH, and specific conductivity) that resulted in over 1,800 individual parameter measurements.

Overall, the MAP2 lakes assessment found that lakes across the Commonwealth were degraded, particularly concerning the attainment of certain designated uses established in the Massachusetts Surface Water Quality Standards (i.e., the *Aquatic Life Use*, *Recreational Use*, and *Fish Consumption Use*). Nearly half of the lakes in the target population do not support the *Aquatic Life Use* (44.2%) or *Recreational Use* (46.3% for Primary Contact Recreation and 42.5% for Secondary Contact Recreation). Key stressors adversely affecting *Aquatic Life Use* and *Recreational Use* attainment in the target population are low dissolved oxygen (37.1% of the target population), excessive aquatic macrophyte biovolume (34.6% of the target population), low or high pH (34.0% of the target population), presence of non-native aquatic macrophytes (24.6% of the target population), and nutrient enrichment (15.9% of the target population). For the *Fish Consumption Use,* over half the lakes in the target population (60.1%) either have a site-specific fish consumption advisory (37.3%) or violations of the human health water quality criterion in the Massachusetts SWQS for mercury in fish tissue (22.8%). The prevalence of impoundments in the target population may contribute to the extent and significance of stressor impacts (e.g., excessive aquatic macrophyte biovolume, nutrient enrichment). The development of more refined assessment tools and methodologies for lakes would improve the accuracy of designated use and stressor assessments, thus improving population estimates in future lake probabilistic surveys. Some potential areas of refinement include numeric nutrient criteria, indices of biotic integrity for multiple biological assemblages (e.g., macroinvertebrates, phytoplankton), and natural background condition protocols for dissolved oxygen and pH. The probabilistic survey design only provides an unbiased and statistically valid assessment overview of lakes in the Commonwealth; the design provides information to the public and USEPA (through the Assessment, Total Maximum Daily Load [TMDL] Tracking and Implementation System [ATTAINS]) on the status of lakes and can advance prioritization or resource allocation efforts. The survey design does not identify specific unsampled lakes that require restoration due to being impaired or degraded. Identifying these lakes can only be accomplished by a targeted, resource intensive census of the waterbodies.

MassDEP also completed a probabilistic assessment of coastal waters in the Commonwealth, the Massachusetts Coastal Condition Assessment, that was conducted from 2020 through 2023.

Similar to this MAP2 lakes assessment report, WPP will publish the results of the coastal condition assessment in a future report.

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Appendix A. Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) Lakes Survey Design 2016 - 2018

Target Population

The target population is defined as all permanent freshwater lakes, reservoirs, and ponds greater than two hectares (ha) in surface area and deeper than two meters (m) at maximum depth within the Commonwealth of Massachusetts. The word "lake" in the remainder of this document includes lakes, reservoirs, and ponds. Lakes that are saline are excluded as are those used for aquaculture, disposal-tailings, sewage treatment, evaporation, or other unspecified disposal use.

Sample Frame

The sample frame was derived from the high-resolution National Hydrography Dataset 1:24,000 (NHD). Once the initial shapefile that included all waterbody objects in NHD was prepared, additional attributes (e.g., feature type, area, etc.) included in the shapefile were used to construct the final sample frame.

Waterbodies included in the sample frame were those lakes with feature codes equal to:
Lake/Pond: feature type only: no attributes
Lake/Pond: Hydrographic Category = perennial
Lake/Pond: Hydrographic Category = perennial; Stage = average water elevation
Lake/Pond: Hydrographic Category = perennial; Stage = normal pool
Lake/Pond: Hydrographic Category = perennial; Stage = spillway elevation
Reservoir: feature type only: no attributes
Reservoir: Reservoir Type = water storage; Construction Material = non-earthen
Reservoir: Reservoir Type = unspecified; Construction Material = earthen
Reservoir: Reservoir Type = unspecified; Construction Material = non-earthen

Waterbodies excluded in the sample frame were those lakes with feature codes equal to:
Reservoir: Reservoir Type = aquaculture
Reservoir: Reservoir Type = disposal-unspecified
Reservoir: Reservoir Type = treatment-cooling pond
Reservoir: Reservoir Type = treatment-filtration pond
Reservoir: Reservoir Type = treatment-sewage treatment pond
Reservoir: Reservoir Type = treatment
Swamp/Marsh: feature type only: no attributes

There are other feature codes within the NHD classification scheme that are not represented in Massachusetts. The inclusion list combined with the exclusion list accounts for all the feature codes that are represented in Massachusetts. The last step was to remove any lakes with a surface area greater than 2 ha. Any remaining non-target categories (e.g., tidal) will be identified during the candidate lake evaluation process.

Survey Design

A Generalized Random Tessellation Stratified (GRTS) survey design for a finite resource was used with stratification and unequal probability of selection. The design includes reverse hierarchical ordering of the selected lakes.

Stratification

The survey design is stratified by three geographic regions within Massachusetts to improve sampling logistics (Figure 1). One region will be targeted and sampled each year from 2016 to 2018, starting with the west region in 2016 and concluding with southeast in 2018.

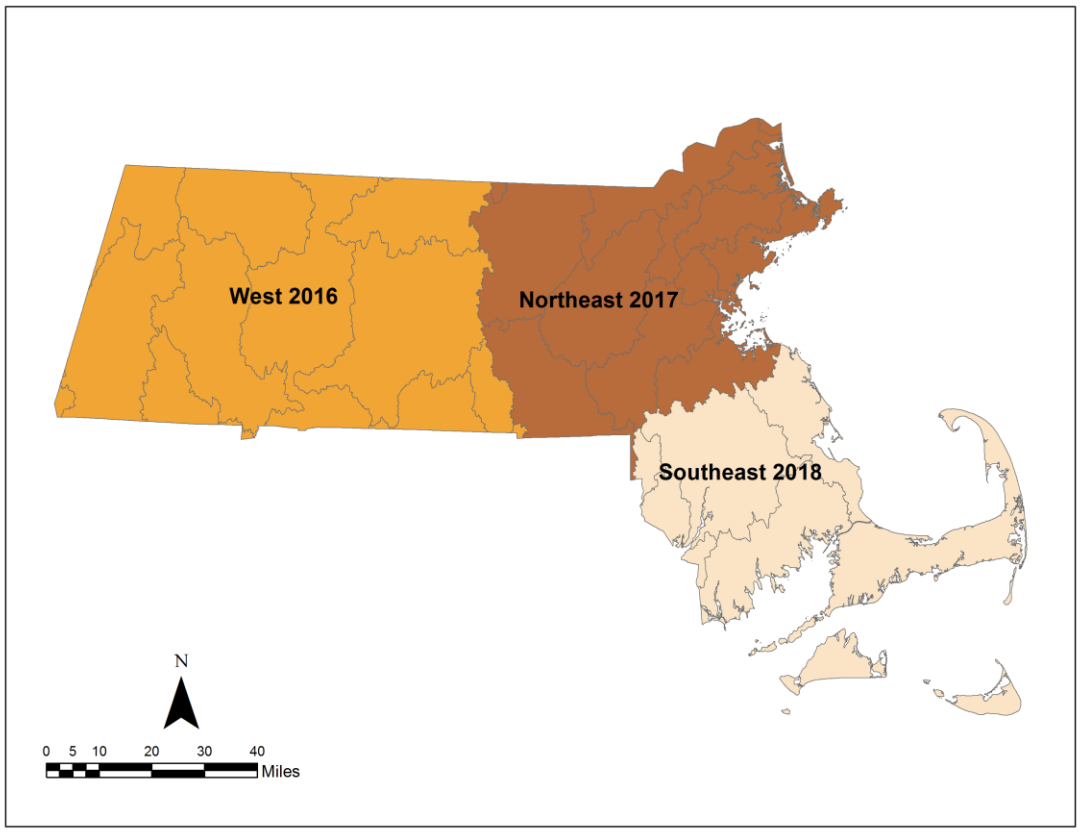

Figure 1. Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) Lakes Stratification Regions

Unequal Probability Categories

The Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) lakes design is an unequal probability design within each regional stratum. The two unequal probability categories were defined based on lake area: 2 to 20 ha and greater than 20 ha.

Panels

This survey design has a single panel.

Expected Sample Size

The designed sample size is 75 lakes for the state, with 25 lakes in each stratum. In addition, 100 oversample sites were selected in each stratum. The sample size within each stratum for the unequal probability categories was 13 for the 2 to 20 ha category and 12 for the greater than 20 ha category. The rationale for these sample sizes is based on the experience that smaller lakes, compared to larger lakes, are more likely to be inaccessible or not lakes. When lakes are replaced, the process is expected to more likely result in an equal number of lakes sampled by the lake area category.

Lake Use and Replacement

Each lake selected to be sampled is given a unique lake identification (lake ID), which consists of the project abbreviation (MAP2L) and a number between 001 and 375. Within each region stratum, lakes evaluated for potential sampling must have all lake IDs from the largest to the lowest number evaluated. For example, if MAPL-178 is the largest lake ID evaluated within the northeast stratum, then all lake IDs that are lower than 178 within the northeast stratum must be evaluated. Even more critical is that if MAP2L-178 is the largest lake ID sampled in the field, then all lower lake IDs within the northeast stratum that are evaluated to be a target lake and are accessible must be sampled in the field.

Sample Frame Summary

Stratum	Lakes 2 to 20 ha	Lakes > 20 ha	Total
West	593	180	773
Northeast	678	204	882
Southeast	800	163	963
Total	2071	547	2618

Site Selection Summary

	Stratum	Lakes 2 to 20 ha	Lakes > 20 ha	Total
Primary	West	13	12	25
	Northeast	12	13	25
	Southeast	14	11	25
	Total	39	36	75
Oversample	West	43	57	100
	Northeast	43	57	100
	Southeast	48	52	100
	Total	134	166	300

Description of Sample Design Output

Variable Name	Description
Lake ID	Unique identification label for each lake in the sample.
Longitude	Lake location longitude in decimal degrees coordinates (see projection below for datum).
Latitude	Lake location latitude in decimal degrees coordinates (see projection information below).
xcoord	X-coordinate of lake centroid (see projection information below).
ycoord	Y-coordinate of lake centroid (see Albers projection information below).
mdcaty	Multi-density categories used for unequal probability selection
weight	Weight (lakes), inverse of inclusion probability, to be used in statistical analyses
stratum	Strata used in the survey design
panel	Identifies and Oversample
EvalStatus	Site evaluation decision for site: TS: target and sampled, LD: landowner denied access, etc. (see below)
EvalReason	Site evaluation text comment
auxiliary variables	Remaining columns are from the sample frame provided

Appendix B. Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) Evaluated Lakes 2016 – 2018

Evaluation Category Key
Target = Sampled, WE = Wetland, ME = Map Error, RR = Run-of-River, SL = Shallow (<2 m), TI = Tidal, APD = Access permission denied, NRL = No response from landowner, PI = Physically inaccessible

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-001	Primary	WE	Unnamed	2.9	West	42.06755	-73.21741	25.78
MAP2L-002	Primary	Target	Hamilton Reservoir	97	West	42.05386	-72.15774	7.50
MAP2L-003	Primary	Target	Atkins Reservoir	18.8	West	42.42301	-72.48375	25.78
MAP2L-004	Primary	Target	Robin Hood Lake	25.7	West	42.24756	-73.06266	7.50
MAP2L-005	Primary	APD	Borden Brook Reservoir	85.3	West	42.12972	-72.94603	7.50
MAP2L-006	Primary	Target	Buckley Dunton Lake	62.2	West	42.31263	-73.13785	7.50
MAP2L-007	Primary	ME	Unnamed	3.7	West	42.57433	-72.27778	25.78
MAP2L-008	Primary	Target	Lake Monomonac	240.2	West	42.72462	-71.98860	7.50
MAP2L-009	Primary	ME	Unnamed	2.1	West	42.09206	-72.61357	25.78
MAP2L-010	Primary	WE	Berle Pond	3	West	42.22944	-73.31890	25.78
MAP2L-011	Primary	Target	Pequot Pond	62.7	West	42.18131	-72.69846	7.50
MAP2L-012	Primary	Target	Gaston Pond	6.2	West	42.45560	-72.13002	25.78
MAP2L-013	Primary	Target	Buffumville Lake	42.8	West	42.11651	-71.90974	7.50
MAP2L-014	Primary	WE	Unnamed	2.1	West	42.48657	-72.32533	25.78
MAP2L-015	Primary	Target	Damon Pond	31.4	West	42.41721	-72.83204	7.50
MAP2L-016	Primary	WE	Cusky Pond	11.5	West	42.32384	-72.09205	25.78
MAP2L-017	Primary	APD	Pelton Reservoir	6.9	West	42.05769	-73.12344	25.78
MAP2L-018	Primary	Target	Long Pond	66.9	West	42.11395	-72.13258	7.50
MAP2L-019	Primary	WE	Unnamed	2.7	West	42.26702	-72.37915	25.78
MAP2L-020	Primary	RR	Lower Reservoir Bear Swamp	43.4	West	42.68902	-72.97112	7.50
MAP2L-021	Primary	SL	Trout Pond	16.4	West	42.10176	-73.00103	25.78

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-022	Primary	Target	Lower Spectacle Pond	28.3	West	42.16309	-73.11985	7.50
MAP2L-023	Primary	ME	Unnamed	32.8	West	42.52304	-72.29175	7.50
MAP2L-024	Primary	Target	Queen Lake	56.2	West	42.53453	-72.11497	7.50
MAP2L-025	Primary	SL	Wheeler Pond	6.4	West	42.11828	-72.21204	25.78
MAP2L-026	Oversample	Target	Card Pond	4.6	West	42.32619	-73.36669	25.78
MAP2L-027	Oversample	NRL	Whiting Street Reservoir	41.5	West	42.24187	-72.63570	7.50
MAP2L-028	Oversample	Target	Long Pond	39.3	West	42.35119	-71.99296	7.50
MAP2L-029	Oversample	Target	Lake Chaubunagungamaug	517.4	West	42.04051	-71.84415	7.50
MAP2L-030	Oversample	WE	Unnamed	3.8	West	42.36225	-72.23875	25.78
MAP2L-031	Oversample	SL	Unnamed	2.4	West	42.40726	-72.91148	25.78
MAP2L-032	Oversample	Target	Quacumquasit Pond	90.1	West	42.17221	-72.07299	7.50
MAP2L-033	Oversample	NRL	Mirror Lake	5.7	West	42.07879	-73.09568	25.78
MAP2L-034	Oversample	Target	Windsor Lake	9.7	West	42.68703	-73.09250	25.78
MAP2L-035	Oversample	Target	Hardwick Pond	27.2	West	42.31296	-72.24029	7.50
MAP2L-036	Oversample	Target	Hallockville Pond	7.5	West	42.54946	-72.94498	25.78
MAP2L-037	Oversample	Target	Congamond Lakes South Pond	58.3	West	42.01398	-72.76443	7.50
MAP2L-038	Oversample	PI	Mud Pond	2.3	West	42.22065	-73.14882	25.78
MAP2L-039	Oversample	Target	Tully Pond	28.4	West	42.63653	-72.24003	7.50
MAP2L-040	Oversample	SL	Wrights Reservoir	53	West	42.54672	-71.97337	7.50
MAP2L-041	Oversample	Target	Vinica Pond	4.1	West	42.05061	-72.24648	25.78
MAP2L-042	Oversample	Target	Ashley Lake	37.9	West	42.37911	-73.15916	7.50
MAP2L-043	Oversample	Target	Roaring Brook Reservoir	8	West	42.47124	-72.66818	25.78
MAP2L-044	Oversample	Target	Sargent Pond	26.4	West	42.24906	-71.91643	7.50
MAP2L-045	Oversample	SL	Pistol Pond	2.1	West	42.11566	-72.06956	25.78
MAP2L-046	Oversample	RR	Aldrich Lake	8.1	West	42.28265	-72.52629	25.78
MAP2L-047	Oversample	Target	Benton Pond	24.9	West	42.18523	-73.04944	7.50

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-126	Primary	Target	Kettle Brook Reservoir No. 1	4.6	Northeast	42.25855	-71.89166	30.59
MAP2L-127	Primary	Target	Gleason Pond	4.3	Northeast	42.28654	-71.41272	30.59
MAP2L-128	Primary	Target	Cambridge Reservoir	215.3	Northeast	42.41028	-71.26745	8.12
MAP2L-129	Primary	Target	Lake Boon	70.2	Northeast	42.39611	-71.49500	8.12
MAP2L-130	Primary	RR	Hopedale Pond	35.6	Northeast	42.14157	-71.55696	8.12
MAP2L-131	Primary	RR	Harris Pond	24.4	Northeast	42.01800	-71.50735	8.12
MAP2L-132	Primary	Target	Nabnasset Pond	55.6	Northeast	42.61678	-71.42794	8.12
MAP2L-133	Primary	WE	Unnamed	8.2	Northeast	42.19898	-70.95295	30.59
MAP2L-134	Primary	Target	Badluck Lake	38.9	Northeast	42.04755	-71.76821	8.12
MAP2L-135	Primary	ME	Bryant Pond	2.5	Northeast	42.34352	-71.85364	30.59
MAP2L-136	Primary	Target	Crystal Lake	65.1	Northeast	42.79864	-71.14395	8.12
MAP2L-137	Primary	Target	Upper Artichoke Reservoir	70.8	Northeast	42.79895	-70.93259	8.12
MAP2L-138	Primary	Target	Sudbury Reservoir	368	Northeast	42.31713	-71.50129	8.12
MAP2L-139	Primary	Target	Heart Pond	38	Northeast	42.56632	-71.38814	8.12
MAP2L-140	Primary	Target	Fall Brook Reservoir	35.5	Northeast	42.49421	-71.78351	8.12
MAP2L-141	Primary	WE	Unnamed	11.8	Northeast	42.43653	-71.01497	30.59
MAP2L-142	Primary	RR	Curtis Ponds	12.6	Northeast	42.24222	-71.83675	30.59
MAP2L-143	Primary	SL	Reservoir Pond	101.7	Northeast	42.16887	-71.12315	8.12
MAP2L-144	Primary	ME	Unnamed	4.7	Northeast	42.55120	-71.21125	30.59
MAP2L-145	Primary	Target	Robbins Pond	4.6	Northeast	42.53756	-71.60462	30.59
MAP2L-146	Primary	Target	Little Chauncy Pond	17.5	Northeast	42.30593	-71.61721	30.59
MAP2L-147	Primary	Target	Wachusett Lake	52.2	Northeast	42.50831	-71.88118	8.12
MAP2L-148	Primary	WE	Martins Pond	7.6	Northeast	42.61583	-71.55553	30.59
MAP2L-149	Primary	WE	Unnamed	5.5	Northeast	42.24347	-70.88199	30.59
MAP2L-150	Primary	Target	Reservoir No. 6	5.8	Northeast	42.11456	-71.74228	30.59
MAP2L-151	Oversample	Target	Stodge Meadow Pond	50.5	Northeast	42.66140	-71.88251	8.12

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-152	Oversample	WE	Unnamed	3.2	Northeast	42.67798	-71.40033	30.59
MAP2L-153	Oversample	WE	Mile Brook Reservoir	7	Northeast	42.63975	-70.92141	30.59
MAP2L-154	Oversample	Target	Lake Pearl	95.8	Northeast	42.06162	-71.34470	8.12
MAP2L-155	Oversample	ME	Chestnut Hill Reservoir	33.4	Northeast	42.33539	-71.15845	8.12
MAP2L-156	Oversample	Target	Lily Ponds	2.1	Northeast	42.37666	-71.76955	30.59
MAP2L-157	Oversample	Target	Walden Pond	90.3	Northeast	42.49518	-71.00503	8.12
MAP2L-158	Oversample	RR	Cook Pond	6.8	Northeast	42.28454	-71.85794	30.59
MAP2L-159	Oversample	Target	Ponkapoag Pond	86.5	Northeast	42.19190	-71.09246	8.12
MAP2L-160	Oversample	Target	South Reservoir	29.3	Northeast	42.44469	-71.11582	8.12
MAP2L-161	Oversample	Target	Barkers Pond	2.4	Northeast	42.46078	-71.43226	30.59
MAP2L-162	Oversample	RR	Hovey Pond	8.2	Northeast	42.23406	-71.71470	30.59
MAP2L-163	Oversample	Target	Crow Hills Pond	5.5	Northeast	42.51680	-71.85545	30.59
MAP2L-164	Oversample	Target	Field Pond	22.9	Northeast	42.60748	-71.10978	8.12
MAP2L-165	Oversample	TI	Clark Pond	4.2	Northeast	42.57736	-70.72351	30.59
MAP2L-166	Oversample	ME	Unnamed	14.5	Northeast	42.29524	-71.52570	30.59
MAP2L-167	Oversample	Target	Fitchburg Reservoir	60.6	Northeast	42.64879	-71.84345	8.12
MAP2L-168	Oversample	Target	Fort Pond	30.8	Northeast	42.52343	-71.68708	8.12
MAP2L-169	Oversample	Target	Stiles Pond	23.9	Northeast	42.68899	-71.03706	8.12
MAP2L-170	Oversample	SL	Turner Pond	7.1	Northeast	42.15167	-71.26285	30.59
MAP2L-171	Oversample	ME	Fairhaven Bay	29.1	Northeast	42.42591	-71.35253	8.12
MAP2L-172	Oversample	Target	Bartlett Pond	21	Northeast	42.31679	-71.61846	8.12
MAP2L-251	Primary	TI	Allens Pond	79.5	Southeast	41.51265	-71.01564	4.94
MAP2L-252	Primary	WE	Witch Pond	4.1	Southeast	42.01832	-71.28602	25.00
MAP2L-253	Primary	TI	Oyster Pond	55	Southeast	41.67976	-69.97184	4.94
MAP2L-254	Primary	TI	Mill Pond	26.6	Southeast	41.70409	-70.20692	4.94
MAP2L-255	Primary	SL	Unnamed	4	Southeast	41.88365	-70.95047	25.00

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-256	Primary	TI	Chilmark Pond	65.4	Southeast	41.34863	-70.69419	4.94
MAP2L-257	Primary	Target	Halfway Pond	86.8	Southeast	41.85193	-70.61404	4.94
MAP2L-258	Primary	Target	Shubael Pond	22.2	Southeast	41.67180	-70.39343	4.94
MAP2L-259	Primary	Target	South Watuppa Pond	595.4	Southeast	41.66216	-71.12691	4.94
MAP2L-260	Primary	TI	Salt Pond	24.5	Southeast	41.54360	-70.62670	4.94
MAP2L-261	Primary	ME	Golden Field Pond	5.4	Southeast	41.82114	-70.72644	25.00
MAP2L-262	Primary	ME	Plympton Bog North Reservoir	4	Southeast	41.96138	-70.80106	25.00
MAP2L-263	Primary	Target	Cleveland Pond	38.9	Southeast	42.12042	-70.98827	4.94
MAP2L-264	Primary	Target	Williams Pond	3.3	Southeast	41.96411	-70.00772	25.00
MAP2L-265	Primary	NRL	Unnamed	8.2	Southeast	41.90699	-70.81299	25.00
MAP2L-266	Primary	ME	Bay State Co. Bog Reservoir	4	Southeast	41.96026	-70.78643	25.00
MAP2L-267	Primary	TI	Richmond Pond	18.8	Southeast	41.50404	-71.11328	25.00
MAP2L-268	Primary	Target	Lake Hiawatha	21.9	Southeast	41.96790	-71.32400	4.94
MAP2L-269	Primary	Target	Stillwater Pond	7.4	Southeast	41.70309	-69.98553	25.00
MAP2L-270	Primary	Target	Long Pond	21.9	Southeast	41.67103	-70.19370	4.94
MAP2L-271	Primary	ME	Somerset Reservoir	66.5	Southeast	41.78271	-71.13925	4.94
MAP2L-272	Primary	SL	Crystal Lake	5.1	Southeast	41.46815	-70.57273	25.00
MAP2L-273	Primary	APD	Wall Pond	4.8	Southeast	41.82562	-70.60149	25.00
MAP2L-274	Primary	Target	Long Pond	20.4	Southeast	41.66710	-70.44415	4.94
MAP2L-275	Primary	Target	Ames Long Pond	20.6	Southeast	42.09604	-71.12473	4.94
MAP2L-276	Oversample	TI	Eel Pond	108.8	Southeast	41.55427	-70.54347	4.94
MAP2L-277	Oversample	WE	Ten Acre Reservoir	2.5	Southeast	41.88683	-70.71966	25.00
MAP2L-278	Oversample	SL	Burrage Pd - Lower Reservoir	32.3	Southeast	42.01827	-70.87826	4.94
MAP2L-279	Oversample	SL	Coopers Pond	4.9	Southeast	41.94730	-71.25360	25.00
MAP2L-280	Oversample	Target	Jemima Pond	2.2	Southeast	41.82959	-69.98464	25.00
MAP2L-281	Oversample	WE	Unnamed	4.5	Southeast	41.77224	-70.79321	25.00

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-282	Oversample	SL	Blackwater Pond	3.2	Southeast	42.00612	-70.73715	25.00
MAP2L-283	Oversample	ME	Unnamed	3.2	Southeast	41.77586	-71.30332	25.00
MAP2L-284	Oversample	PI	Unnamed	5.1	Southeast	41.25406	-70.80631	25.00
MAP2L-285	Oversample	Target	Fresh Pond	24.2	Southeast	41.90289	-70.55445	4.94
MAP2L-286	Oversample	SL	Fawcetts Pond	3.3	Southeast	41.65006	-70.30320	25.00
MAP2L-287	Oversample	NRL	Unnamed	2.3	Southeast	41.76071	-70.98773	25.00
MAP2L-288	Oversample	TI	Oyster Pond	76.1	Southeast	41.35131	-70.60308	4.94
MAP2L-289	Oversample	Target	Ezekiel Pond	14.4	Southeast	41.80459	-70.61235	25.00
MAP2L-290	Oversample	Target	Mashpee/Wakeby Pond	294.8	Southeast	41.66054	-70.48678	4.94
MAP2L-291	Oversample	RR	Town River Reservoir	11.4	Southeast	42.00784	-70.98799	25.00
MAP2L-292	Oversample	TI	Quicks Hole Pond	31.9	Southeast	41.43313	-70.85196	4.94
MAP2L-293	Oversample	SL	Unnamed	27.1	Southeast	41.79046	-70.85952	4.94
MAP2L-294	Oversample	Target	Furnace Pond	41.5	Southeast	42.05579	-70.82597	4.94
MAP2L-295	Oversample	Target	Watson Pond	31.4	Southeast	41.95079	-71.11868	4.94
MAP2L-296	Oversample	Target	Hinckleys Pond	66.1	Southeast	41.71135	-70.08607	4.94
MAP2L-297	Oversample	Target	Marys Pond	32.8	Southeast	41.75531	-70.79057	4.94
MAP2L-298	Oversample	WE	Stump Pond	45.6	Southeast	42.08158	-70.77231	4.94
MAP2L-299	Oversample	ME	Forge Pond	22.6	Southeast	41.80553	-71.05063	4.94
MAP2L-300	Oversample	TI	Hummock Pond	81.6	Southeast	41.25900	-70.15123	4.94
MAP2L-301	Oversample	Target	Island Pond	21	Southeast	41.81194	-70.57670	4.94
MAP2L-302	Oversample	SL	Lumbert Pond	3.9	Southeast	41.65932	-70.37692	25.00
MAP2L-303	Oversample	WE	Hamlins Pond	5.1	Southeast	41.69690	-70.91455	25.00
MAP2L-304	Oversample	Target	Coonamessett Pond	64.4	Southeast	41.61928	-70.56697	4.94
MAP2L-305	Oversample	Target	Parker Mills Pond	29.6	Southeast	41.77638	-70.71615	4.94
MAP2L-306	Oversample	Target	Cooks Pond	8.6	Southeast	41.92072	-70.66541	25.00
MAP2L-307	Oversample	Target	Robbins Pond	50.1	Southeast	42.00417	-70.90441	4.94

Lake ID	Panel	Evaluation Category	Waterbody Name	Area (ha)	Stratum	Centroid Latitude	Centroid Longitude	Adjusted Weight
MAP2L-308	Oversample	TI	Rushy Marsh Pond	5.6	Southeast	41.59952	-70.44498	25.00
MAP2L-309	Oversample	WE	Unnamed	2.8	Southeast	41.84467	-70.85919	25.00
MAP2L-310	Oversample	ME	Unnamed	2.2	Southeast	41.93117	-70.76226	25.00
MAP2L-311	Oversample	ME	Unnamed	4.7	Southeast	42.00820	-71.21698	25.00
MAP2L-312	Oversample	Target	Mill Pond	4.8	Southeast	41.72546	-70.03974	25.00
MAP2L-313	Oversample	TI	Unnamed	2.1	Southeast	41.73111	-70.62319	25.00
MAP2L-314	Oversample	PI	Factory Pond	20.8	Southeast	42.08843	-70.87388	4.94
MAP2L-315	Oversample	Target	White Pond	4.2	Southeast	41.70242	-70.13274	25.00

Appendix C. Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) Target Sampled Lakes 2016 – 2018 Site Locations (Index and Shoreline)

Index

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-002	2016 West	Hamilton Reservoir	Quinebaug	W2619	[index site, southwestern quadrant of northern lobe, Holland]	42.05296	-72.15852
MAP2L-003	2016 West	Atkins Reservoir	Connecticut	W2620	[index site, northwestern portion of reservoir, Shutesbury]	42.42485	-72.48672
MAP2L-004	2016 West	Robin Hood Lake	Westfield	W2621	[index site, northeastern lobe of lake, Becket]	42.25157	-73.06217
MAP2L-006	2016 West	Buckley-Dunton Lake	Westfield	W2622	[index site, southeastern quadrant, Becket]	42.31238	-73.13334
MAP2L-008	2016 West	Lake Monomonac	Millers	W2623	[index site, northern portion of lake, Rindge, New Hampshire]	42.72688	-71.98870
MAP2L-011	2016 West	Pequot Pond	Westfield	W1751	[deep hole, Southampton/Westfield]	42.18433	-72.69383
MAP2L-012	2016 West	Gaston Pond	Chicopee	W2624	[index site, northern end of pond, Barre]	42.45861	-72.13100
MAP2L-013	2016 West	Buffumville Lake	French	W2625	[index site, northern end of southern lobe, Charlton]	42.11699	-71.90951
MAP2L-015	2016 West	Damon Pond	Westfield	W2626	[index site, southern end of pond, Chesterfield]	42.41221	-72.83426
MAP2L-018	2016 West	East Brimfield Reservoir	Quinebaug	W2627	[index site, just south of center of northern portion (Long Pond) of reservoir, Sturbridge]	42.12009	-72.13122

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-022	2016 West	Lower Spectacle Pond	Farmington	W2628	[index site, southern end of pond, Sandisfield]	42.16259	-73.11804
MAP2L-024	2016 West	Queen Lake	Chicopee	W2629	[index site, approximate center of lake, Phillipston]	42.53539	-72.11402
MAP2L-026	2016 West	Card Pond	Housatonic	W2630	[index site, northern end of pond, West Stockbridge]	42.32792	-73.36696
MAP2L-028	2016 West	Long Pond	Chicopee	W2631	[index site, in southern most portion of pond, Rutland]	42.35064	-71.99241
MAP2L-029	2016 West	Webster Lake	French	W1295	[deep hole, Webster]	42.05364	-71.84808
MAP2L-032	2016 West	Quacumquasit Pond	Chicopee	W1005	[deep hole, East Brookfield]	42.17302	-72.07108
MAP2L-034	2016 West	Windsor Lake	Hudson	W2632	[index site, North Adams]	42.68634	-73.09319
MAP2L-035	2016 West	Hardwick Pond	Chicopee	W2633	[index site, southern end of pond, Hardwick]	42.31218	-72.23904
MAP2L-036	2016 West	Hallockville Pond	Deerfield	W2634	[index site, northeastern end of pond, Plainfield]	42.55110	-72.94258
MAP2L-037	2016 West	Congamond Lakes	Westfield	W0925	[deep hole, center of South Pond, Southwick]	42.01472	-72.76362
MAP2L-039	2016 West	Tully Pond	Millers	W2635	[index site, western lobe, Orange]	42.63693	-72.24685
MAP2L-041	2016 West	Vinica Pond	Chicopee	W2637	[index site, Wales]	42.05026	-72.24662
MAP2L-042	2016 West	Ashley Lake	Housatonic	W2638	[index site, Washington]	42.38137	-73.16073

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-043	2016 West	Roaring Brook Reservoir	Connecticut	W2639	[index site, eastern lobe, Conway]	42.46965	-72.66562
MAP2L-044	2016 West	Sargent Pond	French	W2640	[index site, southern end of southern lobe, Leicester]	42.24539	-71.91673
MAP2L-047	2016 West	Benton Pond	Farmington	W0347	[deep hole, Otis]	42.18360	-73.04390
MAP2L-126	2017 Northeast	Kettle Brook Reservoir No. 1	Blackstone	W2666	[index site, Leicester]	42.25855	-71.89166
MAP2L-127	2017 Northeast	Gleasons Pond	Concord	W2668	[index site, Framingham]	42.28654	-71.41272
MAP2L-128	2017 Northeast	Cambridge Reservoir	Charles	W2670	[index site, southern end of reservoir, Waltham]	42.41028	-71.26745
MAP2L-129	2017 Northeast	Boons Pond	Concord	W2672	[index site, south central lobe, Stow]	42.39611	-71.49500
MAP2L-132	2017 Northeast	Nabnasset Pond	Merrimack	W2674	[index site, north of Lake Shore Drive, Westford]	42.61678	-71.42794
MAP2L-134	2017 Northeast	Crystal Lake	Blackstone	W2676	[index site, Douglas]	42.04755	-71.76821
MAP2L-136	2017 Northeast	Crystal Lake	Merrimack	W2678	[index site, southeastern lobe of lake, Haverhill]	42.79864	-71.14395
MAP2L-137	2017 Northeast	Upper Artichoke Reservoir	Merrimack	W2680	[index site, West Newbury]	42.79895	-70.93259
MAP2L-138	2017 Northeast	Sudbury Reservoir	Concord	W2682	[index site, in portion of reservoir south of Route 30 and north of the rail crossing, Southborough]	42.30195	-71.51287
MAP2L-139	2017 Northeast	Heart Pond	Concord	W2684	[index site, western lobe, Chelmsford]	42.56632	-71.38814

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-140	2017 Northeast	Fall Brook Reservoir	Nashua	W2686	[index site, Leominster]	42.49421	-71.78351
MAP2L-145	2017 Northeast	Robbins Pond	Nashua	W2688	[index site, Harvard]	42.53756	-71.60462
MAP2L-146	2017 Northeast	Little Chauncy Pond	Concord	W2690	[index site, Northborough]	42.30593	-71.61721
MAP2L-147	2017 Northeast	Wachusett Lake	Nashua	W2692	[index site, Westminster]	42.50831	-71.88118
MAP2L-150	2017 Northeast	Reservoir No. 6	Blackstone	W2694	[index site, Sutton]	42.11456	-71.74228
MAP2L-151	2017 Northeast	Stodge Meadow Pond	Merrimack	W2696	[index site, southeastern lobe of pond, Ashburnham]	42.66140	-71.88251
MAP2L-154	2017 Northeast	Lake Pearl	Charles	W0970	[deep hole, Wrentham]	42.06605	-71.35204
MAP2L-156	2017 Northeast	Lily Pond	Nashua	W2699	[Middle Basin, index site, West Boylston]	42.37666	-71.76955
MAP2L-157	2017 Northeast	Walden Pond	North Coastal	W2701	[index site, Saugus]	42.49518	-71.00503
MAP2L-159	2017 Northeast	Ponkapoag Pond	Boston Harbor	W2097	[deep hole, Randolph]	42.19218	-71.09297
MAP2L-160	2017 Northeast	South Reservoir	Boston Harbor	W2704	[index site, Medford]	42.44469	-71.11582
MAP2L-161	2017 Northeast	Barkers Pond	Concord	W2706	[index site, Acton]	42.46078	-71.43226
MAP2L-163	2017 Northeast	Lower Crow Hill Pond	Nashua	W2708	[index site, Princeton]	42.51680	-71.85545

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-164	2017 Northeast	Field Pond	Ipswich	W2710	[index site, Andover]	42.60748	-71.10978
MAP2L-167	2017 Northeast	Fitchburg Reservoir	Nashua	W2712	[index site, Ashby]	42.64879	-71.84345
MAP2L-168	2017 Northeast	Fort Pond	Nashua	W0603	[Lancaster]	42.52347	-71.68809
MAP2L-169	2017 Northeast	Stiles Pond	Ipswich	W2715	[index site, Boxford]	42.68899	-71.03706
MAP2L-172	2017 Northeast	Bartlett Pond	Concord	W2717	[index site, Northborough]	42.31679	-71.61846
MAP2L-257	2018 Southeast	Halfway Pond	Buzzards Bay	W2796	[index site, eastern lobe, Plymouth]	41.85294	-70.61467
MAP2L-258	2018 Southeast	Shubael Pond	Cape Cod	W2808	[index site, Barnstable]	41.67104	-70.39372
MAP2L-259	2018 Southeast	South Watuppa Pond	Mount Hope Bay	W2775	[index site, Fall River/Westport]	41.67155	-71.12648
MAP2L-263	2018 Southeast	Cleveland Pond	Taunton	W2778	[index site, in southern lobe near the Ames Pond Dam (NATID: MA00347), Abington]	42.11455	-70.97910
MAP2L-264	2018 Southeast	Williams Pond	Cape Cod	W2814	[index site, Wellfleet]	41.96411	-70.00772
MAP2L-268	2018 Southeast	Lake Hiawatha	Ten Mile	W0958	[North Basin, deep hole of a Ten Mile River impoundment, North Attleborough]	41.96890	-71.32511
MAP2L-269	2018 Southeast	Stillwater Pond	Cape Cod	W2810	[index site, Chatham]	41.70339	-69.98612

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-270	2018 Southeast	Long Pond	Cape Cod	W2803	[index site, eastern half of pond, west of Station Avenue, Yarmouth]	41.67169	-70.19327
MAP2L-274	2018 Southeast	Long Pond	Cape Cod	W2805	[index site, west of Santuit Newton Road, Barnstable]	41.66710	-70.44415
MAP2L-275	2018 Southeast	Ames Long Pond	Taunton	W0940	[deep hole, southern end of southern basin of pond, Easton]	42.07840	-71.11555
MAP2L-280	2018 Southeast	Jemima Pond	Cape Cod	W2801	[index site, Eastham]	41.82959	-69.98464
MAP2L-285	2018 Southeast	Fresh Pond	South Coastal	W1092	[deep hole, Plymouth]	41.90533	-70.55598
MAP2L-289	2018 Southeast	Ezekiel Pond	Buzzards Bay	W2789	[index site, Plymouth]	41.80491	-70.61197
MAP2L-290	2018 Southeast	Mashpee Pond	Cape Cod	W1308	[deep hole, Mashpee]	41.65691	-70.48391
MAP2L-294	2018 Southeast	Furnace Pond	South Coastal	W1093	[deep hole, southeastern lobe, Pembroke]	42.05376	-70.82256
MAP2L-295	2018 Southeast	Watson Pond	Taunton	W0947	[deep hole, center of pond, approximately 275 feet south from north central shore, Taunton]	41.95143	-71.11913
MAP2L-296	2018 Southeast	Hinckleys Pond	Cape Cod	W1237	[deep hole, Harwich]	41.71378	-70.09063
MAP2L-297	2018 Southeast	Marys Pond	Buzzards Bay	W2791	[index site, Rochester]	41.75446	-70.79039
MAP2L-301	2018 Southeast	Island Pond	South Coastal	W2787	[index site, Plymouth]	41.81194	-70.57670
MAP2L-304	2018 Southeast	Coonamessett Pond	Cape Cod	W2798	[index site, Falmouth]	41.62035	-70.56532

Lake ID	Year Stratum	Waterbody Name	Watershed	Index Unique ID	Index Site Description	Index Latitude	Index Longitude
MAP2L-305	2018 Southeast	Parker Mills Pond	Buzzards Bay	W0776	[deep hole in southern end of Wankinco River impoundment, Wareham]	41.77019	-70.72206
MAP2L-306	2018 Southeast	Cooks Pond	South Coastal	W2783	[index site, southern lobe, Plymouth]	41.92072	-70.66541
MAP2L-307	2018 Southeast	Robbins Pond	Taunton	W2780	[index site, off eastern tip of Osceola Island, East Bridgewater]	42.00618	-70.90628
MAP2L-312	2018 Southeast	Mill Pond	Cape Cod	W2773	[Mill Pond, index site, Harwich/Brewster]	41.72546	-70.03974
MAP2L-315	2018 Southeast	White Pond	Cape Cod	W2812	[index site, Dennis/Harwich]	41.70242	-70.13274

Shoreline

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-002S	2016 West	Hamilton Reservoir	Quinebaug	W2602	[northwestern side of reservoir, at beach just southeast of the Chandler Road, Mashapaug Road intersection, Holland]	42.05458	-72.16026
MAP2L-003S	2016 West	Atkins Reservoir	Connecticut	W2605	[northern end of reservoir, at the Atkins Reservoir Dam (NATID: MA00508), south of January Hills Road, Shutesbury]	42.42566	-72.48684
MAP2L-004S	2016 West	Robin Hood Lake	Westfield	W2612	[beach south of Robin Hood Lake Dam (NATID: MA00206), west off Will Scarlet Drive, Becket]	42.25138	-73.06162

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-006S	2016 West	Buckley-Dunton Lake	Westfield	W2615	[eastern side of lake, at southern end of Buckley-Dunton Lake Dam (NATID: MA00202), west of Buckley Dam Road, Becket]	42.31224	-73.13211
MAP2L-008S	2016 West	Lake Monomonac	Millers	W2597	[east off Route 202 at New Hampshire/Massachusetts border]	42.71454	-72.01505
MAP2L-011S	2016 West	Pequot Pond	Westfield	W2607	[southeastern edge of pond, at Kingsley Beach, north of Old Apremont Way, Westfield]	42.18020	-72.69194
MAP2L-012S	2016 West	Gaston Pond	Chicopee	W2601	[northern end of pond, east of pond outlet, south off Mill Road, Barre]	42.45874	-72.13075
MAP2L-013S	2016 West	Buffumville Lake	French	W2593	[Buffumville Lake Beach, north of Oxford Road, Charlton]	42.12297	-71.91179
MAP2L-015S	2016 West	Damon Pond	Westfield	W2609	[southern end of pond, at beach west of Damon Pond Dam (NATID: MA00060), west off Damon Pond Road, Chesterfield]	42.41193	-72.83467
MAP2L-018S	2016 West	East Brimfield Reservoir	Quinebaug	W2600	[northeastern end of reservoir, beach at southern end of Old Streeter Road, south off Route 20 (Brimfield Road), Sturbridge]	42.11005	-72.13031
MAP2L-022S	2016 West	Lower Spectacle Pond	Farmington	W2614	[at southern end of pond, east of Lower Spectacle Pond Dam (NATID: MA00290), east of Cold Spring Road, Sandisfield]	42.16130	-73.12014

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-024S	2016 West	Queen Lake	Chicopee	W2599	[southern end of lake, east of boat ramp, north off Route 101 (Queen Lake Road), Phillipston]	42.52603	-72.11634
MAP2L-026S	2016 West	Card Pond	Housatonic	W2617	[beach at northern end of pond, west of Route 41 (Great Barrington Road), West Stockbridge]	42.32793	-73.36662
MAP2L-028S	2016 West	Long Pond	Chicopee	W2596	[south off the Long Pond boat launch parking area, west off Route 122 (Barre Paxton Road), Rutland]	42.35815	-71.99282
MAP2L-029S	2016 West	Webster Lake	French	W2465	[Memorial Beach Park, northwestern portion of lake (locally 'North Pond'), east of Memorial Beach Drive, Webster]	42.05356	-71.85565
MAP2L-032S	2016 West	Quacumquasit Pond	Chicopee	W2598	[northern end of pond, west of boat ramp, south of Lake Road, Brookfield]	42.18090	-72.07374
MAP2L-034S	2016 West	Windsor Lake	Hudson	W2613	[beach at southwestern edge of lake, east off Windsor Lake Road, North Adams]	42.68609	-73.09424
MAP2L-035S	2016 West	Hardwick Pond	Chicopee	W2603	[southern end of pond, at pond outlet, from boat launch north of Hardwick Pond Road, Hardwick]	42.31079	-72.24156
MAP2L-036S	2016 West	Hallockville Pond	Deerfield	W2610	[northern end of pond, west of Hallockville Pond Dam (NATID: MA00465), west of Route 8A (West Hawley Road), Hawley]	42.55155	-72.94204

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-037S	2016 West	Congamond Lakes	Westfield	W2608	[South Basin, beach east of Beach Road, south off Route 168 (Congamond Road), Southwick]	42.01777	-72.76673
MAP2L-039S	2016 West	Tully Pond	Millers	W2604	[western edge of pond, at Tully Pond Dam (NATID: MA00505), east of Tully Road, Orange]	42.63659	-72.24723
MAP2L-041S	2016 West	Vinica Pond	Chicopee	W2618	[southern end of pond, in the Norcross Wildlife Sanctuary, south of Monson Road, Wales]	42.04972	-72.24685
MAP2L-042S	2016 West	Ashley Lake	Housatonic	W2616	[southwestern end of lake, west of Washington Mountain Road, Washington]	42.37675	-73.16236
MAP2L-043S	2016 West	Roaring Brook Reservoir	Connecticut	W2606	[southeastern end of reservoir, at the southern end of the Roaring Brook Dam (NATID: MA01056), reservoir is east of Roaring Brook Road, Conway]	42.46910	-72.66544
MAP2L-044S	2016 West	Sargent Pond	French	W2594	[southern lobe of pond, west of the cemetery, north of Route 9 (Main Street), Leicester]	42.24541	-71.91615
MAP2L-047S	2016 West	Benton Pond	Farmington	W2611	[western edge of pond, just off Route 23 (East Otis Road), Otis]	42.18322	-73.05049
MAP2L-126S	2017 Northeast	Kettle Brook Reservoir No. 1	Blackstone	W2667	[southeastern end of lake west of Mulberry Street, Leicester]	42.25722	-71.89057

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-127S	2017 Northeast	Gleasons Pond	Concord	W2669	[eastern side of lake opposite the Mansfield Street/Route 126 intersection (Gallagher Park), Framingham]	42.28615	-71.41248
MAP2L-128S	2017 Northeast	Cambridge Reservoir	Charles	W2671	[western side of reservoir approximately 0.2 miles south of Lincoln/Waltham corporate boundary, Winter Street, Waltham]	42.40841	-71.27217
MAP2L-129S	2017 Northeast	Boons Pond	Concord	W2673	[eastern edge of northern lobe at the town beach of Pine Bluff Recreation Area, west of Sudbury Road, Stow]	42.40610	-71.49952
MAP2L-132S	2017 Northeast	Nabnasset Pond	Merrimack	W2675	[southeastern edge of pond at Edwards Beach (off northern end of Williams Avenue), Westford]	42.61658	-71.41947
MAP2L-134S	2017 Northeast	Crystal Lake	Blackstone	W2677	[off Douglas State Forest trail at northwestern edge of pond, Douglas]	42.04924	-71.76931
MAP2L-136S	2017 Northeast	Crystal Lake	Merrimack	W2679	[eastern edge of western lobe, off Crystal Shores Conservation Area trail, east of Crystal Street, Haverhill]	42.80397	-71.15597
MAP2L-137S	2017 Northeast	Upper Artichoke Reservoir	Merrimack	W2681	[northwestern side of reservoir, off Withers Conservation Area trail, south of Middle Street, West Newbury]	42.80134	-70.93234

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-138S	2017 Northeast	Sudbury Reservoir	Concord	W2683	[northwestern lobe, east of Acre Bridge Road (just north of the 9/11 Memorial Field), Southborough]	42.32768	-71.52917
MAP2L-139S	2017 Northeast	Heart Pond	Concord	W2685	[northeastern edge of pond, at beach off Pond Street, Chelmsford]	42.56838	-71.38199
MAP2L-140S	2017 Northeast	Fall Brook Reservoir	Nashua	W2687	[southeastern end of lake, north of May Street, Leominster]	42.49015	-71.78266
MAP2L-145S	2017 Northeast	Robbins Pond	Nashua	W2689	[northern edge of pond, west of the Willow Brook outlet, south of Barnum Road, Harvard]	42.53859	-71.60508
MAP2L-146S	2017 Northeast	Little Chauncy Pond	Concord	W2691	[eastern shore, near boat launch off Lyman Street, Northborough]	42.30520	-71.61480
MAP2L-147S	2017 Northeast	Wachusett Lake	Nashua	W2693	[northwestern edge of lake, off Mile Hill Road (approximately 0.2 miles south of Route 140), Westminster]	42.51261	-71.88553
MAP2L-150S	2017 Northeast	Reservoir No. 6	Blackstone	W2695	[eastern edge of pond, near the Reservoir #6 Dam (NATID: MA00899), Sutton]	42.11440	-71.74067
MAP2L-151S	2017 Northeast	Stodge Meadow Pond	Merrimack	W2697	[northeastern edge of pond, approximately 300 feet south of Stodge Meadow Pond Dam (NATID: MA00009) outlet, Ashburnham]	42.66917	-71.88144
MAP2L-154S	2017 Northeast	Lake Pearl	Charles	W2698	[northwestern edge of lake, at Sweatt Beach, east off Woolford Road, Wrentham]	42.06838	-71.35576
MAP2L-156S	2017 Northeast	Lily Pond	Nashua	W2700	[Middle Basin, southwestern edge of pond, West Boylston]	42.37663	-71.77066

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-157S	2017 Northeast	Walden Pond	North Coastal	W2702	[eastern edge of pond at the Walden Pond East End Dam (NATID: MA00235) north of Great Woods Road, Lynn]	42.49313	-70.97941
MAP2L-159S	2017 Northeast	Ponkapoag Pond	Boston Harbor	W2703	[southern end of pond, at boat ramp north of Randolph Street, Canton]	42.18838	-71.09356
MAP2L-160S	2017 Northeast	South Reservoir	Boston Harbor	W2705	[eastern lobe of pond at the South Reservoir East Dike Dam (NATID: MA01278), Medford]	42.44328	-71.11293
MAP2L-161S	2017 Northeast	Barkers Pond	Concord	W2707	[western edge of pond, east of the bend of Pond View Drive, Acton]	42.46067	-71.43300
MAP2L-163S	2017 Northeast	Lower Crow Hill Pond	Nashua	W2709	[upper northwestern edge of pond, east of Route 31, from public access area southwest of Upper Crow Hills Pond Dam (NATID: MA03273), Princeton]	42.51833	-71.85576
MAP2L-164S	2017 Northeast	Field Pond	Ipswich	W2711	[northern edge of pond, from the public access area south of Harold Parker Road, Andover]	42.61036	-71.10753
MAP2L-167S	2017 Northeast	Fitchburg Reservoir	Nashua	W2713	[northern most tip of reservoir south off Richardson Road, Ashby]	42.65349	-71.84393
MAP2L-168S	2017 Northeast	Fort Pond	Nashua	W2714	[southwestern edge of pond, at public boat launch north of Fort Pond Road, Lancaster]	42.52062	-71.69057

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-169S	2017 Northeast	Stiles Pond	Ipswich	W2716	[western edge of pond at Stiles Pond Beach, north of Stiles Pond Road, Boxford]	42.68665	-71.04218
MAP2L-172S	2017 Northeast	Bartlett Pond	Concord	W2718	[eastern edge of pond at boat launch west of Lyman Street, Northborough]	42.31776	-71.61580
MAP2L-257S	2018 Southeast	Halfway Pond	Buzzards Bay	W2797	[northwestern point of pond, off Mast Road, Plymouth]	41.85667	-70.62355
MAP2L-258S	2018 Southeast	Shubael Pond	Cape Cod	W2809	[northwestern edge of pond off Willimantic Drive, Barnstable]	41.67423	-70.39493
MAP2L-259S	2018 Southeast	South Watuppa Pond	Mount Hope Bay	W2776	[northwestern edge of pond, at boat launch off Jefferson Street, Fall River]	41.67417	-71.13961
MAP2L-263S	2018 Southeast	Cleveland Pond	Taunton	W2779	[western edge of southern lobe, west of Ames Pond Dam (NATID: MA00347), Abington]	42.11430	-70.97981
MAP2L-264S	2018 Southeast	Williams Pond	Cape Cod	W2815	[northeastern edge of pond, Wellfleet]	41.96535	-70.00757
MAP2L-268S	2018 Southeast	Lake Hiawatha	Ten Mile	W2588	[North Basin, from the town beach on Falls Pond (a Ten Mile River impoundment), North Attleboro]	41.96888	-71.32623
MAP2L-269S	2018 Southeast	Stillwater Pond	Cape Cod	W2811	[western tip of lake off Stillwater Road, Chatham]	41.70306	-69.98764
MAP2L-270S	2018 Southeast	Long Pond	Cape Cod	W2804	[southeastern edge of pond, north of the intersection of Samoset Road and Indian Memorial Drive, Yarmouth]	41.67154	-70.19157

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-274S	2018 Southeast	Long Pond	Cape Cod	W2806	[beach on northeastern edge of pond, south of Lake Shore Drive, Barnstable]	41.66845	-70.44295
MAP2L-275S	2018 Southeast	Ames Long Pond	Taunton	W2777	[western edge of southern lobe, at the town beach off Highland Street, Stoughton]	42.08171	-71.11755
MAP2L-280S	2018 Southeast	Jemima Pond	Cape Cod	W2802	[northeastern edge of pond near the intersection of Great Pond and Samoset roads, Eastham]	41.83020	-69.98435
MAP2L-285S	2018 Southeast	Fresh Pond	South Coastal	W2785	[beach at southern edge of pond, north off Bartlett Road, Plymouth]	41.90092	-70.55537
MAP2L-289S	2018 Southeast	Ezekiel Pond	Buzzards Bay	W2790	[southwestern edge of pond, between Hudson Street and Kendall Avenue, Plymouth]	41.80256	-70.61433
MAP2L-290S	2018 Southeast	Mashpee Pond	Cape Cod	W2807	[southern tip of pond, north off Lake Avenue, Mashpee]	41.65145	-70.48333
MAP2L-294S	2018 Southeast	Furnace Pond	South Coastal	W2786	[southern edge of pond, north off Furnace Colony Drive, Pembroke]	42.05062	-70.82231
MAP2L-295S	2018 Southeast	Watson Pond	Taunton	W2782	[eastern edge of pond, from picnic area west off Bay Street, Taunton]	41.94985	-71.11562
MAP2L-296S	2018 Southeast	Hinckleys Pond	Cape Cod	W2800	[eastern edge of pond approximately 350 feet from Route 124 intersection with rail trail, Harwich]	41.71175	-70.08254
MAP2L-297S	2018 Southeast	Marys Pond	Buzzards Bay	W2792	[northwestern tip of pond, off Mary's Pond Road, Rochester]	41.75680	-70.79453

Lake ID	Year Stratum	Waterbody Name	Watershed	Shoreline Unique ID	Shoreline Site Description	Shoreline Latitude	Shoreline Longitude
MAP2L-301S	2018 Southeast	Island Pond	South Coastal	W2788	[southeastern lobe, edge of lobe north of Muddy Pond, east of Gardner Drive, Plymouth]	41.80957	-70.57505
MAP2L-304S	2018 Southeast	Coonamessett Pond	Cape Cod	W2799	[western lobe of pond, east of Coonamessett River outlet, Falmouth]	41.61934	-70.57226
MAP2L-305S	2018 Southeast	Parker Mills Pond	Buzzards Bay	W2793	[southern lobe of a Wankinko River impoundment, just east of the fish ladder, north of Elm Street, Wareham]	41.76760	-70.72223
MAP2L-306S	2018 Southeast	Cooks Pond	South Coastal	W2784	[northern edge of pond, approximately 200 feet east of Cooks Pond Dam (NATID: MA01027), south off Cooks Pond Road, Plymouth]	41.92430	-70.66587
MAP2L-307S	2018 Southeast	Robbins Pond	Taunton	W2781	[south of Pond Street, approximately 75 feet west of outlet, East Bridgewater]	42.00894	-70.90797
MAP2L-312S	2018 Southeast	Mill Pond	Cape Cod	W2774	[Mill Pond, eastern edge of pond, north of Mill Pond Road, Harwich]	41.72562	-70.03837
MAP2L-315S	2018 Southeast	White Pond	Cape Cod	W2813	[southeastern edge of pond, north off Old Chatham Road, Harwich]	41.70165	-70.13195

Appendix D. Summary of Assessment Methodologies, Data Evaluation Procedures, Thresholds, and Criteria

The primary source for designated uses was the *Massachusetts Surface Water Quality Standards (SWQS)* (MassDEP 2021). For indicator assessment methodologies and data evaluation procedures, the primary sources were the *Massachusetts Consolidated Assessment and Listing Methodology (CALM) Guidance Manual for the 2022 Reporting Cycle* (MassDEP 2022), and the *National Lakes Assessment 2012: Technical Report* (USEPA 2017). The Massachusetts SWQS establish protective narrative and numeric criteria to support designated uses. The Massachusetts CALM Guidance Manual describes the SWQS criteria, data evaluation methodologies, and assessment thresholds used to assess designated use attainment and surface water quality conditions in the state. The *National Lakes Assessment 2012: Technical Report* describes the data evaluation methodologies and assessment thresholds used to assess water quality and habitat conditions for the NLA surveys.

Aquatic Life Use

Waters supporting the *Aquatic Life Use* should be a suitable habitat for sustaining a native, naturally diverse, community of aquatic flora and fauna (MassDEP 2021). The *Aquatic Life Use* includes reproduction, migration, growth, and other critical functions. All available biological and physicochemical data from the MAP2 surveys were considered in assessing the *Aquatic Life Use*. The type, quality, and amount of data generated for each indicator are first evaluated to determine if they are appropriate for use in the assessment decision-making process. Where data are available from multiple indicators and the data are equally usable, such as the MAP2 dataset, the biological community data (macrophytes, macroinvertebrates, phytoplankton), particularly those assessed using calibrated and verified multimetric indices of biotic integrity, usually outweigh all other data types in the decision-making process because they are considered an integration of the effects of pollutants and other conditions over time (MassDEP 2022). However, multimetric indices calibrated and verified for use in Massachusetts lakes do not currently exist for macrophytes, macroinvertebrates, or phytoplankton. Thus, assuming all data are equally usable, the weight-of-evidence approach with both biological and physicochemical data viewed equally was used to assess *Aquatic Life Use*. The non-native aquatic macrophyte species indicator was the sole exception to the weight-of-evidence approach. Violation of this assessment threshold resulted in impairment assessment decision (Table 1). The SWQS criteria, assessment thresholds, and assessment methodologies for all indicators used to assess the *Aquatic Life Use* are described in the following sections.

Non-native Macrophyte Species

Non-native (or exotic) species often have few or no natural controls, which can result in these species being extremely invasive (dominating and/or eliminating native biota). Invasive non-native species can displace a healthy and desirable native aquatic community and produce economically and recreationally severe impacts (MassDEP 2022).

In the assessments for this report, a violation of the narrative *Aquatic Life Use* criterion is considered to exist if non-native aquatic macrophyte species were observed at more than a single location (e.g., one rake throw point or one littoral plot) in the lake. If non-native aquatic macrophyte species were observed at only a single location, additional indicators of impairment (e.g., a highly disturbed macroinvertebrate community, dissolved oxygen concentrations below the assessment threshold) would need to be present for an *Aquatic Life Use* impairment. This is a modification of the existing non-native aquatic macrophyte species assessment methodology in the Massachusetts CALM Guidance Manual (MassDEP 2022). This modification was used due to the additional information contained in the MAP2 dataset regarding the extent of the non-native aquatic macrophyte species in a lake.

Table 1. *Aquatic Life Use* weight-of-evidence assessment decision approach.

Indicators Violating Aquatic Life Use Assessment Thresholds	Description	Assessment Decision
0	All indicators met assessment thresholds. Providing significant evidence of support.	Support
1	Non-native aquatic macrophyte species assessment threshold violated.	Impaired
1	One indicator violated assessment thresholds.	Support
2	Two indicators violated assessment thresholds and weight of evidence indicates impairment.	Impaired
2	Two indicators violated assessment thresholds, but weight of evidence indicates support.	Support
≥ 3	Three or more indicators violated assessment thresholds. Providing significant weight of evidence of impairment.	Impaired

Note: The term "assessment threshold" is used in this table as a generic term to describe criteria from the Massachusetts Surface Water Quality Standards, Massachusetts Consolidated Assessment and Listing Methodology Guidance Manual for the 2022 Reporting Cycle derived thresholds, National Lakes Assessment 2012: Technical Report derived thresholds, and thresholds specifically derived for this report.

Phytoplankton Community

The lake data collected, including algal identifications and biovolumes, were used to make 'best professional judgements' on whether the observed algal community may have affected other aquatic life communities (zooplankton, macroinvertebrates, fish). These assessments used a weight of evidence approach in evaluating the algal community and other related factors discussed in this section. These assessments were given good, fair, or poor ratings based on the interpretation of the algal assemblage and the aquatic life stressors that were identified.

In the lake data review, both water quality criteria for Class B inland waters and Warm Water Fishery in the Massachusetts SWQS and assessment thresholds in the Massachusetts CALM Guidance Manual were used to determine suitable thresholds for dissolved oxygen saturation, pH, and temperature for fish, zooplankton, algae, etc., found in the sampled lakes (MassDEP 2022; MassDEP 2021). These criteria were used to assist in determining good, fair, and poor ratings for the algal assemblage in each lake. A poor rating for the algal assemblage is considered a violation of the phytoplankton community assessment threshold for this report.

Phytoplankton samples collected for MAP2 lakes were taxonomically identified to genus level. The genera were counted and the total biovolumes of the genera were calculated for each lake. In addition to genus level identifications, biovolumes, and cell counts, other parameters collected along with the phytoplankton (or other related factors) were also used to determine ratings for the algal community.

The additional parameters used to determine the ratings were as follows:

- Maximum dissolved oxygen saturation
- Maximum temperature
- Total phosphorus concentrations at the surface
- Total nitrogen concentrations at the surface
- Chlorophyll-*a* concentrations
- Secchi disk depth
- pH
- Alkalinity
- Specific conductance
- Mean lake depth
- True color
- Seasonality (early, middle, and late summer)

Algal assemblages offer clues on the trophic status of a lake as well as limiting factors within the environment. The algal assemblages and biovolumes, indicators of algal production, were examined by month (June, July, August/September) and described as early, middle, and late summer months. The biovolumes over the entire summer were totaled by lake and were used in the evaluation, especially if these biovolumes suggested unnatural low algal productivity, which could affect fish and zooplankton populations. Included in the evaluation were divisions and genera that were present, especially the top five dominant divisions and genera by biovolume. The divisions and their more common names are Bacillariophyta (diatoms), Chrysophyta (chrysophytes), Chlorophyta (greens), Cryptophyta (cryptophytes, cryptomonads), Cyanophyta (cyanobacteria), Euglenophyta (euglenoids), Haptophyta (haptophytes), and Pyrrophyta (dinoflagellates).

Questions and factors considered in the evaluation:

- Reviewed all algal data by the order (early, middle, and late summer) collected. What groups had the highest biovolumes and when did they occur? Were there cyanobacteria blooms? Were algae covering the surface? Were Secchi disk readings between surveys increasing or decreasing (indicating a bloom in the water column)? Did two of the three seasons sampled have blooms? This indicates a higher likelihood that water quality is deteriorating.
- Were there food sources available for zooplankton and fish, in particular diatoms, chrysophytes cryptophytes (Cryptomonas), and other flagellates?
- Reviewed water quality parameters. Were any parameters above suitable levels in the Massachusetts SWQS or literature? Was dissolved oxygen saturation between 100-125 percent? If below 100 percent, was it near saturation or less than 80 percent? Was the percent saturation higher than 125 percent? Would a fish be stressed?
- Was the total phosphorus at the surface less than 0.010 mg/L (evaluation threshold based on best professional judgement) or much higher?
- Specific conductance values of 50 to less than 100 microsiemens per centimeter (evaluation threshold based on best professional judgement) are considered acceptable in most cases especially if these values remained consistent over the summer. While some taxa are tolerant of high specific conductance others can be greatly affected. In some cases, high specific conductivity can lead to greater algal production (Dreyup and Vadeboncoeur 2016).
- The freshwater pH criterion range (6.5-8.3 standard units) in the Massachusetts SWQS supports algal production and diversity, but values outside of this range will impact the algal community and lead to gaps in the available food supply for fish.

- Alkalinity works to help stabilize and buffer pH changes, which is important for all living organisms. Low alkalinity and low pH lead to lower algal production and changes in the algal community.
- Secchi disk is an indicator of the level of algal phytoplankton production. If production is high, then visibility or transparency through the water column would be low. Thus, the visibility of a black and white disk in the water column from the water surface provides information on lake productivity. Although low Secchi readings can be caused by non-algal particles and dissolved constituents (e.g., DOC), these readings can be used with other data to confirm algal bloom conditions and related impacts.
- Mean depth gives an indication of whether the lake will stratify or not. Shallow lakes do not usually stratify but are continuously mixed. Shallow lakes will often be more turbid as the sediments may be disturbed by wind, passing boats, and recreationists. Also, shallow lakes are often adjacent to wetlands and may have humic acid 'tea-stained' waters. Productivity can be lower when humic acid amounts are high because light penetration is adversely impacted.
- The true color of a waterbody, particularly, above 15 platinum cobalt color (evaluation threshold based on best professional judgement), can hurt or help an organism. High levels of true color in a waterbody will limit the penetration of light through the water column and have significant effects on aquatic plant and algal growth. Other organisms, such as fish, can take advantage of high true color values that often offer protection from predators (e.g., birds). If true color is produced by small organic particles, these particles can bind metals and ultimately reduce the bioavailability of metals, which affects organisms that need metals to grow.

Macroinvertebrate Community

The MAP2 lakes macroinvertebrate community data was assessed using multimetric indices (MMI) developed and calibrated by the United States Environmental Protection Agency (USEPA) for the 2012 NLA. The 2012 NLA was a nationwide probabilistic survey and multiple MMI were developed and calibrated for different regions (Western Mountains, Upper Midwest, Plains, Eastern Highlands, Coastal Plains) of the country (USEPA 2017). The Eastern Highlands MMI was used for MAP2 lakes located in Ecoregions 58 (Northeast Highlands) and 59 (Northeast Coastal Plains) and the Coastal Plains MMI was used for MAP2 lakes located in Ecoregion 84 (Atlantic Coastal Pine Barrens).

Each of the six selected metrics for the Eastern Highlands MMI and Coastal Plains MMI were scored on a 0–10 scale by interpolating metrics between a floor and ceiling value. The scaled scores were then summed and normalized to a 0–100 scale by multiplying by 100/60 to calculate the final MMI (USEPA 2017). The metrics used in the two USEPA regions, the corresponding

Massachusetts ecoregion, metric direction, metric class, and floor and ceiling values from USEPA and the MAP2 lakes dataset are summarized in Table 2. Scoring equations are different depending on if the metric responds positively (high values good) or negatively (high values bad) with disturbance. For positive metrics, values above the ceiling receive 10 points, and values below the floor receive 0 points. For negative metrics, values above the ceiling receive 0 points, and values below the floor receive 10 points. The interpolation equations for normalizing the metric values to a 0-10 scale between the floor and ceiling values are,

Positive Metrics: Metric Points = 10*((metric value-floor)/(ceiling-floor))
Negative Metrics: Metric Points = 10 * (1 - ((metric value-floor)/(ceiling-floor))) (USEPA 2017).

For the MMI metrics, USEPA floor values were set at the 5th percentile of all samples in the region, USEPA ceiling values are the 95th percentile of reference sites in the region (USEPA 2017). Since the NLA MMI were developed and calibrated using data from a larger geographic region than Massachusetts, the range of metric values for some metrics were significantly different from the range of metric values observed in the MAP2 lakes dataset (e.g., % Chironomid Individuals in Top 3 most abundant Chironomid Taxa). Due to this difference in metric value ranges, the floor and ceiling values from the MAP2 lakes dataset were used to normalize the metric values in place of the USEPA floor and ceiling values. MAP2 lakes floor and ceiling values were set at the 5th and 95th percentiles, respectively, of all samples in the MAP2 lakes dataset (Table 2) thus creating a MAP2 Lakes Adjusted MMI Score.

Table 2. Metrics used in the two United States Environmental Protection Agency (USEPA) regions, the corresponding Massachusetts ecoregion, metric direction, and floor and ceiling values from USEPA and the Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) lakes dataset (USEPA 2017).

					US EPA		MAP2 Lakes	
USEPA Region	**MA Ecoregion**	**Metric Class**	**Metric name***	**Metric Direction**	**Floor Value**	**Ceiling Value**	**Floor Value**	**Ceiling Value**
Coastal Plains	84	Composition	NOINPTAX	Negative	21.88	55.17	19.9	46.4
Coastal Plains	84	Diversity	CHIRDOM3PIND	Negative	38.57	96.08	3.5	35.9
Coastal Plains	84	Feeding Group	PREDRICH	Positive	6.00	23.0	7.8	18.4
Coastal Plains	84	Habit	SPWLRICH	Positive	5.00	15.0	4.0	11.0
Coastal Plains	84	Richness	EPT_RICH	Positive	1.00	8.00	3.0	10.0
Coastal Plains	84	Tolerance	NTOLPIND	Positive	6.33	64.33	4.7	39.0

					US EPA		MAP2 Lakes	
USEPA Region	**MA Ecoregion**	**Metric Class**	**Metric name***	**Metric Direction**	**Floor Value**	**Ceiling Value**	**Floor Value**	**Ceiling Value**
E. Highlands	58/59	Composition	NOINPTAX	Negative	13.79	48.72	19.9	46.4
E. Highlands	58/59	Diversity	CHIRDOM3PIND	Negative	39.87	85.94	3.5	35.9
E. Highlands	58/59	Feeding Group	COGARICH	Positive	8.00	27.0	12.0	26.0
E. Highlands	58/59	Habit	CLNGRICH	Positive	3.00	12.0	2.0	12.0
E. Highlands	58/59	Richness	EPOTRICH	Positive	2.00	14.0	5.0	13.2
E. Highlands	58/59	Tolerance	TL23RICH	Positive	1.00	9.00	0.0	4.0

***Metric Abbreviations** → NOINPTAX= % Non-Insect Taxa (Non-Insect Taxa Richness / Total Taxa Richness*100), CHIRDOM3PIND = % Chironomid Individuals in Top 3 most abundant Chironomid Taxa, PREDRICH = Predator Taxa Richness, COGARICH = Collector-Gatherer Taxa Richness, SPWLRICH = Sprawler Taxa Richness, CLNGRICH = Clinger Taxa Richness, EPT_RICH = Ephemeroptera + Plecoptera + Trichoptera Taxa Richness, EPOTRICH = Ephemeroptera + Plecoptera + Trichoptera + Odonata Taxa Richness, NTOLPIND = % Individuals with pollutant tolerance values < 6, TL23RICH = Taxa Richness of taxa with pollutant tolerance values ≥ 2.0 and < 4.0

USEPA set MMI score thresholds to define three classes of biotic integrity, Most Disturbed, Least Disturbed, and Other (Table 3). The USEPA MMI thresholds were adjusted to account for the usage of the MAP2 lakes floor and ceiling values to normalize the metric values. A linear regression relationship between MMI scores using USEPA floor/ceiling values and MMI scores using MAP2 lakes floor/ceiling values for each MMI was used to adjust the biotic integrity classification threshold (Table 3). The linear regression relationships are illustrated in Figure 1.

Table 3. United States Environmental Protection Agency (USEPA) and Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) multimetric indices (MMI) score thresholds for the biotic integrity classes (USEPA 2017).

		US EPA		MAP2 Lakes	
USEPA Region	**MA Ecoregion**	**Least Disturbed Threshold**	**Most Disturbed Threshold**	**Least Disturbed Threshold**	**Most Disturbed Threshold**
Coastal Plains	84	≥ 54.8	< 44.1	≥ 49.1	< 35.7
Eastern Highlands	58/59	≥ 51.5	< 40.8	≥ 49.0	< 34.2

In the assessments for this report, a violation of the narrative *Aquatic Life Use* criteria is considered to exist if the MAP2 Lakes Adjusted MMI Score indicates a biotic integrity classification

of “Most Disturbed” (i.e., less than 35.7 for Coastal Plains and 34.2 for Eastern Highlands). A violation of the narrative *Aquatic Life Use* criteria does not exist if the MAP2 Lakes Adjusted MMI Score indicates a biotic integrity classification of “Other” or “Least Disturbed”.

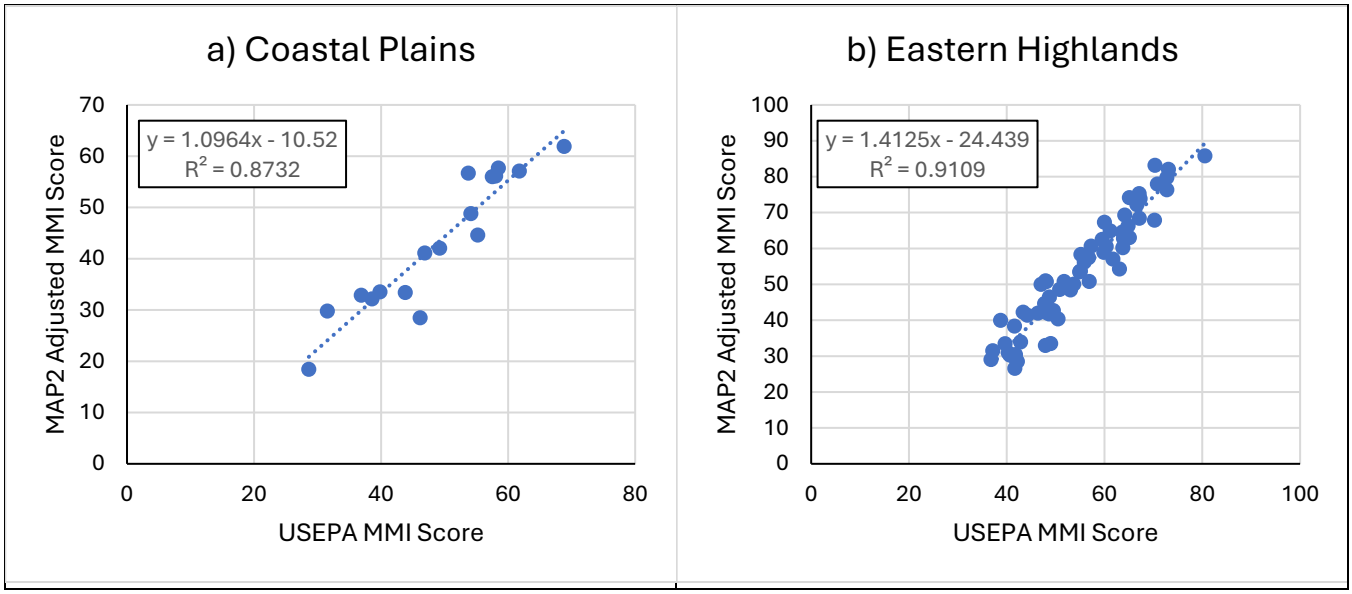

Figure 1. Linear regression relationship between United States Environmental Protection Agency (USEPA) multimetric indices (MMI) scores and Massachusetts Probabilistic Monitoring & Assessment Program (MAP2) adjusted MMI scores for the a) Coastal Plains and b) Eastern Highlands.

Nutrient Enrichment

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for nutrient enrichment assessment methodology (MassDEP 2022).

Temperature

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for temperature assessment methodology (MassDEP 2022).

Dissolved Oxygen

Dissolved Oxygen (DO) is a very important indicator of a waterbody's ability to support aquatic life. DO enters water by diffusion directly from the atmosphere, by mechanical aeration (e.g., a spillway or dam), or as a result of photosynthesis by aquatic plants and algae and is removed from the water by respiration of aquatic organisms and decomposition of organic matter. DO exhibits natural daily and seasonal fluctuations. The Massachusetts SWQS (MassDEP 2021) freshwater criteria for DO in mg/L are as follows:

- Class A and Class B cold water fisheries (those assigned a Cold Water qualifier): ≥ 6.0 mg/L
- Class A and Class B warm water fisheries (those assigned a Warm Water qualifier): ≥ 5.0 mg/L.
- Class C: Not < 5.0 mg/L at least 16 hours of any 24-hour period and not < 3.0 mg/L at any time

The target population consists of Class A and Class B Warm Waters, so the value of 5.0 mg/L was used for the DO criteria.

The bathymetric grid data from BioBase and the DO profiles were used to calculate the volume of the lake with DO less than 5.0 mg/L. for each sampling event. If the volume of the lake with DO less than 5.0 mg/L was greater than 25% of the total lake volume at any sampling event, the DO criterion was considered violated for the purposes of this report. This is a modification of the existing DO assessment methodology in the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle, which uses the percent of lake area (based on bathymetric contour maps), with DO less than the criteria as the assessment threshold (MassDEP 2022). The volume of a lake meeting the DO criterion provides a better estimate of aquatic habitat supporting aquatic life than the area of a lake meeting the DO criterion. This modification was used due to the additional volumetric information contained in the MAP2 dataset from BioBase. The determination of whether hypolimnetic DO depletion is natural or not involves many factors and was not considered for this report (i.e., DO depletion was assumed to be due to anthropogenic factors over time).

pH

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for pH assessment methodology (MassDEP 2022).

Chloride

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for chloride assessment methodology (MassDEP 2022).

Recreational Use

Recreational Use is divided into two types of uses based on the level of contact with the water. Waters supporting the *Primary Contact Recreational Use* are suitable for any recreation or other water use in which there is prolonged and intimate contact with the water with a significant risk of ingestion of water during the primary contact recreation season (MassDEP 2021). Activities include, but are not limited to, wading, swimming, diving, surfing, and water skiing. The primary

contact recreation period each year is defined as April 1st to October 31st. Waters supporting the *Secondary Contact Recreational Use* are suitable for any recreation or other water use in which contact with the water is either incidental or accidental (MassDEP 2021). These include, but are not limited to, fishing, including human consumption of fish, boating, and limited contact incident to shoreline activities. The secondary contact recreation period is year-round (MassDEP 2022).

The assessment of the *Primary and Secondary Contact Recreational Uses* are based on public health (i.e., bacterial indicators of pathogens, harmful algal blooms (HAB) presence), safety (e.g., Secchi disk transparency), and/or aesthetic (i.e., desirability) factors. These uses are assessed as supporting when public health, safety, and aesthetic conditions are suitable for the associated contact. The current bacteria criteria for Massachusetts surface waters includes both geometric mean and statistical threshold values (MassDEP 2021). The bacteria assessment decisions are based on samples meeting both these criteria magnitudes for *Primary and Secondary Contact Recreation Uses* (MassDEP 2022).

The assessment methodologies, thresholds, and criteria for all indicators used to assess *Recreational Use* are described in the following sections.

E. coli

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for E. coli assessment methodology (MassDEP 2022).

Cyanobacteria

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for cyanobacteria and HAB assessment methodology (MassDEP 2022).

Algal Toxins – Microcystins, Cylindrospermopsin

The recommended water quality criteria in the USEPA guidance document titled *Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin* were used to determine exceedances of the assessment thresholds for algal toxins. USEPA recommends a concentration of 8 ug/L for microcystins and 15 ug/L for cylindrospermopsin (USEPA 2019). The frequency of algal toxin sampling was too low to adopt USEPA recommendations for frequency and duration, so a conservative approach was used for this report. In the assessments for this report, a violation of the assessment threshold for algal toxins is considered to exist if one or more samples had a microcystin or cylindrospermopsin concentration greater than USEPA recommended criteria.

Secchi disk transparency

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for Secchi disk transparency assessment methodology (MassDEP 2022).

Aesthetics

See the Massachusetts CALM Guidance Manual for the 2022 Reporting Cycle for aesthetics assessment methodology (MassDEP 2022).

Fish Consumption

The definition of *Secondary Contact Recreation* in the Massachusetts SWQS includes the statement that waters supporting the *Secondary Contact Recreational Use* are suitable for "[a]ny recreation or other water use in which contact with the water is either incidental or accidental. These include, but are not limited to, fishing, including human consumption of fish, boating and limited contact incident to shoreline activities" (MassDEP 2021). For assessments in this report, however, the status of the *Fish Consumption Use* (human consumption of fish) is reported as its own use rather than part of the *Secondary Contact Recreational Use*. The Massachusetts SWQS, at 314 CMR4.05(5)(e)2. a. ii., also state that "pollutants shall not result in unacceptable concentrations in edible portions of marketable fish or for the recreational use of fish, shellfish, other aquatic life or wildlife for human consumption" (MassDEP 2021).

The assessment of the *Fish Consumption Use* for this report relies on the July 2022 fish consumption advisory list issued by the Massachusetts Department of Public Health (MA DPH) and the concentrations of toxic pollutants (e.g., mercury, polychlorinated biphenyls (PCBs)) in the fish tissue collected during the MAP2 surveys (MA DPH 2022). MA DPH evaluated MAP2 fish tissue data to determine if a site-specific fish consumption advisory needed to be issued for any of the toxic pollutants that were analyzed for MAP2. A statewide consumption advisory, targeting sensitive populations (i.e., women who may become pregnant or are pregnant or nursing, and children under 12 years of age), for fish caught in freshwater lakes and ponds is in effect for Massachusetts. This statewide advisory is in response to mercury contamination and prevents assessing any portion of the target population as supporting the *Fish Consumption Use*.

Assessing the status of *Fish Consumption Use* in the target population for this report does not follow the traditional Support/Impaired structure of other designated uses due to the statewide freshwater fish consumption advisory. Instead, *Fish Consumption Use* status was assessed by classifying the target population into three categories based on site-specific fish consumption advisories and the toxic pollutant concentrations in fish tissue samples: 1) site-specific fish consumption advisory issued, 2) no site-specific fish consumption advisory issued but Massachusetts SWQS violations for mercury in fish tissue are present, and 3) no site-specific fish

consumption advisory issued or Massachusetts SWQS violations for mercury in fish tissue, but the statewide fish consumption advisory is applicable.

Fish Consumption Advisories

The July 2022 fish consumption advisory list issued by MA DPH was reviewed to determine if any lakes sampled for the MAP2 surveys had a site-specific fish consumption advisory for any of the toxic pollutants that were analyzed for MAP2. If a site-specific fish consumption advisory was issued for any MAP2 lake, the lake was placed in category 1 described in the preceding section. This methodology was followed regardless of the fish tissue data source that led to the issuance of the site-specific fish consumption advisory. Some of the MAP2 sampled lakes had a pre-existing site-specific advisory (n=12) before any MAP2 fish tissue data were collected and others had a site-specific advisory issued based on the MAP2 fish tissue data (n=24). In all cases where a pre-existing fish consumption advisory existed for a sampled MAP2 lake, the fish tissue data collected for MAP2 confirmed the advisory.

Fish Tissue Data

In addition to fish consumption advisories, concentrations of mercury in fish tissue can be compared to SWQS criteria for mercury to evaluate use attainment (MassDEP 2021). The fish tissue data from sampled MAP2 lakes was summarized by averaging the concentrations in the 3 – 5 species composite tissue samples and the 10 -12 individual tissue samples for each toxic pollutant. If either the composite average or the individual average exceeded the SWQS for mercury in fish tissue and the sampled MAP2 lake did not have a site-specific fish consumption advisory, it was placed in category 2 described in a preceding section. Any sampled MAP2 lake that did not fall into category 1 or 2 was placed in category 3.

Appendix D Cited Sources

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periphytic cyanobacteria from Lake Tahoe and Lake Tanganyika. Phycologia. 55:295-298.

MA DPH. 2022. *Freshwater Fish Consumption Advisory List – July 2022*. Massachusetts Department of Public Health, Bureau of Environmental Health Assessment, Boston, MA. (List available online @ https://www.mass.gov/doc/public-health-freshwater-fish-consumption-advisories-2022/download/ public-health-freshwater-fish-consumption-advisories–2022.pdf).

MassDEP. 2021. *Massachusetts Surface Water Quality Standards* (314 CMR 4.00, effective November 11, 2021). Massachusetts Department of Environmental Protection, Boston, MA.

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