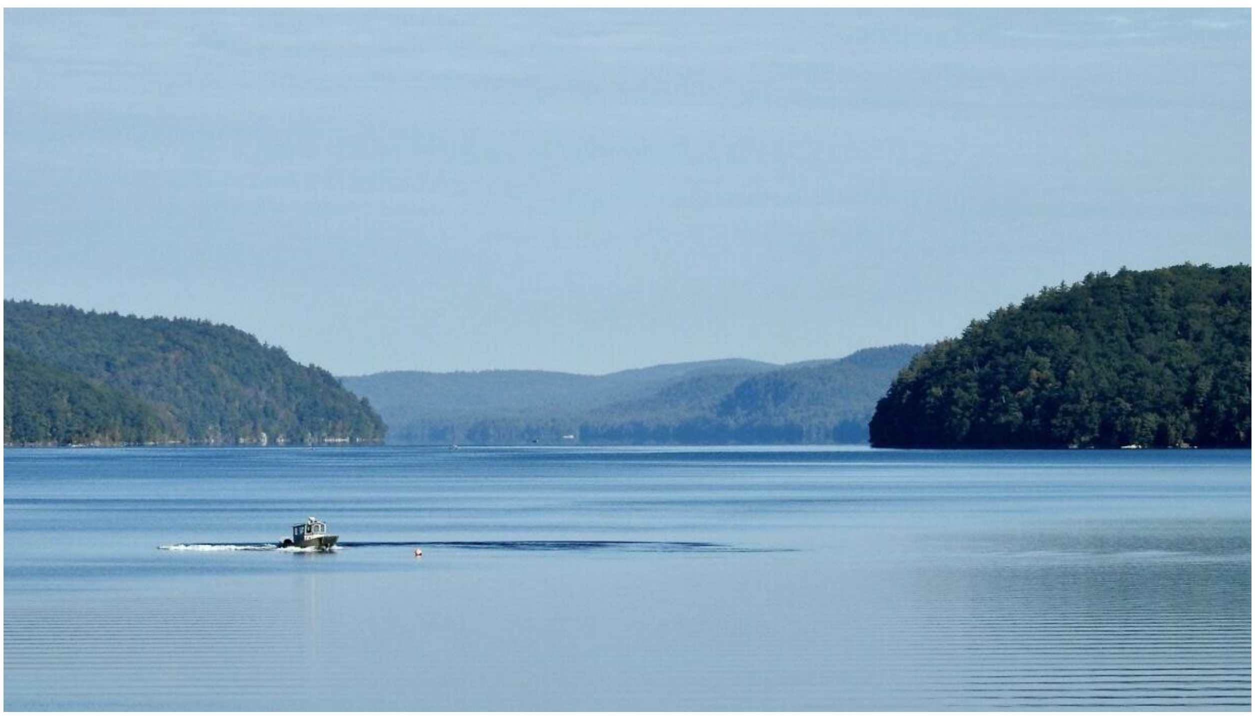
Water Quality Report: 2024
Quabbin Reservoir Watershed
Ware River Watershed



DWSP Monitoring, Quabbin Reservoir (Shasten Sherwell, 2024)

August 2025

Massachusetts Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management
Quabbin/Ware Region

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Abstract

This report is a summary of water quality monitoring methods and results from 24 surface water sites located throughout the Quabbin Reservoir and the Quabbin Reservoir and Ware River Watersheds, annual hydrological and meteorological summaries, and results from special investigations. The Department of Conservation and Recreation (DCR), Division of Water Supply Protection (DWSP), is the state agency charged with the responsibility of managing the Quabbin Reservoir and Quabbin Reservoir and Ware River watersheds and the surrounding natural resources owned by the Commonwealth in each watershed in order to protect, preserve, and enhance the environment of the Commonwealth and to assure the availability of safe drinking water for future generations. The Environmental Quality Section manages a comprehensive water quality monitoring program to ensure that Quabbin Reservoir water meets state drinking water quality standards. As part of this task, the Environmental Quality Section performs field work, collects water samples, interprets water quality data, and prepares reports of findings. This annual summary is intended to meet the needs of watershed managers, the interested public, and others whose decisions must incorporate regional water quality considerations.

The Quabbin Reservoir water quality satisfied the requirements of the Filtration Avoidance Criteria established under the Environmental Protection Agency Surface Water Treatment Rule for the entirety of 2024. Monitoring of major tributary inflows is a proactive measure aimed at identifying water quality patterns and potential problem areas that may require additional investigation or corrective action. Results from tributary monitoring were largely below state surface water quality thresholds; any exceedances were attributed to storm events, impacts of prolonged fall drought, wildlife impacts on water quality, and/or landscape attributes.

The appendices to this report include field investigation reports. Some of the ancillary data presented in this report has been compiled with the assistance of outside agencies (e.g., U.S. Geological Survey) and other workgroups within DWSP whose efforts are acknowledged in the further sections.

CITATION

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Abbreviations

The following abbreviations are used in this report:

AIS	Aquatic Invasive Species
BWTF	Brutsch Water Treatment Facility
Cl	Chloride
CFR	Cold water fish habitat
CVA	Chicopee Valley Aqueduct
DCR	Massachusetts Department of Conservation and Recreation
DL	Laboratory detection limit
DWSP	Division of Water Supply Protection
EPA	U.S. Environmental Protection Agency
EQA	Environmental Quality Assessment
E. coli	*Escherichia coli*
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MCL	Maximum Contaminant Level
MLE	Maximum likelihood estimation
MWRA	Massachusetts Water Resources Authority
NEON	National Ecological Observatory Network
N/A	Not applicable
OWM	Office of Watershed Management
NH_3-N	Ammonia-nitrogen
NH_4-N	Ammonium-nitrogen
NO_2-N	Nitrite-nitrogen
NO_3-N	Nitrate-nitrogen
NOAA	National Oceanographic and Atmospheric Administration
POR	Period of Record
Si	Silica
SMCL	Secondary Maximum Contaminant Level
SOP	Standard Operating Procedure
SWE	Snow Water Equivalent
SWTR	Surface Water Treatment Rule
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
UMass	University of Massachusetts, Amherst
U.S.	United States
UV_{254}	Ultraviolet Absorbance at 254 Nanometers
USGS	U.S. Geological Survey
WDI	Winsor Dam Intake
WRF	Warm water fish habitat

Units of Measurement

Chemical concentrations of constituents in solution or suspension are reported in milligrams per liter (mg/L) or micrograms per liter (μg/L). These units express the concentration of chemical constituents in solution as mass (mg or μg) of solute per unit of volume of water (L). One mg/L is equivalent to 1,000 μg/L. Fecal coliform results are reported as the number of presumptive colony forming units per 100 milliliters of water (CFU/100 mL). Total coliform and *Escherichia coli (E. coli)* are reported as the most probable number (MPN/100 mL), which is equivalent to CFU/100 mL and acceptable for regulatory reporting. UV_{254} results are reported as the amount of ultraviolet light at a 254 nm wavelength that is able to transmit through a water sample in absorbance units per centimeter of path length (ABU/cm).

The following units of measurement are used in this report:

ABU/cm	Absorbance units per centimeter of path length
ASU/mL	Areal standard units per milliliter
cfs	Cubic feet per second
CFU	Colony-forming unit
°C	Degrees Celsius
ft	Feet
in	Inches
μS/cm	Microsiemens per centimeter
L/mg-M	Liters per milligram per meter
MG	Million gallons
MGD	Million gallons per day
µg/L	Microgram per liter
mg/L	Milligram per liter
m	Meters
MPN	Most probable number (equivalent to CFU)
nm	Nanometers
NTU	Nephelometric turbidity units
S. U.	Standard Units (pH)

1 Introduction

The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management (DWSP) manages and maintains a system of watersheds and reservoirs to provide water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies unfiltered drinking water to approximately 2.7 million people in 53 communities in Massachusetts. The watershed system includes the Quabbin Reservoir, Ware River, Wachusett Reservoir, and Sudbury Reservoir Watersheds, interconnected by a series of aqueducts (Figure 1).

The U.S. EPA introduced the Federal Surface Water Treatment Rule (SWTR) in 1989, followed by the introduction of the Interim Enhanced Surface Water Treatment Rule (IESWTR) in 1998, and the Final Long Term Enhanced Surface Water Treatment Rule Term 1 (2002) and Term 2 (2006) (US EPA, 1989; 1998; 2002; 2006), to ensure that public water supply systems using surface water, or groundwater under the direct influence of surface water, provide safeguards against the contamination of water by viruses and bacteria. The regulations require filtration by every surface water supplier unless strict source water quality criteria and watershed protection goals can be met, including the development and implementation of a detailed watershed protection plan (US EPA, 2003). The DWSP and the MWRA have maintained a joint waiver for the filtration requirement of the SWTR since 1998 and work together to manage the watersheds and reservoirs in fulfillment of the waiver.

DWSP monitors the water quality and quantity within the watersheds and reservoirs (Commonwealth of MA, 2004). Water quality sampling and field inspections help identify surface waters with potential water quality issues, aid in the implementation of watershed protection plans, and ensure compliance with state and federal water quality criteria for public drinking water supply sources (e.g., the filtration avoidance requirements stipulated under the SWTR). Routine monitoring of bacteria and nutrients in the reservoirs and tributaries provides an indication of the sanitary quality of water sources, ensuring the security of water resources and public health. Monitoring is also conducted by DWSP staff to better understand the responses of the reservoir and tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoirs and watersheds. A long-term record of water quality monitoring provides information regarding potential controls on observed changes in water quality over time and represents a proactive effort to identify emerging threats to water quality.

This report summarizes the water quality monitoring performed by DWSP in the Quabbin Reservoir and the Quabbin Reservoir and Ware River Watersheds during 2024.

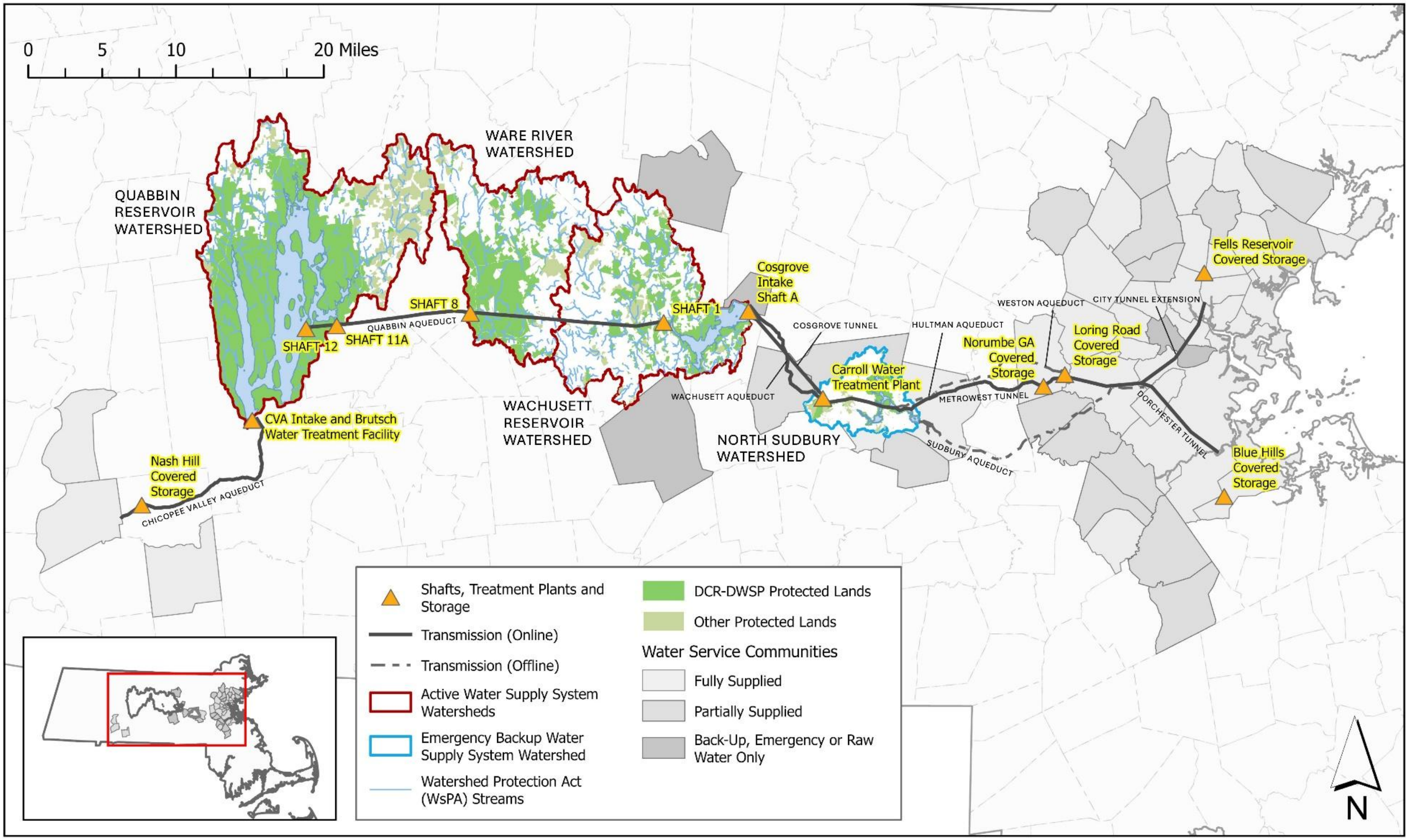


Figure 1. *Quabbin Reservoir, Ware River, and Wachusett Reservoir Watershed system. Inset map in the lower left depicts location of the watershed system relative to MA.*

1.1 Public Water Supply System Regulations

Source water quality criteria rely on an indicator organism (fecal coliform bacteria) and a surrogate parameter (turbidity) to provide a measure of the sanitary quality of the water. The SWTR requires that fecal coliform concentrations at the intake of an unfiltered surface water supply shall not exceed 20 colony-forming units (CFU) per 100 mL in ninety percent of the samples in any six-month period. There are two standards for turbidity levels at source water intakes. The SWTR requires that turbidity levels at the intake remain below five NTU. MassDEP regulations require that turbidity levels at the point of consumption for all public drinking water can only be above one NTU if it does not interfere with effective disinfection. Authority to enforce the US EPA's SWTR has been delegated to MassDEP.

The Quabbin Reservoir is designated as Class A Public Water Supply (314 CMR 4.06(1)(d)1) and thereby is considered an Outstanding Resource Water (ORW) for the purposes of water quality protection (314 CMR 4.06) in Massachusetts. Massachusetts DEP has developed numerical Class A water quality criteria for several parameters (see DCR 2023a, Appendix A). Required monitoring for additional constituents at different stages in the system (e.g., after treatment, after disinfection, and at the point of consumption) is conducted by MWRA. These elements and compounds include arsenic, polychlorinated biphenyls (PCBs), haloacetic acids, and per- and polyfluoroalkyl substances (PFAS). As MWRA produces reports that detail results of regulatory monitoring, monitoring results at each of the water system stages is not discussed as part of this report.

1.2 DWSP Monitoring Program Objectives

MWRA, as an unfiltered water supplier, is required to have a watershed protection program intended to promote and preserve high quality source water. A primary function of DWSP is to design and implement this watershed protection program for the DCR/MWRA water supply system. Watershed protection measures enacted by DWSP have been detailed in DWSP Watershed Protection Plans (WPPs) and WPP updates since 1991 (DWSP, 2023b). The goals of WPPs are to provide structured methodology to assess changes in existing threats to water quality across DWSP-managed watersheds, develop proactive strategies to prevent threats to water quality, and respond to potential threats to water quality to limit negative impacts. Environmental quality monitoring is one element of the WPPs developed by DWSP. The Watershed Protection Act of 1992 and associated Watershed Protection regulations (313 CMR 11.00) give DWSP the authority to regulate certain land uses and activities that take place within critical areas of the watershed in order to protect drinking water quality. The consistent high water quality of the Quabbin Reservoir can be attributed largely to the effectiveness of the WPPs.

DWSP staff rely on data generated by long-term monitoring programs to inform modifications to current WPPs. Data generated by long-term monitoring programs conducted by DWSP are used to assess current and historical water quality conditions, establish expected ranges of various water quality parameters, allow for routine screening of potential threats to water quality, provide early detection of change, and assess current watershed trends. Shorter-term investigations may also be conducted to evaluate specific issues. Monitoring efforts are reviewed and updated annually by DWSP to ensure that DWSP programs remain current, appropriate, and informative for the WPP goals. Changes to annual water quality monitoring programs performed by DWSP staff are discussed in each annual water quality report.

The overarching objectives of the water quality and hydrological monitoring programs conducted by DWSP are directly related to the WPP goals. These objectives are as follows:

- Maintain long-term water quality statistics relative to the protection of public health.
- Document achievements of watershed control criteria applicable to the filtration avoidance requirements stipulated under the EPA's Surface Water Treatment Rule (SWTR).
- Identify streams and water bodies that do not meet water quality standards and where specific control measures may be initiated to eliminate or mitigate pollution sources.
- Conduct proactive surveillance of water quality trends to identify emerging issues and support ongoing assessments of threats to water quality.

DWSP monitoring programs continuously adapt to emergent and high priority threats to water quality, while utilizing current scientific information, tools, and technologies. The achievement of water supply protection goals, including specific water quality targets, can be credited to the coordinated implementation of DWSP's many programs.

1.3 Overview of DCR/MWRA Water Supply System, Quabbin Reservoir and Ware River Watersheds

The Quabbin Aqueduct connects three water sources that serve as a source of drinking water to 50 communities in Massachusetts (with an additional three communities served directly from Quabbin Reservoir). The water sources connected by the Quabbin Aqueduct, from west to east, include the Quabbin Reservoir, the Ware River, and the Wachusett Reservoir (Figure 1). The Quabbin Reservoir is the largest of the sources, with a capacity of 412 billion gallons (Table 1, see also DWSP, 2023a for further context). In comparison, the Wachusett Reservoir holds 65 billion gallons at full capacity

Water from the Quabbin Reservoir is transferred to the Wachusett Reservoir via the Quabbin Aqueduct Intake at Shaft 12 (Figure 1). Transfers at Shaft 12 typically account for more than half of the MWRA system supply. Water is also transferred directly to three western Massachusetts communities daily via the Chicopee Valley Aqueduct (CVA) from the Winsor Dam Intake (WDI). Water from the Ware River may be used to supplement Quabbin Reservoir. Ware River water is diverted into the Quabbin Aqueduct at Shaft 8 in Barre, MA, near DWSP Core tributary monitoring location 101 and delivered to the Quabbin Reservoir via gravity flow. Ware River water enters the reservoir at Shaft 11A, east of the baffle dams in Hardwick, MA. The diversion of water from the Ware River is limited to the period from October 15 to June 15 and is not permitted when mean daily flow at Shaft 8 is less than 85 MGD (131.5 cfs), per Chapter 375 of the Massachusetts Acts of 1926. DWSP and MWRA coordinate at least annually on diversion timing and duration.

Table 1. *General information on a) Quabbin Reservoir, b) Quabbin Reservoir Watershed, and c) Ware River Watershed.*

a) Quabbin Reservoir General Information

Description	Units	Quantity
Reservoir Capacity	Billion gallons	412
Reservoir Surface Area (at full capacity – elev. 530 feet)	Acres	24,469
Length of Reservoir Shoreline	Miles	118
Maximum Reservoir Depth	Feet	141
Mean Depth	Feet	45
Surface Elevation, at Full Capacity	Feet, relative to Boston City Base	530
Reservoir gain (average) from 1 inch of precipitation	Billion gallons	1.6

b) Quabbin Reservoir Watershed General Information

Description	Units	Quantity
Watershed Area (includes Quabbin Reservoir surface area)	Acres	119,946
Land Area (excludes Quabbin Reservoir surface area)	Acres	95,364
Proportion of Land Area in Watershed	Percentage	80
DWSP Controlled Watershed Area	Acres	88,066
Proportion of DWSP Controlled Area in Watershed	Percentage	73
Total Protected Land Area (includes DWSP, DWSP Fee, DWSP WPR, and other protected lands)	Acres	73,535
Proportion of Protected Land Area	Percentage	77

c) Ware River Watershed General Information

Description	Units	Quantity
Watershed Area	Acres	61,671
DWSP Controlled Watershed Area	Acres	25,756
Proportion of DWSP Controlled Watershed Area	Percentage	41
Total Protected Watershed Area (includes DWSP, DWSP Fee, DWSP WPR, and other protected lands)	Acres	33,081
Proportion of Protected Watershed Area	Percentage	54

1.4 Description of Quabbin Reservoir and Ware River Watersheds

The Quabbin Reservoir Watershed is located in the Swift River sub-basin of the Chicopee River, a major tributary of the Connecticut River, and part of the Central Uplands of north central Massachusetts (Figure 2). The Quabbin Reservoir Watershed encompasses approximately 187.5 sq. mi. (119,946 acres), including nearly all of the towns of New Salem and Petersham, considerable portions of Pelham, Shutesbury, and Wendell, and smaller portions of Orange, Hardwick, Phillipston, Belchertown, Ware, and Athol, MA. At full capacity, the surface area of the Quabbin Reservoir spans roughly 38.2 sq. mi. (24,469 acres), or 20% of the total watershed area, with nearly 118 miles of shoreline (Table 1). Mean and maximum depths of the Quabbin Reservoir are 45 and 141 ft, respectively.

Approximately 88% of the land surface in the Quabbin Reservoir Watershed is forested cover, with a total area comprised of less than 2% each of developed (further classified as rural-residential) or agricultural cover (Table 2). DWSP owns and controls 63,484 acres (62% of the total watershed land area) for water supply protection purposes, and approximately 77% of the total land area in the watershed is protected through other means (Table 1). The relatively high proportion of forested, protected lands in the Quabbin Reservoir Watershed helps maintain exceptional water quality in the Quabbin Reservoir.

The Ware River Watershed is the geographical drainage area to Shaft 8 Intake on the Ware River in Barre, MA. This watershed neighbors the Quabbin Reservoir Watershed to the east (Figure 3). The Ware River begins as two branches (the East Branch and West Branch Ware River) that converge to form the Ware River in Hubbardston, MA. The Ware River Watershed area monitored by DWSP intersects portions of the municipalities of Barre, Phillipston, Hubbardston, Oakham, Rutland, Princeton, Templeton, and Westminster, MA. DWSP monitors an area of 96.5 square miles (61,737 acres) of the Ware River Watershed upstream of the Quabbin Aqueduct at Shaft 8 in Barre, MA. Further downstream, the Ware River joins the Quaboag River in Three Rivers, MA to form the Chicopee River.

Land cover in the Ware River Watershed is predominantly forest (75%), with approximately 41% of the watershed area (25,756 acres) controlled by DWSP (Table 1, Table 2). The Army Corps of Engineers controls approximately 600 acres (less than 1%) for flood control associated with the Barre Falls Dam on the Ware River in Barre, MA. Agriculture comprises less than 3% of total watershed area for the Ware River Watershed. Additional information regarding land use and ownership in the Quabbin Reservoir and Ware River Watersheds, as well as the calculation of statistics, is documented in the *Watershed Protection Plan FY24-FY28* (DWSP, 2023b) and the *2017 Land Management Plan* (DWSP, 2018a).

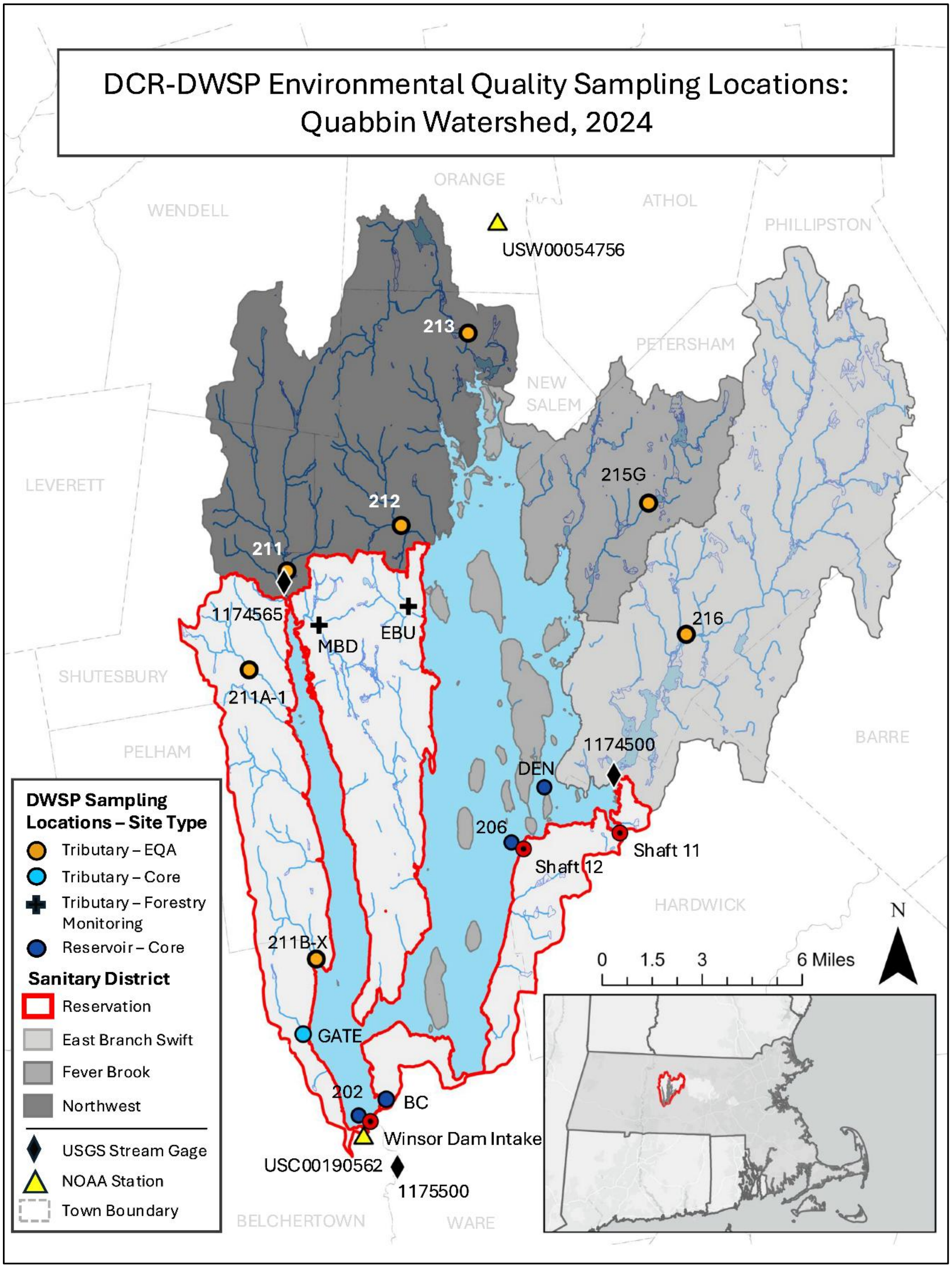


Figure 2. *Map of Quabbin Reservoir Watershed showing locations of Core and EQA monitoring sites sampled in 2024. Also shown are DWSP sanitary districts. Inset map depicts the watershed relative to Massachusetts.*

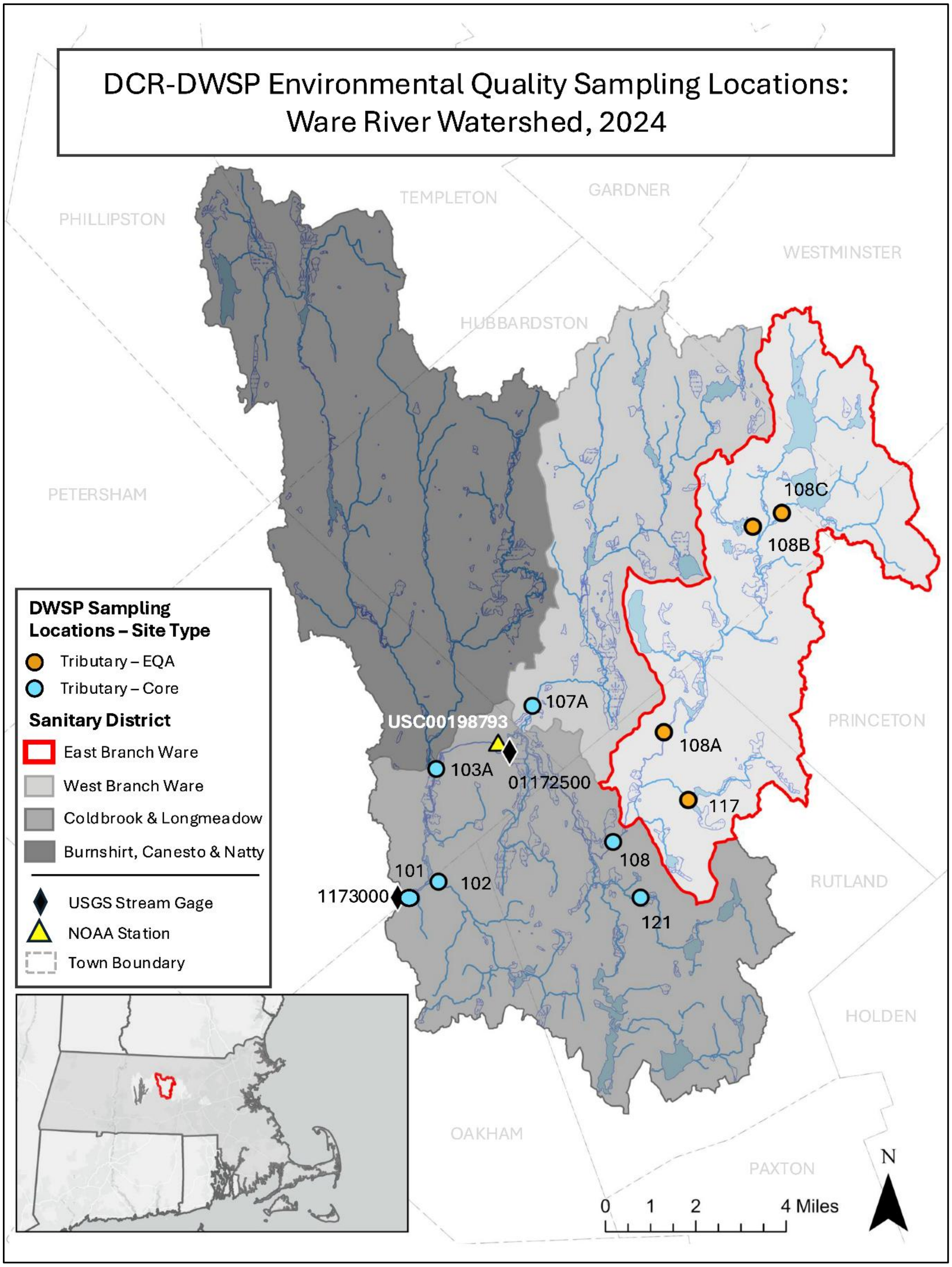


Figure 3. *Map of Ware River Watershed showing locations of Core and EQA monitoring sites sampled in 2024. Also shown are DWSP sanitary districts. Inset map depicts the watershed relative to Massachusetts.*

Table 2. *Proportion of total land area falling under land cover/land uses classes across Quabbin Reservoir and Ware River Watershed (adapted from DWSP 2023b).*

Land Cover/ Land Use Class	Quabbin Reservoir Watershed Proportion of Land Area (percent)	Ware River Watershed Proportion of Land Area (percent)
Forest	87.62	74.77
Wetland	4.99	11.61
Agriculture	3.42	3.81
Open Water	1.25	3.22
Residential	0.24	0.87
Commercial/Industrial	0.01	0.06
Other Non-Impervious	1.82	3.19
Other Impervious	1.33	2.47

2 Methods

DWSP water quality monitoring programs in the Quabbin Reservoir and Ware River Watersheds seek to proactively assess and identify threats to water quality from biological, geological, and chemical sources. These programs include the collection and analysis of water quality samples from watershed surface waters, collection and enumeration of Quabbin Reservoir phytoplankton samples, record collection of *in situ* measurements from water quality probes, hydrological monitoring from USGS stream gages, meteorological monitoring from NOAA weather stations, monitoring for and management of aquatic invasive species within watershed water bodies, and the implementation of the Quabbin Boat Seal Program and associated Boat Decontamination Program. Standard operating procedures outlining specific details (e.g., make/model of equipment used) were developed by DWSP staff, and generally follow methods outlined in USGS and EPA protocols. Further documentation of parameter collection is provided in Section 6.1 of this report.

2.1 Monitoring Programs

In 2024, DWSP staff monitored water quality at 21 surface water sites in the Quabbin Reservoir and Ware River Watersheds and three sites within the Quabbin Reservoir. In addition, watershed ponds were monitored for aquatic invasive species (AIS) , and hydrological and meteorological stations were monitored (Figure 2, Figure 3). The tributary monitoring locations within each watershed included Core sites and Environmental Quality Assessment (EQA) sites. Core sites represent long-term monitoring sites throughout the watershed that are included in the monitoring plan each year. Core sites are critical for DWSP assessments, as they provide a long-term record of water quality data from primary tributaries within each watershed. Each watershed is divided into sub-watersheds, referred to as sanitary districts (Figure 2, Figure 3). EQA sites within a single sanitary district are sampled approximately once every four to five years. Data from EQA sites are used to support assessments of potential threats to water quality within each sanitary district. Monitoring of EQA sites provides a year-long assessment of water quality within a specific area of each watershed, allowing for greater spatial coverage, a higher-resolution understanding of transport processes operating across the catchments embedded within the greater watershed, and elucidation of potential upstream impacts to Core sites. The Quabbin Reservation sanitary district within the Quabbin Reservoir Watershed and the East Branch Ware sanitary district within the Ware River Watershed were monitored in 2024. AIS investigations often follow EQA rotations, assessing long-term priority sites while incorporating regional waterbodies in line with sanitary districts of focus. Reservoir monitoring locations are long-term sampling sites located near shaft intakes and/or major stream inflows. In addition to DWSP sampling efforts, select hydrological and meteorological data from partner agencies is also routinely accessed and analyzed to better understand water quality patterns and potential drivers.

DWSP staff also conduct special investigations spanning multiple years. These vary across watersheds, but include storm water sampling, monitoring of potential water quality changes following forest management activities, and evaluation of spatial and temporal trends in elevated bacteria results relative to meteorological patterns. Results of special investigative efforts are further discussed in Sections 3.2.8, as well as being described in previous versions of DWSP annual water quality reports (DWSP 2023a).

2.1.1 Meteorological Monitoring

In 2024, daily precipitation and air temperature data were collected at three monitoring stations across the Quabbin Reservoir and Ware River Watersheds (Table 3; Figure 2; Figure 3). The DWSP Civil Engineering team operates a weather station at the DCR Quabbin Administration Building in Belchertown, MA within the Quabbin Reservoir Watershed. Additional weather data was accessed through NOAA's Climate Data Online portal (National Center for Environmental Information), which provides records from stations at Orange Municipal Airport (Orange, MA) and the US Army Corps of Engineers Barre Falls Dam (Barre, MA). This report's meteorological analyses are based on data from these DWSP (USC00190562) and NOAA stations (USW00054756; USC00190408).

During periods of snow cover, DWSP personnel conducted weekly measurements of snow depth and snow water equivalent (SWE) at six locations throughout the Quabbin Reservoir watershed (Table 3). Each site's snowpack measurements represent averages from six snow cores collected per visit. These weekly findings were submitted to NOAA and the National Operational Hydrological Remote Sensing Center (NOHRSC).

Table 3. *Meteorologic and hydrologic monitoring stations in the Quabbin Reservoir and Ware River Watersheds. Air temperature data was not recorded at the Ware, MA station, and the NEON and DFW-DER streamflow sites were excluded from the 2024 data analysis.*

Measurement	Site Name	Site ID	Managed by	Period of Record (POR)
Air Temperature/ Precipitation	Belchertown, MA	USC00190562	DWSP	1947-2024
Air Temperature/ Precipitation	Orange Municipal Airport, Orange, MA	USW00054756	NOAA	1996-2024
Air Temperature/ Precipitation	Barre Falls Dam, Barre, MA	USC00190408	NOAA	1959-2024
Air Temperature/ Precipitation	Ware, MA	USC00198793	NOAA	1947-2017
Snowpack	4NW Hardwick – Q1 (Gate 43A)	Q1	DWSP	2018-2024
Snowpack	3SW Petersham – Q2 (Gate 40)	Q2	DWSP	2018-2024
Snowpack	2NW New Salem – Q3 (West of 202)	Q3	DWSP	2018-2024
Snowpack	1N Pelham – Q4 (Pelham Lookout)	Q4	DWSP	2018-2024
Snowpack	4E Belchertown – Q5 (Blue Meadow)	Q5	DWSP	2018-2024
Snowpack	3NW Petersham – Q6 (Balls Corner)	Q6	DWSP	2018-2024
Mean Daily Streamflow	Ware River, Barre	1172500	USGS	1987-2024
Mean Daily Streamflow	Ware River, Intake Works, Barre	1173000	USGS	1987-2024
Mean Daily Streamflow	Ware River, Gibbs Crossing	1173500	USGS	1987-2024
Mean Daily Streamflow	Swift River, West Ware	1175500	USGS	1987-2024
Mean Daily Streamflow	East Branch Swift River, Hardwick	1174500	USGS	1987-2024
Mean Daily Streamflow	West Branch Swift River, Shutesbury	1174565	USGS	1995-2024
Mean Daily Streamflow	Lower Hop Brook	-	NEON	2017-2024
Mean Daily Streamflow	Parker’s Brook	-	DFW-DER	2012-2024
Reservoir Elevation	Quabbin Reservoir, at Winsor Dam	-	DWSP	1980-2024

2.1.2 Hydrological Monitoring

The U.S. Geological Survey (USGS) recorded mean daily streamflow for six tributaries in the Quabbin and Ware River Watersheds (three per watershed) in 2024 (Table 3). USGS stations have continuously monitored mean daily streamflow in these watersheds since October 1987, with the exception of the monitoring station along the West Branch Swift River (DWSP site ID 211; USGS 01174565), which began operations in 1995. The Massachusetts Department of Fish and Wildlife's Division of Ecological Restoration (DER) maintains a stream gage at Parkers Brook in the Ware River Watershed (DWSP site 102), providing daily streamflow data since late 2012. In 2017, the National Ecological Observatory Network (NEON) established a streamflow monitoring station along Lower Hop Brook (DWSP site 212), with daily data available from late 2020 onward (NEON, 2020).

Throughout 2024, DWSP maintained staff gages and collected water level data at several additional monitoring locations (sites GATE, 211, 213, 215G, and 216). DWSP Civil Engineering staff also maintain comprehensive records of Quabbin Reservoir elevation, with paper records dating back to the 1940s. Currently, reservoir elevation is measured at 15-minute intervals using a Stevens-Connect continuous sensor. For comparative analysis in this report, historical reservoir elevation records from 1980-2023 were utilized alongside current annual data.

2.1.3 Tributary Monitoring

DWSP staff monitored water quality at 19 stream sampling locations across the Quabbin Reservoir and Ware River Watersheds in 2024 (Table 4), along with two long-term study sites associated with a forest management study (Section 2.1.6.1). The tributary monitoring locations include Core sites and Environmental Quality Assessment (EQA) sites (Figure 2, Figure 3). Tributary locations vary in upstream catchment characteristics including land use and proportion wetland, as well as stream attributes (e.g., stream order, gradient, discharge, etc.). Sites are selected to characterize major inflows to the Quabbin Reservoir and Ware River, as well as to monitor areas of special interest and gather data on streams of varying upstream catchment and reach-scale attributes.

Samples were collected every other week (hereafter: biweekly) at tributary sites in 2024, with sampling in Quabbin Reservoir Watershed and Ware River Watershed alternating weekly. Monitoring frequency of analytes varied across watersheds, with less frequent analysis of nutrients in Ware River EQA sites (quarterly vs. biweekly) and a quarterly sampling interval for all alkalinity analyses (Table 5). Samples were analyzed by MWRA laboratories per standard methods (Table 5). Sampling plans, locations, and sample collection frequencies vary across the period of record. Further discussion on changes to analytical methods across parameters and sampling frequencies across sites are detailed in Section 2.2. Further documentation on monitoring parameters is included in Section 6.1.

Table 4. *Drainage basin characteristics of DWSP tributary monitoring sites for Quabbin Reservoir Watershed and Ware River Watershed, 2024.*

Quabbin Reservoir Watershed

Site Type	Site ID	Site Description	Area (mi^2)	DWSP Land (mi^2)	DWSP Land (percent)	Wetland (mi^2)	Wetland (percent)
Core	211	West Branch Swift River	13.6	6.4	46.8	0.5	3.5
Core	212	Hop Brook	4.5	1.5	32.8	0.1	2.6
EQA	213	Middle Branch Swift River	9.1	2.2	23.8	0.8	8.3
EQA	215G	East Branch of Fever Brook	4.1	0.6	13.9	0.5	12.9
EQA	216	East Branch Swift River	30.1	0.6	2.08	2.8	9.4
EQA	BC	Boat Cove Brook	<0.1	<0.1	100	0.0	1.0
EQA	GATE	Gates Brook	0.9	0.9	100	<0.1	3.1
EQA	211A-1	Atherton Brook	2.0	0.9	46.8	0.1	3.6
EQA	211B-X	Cadwell Creek	2.8	2.8	100	0.1	2.6

Ware River Watershed

Site Type	Site ID	Site Description	Area (mi^2)	DWSP Land (mi^2)	DWSP Land (percent)	Wetland (mi^2)	Wetland (percent)
Core	101	Ware River, near Shaft 8	96.5	36.5	37.8	13.4	13.9
Core	102	Parkers Brook	5.4	4.6	84.8	0.5	9.5
Core	103A	Burnshirt River	4.0	2.8	70.7	0.3	7.1
Core	107A	West Branch Ware River	16.0	7.3	45.3	2.7	16.9
Core	108	East Branch Ware River	22.2	3.0	13.4	3.8	17.3
Core	121	Mill Brook	3.0	0.3	9.4	0.5	15.8
EQA	108A	East Branch Ware River (68)	17.6	1.9	10.5	2.1	11.8
EQA	108B	Cushman Pond Outlet	0.9	<0.1	0.5	0.2	22.2
EQA	108C	East Branch Ware (Lombard)	6.8	0	0	0.5	7.4
EQA	117	Pommogussett Brook	2.1	0	0	0.4	18.4

Table 5. *Analytes included in DWSP tributary monitoring programs, analytical methods, and monitoring frequency for 2024. Biweekly sampling denotes samples collected on an every-other-week interval. Nutrient sampling was bi-weekly for all Quabbin tributary sites and Ware EQA sites, and quarterly for Ware Core sites.*

Group	Analyte	Method (2024)	Monitoring Frequency (2024)
Bacteria	Total Coliform	SM 9223B	Biweekly
Bacteria	*E. coli*	SM 9223B	Biweekly
Physical	Turbidity	SM 2130 B	Biweekly
Chemical	Alkalinity	SM 2320 B	Quarterly
Nutrients	NO_3-N	EPA 353.2	Biweekly or Quarterly
Nutrients	NH_3-N	EPA 350.1	Biweekly or Quarterly
Nutrients	TKN	EPA 351.2	Biweekly or Quarterly
Nutrients	TP	EPA 365.1	Biweekly or Quarterly
Organic Matter	TOC	SM 5310 B	Biweekly (Quabbin Sites and Ware Site 101)
Organic Matter	UV_{254}	SM 5910B 19th edition	Biweekly
Major Ions	Na	EPA 200.7	Biweekly
Major Ions	Cl	EPA 300.0	Biweekly
Field Parameters	Temperature	Gibs et al. (2012)	Biweekly
Field Parameters	Dissolved Oxygen	Gibs et al. (2012)	Biweekly
Field Parameters	pH	Gibs et al. (2012)	Biweekly
Field Parameters	Specific Conductance	Gibs et al. (2012)	Biweekly

2.1.4 Reservoir Monitoring

2.1.4.1 Surface Water Treatment Rule Compliance Monitoring

MWRA monitors Quabbin Reservoir water prior to disinfection to ensure compliance with the Surface Water Treatment Rule. Daily monitoring is performed by MWRA at the Brutsch Water Treatment facility in Ware, MA. MWRA provides annual turbidity and fecal coliform data from the Winsor Dam Intake, collected at the BWTF. Average and maximum daily turbidity readings and daily fecal coliform counts are summarized to account for SFWR compliance for the Quabbin Reservoir.

2.1.4.2 Reservoir Monitoring by DWSP

DWSP reservoir monitoring includes plankton monitoring, water quality sample collection, and the use of *in situ* sensors for water quality data collection. The Quabbin Reservoir was sampled regularly in 2024 to monitor phytoplankton densities to anticipate potential taste and odor problems and recommend management actions as necessary. At site 202, phytoplankton was sampled every week from May to September and monthly from January to April and October to December. At sites 206 and Den Hill, phytoplankton was sampled monthly year-round (ice conditions permitting). A response plan to elevated phytoplankton densities was set so that if any of the taxa of concern exceeded the established alert levels, frequency of monitoring increased to twice a week for site 202 and twice a month for sites 206 and Den Hill (see Table 53). In 2024, phytoplankton sampling frequency increased to twice a week at site 202 from July 9 to September 12, to twice per month at site 206 from July 9 to September 3, and to twice per month at Den Hill from July 9 to August 20, in response to elevated densities of *Chrysosphaerella*. See Figure 2 and Table 6 for reservoir sampling locations.

Water samples were collected monthly in 2024 from April to December at three depths from three stations within the reservoir for analyses of UV_{254}, total organic carbon, turbidity, and bacteria. Water samples for analyses of nutrients, silica, alkalinity, pH, sodium, and chloride were collected quarterly (May, July, October, and December), with an additional collection date in August to capture physiochemical reservoir conditions during observed elevated phytoplankton densities (*Chrysosphaerella* aggregation) in the summer. Calcium monitoring was discontinued in 2023, due to low calcium levels observed in the reservoir in the past two years (e.g., 1.81 to 2.33 mg/L in 2022) demonstrating low risk of zebra mussel colonization (DWSP, 2023a).

Manual water-column profiles of temperature, pH, dissolved oxygen, specific conductance, chlorophyll *a*, and phycocyanin were measured via a Yellow Springs Instruments (YSI) EXO2 sonde coincident to phytoplankton and water quality sampling at each site. In addition to manual water column profiles, a remote sensing profiling buoy was deployed by MWRA and DWSP in 2020; it is located close to sampling site 202 in Winsor Basin. Profiles are collected with YSI EXO2 sondes, identical to those used by DWSP for manual profiles. The profilers automatically run every six hours (12 am, 6 am, 12 pm, and 6 pm) and collect data at 1-m increments. Results are frequently used by DWSP to augment the routine profiles and phytoplankton sampling program. For example, if elevated chlorophyll *a* values are observed in remote sensing data, DWSP may sample earlier than scheduled to capture associated phytoplankton data. The high frequency profile data also allows for identification and visualization of diurnal patterns and both short and long-term effects of environmental forces such as cooling temperatures during turnover and seiche effects due to wind events. Reservoir monitoring results are discussed in Section 3.3 of this report.

Table 6. *Core monitoring locations in Quabbin Reservoir, 2024.*

Site Name	Site ID	Location	Maximum Depth (m)
Winsor Dam	202	Quabbin Reservoir west arm, offshore of Winsor Dam along former Swift River riverbed	42
Shaft 12	206	Quabbin Reservoir, offshore of Shaft 12	28
Den Hill	Den Hill	Quabbin Reservoir eastern basin, near Shaft 11a	19

2.1.5 Aquatic Invasive Species Monitoring and Management

DWSP implements an annual monitoring program for AIS in the watersheds. Several water bodies within the Quabbin Reservoir and Ware River Watersheds are monitored for AIS annually, whereas additional water bodies are evaluated every five years as a component of the current Environmental Quality Assessment cycle. Thus, the waterbodies in a single sanitary district, for each of the watersheds, are surveyed for AIS every five years as time allows. Select waterbodies in the Quabbin Reservation sanitary district and East Branch Ware sanitary district were surveyed for AIS in 2024. Bassett Pond and Pepper's Mill Pond are located outside of the watersheds but are included in monitoring due to their proximity to Quabbin Reservoir.

Ten water bodies in the Quabbin Reservoir Watershed (three total) and Ware River Watershed (seven total) were surveyed by DWSP for the presence of aquatic invasive species (AIS) in 2024 (Table 7). In addition, the reservoir's two regulating ponds (O'Loughlin and Pottapaug) and portions of the Reservoir shoreline (Boat Launch Areas 1, 2, and 3) and Ware River were also surveyed for AIS in 2024. Assessments conducted by TRC were completed under a MWRA contract. MWRA and the contracted consultant assist DWSP with early detection of AIS by surveying portions of the Quabbin Reservoir and the Ware River annually. MWRA also manages AIS in the Ware River via a drawdown of the river system and manual harvest of invasives along the riverbed.

Additional programs are also implemented to protect against the spread of invasives in the Quabbin Reservoir. Oblique tows (1 minute duration; 53-µm mesh) were performed quarterly in proximity to the three reservoir Boat Launch Areas, and vertical tows (net lowered to 2 m above bottom, 53-µm mesh) were collected at the three phytoplankton sampling sites (202, 206, and DEN). Samples collected via oblique net tows were screened to monitor for invasive zooplankton, whereas vertical tow samples were concentrated, preserved in alcohol, and later analyzed under a dissecting microscope. As a preventative means to further limit potential undesirable impacts to water quality resulting from AIS, DWSP staff coordinate boat inspections, boat/motor/equipment decontaminations, and monitoring of boat ramps in Quabbin Reservoir and Ware River Watersheds.

Table 7. *Water bodies surveyed in 2024 for aquatic invasive macrophyte species in Quabbin Reservoir and Ware River Watersheds. *Waterbodies located outside of the watershed but included due to proximity to drinking water resources.*

Quabbin Reservoir Watershed

Water Body Name	Location	Surveyed by	Date
Quabbin Reservoir	New Salem, Petersham, Hardwick	TRC	8/5- 8/14/2024
Quabbin Reservoir, West Arm	Pelham, New Salem	TRC	8/14/2024
O'Loughlin Pond	New Salem	TRC and DWSP	4/19, 4/26, 4/30, 5/21, and 8/13/2024
Pottapaug Pond	Hardwick	TRC and DWSP	5/14, 8/28, and 8/30/2024
Quabbin Reservoir, Boat Launch Area 1	Belchertown	DWSP	7/25/2024
Quabbin Reservoir, Boat Launch Area 2	New Salem	DWSP	6/28/2024
Quabbin Reservoir, Boat Launch Area 3	Petersham	DWSP	8/1/2024
* Bassett Pond	New Salem	DWSP	6/28/2024
Lake Mattawa	Orange	DWSP	7/29/2024
* Peppers Mill Pond	Ware	DWSP	6/6/2024

Ware River Watershed

Water Body Name	Location	Surveyed by	Date
Ware River, Upstream of Shaft 8	Barre	TRC	7/26/2024
Asnacomet Pond	Hubbardston	DWSP	9/24/2024
Brigham Pond	Hubbardston	DWSP	9/17/2024
Cloverdale Pond	Rutland	DWSP	7/23/2024
Demond Pond	Rutland	DWSP	7/18/2024
Long Pond	Rutland	DWSP	8/15/2024
Queen Lake	Phillipston	DWSP	6/20/2024
Whitehall Pond	Rutland	DWSP	6/11/2024

2.1.6 Special Investigations

DWSP conducts both short-term and long-term investigations on select projects based on water quality concerns in the region. Forestry monitoring and Environmental Quality Assessments are current long-term programs to investigate water quality and landscape patterns related to land management.

2.1.6.1 Forestry Monitoring

DWSP continued to monitor water quality associated with its long-term study to assess the potential impacts of timber harvesting on water quality at two surface water sites in the Quabbin Reservoir Watershed (Figure 2). The monitoring uses a paired-watershed study design, where data is collected at a control and treatment watershed before and after timber operations and to document any changes that can be attributed to forest management. The paired watershed study design was selected for its robust approach to detect long-term changes in water quality conditions. The paired watershed study design statistically controls climate and hydrological differences over years, allowing for attribution of water quality changes to treatment rather than broader climatic drivers (Hewlett and Pienaar, 1973).

Water quality sampling at paired-watershed site locations is conducted at two intervals to ensure that monitoring captures a full range of streamflow conditions and solute mobilization contexts. Routine monthly-grab sampling and quarterly event-based sampling continued in 2024, meeting annual sampling objectives for the project. Monthly grab samples have been collected at the Middle Branch Dickey (MBD) Brook (control site) and the East Branch Underhill (EBU) Brook (treatment site) on Prescott Peninsula since April 2002. Monthly grab samples have been analyzed for nutrients (NO_3-N, NO_2-N, TKN, and TP) since 2002 and total suspended solids (TSS), UV_{254}, NH_3-N, TOC, and DOC since 2014, and data analysis continued through 2024. Periodic event-based sampling of MBD and EBU was initiated in 2014 to characterize stream response during a variety of hydrological events (e.g., high- and low-intensity rainfall, rain-on-snow). Primary data generated by DWSP includes measurements of precipitation, stream flow, and concentrations of solutes collected across the event hydrograph (NO_3-N, NH_3-N, NO_2-N, TKN, TP, TSS, UV_{254}, TOC, and DOC), as well as investigations into hydrograph separation using stable water isotopes (Boutt, 2021). Concentration data collected during events serves to characterize the range of nutrient and sediment concentrations observed in these watersheds and provide an estimate of event-based solute loading for MBD and EBU when coupled with event discharge data. Long-term forestry monitoring of water quality in MBD and EBU in 2024 also included training of new DWSP staff, installation and routine maintenance of water-level loggers and precipitation gages, downloading of field data, monitoring of weather forecasts, sample collection, and associated data analysis.

2.1.6.2 Environmental Quality Assessments

DWSP conducts annual Environmental Quality Assessments (EQAs) of a single sanitary district in each watershed to assess potential sources of contamination across the watershed system. Each sanitary district is comprehensively evaluated by DWSP once every five years. Water quality monitoring of select Core and EQA sites within the selected sanitary district constitutes a component of the EQA. The EQA reporting in 2024 focused on the Quabbin Reservation sanitary district in Quabbin Reservoir Watershed (Figure 2) and the East Branch Ware sanitary district in the Ware River Watershed (Figure 3).

2.2 Watershed Monitoring Parameters and Historical Context

DWSP water quality monitoring was comprised of 24 unique water quality characteristics (e.g., physical, chemical, and biological) measured in the Quabbin Reservoir and Ware River Watersheds in 2024 (Section 6.1). Parameters monitored by DWSP included those that may directly affect water quality (and thus, potability) and/or may indicate the presence of potential future negative impacts to water quality. An extensive discussion, including relevant regulatory and guidance thresholds for the parameters monitored by DWSP, was documented in the 2022 Quabbin/Ware Region Water Quality Report (DWSP 2023a, Appendix A). Analytical methods for concentration data are provided in Table 5. Results for various water quality parameters are compared to regulatory levels when applicable (DWSP 2023a, Appendix A).

DWSP updates sampling plans annually to align with Environmental Quality Assessments, assess potential water quality concerns, and/or to focus on new regions or sites of interest. Thus, historical sampling frequency of analytes varies across time and space (Figures 4-6). For example, monitoring frequency of several parameters was increased in Core tributaries from quarterly to biweekly in 2020 (DWSP, 2021a). Monitoring frequency of select analytes in Quabbin Reservoir also changed from quarterly to monthly in 2020. Bacteria analyses include total coliform and *E. coli*, the latter of which was added to DWSP monitoring programs in 2005. Inorganic N represents NO3-N and NH3-N, with the addition of NH3-N in 2011. Organics include UV254, with the addition of total organic carbon at Quabbin Reservoir sites in 2020, at Quabbin Reservoir Watershed tributary sites in 2021, and Ware River site 101 in 2023. Metals and anions incorporate Na and Cl concentrations and were added within the last 5 years due to increasing concern over specific conductance trends in waterways of the Northeastern USA (DWSP 2023a). Further documentation on changes to water quality sampling plans is available in previous versions of this annual water quality report.

Annual sampling coverage varies between Core and EQA tributary sites due to programmatic goals. Core sites are monitored annually for long-term coverage and a resulting period of record that is at a relatively fine temporal scale. For many sites with long-term water quality monitoring records locations, this allows for a more robust discussion of changes in water quality patterns over time (20-30 years), or more near-term (e.g., five-year or less) analysis of certain patterns for more recently added analytes (e.g., anions, TOC). In contrast, monitoring of EQA sites follows a five-year rotation focusing on different sub-basins within each of the two water supply watersheds. This monitoring is intended as a synoptic snapshot of conditions during the writing of these assessments, and thus these data have a significantly shorter period of record compared with Core monitoring locations. Period-of-record results from EQA sites rarely exceed three to four years of observation and are staggered in time. Due to these differences in temporal coverage, comparisons of conditions between 2024 results and historical records for EQA sites are less robust compared to the longer period of record for Core monitoring locations.

Select tributary monitoring sites previously established as EQA sites were converted to long-term (Core) monitoring sites in 2021 to provide better spatial coverage and consistent sampling of priority areas within either watershed (215G replaced 215 in the Quabbin Reservoir Watershed and 121 replaced 121B in the Ware River Watershed). Parkers Brook (102) was added to the Ware River Watershed monitoring program as a Core site in 2021. Changes in the frequency of analysis of select analytes, or transitions from EQA to Core site sampling frequencies may impact seasonal statistics, long-term patterns in water quality, and comparisons to historical ranges relative to sites that have not undergone significant changes to monitoring program structure. These considerations are further discussed within the water quality result narratives for the tributary and reservoir monitoring results.

There are a few notable shifts in analytical methods and detection limits over the period of record. Analytical methods for TKN returned to EPA Method 351.2 (O'Dell, 1993a) in 2023, consistent with all results prior to 2020. Beginning in 2020, analysis had shifted to Valderrama (1981) to facilitate monthly monitoring frequencies of N-species in Core sites in Quabbin Reservoir and biweekly monitoring in Core tributary sites. Results were reported as total nitrogen (TN) in 2020-2022. During the period of 2020-2022, TKN concentrations were derived by subtracting concentrations of NO_3-N and NO_2-N from TN concentrations. NO_2-N has been measured previously (2010) in samples collected from Core sites and was below laboratory detection limits in all samples in the Quabbin Reservoir (n = 18) and in all but four samples (n = 2,005 total measurements) in Core tributaries. Thus, NO_2-N was assumed to remain below laboratory detection limits (less than 0.005 mg/L) in all samples collected in 2020 and 2022. DWSP did not modify sample collection methods, thus uncertainty associated with TKN concentration data from this period is limited to assumptions made during calculations and/or sensitivity of different analytical methods. The detection limits for TN via Valderrama (1981) were 0.0034 mg/L. Results for TKN for tributary monitoring included in this report date from 2010 to the present.

Analytical methods for TP were modified in 2020. TP concentrations for tributaries were derived via EPA Method 365.1 (O'Dell, 1993b) until January 01, 2020. Analysis was performed via Valderrama (1981) thereafter to facilitate increased monitoring frequencies of TP in Core tributaries (e.g., every two weeks). Analytical methods for TP returned to EPA methods in 2021. Uncertainty associated with TP concentration data for 2020 is limited to sensitivity of different analytical methods, as sample collection and storage were not altered in 2020. Because of the variation associated with the change in TP methods for 2020, TP concentration data corresponding to samples collected in 2020 were excluded from calculations for period-of-record statistics. Also of note is that alkalinity concentration results were historically reported by titration to pH of 4.5 endpoint via Standard Method 2320B (DWSP, 2018b).

Sensors used for collection of *in situ* parameters by DWSP also vary over the period of record. Before 2021, DWSP staff used a Eureka Manta2 field sonde for data collection at Quabbin

Reservoir. Starting 2021, a shift was made to the YSI EXO2 sonde to better align data collection with MWRA and DWSP-Wachusett methods. Changes in sensor manufacturers, sonde configurations, and water column profile collection methods complicate direct comparisons to historical data for physiochemical parameters. These considerations are further discussed throughout the report.

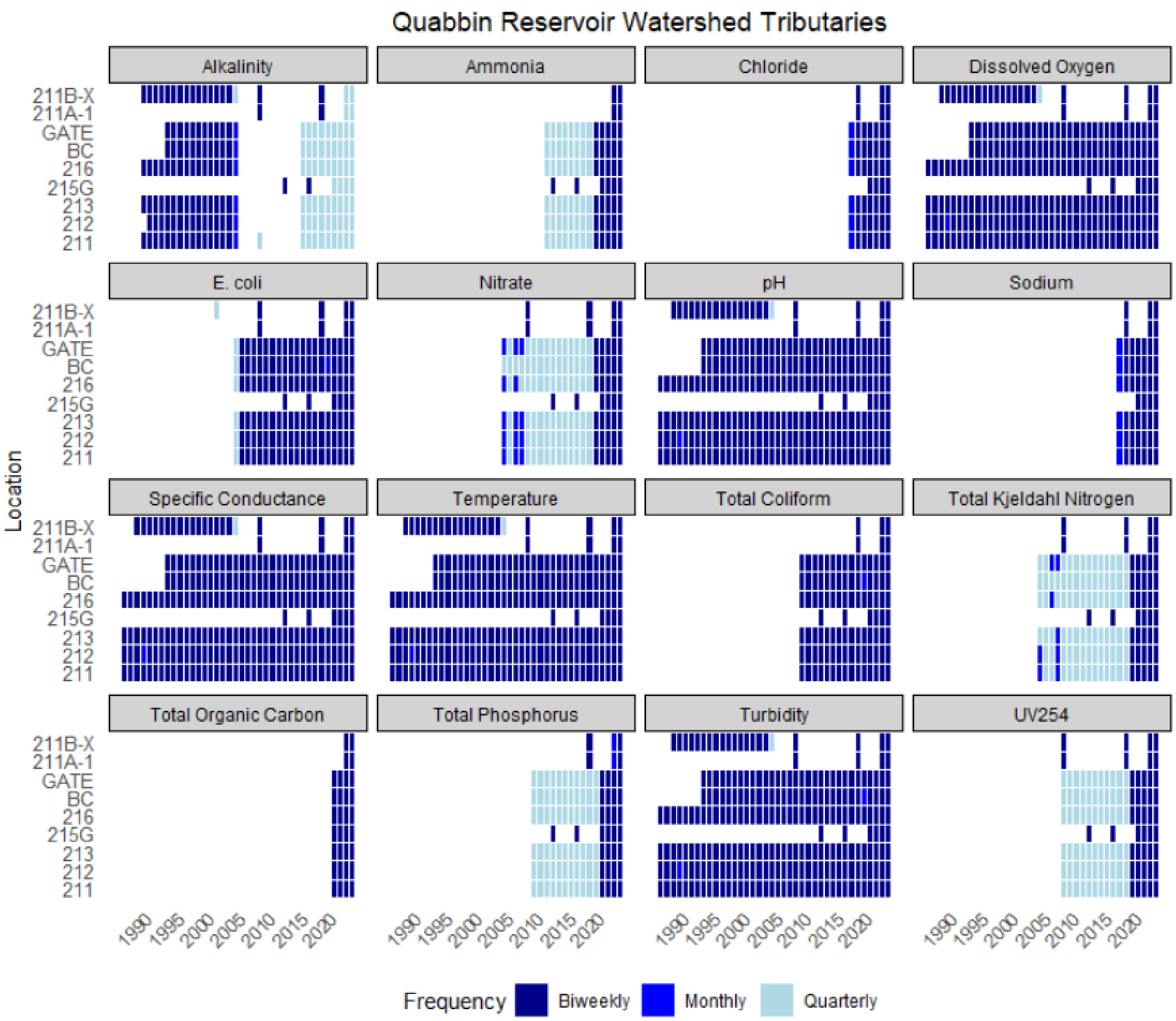


Figure 4. *Period of record for analytes measured in 2024 tributaries monitoring sites in Quabbin Reservoir Watershed.*

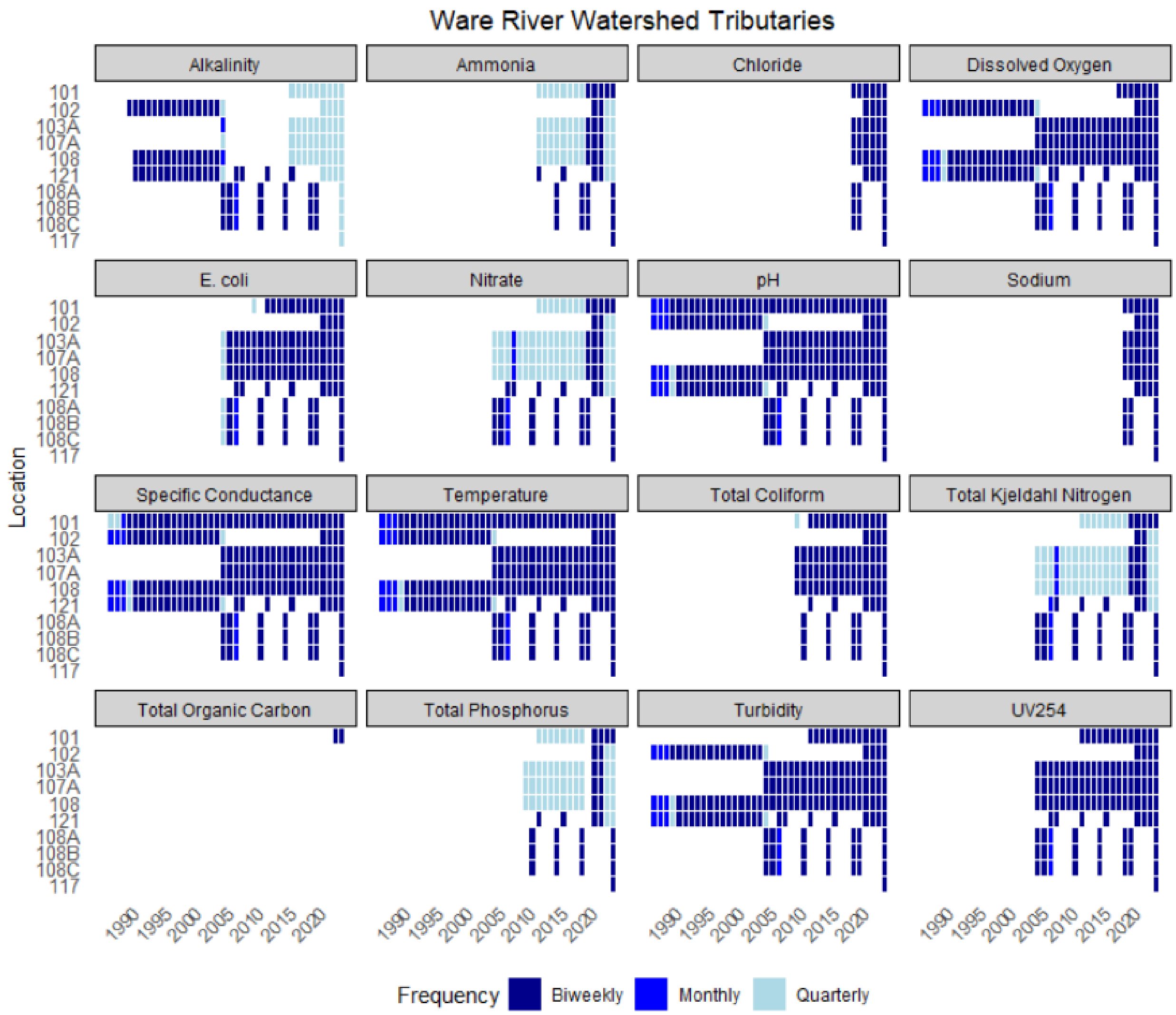


Figure 5. *Period of record for analytes measured in 2024 tributaries monitoring sites in Ware River Watershed.*

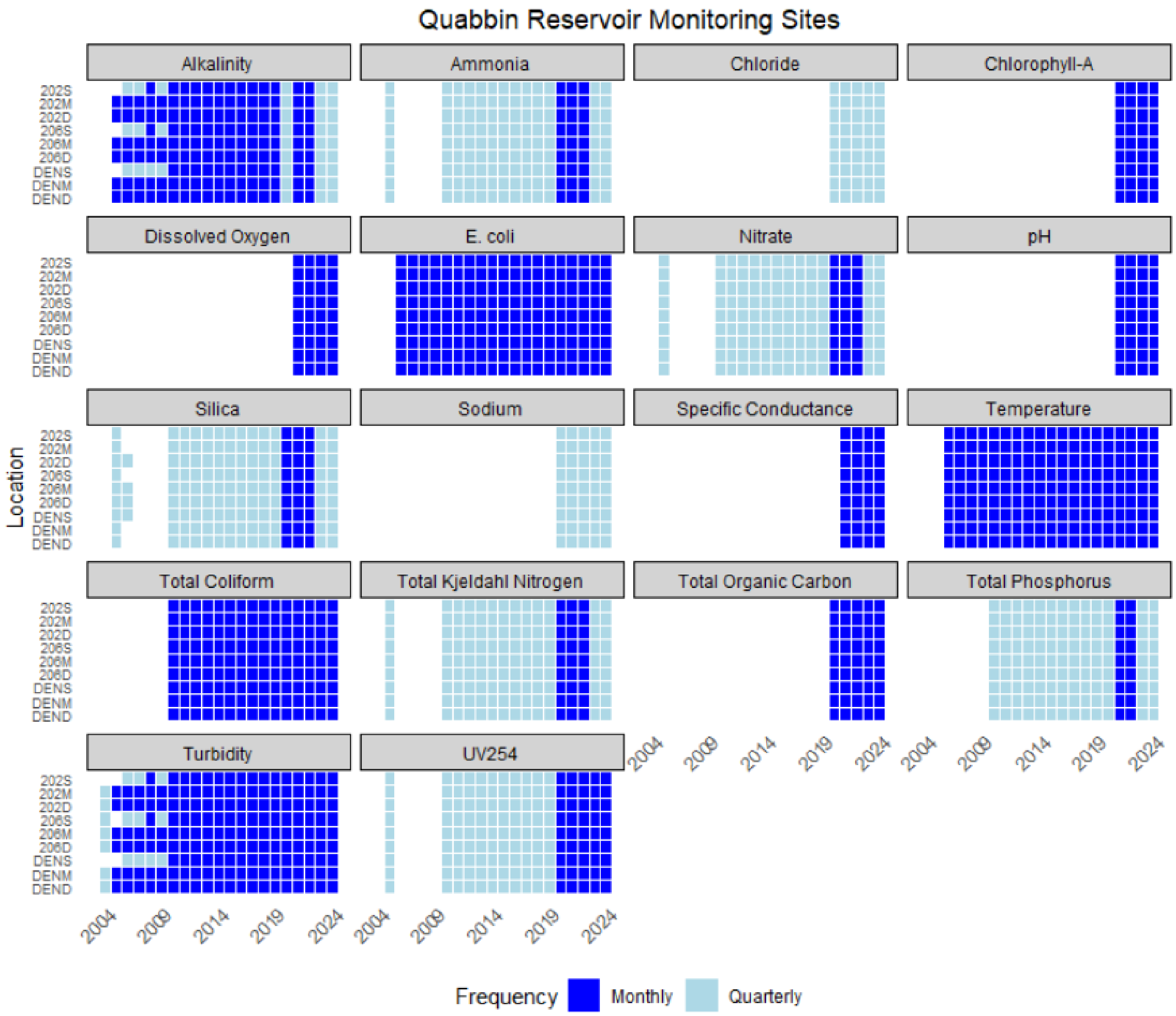


Figure 6. *Period of record for analytes measured in Quabbin Reservoir monitoring sites.*

2.3 Data Management and Statistical Methods

Water quality, precipitation, and streamflow data collected since 1989 are stored in a Microsoft SQL Server database, maintained by DWSP-EQ. Database development efforts continue to build off the database migrated to a SQL Server platform in 2021 for cloud-based storage and easy access for filtering and analyzing historical records. The current database contains historical water quality data including field parameters (water temperature, dissolved oxygen, oxygen saturation, specific conductance, pH, Secchi depth, chlorophyll *a*, and phycocyanin) and constituent concentration results (alkalinity, NO_3-N, NO_2-N, NH_3-N, TP, TKN, Ca, Na, Cl, Si, dissolved and total carbon, *E. coli*, total and fecal coliform, hardness, UV_{254}, and turbidity), spanning the onset of DWSP monitoring (1987) through the present. Laboratory data, including concentrations of various constituents, were provided by MWRA staff and then uploaded to the DWSP water quality database via R-scripts and Shiny application tools designed for data download and database standardization (R Core Team, 2019; Winston et al., 2019). Plankton density summaries were generated by DWSP-EQ staff and included in database tables for long-term record keeping. Workflows are developed using R, RStudio, ArcGIS, and SQL Server Management software to automate QA/QC and data import processes for incoming raw data generated from field equipment (e.g., multiparameter probes), MWRA lab results, and phytoplankton identification and enumeration, as well calibration records and field notes.

DWSP continued to develop its water-quality database in 2024, processing and importing data from numerous monitoring workflows and organizing historical data records. Work related to DWSP data management and integration of historical records (prior to 2010) remains ongoing. This includes documentation of historical detection limits, verification of results, attribution of data flags, and ensuring completeness of record.

Annual water quality monitoring data are reviewed before being imported and periodically throughout the year for data accuracy and to compare results against seasonal normal ranges (25-75%) based on the site-specific monitoring period of record. Data flags are added to records that require qualifiers for analytical use and interpretation, or for records that should be excluded from analysis due to instrumentation error, sensor calibration issues, sample collection inconsistencies, environmental factors, or other considerations. A small subset of monitoring records were flagged and removed from summary reporting following review by DWSP and MWRA staff (less than 1% of records). For example, 2023 ammonia results from October were excluded from reporting due to documented linearity issues with the NH_3-N calibration curve during this period (Gottshall, 2024). In 2024, select records from water quality sensor data were removed following post-sample calibration tests that did not pass QA/QC checks.

Concentrations below laboratory reporting limits were replaced with the detection limit for all calculations performed in this report. Concentrations above upper reporting limits were assigned as equal to the upper detection limit. Censored data are flagged in the DWSP database. This method of handling censored data is consistent with that used in recent annual water quality reports for the Quabbin Reservoir and Ware River Watershed (DWSP, 2023a; DWSP 2024a). Due to the inherent non-normal distribution of environmental monitoring data, non-parametric measures of central tendency (median, interquartile range) were used to evaluate the variability of constituents observed in 2024 (Helsel, 2012).

Seasonal statistics (mean, median, geometric mean) were calculated using methods depending on the occurrence of non-detects within each data grouping. Left-censored results were substituted with the detection limit concentration and the normal statistic was calculated using base R functions when fewer than four values are detected in a data group. Statistics were calculated using functions from the NADA package (Lee, 2020) when four or more censored values were present in a data group. A parametric method, Maximum Likelihood Estimation (MLE), was used to compute annual geometric mean *E. coli* concentrations. A non-parametric method, Regression on Order Statistics (ROS), was used with other censored data (namely nutrients) to calculate seasonal mean and median concentrations. This modification to statistical methods may produce deviations from standard methods for calculating measures of central tendency for select parameters, as reported previously (DWSP, 2021b-c; DWSP, 2023a). For some analytes where most results are below detection limits (e.g., NH_3-N and NO_3-N), minimum values are reported at detection limits while mean and median values may be lower than detection limits based on ROS methods. Methods for determining measures of central tendency remain unchanged from prior reports for constituents with no censored values. These methods of handling censored data are expected to produce more robust and unbiased results. Many of the reported calculations in this analysis did not deviate substantially from those derived via prior methods.

Seasonal summary statistics (minimum, median, mean, and maximum values) of results from 2024 monitoring are reported along with seasonal statistics from the period of record (POR) available from DCR-DWSP data records. Results from each analyte's POR provide the range of variability expected at sampling locations and allow for comparison of 2024 seasonal results against their historical context. Inferences into seasonal dynamics or interannual variability are limited for sites with short-duration or intermittent temporal coverage (e.g., EQA sites, more recently added Core sites, see Figures 4-6), as well as parameters with quarterly sample collection, and are provided as a point of reference to a still-emerging understanding of seasonal variability for different parameters at different sites.

3 Results

3.1 Hydrology and Climate

The northerly latitude and geographic location of the Northeastern United States has made it prone to the moderating and moistening effects of the Atlantic Ocean, as well as the influence of hot and cold air masses from the continent's interior (Brown et al., 2010). This has resulted in a climate with a distinct seasonality historically characterized by cold, snowy winters and warm, humid summers. Additionally, the region's proximity to the northern hemisphere polar jet stream has led to highly variable weather patterns, reflected in a broad range of daily and annual temperatures and generally abundant precipitation throughout the year (Rustad et al., 2012). These patterns have begun to shift, however, as anthropogenic influences (e.g., the burning of fossil fuels) have led to a steady climb in global temperatures with a global 3°C rise predicted by the end of the century (United Nations Environment Programme, 2023). In the contiguous United States, the fastest warming region has been identified as the Northeast where seasonal differences in temperature have decreased in recent years as winters have warmed three times faster than summers (Horton et al., 2014; Young and Young, 2021). Due to the rate of warming in the Northeast, this region is projected to warm by an additional 1°C as global warming reaches 2°C (Karmalkar and Bradley, 2017).

Massachusetts has historically been susceptible to extreme weather events such as tropical storms, nor'easters, and recurring prolonged summer droughts, and the impact of these events can vary widely across the region due to its diverse topography and locational proximity to storm tracks (Thibeault and Seth, 2014; Siddique et al., 2020). Warming temperatures as the result of climate change have led to an increase in the frequency and magnitude of these events over time which has broadly impacted freshwater systems (Demaria et al., 2016). Hydrology for the region has traditionally been characterized by spring snowmelt floods with a falling hydrograph throughout the remainder of the growing season; however, an uptick in the frequency and duration of periodic high-intensity rainfall events has led to a less predictable hydrograph with high flow conditions occurring throughout the year regardless of seasonal influence (Siddique et al., 2020). Additionally, rising temperatures have been increasing the frequency of rain-on-snow events during winter months and melting snow earlier in the spring, causing winter-spring peak flows to occur approximately six days earlier in Massachusetts as compared to a century ago (Notaro et al., 2014; Demaria et al., 2016). Alterations to streamflow have been coupled with greater rates of evaporation throughout the region, causing precipitation during summer and fall months to fall on increasingly dry soils (Dudley et al., 2017). This leads to broad-scale impacts to water quality in the region as more particulates are flushed from the landscape into streams and rivers to be carried downstream (Willis and McDowell, 1982). Therefore, understanding annual hydrologic and meteorologic patterns in relation to both historical and predicted contexts provide valuable insights into water quality patterns for both the Quabbin Reservoir and Ware River watersheds.

3.1.1 Climatic Conditions

3.1.1.1 Air Temperature

Annual mean air temperature results (calculated from daily median air temperatures) of 10.4°C, 10.5°C, and 10.2°C were observed at the Quabbin Reservoir watershed and Ware River watershed weather stations in 2024 (Barre, Belchertown and Orange respectively). These values were + 0.2°C, + 0.3°C, and + 0.4°C as compared to 2023 observations, and were + 3°C, + 1.1°C, and + 2.1°C as compared to mean values from the period of record for each station (defined in Table 3). Minimum and maximum daily recorded temperatures ranged from -18.9°C to 36.7°C in Barre, -18.3°C to 33.3°C in Belchertown, and from -20°C to 33.9°C in Orange. Of the ten coldest days recorded in 2024, six were observed in the Quabbin Reservoir watershed at the Orange monitoring station, ranging between -20°C and -17.2°C. The five warmest days of the year were recorded in the Ware River watershed, ranging from 36.7°C to 35.6°C, with the warmest three recorded in June of 2024.

Though median daily temperatures for 2024 largely remained within the historical temperature range, deviations were observed during the winter months, as well as some higher peaks in summertime temperatures (June and July; Figure 7). When compared to daily median temperatures for the period of record, 67% of daily median temperatures recorded at the Barre weather station exceeded mean daily median temperatures for the period of record by more than 2°C or less than -2°C. In the Quabbin Reservoir watershed, 63.5% of days exceeded these thresholds. It is worth noting that, given the variable nature of temperature patterns in the Northeast, such deviations could be deemed within normal bounds when assessed against historical temperature data spanning 5, 10, and 20 years.

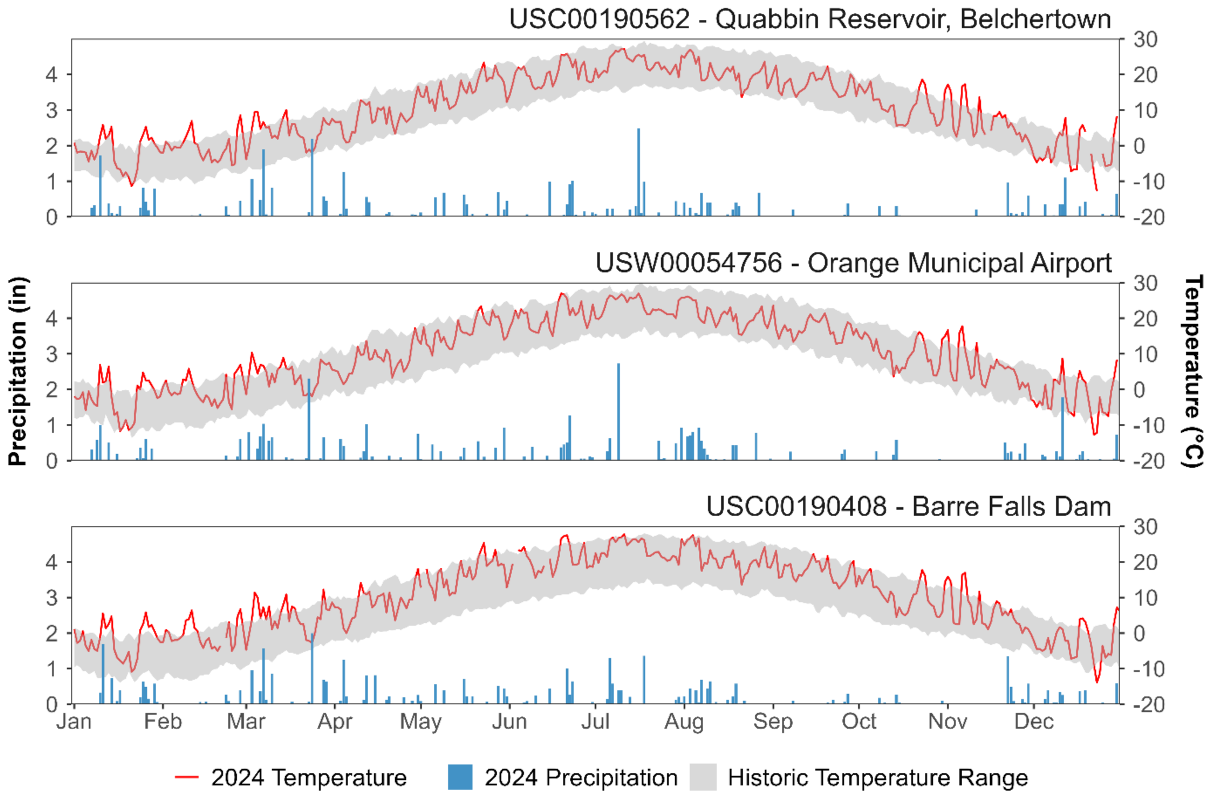


Figure 7. *Climatograph of precipitation totals and daily median temperatures (in degrees Celsius) for weather stations in the Quabbin Reservoir and Ware River. The shaded band represents historical mean daily temperature ranges (minimum to maximum temperature) for Belchertown (1990-2024), Orange (1997-2024), and Barre (1960-2024) weather stations. Gaps in data can be observed as breaks in the line.*

Monthly mean temperatures for 2024 ranged from a minimum of -8.2°C in December to a maximum of 31 °C in July, both recorded in the Ware River watershed (

Table **8**). This compares to a mean historical range of -11.8°C (January) to 28.3°C (July) across both the Quabbin Reservoir and Ware River watersheds. Mean monthly winter temperatures (December, January, and February) for 2024 ranged from -8.2°C to 6.0°C across both watersheds as compared to the mean historical range of -11.8°C to 4.1°C for the same season. Spring (March, April, and May) mean monthly temperatures ranged from -1.9°C to 25.5°C, falling inside the range for both mean temperature minimums and maximums observed for the period of record (-5.8°C to 20.8°C). Mean monthly maximums for summer (June, July, August) exceeded recorded mean maximum temperatures for most summer months at all monitoring stations (August was cooler in the Quabbin Reservoir watershed). The peak mean of 31°C observed during June in the Ware River watershed was well above the historic mean for that month (27°C), with the mean monthly minimum also exceeding the historic mean (+2.1°C). Temperature ranges for autumn (September, October, and November) were recorded as ranging from -0.6°C to 25.7°C as

Table 8. *Monthly mean values of daily minimum and maximum temperature for the period of record and for 2024. Delta (Δ) represents the difference between 2024 monthly means compared to the period of record. Temperature variations are highlighted by an orange-red gradient, with temperatures deviations > 2°C becoming darker based on magnitude.*

Weather Station	Month	Mean Daily Min POR	Mean Daily Min 2024	Mean Daily Min Δ	Mean Daily Max POR	Mean Daily Max 2024	Mean Daily Max Δ
Barre	Jan	-11.83	-6.67	5.16	-0.47	2.19	2.66
Barre	Feb	-11.19	-7.06	4.13	0.98	5.96	4.98
Barre	Mar	-5.81	-1.94	3.87	6.22	10.66	4.44
Barre	Apr	-0.23	0.79	1.02	12.95	15.93	2.97
Barre	May	5.35	8.96	3.61	19.89	24.51	4.62
Barre	Jun	10.24	12.27	2.03	24.17	29.03	4.86
Barre	Jul	13.31	16.27	2.96	27.02	31.02	4.00
Barre	Aug	12.20	13.45	1.25	25.91	28.44	2.53
Barre	Sep	7.71	9.28	1.58	21.88	25.70	3.81
Barre	Oct	1.96	1.70	-0.26	15.54	19.69	4.16
Barre	Nov	-2.50	-0.63	1.87	8.87	12.73	3.86
Barre	Dec	-8.09	-8.23	-0.14	2.34	2.65	0.31
Belchertown	Jan	-8.59	-6.07	2.52	0.82	2.28	1.46
Belchertown	Feb	-8.39	-5.68	2.71	2.59	5.03	2.44
Belchertown	Mar	-3.97	-1.26	2.71	7.17	9.18	2.01
Belchertown	Apr	1.61	1.72	0.11	14.02	14.01	-0.01
Belchertown	May	7.91	9.83	1.92	20.67	21.92	1.25
Belchertown	Jun	12.64	13.33	0.69	24.77	26.80	2.02
Belchertown	Jul	16.45	17.55	1.11	28.29	28.82	0.53
Belchertown	Aug	15.30	14.51	-0.79	27.24	26.55	-0.69
Belchertown	Sep	11.51	11.03	-0.48	23.34	23.57	0.23
Belchertown	Oct	5.64	4.42	-1.22	16.45	18.82	2.37
Belchertown	Nov	-0.70	1.33	2.03	9.67	13.05	3.38
Belchertown	Dec	-4.53	-7.26	-2.72	4.15	3.32	-0.83
Orange	Jan	-10.18	-6.93	3.25	0.49	1.81	1.32
Orange	Feb	-9.29	-5.94	3.35	2.42	5.20	2.79
Orange	Mar	-4.62	-1.04	3.58	7.12	9.38	2.26
Orange	Apr	0.74	1.61	0.88	14.34	14.48	0.13
Orange	May	6.91	10.05	3.15	20.80	22.51	1.71
Orange	Jun	12.25	13.76	1.51	25.20	27.33	2.14
Orange	Jul	15.37	17.54	2.17	28.22	29.44	1.22
Orange	Aug	14.58	14.76	0.18	27.30	26.61	-0.68
Orange	Sep	10.06	10.35	0.30	23.16	23.95	0.79
Orange	Oct	3.66	2.55	-1.11	16.01	18.27	2.27
Orange	Nov	-1.94	-0.59	1.36	9.48	12.09	2.61
Orange	Dec	-6.51	-7.41	-0.90	3.65	2.93	-0.72

compared to the historical range of -2.5°C to 23.3 °C. The Ware River watershed exhibited the greatest disparities between historical and 2024 mean monthly temperature, with the most pronounced variations in minimum temperatures recorded in January, February, and March (+5.2°C, +4.1°C, +3.9°C respectively). For maximum temperatures, the greatest differences were observed during February, May, and June (+5°C, +4.9°C, +4.6°C respectively).

3.1.1.2 Precipitation

Cumulative annual precipitation across Quabbin Reservoir and Ware River watershed weather stations in 2024 fell below historical averages at all monitoring locations (Figure 8). Annual rainfall totals ranged from 40.34 inches in Barre to 41.51 inches in Orange, all falling below historical averages. Barre recorded a 4.24-inch deficit (9.5% below normal), Belchertown experienced the largest shortfall at 5.48 inches (13.3% below normal), and Orange had the smallest deficit at 1.16 inches (2.8% below normal). These persistent precipitation deficits contributed to progressively worsening drought conditions throughout the watershed over the course of the year.

Results from snow monitoring the Quabbin Reservoir watershed are presented in an annual memo summarizing seasonal patterns and multi-year trends prepared by the DWSP Civil Engineering Section (DWSP 2025). From 1947 to 2023, Belchertown recorded a mean snowfall of 50.1 inches. In 2024, Belchertown recorded a total snowfall of 28 inches, falling within the lower 25% of snowfall for the period of record.

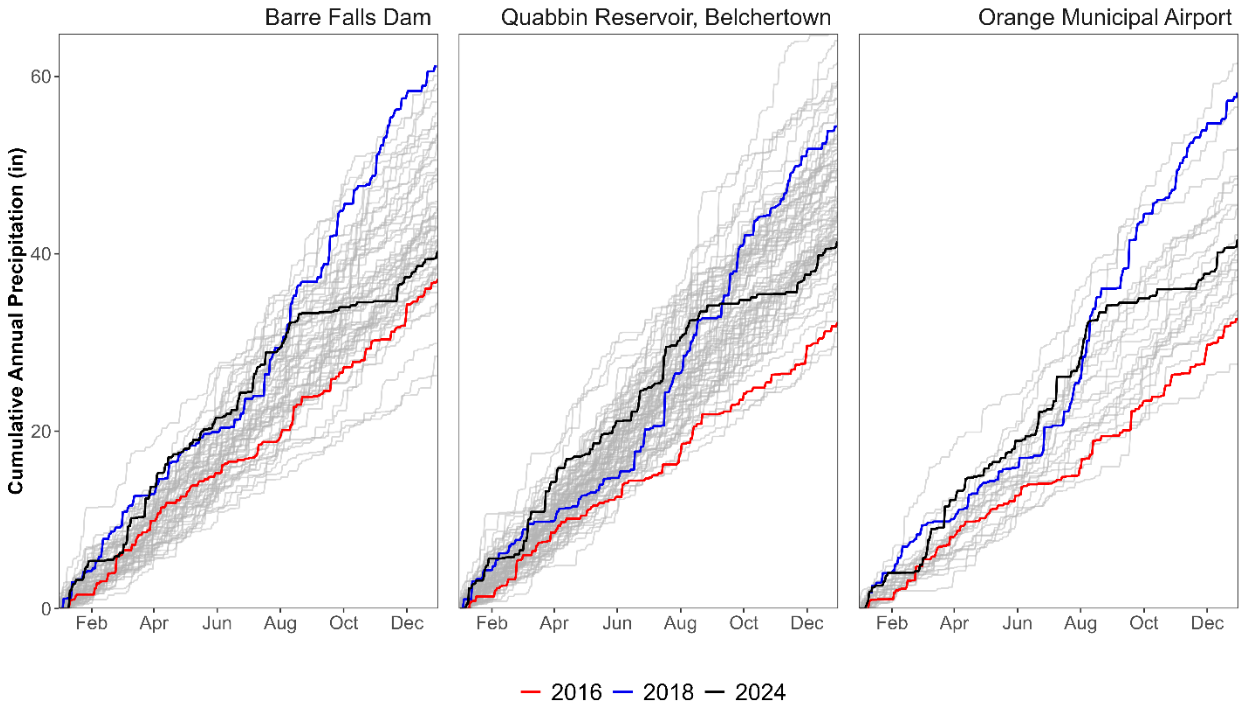


Figure 8. *Annual cumulative precipitation totals for Quabbin Reservoir and Ware River watershed weather stations. Red and blue lines indicate recent years of high and low annual precipitation totals (2016 and 2018, respectively) compared to the period of record (shaded lines; see Table 3 for site-specific record ranges) and to 2024 (black line).*

All three weather stations recorded above-mean monthly cumulative precipitation for January, with Barre recording 5.38 inches of cumulative precipitation (+2.11 inches), Belchertown recording 5.65 inches (+2.22), and Orange recording 4.04 inches (+1.44; Table 9). Precipitation then sharply declined in February, with all stations falling below historical means (between -1.31 and -1.82 inches). March then set a historical record for the month, exceeding historical mean monthly precipitation by more than four inches at all weather stations, and this exceedance carried through to April. Belchertown was the only station to record an April cumulative rainfall deficit at 3.03 inches (-0.86), with Barre recording 4.22 inches (+0.34) of rainfall and Orange recording 3.53 inches (+0.10). Cumulative precipitation then proceeded to drop below historical means across both watersheds through the end of June before seeing a greater than 0.8-inch increase above historical means at all stations for the month of July (4.87 inches, 5.36 inches, and 5.73 inches for Barre, Belchertown and Orange respectively). These conditions were reflected in Massachusetts' drought status, where minimal drought conditions (less than or equal to 5% of state) were observed through early June, with abnormally dry (D0) conditions gradually increasing around mid-June and peaking at 26.5% of the state in mid-July, with late July seeing 3% of the state enter moderate drought (D1) conditions.

Table 9. *Monthly mean cumulative precipitation (inches) from the period of record and monthly cumulative precipitation for 2024.* Delta (Δ) represents *the difference between 2024 total monthly precipitation compared to the POR. Precipitation variations are highlighted by an orange-red gradient, with precipitation deviations > 2" becoming darker based on magnitude.*

Station	Month	POR	2024	Δ
Barre	Jan	3.27	5.38	2.11
Barre	Feb	2.68	1.37	-1.31
Barre	Mar	3.36	7.45	4.09
Barre	Apr	3.88	4.22	0.34
Barre	May	3.81	3.57	-0.24
Barre	Jun	3.89	2.88	-1.01
Barre	Jul	4.00	4.87	0.87
Barre	Aug	4.14	4.05	-0.09
Barre	Sep	4.01	0.65	-3.36
Barre	Oct	4.14	0.68	-3.46
Barre	Nov	3.62	2.71	-0.91
Barre	Dec	3.78	2.51	-1.27
Belchertown	Jan	3.43	5.65	2.22
Belchertown	Feb	3.01	1.41	-1.60
Belchertown	Mar	3.62	7.69	4.07
Belchertown	Apr	3.89	3.03	-0.86
Belchertown	May	3.92	3.85	-0.07
Belchertown	Jun	4.08	3.71	-0.37
Belchertown	Jul	4.36	5.36	1.00
Belchertown	Aug	4.53	3.95	-0.58
Belchertown	Sep	4.22	0.62	-3.60
Belchertown	Oct	3.99	0.68	-3.31
Belchertown	Nov	3.82	2.00	-1.82
Belchertown	Dec	3.89	3.34	-0.55
Orange	Jan	2.60	4.04	1.44
Orange	Feb	2.71	0.89	-1.82
Orange	Mar	3.06	7.31	4.25
Orange	Apr	3.43	3.53	0.10
Orange	May	3.22	3.15	-0.07
Orange	Jun	4.29	3.56	-0.73
Orange	Jul	4.19	5.73	1.54
Orange	Aug	3.82	6.01	2.19
Orange	Sep	4.43	0.74	-3.69
Orange	Oct	4.44	1.07	-3.37
Orange	Nov	3.08	1.70	-1.38
Orange	Dec	3.56	3.78	0.22

August rainfall varied significantly between monitoring stations. Both Barre and Belchertown recorded slightly below-average precipitation (-0.09 and -0.58 inches respectively), while Orange received substantially above-average rainfall (+2.19 inches, totaling 6.01 inches, Table 9). This disparity was likely attributable to a concentrated rainfall event between August 2 and August 9 that delivered 4.17 inches to the Orange weather station. This localized variation in rainfall patterns, while specific to these stations, reflected broader precipitation trends across Massachusetts, as evidenced by shifting drought designations across the state. While the first week of August saw 20.86% of the state experiencing abnormally dry to moderate drought status, by the second week, drought-affected areas had shrunk dramatically to just 3% of the state. September saw a severe rainfall deficit when compared to historical cumulative means, with Barre recording a mere 0.65 inches of rainfall (-3.36 inches), Belchertown recording 0.62 inches (-3.60 inches), and Orange recording only 0.74 inches (-3.69 inches). This coincided with a pronounced intensification of drought conditions in late September, when 72% of Massachusetts experienced abnormally dry conditions and 4% moderate drought.

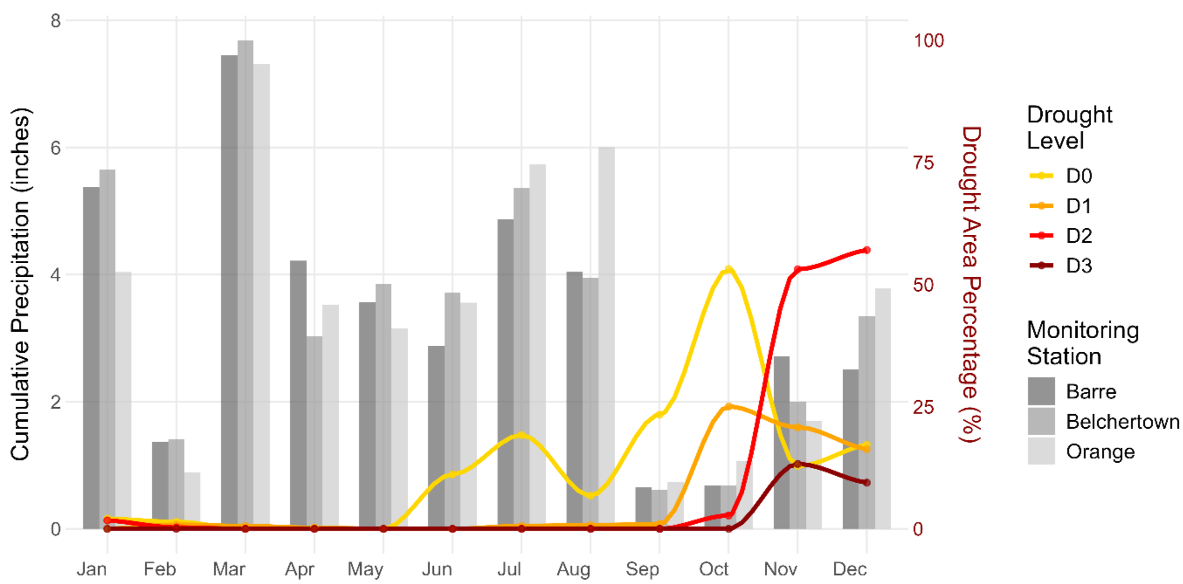


Figure 9. *Monthly cumulative precipitation at Quabbin Reservoir and Ware River watershed weather stations and mean monthly drought conditions for 2024. For historical mean monthly precipitation, see Table 9. Each line represents a different level of drought severity (D0 = Abnormally Dry; D1 = Moderate Drought; D2 = Severe Drought; D4 = Extreme Drought). Reported drought conditions are monthly means for the state of Massachusetts as a whole.*

Precipitation deficits continued into November with Barre recording a cumulative 2.71 inches of rainfall (historical mean = 3.62 inches), Belchertown recording two inches (historical mean = 3.82 inches), and Orange recording 1.70 inches (historical mean = 3.08 inches). These relatively low precipitation values culminated with 100% of the state experienced drought conditions, including

26.57% in extreme (D3) drought, by the end of the month. An important caveat to these data is that all weather stations did see an overall increase in precipitation from October through the end of the year, with Orange recording 3.34 inches of December rainfall, which exceeded the historical mean by 0.55 inches, though all other stations remained below average for that month (Barre = 2.51 inches; Belchertown = 3.34 inches). Even with this gradual increase, year-end data showed Massachusetts with 25.47% moderate drought, 25.05% extreme drought, and 49.48% severe (D2) drought conditions. These conditions are likely a holdover from the consistently below-average rainfall observed earlier in the year, as well as the more extreme drought conditions observed in September.

Drought designation data for Massachusetts has been collected since 2000 by the U.S. Drought Monitor (U.S. Drought Monitor, 2024). Based on these data, 2024 ranked as the sixth worst drought in the 24-year period of record, with 2016 being the worst drought year on record. The average area experiencing moderate or worse drought in 2024 was 17.5%, compared to the historical average of 11.4%. At its peak, 90.8% of Massachusetts experienced moderate or worse drought conditions in 2024, above the historical average maximum of 46.4%. Massachusetts experienced 32 weeks with some moderate or worse drought in 2024, compared to a historical average of 12.4 weeks per year.

3.1.2 Streamflow

Streamflow was recorded at six USGS gages throughout the Quabbin Reservoir and Ware River watersheds. Three gages recorded streamflow rates (cubic feet per second; hereafter cfs) in two major tributaries and one outflow of the Quabbin Reservoir watershed (East Branch Swift River, Hardwick [01174500]; Swift River, West Ware [1175500]; West Branch Swift River, Shutesbury [1174565]) and three recorded streamflow in the Ware River Watershed (Ware River, Barre [1172500]; Ware River, Intake Works, Barre [1173000]; Ware River, Gibbs Crossing [1173500]; Table 3). Typically, these systems are influenced by seasonal meteorological trends, with higher flows in the spring due to snowmelt and lower flows in the summer due to variable precipitation and higher rates of evapotranspiration. However, studies have increasingly observed that the Northeast is experiencing a trend of above-average winter temperatures, attributed to global climate changes (Siddique et al., 2020; Young and Young, 2021). This phenomenon has resulted in a marked shift in winter precipitation, with a greater proportion falling as rain rather than snow (Wuebbles et al., 2017). Consequently, these climatic alterations have had clear impacts on the hydrology of rivers and streams in the region (Figure 10). For this report, the term 'average mean daily streamflow' refers the mean amount of water flowing through the stream on a daily basis, averaged over the entire month for a given location.

Annual precipitation in 2024 fell below historic averages across NOAA weather stations in the Quabbin Reservoir and Ware River watersheds, with an average of 17.5% of the state experiencing drought for the full year. Despite this overall shortage, with six months seeing below-average precipitation throughout the region, January, March, and July recorded above-average rainfall. These rainfall extremes, both above and below average, were reflected in the hydrology of both watersheds. January precipitation exceeded historical means by an average of 1.92 inches, with all USGS gages recording streamflow at least 25 cfs above historical average

Table 10. *Monthly mean stream discharge (calculated from daily mean discharge records; cubic feet per second [cfs]) for 2024 compared to the period of record at USGS gages in the Quabbin Reservoir and Ware River watersheds. Years with incomplete records (e.g., missing greater than 5% of measurements) were excluded from analysis.*

Quabbin Reservoir Watershed

West Branch Swift (01174565)

Month	POR	2024
Jan	32.29	70.06
Feb	28.09	25.59
Mar	42.93	89.18
Apr	45.73	51.39
May	25.55	18.85
Jun	18.96	8.01
Jul	13.81	4.82
Aug	9.73	14.33
Sep	10.96	1.74
Oct	17.72	2.39
Nov	21.69	4.41
Dec	31.75	28.64

East Branch Swift (01174500)

Month	POR	2024
Jan	105.99	234.84
Feb	100.19	138.25
Mar	141.46	297.87
Apr	155.69	210.47
May	95.74	120.90
Jun	60.90	64.27
Jul	48.75	133.48
Aug	37.91	59.09
Sep	37.28	8.95
Oct	59.71	4.50
Nov	76.29	13.39
Dec	107.17	58.67

Swift River, West Ware (1175500)

Month	POR	2024
Jan	120.78	147.99
Feb	115.28	308.04
Mar	125.40	688.74
Apr	207.09	806.87
May	198.89	352.52
Jun	120.75	164.41
Jul	81.98	43.11
Aug	77.80	46.84
Sep	85.73	103.61
Oct	71.35	131.39
Nov	70.36	121.41
Dec	100.29	44.98

Ware River Watershed

Ware River, Intake Works (01173000)

Month	POR	2024
Jan	206.75	470.19
Feb	203.66	223.25
Mar	303.85	508.00
Apr	365.62	473.43
May	206.22	167.33
Jun	127.26	79.92
Jul	87.31	106.19
Aug	68.62	55.00
Sep	68.55	14.61
Oct	114.18	13.39
Nov	160.22	26.09
Dec	217.63	77.77

Ware River, Barre (1172500)

Month	POR	2024
Jan	116.04	192.82
Feb	114.96	110.37
Mar	169.02	228.72
Apr	213.74	249.11
May	118.67	86.06
Jun	70.42	41.56
Jul	46.76	29.69
Aug	36.58	25.31
Sep	36.75	4.86
Oct	65.60	5.33
Nov	93.75	14.18
Dec	121.60	47.80

Ware River, Gibbs Crossing (1173500)

Month	POR	2024
Jan	440.95	969.35
Feb	414.59	447.29
Mar	599.71	1009.48
Apr	669.10	818.37
May	401.41	304.55
Jun	261.99	136.61
Jul	191.72	174.13
Aug	154.25	90.09
Sep	159.04	30.48
Oct	235.04	29.64
Nov	312.15	49.67
Dec	445.41	148.36

mean daily streamflow (Table 10). The Ware River's Gibbs Crossing gage, the furthest downstream monitoring location on the Ware River, registered January 2024's highest average mean daily flow at 969.35 cfs — 528.40 cfs above the historical mean. The West Branch Swift River recorded the lowest January average mean daily flows at 70.06 cfs, though this still exceeded its historical mean of 32.29 cfs. Precipitation fell below historical means in February, and though flows decreased at many monitoring locations, only two gages – the Ware River, Barre, and the West Branch Swift River – fell below historical average mean daily streamflow (-4.59 cfs and -2.50 cfs respectively).

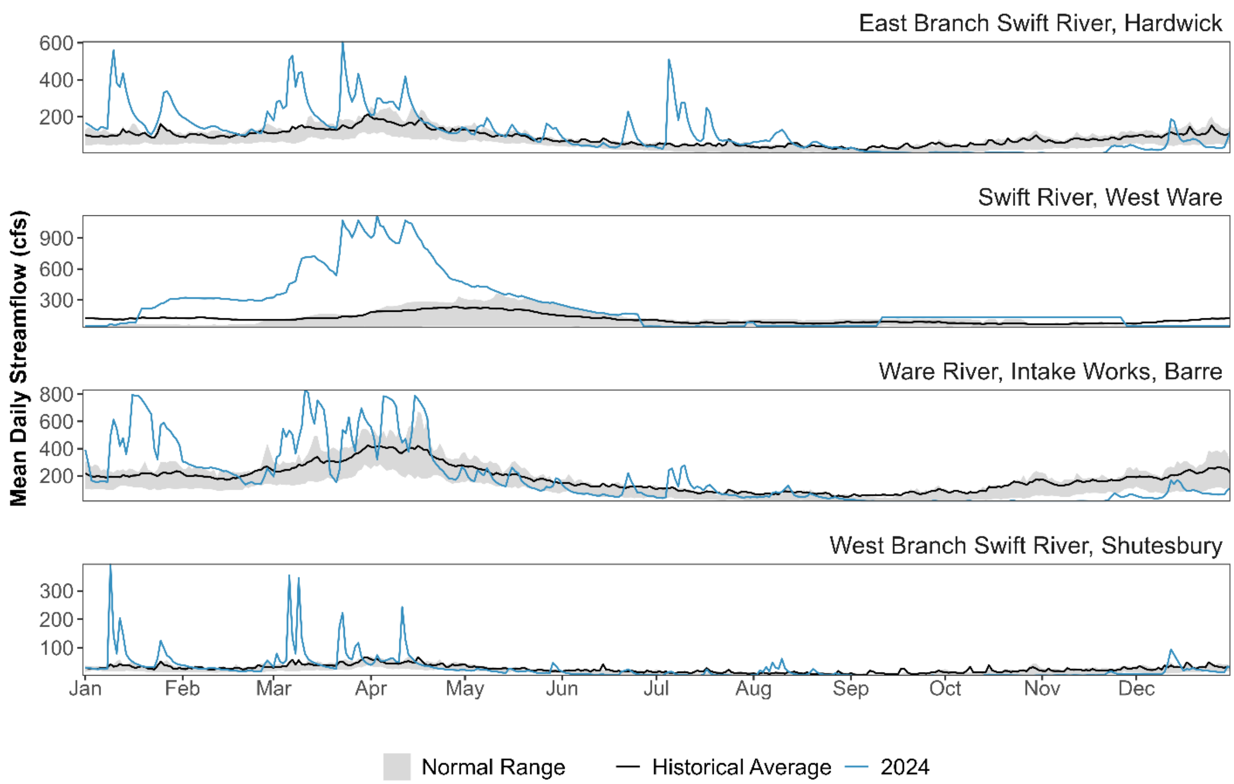


Figure 10. *Hydrograph of mean daily streamflow (cfs) at four USGS stream gages in the Quabbin Reservoir and Ware River watersheds. The mean values of all mean daily flows for the period of record are represented by the solid black line. Daily mean flows for 2024 are represented by the blue line. The gray band denotes the normal (25th to 75th percentile) flow range for the period of record.*

Precipitation increased in March, with all three NOAA monitoring stations exceeding historical monthly means by an average of 4.15 inches, resulting in one of the highest average mean daily flow rates for 2024. The Gibbs Crossing gage recorded 1009.48 cfs, surpassing the historical mean of 599.71 cfs. The Swift River, West Ware gage also exceeded historical means by more than 560 cfs. The lowest average mean daily flows for the month were recorded at the West Branch Swift River at 89.19 cfs (historical mean = 355 cfs), with this low-flow pattern continuing through much of the year. Drier than average conditions developed in April, with the highest average flows recorded at the Ware River, Gibbs Crossing gage (818.37 cfs; historical mean = 669.10 cfs) and the lowest average flows recorded at the West Branch Swift (51.39 cfs; historical mean = 45.73 cfs). Despite the emerging dry spell, many stream gages initially maintained flows above historical means, however, as drought conditions persisted, streamflow gradually declined below historical averages at most locations. Only two gages consistently remained above historical means during the March to June period: the East Branch Swift, which averaged 42.01 cfs above historical means from April to June, and the Swift River at West Ware, which maintained elevated flows throughout the year. The most significant low-flow conditions were recorded at the West Branch Swift in June 2024, where measurements dropped to just 8.01 cfs—less than half the historical average mean daily flow of 18.69 cfs.

Precipitation levels rebounded in July as cumulative monthly rainfall exceeded historical means by an average of 1.14 inches. The resulting runoff was reflected in flows at all gages except for the Ware River, Barre, and the West Branch Swift River where streamflow continued to drop. Both the East Branch Swift River and Ware River, Intake Works gages saw flows exceeding historical means, recording +84.73 cfs (historical mean = 48.75) and +18.88 cfs (historical mean = 87.31) respectively.

After the July rainfall events, both the Barre and Belchertown weather stations saw a decline in precipitation, with cumulative totals falling slightly below the historical mean. Orange, however, saw rainfall exceed historical means by more than two inches, likely due to a weeklong rainfall event from August 2nd to 9th. Since this station is located north of the Quabbin Reservoir, what was likely a localized precipitation event with a narrow band of influence was not strongly reflected in flow rates for the Ware River watershed. The East Branch Swift and West Branch Swift, however, recorded average mean daily streamflow for the month of August at 59.09 cfs (historical mean = 37.91) and 14.33 cfs (historical mean = 9.73) respectively. These rainfall patterns exhibited an immediate response in flow rates for the West Branch Swift where flows increased from 3.97 cfs on August 2nd to 20.5 cfs on August 3rd (Figure 10). The hydrograph peaked on the 10th at 61.2 cfs and then steadily fell, reaching 3.95 cfs on August 17th before increasing again slightly. The East Branch Swift appeared to have a more delayed, albeit stronger, response, either to this rainfall event or to another localized storm, with the hydrograph beginning to climb from around 60 cfs up to 111 cfs on August 8th. This pulse peaked at 129 cfs on August 10th, then began to steadily fall, reaching 31.7 cfs on August 17th.

September marked a significant worsening of drought conditions as all weather stations recorded substantial precipitation deficits. Orange, Belchertown, and Barre all measured cumulative monthly rainfall totals more than three inches below historical September means. The Swift River at West Ware was the only USGS gage that recorded average mean daily streamflow above historical means, resulting from managed releases from the upstream Quabbin Reservoir. All other stations fell below historical means, with the West Branch Swift River experiencing extreme drying - flows measured just 1.74 cfs, the lowest recorded average mean daily value of 2024, compared to its historic mean of 10.96 cfs. The Ware River at Gibbs Crossing, typically known for sustained high-volume flows, recorded only 30.48 cfs in September 2024. This represents a significant drop of 128.56 cfs below historical means and falls below the 25th percentile for average mean daily flows during the month of September at this monitoring location. All other monitoring locations measured flows marginally above the 25th percentile for their location, exceeding it by no more than 3.75 cfs at any one site.

Though discharge from the Quabbin Reservoir maintained high flows in the Swift River, West Ware gage, flows continued to remain below historical averages at all other monitoring locations through October as statewide drought increased in severity. Paradoxically, though November recorded some of the worst drought conditions of the year, nearly all the gages recorded an increase in average mean daily flows relative to the previous month. These values continued to rise into December, with many locations seeing a nearly 200% increase or more in flows between the two months. This is likely due in part to a gradual increase in precipitation from October to December as precipitation deficits began to resolve themselves. Though Barre and Belchertown precipitation fell below historical means, all three monitoring stations saw more than 2.50 inches of rainfall in the month of December, with Orange receiving a cumulative 3.78 inches of rainfall, 0.22 inches greater than its historical mean.

It's worthwhile to note that minimum mean daily flows, or the lowest daily mean value for that month at that location, largely remained above historical minimum mean daily flows for all months at all streamflow gages, apart from November flows for the Ware River, Barre and the Ware River, Intake Works gages which were equivalent to historical means. So, while overall monthly means were frequently lower than historical averages, the monitored rivers in the Quabbin Reservoir and Ware River watershed did not fall below historical monthly lows at any point in 2024. In fact, flows frequently exceeded historical medians, especially during the first half of the year.

A wide range of maximum and minimum daily streamflow rates were observed across all sites during 2024 for both the Quabbin Reservoir and Ware River watersheds. The top 25 lowest mean daily flows—and overall lowest flows for 2024—were observed at the West Branch Swift, ranging from 1.09 cfs on October 6^{th} to 1.59 cfs on September 4^{th} (Figure 10). The 25 highest flows for 2024 were recorded at the Ware River, Gibbs Crossing, ranging in magnitude from 1160 cfs to 1800 cfs, and the highest mean annual flows were recorded at the Ware River, Gibbs Crossing (350.88 cfs), Swift River, West Ware (246.69 cfs), and the Ware River, Intake Works (184.68 cfs). The highest all-time mean annual flows for each location are as follows: 158.71 cfs at the Ware River, Barre (2011); 279.33 cfs at the Ware River, Intake Works (2011); 615.46 cfs at the Ware River, Gibbs Crossing (1996); 157.13 cfs at the East Branch Swift (2023); 43.89 cfs at the West Branch Swift (2018); and 319.55 cfs at the Swift River, West Ware (1997).

Cumulative annual discharge was calculated from USGS daily mean discharge records at each of the gage locations and reported in millions of gallons (MG; Figure 11). Three key sites were analyzed—the East Branch Swift River, Hardwick (01174500), the West Branch Swift River, Shutesbury (01174565), and the Ware River, Intake Works, Barre (01173000). Both the East and West Branch Swift Rivers are the primary tributaries contributing discharge to the Quabbin

Reservoir, while the Ware River Intake Works gage marks the point where water can be diverted from the Ware River to the Quabbin Reservoir. The West Branch Swift recorded a cumulative annual discharge of 6,161 MG for 2024, falling within the upper 50% of cumulative totals for the 28-year POR and above the historical mean of 5,926 MG, with extremes ranging from 2,871 MG (2002) to 10,354 MG (2018). Historical data shows that the East Branch Swift consistently contributes higher volumes of flow downstream to the Quabbin Reservoir than its western counterpart, and this was reflected in a cumulative annual discharge of 27,319 MG in 2024. This was lower than the previous year's 38,588 MG but well above both the historical mean of 20,265 MG and the 75th percentile (25,179 MG). Historical extremes span 8,138 MG (2002) to 38,588 MG (2023). The Ware River, Intake Works gage recorded a cumulative 44,522 MG in 2024. This slightly exceeded the historical mean of 42,001 MG and fell between the recorded extremes of 21,196 MG (2016) and 65,987 MG (1996).

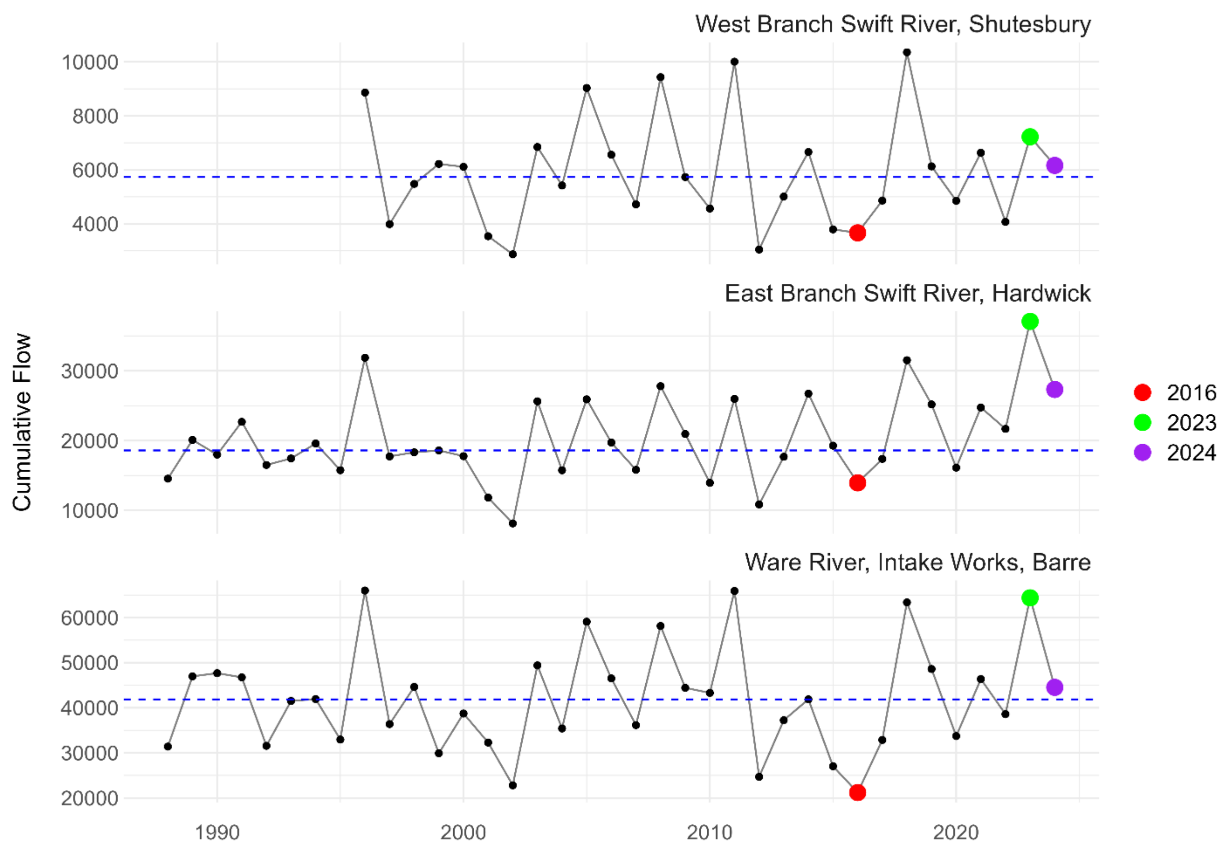


Figure 11. *Cumulative annual discharge in millions of gallons (MG) for the West Branch Swift, East Branch Swift and Ware River, Intake Works, gages. The highlighted years represent the current reporting year (purple; 2024), a year of high precipitation (green; 2023), and a drought year (red; 2016). The blue dashed line represents median annual discharge.*

3.1.3 Reservoir Water Level Elevation

The water surface elevation of the Quabbin Reservoir remained within the historical normal range (25th to 75th percentile) during the middle of the year (May to October), but dropped below the normal range during the winter months (Figure 12). Elevations ranged from a minimum of 522.12 ft Boston City Base (BCB) on November 20 to a maximum of 530.52 ft BCB on April 4. BCB is defined as the water elevation of the Quabbin Reservoir in relation to a datum point located in Boston, Massachusetts.

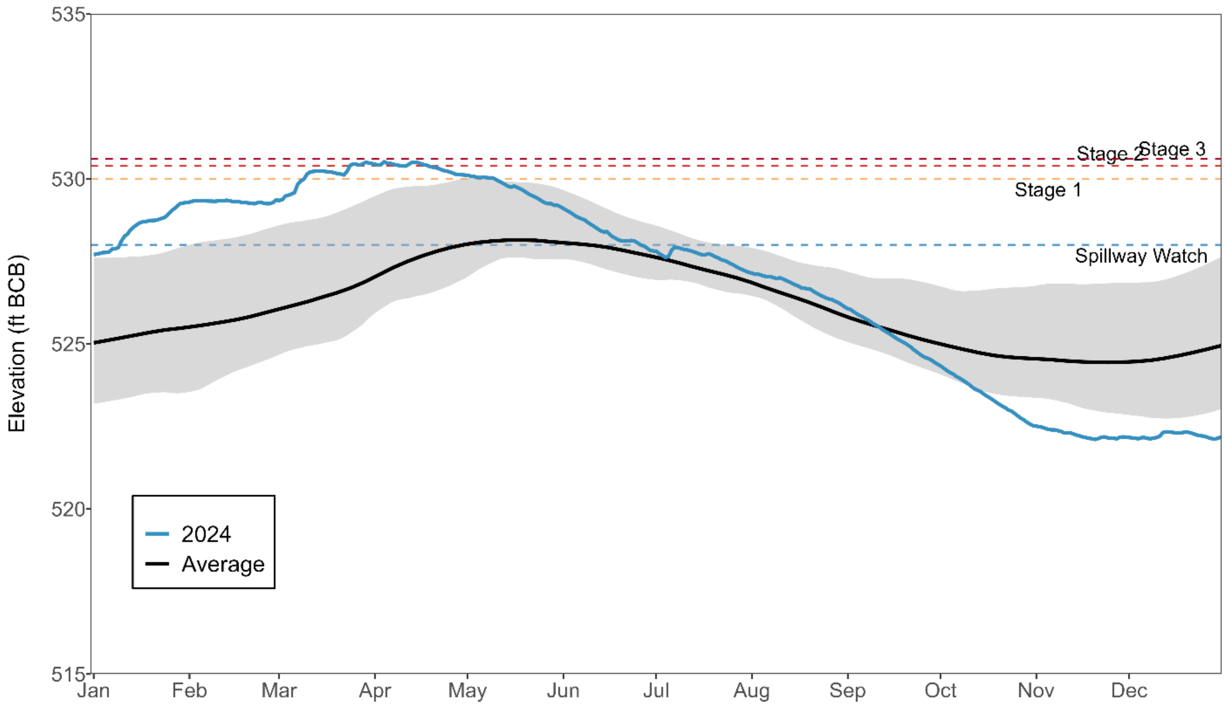


Figure 12. *Daily elevation of the Quabbin Reservoir from January 1 through December 31, 2024, relative to spillway watch triggers (Stage 1 = Flood Watch; Stage 2 = Flood Warning; Stage 3 = Flood Alert) established by DWSP Civil Engineering Section (DWSP, 2019d). The gray band represents the normal daily elevation range (defined as the 25th to 75th percentiles) and the black line is the mean daily elevation for the period of record (1980 through 2023).*

Precipitation in 2023 was above normal at all three monitoring stations at the Quabbin Reservoir and Ware River watersheds, especially during the fall and winter months. As a result, reservoir elevation was above the normal operating range on January 1, 2024, measuring 527.70 ft (75th percentile = 527.56 ft). Above-average cumulative precipitation in January 2024 resulted in a spike in reservoir elevation, with elevation rising from 527.70 ft to 529.28 by January 31. Even though rainfall conditions in February were below average, reservoir elevations remained around 529 ft through March, when higher than average rainfall resulted in an increase in elevation up to 530.50 ft on March 29. Reservoir elevation continued to climb through April, reaching the maximum elevation for the year on April 4, before beginning a steady decline through the summer months, corresponding with water supply transfers to Wachusett Reservoir. Summertime elevation fell within normal limits for the Quabbin Reservoir; however, a dry latter half of the year, where rainfall deficits were consistently below historical means, led to a drop below the historic range (e.g., 25th percentile) in mid-October. Reservoir elevation continued to decline, reaching its minimum for the year in November, before rising slightly corresponding to winter rainfall and rain-on-snow runoff. Elevation remained around 522 ft from November 20 through the end of the year (minimum = 522.12; maximum = 522.34), with 2025 beginning below the 25th percentile based on the reporting period of record (elevation = 522.18 ft; 25th percentile = 523 ft). At no point in the year did the reservoir exceed Stage 3 (530.60 ft); however, elevation did exceed Stage 2 (530.45 ft) on multiple dates from March 25 through April 4. Reservoir elevation exceeded Stage 1 (530 ft) from March 10 through May 9, 2024.

3.2 Tributary Monitoring

3.2.1 Water Temperature and Dissolved Oxygen

3.2.1.1 Water Temperature

Water temperature in Quabbin Reservoir watershed tributaries ranged from 0.4 to 27.0˚C in 2024, compared to the historical range of -0.5 to 25.8 ˚C (Figure 13, Table 11). The maximum temperature recorded at these sites in 2024 (27.0˚C at site 215G on July 16, 2024) was a new record maximum temperature for these sites. Four sites with long term records established new summer maximums in 2024 (212, 213, 215G, 216) as well as less frequently monitored EQA sites 211A-1 and 211B-X, all on July 16, 2024. Seasonal averages (median and mean) were elevated in 2024 relative to historical seasonal averages at most sites during most seasons. The 2024 monitoring results above historical seasonal averages were most pronounced in spring and summer. Prolonged fall drought effects also led to elevated fall stream temperatures in 2024, most pronounced at Hop Brook site 212 (fall median temp +1.8˚C compared to fall historical median) and East Branch Swift site 216 (+1.7˚C compared to fall historical median). These results follow seasonal patterns of above-normal air temperatures recorded at nearby weather stations during these seasons in 2024 (see Section 3.1.1). Boat Cove Brook (site BC) went dry for nearly all fall months in response to seasonal drought and thus was not sampled during this time.

MassDEP designates cold water fish habitats as rivers and streams in which mean and maximum daily temperatures over a seven-day period generally do not exceed 20˚C (314 CMR 4.06). Warm water fish habitats generally exceed 20˚C but may not surpass 28.3˚C. Water temperature data generated by DWSP represent a discrete collection time, thus these data cannot be compared directly to cold water fish habitat criteria. Rather, comparisons to these thresholds may indicate the potential for a location to become impaired. Core sites 211, 212, and 216 in the Quabbin Reservoir watershed represent rivers that have been identified as suitable habitat for cold water fish by MassDEP. Instantaneous water temperatures exceeded the 20˚C threshold on one date at sites 211 and 212 (20.7 ˚C and 23.1, respectively, on 7/16/2024), and six dates at site 216 throughout the summer in 2024 (20.5 to 25.5 ˚C). No sites in the Quabbin Reservoir watershed exceeded the temperature criteria for warm water fish habitat (28.3˚C) in 2024.

Water temperature in Ware River watershed Core tributaries ranged from -1.4 to 27.0˚C in 2024 (Table 12). In contrast to the Quabbin Reservoir watershed Core tributaries, no historical seasonal maximum records were exceeded in 2024, with the exception of a new spring maximum recorded at Parkers Brook (site 102), a lower order stream inflow to the Ware River just upstream of the Shaft 8 Intake (site 101). All sites recorded elevated seasonal average (mean and median) temperatures in spring and summer relative to historical seasonal averages, corresponding with the higher-than-average air temperatures recorded in the watershed (see Table 8). The exception to this was Pommogussett Brook (site 117), a new EQA site with no previous monitoring history. This site also experienced no-flow conditions during the fall season and thus was not sampled during this time. Mean water temperature at individual Core sites were 1.8 to 3.4˚C warmer during the spring of 2024 relative to the period of record and summer mean water temperatures were 0.8 to 2.7˚C warmer. These above-normal thermal conditions varied across sites and seasons, reflecting upstream catchment-specific characteristics (canopy cover, catchment scale, upstream inputs, groundwater contributions) that vary across these sampling locations and can affect stream temperature response to weather variability (Mosley et al., 2012; Sprague, 2005).

Core sites 102, 107A, and 108 in the Ware River watershed are rivers that have been identified as suitable habitat for cold water fish by MassDEP. Instantaneous water temperatures exceeded the 20˚C threshold in the summer on four dates at West Branch Ware (site 107A) and six dates in summer and late spring at East Branch Ware in 2024 (20.4-25.9˚C). No sites in the Ware River watershed exceeded the temperature criteria for warm water fish habitat (28.3˚C) in 2024 (Figure 13).

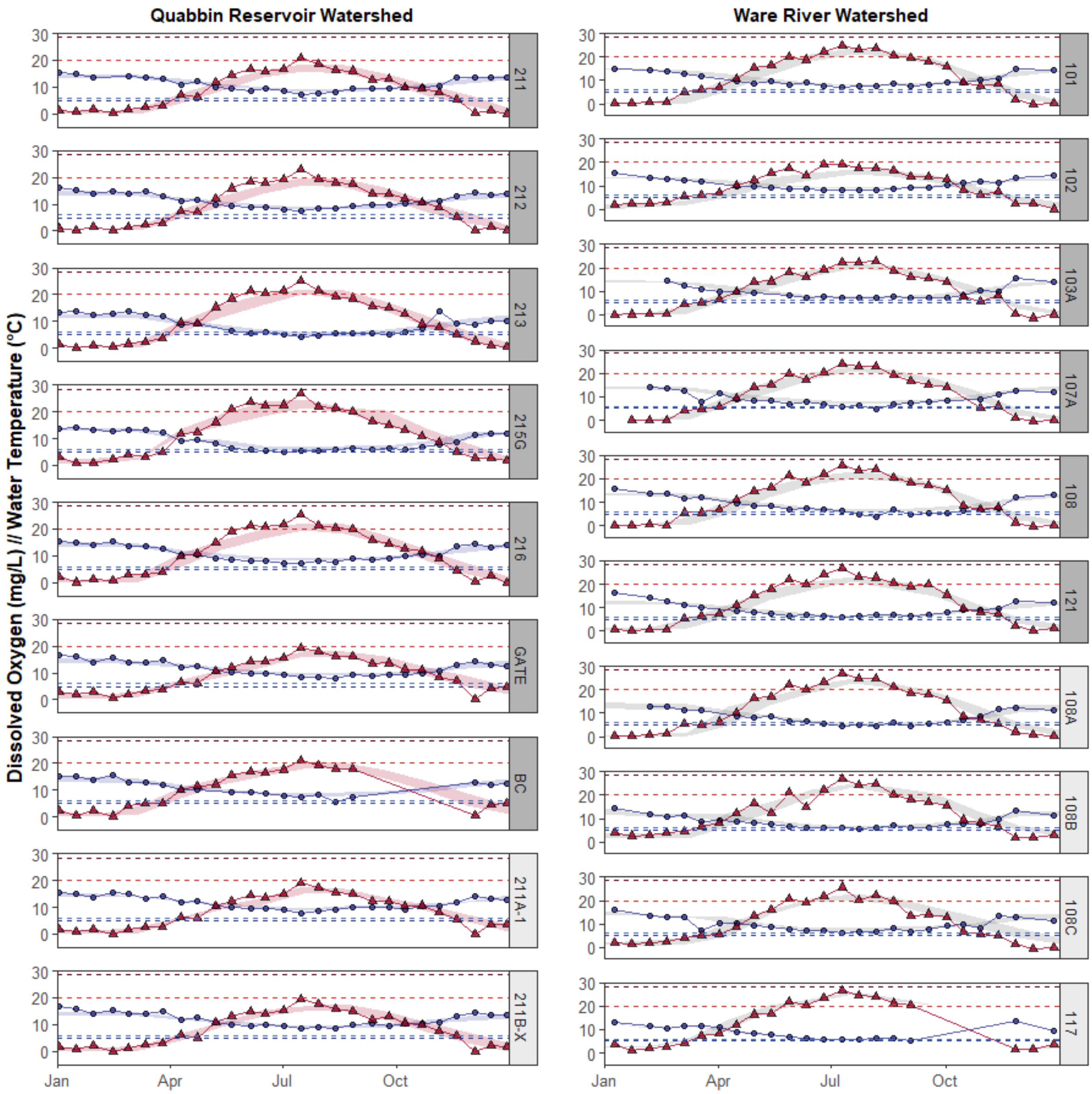


Figure 13. *Time series of water temperature (blue) and dissolved oxygen (red) measured in 2024 tributary sites. The shaded bands represent seasonal interquartile ranges (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations. The dashed horizontal lines correspond to the lower recommended dissolved oxygen concentration for CFR (6.0 mg/L; light blue) and WFR (5.0 mg/L; dark blue), and the upper temperature limits for CFR (20˚C; light red) and WFR (28.3˚C; dark red) waters.*

Table 11. *Seasonal statistics for water temperature measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

Water Temperature (°C)

Location	Season	*Count 2024*	*Count POR*	*Min 2024*	*Min POR*	*Median 2024*	*Median POR*	*Mean 2024*	*Mean POR*	*Max 2024*	*Max POR*
211	Winter	8	261	0.1	-0.4	1.0	0.4	0.9	0.8	1.6	5.6
211	Spring	6	260	2.6	-0.1	6.8	6.0	7.6	5.8	14.7	18.2
211	Summer	7	263	15.7	9.0	16.6	16.2	17.3	16.2	20.7	21.0
211	Fall	6	256	5.3	0.0	9.7	9.0	9.7	9.0	13.0	19.1
212	Winter	8	242	0.0	-0.4	0.7	0.1	0.8	0.7	1.7	6.0
212	Spring	6	248	2.3	-0.4	7.2	6.2	8.0	6.3	16.0	19.7
212	Summer	7	252	17.4	10.0	18.6	17.1	19.2	17.2	23.1	22.6
212	Fall	6	241	5.1	0.0	11.4	9.6	10.7	9.5	13.9	20.0
213	Winter	8	253	0.1	-0.2	1.1	0.2	1.1	0.6	2.6	9.0
213	Spring	6	257	2.3	-0.4	9.4	7.8	9.8	7.7	18.6	23.1
213	Summer	7	257	18.6	5.3	21.4	20.0	21.1	19.7	25.4	24.8
213	Fall	6	246	5.1	1.0	11.1	10.0	11.0	10.2	15.8	21.3
215G	Winter	8	27	0.7	0.0	2.5	1.6	2.3	1.9	4.1	6.0
215G	Spring	6	32	3.1	0.3	12.2	12.1	11.6	10.5	21.1	19.9
215G	Summer	7	32	20.3	14.2	22.3	21.1	22.8	21.1	27.0	25.8
215G	Fall	6	31	4.8	1.5	12.2	13.3	11.6	12.1	16.6	22.0
216	Winter	8	258	0.0	-0.5	0.9	0.1	1.3	0.8	3.1	6.5
216	Spring	6	259	3.0	-0.5	10.3	8.4	10.2	8.1	19.1	22.5
216	Summer	7	263	19.9	8.8	21.4	20.0	21.6	19.7	25.5	25.2
216	Fall	6	252	4.5	0.3	12.2	10.5	11.4	10.5	16.0	21.7
BC	Winter	8	188	0.3	-0.4	2.5	1.0	2.6	1.5	5.2	10.0
BC	Spring	6	196	5.0	0.0	10.9	8.3	10.0	8.1	15.6	20.1
BC	Summer	7	163	16.5	11.1	17.9	18.2	18.2	18.1	21.1	23.6
BC	Fall	-	169	-	0.1	-	10.6	-	10.7	-	20.9
GATE	Winter	8	187	0.0	-0.4	2.5	1.4	2.5	2.0	4.9	7.0
GATE	Spring	6	190	3.6	0.0	6.4	6.6	7.2	6.2	12.1	15.1
GATE	Summer	7	192	14.3	9.8	16.0	16.0	16.3	15.8	19.4	20.1
GATE	Fall	6	206	7.1	0.3	11.3	10.6	10.9	10.5	13.7	19.2
211A-1	Winter	8	21	-0.1	-0.2	1.9	1.2	1.8	1.5	3.8	5.8
211A-1	Spring	6	19	2.8	0.6	6.1	5.5	6.8	5.4	12.5	10.8
211A-1	Summer	7	21	13.8	9.6	15.1	15.1	15.8	14.6	19.2	18.1
211A-1	Fall	6	18	5.4	2.2	10.6	9.9	9.9	9.5	12.5	17.7
211B-X	Winter	8	119	0.0	-0.1	1.3	0.4	1.2	1.1	2.3	7.0
211B-X	Spring	6	116	2.8	0.0	5.8	5.7	6.9	5.5	13.1	13.2
211B-X	Summer	7	126	14.2	9.0	15.3	15.6	16.1	15.4	19.7	19.2
211B-X	Fall	6	119	5.6	1.0	10.3	9.0	9.8	9.2	13.2	18.1

Table 12. *Seasonal statistics for water temperature measured in Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

		Water Temperature (°C)									
Location	Season	*Count 2024*	*Count POR*	*Min 2024*	*Min POR*	*Median 2024*	*Median POR*	*Mean 2024*	*Mean POR*	*Max 2024*	*Max POR*
101	Winter	6	216	-0.5	-0.5	0.4	0.1	0.3	0.6	0.6	8.0
101	Spring	7	223	4.9	-0.5	10.9	9.0	11.6	8.6	20.0	21.3
101	Summer	6	227	18.8	11.5	22.8	21.0	22.3	21.0	24.9	27.0
101	Fall	7	228	2.0	0.8	9.3	10.9	11.6	11.0	19.4	23.9
102	Winter	6	121	0.1	0.0	2.3	1.2	2.0	1.5	2.9	8.0
102	Spring	7	124	5.7	1.0	10.5	7.2	10.6	7.2	17.5	17.3
102	Summer	6	126	14.5	10.0	17.7	15.0	17.4	15.1	19.2	20.6
102	Fall	7	125	2.6	1.0	8.0	8.0	9.3	8.6	13.9	19.0
103A	Winter	6	92	-1.4	-0.4	0.2	0.2	0.0	0.7	0.5	7.0
103A	Spring	7	110	4.5	-0.4	9.8	9.0	10.3	8.5	18.3	19.6
103A	Summer	6	121	16.2	11.5	20.8	19.7	20.3	19.5	22.7	27.0
103A	Fall	7	122	0.3	0.5	8.5	9.9	9.7	9.9	16.0	21.7
107A	Winter	5	101	-0.5	-0.5	0.1	0.1	0.0	0.6	0.1	7.0
107A	Spring	7	116	4.0	-0.1	9.2	8.9	10.4	8.6	19.8	22.1
107A	Summer	6	119	17.2	11.7	21.7	20.6	21.2	20.2	24.1	25.6
107A	Fall	6	122	0.9	0.4	10.2	10.1	9.7	10.2	16.9	23.0
108	Winter	6	212	-0.5	-0.5	0.1	0.0	0.1	0.6	0.4	7.3
108	Spring	7	221	5.6	-0.5	10.9	8.3	11.6	8.3	21.3	22.5
108	Summer	6	221	18.5	12.2	22.8	20.6	22.4	20.4	25.9	26.3
108	Fall	7	222	1.4	0.0	8.5	10.0	10.8	10.4	18.4	23.6
121	Winter	6	135	0.2	0.0	0.7	0.6	0.7	1.0	1.2	8.0
121	Spring	7	137	5.6	0.0	11.2	9.8	12.3	9.4	21.9	24.1
121	Summer	6	144	20.2	12.0	23.2	21.0	23.0	20.4	26.7	28.0
121	Fall	7	147	2.1	1.0	9.7	10.0	11.6	10.5	19.9	22.7
108A	Winter	6	38	0.1	-0.4	0.6	0.2	0.6	1.1	1.3	6.9
108A	Spring	7	41	5.2	-0.4	10.2	6.8	11.8	7.4	22.1	19.6
108A	Summer	6	39	19.9	13.7	24.0	22.1	23.5	21.6	26.8	26.2
108A	Fall	7	36	2.1	2.3	8.8	10.7	10.9	11.6	18.7	22.0
108B	Winter	6	38	1.7	0.1	3.0	2.8	3.0	3.0	3.9	6.7
108B	Spring	7	41	4.6	0.3	12.2	7.3	11.7	8.5	21.2	19.1
108B	Summer	6	38	15.1	14.6	23.4	22.7	22.3	22.1	26.8	26.7
108B	Fall	7	37	2.1	3.8	9.5	12.3	11.0	12.7	18.3	22.3
108C	Winter	6	38	-0.5	-0.5	1.8	1.9	1.3	2.3	2.4	7.0
108C	Spring	7	41	4.3	-0.5	9.0	5.9	10.7	7.5	20.8	16.7
108C	Summer	6	38	19.2	15.1	21.0	20.6	21.5	20.4	25.8	24.8
108C	Fall	7	35	1.4	3.7	6.7	11.2	8.5	11.2	14.3	21.2
117	Winter	6	-	1.3	-	2.4	-	2.5	-	3.7	-
117	Spring	7	-	4.3	-	11.9	-	12.4	-	21.9	-
117	Summer	6	-	20.4	-	23.9	-	23.5	-	26.8	-
117	Fall	2	-	1.8	-	11.2	-	11.2	-	20.5	-

3.2.1.2 Dissolved Oxygen

Dissolved oxygen (DO) concentrations in Quabbin Reservoir watershed tributaries ranged from 4.1 to 16.6 mg/L in 2024 (Table 13). Dissolved oxygen concentrations demonstrated a typical seasonality during 2024 and were relatively depleted during warmer months and elevated in winter and fall; DO was inversely related to water temperature (Figure 13). Despite elevated summer water temperatures across the watershed, summer average dissolved oxygen concentrations in 2024 were only slightly lower than historical seasonal averages. This lower-than-average dissolved oxygen was most pronounced at the wetland dominated East Branch of Fever Brook (215G, 2024 summer mean DO of 5.7 mg/L compared to 6.7 mg/L historical summer mean) and the first-order Boat Cover Brook (BC, 2024 summer mean of 7.7 mg/L compared to 8.5 historical summer mean). Record low spring and fall dissolved oxygen concentrations were observed at 215G in 2024, although this may reflect the considerably shorter period of record compared to the other Quabbin Core sites (Table 13, POR n = ~30 compared to 100+ for other Core sites).

Dissolved oxygen concentrations of Class A inland waters are a criterion used to determine the suitability of water resources for aquatic habitat. MassDEP designates cold water fish habitats as rivers and streams in which dissolved oxygen remains above 6 mg/L and warm water fish habitats as those with dissolved oxygen concentrations greater than 5 mg/L (314 CMR 4.06). Dissolved oxygen concentrations remained above 6 mg/L at locations in the Quabbin Reservoir watershed identified as cold-water fish habitats (e.g., 211, 212, 216) for the entirety of 2024.

Dissolved oxygen concentrations in Ware River watershed tributaries ranged from 3.6 to 16.2 mg/L in 2024 (Table 14), following typical seasonal elevated patterns in winter and fall as well as relatively depleted concentrations in the warmer months. Ware River tributary dissolved oxygen concentrations were largely within established seasonal ranges in 2024. Seasonal average dissolved oxygen concentrations in 2024 were slightly lower relative to historical averages at several sites, most pronounced during the spring. Among Core monitoring locations, spring mean DO values were 1.3 to 1.9 mg/L lower than historical spring means. These lower averages correspond to the relatively elevated stream temperatures recorded during this season throughout Ware River Watershed. Relevant to the class A inland water criteria of DEP fisheries habitat designations, dissolved oxygen concentrations fell below 6 mg/L at site 108 on five dates and at site 107A on two dates in summer and fall of 2024. Dissolved oxygen concentrations remained above 6 mg/L at site 102 for the entirety of 2024. Concentrations of dissolved oxygen fell below 5 mg/L three times in 2024: on August 6th at both 108 and 107A (3.6 and 4.5 mg/L, respectively) as well as on September 3rd at 108 (4.8 mg/L).

Several winter DO observations at Ware River Watershed were flagged and omitted from analysis in 2024 due to sensor issues related to the field probe. Further QA/QC was completed in 2024 on historical dissolved oxygen concentration results. Historical records were flagged and omitted from analysis following evaluation of calibration records, sensor performance issues, and outlier analysis. As a result, period of record statistics for this analysis are to be considered more accurate relative to previous reporting.

Table 13. *Seasonal statistics for dissolved oxygen measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

Dissolved Oxygen (mg/L)

Location	Season	*Count* 2024	*Count* POR	*Min* 2024	*Min* POR	*Median* 2024	*Median* POR	*Mean* 2024	*Mean* POR	*Max* 2024	*Max* POR
211	Winter	7	251	13.6	10.2	13.7	13.7	14.2	13.8	15.6	17.7
211	Spring	6	256	9.4	6.5	11.5	12.2	11.5	12.3	13.5	17.6
211	Summer	7	262	7.0	4.7	8.6	9.0	8.5	8.9	9.6	12.2
211	Fall	6	255	9.3	5.8	9.9	10.7	10.5	10.9	13.8	16.2
212	Winter	8	236	13.5	10.7	14.2	13.8	14.5	14.0	16.1	18.0
212	Spring	6	243	9.3	6.3	11.3	12.1	11.5	12.2	14.7	16.8
212	Summer	7	251	7.6	4.5	8.5	8.9	8.5	8.8	9.4	11.8
212	Fall	6	240	9.8	4.9	10.4	10.7	10.8	10.9	13.1	16.3
213	Winter	8	251	8.6	7.2	12.7	11.6	11.9	11.8	13.9	17.1
213	Spring	5	257	6.4	3.6	9.3	9.8	9.7	9.9	12.6	18.0
213	Summer	7	255	4.1	1.6	5.4	5.4	5.3	5.4	6.1	10.0
213	Fall	6	246	5.2	2.5	6.7	7.5	7.9	7.9	13.6	15.9
215G	Winter	8	27	11.3	11.3	13.0	12.9	12.8	13.0	14.2	14.9
215G	Spring	6	32	6.4	7.1	9.5	9.9	9.8	10.7	13.1	15.4
215G	Summer	7	31	4.9	4.6	5.6	6.7	5.7	6.7	6.6	9.3
215G	Fall	6	31	5.9	6.3	6.5	8.9	6.9	9.2	8.4	14.2
216	Winter	8	254	13.3	9.8	14.2	13.9	14.4	14.0	15.5	17.7
216	Spring	6	256	8.4	5.8	10.3	11.8	10.8	11.8	13.6	17.2
216	Summer	7	261	7.2	4.7	8.2	8.6	8.0	8.5	8.9	11.6
216	Fall	6	252	8.7	5.7	9.9	10.6	10.3	10.8	13.6	16.7
BC	Winter	8	183	12.0	10.9	13.3	13.4	13.7	13.7	15.6	17.2
BC	Spring	5	195	9.1	6.0	10.3	11.4	10.9	11.6	13.0	17.9
BC	Summer	7	162	5.6	4.6	7.9	8.5	7.7	8.5	9.1	11.5
BC	Fall	-	169	-	5.5	-	10.3	-	10.5	-	16.1
GATE	Winter	8	175	12.7	10.5	14.2	14.1	14.6	14.2	16.6	18.0
GATE	Spring	6	183	10.4	6.9	12.3	12.4	12.5	12.7	15.0	17.4
GATE	Summer	7	191	8.0	5.1	9.2	9.5	9.0	9.5	9.7	14.4
GATE	Fall	6	205	8.8	6.1	9.5	11.0	10.2	11.1	13.1	17.2
211A-1	Winter	8	21	13.0	12.4	14.7	14.2	14.5	14.1	15.7	15.3
211A-1	Spring	6	18	10.2	10.9	12.2	12.4	12.1	12.7	14.4	14.5
211A-1	Summer	7	19	7.9	8.7	9.2	9.7	9.1	10.0	9.9	11.9
211A-1	Fall	6	18	9.3	9.0	10.1	11.4	10.3	11.3	12.1	14.9
211B-X	Winter	8	119	13.5	9.5	14.4	13.6	14.7	13.6	16.6	16.6
211B-X	Spring	6	116	10.1	9.0	12.3	12.4	12.4	12.4	14.7	15.6
211B-X	Summer	7	125	8.4	8.0	9.2	9.3	9.2	9.4	10.0	11.9
211B-X	Fall	6	119	9.6	7.9	10.4	10.9	10.8	11.0	13.0	15.5

Table 14. *Seasonal statistics for dissolved oxygen measured in Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

Dissolved Oxygen (mg/L)

Location	Season	*Count 2024*	*Count POR*	*Min 2024*	*Min POR*	*Median 2024*	*Median POR*	*Mean 2024*	*Mean POR*	*Max 2024*	*Max POR*
101	Winter	4	37	13.9	11.9	14.2	14.6	14.4	14.5	15.2	16.1
101	Spring	6	38	8.0	7.4	9.8	11.3	10.2	11.5	12.9	16.3
101	Summer	6	36	7.1	5.1	7.6	8.3	7.9	8.2	9.2	10.9
101	Fall	7	39	7.4	7.3	9.3	10.9	10.0	11.0	14.7	14.4
102	Winter	4	120	13.0	9.1	13.9	13.1	14.1	13.2	15.8	16.6
102	Spring	6	124	8.5	6.2	9.7	11.5	10.2	11.6	12.3	15.9
102	Summer	6	126	8.1	7.7	8.3	9.3	8.4	9.3	9.0	11.0
102	Fall	7	125	9.0	7.6	11.1	11.1	11.0	11.0	13.7	15.4
103A	Winter	2	88	14.1	11.2	14.4	14.1	14.4	14.2	14.6	17.5
103A	Spring	6	106	8.1	6.6	10.0	10.9	10.2	11.2	12.6	17.3
103A	Summer	6	121	7.0	4.2	7.1	7.5	7.3	7.4	8.0	10.0
103A	Fall	7	120	7.1	4.1	8.4	10.1	9.4	10.3	15.5	17.0
107A	Winter	3	96	12.2	11.3	13.7	13.6	13.3	13.7	14.1	17.7
107A	Spring	7	115	6.7	6.7	8.6	10.7	9.2	11.1	12.4	17.7
107A	Summer	6	119	4.5	4.9	6.5	7.6	6.4	7.6	7.7	10.1
107A	Fall	6	121	7.5	6.5	8.7	10.1	9.4	10.5	12.4	17.4
108	Winter	4	207	13.1	4.9	13.6	13.0	14.0	13.1	15.9	17.7
108	Spring	6	219	6.7	4.6	9.0	10.6	9.4	10.7	12.1	17.2
108	Summer	6	221	3.6	3.5	6.4	6.5	6.0	6.5	7.3	9.3
108	Fall	7	221	4.8	4.1	6.2	8.7	6.9	9.0	12.0	15.5
121	Winter	4	135	12.1	9.4	13.4	12.3	13.7	12.2	16.2	15.2
121	Spring	6	137	6.2	6.5	8.1	9.7	8.6	9.9	11.2	13.6
121	Summer	6	144	5.9	4.1	6.7	6.5	6.5	6.6	6.8	10.1
121	Fall	7	147	6.5	6.1	9.0	8.8	8.9	8.9	12.7	14.3
108A	Winter	3	38	11.3	9.8	12.8	12.6	12.4	12.9	13.1	17.0
108A	Spring	6	41	6.6	7.3	8.6	11.1	9.0	11.1	11.3	17.5
108A	Summer	6	39	4.3	4.0	5.3	5.4	5.4	5.7	6.7	9.6
108A	Fall	7	36	4.7	5.9	7.1	8.2	8.0	8.8	12.5	14.8
108B	Winter	4	38	10.9	10.9	11.5	11.9	12.1	12.6	14.5	17.1
108B	Spring	7	41	6.8	7.9	8.5	10.4	8.6	10.7	11.3	16.1
108B	Summer	6	38	5.6	2.8	6.0	6.8	6.1	6.5	7.1	9.0
108B	Fall	7	37	6.0	5.9	7.8	8.7	8.3	9.3	13.2	15.0
108C	Winter	4	35	11.6	11.8	13.3	13.8	13.5	13.9	16.0	17.3
108C	Spring	7	40	7.3	8.1	9.5	12.2	9.6	12.0	12.8	16.3
108C	Summer	6	38	6.5	3.4	7.0	8.1	7.1	7.8	8.0	9.3
108C	Fall	7	35	6.8	7.1	9.3	10.1	9.8	10.4	13.4	15.2
117	Winter	4	-	9.5	-	10.9	-	11.1	-	13.1	-
117	Spring	7	-	6.9	-	9.0	-	9.5	-	11.6	-
117	Summer	6	-	5.5	-	6.0	-	6.0	-	6.4	-
117	Fall	2	-	5.2	-	9.4	-	9.4	-	13.5	-

3.2.2 Specific Conductance, Sodium, and Chloride

3.2.2.1 Specific Conductance

Specific conductance ranged from 20.0 to 143.0 µS/cm across Quabbin Reservoir watershed monitoring tributaries and from 56.9 to 401.3 across monitoring tributaries in the Ware River watershed during 2024 (Table 15, Table 16). Patterns of specific conductance generally followed patterns of streamflow and reflected spatial variability of rainfall within and between the watershed systems. Generally, specific conductance values were within seasonal normal or below normal ranges in the first half of 2024 (Figure 14), corresponding to high flow conditions across both watersheds (see Figure 10). The prolonged drought of fall 2024 led to slightly elevated to elevated specific conductance reading across nearly all watershed tributaries due to lack of dilution, with the duration of elevated readings varying based on spatial variability in summer and winter rainfall patterns (see Figure 7).

Across Quabbin Reservoir Watershed Core monitoring locations, fall 2024 mean results were elevated by 5.9-44.8 µS/cm in 2024 compared to the period of record, with the exception of 215G (2024 fall mean 1.5 µS/cm below historical fall mean) and BC which was not sampled in the fall due to a lack of streamflow. Relative to historical records and normal ranges, summer average specific conductance values varied across Quabbin tributary monitoring sites. For example, the summer mean specific conductance from the East Branch Swift monitoring location (216) in 2024 was 9 µS/cm lower than the summer historical mean and consistently below the seasonal normal range, while Hop Brook (212) recorded a 2024 summer mean specific conductance 24.4 µS/cm higher than historical average. Differences in timing and magnitude of specific conductance concentrations within Quabbin Reservoir watershed can be attributed in part to variations in summer streamflow between west and east Quabbin sites (Figure 10) as well as variations in hydrogeologic context between parts of the watershed. Despite the largely elevated fall average results and select elevated average results from certain sites in certain seasons, the range of results observed in 2024 (min-max) were largely within established seasonal ranges, with the exception of slightly higher winter maximum values recorded at 215G (122.0 µS/cm) and BC (134.4 µS/cm) in 2024.

For 2024, Ware River tributary mean fall specific conductance values ranged from 0-125.9 µS/cm higher than higher than fall historical means, apart from Pommogussett Brook (site 117) which went dry and was not sampled in the fall. While the small Parker's Brook stream (site 102) and Ware River at the Burnshirt River confluence (103A) had mean fall specific conductance within 2 µS/cm of historical fall means, the mainstem Ware River at Shaft 8 intake (site 101) was 22.8 µS/cm above the historical fall mean. Notably, site 101 and several other major Ware River tributaries (sites 108 and 121), as well as all EQA sites with previous monitoring record (sites 108A, 108B, and 108C), recorded seasonal mean values above historical seasonal means for all seasons (Table 16). While seasonal average results were elevated at numerous sites during numerous seasons, the range of results observed in 2024 in Ware River Watershed were largely within established seasonal ranges, apart from slightly higher winter maximum values recorded at 101 (150.3 µS/cm) and several new seasonal maximums recorded at less frequently monitored EQA sites.

Elevated specific conductance in surface waters in the northeast USA is attributed to legacy contributions from deicing salts via groundwater discharge to baseflow (Kelly et al., 2008). Site 121 continues to be a hot spot of specific conductance in the Ware River watershed, representing the drainage area of a large portion of Rutland, which contains areas of high road density in residential developments. Contributions of road-salt laden runoff originating in the upstream reaches of the Mill Brook (e.g., potentially sourced from several high-density residential housing developments, and runoff from Route 122 and 56 in Rutland, MA) may drive the dynamics observed in downstream reaches. The site has elevated specific conductance values relative to the other monitoring locations, requiring a separate axis on the time-series figure to show the annual range of values at this location (Figure 14). The Mill Brook (site 121) upstream drainage basin will be the focus of DWSP evaluations of land use and water quality patterns in 2025 as part of the Environmental Quality Assessment (EQA) reporting cycle, with an EQA report anticipated in 2026.

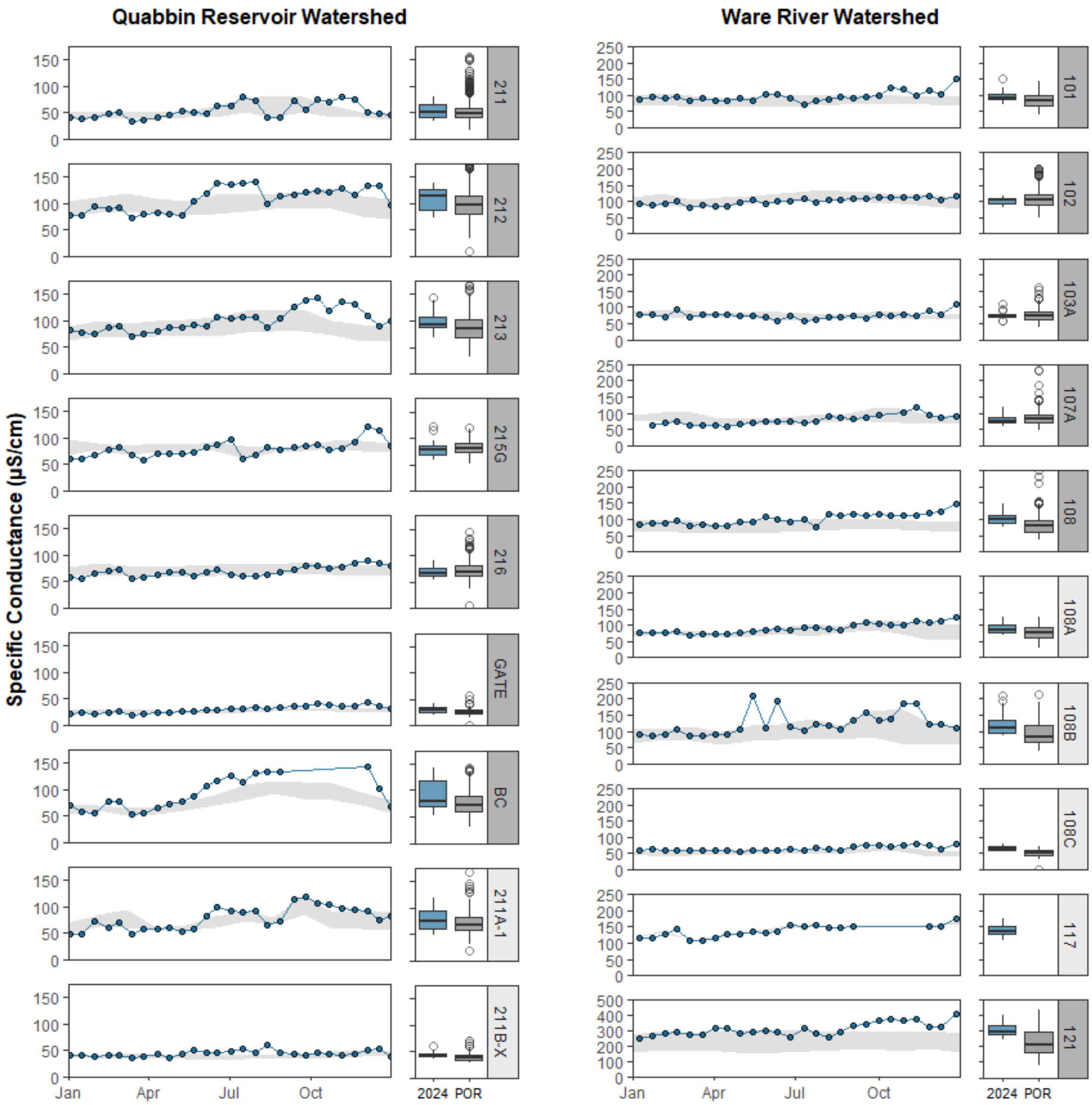


Figure 14. *Time series and boxplots of specific conductance results (blue) from tributary monitoring sites during 2024 compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 15. *Seasonal statistics for specific conductance measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

Specific Conductance (µS/cm)

Location	Season	2024	POR	2024	POR	2024	POR	2024	POR	2024	POR
211	Winter	8	261	37.6	17.7	47.6	43.3	45.7	45.7	51.6	194.0
211	Spring	6	260	33.7	28.0	43.6	45.0	43.2	47.3	52.6	130.0
211	Summer	7	263	40.2	25.0	62.1	57.0	57.9	61.5	78.9	156.7
211	Fall	6	256	55.0	26.7	73.9	50.0	71.4	55.9	79.2	151.7
212	Winter	8	242	76.6	10.5	93.2	92.0	99.4	95.6	134.0	212.0
212	Spring	6	248	73.4	35.0	80.4	94.0	83.4	96.0	103.9	190.0
212	Summer	7	252	98.7	52.0	136.8	101.4	126.4	102.0	140.0	170.0
212	Fall	6	241	117.0	48.0	121.3	99.7	121.8	103.8	128.5	180.0
213	Winter	8	253	75.9	42.0	88.4	79.2	89.0	78.8	109.1	135.9
213	Spring	6	257	69.0	33.0	84.5	83.0	82.4	83.3	91.9	141.2
213	Summer	7	257	86.6	42.0	105.2	97.0	100.7	96.7	107.4	168.9
213	Fall	6	246	118.7	40.0	133.3	85.2	132.4	87.5	142.9	165.7
215G	Winter	8	27	59.3	54.8	79.7	80.7	83.6	83.9	122.0	119.7
215G	Spring	6	32	57.8	64.9	69.7	82.2	67.8	82.8	72.0	115.2
215G	Summer	7	32	61.0	52.1	82.0	78.4	79.4	78.8	96.2	116.3
215G	Fall	6	31	77.4	63.0	82.9	84.9	83.5	85.0	92.1	113.9
216	Winter	8	258	55.7	5.6	71.1	70.0	71.9	73.2	90.8	190.0
216	Spring	6	259	54.5	40.0	60.9	68.7	61.3	69.1	67.3	115.2
216	Summer	7	263	60.3	38.0	64.0	72.8	64.7	73.7	71.4	144.0
216	Fall	6	252	72.6	43.0	78.5	70.0	77.9	73.0	83.6	132.7
BC	Winter	8	188	54.9	37.0	73.2	64.6	81.4	66.6	143.4	137.0
BC	Spring	6	196	51.8	30.0	68.7	60.0	68.4	61.6	87.3	100.9
BC	Summer	7	163	105.7	40.0	125.2	90.0	122.8	90.5	133.5	141.5
BC	Fall	-	169	-	29.9	-	90.0	-	90.4	-	141.1
GATE	Winter	8	187	21.5	17.0	25.2	25.5	28.3	25.9	42.8	48.5
GATE	Spring	6	190	20.0	18.1	24.1	23.0	23.2	24.1	25.6	30.0
GATE	Summer	7	192	28.1	1.7	31.1	25.9	31.4	25.6	34.1	58.0
GATE	Fall	6	206	35.5	15.0	37.1	28.0	37.5	27.8	40.1	42.0
211A-1	Winter	8	21	48.0	19.0	70.3	64.5	68.3	67.8	92.2	168.2
211A-1	Spring	6	18	48.5	47.1	57.2	62.7	55.6	70.7	60.1	129.5
211A-1	Summer	7	21	65.7	45.0	89.3	72.0	84.6	79.1	98.1	139.3
211A-1	Fall	6	18	93.7	49.0	104.9	67.0	105.4	78.5	118.2	145.9
211B-X	Winter	8	119	38.0	28.4	40.7	40.0	42.9	40.3	52.4	70.0
211B-X	Spring	6	116	35.6	28.0	40.8	38.0	41.6	39.4	51.3	60.0
211B-X	Summer	7	126	44.5	28.0	46.4	37.0	48.5	37.6	59.0	60.0
211B-X	Fall	6	119	41.6	30.0	42.8	38.0	43.1	41.0	44.9	70.0

Table 16. *Seasonal statistics for specific conductance measured in Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

Specific Conductance (µS/cm)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	210	86.2	43.0	94.3	87.0	103.4	85.7	150.3	142.3
101	Spring	7	218	85.2	43.0	85.6	80.0	89.4	80.4	103.0	125.8
101	Summer	6	220	71.6	42.0	89.7	88.0	89.2	85.7	103.6	137.0
101	Fall	7	220	92.6	40.0	100.8	82.7	106.9	84.1	122.7	140.0
102	Winter	6	121	87.7	58.0	96.6	98.4	98.6	104.0	116.5	270.0
102	Spring	7	124	82.5	50.0	87.4	97.0	90.6	102.9	104.5	200.0
102	Summer	6	126	97.7	55.0	103.2	111.6	103.1	120.2	106.8	200.0
102	Fall	7	125	109.8	55.0	111.8	103.1	112.2	111.1	116.4	200.0
103A	Winter	6	92	70.3	54.0	78.4	78.3	84.5	78.5	109.2	109.4
103A	Spring	7	110	68.9	50.0	74.9	75.3	74.5	76.7	79.4	125.5
103A	Summer	6	120	56.9	38.0	66.6	70.3	65.2	74.9	72.5	162.7
103A	Fall	7	118	66.0	52.0	73.5	71.0	75.2	75.2	88.2	140.8
107A	Winter	5	101	61.6	57.0	76.5	86.4	78.2	87.0	92.7	132.5
107A	Spring	7	116	60.6	47.0	65.0	78.5	66.3	79.6	76.0	128.6
107A	Summer	6	119	71.7	46.0	75.9	83.0	79.4	83.4	91.1	141.7
107A	Fall	6	122	83.9	50.0	94.3	80.6	96.7	90.9	118.0	233.1
108	Winter	6	212	85.4	40.0	90.5	80.0	103.7	81.8	146.4	209.0
108	Spring	7	221	79.2	43.0	83.9	71.7	88.0	77.5	108.4	250.0
108	Summer	6	221	77.7	42.0	99.5	80.0	99.9	83.3	117.1	150.7
108	Fall	7	222	111.6	38.0	112.6	80.0	114.5	84.9	120.0	156.7
121	Winter	6	135	246.6	108.0	284.5	220.0	300.0	226.8	401.3	422.9
121	Spring	7	136	270.9	92.0	290.5	193.5	291.1	219.0	314.1	430.8
121	Summer	6	144	253.4	78.0	284.2	210.9	279.2	222.7	310.2	432.7
121	Fall	7	147	318.6	90.0	360.1	226.2	349.6	223.7	367.9	400.0
108A	Winter	6	38	76.0	30.0	78.9	77.2	91.4	73.5	125.6	107.1
108A	Spring	7	41	69.6	45.0	74.9	72.0	76.3	72.7	85.9	99.4
108A	Summer	6	39	84.4	48.0	88.1	85.0	88.4	83.4	91.9	117.9
108A	Fall	7	36	99.2	49.0	105.0	98.5	105.3	89.4	113.5	126.7
108B	Winter	6	38	86.9	52.6	98.8	92.2	101.1	87.8	120.9	133.4
108B	Spring	7	41	84.7	45.0	89.6	70.0	110.4	85.7	207.3	184.8
108B	Summer	6	38	100.5	53.8	114.7	82.5	125.0	100.1	194.0	171.5
108B	Fall	7	37	122.7	37.0	139.3	97.0	151.3	107.4	186.1	212.3
108C	Winter	6	38	59.6	35.0	62.6	50.8	64.7	49.7	78.0	67.0
108C	Spring	7	41	56.9	31.0	59.1	50.0	59.0	59.8	60.8	286.8
108C	Summer	6	38	59.1	35.0	62.1	53.8	62.4	67.2	67.4	332.2
108C	Fall	7	35	71.7	0.0	74.7	57.0	74.8	53.2	78.4	71.7
117	Winter	6	-	115.1	-	136.9	-	139.2	-	175.9	-
117	Spring	7	-	106.5	-	126.8	-	122.5	-	137.5	-
117	Summer	6	-	137.6	-	149.8	-	149.5	-	157.4	-
117	Fall	2	-	150.0	-	151.1	-	151.1	-	152.2	-

3.2.2.2 Sodium and Chloride

Routine monitoring for sodium (Na) and chloride (Cl) began in DWSP Core monitoring sites on Quabbin Reservoir watershed in September 2018 and Ware River watershed in January 2019. Concentrations of Na and Cl observed in monitoring tributaries in the Ware River watershed ranged from 4.86 to 48.1 mg/L and from 4.36 to 97.4 mg/L, respectively, in 2024. Consistent with previous years, concentrations of these solutes in tributaries in the Quabbin Reservoir watershed continue to be notably lower (1.48 to 16.9 mg/L for Na and 0.64 to 27.1 mg/L for Cl) relative to Ware. Timeseries patterns for these major ions are also consistent with patterns observed from specific conductance observation (Figure 15, Figure 16). Lower-than-normal concentrations observed in the winter and spring due to a sustained dilution from long-duration high streamflow conditions in both watersheds, while elevated concentrations were observed at several sites coincident to prolonged and widespread fall drought conditions (Figure 10).

The secondary MCL for Cl in drinking water (250 mg/L) established by the US EPA was not exceeded in any tributary samples collected in 2024 from the Quabbin Reservoir or Ware River watersheds. The MassDEP Office of Research and Standards (ORS) guidelines for Na in drinking water (threshold of 20 mg/L Na) was exceeded at four sites in the Ware River Watershed during 2024. Once at EQA site Pommogussett Brook (site 117), once at West Branch Ware (site 107A), four times at EQA site Cushing Pond outlet (site 108B), and for the entirety of samples collected at Mill Brook (121) in the Ware River watershed (26 samples greater than 20 mg/L Na).

The spatial heterogeneity in concentrations of Na and Cl observed in 2024 was consistent with prior monitoring. This reflects differences in land cover and watershed characteristics, such as impervious surface cover, that contribute to variable inputs of Na and Cl to individual tributaries across the two watersheds. Average annual concentrations of Na, Cl, and specific conductance are consistently greater in Core tributaries within the Ware River watershed relative to Core monitoring sites in the Quabbin Reservoir watershed. This may be reflective of the high ratio of protected, forested lands relative to developed lands in the Quabbin Reservoir watershed, with comparatively more developed areas in Ware River watershed (see Table 4). Previously documented analyses of Na, Cl, and specific conductance found approximately a 1:1 molar ratios of Na to Cl and linear relationship between Cl concentrations and specific conductance in surface waters (DWSP 2023a). This suggests that increasing concentrations of Cl, likely from road salt contributions, may be driving increasing trends in annual median specific conductance for the certain Core monitoring tributaries (see also Soper et al., 2021; DWSP 2024b).

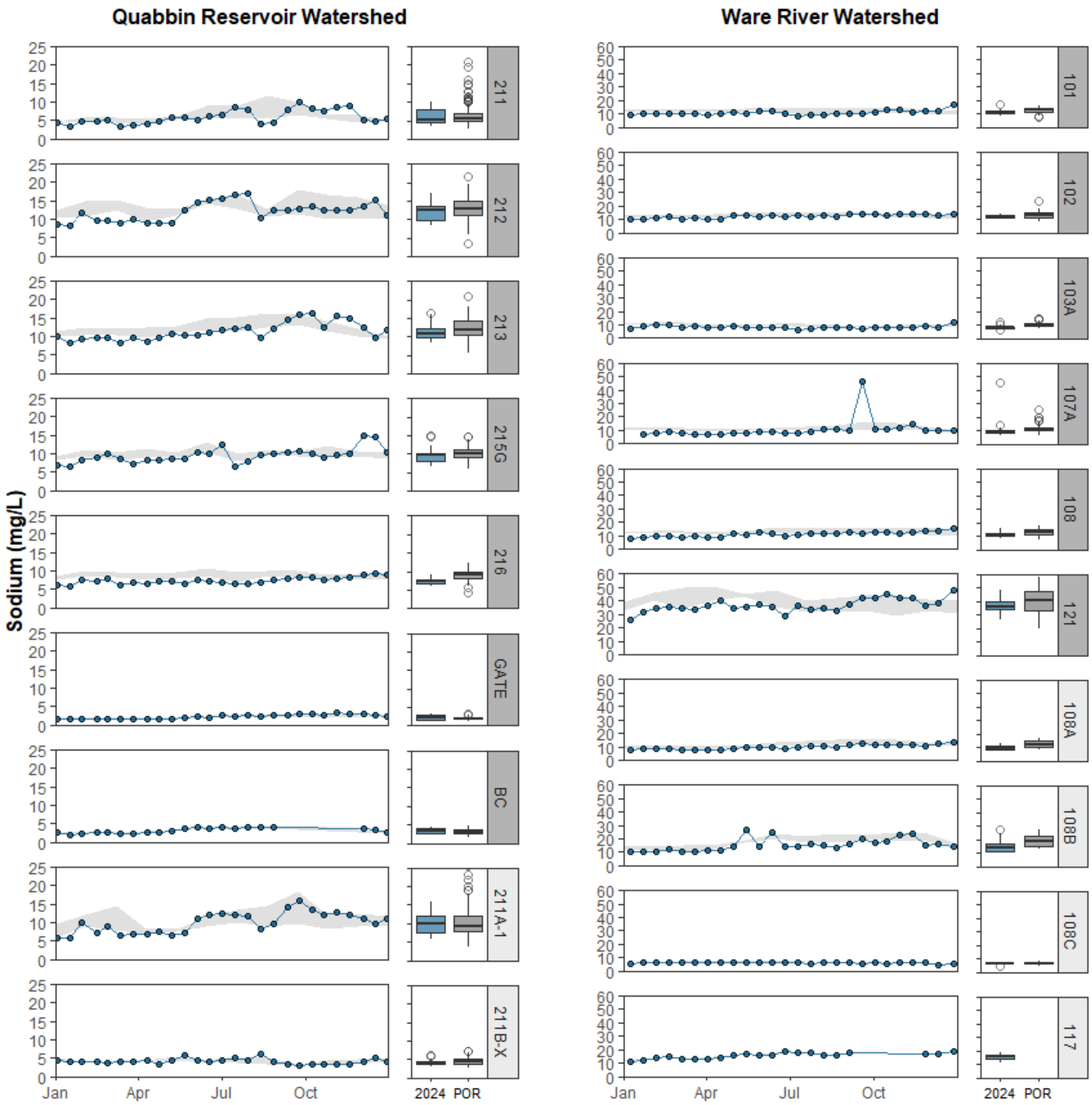


Figure 15. *Time series and boxplots of sodium results (blue) from tributary monitoring sites during 2024 compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

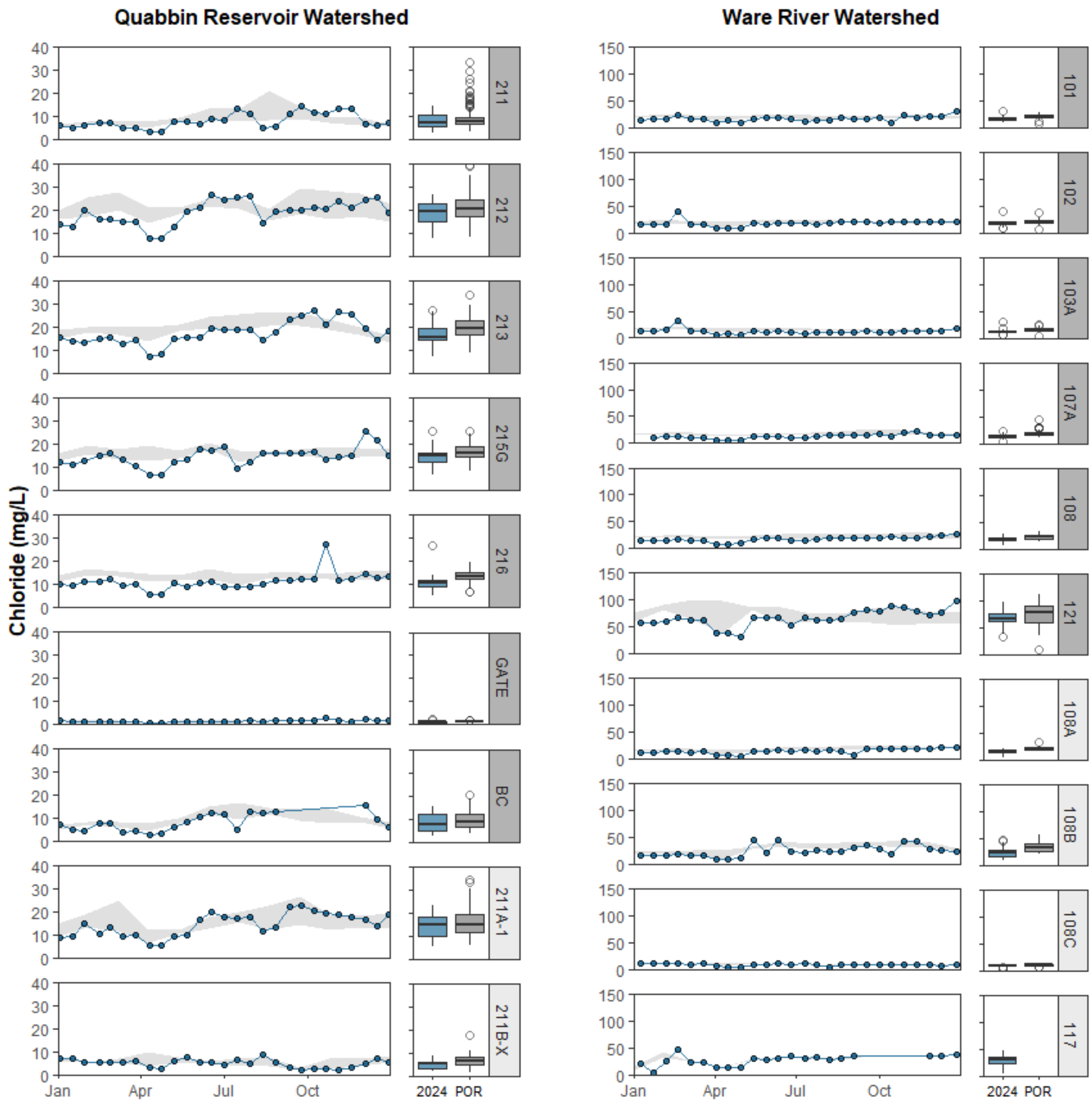


Figure 16. *Time series and boxplots of chloride results (blue) from tributary monitoring sites during 2024 compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

3.2.3 Turbidity

Turbidity ranged from 0.12 to 18 NTU in Quabbin Reservoir tributaries and from 0.13 to 4.6 NTU in Ware River Watershed Core tributaries during 2024 (Table 17, Table 18). Turbidity results in the Quabbin Reservoir and Ware River watershed reflected spatial and temporal variability of rainfall and subsequent runoff, following the year's seasonal patterns of high stream flows followed by drought conditions (Figure 17). Two prominent rainfall events during 2024 are reflected in turbidity records from Quabbin Reservoir Watershed monitoring sites. A localized May 8th high intensity rainfall (0.68" recorded at Belchertown weather station) resulted in elevated samples at several West and Central Quabbin Watershed sampling sites (e.g., 211, 212, 211A-1, 211B-X). Similarly, a winter rain-on-snow event on December 30th (0.72" rainfall recorded at Orange weather station) resulted in elevated turbidity across numerous Quabbin Reservoir Watershed monitoring locations. This event resulted in new winter maximum turbidity results being set at three Core monitoring locations (212, 215G, GATE). Although these elevated results are noticeable outliers, results from these two events were within historical ranges for most sites, indicating that this type of discrete sediment loading event represents the upper range of sediment concentrations at these locations. These rainfall-driven events represent discrete instances of sediment transport within catchments, as turbidity levels returned to pre-event concentrations in subsequent samples.

Overall 2024 seasonal average turbidity values (both median and mean) were above historical seasonal averages across a majority of tributary sites monitored in both the Quabbin Reservoir and Ware River watersheds (Table 17, Table 18). The average (mean) difference of seasonal medians compared to the period of record varied from +0.24 NTU (winter) to +0.48 NTU (fall) across Core monitoring locations. Elevated winter and spring turbidity levels reflect seasonal elevated streamflow (Table 10), as thawing, snowmelt, and rainfall processes in winter and spring deliver terrestrial sediment to stream channels and subsequent high flows erode streambanks and disturb stream bed, further mobilizing sediment. Summer thunderstorms characteristic of New England can lead to elevated turbidity due to rainfall intensity and the subsequent erosion of soils. The low streamflow periods observed in fall 2024 can lead to increased turbidity due to the accumulation of leaf litter and organic debris within stream channels, as well as the decomposition of these materials. Further variability in turbidity across sites may be attributed to differences in land use, the geomorphic context of the sampling location's upstream catchment, localized meteorological effects, and sub-catchment hydrology.

Although average turbidity values were elevated in 2024, limited new record seasonal maximum values were observed in long-term Core monitoring location (with the exception of three winter maximums in Quabbin Reservoir Watershed tributaries, cited above). Further, 2024 seasonal median values remained below 1 NTU at most Quabbin sites (below 2 NTU at 212, BC, and 215G). Overall turbidity level remained consistent with previous monitoring records within these watersheds.

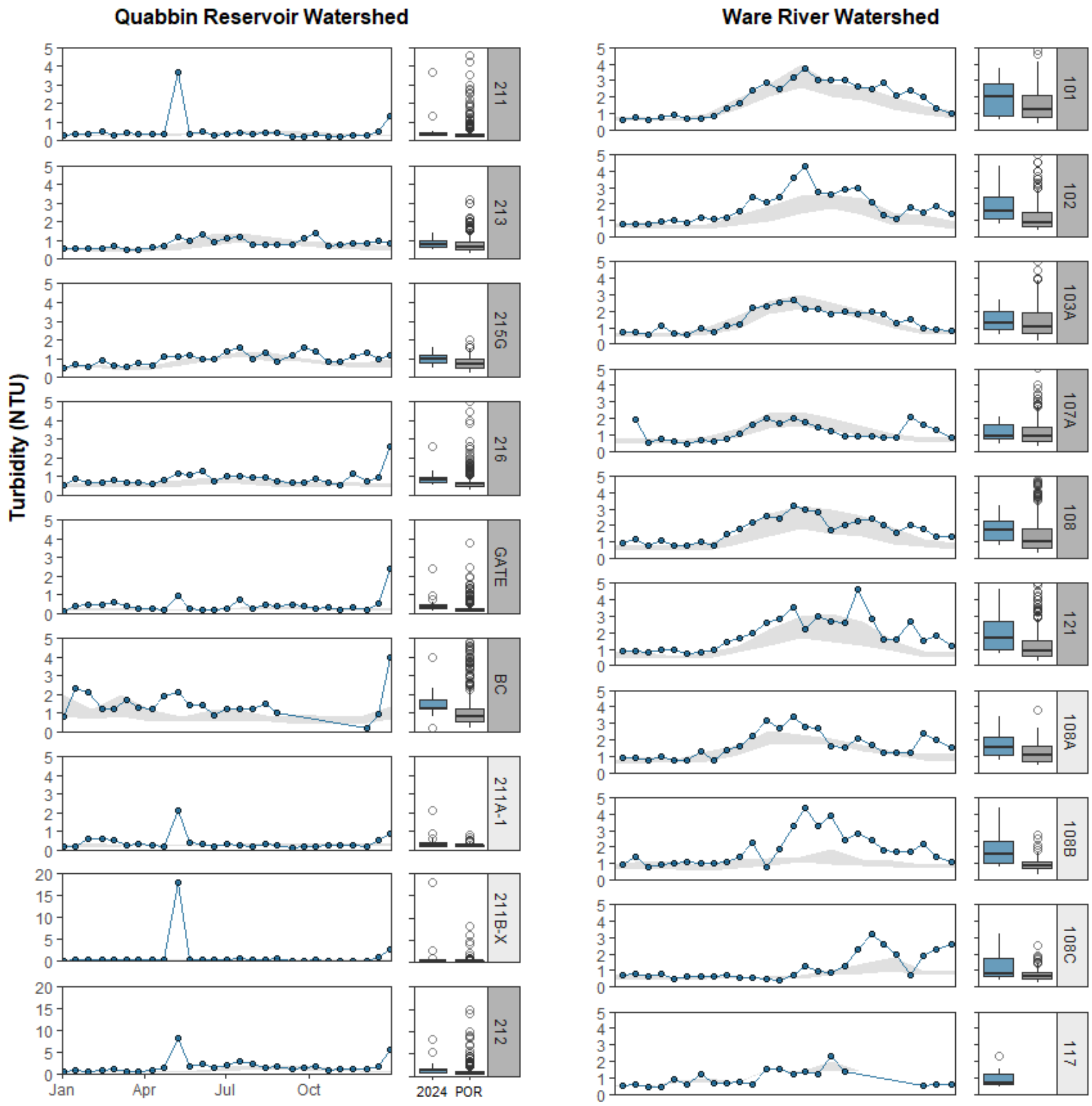


Figure 17. *Time series and boxplots of turbidity results (blue) from tributary monitoring sites during 2024 compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 17. Seasonal statistics for turbidity measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).

Turbidity (NTU)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	260	0.27	0.16	0.38	0.28	0.49	0.31	1.30	2.70
211	Spring	6	255	0.34	0.15	0.38	0.30	0.93	0.37	3.70	8.00
211	Summer	7	261	0.33	0.20	0.42	0.36	0.41	0.49	0.50	4.58
211	Fall	6	256	0.25	0.18	0.26	0.30	0.28	0.39	0.36	2.76
212	Winter	8	239	0.54	0.20	0.93	0.45	1.52	0.53	5.50	3.00
212	Spring	6	243	0.65	0.20	1.22	0.45	2.29	0.63	8.30	10.00
212	Summer	7	250	1.40	0.30	2.00	1.20	2.01	1.51	2.90	15.00
212	Fall	6	242	0.78	0.30	1.20	0.80	1.21	1.08	1.60	8.46
213	Winter	8	252	0.57	0.29	0.65	0.49	0.71	0.53	1.00	2.14
213	Spring	6	250	0.48	0.30	0.67	0.50	0.76	0.60	1.20	3.00
213	Summer	7	257	0.76	0.40	0.91	1.00	0.98	1.07	1.30	3.17
213	Fall	6	245	0.72	0.30	0.80	0.73	0.93	0.79	1.40	2.00
215G	Winter	8	28	0.47	0.21	0.81	0.55	0.84	0.57	1.30	1.00
215G	Spring	6	32	0.56	0.28	0.94	0.51	0.89	0.59	1.20	1.50
215G	Summer	7	34	0.80	0.56	1.00	1.10	1.15	1.11	1.60	2.00
215G	Fall	6	31	0.84	0.40	1.15	0.76	1.17	0.74	1.60	1.60
216	Winter	8	256	0.52	0.30	0.79	0.50	0.98	0.57	2.60	2.88
216	Spring	6	253	0.64	0.30	0.75	0.52	0.85	0.64	1.20	5.00
216	Summer	7	260	0.74	0.30	0.99	0.70	0.97	0.77	1.30	2.24
216	Fall	6	254	0.55	0.29	0.71	0.60	0.79	0.66	1.20	5.86
BC	Winter	8	181	0.18	0.30	1.20	0.99	1.60	1.29	4.00	6.85
BC	Spring	6	189	1.20	0.30	1.55	0.80	1.60	1.16	2.10	6.00
BC	Summer	7	155	0.91	0.23	1.20	0.72	1.20	1.14	1.50	23.00
BC	Fall	-	146	-	0.16	-	0.53	-	0.98	-	6.59
GATE	Winter	8	181	0.13	0.08	0.46	0.20	0.65	0.24	2.40	2.00
GATE	Spring	6	186	0.21	0.09	0.30	0.20	0.41	0.28	0.95	8.00
GATE	Summer	7	192	0.22	0.10	0.29	0.21	0.37	0.35	0.78	11.00
GATE	Fall	6	186	0.20	0.08	0.31	0.20	0.33	0.30	0.48	3.80
211A-1	Winter	8	21	0.15	0.09	0.53	0.19	0.45	0.23	0.87	0.81
211A-1	Spring	6	19	0.20	0.11	0.30	0.22	0.59	0.23	2.10	0.47
211A-1	Summer	7	21	0.19	0.14	0.24	0.25	0.27	0.55	0.35	6.60
211A-1	Fall	6	18	0.12	0.14	0.20	0.26	0.20	0.30	0.27	0.65
211B-X	Winter	8	118	0.19	0.14	0.34	0.30	0.66	0.31	2.60	2.20
211B-X	Spring	6	116	0.25	0.16	0.32	0.30	3.27	0.40	18.00	8.00
211B-X	Summer	7	126	0.26	0.10	0.33	0.30	0.40	0.39	0.57	6.00
211B-X	Fall	6	119	0.13	0.12	0.16	0.20	0.17	0.26	0.28	0.90

Table 18. Seasonal statistics for turbidity measured in Ware River Watershed tributary sites.

Turbidity (NTU)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	77	0.59	0.47	0.76	0.74	0.84	0.78	1.30	1.60
101	Spring	7	74	0.65	0.40	0.90	0.88	1.19	1.08	2.40	2.71
101	Summer	6	75	2.50	1.20	3.00	2.50	3.05	2.62	3.70	5.20
101	Fall	7	79	2.00	0.68	2.50	1.50	2.50	1.60	3.00	3.20
102	Winter	6	121	0.79	0.40	0.89	0.70	1.11	0.78	1.90	2.50
102	Spring	7	124	0.86	0.40	1.20	0.61	1.34	0.79	2.40	5.00
102	Summer	6	124	2.10	0.60	2.65	1.70	2.95	1.88	4.30	4.50
102	Fall	7	126	1.10	0.50	1.80	1.20	1.96	1.46	3.00	17.00
103A	Winter	6	97	0.56	0.33	0.80	0.61	0.82	0.69	1.10	2.70
103A	Spring	7	114	0.61	0.19	1.00	0.74	1.07	0.94	2.20	3.83
103A	Summer	6	119	1.80	0.83	2.20	2.34	2.25	2.45	2.70	6.63
103A	Fall	7	126	0.98	0.33	1.80	1.09	1.63	1.29	2.00	5.63
107A	Winter	5	101	0.54	0.35	0.86	0.61	1.08	0.70	1.90	2.54
107A	Spring	7	115	0.47	0.32	0.67	0.74	0.84	0.92	1.60	8.93
107A	Summer	6	116	1.20	0.82	1.75	1.70	1.70	1.88	2.00	5.05
107A	Fall	7	126	0.80	0.42	0.89	0.89	1.15	1.00	2.10	2.89
108	Winter	6	211	0.80	0.30	1.15	0.67	1.11	0.75	1.30	3.10
108	Spring	7	219	0.75	0.30	0.98	0.70	1.26	0.93	2.20	2.94
108	Summer	6	218	1.70	0.60	2.70	2.20	2.62	2.34	3.20	5.50
108	Fall	7	226	1.60	0.30	2.00	1.20	2.01	1.41	2.40	5.40
121	Winter	6	134	0.77	0.30	0.92	0.60	1.08	0.67	1.80	3.00
121	Spring	7	137	0.76	0.30	1.00	0.60	1.23	0.72	2.00	2.20
121	Summer	6	141	2.20	0.65	2.75	1.80	2.80	2.27	3.50	9.80
121	Fall	7	148	1.50	0.30	2.60	1.04	2.49	1.44	4.60	7.65
108A	Winter	6	38	0.75	0.44	0.98	0.70	1.19	0.77	2.00	1.60
108A	Spring	7	40	0.74	0.46	1.30	0.87	1.25	1.00	2.20	2.73
108A	Summer	6	36	1.60	0.91	2.75	1.99	2.73	1.98	3.40	3.83
108A	Fall	7	39	1.20	0.50	1.50	1.12	1.61	1.16	2.40	2.02
108B	Winter	6	38	0.78	0.45	1.03	0.84	1.10	0.89	1.40	2.72
108B	Spring	7	39	1.00	0.33	1.10	0.70	1.27	0.83	2.30	2.49
108B	Summer	6	35	0.75	0.52	3.30	1.10	2.93	1.33	4.40	7.31
108B	Fall	7	39	1.70	0.41	2.20	0.90	2.14	0.88	2.80	1.52
108C	Winter	6	38	0.61	0.28	0.83	0.59	1.32	0.64	2.60	1.30
108C	Spring	7	40	0.52	0.33	0.62	0.54	0.62	0.56	0.73	1.34
108C	Summer	6	36	0.44	0.29	0.81	0.66	0.80	0.77	1.30	2.53
108C	Fall	7	37	0.75	0.48	2.00	0.93	2.01	1.01	3.20	1.92
117	Winter	6	-	0.42	-	0.55	-	0.53	-	0.61	-
117	Spring	7	-	0.56	-	0.71	-	0.78	-	1.20	-
117	Summer	6	-	1.20	-	1.45	-	1.52	-	2.30	-
117	Fall	2	-	0.50	-	0.95	-	0.95	-	1.40	-

3.2.4 Total Coliform and *E. coli* Bacteria

Water quality monitoring of bacteria in the Quabbin Reservoir and Ware River Watershed tributary sites focused on *E. coli* and total coliform bacteria in 2024. Elevated bacteria results from Quabbin Reservoir and Ware River tributaries that exceed the upper bounds of seasonal norms (75th percentiles) that cannot be attributed to a recent meteorological event are followed up with site inspection and re-sampling for *E. coli* concentrations. Historically, follow-up sampling typically attributed elevated *E. coli* concentrations to wildlife activity, recent precipitation, and/or high flow conditions. Follow-up *E. coli* samples were collected from Boat Cove Brook in 2024 (see Section 6.2, Appendix B).

3.2.4.1 Total Coliform

Total coliform concentrations observed in tributaries in Quabbin Reservoir and Ware River Watersheds were characterized by distinct seasonality (Figure 18) consistent with stream temperatures throughout 2024 (Section 3.2.1.1). Intra-annual variability is high for observed concentrations of this parameter across DWSP monitoring sites. Total coliform in Quabbin Reservoir Watershed monitoring tributaries ranged from 97 to greater than 24,200 MPN/100 mL (Table 19) and from 30 to greater than 24,200 MPN/100 mL in monitoring tributaries in the Ware River Watershed in 2024 (Table 20). Seasonal total coliform concentrations for samples collected in 2024 were generally within seasonal normal ranges for the period of record. New record seasonal maximums were observed at several sites in 2024, varying by season and attributable to high-flow events (e.g., new winter maximums observed at 211, 212, and GATE coinciding with the December 30, 2024 rain-on-snow event). Median seasonal total coliform concentrations in 2024 were slightly elevated at some sites in the Quabbin Reservoir Watershed during some seasons, but without a consistent seasonal pattern (Table 19). In contrast, summer median concentrations higher than historical seasonal averages were more consistently observed at sites in the Ware River Watershed (101, 102, 107A, 108, 121, EQA sites). Differences in elevated results relative to seasonal patterns across the two watersheds may be attributed to several factors including timing of sample collection relative to rainfall events, variation in streamflow magnitude and timing across watersheds, variation in upstream catchment geomorphic and wetland characteristics, and differences in hydrological patterns and controls between the two watersheds.

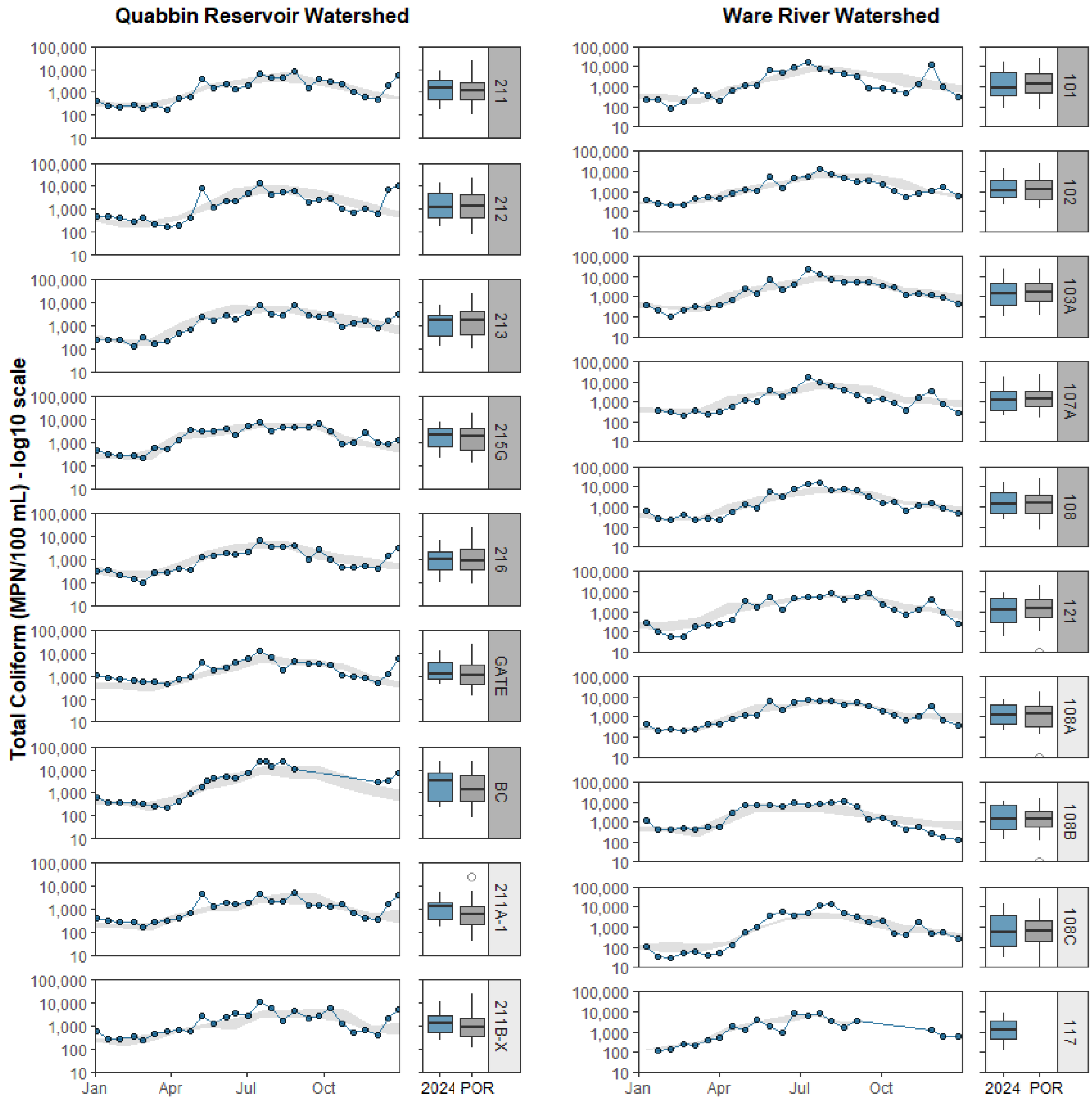


Figure 18. *Time series and boxplots of total coliform results (blue) from tributary monitoring sites during 2024 compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 19. *Seasonal statistics for total coliform measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

Total Coliform (MPN/100 mL)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	88	213	110	360	428	1202	519	5790	2190
211	Spring	6	89	171	108	604	670	1225	894	4110	3450
211	Summer	7	91	1410	1220	4160	3450	4063	5454	8160	24200
211	Fall	6	91	644	488	1885	1520	2016	3001	3650	24200
212	Winter	8	87	305	98	469	368	2552	516	10500	2850
212	Spring	6	90	171	84	317	495	1799	904	8660	8660
212	Summer	7	93	2360	813	4880	5790	5556	8124	13000	24200
212	Fall	6	91	749	393	1435	2190	1643	4344	2760	24200
213	Winter	8	88	134	121	280	339	888	635	3440	6870
213	Spring	6	91	175	97	571	794	950	2040	2380	24200
213	Summer	7	93	1920	1720	3450	4880	4424	6619	8160	24200
213	Fall	6	91	908	327	2005	1860	2011	3420	3080	24200
215G	Winter	8	28	218	156	383	325	571	366	1250	1320
215G	Spring	6	32	529	122	2205	1420	2005	1714	3450	5480
215G	Summer	7	34	2100	1860	4880	5325	4581	5715	7700	17300
215G	Fall	6	31	933	504	3010	1780	3299	3035	7270	19900
216	Winter	8	88	97	86	325	353	752	583	3080	6490
216	Spring	6	89	262	95	371	520	668	889	1500	5170
216	Summer	7	91	1530	759	3450	3650	3279	5731	6490	24200
216	Fall	6	91	426	285	740	1080	1029	2181	2760	24200
BC	Winter	8	87	336	122	498	393	1931	682	6870	8660
BC	Spring	7	91	216	86	911	703	1634	1602	4350	15500
BC	Summer	8	88	4110	1110	11750	7070	14045	8566	24200	24200
BC	Fall	-	90	-	228	-	2875	-	5679	-	24200
GATE	Winter	8	87	480	135	770	355	1376	397	5480	1270
GATE	Spring	6	90	464	195	802	606	1417	861	4110	7270
GATE	Summer	7	88	1920	631	4350	3760	5464	5773	13000	24200
GATE	Fall	6	88	826	355	2070	2235	2111	3815	3450	24200
211A-1	Winter	8	14	161	96	348	204	962	239	4110	728
211A-1	Spring	6	13	281	41	587	368	1335	503	4880	1210
211A-1	Summer	7	14	1660	554	2100	1480	2904	3520	5790	24200
211A-1	Fall	6	12	399	336	1370	1097	1179	2267	1720	6490
211B-X	Winter	8	13	259	109	382	292	1243	348	5480	836
211B-X	Spring	6	13	473	146	620	546	1072	584	2850	1170
211B-X	Summer	7	14	1720	448	3650	2440	4620	3796	11200	24200
211B-X	Fall	6	12	521	369	1695	2070	2330	3649	6490	9210

Table 20. *Seasonal statistics for total coliform measured in Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

Total Coliform (MPN/100 mL)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	78	84	109	215	392	329	632	985	3450
101	Spring	7	75	195	73	602	842	1491	1112	6490	7700
101	Summer	6	75	4110	1300	7145	5790	8255	7214	17300	24200
101	Fall	7	81	487	331	857	2010	2953	3263	13000	24200
102	Winter	6	18	216	145	325	314	560	361	1670	884
102	Spring	7	20	435	181	839	829	1500	1133	5790	4350
102	Summer	6	19	1470	1720	5480	4350	6290	5089	13000	10500
102	Fall	7	21	521	435	1140	2490	1808	4660	3450	24200
103A	Winter	6	78	97	173	282	420	379	648	959	6490
103A	Spring	7	83	288	110	697	1010	1879	1322	7270	5170
103A	Summer	6	89	2380	1850	6220	6490	9315	8291	24200	24200
103A	Fall	7	91	1160	404	2920	2600	3043	3959	5790	24200
107A	Winter	5	86	203	160	298	461	387	650	798	4350
107A	Spring	7	88	228	160	583	1029	1058	1542	3780	9210
107A	Summer	6	88	1990	959	4950	4230	7107	6023	17300	24200
107A	Fall	7	91	355	383	1410	1550	1574	3148	3450	24200
108	Winter	6	90	216	75	447	339	473	569	865	4610
108	Spring	7	88	235	121	512	859	1318	1215	5790	5790
108	Summer	6	90	3260	1520	8160	5365	9642	6679	17300	24200
108	Fall	7	91	683	504	1540	1780	2393	3258	6870	24200
121	Winter	6	31	62	109	185	305	293	520	984	2490
121	Spring	7	33	197	121	402	1100	1712	1587	5790	6130
121	Summer	6	32	1350	1580	5200	4880	4968	5548	8160	19900
121	Fall	7	34	663	10	2140	1945	3480	3106	9210	14100
108A	Winter	6	26	203	10	305	297	356	630	677	2610
108A	Spring	7	22	231	134	738	921	1553	1308	6490	5170
108A	Summer	6	25	2140	1720	5480	4350	5077	5879	7700	17300
108A	Fall	7	25	689	473	1940	1410	2487	1882	5480	4350
108B	Winter	6	26	121	10	401	498	470	616	1250	2140
108B	Spring	7	22	393	109	2760	948	3451	2767	6870	15500
108B	Summer	6	25	6130	1520	8410	3450	8322	4305	10500	11200
108B	Fall	7	25	262	355	934	1440	1541	1635	5790	4350
108C	Winter	6	26	30	41	81	199	176	283	561	1380
108C	Spring	7	22	41	10	122	202	810	471	3870	3650
108C	Summer	6	24	3650	1140	5480	2495	7415	3243	13000	15500
108C	Fall	7	23	431	231	1720	959	1424	2278	2990	24200
117	Winter	5	-	122	-	259	-	345	-	624	-
117	Spring	7	-	203	-	1260	-	1543	-	4350	-
117	Summer	6	-	960	-	4970	-	4823	-	8160	-
117	Fall	2	-	1310	-	2480	-	2480	-	3650	-

3.2.4.2 E. coli

E. coli concentrations ranged from less than 10 to 1530 MPN/100 mL in Quabbin Reservoir Watershed tributaries (Table 21) and from less than 10 to 1720 MPN/100 mL in the Ware River Watershed tributaries in 2024 (Table 22). Across all sites, annual median 2024 results were largely within normal historical ranges (Figure 19). Exceptions to this included elevated summer median *E. coli* at sites 101, 103A, and GATE and all seasons at BC. Thus, *E. coli* concentrations in Core tributaries in 2024 continued to demonstrate an overall high sanitary quality.

Of the 493 samples collected from tributaries in Quabbin Reservoir and Ware River Watershed tributaries and analyzed for *E. coli* in 2024, approximately 40% (n = 198) were below detection limits (less than 10 MPN/100 mL). Ten samples (2% of samples) exceeded the Class A statistical threshold value of 410 CFU/100 mL, which is not to be exceeded by more than 10% of samples in any 90 day or shorter period. This standard applies to surface waters designated for primary contact recreation and are not applicable for DWSP water supply waters, and are used as a point of comparison only. Of this subset greater than 410 MPN/100 mL, three were from Boat Cove Brook (site BC) in the Quabbin Reservoir Watershed. Further evaluation of water quality patterns and follow-up investigations are documented in Section 6.2, Appendix B of this report. In most cases, no potential sources of pollution were observed during sample collection, and *E. coli* concentrations decreased in subsequent samples.

The maximum *E. coli* result (1720 MPN/100mL) observed in 2024 occurred on July 10, 2024. This sample was collected on the Ware River downstream of the confluence with the Burnshirt River (site 103A) following a five-day antecedent period of consistent rainfall, with a cumulative rainfall total of 2.7” recorded at the nearby Barre Falls Dam NOAA station. In follow up field investigations, DWSP staff noted flows above bankful as well as upstream beaver activity in the wetland complex surrounding the confluence. Subsequent results were within seasonal normal range, and DWSP staff continued to follow up with field documentation of conditions.

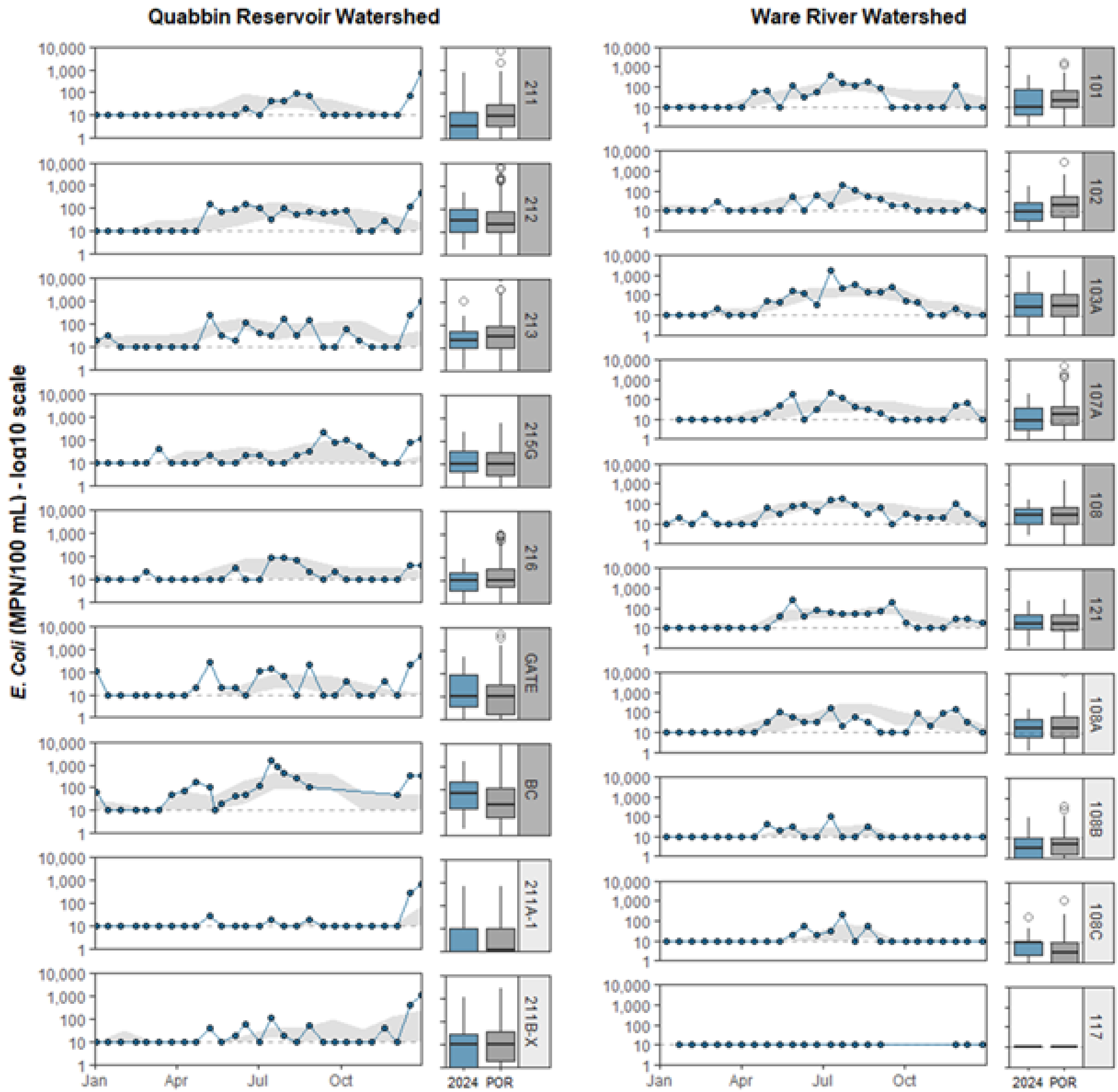


Figure 19. *Time series and boxplots of E. coli results (blue) from tributary monitoring sites during 2024 compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. The horizontal dashed grey and red lines correspond to laboratory detection limits (10 MPN/100 mL). Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 21. *Seasonal statistics for E. coli measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

E. coli **(MPN/100 mL)**

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	119	10	10	10	10	107	13	723	63
211	Spring	6	113	10	10	10	10	10	21	10	156
211	Summer	7	119	10	10	41	30	42	174	97	6870
211	Fall	6	117	10	10	10	10	10	42	10	644
212	Winter	8	117	10	10	10	10	87	18	512	189
212	Spring	6	114	10	10	10	10	43	37	145	481
212	Summer	7	121	31	10	97	75	89	392	148	7700
212	Fall	6	117	10	10	47	41	45	117	85	2360
213	Winter	8	119	10	10	15	10	178	32	1090	327
213	Spring	6	115	10	10	10	31	52	51	241	426
213	Summer	7	122	20	10	41	63	79	576	173	24200
213	Fall	6	117	10	10	10	41	21	151	63	3260
215G	Winter	8	28	10	10	10	10	32	15	120	84
215G	Spring	6	32	10	10	10	10	17	17	40	63
215G	Summer	7	34	10	10	20	25	17	68	30	573
215G	Fall	6	31	10	10	63	10	80	41	228	546
216	Winter	8	119	10	10	10	10	19	21	41	292
216	Spring	6	113	10	10	10	10	10	20	10	187
216	Summer	7	119	10	10	30	31	44	97	86	1010
216	Fall	6	116	10	10	10	20	12	44	20	727
BC	Winter	8	117	10	10	31	10	107	40	355	990
BC	Spring	7	115	10	10	52	10	63	45	168	697
BC	Summer	8	115	41	10	194	161	420	805	1530	19900
BC	Fall	-	108	-	10	-	52	-	258	-	3870
GATE	Winter	8	116	10	10	10	10	112	16	537	249
GATE	Spring	6	114	10	10	15	10	58	24	279	529
GATE	Summer	7	115	10	10	63	31	82	115	213	3650
GATE	Fall	6	114	10	10	10	10	20	121	41	5170
211A-1	Winter	8	21	10	10	10	10	128	10	670	10
211A-1	Spring	6	19	10	10	10	10	13	10	30	10
211A-1	Summer	7	21	10	10	10	10	13	37	20	389
211A-1	Fall	6	18	10	10	10	10	10	14	10	31
211B-X	Winter	8	20	10	10	10	10	207	22	1190	86
211B-X	Spring	6	20	10	10	10	10	15	11	41	20
211B-X	Summer	7	21	10	10	20	20	42	209	121	2610
211B-X	Fall	6	18	10	10	10	69	15	82	40	253

Table 22. *Seasonal statistics for E. coli measured in Ware River Watershed tributary sites.*

E. coli (MPN/100 mL)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	78	10	10	10	10	10	20	10	146
101	Spring	7	75	10	10	10	20	37	31	108	228
101	Summer	6	75	31	10	136	75	157	133	399	1220
101	Fall	7	81	10	10	10	31	35	73	109	1550
102	Winter	6	18	10	10	10	10	12	24	20	110
102	Spring	7	20	10	10	10	10	19	33	52	256
102	Summer	6	19	10	10	58	63	74	111	189	697
102	Fall	7	21	10	10	10	41	17	214	41	2910
103A	Winter	6	97	10	10	10	10	10	17	10	197
103A	Spring	7	108	10	10	20	20	43	37	160	228
103A	Summer	6	113	31	30	184	134	432	206	1720	1420
103A	Fall	7	121	10	10	41	41	75	112	259	1940
107A	Winter	5	101	10	10	10	10	21	16	63	96
107A	Spring	7	111	10	10	10	10	43	28	187	332
107A	Summer	6	110	10	10	36	52	75	91	216	1400
107A	Fall	7	121	10	10	10	20	17	143	52	4880
108	Winter	6	116	10	10	15	10	19	15	31	107
108	Spring	7	116	10	10	10	10	30	39	74	355
108	Summer	6	114	31	10	86	86	98	131	181	1470
108	Fall	7	121	10	10	20	41	37	90	97	1400
121	Winter	6	39	10	10	10	10	15	19	31	148
121	Spring	7	43	10	10	10	20	50	33	256	238
121	Summer	6	44	41	10	52	47	57	78	84	309
121	Fall	7	48	10	10	20	20	51	56	199	282
108A	Winter	6	38	10	10	10	10	14	14	31	75
108A	Spring	7	33	10	10	10	10	35	22	110	84
108A	Summer	6	31	20	20	31	98	56	654	161	12000
108A	Fall	7	34	10	10	20	31	53	67	135	282
108B	Winter	6	38	10	10	10	10	10	17	10	122
108B	Spring	7	33	10	10	10	10	19	11	41	31
108B	Summer	6	31	10	10	10	20	30	33	110	262
108B	Fall	7	34	10	10	10	10	10	32	10	395
108C	Winter	6	38	10	10	10	10	10	13	10	86
108C	Spring	7	33	10	10	10	10	11	10	20	10
108C	Summer	6	30	10	10	42	15	61	39	199	262
108C	Fall	7	32	10	10	10	10	10	71	10	1350
117	Winter	5	-	10	-	10	-	10	-	10	-
117	Spring	7	-	10	-	10	-	10	-	10	-
117	Summer	6	-	10	-	10	-	10	-	10	-
117	Fall	2	-	10	-	10	-	10	-	10	-

The annual geometric mean *E. coli* concentration remained below 126 MPN/100 mL for all Core monitoring sites in 2024 (Figure 20, Table 23, Table 24). Annual geometric mean results from 2024 were within established historical ranges. Temporal variability in annual geometric mean *E. coli* concentrations exhibited a non-uniform response to climate extremes (e.g., drought in 2016, 2020, and 2024; extreme precipitation in summer 2021 and 2023). This contrast may reflect the timing of sample collection relative to precipitation events throughout the period of record, differences in the degree to which the two watersheds may have been impacted by saturation excess overland flow, or variations in factors controlling the sources of *E. coli* to the watersheds.

Overall, long-term records of annual geometric mean *E. coli* results do not exhibit unidirectional trends in the monitoring sites sampled in 2024. Boat Cove Brook, in the Quabbin Reservoir Watershed, has demonstrated a recent upward trend in annual *E. coli* concentrations from 2022 until present. Investigations and follow-up sampling were taken in 2023 following several persistent high counts (Section 6.2, Appendix B). Further assessment of Boat Cove Brook's water quality conditions will be summarized in the upcoming EQA report for the Quabbin Reservation District, anticipated in 2025. Annual geometric mean *E. coli* at monitoring sites in the Ware River Watershed were lower than recent years at several sites, most notably at the Ware River Shaft 8 intake location (site 101), where a new minimum annual geometric mean *E. coli* was recorded in 2024 (13 MPN/100 mL). EQA sites across Quabbin Reservoir (211B-X, 211A-1) and most within Ware River Watershed (108A, 108B) exhibit a decline or a result matching previous minimums in annual geometric mean *E. coli* for 2024 results compared to the last year of sampling, indicating a lack of persistent bacterial issues at these sites.

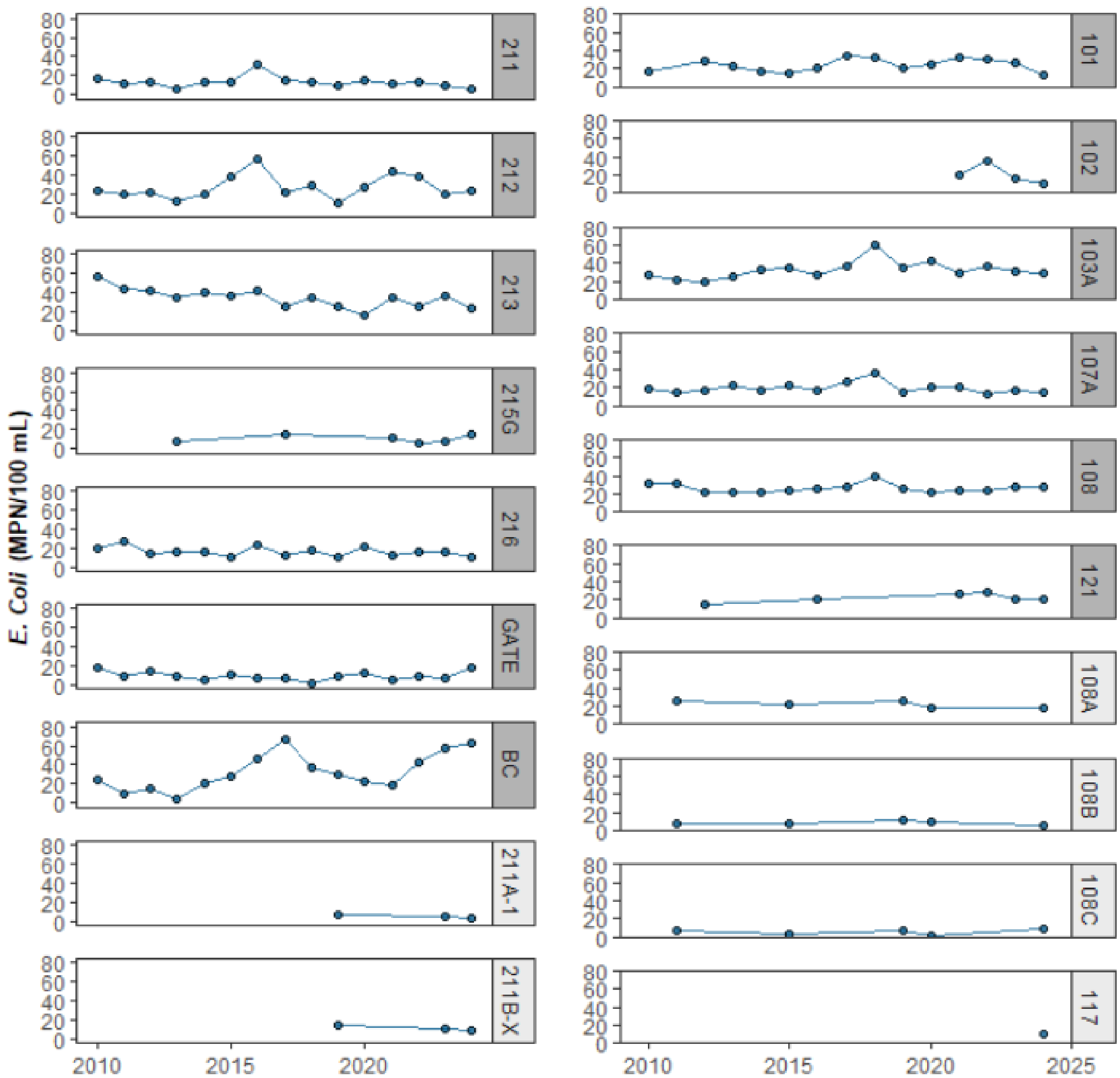


Figure 20. *Time series of annual geometric mean E. coli in tributary sites from 2010 to 2024. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 23. *Annual geometric mean E. coli for Quabbin Reservoir Watershed tributary sites from historical sampling period of record.*

Annual Geometric Mean *E. coli* (MPN/100 mL)

Year	211	212	213	215G	216	BC	GATE	211A-1	211B-X
2005	10	28	13	-	13	36	10	-	-
2006	7	8	20	-	10	14	6	-	-
2007	15	16	26	-	19	10	10	-	-
2008	6	10	17	-	16	6	5	-	-
2009	12	13	31	-	12	9	8	-	-
2010	18	24	57	-	19	25	18	-	-
2011	11	19	44	-	26	9	9	-	-
2012	13	21	43	-	14	15	15	-	-
2013	6	13	34	8	15	5	10	-	-
2014	14	20	41	-	15	21	6	-	-
2015	13	38	37	-	11	28	11	-	-
2016	32	56	43	-	24	47	8	-	-
2017	15	22	25	15	13	66	8	-	-
2018	13	29	35	-	18	38	2	-	-
2019	9	11	25	-	11	30	10	6	14
2020	15	26	16	-	21	23	13	-	-
2021	12	44	34	11	13	19	6	-	-
2022	14	38	26	7	16	42	9	-	-
2023	10	20	37	8	16	58	8	4	11
2024	7	24	23	15	11	62	19	3	9

Table 24. *Annual geometric mean E. coli for Ware River Watershed tributary sites from historical sampling period of record.*

Annual Geometric Mean *E. coli* (MPN/100 mL)

Year	101	102	103A	107A	108	121	108A	108B	108C	117
2005	-	-	17	10	13	-	-	-	-	-
2006	-	-	29	14	20	-	-	-	-	-
2007	-	-	34	46	22	67	-	-	-	-
2008	-	-	40	40	30	19	-	-	-	-
2009	-	-	21	18	23	-	-	-	-	-
2010	18	-	28	19	31	-	-	-	-	-
2011	-	-	21	14	32	-	25	7	7	-
2012	29	-	20	17	22	15	-	-	-	-
2013	23	-	26	22	21	-	-	-	-	-
2014	17	-	33	16	21	-	-	-	-	-
2015	16	-	35	23	24	-	23	7	4	-
2016	20	-	28	17	25	21	-	-	-	-
2017	34	-	36	26	27	-	-	-	-	-
2018	33	-	59	36	40	-	-	-	-	-
2019	21	-	35	14	25	-	25	12	7	-
2020	24	-	42	21	22	-	19	9	2	-
2021	33	20	29	20	23	26	-	-	-	-
2022	30	36	36	12	23	28	-	-	-	-
2023	27	17	31	16	27	20	-	-	-	-
2024	13	11	29	14	27	21	19	6	9	10

3.2.5 Nutrients

DWSP monitored concentrations of nitrogen and phosphorus at tributary monitoring locations in the Quabbin Reservoir and Ware River Watersheds. Samples were analyzed for concentrations of nitrogen species (Ammonia-Nitrogen, Nitrate-Nitrogen, and Total Kjeldahl Nitrogen) and Total Phosphorus in 2024. Information on changes in analytical methods relative to the interpretation of 2024 results compared to the period of record are detailed in Section 2.2. Seasonal patterns and site-specific variations in contributions of N-species are more limited at numerous Ware River sites due to variations in sampling frequency (quarterly vs. biweekly, Figure 5). For example, the majority of historical nutrient sampling at site 101 was quarterly, affecting the timescale of comparison and limiting observations of water quality patterns relative to parameters more consistently monitored at finer temporal intervals (e.g., turbidity, bacteria analyses). In 2024, biweekly nutrient sampling was completed at all Quabbin Reservoir Watershed tributary sites, at Ware River downstream of Shaft 8 Intake (site 101), and at Ware River Watershed EQA sites. The remaining Ware River Watershed Core monitoring locations were sampled on a quarterly basis.

3.2.5.1 Total Nitrogen

Organic nitrogen (TKN - NH_3-N) was the most abundant nitrogen form in tributaries in either watershed in 2024 (Figure 21). Dominance of organic nitrogen in headwater streams in the US has been documented previously (Scott et al., 2007). Streams in both Quabbin Reservoir and Ware River Watersheds exhibited a clear ramp up of nitrogen export in the late spring and summer months coincident to increased biological activity and plant growth. Among streams monitored in Quabbin Reservoir Watershed, organic nitrogen was higher and more consistently high in streams with a higher proportion of upstream wetland area (e.g., 215G, 216, and 213 compared to other sites, see Table 4). The previously discussed May and December 2024 rainfall events coincident with tributary sampling in these watersheds results in elevated N transport documented in summer and winter. Patterns of nitrogen varied at EQA sites in the Ware River Watershed in 2024 (see Sections 3.2.5.1.1-3).

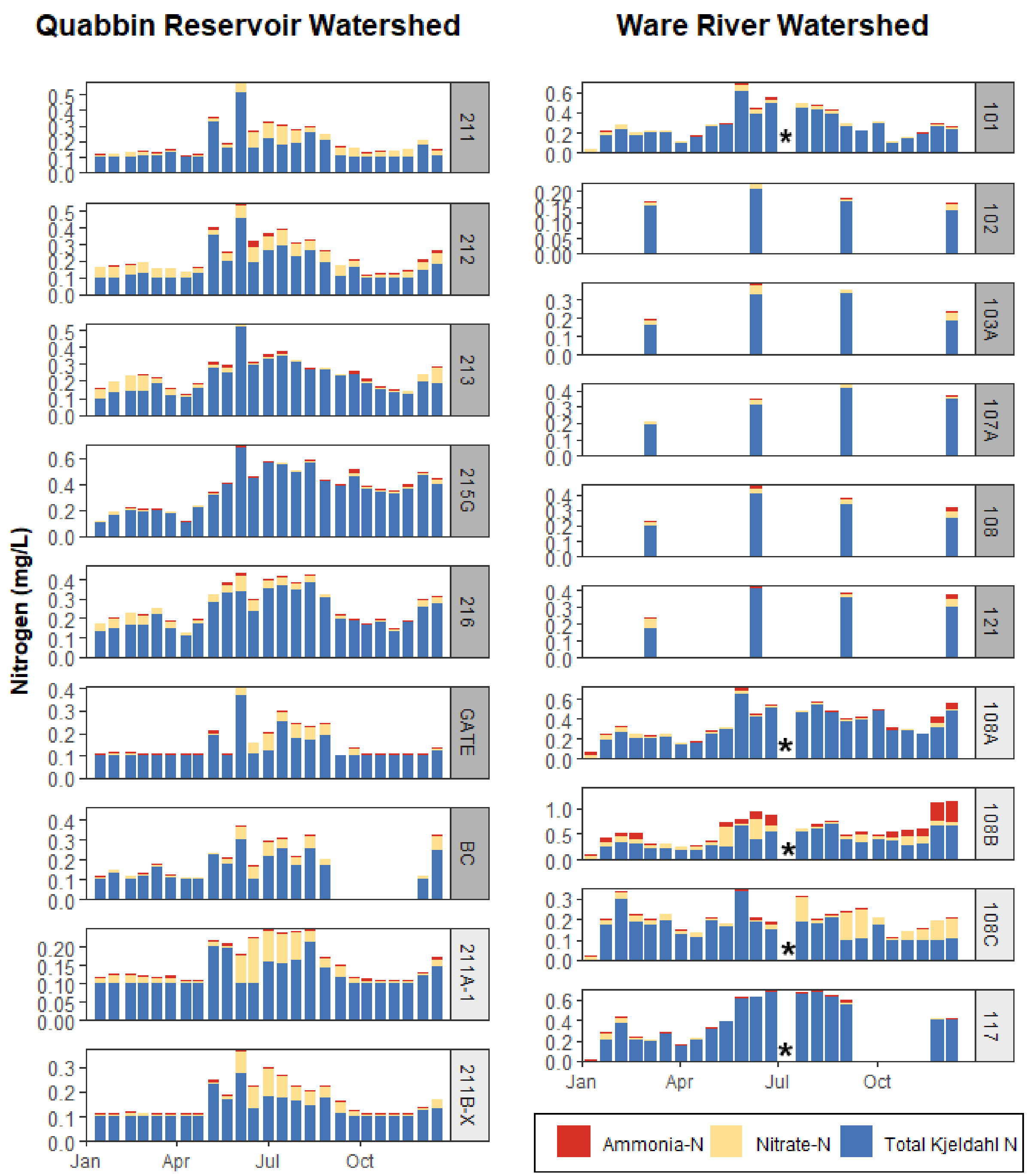


Figure 21. *Bar plots depicting the temporal distributions of nitrogen observed in Quabbin Reservoir Watershed and Ware River Watershed tributary sites during 2024. Asterisk (*) signifies result removed from analysis due to documented sample processing hold time issues. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

3.2.5.1.1 Ammonia-Nitrogen

Concentrations of ammonia (NH_3-N) in Quabbin Reservoir and Ware River Watershed tributaries have routinely been below detection limits (48% of samples from tributaries in 2024). Concentrations of NH_3-N in Quabbin Reservoir and Ware River Watershed Core monitoring tributaries ranged from less than 0.005 to 0.044 mg/L and less than 0.005 to 0.448 mg/L, respectively, in 2024 (Table 25, Table 26). Concentrations of NH_3-N in Core monitoring tributaries in the Quabbin Reservoir and Ware River Watersheds were below the MA acute and chronic aquatic life criteria (17 mg/L and 1.9 mg/L, respectively) and the WHO taste and odor thresholds for drinking water (1.5 mg/L and 1.9 mg/L) for the entirety of 2024.

Seasonal average concentrations of NH_3-N observed in 2024 varied little from those of the period of record across Quabbin Reservoir Watershed monitoring streams. Periodic elevated results were noted at several sites during varying seasons (Figure 22). The December rain-on-snow events following extended fall low flows and subsequent high streamflow runoff led to some elevated ammonia concentrations at several sites in the Quabbin, as well as a new winter maximum ammonia concentration at Hop Brook (site 212; 0.042 mg/L). Summer and fall pulses in ammonia concentrations were uniquely observed in Hop Brook (site 212) and East Branch Fever Brook (site 215G). These locations have documented in-stream and near-stream beaver activity upstream of sampling locations on numerous occasions during their historical sampling period. Beaver dams may alter in-stream biogeochemical pathways, acting as sinks for NO_3-N (via denitrification) and subsequent sources for ammonium in stream settings (Lazer et al., 2015; Bason et al., 2017). The notably greater NH_3N concentrations suggest that beaver impacted N-cycling in the upstream reaches of these catchments during 2024.

Seasonal average concentrations of NH_3-N observed in 2024 also varied little from those of the period of record across Ware River Watershed Core monitoring streams. Among Ware River Watershed EQA monitoring sites, a series of above-normal Ammonia results were observed in summer (site 108B) and late fall/winter 2024 (sites 108A, 108B, 108C). In particular, the outlet of Cushman Pond (108B) exhibited elevated NH_3-N concentration relative to previous sampling years (2020, 2019, 2015). Fall and winter median NH_3-N at this site were 0.086 and 0.050 mg/L higher in 2024 compared to historical seasonal medians. Cushman Pond is a shallow vegetated pond upstream of the sampling location where prolonged drought conditions likely lead to declining water level elevations and the subsequent die off of aquatic plants throughout the fall. Further upstream investigation is planned for 2025 to follow-up on water quality patterns observed at this site.

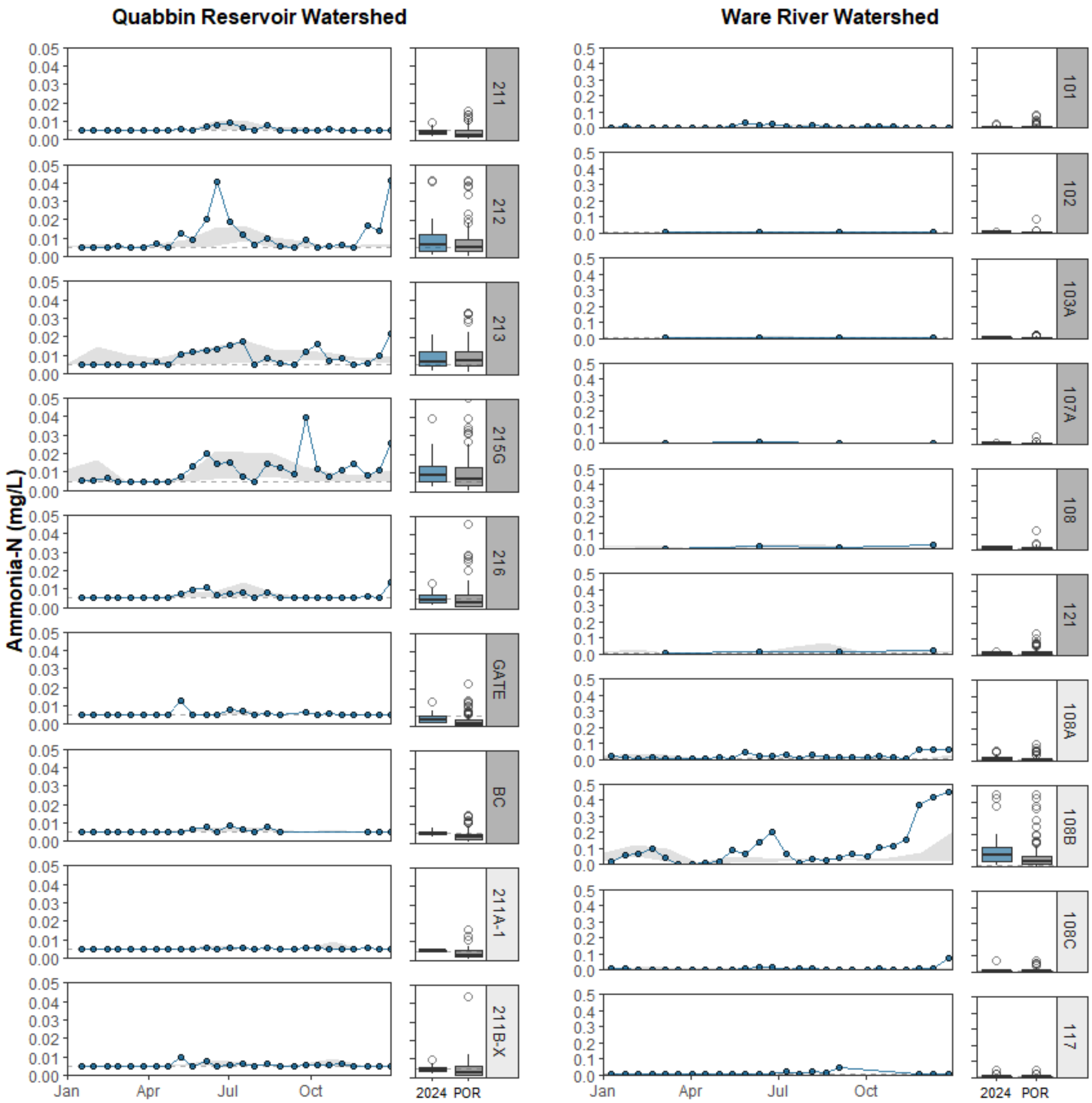


Figure 22. *Time series and boxplots of 2024 ammonia results (blue) from tributary monitoring sites compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 25. *Seasonal statistics for ammonia measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR). Detection limits for NH_3-N were less than0.005 mg/L.*

Ammonia (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	7	33	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.008
211	Spring	6	34	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.008
211	Summer	7	34	0.005	0.005	0.007	0.005	0.007	0.010	0.009	0.082
211	Fall	6	32	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.010
212	Winter	7	32	0.005	0.005	0.006	0.005	0.013	0.006	0.042	0.016
212	Spring	6	34	0.005	0.005	0.006	0.005	0.007	0.008	0.013	0.034
212	Summer	7	34	0.006	0.005	0.012	0.010	0.016	0.011	0.040	0.039
212	Fall	6	32	0.005	0.005	0.005	0.005	0.006	0.007	0.009	0.038
213	Winter	7	33	0.005	0.005	0.005	0.006	0.008	0.008	0.021	0.033
213	Spring	6	34	0.005	0.005	0.005	0.005	0.007	0.014	0.012	0.198
213	Summer	7	34	0.005	0.005	0.013	0.011	0.011	0.012	0.018	0.033
213	Fall	6	32	0.005	0.005	0.008	0.008	0.009	0.009	0.016	0.020
215G	Winter	7	28	0.005	0.005	0.007	0.005	0.008	0.010	0.025	0.033
215G	Spring	6	32	0.005	0.005	0.005	0.005	0.007	0.006	0.013	0.023
215G	Summer	7	34	0.005	0.005	0.015	0.013	0.013	0.017	0.020	0.056
215G	Fall	6	30	0.008	0.005	0.012	0.005	0.016	0.007	0.040	0.017
216	Winter	7	33	0.005	0.005	0.005	0.005	0.006	0.008	0.014	0.046
216	Spring	6	34	0.005	0.005	0.005	0.005	0.006	0.008	0.010	0.054
216	Summer	7	34	0.005	0.005	0.007	0.006	0.007	0.011	0.011	0.104
216	Fall	6	32	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.013
BC	Winter	7	33	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.015
BC	Spring	6	34	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0.007
BC	Summer	7	29	0.005	0.005	0.007	0.005	0.007	0.007	0.008	0.015
BC	Fall	-	29	-	0.005	-	0.005	-	0.005	-	0.012
GATE	Winter	7	33	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.007
GATE	Spring	6	34	0.005	0.005	0.005	0.005	0.006	0.005	0.013	0.006
GATE	Summer	7	32	0.005	0.005	0.005	0.005	0.006	0.006	0.008	0.022
GATE	Fall	5	32	0.005	0.005	0.005	0.005	0.006	0.006	0.007	0.012
211A-1	Winter	7	6	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.007
211A-1	Spring	6	7	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006
211A-1	Summer	7	7	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.011
211A-1	Fall	6	5	0.005	0.005	0.005	0.005	0.005	0.007	0.006	0.013
211B-X	Winter	7	6	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.012
211B-X	Spring	6	7	0.005	0.005	0.005	0.005	0.006	0.005	0.010	0.006
211B-X	Summer	7	7	0.005	0.005	0.006	0.005	0.006	0.006	0.008	0.009
211B-X	Fall	6	5	0.005	0.005	0.005	0.005	0.005	0.007	0.006	0.012

Table 26. *Seasonal statistics for ammonia measured in Ware River Watershed tributary sites.*

Ammonia (mg/L)											
Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	33	0.005	0.005	0.005	0.005	0.006	0.007	0.007	0.024
101	Spring	7	32	0.005	0.005	0.005	0.005	0.009	0.008	0.030	0.031
101	Summer	6	34	0.005	0.005	0.014	0.011	0.014	0.016	0.022	0.082
101	Fall	7	33	0.005	0.005	0.005	0.006	0.006	0.009	0.009	0.055
102	Winter	1	13	0.005	0.005	0.005	0.006	0.005	0.008	0.005	0.017
102	Spring	1	14	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.014
102	Summer	1	14	0.007	0.005	0.007	0.005	0.007	0.008	0.007	0.016
102	Fall	1	15	0.005	0.005	0.005	0.005	0.005	0.011	0.005	0.093
103A	Winter	1	29	0.008	0.005	0.008	0.005	0.008	0.009	0.008	0.027
103A	Spring	1	25	0.005	0.005	0.005	0.005	0.005	0.008	0.005	0.028
103A	Summer	1	29	0.009	0.005	0.009	0.007	0.009	0.010	0.009	0.027
103A	Fall	1	29	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.012
107A	Winter	1	29	0.005	0.005	0.005	0.006	0.005	0.008	0.005	0.018
107A	Spring	1	26	0.005	0.005	0.005	0.005	0.005	0.008	0.005	0.046
107A	Summer	1	29	0.012	0.005	0.012	0.006	0.012	0.008	0.012	0.019
107A	Fall	1	29	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.017
108	Winter	1	29	0.026	0.005	0.026	0.008	0.026	0.014	0.026	0.123
108	Spring	1	26	0.005	0.005	0.005	0.005	0.005	0.010	0.005	0.039
108	Summer	1	29	0.021	0.005	0.021	0.020	0.021	0.020	0.021	0.037
108	Fall	1	29	0.007	0.005	0.007	0.008	0.007	0.009	0.007	0.017
121	Winter	1	26	0.023	0.005	0.023	0.010	0.023	0.020	0.023	0.069
121	Spring	1	27	0.007	0.005	0.007	0.005	0.007	0.008	0.007	0.020
121	Summer	1	27	0.013	0.005	0.013	0.021	0.013	0.031	0.013	0.136
121	Fall	1	28	0.012	0.005	0.012	0.006	0.012	0.016	0.012	0.103
108A	Winter	6	19	0.009	0.005	0.018	0.009	0.029	0.020	0.059	0.083
108A	Spring	7	16	0.005	0.005	0.005	0.005	0.011	0.015	0.042	0.103
108A	Summer	6	19	0.005	0.005	0.024	0.014	0.021	0.015	0.028	0.031
108A	Fall	7	19	0.005	0.005	0.014	0.007	0.020	0.008	0.062	0.016
108B	Winter	6	19	0.023	0.005	0.082	0.032	0.186	0.074	0.448	0.286
108B	Spring	7	16	0.007	0.005	0.021	0.013	0.035	0.047	0.091	0.354
108B	Summer	6	18	0.009	0.005	0.055	0.028	0.081	0.028	0.202	0.047
108B	Fall	7	19	0.041	0.005	0.108	0.022	0.130	0.023	0.372	0.054
108C	Winter	6	19	0.005	0.005	0.007	0.013	0.018	0.017	0.072	0.056
108C	Spring	7	16	0.005	0.005	0.005	0.006	0.006	0.011	0.010	0.051
108C	Summer	6	18	0.005	0.005	0.006	0.005	0.009	0.007	0.015	0.015
108C	Fall	7	17	0.005	0.005	0.005	0.005	0.006	0.006	0.009	0.014
117	Winter	6	-	0.005	-	0.005	-	0.006	-	0.007	-
117	Spring	7	-	0.005	-	0.005	-	0.005	-	0.007	-
117	Summer	6	-	0.005	-	0.010	-	0.012	-	0.024	-
117	Fall	2	-	0.005	-	0.024	-	0.024	-	0.043	-

3.2.5.1.2 Nitrate-Nitrogen

Concentrations of nitrate (NO_3-N) ranged from less than 0.005 to 0.139 mg/L in Quabbin Reservoir Watershed sites in 2024 (Table 27, Figure 23). Summer median nitrate concentrations were elevated in 2024 compared to the period of record at most of the Quabbin Reservoir Watershed tributary sampling locations (211, 212, 216, BC, GATE). Instream concentrations of NO_3-N generally followed established historical seasonal patterns in the Quabbin Reservoir Watershed, varying considerably across sites due to upstream catchment context. Three general time series patterns were observed. West Quabbin sites (BC, GATE, 211, 211A-1, 211B-X) were characterized by nitrate level increasing in late spring, peaking in summer, and declining into winter. Seasonal nitrate transport patterns at these relatively high-gradient low-order streams was likely driven by seasonal nutrient release from vegetation and soil, patterns of summer runoff and mobilization, and the timing of plant uptake of available nitrates. Central Quabbin tributaries East Branch Fever Brook (site 215G) and Middle Branch Swift (site 213) are sites with a relatively higher proportion of upstream wetland landcover (see Table 4). Time series of nitrate concentrations at these sites showed increased concentrations during winter, although the magnitude of these increases varied across sites. Wetlands can act as nutrient sinks during growing seasons and can release nitrates during winter when ground is frozen, leading to increased NO_3-N downstream (Johnston 1991). Reduced plant uptake of nitrates during the winter months also allows for accumulation in soils and subsequent leaching during winter rains and/or snowmelt. Seasonal patterns at Hop Brook (site 212) and East Branch Swift (site 216) exhibited both winter and summer increases in nitrate concentrations. These variable patterns indicated key differences in controls on biogeochemical N-cycling that could include variations in land cover, hydrological differences in groundwater recharge and overall difference in hydrologic complexity, and/or soil characteristics.

Concentrations of nitrate (NO_3-N) ranged from less than 0.005 to 0.406 mg/L in Ware River Watershed sites in 2025 (Table 28, Figure 23). The summer 2024 median nitrate concentration was slightly elevated relative to the period of record (0.035 mg/L compared with 0.019 mg/L, respectively) at the Ware River at Shaft 8 sampling location (site 101). Two NO_3-N result outliers from spring and early summer of 2024 were recorded at the Cushman Pond EQA sampling location (site 108B). These annual maximum results recorded at 108B (0.406 and 0.399 mg/L) were the only results above local ecoregional background levels for nitrate (0.16 - 0.31 mg/L). These elevated results could be due to nutrient release from plant decay, residential runoff, and/or seasonal changes in biological activity. Further investigation into this location is scheduled for 2025. Overall, monitoring tributaries in the Quabbin Reservoir and Ware River Watersheds were well below the EPA MCL for drinking water of 10 mg/L for the entirety of 2024.

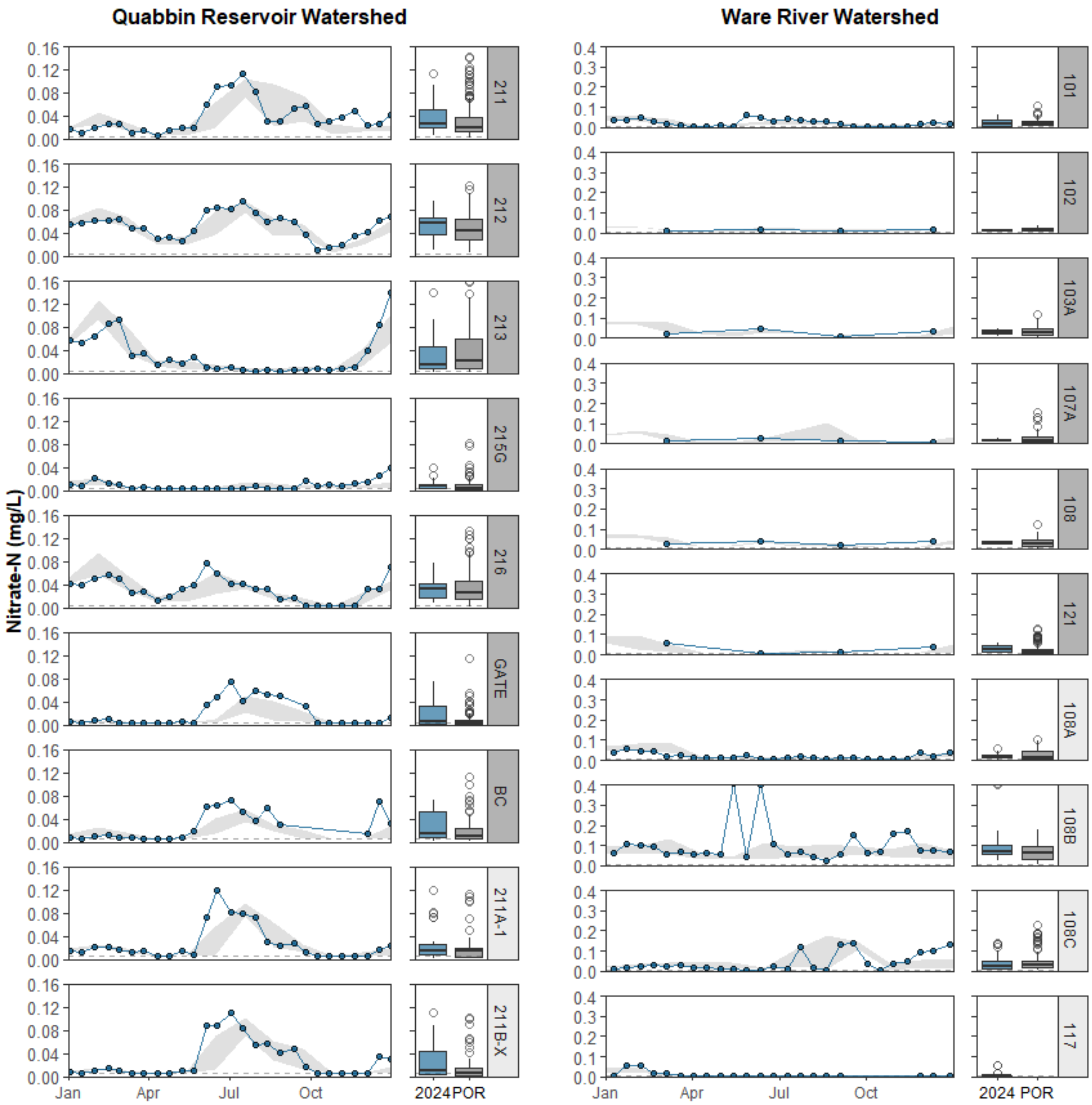


Figure 23. *Time series and boxplots of 2024 nitrate results (blue) from tributary monitoring sites compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. The horizontal dashed grey lines correspond to laboratory detection limits (0.005 mg/L). Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 27. *Seasonal statistics for nitrate measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR). Detection limits for NO_3-N were less than 0.005 mg/L.*

Nitrate (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	38	0.012	0.008	0.025	0.019	0.024	0.022	0.043	0.052
211	Spring	6	42	0.005	0.005	0.015	0.014	0.014	0.019	0.020	0.071
211	Summer	7	43	0.030	0.005	0.081	0.034	0.071	0.052	0.114	0.143
211	Fall	6	43	0.026	0.005	0.043	0.021	0.042	0.038	0.059	0.139
212	Winter	8	37	0.041	0.033	0.063	0.054	0.059	0.057	0.069	0.088
212	Spring	6	42	0.027	0.005	0.038	0.046	0.039	0.049	0.050	0.122
212	Summer	7	42	0.061	0.008	0.079	0.050	0.078	0.056	0.095	0.116
212	Fall	6	43	0.011	0.005	0.027	0.031	0.030	0.031	0.061	0.078
213	Winter	8	38	0.040	0.018	0.074	0.070	0.077	0.079	0.139	0.157
213	Spring	6	42	0.014	0.005	0.026	0.035	0.025	0.051	0.036	0.186
213	Summer	7	42	0.005	0.005	0.007	0.008	0.008	0.012	0.011	0.044
213	Fall	6	43	0.006	0.005	0.008	0.011	0.008	0.017	0.011	0.058
215G	Winter	8	28	0.009	0.005	0.015	0.012	0.019	0.014	0.040	0.043
215G	Spring	6	32	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.021
215G	Summer	7	32	0.005	0.005	0.005	0.006	0.005	0.014	0.008	0.082
215G	Fall	6	31	0.005	0.005	0.009	0.005	0.010	0.006	0.018	0.018
216	Winter	8	38	0.033	0.017	0.046	0.046	0.047	0.051	0.070	0.119
216	Spring	6	42	0.014	0.005	0.028	0.028	0.027	0.040	0.040	0.133
216	Summer	7	42	0.015	0.007	0.042	0.026	0.043	0.034	0.078	0.096
216	Fall	6	42	0.005	0.005	0.005	0.009	0.007	0.013	0.018	0.030
BC	Winter	8	38	0.006	0.005	0.012	0.012	0.021	0.018	0.070	0.099
BC	Spring	6	42	0.005	0.005	0.007	0.009	0.009	0.012	0.020	0.043
BC	Summer	7	34	0.030	0.005	0.060	0.025	0.054	0.030	0.072	0.072
BC	Fall	-	36	-	0.005	-	0.005	-	0.016	-	0.114
GATE	Winter	8	38	0.005	0.005	0.005	0.005	0.007	0.007	0.014	0.024
GATE	Spring	6	42	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.014
GATE	Summer	7	39	0.034	0.005	0.050	0.007	0.052	0.015	0.076	0.115
GATE	Fall	5	41	0.005	0.005	0.005	0.005	0.010	0.011	0.032	0.055
211A-1	Winter	8	21	0.005	0.005	0.017	0.020	0.017	0.017	0.025	0.026
211A-1	Spring	6	19	0.005	0.005	0.011	0.005	0.010	0.011	0.015	0.037
211A-1	Summer	7	19	0.025	0.005	0.074	0.022	0.069	0.047	0.119	0.113
211A-1	Fall	6	18	0.005	0.005	0.005	0.006	0.010	0.014	0.028	0.070
211B-X	Winter	8	20	0.005	0.005	0.010	0.010	0.015	0.009	0.035	0.017
211B-X	Spring	6	19	0.005	0.005	0.005	0.005	0.007	0.008	0.011	0.030
211B-X	Summer	7	19	0.042	0.005	0.084	0.032	0.075	0.045	0.111	0.102
211B-X	Fall	6	18	0.005	0.005	0.005	0.005	0.014	0.014	0.047	0.060

Table 28. *Seasonal statistics for nitrate measured in Ware River Watershed tributary sites.*

Nitrate (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	33	0.016	0.012	0.033	0.040	0.031	0.038	0.048	0.068
101	Spring	7	32	0.005	0.005	0.009	0.010	0.016	0.021	0.060	0.105
101	Summer	6	33	0.029	0.006	0.035	0.019	0.037	0.021	0.051	0.048
101	Fall	7	35	0.005	0.005	0.006	0.010	0.009	0.011	0.019	0.028
102	Winter	1	13	0.017	0.013	0.017	0.025	0.017	0.024	0.017	0.031
102	Spring	1	14	0.010	0.005	0.010	0.008	0.010	0.011	0.010	0.026
102	Summer	1	14	0.015	0.005	0.015	0.016	0.015	0.018	0.015	0.033
102	Fall	1	15	0.008	0.005	0.008	0.012	0.008	0.013	0.008	0.021
103A	Winter	1	35	0.037	0.010	0.037	0.065	0.037	0.054	0.037	0.092
103A	Spring	1	33	0.022	0.005	0.022	0.032	0.022	0.041	0.022	0.115
103A	Summer	1	38	0.051	0.005	0.051	0.026	0.051	0.032	0.051	0.071
103A	Fall	1	39	0.012	0.005	0.012	0.009	0.012	0.011	0.012	0.041
107A	Winter	1	35	0.009	0.011	0.009	0.036	0.009	0.037	0.009	0.070
107A	Spring	1	33	0.014	0.005	0.014	0.015	0.014	0.029	0.014	0.132
107A	Summer	1	38	0.025	0.005	0.025	0.019	0.025	0.030	0.025	0.158
107A	Fall	1	39	0.015	0.005	0.015	0.006	0.015	0.012	0.015	0.052
108	Winter	1	35	0.042	0.012	0.042	0.049	0.042	0.049	0.042	0.078
108	Spring	1	34	0.026	0.008	0.026	0.028	0.026	0.037	0.026	0.122
108	Summer	1	38	0.037	0.005	0.037	0.034	0.037	0.031	0.037	0.082
108	Fall	1	39	0.023	0.005	0.023	0.010	0.023	0.012	0.023	0.034
121	Winter	1	33	0.041	0.006	0.041	0.056	0.041	0.054	0.041	0.130
121	Spring	1	35	0.056	0.005	0.056	0.010	0.056	0.016	0.056	0.081
121	Summer	1	36	0.006	0.005	0.006	0.010	0.006	0.015	0.006	0.092
121	Fall	1	41	0.014	0.005	0.014	0.007	0.014	0.015	0.014	0.087
108A	Winter	6	38	0.022	0.005	0.042	0.048	0.041	0.049	0.055	0.085
108A	Spring	7	40	0.011	0.005	0.015	0.017	0.017	0.034	0.027	0.102
108A	Summer	6	39	0.005	0.005	0.012	0.010	0.011	0.012	0.017	0.026
108A	Fall	7	38	0.005	0.005	0.009	0.007	0.013	0.030	0.039	0.496
108B	Winter	6	38	0.066	0.013	0.086	0.068	0.086	0.062	0.107	0.102
108B	Spring	7	39	0.041	0.009	0.059	0.049	0.108	0.079	0.406	0.543
108B	Summer	6	38	0.026	0.009	0.065	0.073	0.117	0.074	0.399	0.174
108B	Fall	7	38	0.056	0.011	0.079	0.064	0.107	0.069	0.170	0.177
108C	Winter	6	38	0.015	0.005	0.028	0.025	0.054	0.026	0.133	0.062
108C	Spring	7	39	0.006	0.005	0.018	0.039	0.016	0.034	0.029	0.058
108C	Summer	6	39	0.005	0.005	0.013	0.036	0.030	0.073	0.120	0.227
108C	Fall	7	36	0.005	0.005	0.053	0.029	0.071	0.056	0.140	0.192
117	Winter	6	-	0.005	-	0.011	-	0.024	-	0.058	-
117	Spring	7	-	0.005	-	0.005	-	0.007	-	0.016	-
117	Summer	6	-	0.005	-	0.005	-	0.005	-	0.006	-
117	Fall	2	-	0.005	-	0.005	-	0.005	-	0.005	-

3.2.5.1.3 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) concentrations in Quabbin Reservoir Watershed Core tributary sites ranged from 0.1 to 0.679 mg/L in 2024 (Table 29). TKN concentrations in Ware River Watershed Core tributary sites ranged from 0.1 to 0.893 mg/L during 2024 (Table 30). TKN dynamics in Core tributaries in the Quabbin Reservoir and Ware River Watersheds loosely mirrored that of TP and organic content, with enrichment during summer months coinciding with biological productivity and vegetative growth cycles (Figure 24). Median summer results were slightly elevated in 2024 relative to historical summer medians at several sites across both watersheds (101, 211, 212, 213, 215G, 216, GATE). A new spring TKN maximum was recorded at the Ware River at Shaft 8 Intake (site 101) in 2023 (0.619 mg/L on May 28, 2024). Periodic elevated TKN results in the spring and summer documented at sites across watersheds were mostly attributed to samples collected during or following rainfall events. The increased turbulence and mixing of water during high flow events following precipitation can resuspend sediment and organic matter from the streambed, releasing stored nutrients like TKN into the water column. Fall results were lower than normal at several sites (e.g., 211, 212, 213, 216, 101) due to decreased streamflow and subsequent nutrient transport during the 2024 drought period. Above normal TKN concentrations were observed in results at numerous sites in the Quabbin Reservoir Watershed (e.g., 212, 216, GATE, BC) during the Dec 30 rain-on-snow event. Monitoring results of TKN from 2024 reflect the importance of seasonal hydrological dynamics in influencing TKN transport, particularly the role of precipitation events in nutrient mobilization during the growing season, as well as the impact of drought conditions on nutrient availability in the fall. Continued nutrient monitoring at these tributaries provide insights into how changing weather patterns and climatic conditions (e.g., varying seasonal drought and flood cycles) may affect nitrogen dynamics in these forested watersheds.

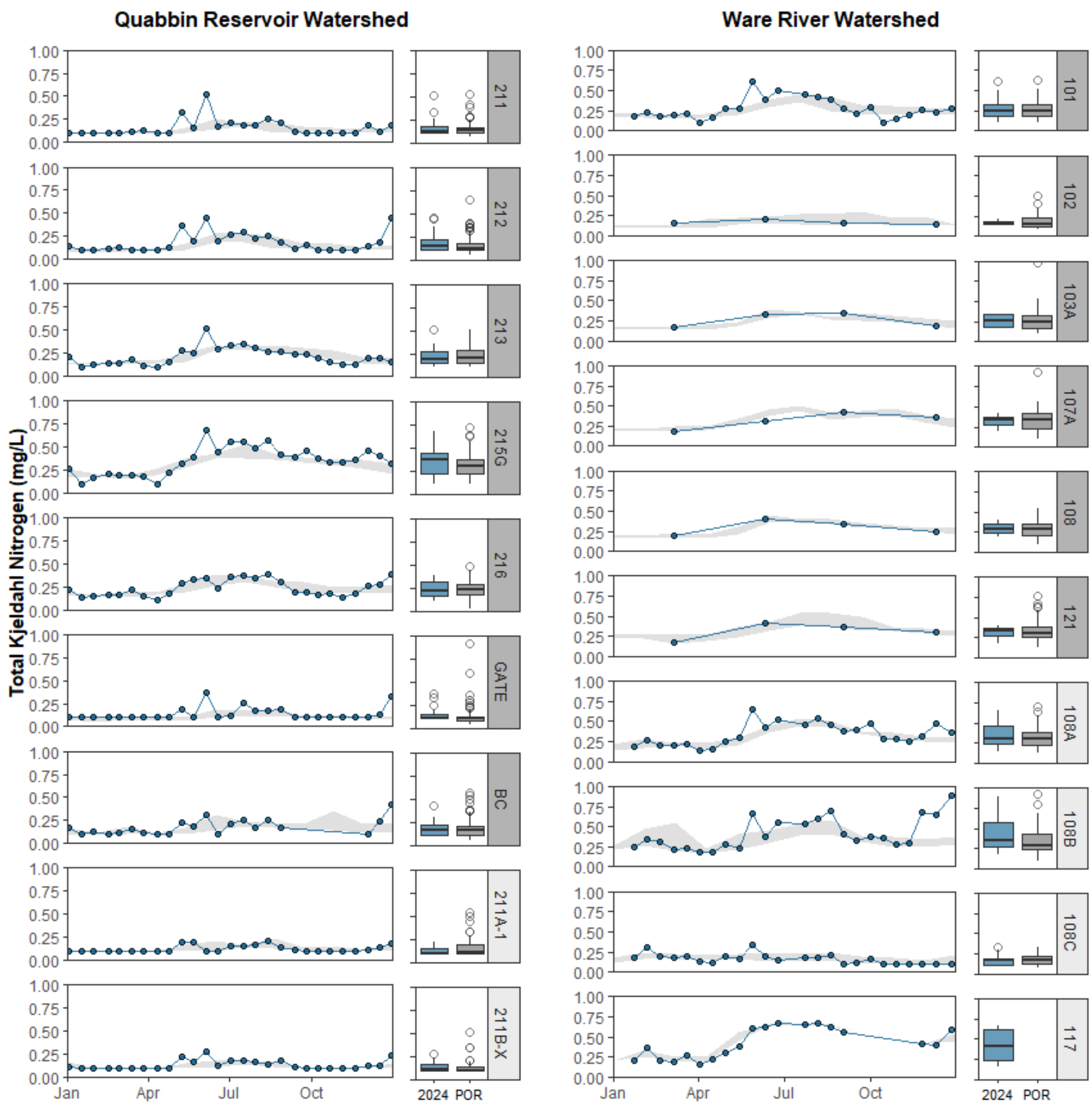


Figure 24. *Time series and boxplots of 2024 TKN results (blue) from tributary monitoring sites compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 29. *Seasonal statistics for Total Kjeldahl Nitrogen measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR). Detection limits for TKN were less than 0.100 mg/L.*

Total Kjeldahl Nitrogen (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	38	0.100	0.060	0.105	0.100	0.123	0.119	0.181	0.281
211	Spring	6	42	0.100	0.071	0.121	0.100	0.156	0.108	0.328	0.187
211	Summer	7	45	0.165	0.068	0.213	0.160	0.249	0.187	0.515	0.520
211	Fall	6	43	0.100	0.086	0.100	0.146	0.102	0.148	0.110	0.219
212	Winter	8	37	0.100	0.057	0.132	0.100	0.168	0.120	0.442	0.358
212	Spring	6	42	0.100	0.047	0.112	0.100	0.164	0.123	0.360	0.387
212	Summer	7	44	0.190	0.100	0.260	0.186	0.268	0.215	0.454	0.653
212	Fall	6	43	0.100	0.073	0.100	0.128	0.111	0.143	0.159	0.257
213	Winter	8	38	0.100	0.100	0.145	0.137	0.156	0.159	0.202	0.402
213	Spring	6	42	0.101	0.100	0.169	0.157	0.182	0.169	0.280	0.330
213	Summer	7	43	0.263	0.190	0.312	0.303	0.333	0.302	0.516	0.504
213	Fall	6	43	0.126	0.133	0.171	0.231	0.178	0.248	0.238	0.426
215G	Winter	8	28	0.100	0.100	0.232	0.219	0.262	0.228	0.462	0.392
215G	Spring	6	32	0.100	0.135	0.210	0.220	0.235	0.263	0.393	0.617
215G	Summer	7	34	0.415	0.268	0.554	0.410	0.528	0.400	0.679	0.567
215G	Fall	6	31	0.330	0.191	0.366	0.325	0.373	0.339	0.455	0.713
216	Winter	8	38	0.129	0.100	0.190	0.176	0.217	0.207	0.388	0.348
216	Spring	6	42	0.109	0.100	0.197	0.171	0.212	0.183	0.333	0.311
216	Summer	7	43	0.233	0.016	0.345	0.304	0.333	0.304	0.385	0.441
216	Fall	6	43	0.136	0.151	0.180	0.243	0.173	0.251	0.196	0.480
BC	Winter	8	38	0.100	0.054	0.125	0.149	0.174	0.153	0.425	0.275
BC	Spring	6	42	0.100	0.066	0.138	0.113	0.146	0.131	0.221	0.242
BC	Summer	7	36	0.100	0.100	0.214	0.205	0.210	0.237	0.305	0.562
BC	Fall	-	37	-	0.100	-	0.168	-	0.203	-	0.450
GATE	Winter	8	38	0.100	0.035	0.100	0.091	0.132	0.097	0.330	0.295
GATE	Spring	6	42	0.100	0.044	0.100	0.100	0.116	0.089	0.193	0.146
GATE	Summer	7	40	0.107	0.063	0.180	0.126	0.199	0.175	0.369	0.916
GATE	Fall	6	42	0.100	0.061	0.100	0.100	0.100	0.114	0.100	0.302
211A-1	Winter	8	21	0.100	0.100	0.100	0.100	0.118	0.180	0.177	0.498
211A-1	Spring	6	19	0.100	0.100	0.100	0.100	0.132	0.118	0.198	0.331
211A-1	Summer	7	20	0.100	0.100	0.153	0.155	0.147	0.198	0.212	0.543
211A-1	Fall	6	18	0.100	0.100	0.100	0.133	0.103	0.138	0.116	0.219
211B-X	Winter	8	20	0.100	0.100	0.106	0.100	0.125	0.140	0.231	0.342
211B-X	Spring	6	19	0.100	0.100	0.100	0.100	0.133	0.119	0.228	0.348
211B-X	Summer	7	20	0.129	0.100	0.176	0.133	0.178	0.161	0.276	0.505
211B-X	Fall	6	18	0.100	0.100	0.100	0.100	0.102	0.111	0.110	0.199

Table 30. *Seasonal statistics for TKN measured in the Ware River Watershed tributary sites.*

Total Kjeldahl Nitrogen (mg/L)											
Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	5	33	0.173	0.139	0.227	0.210	0.216	0.223	0.275	0.391
101	Spring	7	32	0.100	0.100	0.205	0.186	0.260	0.191	0.619	0.337
101	Summer	5	34	0.380	0.168	0.426	0.346	0.428	0.350	0.495	0.626
101	Fall	7	34	0.100	0.124	0.211	0.280	0.211	0.278	0.297	0.459
102	Winter	1	1	0.139	0.096	0.139	0.128	0.139	0.133	0.139	0.232
102	Spring	1	1	0.153	0.092	0.153	0.133	0.153	0.156	0.153	0.307
102	Summer	1	1	0.207	0.100	0.207	0.169	0.207	0.203	0.207	0.404
102	Fall	1	1	0.167	0.102	0.167	0.183	0.167	0.219	0.167	0.499
103A	Winter	1	35	0.188	0.117	0.188	0.180	0.188	0.192	0.188	0.391
103A	Spring	1	33	0.165	0.097	0.165	0.168	0.165	0.175	0.165	0.271
103A	Summer	1	37	0.332	0.175	0.332	0.324	0.332	0.351	0.332	0.971
103A	Fall	1	38	0.340	0.137	0.340	0.269	0.340	0.289	0.340	0.513
107A	Winter	1	35	0.352	0.122	0.352	0.219	0.352	0.248	0.352	0.526
107A	Spring	1	33	0.191	0.100	0.191	0.219	0.191	0.236	0.191	0.480
107A	Summer	1	37	0.311	0.327	0.311	0.422	0.311	0.440	0.311	0.926
107A	Fall	1	38	0.420	0.185	0.420	0.382	0.420	0.379	0.420	0.511
108	Winter	1	35	0.246	0.101	0.246	0.208	0.246	0.224	0.246	0.381
108	Spring	1	34	0.196	0.100	0.196	0.205	0.196	0.211	0.196	0.386
108	Summer	1	37	0.403	0.281	0.403	0.375	0.403	0.389	0.403	0.541
108	Fall	1	38	0.341	0.182	0.341	0.311	0.341	0.313	0.341	0.478
121	Winter	1	33	0.306	0.179	0.306	0.259	0.306	0.287	0.306	0.644
121	Spring	1	35	0.172	0.122	0.172	0.250	0.172	0.253	0.172	0.398
121	Summer	1	35	0.407	0.187	0.407	0.399	0.407	0.436	0.407	0.766
121	Fall	1	40	0.360	0.263	0.360	0.352	0.360	0.369	0.360	0.591
108A	Winter	5	38	0.185	0.119	0.266	0.224	0.299	0.229	0.480	0.399
108A	Spring	7	38	0.145	0.124	0.217	0.204	0.274	0.236	0.656	0.638
108A	Summer	5	36	0.427	0.309	0.464	0.434	0.482	0.442	0.539	0.698
108A	Fall	7	38	0.245	0.217	0.314	0.331	0.339	0.323	0.477	0.491
108B	Winter	5	38	0.240	0.100	0.347	0.276	0.487	0.308	0.893	0.690
108B	Spring	7	37	0.180	0.100	0.225	0.212	0.285	0.293	0.664	0.687
108B	Summer	5	36	0.382	0.251	0.555	0.433	0.552	0.442	0.691	0.923
108B	Fall	7	38	0.281	0.172	0.363	0.265	0.389	0.302	0.678	0.498
108C	Winter	5	38	0.101	0.093	0.173	0.188	0.174	0.186	0.301	0.326
108C	Spring	7	38	0.112	0.129	0.173	0.200	0.186	0.194	0.334	0.314
108C	Summer	5	36	0.150	0.091	0.185	0.183	0.183	0.182	0.210	0.302
108C	Fall	7	36	0.100	0.082	0.100	0.113	0.111	0.148	0.170	0.289
117	Winter	5	-	0.212	-	0.371	-	0.357	-	0.584	-
117	Spring	7	-	0.151	-	0.267	-	0.304	-	0.613	-
117	Summer	5	-	0.623	-	0.655	-	0.650	-	0.673	-
117	Fall	2	-	0.410	-	0.483	-	0.483	-	0.556	-

3.2.5.2 Total Phosphorus

Total phosphorus (TP) concentrations measured in monitoring tributaries of the Quabbin Reservoir during 2024 ranged from less than 0.005 to 0073 mg/L (Table 31). In the Ware River Watershed, TP concentrations were between less than 0.005 to 0.061 mg/L in 2024 (Table 32). In tributaries in the Quabbin Reservoir Watershed and Ware River Watershed, TP concentrations exhibited distinct seasonality, with generally higher results during the summer and early fall and comparatively lower during the spring and winter (Figure 25). These patterns are consistent with other forested headwater catchments in the NE USA (Lisboa et al., 2020).

Seasonal median concentrations of TP were comparable to the period of record, with summer median TP concentrations lower than average in certain tributaries of the Ware River Watershed (103A, 108, 121). TP concentrations in the Ware River Watershed were largely within seasonal historical ranges at Core monitoring locations. Elevated total phosphorous coincided with high discharge events from documented spring rain (May) and winter rain-on-snow events (December) in 2024 and resulted in new seasonal maximums for spring (at 211, 212, 216) and winter (at 212, 213, 216) at certain Quabbin Reservoir Watershed Core tributaries. Quabbin Reservoir Watershed EQA sites (211A-1 and 211B-X) were inconsistently sampled for TP in the first half of 2024, obscuring seasonal results for these sites in winter and spring. Variations in TP concentrations across Quabbin Reservoir and Ware River Watersheds sites may be partially attributed to variations in land cover, wetland connectivity, groundwater contributions, and timing of sample collection relative to hydrometeorological events (Reddy et al., 1999; Lisboa et al., 2016).

Table 31. *Seasonal statistics for total phosphorus measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR). Detection limits for TP were 0.005 mg/L.*

Total Phosphorus (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	28	0.005	0.005	0.005	0.009	0.008	0.01	0.02	0.018
211	Spring	6	31	0.005	0.005	0.006	0.01	0.011	0.011	0.03	0.024
211	Summer	7	31	0.007	0.006	0.011	0.013	0.011	0.015	0.014	0.044
211	Fall	6	29	0.005	0.005	0.006	0.01	0.007	0.011	0.009	0.022
212	Winter	8	27	0.005	0.005	0.006	0.011	0.013	0.012	0.05	0.028
212	Spring	6	31	0.005	0.005	0.012	0.014	0.022	0.013	0.073	0.023
212	Summer	7	31	0.015	0.011	0.021	0.019	0.021	0.024	0.027	0.093
212	Fall	6	29	0.005	0.007	0.01	0.014	0.01	0.017	0.016	0.045
213	Winter	8	28	0.005	0.005	0.007	0.012	0.009	0.013	0.018	0.032
213	Spring	6	31	0.005	0.005	0.012	0.013	0.012	0.013	0.019	0.025
213	Summer	7	31	0.013	0.008	0.021	0.021	0.02	0.021	0.023	0.039
213	Fall	6	29	0.007	0.008	0.012	0.016	0.013	0.016	0.019	0.037
215G	Winter	8	27	0.005	0.007	0.005	0.014	0.012	0.013	0.025	0.02
215G	Spring	6	32	0.006	0.007	0.011	0.013	0.012	0.013	0.021	0.027
215G	Summer	7	34	0.016	0.009	0.023	0.022	0.022	0.022	0.026	0.032
215G	Fall	6	31	0.015	0.009	0.017	0.017	0.018	0.017	0.022	0.024
216	Winter	8	28	0.005	0.005	0.007	0.014	0.012	0.015	0.039	0.054
216	Spring	6	31	0.008	0.007	0.011	0.016	0.015	0.015	0.03	0.022
216	Summer	7	31	0.016	0.009	0.022	0.024	0.023	0.024	0.033	0.045
216	Fall	6	29	0.007	0.01	0.011	0.015	0.01	0.017	0.013	0.044
BC	Winter	8	28	0.005	0.007	0.007	0.014	0.012	0.015	0.035	0.031
BC	Spring	6	31	0.007	0.007	0.009	0.018	0.011	0.018	0.017	0.031
BC	Summer	7	28	0.013	0.008	0.021	0.021	0.02	0.023	0.026	0.061
BC	Fall	-	28	-	0.008	-	0.017	-	0.019	-	0.037
GATE	Winter	8	28	0.005	0.005	0.005	0.009	0.01	0.009	0.031	0.017
GATE	Spring	6	31	0.005	0.005	0.005	0.01	0.007	0.01	0.016	0.017
GATE	Summer	7	29	0.012	0.005	0.015	0.013	0.015	0.02	0.02	0.129
GATE	Fall	6	28	0.008	0.005	0.013	0.014	0.012	0.013	0.015	0.025
211A-1	Winter	3	12	0.005	0.005	0.014	0.007	0.013	0.008	0.02	0.012
211A-1	Spring	1	8	0.005	0.005	0.005	0.007	0.005	0.007	0.005	0.011
211A-1	Summer	7	5	0.007	0.008	0.01	0.01	0.011	0.013	0.015	0.021
211A-1	Fall	6	7	0.006	0.012	0.01	0.017	0.01	0.017	0.014	0.023
211B-X	Winter	3	11	0.008	0.006	0.014	0.007	0.016	0.008	0.024	0.011
211B-X	Spring	1	8	0.005	0.005	0.005	0.007	0.005	0.008	0.005	0.011
211B-X	Summer	7	5	0.007	0.008	0.012	0.009	0.011	0.011	0.014	0.017
211B-X	Fall	6	7	0.006	0.011	0.007	0.014	0.009	0.014	0.015	0.019

Table 32. *Seasonal statistics for TP measured in Ware River Watershed tributary sites.*

Total Phosphorus (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	5	27	0.005	0.007	0.006	0.014	0.01	0.014	0.02	0.026
101	Spring	7	28	0.007	0.007	0.009	0.014	0.013	0.014	0.027	0.026
101	Summer	6	27	0.005	0.018	0.03	0.027	0.028	0.03	0.043	0.059
101	Fall	7	28	0.015	0.009	0.02	0.021	0.019	0.022	0.025	0.044
102	Winter	1	13	0.022	0.01	0.022	0.018	0.022	0.017	0.022	0.026
102	Spring	1	14	0.013	0.011	0.013	0.016	0.013	0.02	0.013	0.046
102	Summer	1	14	0.013	0.022	0.013	0.028	0.013	0.028	0.013	0.038
102	Fall	1	15	0.019	0.014	0.019	0.028	0.019	0.033	0.019	0.145
103A	Winter	1	24	0.014	0.008	0.014	0.013	0.014	0.014	0.014	0.029
103A	Spring	1	23	0.022	0.007	0.022	0.013	0.022	0.013	0.022	0.027
103A	Summer	1	24	0.014	0.019	0.014	0.027	0.014	0.028	0.014	0.045
103A	Fall	1	24	0.019	0.011	0.019	0.024	0.019	0.023	0.019	0.04
107A	Winter	1	24	0.021	0.007	0.021	0.013	0.021	0.014	0.021	0.02
107A	Spring	1	24	0.009	0.009	0.009	0.013	0.009	0.014	0.009	0.025
107A	Summer	1	24	0.006	0.017	0.006	0.026	0.006	0.026	0.006	0.043
107A	Fall	1	24	0.014	0.01	0.014	0.022	0.014	0.022	0.014	0.036
108	Winter	1	24	0.015	0.006	0.015	0.012	0.015	0.013	0.015	0.034
108	Spring	1	24	0.008	0.008	0.008	0.011	0.008	0.012	0.008	0.024
108	Summer	1	24	0.005	0.016	0.005	0.023	0.005	0.024	0.005	0.043
108	Fall	1	24	0.016	0.008	0.016	0.02	0.016	0.021	0.016	0.041
121	Winter	1	26	0.017	0.008	0.017	0.013	0.017	0.013	0.017	0.02
121	Spring	1	27	0.008	0.005	0.008	0.013	0.008	0.016	0.008	0.036
121	Summer	1	27	0.005	0.015	0.005	0.026	0.005	0.028	0.005	0.056
121	Fall	1	28	0.013	0.01	0.013	0.016	0.013	0.021	0.013	0.056
108A	Winter	5	19	0.005	0.008	0.008	0.015	0.02	0.014	0.061	0.021
108A	Spring	7	20	0.006	0.008	0.008	0.015	0.012	0.015	0.026	0.031
108A	Summer	6	18	0.011	0.018	0.028	0.028	0.026	0.031	0.033	0.093
108A	Fall	7	19	0.009	0.007	0.017	0.017	0.016	0.018	0.019	0.024
108B	Winter	5	19	0.006	0.007	0.008	0.015	0.012	0.016	0.023	0.025
108B	Spring	7	20	0.007	0.009	0.009	0.015	0.012	0.017	0.023	0.046
108B	Summer	6	18	0.005	0.013	0.029	0.025	0.026	0.04	0.034	0.224
108B	Fall	7	19	0.009	0.006	0.019	0.013	0.017	0.015	0.025	0.023
108C	Winter	5	19	0.005	0.005	0.005	0.009	0.007	0.009	0.01	0.014
108C	Spring	7	20	0.005	0.005	0.005	0.01	0.006	0.01	0.009	0.015
108C	Summer	6	18	0.005	0.005	0.007	0.009	0.007	0.009	0.008	0.016
108C	Fall	7	19	0.005	0.005	0.006	0.009	0.007	0.009	0.012	0.013
117	Winter	5	-	0.005	-	0.005	-	0.01	-	0.021	-
117	Spring	7	-	0.006	-	0.009	-	0.009	-	0.014	-
117	Summer	6	-	0.005	-	0.022	-	0.02	-	0.026	-
117	Fall	2	-	0.01	-	0.015	-	0.015	-	0.02	-

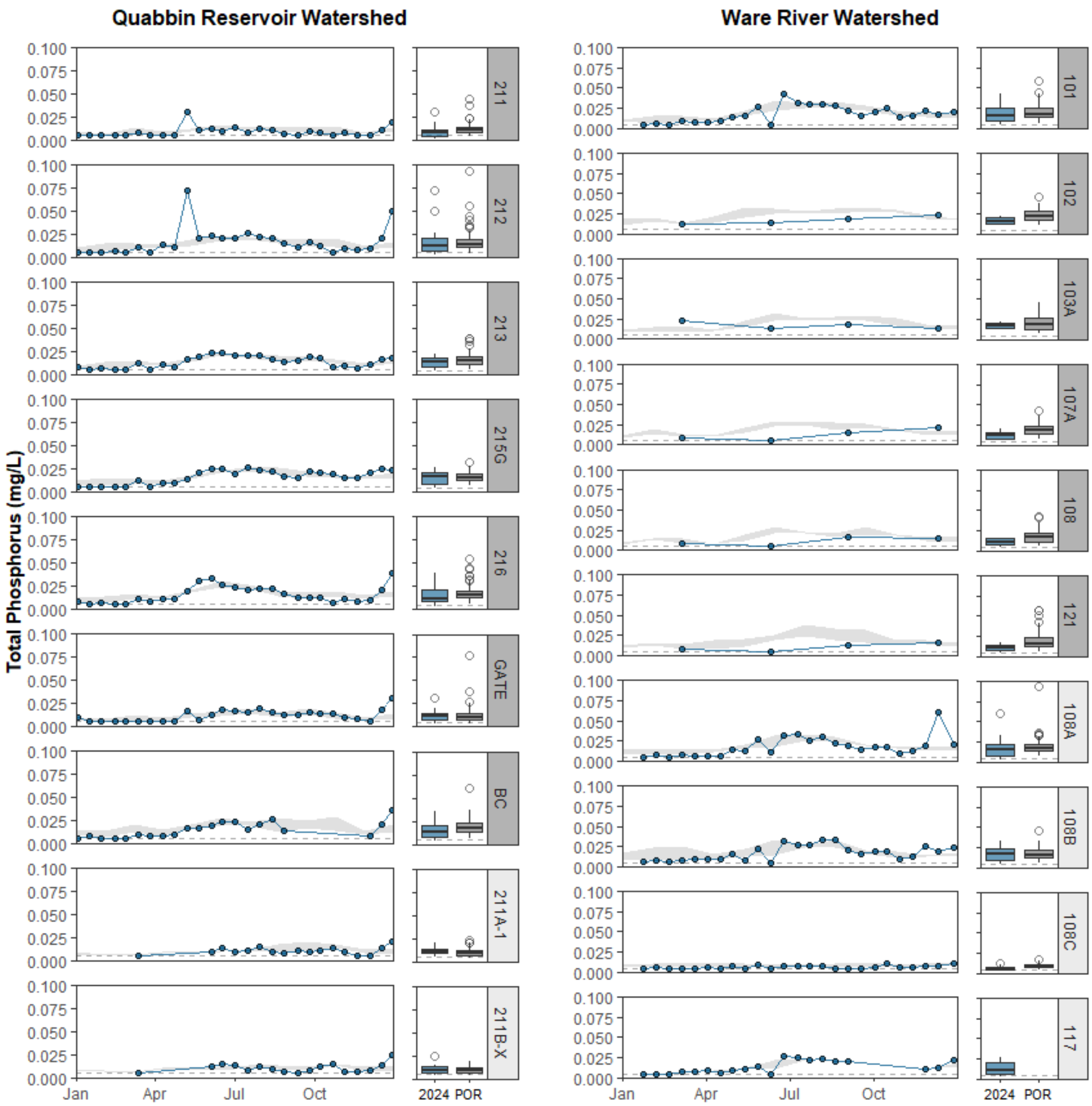


Figure 25. *Time series and boxplots of 2024 total phosphorus results (blue) from tributary monitoring sites compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. The horizontal dashed grey line corresponds to laboratory detection limits (0.005 mg/L). Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

3.2.6 Total Organic Carbon and UV_{254}

3.2.6.1 Total Organic Carbon

Total organic carbon (TOC) was introduced to DWSP monitoring programs in 2021 as an additional proxy for understanding disinfection-byproduct precursor potential of source waters in the Quabbin Reservoir Watershed (Golea et al., 2017). TOC was monitored every two weeks in Core tributaries in the Quabbin Reservoir Watershed beginning in 2021. TOC was added to site 101 (Ware River at Shaft 8 Intake) and EQA sites beginning in 2023. Thus, annual monitoring continues to inform the full range of variability of concentrations of TOC in time and space throughout the Quabbin Reservoir and Ware River watersheds, with limited insight into long-term patterns. However, when considered with historical observations of mean UV_{254}, these analytes provide insight regarding the quantity and type of organic matter, as well as controls on its transport at the catchment scale (Garvey and Tobiason, 2003). High-resolution concentrations of TOC, in tandem with UV_{254} absorbance and streamflow data, may elucidate potential hot spots or hot moments of organic carbon loading to Quabbin Reservoir.

Concentrations of TOC ranged from 1.4 to 12.8 mg/L in tributaries of the Quabbin Reservoir Watershed and site 101 of the Ware River Watershed in 2024 (Table 33). Median seasonal monitoring results for TOC in 2024 were generally comparable or lower to those observed from the previous three years of monitoring for Quabbin Core sites (e.g., 211, 212, 213, 215G, 216, GATE, and BC, see Figure 26). Some notable exceptions are 2024 summer medians at 215G (0.66 mg/L above historical summer median) and 216 (1.11 mg/L above historical summer median). Overall lower annual medians compared to the period of record observations can be in part attributed to the consistent below normal fall TOC concentration at multiple Quabbin Reservoir Core sites. This prolonged drought period of limited rainfall and low streamflow flow conditions allowed for accumulation of fall leaf-fall and detritus within exposed stream channels and streambanks. The return of precipitation in the winter, combined with rain-on-snow flood dynamics, lead to an end-of-year pulse in TOC export, and new winter maximum TOCs were recorded at numerous sites in 2024 (211, 215G, 216, BC, GATE). These new winter maximums were most pronounced at the low-order streams of Quabbin, (i.e., Boat Cove Brook (site BC) and Gates Brook (site GATE)), where winter maximums were 6.24 and 4.84 mg/L higher than previous years. Seasonal average concentrations of total organic carbon were lower at Ware River Shaft 8 monitoring location (site 101) in its second year of monitoring, highlighting the importance of multi-year monitoring for understanding the full range of seasonal variability under different hydrological conditions (e.g., extreme precipitation in summer 2023, prolonged drought in 2024, etc.).

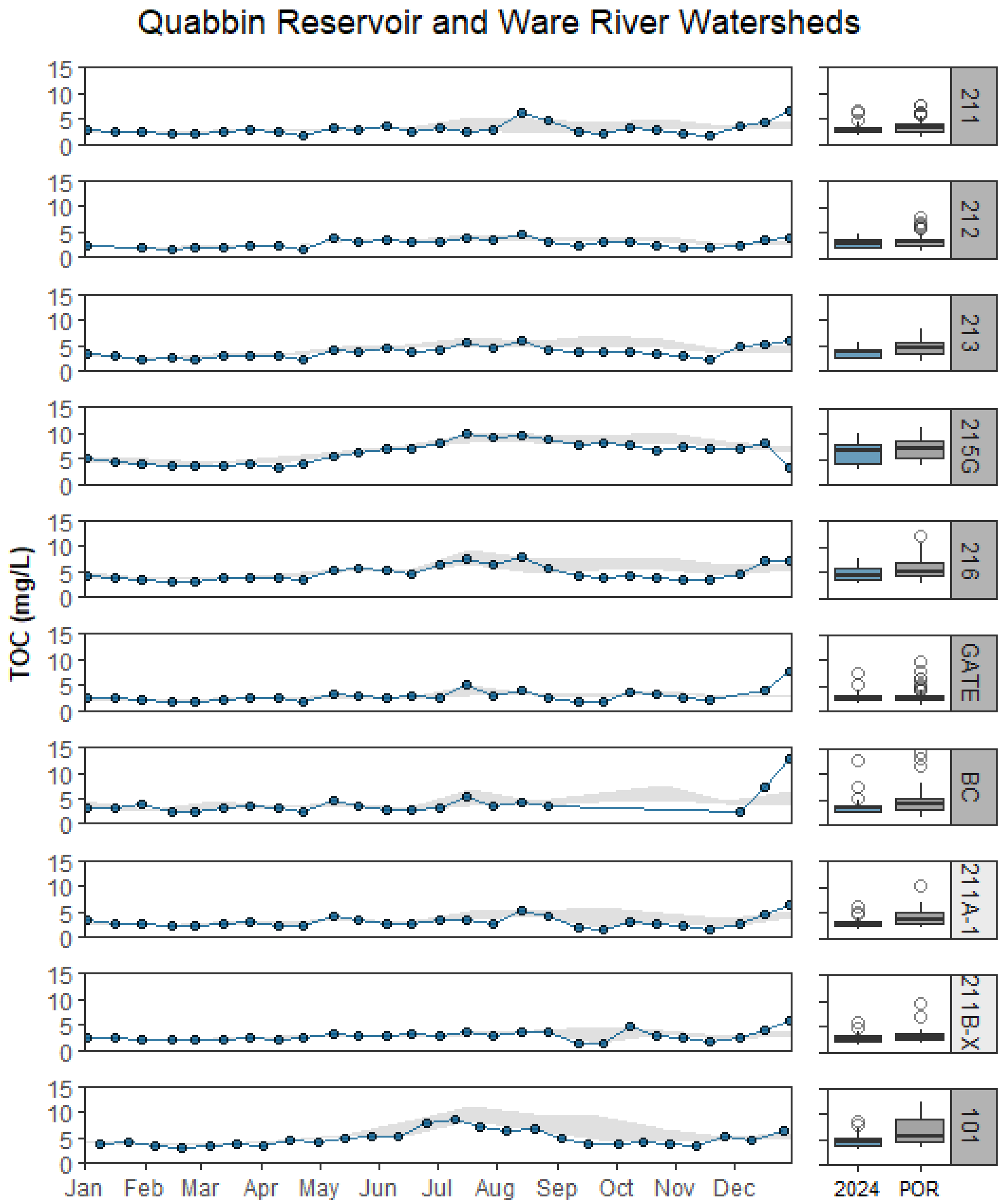


Figure 26. *Time series and boxplots of 2024 total organic carbon results (blue) from tributary monitoring sites compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 33. *Seasonal statistics for total organic carbon measured in the Quabbin Reservoir and Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

Total Organic Carbon (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	17	2.11	1.79	2.70	2.80	3.38	2.93	6.54	5.39
211	Spring	6	21	1.92	2.02	2.72	2.73	2.69	2.92	3.28	4.54
211	Summer	7	21	2.49	1.38	3.46	3.38	3.75	3.84	6.27	7.74
211	Fall	6	18	1.95	2.70	2.37	3.76	2.49	4.37	3.24	7.68
212	Winter	7	17	1.83	1.32	2.33	2.26	2.58	2.37	3.92	4.22
212	Spring	6	21	1.72	1.58	2.37	2.52	2.60	2.63	3.96	4.04
212	Summer	7	20	3.08	2.41	3.56	3.48	3.58	4.01	4.61	7.90
212	Fall	6	18	1.86	2.54	2.32	3.41	2.43	3.75	3.10	6.45
213	Winter	8	18	2.21	1.96	3.05	3.23	3.57	3.37	5.81	5.97
213	Spring	6	21	2.37	2.31	2.89	3.40	3.13	3.76	4.00	6.22
213	Summer	7	21	3.65	4.28	4.47	5.05	4.58	5.56	5.85	8.36
213	Fall	6	18	2.31	3.49	3.55	5.25	3.33	5.41	3.91	7.92
215G	Winter	8	16	3.05	3.78	4.05	5.53	4.79	5.56	8.08	7.96
215G	Spring	6	21	3.33	3.63	4.02	4.69	4.46	5.09	6.24	7.76
215G	Summer	7	20	6.86	6.28	8.93	8.27	8.46	8.60	9.85	11.00
215G	Fall	6	18	6.65	6.28	7.49	8.85	7.43	8.93	8.14	10.80
216	Winter	8	18	3.00	3.44	4.09	4.69	4.59	4.70	7.10	6.77
216	Spring	6	21	3.33	2.99	3.88	4.22	4.30	4.53	5.79	7.00
216	Summer	7	21	4.42	3.69	6.26	5.15	6.25	6.23	7.78	10.60
216	Fall	6	17	3.36	5.05	3.89	7.12	3.85	7.16	4.25	12.20
BC	Winter	8	18	2.30	1.61	3.23	3.86	4.70	4.02	12.80	6.56
BC	Spring	6	21	2.31	2.55	3.20	3.56	3.34	3.83	4.81	6.25
BC	Summer	7	18	2.62	2.38	3.61	3.70	3.63	4.95	5.37	14.30
BC	Fall	-	18	-	3.23	-	4.65	-	5.72	-	13.20
GATE	Winter	7	17	1.86	1.34	2.44	2.42	3.24	2.34	7.65	2.81
GATE	Spring	6	21	1.80	1.82	2.51	2.38	2.53	2.56	3.32	4.07
GATE	Summer	7	19	2.40	1.77	2.80	2.93	3.24	3.53	5.28	9.98
GATE	Fall	6	18	1.88	2.39	2.39	3.00	2.59	3.55	3.59	7.95
211A-1	Winter	8	6	2.35	2.26	2.75	3.04	3.37	3.32	6.34	5.17
211A-1	Spring	6	7	2.14	2.18	2.71	3.28	2.85	3.18	3.96	4.56
211A-1	Summer	7	7	2.47	2.61	3.27	4.72	3.38	5.16	5.24	10.50
211A-1	Fall	6	6	1.64	3.40	1.92	4.96	2.12	4.99	2.90	6.97
211B-X	Winter	8	6	2.07	1.81	2.43	2.45	2.96	2.67	5.85	4.00
211B-X	Spring	6	7	2.02	1.81	2.47	2.81	2.52	2.62	3.12	3.41
211B-X	Summer	7	7	2.74	2.35	3.06	3.64	3.17	4.18	3.66	9.45
211B-X	Fall	6	6	1.40	2.82	2.07	3.62	2.45	3.98	4.85	6.71
101	Winter	6	5	2.93	3.69	4.07	4.52	4.27	4.61	6.32	5.42
101	Spring	7	7	3.34	3.53	4.35	4.86	4.20	4.89	5.28	6.43
101	Summer	6	6	5.39	5.42	6.90	10.25	7.05	9.81	8.79	12.20
101	Fall	7	7	3.54	4.74	3.97	7.04	4.27	7.43	5.31	10.40

3.2.6.2 UV_{254}

UV_{254} absorbance in Quabbin Reservoir Watershed tributary monitoring sites ranged from 0.048 to 0.582 ABU/cm in 2024 (Figure 27, Table 34). UV_{254} followed similar seasonal patterns as Total Organic Carbon in 2024, with results generally elevated above seasonal averages in the summer and results below average in fall. Summer medians were slightly elevated across most of the Quabbin Reservoir Watershed in 2024 (mean difference of 0.03 ABU/cm compared to period of record summer medians), with 2024 summer medians more elevated at sites with a higher proportion of upstream wetland area (216G and 216, see Table 4). A new maximum summer UV_{254} readings was recorded at East Branch Fever Brook in 2024 (site 215G, 0.582 ABU/cm), although 2024 summer maximums at other sites were within established historical ranges. UV_{254} readings dropped considerably in the fall, as a lack of precipitation and subsequent streamflow limited in-stream carbon transport processes. Late winter precipitation following prolonged fall drought conditions lead to a marked increase in UV_{254} readings across the Quabbin Reservoir Watershed tributaries. New winter UV_{254} maximums were recorded at three Quabbin tributary monitoring locations (212, BC, GATE) during the December 30th rain-on-snow event in 2024. Prior to 2020, UV_{254} was measured quarterly in Quabbin Reservoir Watershed Core tributaries (DWSP, 2019a). Thus, some of the variability in UV_{254} observed in 2024 relative to historical seasonal ranges may be attributed to differences in sample frequencies, with more frequent samples more likely to capture hydrological-driven variability in stream UV_{254} dynamics.

UV_{254} absorbance in Ware River Watershed tributary monitoring sites ranged from 0.045 to 0.742 ABU/cm in 2024 (Table 35, Figure 27). Similar to results from the Quabbin watershed sites, and consistent with annual TOC seasonal patterns in Ware River Watershed. Average UV_{254} readings were slightly elevated in the summer and below average in the fall of 2024. Median summer results were about 0.1 ABU/cm elevated in 2024 at sites along the Ware River (101, 103A, and 107A) in 2024. One new summer maximum was recorded in 2024 (Ware River downstream of confluence with the Burnshirt, site 103A, 0.594 ABU/cm). UV_{254} was generally greater in Core tributaries in the Ware River Watershed compared to Core tributaries in the Quabbin Reservoir Watershed. A greater percentage of wetlands comprises the upstream reaches of Core tributaries in the Ware River Watershed (Table 4). The timing of seasonal variability in absorbance values of UV_{254} was comparable between Ware River and Quabbin Reservoir Watersheds for 2024 (e.g., UV_{254} absorbance peaked during summer months for both watersheds, coincident with warmer water temperatures; declining values during fall drought). Moreover, historical variations in sampling frequencies (e.g., quarterly vs. every two weeks) in Core monitoring tributaries in the Quabbin Reservoir Watershed compared to those in the Ware River Watershed may serve to mask inter-watershed differences in pre-2020 data.

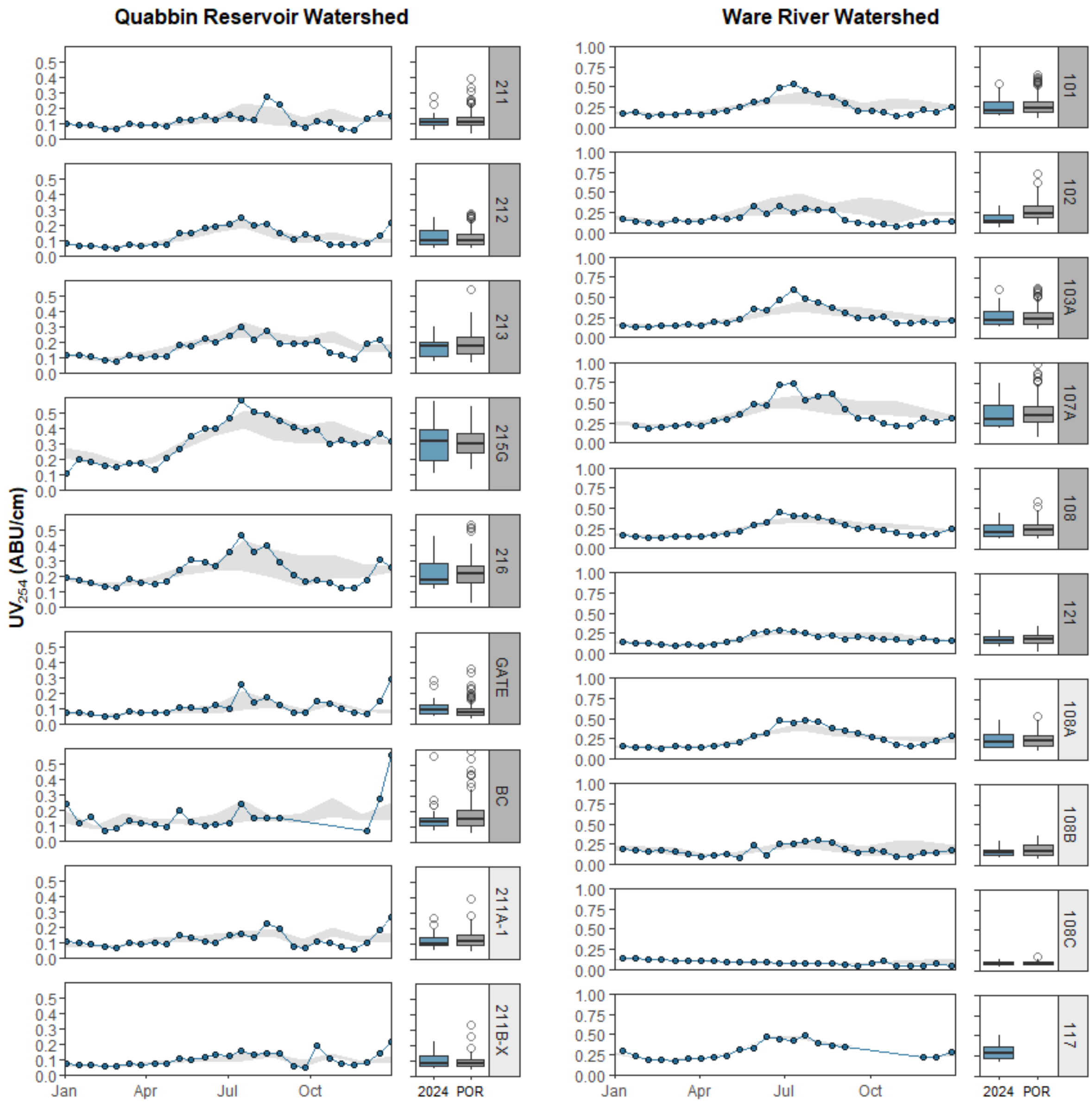


Figure 27. *Time series and boxplots of 2024 UV_{254} results (blue) from tributary monitoring sites compared against each site's period of record (gray). The gray shaded bands represent monthly interquartile range (25th to 75th percentile) for the period of record at each location. Dark gray site labels correspond to Core sampling locations; light gray site labels correspond to EQA sampling locations.*

Table 34. *Seasonal statistics for UV_{254} measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

Mean UV_{254} Absorbance (ABU/cm)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	34	0.063	0.066	0.095	0.108	0.106	0.112	0.164	0.226
211	Spring	6	38	0.080	0.060	0.094	0.086	0.100	0.096	0.123	0.221
211	Summer	7	40	0.122	0.033	0.151	0.128	0.170	0.150	0.274	0.390
211	Fall	6	36	0.058	0.041	0.084	0.131	0.085	0.135	0.111	0.309
212	Winter	8	34	0.052	0.049	0.072	0.079	0.094	0.082	0.216	0.161
212	Spring	6	38	0.066	0.048	0.076	0.078	0.098	0.086	0.150	0.157
212	Summer	7	39	0.148	0.067	0.202	0.167	0.198	0.171	0.248	0.279
212	Fall	6	36	0.073	0.052	0.091	0.112	0.098	0.117	0.141	0.258
213	Winter	8	34	0.074	0.072	0.114	0.127	0.127	0.136	0.212	0.277
213	Spring	6	38	0.097	0.065	0.111	0.116	0.131	0.135	0.184	0.292
213	Summer	7	40	0.194	0.182	0.221	0.238	0.234	0.257	0.298	0.546
213	Fall	6	36	0.094	0.124	0.160	0.202	0.155	0.209	0.207	0.346
215G	Winter	8	28	0.108	0.170	0.190	0.270	0.223	0.264	0.365	0.361
215G	Spring	6	32	0.130	0.132	0.192	0.207	0.216	0.218	0.347	0.342
215G	Summer	7	34	0.395	0.262	0.466	0.386	0.470	0.399	0.582	0.547
215G	Fall	6	31	0.296	0.230	0.356	0.357	0.351	0.361	0.404	0.548
216	Winter	8	34	0.122	0.130	0.176	0.217	0.189	0.215	0.308	0.322
216	Spring	6	38	0.152	0.108	0.172	0.165	0.200	0.180	0.310	0.320
216	Summer	7	40	0.263	0.121	0.357	0.257	0.346	0.283	0.462	0.520
216	Fall	6	36	0.119	0.029	0.160	0.259	0.157	0.249	0.208	0.537
BC	Winter	8	34	0.068	0.052	0.138	0.153	0.195	0.162	0.559	0.290
BC	Spring	6	38	0.092	0.080	0.121	0.114	0.128	0.146	0.200	0.358
BC	Summer	7	34	0.102	0.082	0.147	0.137	0.143	0.192	0.241	0.587
BC	Fall	-	32	-	0.080	-	0.162	-	0.191	-	0.535
GATE	Winter	8	34	0.051	0.041	0.070	0.073	0.102	0.075	0.288	0.175
GATE	Spring	6	38	0.070	0.046	0.077	0.068	0.085	0.076	0.110	0.156
GATE	Summer	7	37	0.094	0.055	0.127	0.104	0.145	0.124	0.254	0.362
GATE	Fall	6	35	0.074	0.062	0.089	0.088	0.101	0.106	0.148	0.333
211A-1	Winter	8	21	0.067	0.059	0.095	0.096	0.121	0.094	0.262	0.207
211A-1	Spring	6	19	0.087	0.044	0.097	0.102	0.108	0.100	0.146	0.154
211A-1	Summer	7	21	0.101	0.086	0.146	0.140	0.149	0.155	0.223	0.387
211A-1	Fall	6	18	0.058	0.064	0.072	0.148	0.079	0.149	0.109	0.282
211B-X	Winter	8	20	0.055	0.042	0.071	0.065	0.095	0.065	0.219	0.131
211B-X	Spring	6	19	0.066	0.043	0.072	0.074	0.081	0.075	0.104	0.103
211B-X	Summer	7	21	0.110	0.052	0.135	0.096	0.134	0.112	0.158	0.333
211B-X	Fall	6	18	0.048	0.050	0.066	0.096	0.087	0.105	0.186	0.254

Table 35. *Seasonal statistics for UV_{254} measured in the Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

Mean UV_{254} Absorbance (ABU/cm)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	78	0.144	0.119	0.179	0.198	0.183	0.206	0.252	0.398
101	Spring	7	76	0.152	0.114	0.188	0.195	0.206	0.208	0.320	0.337
101	Summer	6	78	0.334	0.132	0.430	0.326	0.434	0.343	0.543	0.651
101	Fall	7	77	0.146	0.128	0.200	0.272	0.201	0.294	0.297	0.613
102	Winter	6	18	0.104	0.122	0.138	0.204	0.136	0.204	0.162	0.323
102	Spring	7	20	0.133	0.141	0.174	0.195	0.184	0.204	0.322	0.308
102	Summer	6	19	0.231	0.117	0.284	0.342	0.280	0.361	0.336	0.726
102	Fall	7	21	0.067	0.087	0.112	0.325	0.109	0.322	0.156	0.515
103A	Winter	6	96	0.138	0.103	0.152	0.178	0.163	0.184	0.221	0.384
103A	Spring	7	113	0.147	0.103	0.179	0.176	0.201	0.191	0.355	0.622
103A	Summer	6	120	0.337	0.150	0.451	0.345	0.450	0.349	0.594	0.587
103A	Fall	7	123	0.178	0.136	0.241	0.268	0.233	0.281	0.308	0.609
107A	Winter	5	100	0.189	0.172	0.217	0.270	0.233	0.275	0.308	0.550
107A	Spring	7	117	0.219	0.070	0.277	0.273	0.296	0.289	0.483	0.484
107A	Summer	6	116	0.467	0.155	0.594	0.486	0.611	0.491	0.742	0.985
107A	Fall	7	122	0.213	0.164	0.302	0.406	0.289	0.421	0.419	0.772
108	Winter	6	115	0.131	0.119	0.155	0.176	0.166	0.184	0.239	0.312
108	Spring	7	122	0.145	0.116	0.166	0.173	0.185	0.186	0.292	0.324
108	Summer	6	119	0.319	0.204	0.397	0.333	0.383	0.335	0.446	0.579
108	Fall	7	122	0.159	0.189	0.235	0.266	0.221	0.278	0.296	0.481
121	Winter	6	38	0.119	0.090	0.141	0.146	0.141	0.143	0.165	0.191
121	Spring	7	42	0.095	0.029	0.121	0.125	0.144	0.136	0.256	0.257
121	Summer	6	42	0.213	0.180	0.264	0.243	0.255	0.250	0.291	0.352
121	Fall	7	47	0.150	0.139	0.183	0.216	0.183	0.217	0.205	0.312
108A	Winter	6	38	0.133	0.116	0.150	0.165	0.182	0.178	0.289	0.356
108A	Spring	7	40	0.143	0.114	0.165	0.169	0.185	0.179	0.293	0.293
108A	Summer	6	39	0.320	0.247	0.458	0.343	0.430	0.351	0.484	0.540
108A	Fall	7	38	0.160	0.194	0.238	0.263	0.241	0.272	0.349	0.413
108B	Winter	6	38	0.141	0.104	0.176	0.205	0.171	0.194	0.187	0.303
108B	Spring	7	39	0.085	0.077	0.120	0.119	0.135	0.138	0.234	0.275
108B	Summer	6	38	0.113	0.090	0.259	0.233	0.245	0.226	0.296	0.363
108B	Fall	7	38	0.088	0.070	0.148	0.166	0.140	0.188	0.195	0.358
108C	Winter	6	38	0.045	0.051	0.126	0.115	0.107	0.109	0.140	0.134
108C	Spring	7	40	0.092	0.072	0.104	0.092	0.103	0.095	0.113	0.142
108C	Summer	6	39	0.072	0.052	0.080	0.070	0.080	0.073	0.089	0.177
108C	Fall	7	36	0.046	0.052	0.051	0.081	0.063	0.088	0.111	0.137
117	Winter	6	-	0.183	-	0.230	-	0.234	-	0.293	-
117	Spring	7	-	0.165	-	0.216	-	0.236	-	0.326	-
117	Summer	6	-	0.362	-	0.441	-	0.436	-	0.497	-
117	Fall	2	-	0.219	-	0.284	-	0.284	-	0.349	-

3.2.7 Alkalinity and pH

3.2.7.1 Alkalinity

Alkalinity analyses were performed quarterly during 2024. Alkalinity results among streams in the Quabbin Reservoir Watershed ranged from 0.59 to 27.90 mg/L in 2024 (Table 36). Quarterly results from winter, summer, and fall were elevated above historical averages at all Quabbin core tributary monitoring locations (211, 212, 213, 215G, 216, BC, GATE). Numerous winter (sites 212, 213, 215G, 216, BC, GATE) and fall (sites 211, 213, 216, GATE) 2024 results were new maximum alkalinity values at these sites for these seasons. In 2024, the Quabbin Reservoir Watershed experienced elevated alkalinity levels across all Core tributary monitoring locations, likely influenced by the increased precipitation and high streamflow observed in the first half of the year. The record-high alkalinity values recorded during winter and fall are possibly linked to the hydrologic conditions and biogeochemical inputs associated with the prolonged drought and subsequent return of precipitation.

Alkalinity results among streams in the Ware River Watershed ranged from 2.42 to 28.60 mg/L in 2024 (Table 37). Seasonal patterns were similar to Quabbin Reservoir Watershed sites. Quarterly monitoring results from all seasons were elevated compared to the period of record averages. Numerous record winter maximum alkalinity concentrations were observed in 2024 (e.g., sites 101, 102, 107A, 108, 121). Interpretation of alkalinity results is limited by differences in sampling frequencies of this analyte across sites in this watershed, with period of record counts varying considerably across sites (Table 37). Temporal changes in alkalinity concentrations in surface water may be attributed to a variety of factors (e.g., natural geogenic variability, urbanization and associated chemical weathering of the built environment, acid rain inputs, or changes in or introduced during sample collection and analysis) that vary both across and within these watersheds. Thus, much of the heterogeneity of alkalinity concentrations observed in tributaries within the Quabbin Reservoir and Ware River Watersheds is likely the result of the interactions of multiple variable forces, rather than readily attributable to a single direct cause.

Table 36. *Seasonal statistics for alkalinity measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

Alkalinity (mg/L)

Location	Season	*Count 2024*	*Result 2024*	*Count POR*	*Minimum POR*	*Median POR*	*Mean POR*	*Max POR*
211	Winter	1	2.86	100	1.31	2.61	2.26	2.95
211	Spring	1	1.98	107	1.64	2.36	2.20	2.60
211	Summer	1	5.64	109	2.85	3.83	4.65	7.03
211	Fall	1	7.55	103	2.64	6.01	5.31	7.04
212	Winter	1	11.10	90	5.22	6.50	6.53	7.68
212	Spring	1	4.26	98	4.16	4.80	4.99	6.24
212	Summer	1	13.00	102	8.39	9.76	10.99	15.10
212	Fall	1	15.20	97	8.70	11.80	11.73	15.60
213	Winter	1	8.63	100	2.28	5.95	5.26	6.46
213	Spring	1	4.15	104	4.32	5.11	5.24	6.44
213	Summer	1	11.60	108	6.66	11.90	11.60	17.00
213	Fall	1	17.30	100	6.48	11.80	10.98	15.10
215G	Winter	1	4.87	12	1.65	3.04	2.96	4.02
215G	Spring	1	1.59	13	1.23	1.72	1.90	3.30
215G	Summer	1	5.50	16	2.12	4.23	4.16	5.97
215G	Fall	1	6.38	15	2.26	4.49	4.57	6.39
216	Winter	1	5.75	96	3.04	4.13	4.07	4.91
216	Spring	1	3.01	104	2.52	3.39	3.38	4.69
216	Summer	1	6.71	108	3.52	6.22	6.10	7.90
216	Fall	1	8.84	102	4.56	7.71	6.96	8.62
BC	Winter	1	27.90	70	11.80	16.20	16.28	21.10
BC	Spring	1	10.50	83	10.40	11.10	11.89	14.10
BC	Summer	1	24.28	50	9.10	23.95	22.86	29.20
BC	Fall	0	-	47	3.86	26.80	24.12	36.40
GATE	Winter	1	4.79	71	0.05	0.97	0.90	2.19
GATE	Spring	1	0.59	80	0.05	0.73	0.61	1.13
GATE	Summer	1	3.23	79	1.00	2.04	1.81	2.41
GATE	Fall	1	5.57	76	0.76	3.05	2.59	3.67
211A-1	Winter	1	5.37	15	0.65	1.39	1.42	2.58
211A-1	Spring	1	1.24	13	0.85	1.41	1.43	2.00
211A-1	Summer	1	4.79	15	2.34	4.59	4.38	6.40
211A-1	Fall	1	8.73	13	2.79	4.36	5.10	7.91
211B-X	Winter	1	5.36	107	0.05	0.89	0.94	2.07
211B-X	Spring	1	0.90	103	0.70	1.09	1.09	1.66
211B-X	Summer	1	4.20	115	2.42	4.61	4.55	6.52
211B-X	Fall	1	7.96	109	1.04	3.67	4.50	7.49

Table 37. *Seasonal statistics for alkalinity measured in the Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

Alkalinity (mg/L)

Location	Season	*Count* 2024	*Result* 2024	*Count* POR	*Min* POR	*Median* POR	*Mean* POR	*Max* POR
101	Winter	1	5.35	7	1.39	3.12	2.99	4.45
101	Spring	1	3.41	8	2.85	3.38	3.35	4.19
101	Summer	1	8.32	8	3.64	7.06	6.81	8.55
101	Fall	1	8.46	7	2.41	7.29	6.47	8.95
102	Winter	1	6.39	95	3.47	4.01	4.01	4.55
102	Spring	1	4.02	96	3.68	3.96	3.90	4.07
102	Summer	1	7.52	102	3.20	6.83	5.66	6.95
102	Fall	1	8.50	98	5.24	10.77	10.77	16.30
103A	Winter	1	2.63	7	1.33	2.27	2.77	6.60
103A	Spring	1	2.42	13	1.53	2.11	2.34	3.24
103A	Summer	1	5.73	8	2.99	5.00	5.05	6.30
103A	Fall	1	6.62	7	1.96	6.43	6.63	11.40
107A	Winter	1	4.09	7	1.16	2.04	2.02	2.70
107A	Spring	1	2.95	12	0.05	2.25	2.15	3.01
107A	Summer	1	6.77	8	3.06	5.58	5.42	7.10
107A	Fall	1	8.51	7	1.09	5.34	4.78	6.86
108	Winter	1	7.18	92	2.55	3.75	3.84	5.84
108	Spring	1	3.75	101	2.25	3.43	3.52	5.53
108	Summer	1	8.73	101	4.06	9.12	8.79	11.50
108	Fall	1	12.00	98	3.28	8.60	8.31	14.00
121	Winter	1	17.10	108	9.25	11.00	11.36	15.10
121	Spring	1	7.95	110	7.10	9.71	10.23	16.60
121	Summer	1	17.40	119	9.83	22.60	23.38	44.60
121	Fall	1	28.60	120	7.55	17.00	20.88	37.50
108A	Winter	1	7.96	38	2.09	4.15	4.41	6.43
108A	Spring	1	3.35	40	1.64	3.46	3.87	7.53
108A	Summer	1	8.09	36	2.43	8.74	8.50	12.50
108A	Fall	1	10.90	39	3.29	7.76	7.39	11.60
108B	Winter	1	4.00	38	2.35	4.22	4.96	10.40
108B	Spring	1	4.65	39	1.76	2.84	3.43	8.73
108B	Summer	1	8.90	35	3.50	4.93	4.77	6.39
108B	Fall	1	7.04	39	3.52	4.42	4.81	7.27
108C	Winter	1	12.10	38	2.57	3.15	3.78	10.70
108C	Spring	1	3.14	40	1.33	2.81	2.80	4.28
108C	Summer	1	4.28	36	2.70	4.51	6.49	12.70
108C	Fall	1	11.50	37	2.44	12.00	9.26	13.20
117	Winter	1	3.36	-	-	-	-	-
117	Spring	1	8.43	-	-	-	-	-
117	Summer	1	13.00	-	-	-	-	-
117	Fall	1	5.35	7	1.39	3.12	2.99	4.45

3.2.7.2 pH

The annual precipitation-weighted mean pH of rainfall within the Quabbin Reservoir watershed has increased steadily over the past several decades (Feng et al., 2021). Spatial variability in surface water pH across the Quabbin Reservoir watershed and Ware River watershed may be attributed to variations in watershed characteristics such as geogenic variability, land use, and meteorological drivers. Data QA/QC for historical records of this parameter are ongoing.

The pH in monitoring tributaries ranged from 5.42 to 7.43 in the Quabbin Reservoir Watershed in 2023 and from 5.76 to 7.18 in the Ware River Watershed (Table 38, Table 39). The established pattern of inter-site variability in pH was observed in 2024 , relative to prior years. Observations of pH largely fell within historical seasonal ranges at all sites with long term monitoring records across both watersheds. New record fall maximums were established at 215G, 216, and 102 in 2024. MassDEP has established a recommended range of pH for the protection of aquatic life (6.5 to 8.3 SU and within 0.5 SU of the natural background range). Median pH values observed in monitoring tributaries of both watersheds were within, or fell below, the minimum standards for Class A inland waters as established by MassDEP (6.5 to 8.3) in 2024, consistent with prior observations throughout the period of record (DWSP, 2023a).

Table 38. *Seasonal statistics for pH measured in the Quabbin Reservoir Watershed tributary sites during 2024 compared to the period of record (POR).*

pH											
Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
211	Winter	8	260	6.00	4.10	6.16	6.10	6.19	6.07	6.35	7.23
211	Spring	6	260	6.13	4.85	6.29	6.03	6.29	6.02	6.42	7.09
211	Summer	7	263	6.26	4.40	6.53	6.30	6.47	6.20	6.62	6.93
211	Fall	6	256	6.37	4.90	6.53	6.13	6.53	6.11	6.65	6.93
212	Winter	8	241	6.30	4.86	6.64	6.50	6.64	6.47	6.89	7.38
212	Spring	6	248	6.71	4.65	6.78	6.59	6.80	6.53	7.00	7.64
212	Summer	7	252	7.00	5.10	7.05	6.80	7.04	6.71	7.09	7.43
212	Fall	6	241	6.86	5.56	7.01	6.68	6.99	6.63	7.09	7.13
213	Winter	8	252	5.93	5.01	6.22	6.10	6.18	6.11	6.31	7.07
213	Spring	6	257	6.21	5.02	6.35	6.20	6.32	6.13	6.39	7.07
213	Summer	7	257	6.06	4.95	6.17	6.20	6.14	6.16	6.22	7.20
213	Fall	6	246	6.11	5.04	6.24	6.14	6.25	6.11	6.46	6.60
215G	Winter	8	27	5.81	4.80	5.89	5.66	5.90	5.60	6.02	6.58
215G	Spring	6	32	6.03	4.81	6.06	5.93	6.09	5.74	6.17	6.37
215G	Summer	7	32	5.76	4.77	5.85	5.70	5.88	5.64	6.01	6.37
215G	Fall	6	31	6.02	4.73	6.13	5.78	6.22	5.69	6.73	6.11
216	Winter	8	257	6.42	4.77	6.54	6.40	6.56	6.34	6.70	7.17
216	Spring	6	259	6.57	5.31	6.74	6.40	6.71	6.36	6.81	7.56
216	Summer	7	263	6.76	5.37	6.87	6.70	6.88	6.65	6.97	7.63
216	Fall	6	252	6.83	5.53	6.98	6.57	7.00	6.54	7.24	7.13
BC	Winter	8	187	6.78	4.23	6.92	6.80	6.96	6.73	7.14	7.71
BC	Spring	6	196	7.14	5.59	7.23	6.92	7.23	6.87	7.32	7.97
BC	Summer	7	163	7.32	5.69	7.41	7.14	7.40	7.05	7.43	7.84
BC	Fall	-	169	-	5.15	-	6.96	-	6.91	-	7.50
GATE	Winter	8	186	5.42	4.09	5.99	5.62	5.94	5.68	6.81	7.75
GATE	Spring	6	190	5.74	4.32	5.91	5.48	5.92	5.50	6.16	6.62
GATE	Summer	7	192	6.10	4.39	6.30	6.00	6.34	5.92	6.61	7.21
GATE	Fall	6	206	6.38	4.72	6.57	6.13	6.58	6.03	6.77	7.20
211A-1	Winter	8	21	5.88	5.42	6.17	6.07	6.22	6.19	6.74	7.11
211A-1	Spring	6	19	6.06	5.70	6.23	6.17	6.25	6.14	6.46	6.72
211A-1	Summer	7	21	6.59	5.85	6.68	6.44	6.68	6.43	6.74	6.87
211A-1	Fall	6	18	6.71	6.12	6.80	6.50	6.80	6.52	6.88	6.85
211B-X	Winter	8	119	5.82	5.20	6.20	5.77	6.15	5.79	6.73	6.90
211B-X	Spring	6	116	6.01	5.20	6.18	5.70	6.23	5.75	6.48	6.49
211B-X	Summer	7	126	6.53	5.21	6.64	6.40	6.62	6.34	6.70	7.10
211B-X	Fall	6	119	6.64	5.20	6.79	6.33	6.75	6.23	6.81	6.80

Table 39. *Seasonal statistics for pH measured in the Ware River Watershed tributary sites during 2024 compared to the period of record (POR).*

pH

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
101	Winter	6	218	6.20	5.22	6.34	6.20	6.37	6.21	6.56	7.44
101	Spring	7	230	6.46	5.11	6.52	6.20	6.54	6.20	6.62	7.04
101	Summer	6	225	6.30	5.03	6.57	6.47	6.53	6.41	6.72	7.21
101	Fall	7	225	6.55	4.51	6.75	6.40	6.75	6.34	6.87	7.18
102	Winter	6	121	6.39	5.70	6.53	6.40	6.56	6.36	6.76	6.80
102	Spring	7	124	6.57	5.80	6.62	6.40	6.66	6.34	6.81	6.86
102	Summer	6	126	6.73	5.80	6.80	6.50	6.79	6.50	6.83	6.92
102	Fall	7	125	6.82	5.60	6.99	6.50	7.00	6.47	7.18	6.90
103A	Winter	6	94	5.99	5.16	6.19	6.06	6.26	6.01	6.77	6.81
103A	Spring	7	115	6.28	4.65	6.51	6.10	6.47	6.03	6.57	7.17
103A	Summer	6	118	5.84	4.43	6.48	6.15	6.38	6.05	6.57	7.02
103A	Fall	7	118	6.40	4.56	6.58	6.11	6.58	6.04	6.83	6.90
107A	Winter	5	101	5.78	1.11	6.09	5.80	6.15	5.75	6.47	7.06
107A	Spring	7	116	6.18	4.48	6.26	6.04	6.35	5.98	6.56	6.91
107A	Summer	6	119	6.14	4.77	6.40	6.23	6.38	6.13	6.54	6.85
107A	Fall	6	122	6.46	3.93	6.60	6.07	6.61	6.00	6.73	7.01
108	Winter	6	212	6.19	5.21	6.24	6.10	6.25	6.07	6.33	6.92
108	Spring	7	221	6.46	5.04	6.55	6.20	6.57	6.13	6.68	7.13
108	Summer	6	221	6.36	5.06	6.45	6.30	6.45	6.24	6.57	7.03
108	Fall	7	222	6.38	4.43	6.44	6.20	6.48	6.15	6.76	6.72
121	Winter	6	135	6.43	2.63	6.48	6.40	6.48	6.41	6.52	6.85
121	Spring	7	137	6.65	6.02	6.68	6.50	6.69	6.49	6.75	6.88
121	Summer	6	144	6.60	6.04	6.66	6.60	6.66	6.63	6.76	7.40
121	Fall	7	147	6.58	5.61	6.79	6.50	6.74	6.52	6.83	7.10
108A	Winter	6	38	6.00	4.59	6.10	5.80	6.11	5.80	6.25	6.69
108A	Spring	7	41	6.30	4.69	6.38	5.97	6.38	5.99	6.50	6.75
108A	Summer	6	39	6.11	5.13	6.23	6.09	6.23	6.05	6.34	6.68
108A	Fall	7	36	6.25	4.85	6.34	5.97	6.35	5.96	6.46	6.56
108B	Winter	6	38	5.84	4.96	6.01	5.86	5.99	5.81	6.10	6.62
108B	Spring	7	41	6.10	4.60	6.34	5.90	6.31	5.86	6.43	6.69
108B	Summer	6	38	6.21	5.47	6.29	6.16	6.28	6.13	6.33	7.29
108B	Fall	7	37	6.11	4.83	6.23	6.07	6.23	5.97	6.30	6.68
108C	Winter	6	38	6.37	5.03	6.45	6.02	6.46	5.98	6.59	6.91
108C	Spring	7	41	6.61	4.56	6.70	6.10	6.70	6.10	6.85	6.85
108C	Summer	6	38	6.49	5.79	6.65	6.37	6.65	6.50	6.77	7.38
108C	Fall	7	35	6.63	5.30	6.70	6.27	6.72	6.35	6.84	7.43
117	Winter	6	-	5.76	-	5.93	-	5.96	-	6.32	-
117	Spring	7	-	6.00	-	6.37	-	6.36	-	6.62	-
117	Summer	6	-	6.14	-	6.20	-	6.21	-	6.32	-
117	Fall	2	-	6.28	-	6.47	-	6.47	-	6.66	-

3.2.8 Special Investigations

3.2.8.1 Forestry Monitoring

Timber harvesting in the treatment watershed (EBU) began on December 18, 2019 and was completed October 11, 2020, ending the calibration period of the long-term forestry monitoring study. The post-treatment period of the long-term forestry monitoring project began with data collected in late 2020 and continued into 2025. Preliminary analyses of calibration period data have been summarized in anticipation of study completion and subsequent compilation of a final report, which will focus on analyzing potential changes between pre-treatment and post-treatment study periods.

3.2.8.2 Environmental Quality Assessments

Surface water samples collected in 2024 throughout the Quabbin Reservation and East Branch Ware sanitary districts ultimately revealed no widespread indicators of impairment/degradation of water quality. Observations of elevated results (e.g., results above historical seasonal normal ranges and/or *E. coli* monitoring results above Class A standards) were followed up with field investigations and follow up sampling. Monitoring of EQA sites in the Quabbin Reservoir will shift to sites in the East Branch Swift Sanitary District in 2025, with subsequent reporting in 2026. Monitoring of EQA sites in the Ware River Watershed will shift to sites in the Coldbrook Longmeadow Sanitary District in 2025, with subsequent reporting in 2026.

3.3 Reservoir Monitoring

Water quality of the Quabbin Reservoir in 2024 continued to meet the source water quality criteria stipulated under the SWTR and associated filtration avoidance waiver. The following sections provide a detailed summary of DWSP monitoring efforts conducted in 2024 for the purpose of evaluating the physical, chemical, and biological dynamics of the Quabbin Reservoir. Unless otherwise noted, data presented in this section were collected by DWSP. Section 3.3.1 summarizes regulatory sampling completed by MWRA.

Depth profiles of physiochemical parameters reveal general patterns in water column characteristics such as the timing of seasonal turnover and stratification, the relative position of the epilimnion, metalimnion, and hypolimnion, the general degree of mixing within the water column, and the timing and location of relative increases in primary productivity. For this report, several depth profiles of various physiochemical water quality parameters (temperature, pH, dissolved oxygen, specific conductance, chlorophyll *a*, and phycocyanin) from each site were selected to demonstrate changes in seasonal conditions and show periods of peak primary productivity. An EXO2 multiparameter sonde was used in 2024 for manual depth profiles, replacing the Eureka Manta used from 2006 to 2020. Seasonal descriptive statistics of parameters (water temperature, dissolved oxygen, chlorophyll *a*, pH, and specific conductance) were calculated for each site to summarize the variation of conditions throughout 2024, relative to the period of record. The period of record spans from 2021 to 2023 for all parameters except water temperature, which extends from 2006 to 2023 due to the well-documented near 1:1 correlation between measurements from the Eureka Manta and the EXO2 sensors for this parameter.

3.3.1 Surface Water Treatment Rule Compliance Monitoring

Regulatory monitoring results provided from MWRA fulfilled requirements specified for turbidity and fecal coliform under the SWTR in 2024 (Figure 28). Turbidity is monitored via an in-line turbidity meter inside the BWTF. Turbidity in Quabbin Reservoir source water remained below one NTU for the entirety of 2024. Average (mean) and maximum daily turbidity in source water measured at the BWTF ranged between 0.21 and 0.39 NTU and 0.22 and 0.41 NTU, respectively.

Fecal coliform was not detected above 20 CFU/100-mL from MWRA sampling at BWTF in 2024 (Figure 28). Fecal coliform was below the detection limit (less than 1 CFU/100-mL) for 78% of daily samples in 2024. A population of waterfowl (primarily gulls) that roost on Quabbin Reservoir in fall and winter has previously been identified as the primary source of fecal coliform and *E. coli* to the Quabbin Reservoir (Wolfram, 1996). Additional sources may include semi-aquatic wildlife and inputs from major tributaries. Fecal coliform and *E. coli* in Quabbin Reservoir are historically low, reflecting microbial die-off and predation. *E. coli* was detected at 10 MPN/100 mL in two samples collected by DWSP in Quabbin Reservoir monitoring locations during 2024 (approximately 3% of samples).

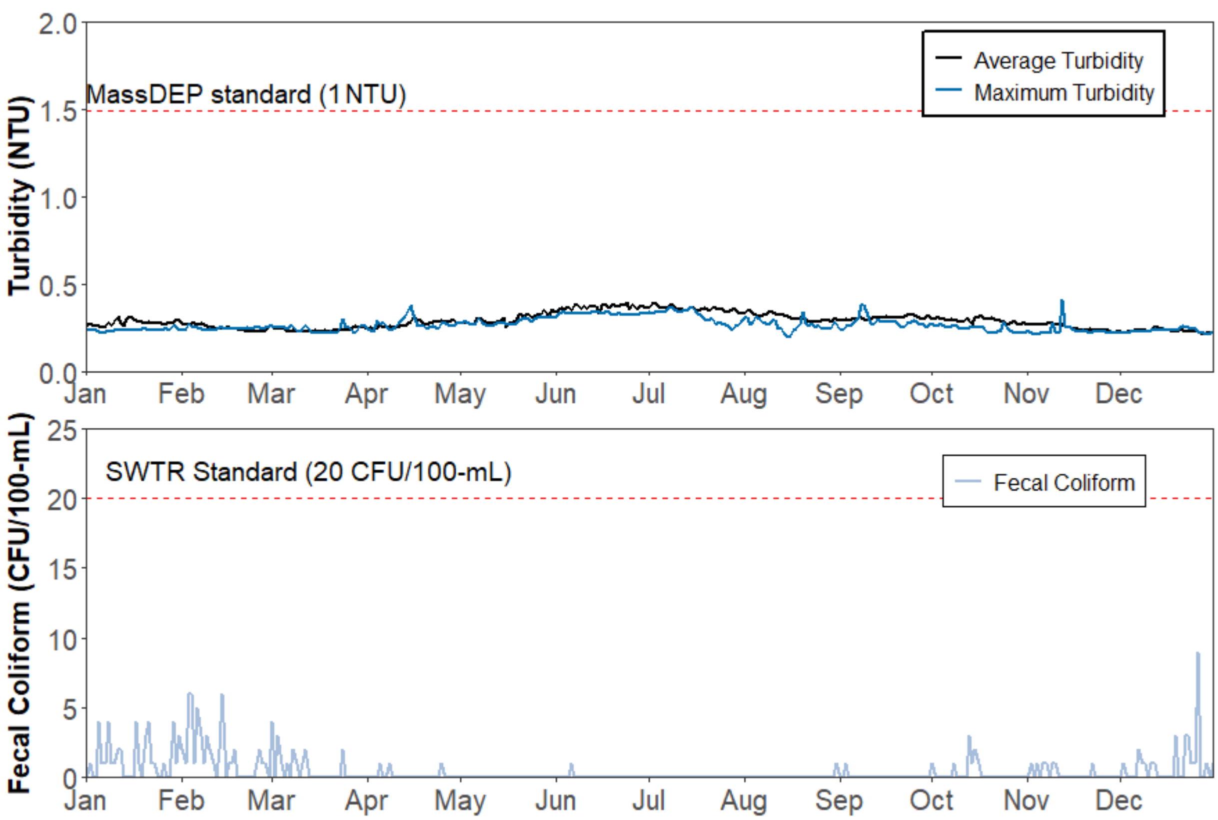


Figure 28. *a) Results of daily average (mean) and maximum turbidity, and b) fecal coliform monitoring of Quabbin Reservoir source water collected from Winsor Dam Intake during 2024.*

3.3.2 Water Temperature

Water column temperature profiles indicate the timing of seasonal changes in stratification throughout the Quabbin Reservoir (Figure 29). Shifts in the timing and extent of the various stages of stratification may have profound implications on water quality, ecology, and primary productivity. Though there were periods of partial ice coverage, the reservoir did not fully freeze in 2024. The timing of seasonal turnover was consistent with the historical record. Minimum temperatures were warmer than that of the period of record across all sites and all seasons, with the greatest divergence from historical minimums during the winter at site Den Hill (5.4°C warmer than the period of record). Overall, mean temperatures measured in 2024 remained within the established historical monitoring range for all sites. Mean summer temperatures for 2024 were slightly greater (around or less than 1°C warmer) than that of the period of record across all sites, with the greatest divergence from seasonal means occurring at site 202 in the fall (1.1°C warmer than the period of record). Maximum temperatures in 2024 did not exceed the established historical range (Table 40). Variations in temporal data coverage across years (resulting from ice coverage) may in part drive deviations in observed temperatures during the winter and spring months. Statistics provided include measurements conducted in conjunction with monthly Quabbin Reservoir water quality monitoring (April to December) and routine phytoplankton sampling (January to December, except for January at site 206, and January and February at Den Hill due to ice conditions).

Table 40. *Seasonal statistics of water temperature in Quabbin Reservoir during 2024 relative to the period of record (2006 -2023) at DWSP monitoring sites.*

Temperature (°C)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Spring	237	2609	4.1	1.3	6.7	6.7	7.3	7.3	17.7	17.0
202	Summer	642	6629	6.6	5.8	10.3	10.6	13.9	13.3	26.2	26.7
202	Fall	242	5172	7.7	7.0	11.4	11.8	14.3	13.2	23.0	23.7
202	Winter	105	942	2.7	2.0	4.1	7.2	5.4	6.5	9.4	10.0
206	Spring	87	1586	3.9	1.8	4.6	7.6	5.6	8.0	11.9	16.9
206	Summer	139	3817	7.4	6.3	11.5	12.6	15.3	14.9	26.1	26.8
206	Fall	103	3055	9.4	6.3	12.0	13.1	15.1	14.5	23.0	23.6
206	Winter	55	640	1.7	1.4	2.0	5.9	4.9	5.5	8.3	9.8
Den Hill	Spring	63	796	4.7	4.4	5.6	8.8	6.7	9.3	13.7	20.2
Den Hill	Summer	120	2117	8.0	7.7	16.6	17.3	17.2	17.3	26.8	26.9
Den Hill	Fall	56	1527	9.5	6.9	14.2	14.8	15.4	15.3	22.0	24.1
Den Hill	Winter	19	284	6.8	1.4	7.3	5.4	7.3	5.1	7.4	8.4

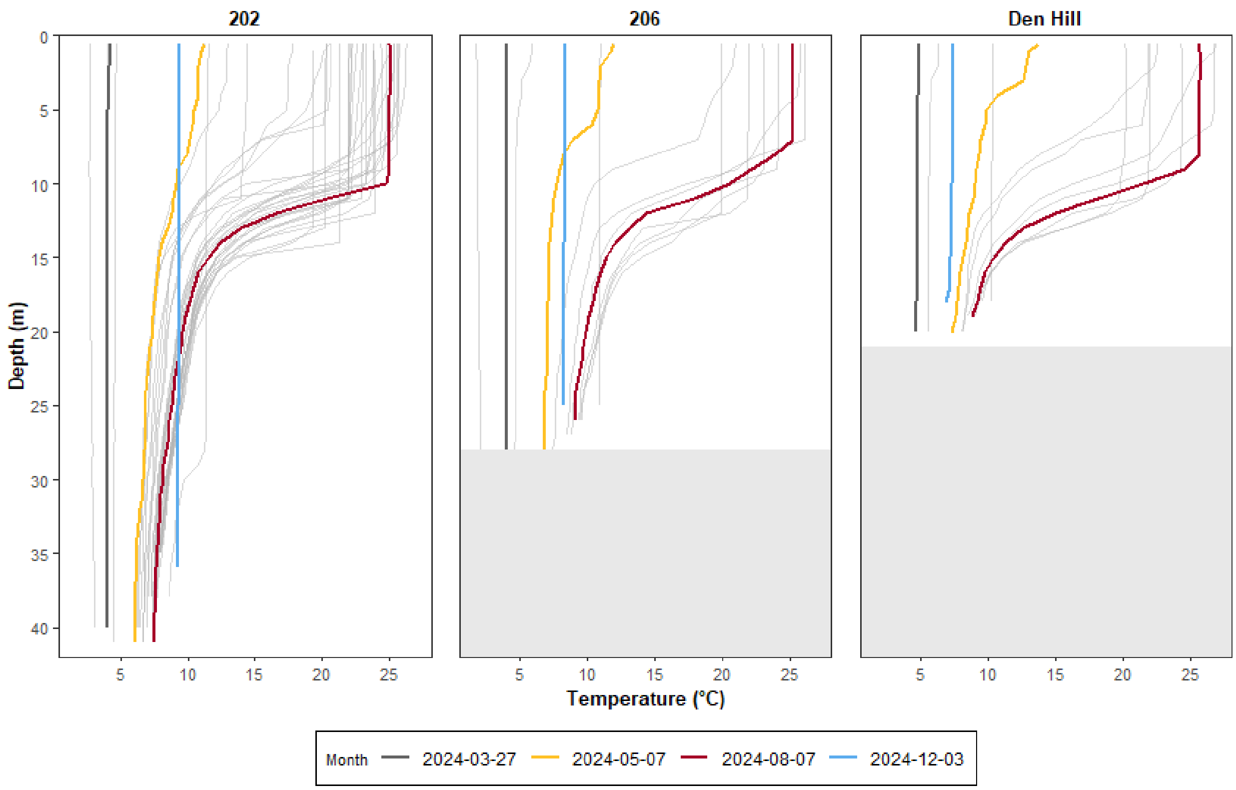


Figure 29. *Profiles of temperature at Quabbin Reservoir Core sites on select dates in 2024. The March profile (dark gray) illustrates spring isothermy, which existed from the start of the sampling season through April at all sites. The May profiles (yellow) correspond to the onset of reservoir stratification. The August profiles (red) represent summer stratification. The December profiles (blue) show a return to isothermy at all sites following fall turnover. Light gray lines in each plot show profiles from other 2024 sample dates. Gray bands at sites 206 and Den Hill indicate the maximum water column depth recorded for 2024.*

3.3.3 Chlorophyll *a*

Chlorophyll *a* may be used to estimate the overall biomass of the phytoplankton community. DWSP staff record *in-situ* measurements of chlorophyll *a* (in addition to concentrations of dissolved oxygen) to determine the location in the water column where samples are collected for phytoplankton enumeration on a given date. On average, chlorophyll *a* concentrations in the reservoir are low and characteristic of low-productivity oligotrophic systems.

In 2024, chlorophyll *a* concentrations during the spring and winter remained low (below approximately 5 µg/L) while elevated concentrations were observed during summer and early fall due to a *Chrysosphaerella* aggregation (Section 3.4.10). The maximum chlorophyll *a* concentrations observed via manual profiles collected by DWSP staff were 39.70 µg/L at site 202 on August 22, 24.09 µg/L at site 206 on August 7, and 21.98 µg/L at Den Hill on July 9 (Table 41, Figure 30). In 2024, the mean summer chlorophyll *a* concentration for the entire water column was 1.46 µg/L at site 202, 1.83 µg/L at site 206, and 1.39 µg/L at site Den Hill for data collected by DWSP via manual profiles (Table 41). Unlike previous years, mean summer chlorophyll *a* was not highest at Den Hill but at 206.

Table 41. *Seasonal statistics for chlorophyll a in Quabbin Reservoir during 2024 relative to the period of record (2021 – 2023) at DWSP monitoring sites.*

Chlorophyll *a* (µg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Spring	237	1386	0.16	0.09	1.89	1.35	1.71	1.92	3.98	24.34
202	Summer	642	2923	0.01	0.00	0.84	1.06	1.46	1.74	39.70	43.15
202	Fall	242	1930	0.07	0.01	0.69	0.99	1.49	1.44	33.24	34.63
202	Winter	105	605	0.15	0.35	1.02	1.48	0.99	1.67	1.55	4.43
206	Spring	87	716	0.19	0.08	3.01	1.69	2.61	2.14	4.32	21.78
206	Summer	139	1125	0.20	0.12	1.04	1.29	1.83	2.10	24.09	29.55
206	Fall	103	870	0.29	0.06	0.85	1.32	1.14	1.62	6.74	13.77
206	Winter	55	394	0.34	0.16	1.12	1.69	1.07	1.79	1.53	6.23
Den Hill	Spring	63	283	0.91	0.57	4.07	2.30	3.87	2.81	5.81	9.22
Den Hill	Summer	120	526	0.42	0.35	1.04	1.60	1.39	2.35	21.98	46.73
Den Hill	Fall	56	457	0.47	0.19	0.89	1.33	0.85	1.47	1.14	8.34
Den Hill	Winter	19	173	0.59	0.61	1.01	1.86	0.99	1.95	1.18	3.35

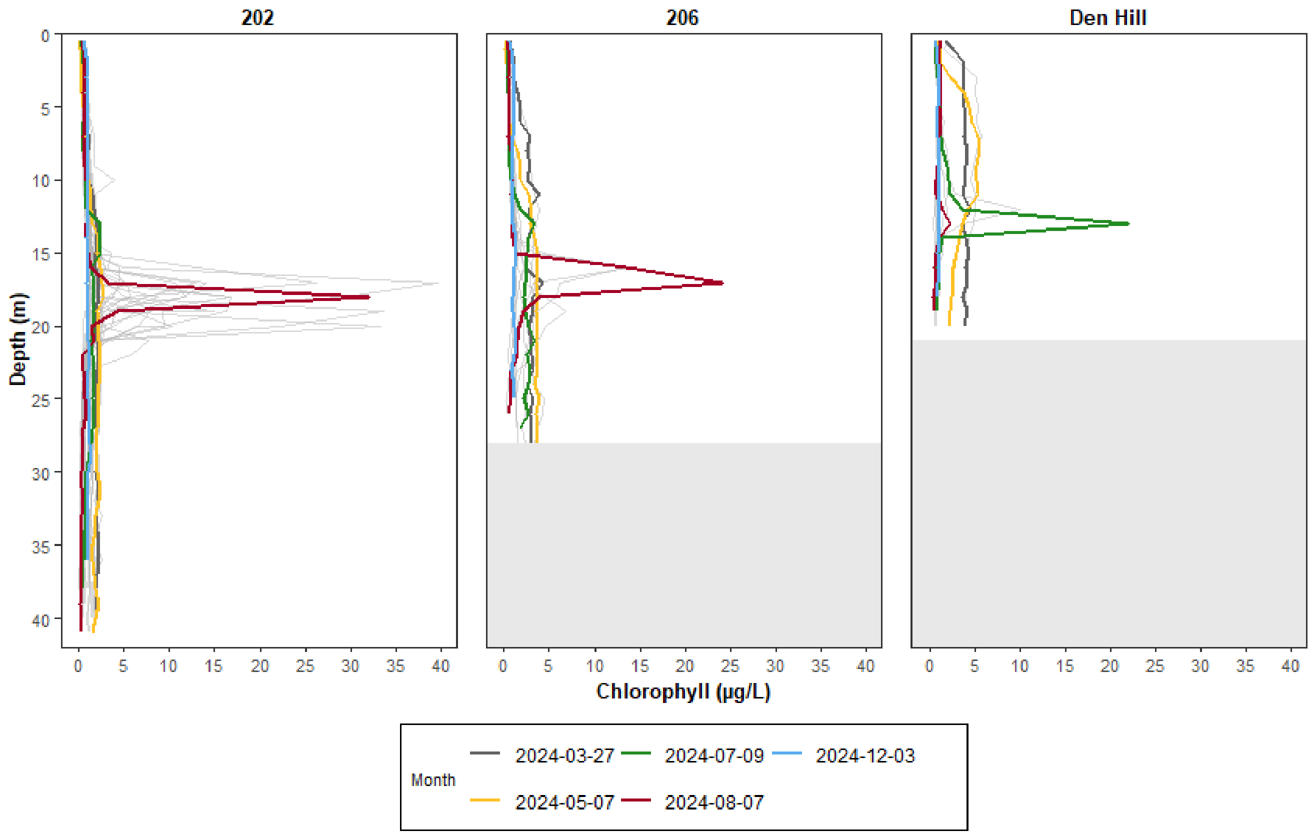
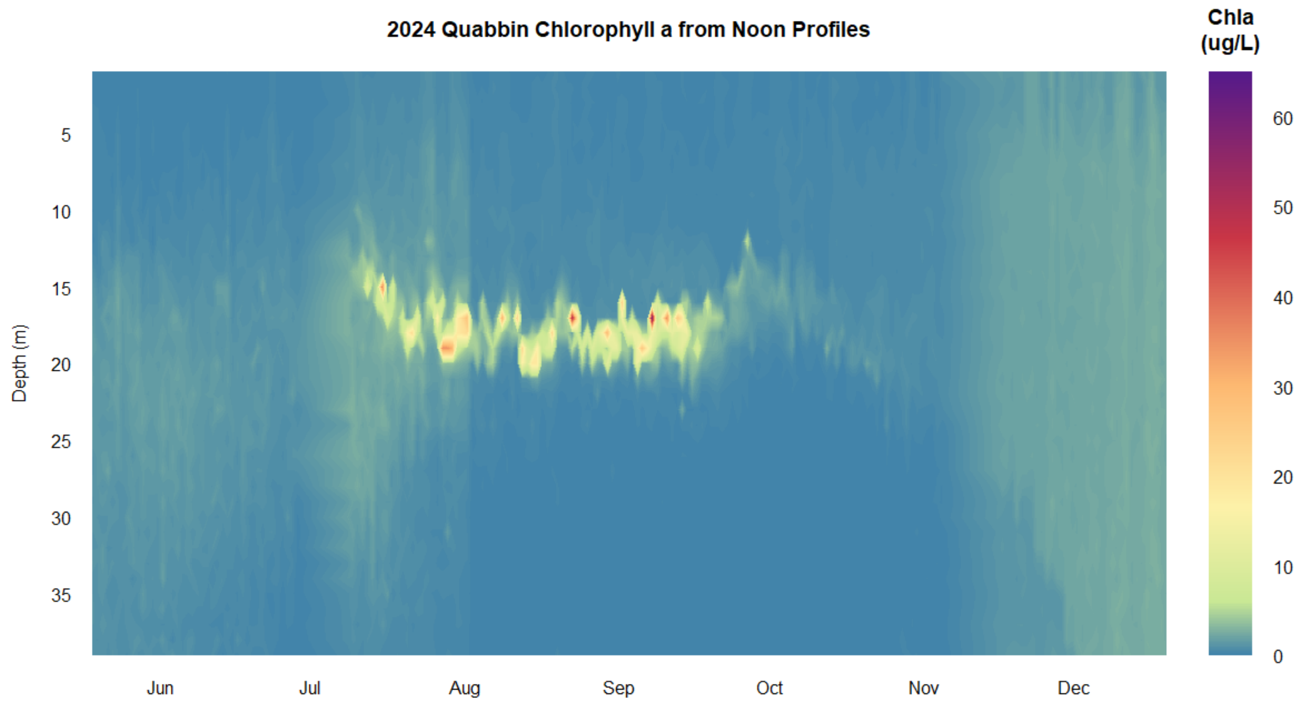


Figure 30. *Profiles of chlorophyll a at Quabbin Reservoir Core sites on select dates in 2024 to represent seasonality. The March profile (dark gray) shows chlorophyll a values during fully mixed water column conditions in the Spring. The May profile (yellow) corresponds to the onset of reservoir stratification. The July and August profiles (green and red) correspond to summer stratification conditions. The December profile (blue) shows a return to a mixed water column following fall turnover. Gray lines in each plot show profiles from other 2024 sample dates. Gray bands at sites 206 and Den Hill indicate the max water column depth recorded for 2024.*

Measurements collected by the MWRA EXO2 buoy, located close to site 202, showed an unusual pattern where multiple chlorophyll *a* measurements were higher at midnight than at noon. The maximum chlorophyll *a* observed at midnight was 63.66 µg/L at 19 m on August 16, while the maximum chlorophyll *a* observed at noon was 60.71 /L at 17 m on September 9 (Figure 31). To better understand the differences between noon and midnight profiles, spatial and temporal statistical analyses were conducted on elevated chlorophyll *a* values. These elevated values were observed between 16 and 20 meters from July 1 to September 15. During this period and depth range, the mean chlorophyll *a* concentration was 6.22 µg/L at noon compared to 7.25 µg/L at midnight. While higher chlorophyll *a* maximums were captured by the MWRA EXO2 buoy compared to the manual profiles, the annual chlorophyll *a* means collected via the buoy were similar to those of the manual profiles.



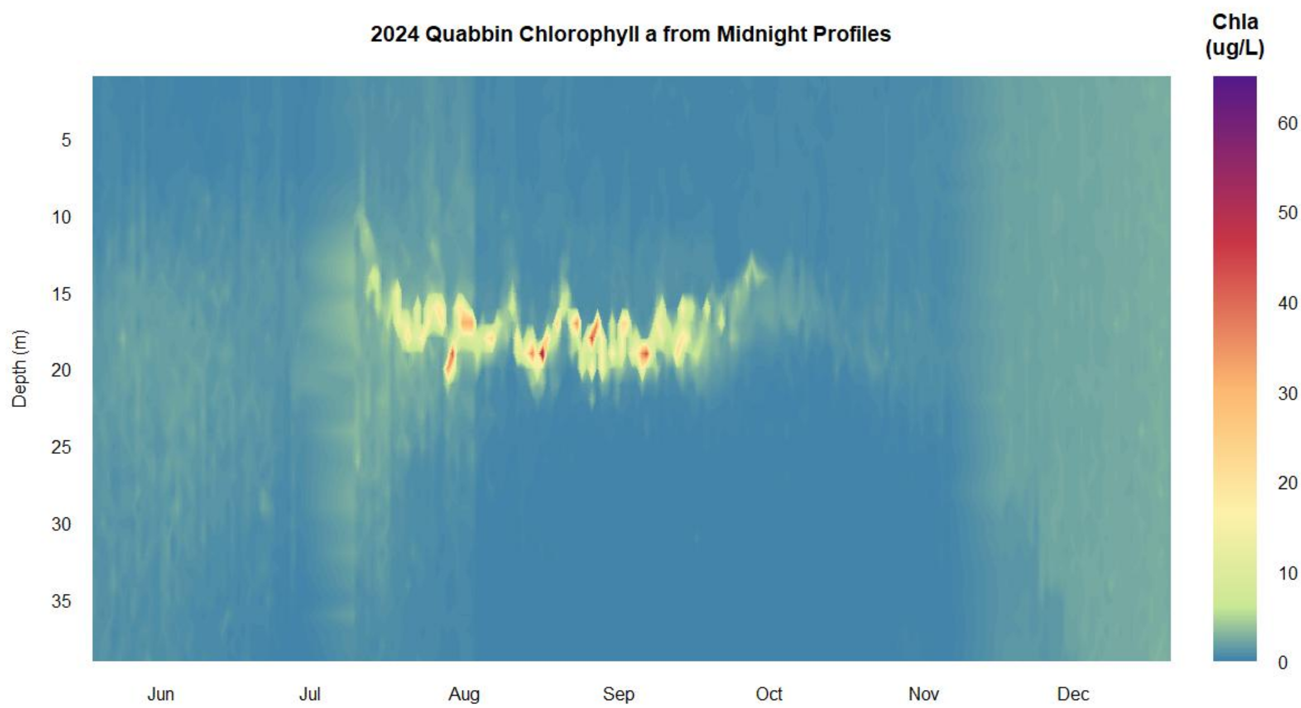


Figure 31: *Chlorophyll a heatmaps from MWRA EXO2 buoy noon (top) and midnight (bottom) profile collections from May through December 2024.*

3.3.4 Dissolved Oxygen

Concentrations of dissolved oxygen in Quabbin Reservoir followed expected seasonal patterns in 2024. Changes in dissolved oxygen concentrations in Quabbin Reservoir generally coincided with changes in water temperatures, followed stratification stages, and/or rose with relative increases in phytoplankton abundance. Dissolved oxygen concentrations were typically greater in the spring and winter, likely attributed to cooler water temperatures, and lowest in fall due to a decline in phytoplankton productivity prior to fall turnover (Table 42). During summer, concentrations of dissolved oxygen in surface water decreased with stratification, as the warmer water in the epilimnion became unable to hold as much oxygen as colder deep water. Once stratified, dissolved oxygen levels below the thermocline became elevated due to cooler water temperature and phytoplankton activity (Figure 32). Mean summer dissolved oxygen levels were slightly higher than the period of record, likely attributed to high phytoplankton productivity in 2024, but maximums remained within historical range (Table 42).

Table 42. *Seasonal statistics for dissolved oxygen in Quabbin Reservoir during 2024 relative to the period of record (2021 – 2023) at DWSP monitoring sites.*

Dissolved Oxygen (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Spring	237	2609	9.9	8.2	11.8	12.3	11.9	12.5	13.0	21.1
202	Summer	642	6628	8.2	4.3	10.9	10.6	10.5	10.5	12.3	17.5
202	Fall	242	5171	7.2	4.0	10.0	9.2	9.9	9.2	12.4	16.4
202	Winter	105	942	10.2	8.4	12.1	11.4	11.7	11.7	12.8	18.3
206	Spring	87	1586	11.3	7.1	12.5	12.2	12.4	12.2	13.1	20.4
206	Summer	139	3817	8.1	2.4	10.6	10.0	10.1	10.0	11.8	14.7
206	Fall	103	3054	8.4	2.9	9.7	9.1	9.5	9.1	11.1	14.2
206	Winter	55	640	10.9	10.2	13.2	12.1	12.2	12.3	13.5	16.7
Den Hill	Spring	63	796	10.5	6.7	12.0	11.3	11.8	11.3	12.6	16.3
Den Hill	Summer	120	2117	5.7	2.6	8.2	8.4	8.4	8.3	10.6	12.2
Den Hill	Fall	56	1526	2.7	1.79	8.3	8.6	8.1	8.3	10.4	14.3
Den Hill	Winter	19	284	11.0	10.4	11.0	12.2	11.0	12.3	11.1	15.8

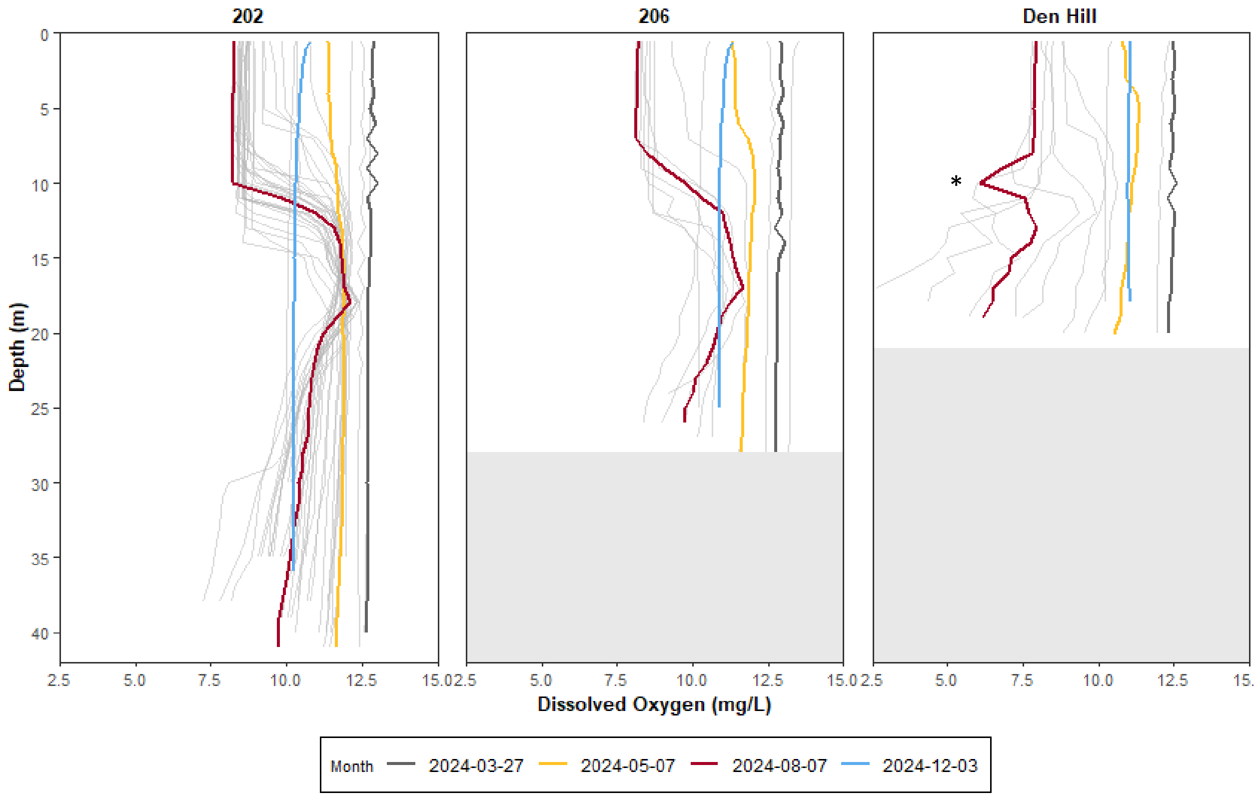


Figure 32: *Profiles of dissolved oxygen at Quabbin Reservoir Core sites on select dates in 2024. The March profile (dark gray) illustrates the dissolved oxygen concentrations of a fully mixed water column in the spring. The May profile (yellow) corresponds to the onset of reservoir stratification. The August profile (red) depicts an increase in dissolved oxygen concentrations at depth, during summer stratification. The December profile (blue) shows a return to a mixed water column following fall turnover. Gray lines in each plot show profiles from other 2024 sample dates. Gray bands at sites 206 and Den Hill indicate the max water column depth recorded for 2024. * This profile shows the likely effect of high stream flow on dissolved oxygen at Den Hill after high rainfall observed from August 2 to August 9.*

Following typical seasonal patterns for Quabbin Reservoir, dissolved oxygen depletion was most pronounced during the late stages of stratification, with concentrations declining with depth at sites 202 and 206 (Figure 32). This was particularly distinct for water below the thermocline that remains isolated from atmospheric influence and where rates of decomposition, a process that consumes oxygen, exceed photosynthesis. The seasonal pattern at Den Hill was different from the other two sites, likely due to the proximity of this site to the East Branch Swift River. After a high rainfall event resulting in high stream flow (documented on August 8; see Section 3.1.2), dissolved oxygen at Den Hill was observed to decline at 10 m (above the established thermocline) on August 7 likely attributed to the increase in stream input bringing in more sediment and potentially increasing turbidity. Dissolved oxygen continued to decrease from August 7 until October 1, 2024, reaching a minimum of 2.7 mg/L at 17 m. High inflow events can impact phytoplankton productivity due to high turbidity water lowering light availability for phytoplankton. This, combined with heterotrophic activity associated with decomposition, could explain the decreasing dissolved oxygen in the water. The decline in dissolved oxygen was observed in the August 7, August 20, September 10, and October 1 profiles. Dissolved oxygen is typically depleted at depth at Den Hill during the late summer and fall, with an annual minimum between 1.79 and 2.7 mg/L in the last four years. In 2024, the observed low dissolved oxygen levels (below 6 mg/L) at Den Hill were limited to the lowermost 5 meters of the water column on October 1.

Following fall turnover in November, oxygen was recirculated throughout the water column at all sites. Dissolved oxygen was the greatest during the winter, with an annual maximum concentration of 13.50 mg/L at 206 (Figure 32, Table 42). The median dissolved oxygen concentrations in 2024 remained above 6 mg/L at all sites (Table 42), sustaining concentrations required to support cold water aquatic species (314 CMR 4.06).

3.3.5 Alkalinity and pH

The dynamics of pH in Quabbin Reservoir are largely governed by the exchange of inorganic carbon between the atmosphere and water (carbon dioxide-bicarbonate-carbonate buffering). The pH of Quabbin Reservoir generally decreases with depth and may vary with changes in photosynthesis and respiration and contributions from various weather events (e.g., surface water inputs). Generally, pH within Quabbin Reservoir is unremarkable, ranging from 5.4 to 7.6 in 2024, and has not exhibited strong temporal trends since the onset of routine monitoring by DWSP. Quabbin Reservoir water remains slightly acidic with median pH at DWSP monitoring sites ranging from 6.4 to 6.9 in 2024 (Table 43).

Table 43. *Seasonal statistics for pH in Quabbin Reservoir during 2024 relative to the period of record (2021 – 2023) at DWSP monitoring sites.*

pH

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Spring	237	2529	6.4	5.5	6.8	6.5	6.8	6.5	7.5	7.8
202	Summer	642	6405	5.8	3.4	6.7	6.5	6.7	6.4	7.4	8.0
202	Fall	242	4845	5.4	4.8	6.6	6.2	6.5	6.2	7.5	7.8
202	Winter	105	911	6.1	5.4	6.6	6.5	6.7	6.5	7.1	7.8
206	Spring	87	1523	6.8	5.6	6.9	6.6	6.9	6.6	7.0	7.9
206	Summer	139	3619	6.0	5.2	6.6	6.5	6.6	6.4	7.0	7.5
206	Fall	103	2826	5.7	5.0	6.5	6.4	6.5	6.3	7.4	7.5
206	Winter	55	625	6.7	5.6	6.9	6.5	6.9	6.5	7.6	7.5
Den Hill	Spring	63	764	6.4	5.4	6.8	6.4	6.8	6.4	7.3	7.7
Den Hill	Summer	120	1994	5.6	4.9	6.4	6.4	6.4	6.3	7.2	7.6
Den Hill	Fall	56	1407	5.6	5.0	6.7	6.4	6.6	6.3	7.5	7.4
Den Hill	Winter	19	277	6.5	5.8	6.6	6.5	6.6	6.5	6.9	7.4

Alkalinity in Quabbin Reservoir remained low (less than 7 mg/L as $CaCO_3$) throughout 2024 and exhibited little variability with depth, changes in stratification, or seasonality (Table 44). Alkalinity concentrations ranged from 3.68 to 6.20 mg/L as $CaCO_3$ in 2024. Median alkalinity was generally greatest at Den Hill in 2024 (4.33 to 4.44 mg/L as $CaCO_3$), relative to other routine monitoring sites in Quabbin Reservoir. This pattern was consistent with previous years. Alkalinity measured at each site in the Quabbin Reservoir during 2024 exceeded historical medians but remained within the established maximum range of values for each site, except for one measurement at site 206 (Table 44). An increase in alkalinity was observed on August 7 in the surface water at site 206, reaching a maximum of 6.20 mg/L, exceeding historical maximums for this site and depth. This increase in alkalinity is most likely attributed to run-off after a high precipitation event in early August. A steady increase in alkalinity has been observed in the Quabbin Reservoir since 2005. Increasing trends in low-alkalinity lakes and large rivers have been observed across the US and attributed to recovery from acid rain and contamination from road salt runoff (Stoddard et al., 1999; Stets et al., 2014; NH DES, 2020). Additionally, the pH (annual precipitation-weighted mean) of rainfall within the Quabbin Reservoir Watershed has been increasing steadily for decades (Feng et al., 2021). Temporal changes in alkalinity concentrations in lakes and reservoirs in New England may be attributed to interactions of multiple factors (e.g., natural geogenic variability, urbanization and associated chemical weathering of the built environment, acid rain inputs, or changes in or introduced during sample collection and analysis).

Table 44. *Seasonal statistics for alkalinity as $CaCO_3$ in Quabbin Reservoir during 2024 relative to the period of record (2005 – 2023) at DWSP monitoring sites.*

Alkalinity

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	138	3.88	2.66	3.99	3.69	4.02	3.58	4.22	6.37
202	Mid	5	153	3.74	2.47	4.00	3.64	3.97	3.50	4.20	4.50
202	Deep	5	160	3.84	2.51	4.06	3.59	4.00	3.47	4.13	4.51
206	Surface	5	137	3.68	2.44	4.12	3.79	4.46	3.62	6.20	4.32
206	Mid	5	151	3.90	2.44	4.08	3.72	4.10	3.56	4.32	4.33
206	Deep	5	158	3.90	2.63	4.20	3.68	4.14	3.54	4.38	5.51
Den Hill	Surface	5	134	4.08	2.54	4.46	3.92	4.44	3.84	4.85	5.10
Den Hill	Mid	5	147	4.12	2.76	4.45	3.87	4.33	3.78	4.48	4.68
Den Hill	Deep	5	154	3.92	2.60	4.45	3.85	4.39	3.82	4.72	7.50

3.3.6 Specific Conductance, Sodium, and Chloride

Specific conductance measured in the Quabbin Reservoir has historically been low, relative to other water bodies in the northeastern United States, such as highly urbanized watersheds that may exceed 1,000 µS/cm. The relatively low observed specific conductance in Quabbin Reservoir waters is likely a reflection of land cover (e.g., percent developed lands, total land miles, and/or percentage of impervious surface cover), the low catchment area-to-surface area ratio of the Quabbin Reservoir, geogenic characteristics of the watershed, and land management practices across the watershed. As is typical for the Quabbin Reservoir, specific conductance in 2024 varied little with depth or season (Table 45). However, slightly higher specific conductance was observed during early spring (April) conditions, before the onset of stratification and then again in the winter after turnover than during stratified conditions (Figure 33). Higher mean specific conductance during spring and winter are consistent with increasing concentrations of specific conductance documented in major east Quabbin tributaries, likely attributed to road salt runoff. Specific conductance measured in Quabbin Reservoir during 2024 ranged from an annual minimum of 45.2 µS/cm at site 202 to an annual maximum of 49.3 µS/cm at Den Hill (Table 45). A spike in specific conductance at Den Hill was observed on August 7 (Figure 33), most likely attributed to high stream flows in the East Branch Swift after a high precipitation event in early August.

Table 45. *Seasonal statistics for specific conductance in Quabbin Reservoir during 2024 relative to the period of record (2021 – 2023) at DWSP monitoring sites.*

Specific Conductance

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Spring	237	2596	45.3	36.1	46.4	46.4	46.5	45.8	47.3	49.4
202	Summer	642	6453	45.5	36.6	46.5	46.3	46.5	45.7	47.6	50.7
202	Fall	242	4999	45.2	4.0	46.5	46.0	46.5	45.5	47.7	56.4
202	Winter	105	924	46.8	37.0	48.1	47.6	47.8	46.8	48.5	56.1
206	Spring	87	1577	45.8	35.7	46.8	46.2	46.9	45.5	47.8	52.8
206	Summer	139	3691	46.0	36.4	46.7	45.3	46.8	45.2	47.5	52.1
206	Fall	103	2942	46.4	33.0	46.9	45.8	47.0	45.3	47.7	51.0
206	Winter	55	624	47.1	36.9	47.2	47.5	47.6	46.6	48.7	51.4
Den Hill	Spring	63	790	46.3	42.5	46.9	49.2	47.0	50.3	48.0	71.2
Den Hill	Summer	120	2047	46.4	38.4	47.3	48.0	47.4	48.0	48.5	66.0
Den Hill	Fall	56	1497	47.4	37.0	48.2	47.8	48.0	47.9	49.3	64.8
Den Hill	Winter	19	275	47.8	40.4	47.9	49.2	47.9	49.8	48.0	57.8

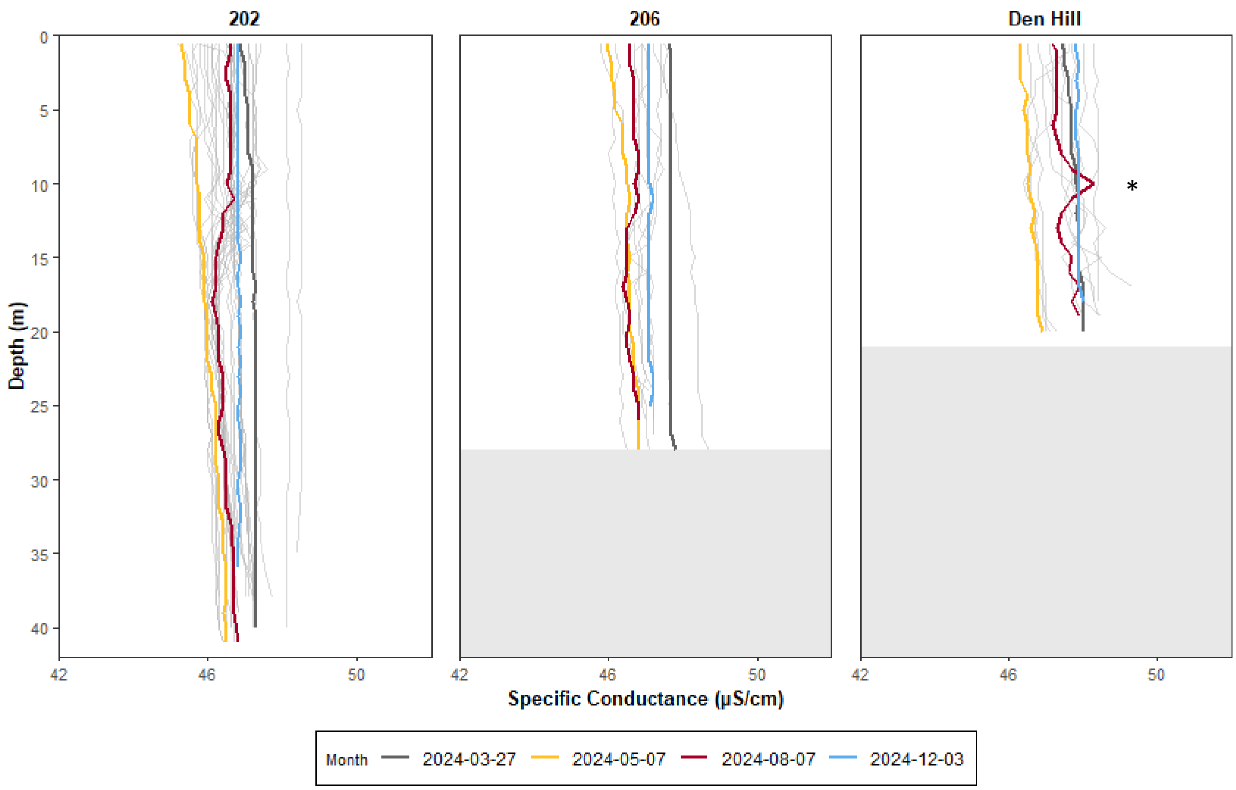


Figure 33. *Profiles of specific conductance at Quabbin Reservoir Core sites in 2024. Selected colors represent the different stages of the water column in a year. The March profile (dark gray) shows specific conductance during mixed water column conditions in the spring. The May profile (yellow) corresponds to the onset of reservoir stratification. The August profile (red) represents summer stratification conditions. The December profile (blue) shows a return to a mixed water column following fall turnover. Light gray lines in each plot show profiles from other 2024 sample dates. * This profile shows the effect of high stream flow on specific conductance at Den Hill after high rainfall observed from August 2 to August 9.*

Routine monitoring of concentrations of sodium (Na) and chloride (Cl) in Quabbin Reservoir began in 2020. In 2024, monitoring for Na and Cl in Quabbin Reservoir was conducted quarterly. Sodium concentrations ranged from a minimum of 5.17 mg/L at the surface of the water column of site Den Hill, to a maximum of 5.83 mg/L at the bottom of the water column of site 202 (Table 46). Chloride concentrations ranged from a minimum of 7.21 mg/L at the surface of the water column at Den Hill to a maximum of 8.40 mg/L in the middle of the water column at site 206 (Table 46). Sodium and chloride concentrations varied little with season or depth in the reservoir. Median annual concentrations of Na and Cl measured in 2024 were comparable to prior results. Neither ORS guidelines for Na (20 mg/L) or the SMCL for Cl (250 mg/L) were exceeded in samples collected from Quabbin Reservoir in 2024 (see Section 6.1).

Table 46. *Concentration results for Na and Cl measured in Quabbin Reservoir during 2024 relative to the period of record (2020 – 2023) at DWSP monitoring sites.*

Sodium

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	16	5.40	5.11	5.54	5.44	5.51	5.44	5.61	5.79
202	Mid	4	16	5.27	4.99	5.50	5.48	5.47	5.47	5.62	5.74
202	Deep	5	16	5.31	5.01	5.51	5.52	5.51	5.54	5.83	6.00
206	Surface	5	16	5.41	5.16	5.55	5.48	5.56	5.56	5.75	6.15
206	Mid	5	16	5.33	5.20	5.57	5.43	5.52	5.49	5.74	6.11
206	Deep	5	16	5.45	5.15	5.53	5.46	5.56	5.50	5.66	6.08
Den Hill	Surface	5	16	5.17	5.30	5.53	5.79	5.49	5.81	5.73	6.45
Den Hill	Mid	5	16	5.45	5.45	5.67	5.69	5.66	5.76	5.80	6.09
Den Hill	Deep	5	16	5.40	5.41	5.62	5.89	5.59	5.87	5.75	6.31

Chloride

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	18	7.65	7.74	7.79	8.04	7.87	8.08	8.31	8.59
202	Mid	5	18	7.67	7.77	7.91	8.10	7.90	8.10	8.29	8.61
202	Deep	5	18	7.39	7.74	7.67	8.06	7.77	8.05	8.32	8.37
206	Surface	5	18	7.53	7.74	7.99	8.05	7.92	8.11	8.37	8.42
206	Mid	5	18	7.44	7.78	7.88	8.08	7.90	8.16	8.40	8.74
206	Deep	5	18	7.41	7.75	7.82	8.02	7.85	8.07	8.35	8.64
Den Hill	Surface	5	18	7.21	8.16	7.74	8.49	7.76	8.62	8.31	9.98
Den Hill	Mid	5	18	7.75	8.17	7.88	8.53	7.94	8.67	8.33	9.51
Den Hill	Deep	5	18	7.41	8.15	7.81	8.57	7.79	8.75	8.32	9.86

3.3.7 Turbidity

Turbidity measured in the Quabbin Reservoir was low and relatively stable throughout the year. Turbidity levels in Quabbin Reservoir ranged from 0.20 NTU to 0.88 NTU during 2024 (Table 47); these levels were slightly higher than last year but fell within the historical range of turbidity observed at DWSP monitoring sites (Figure 34). Turbidity remained below 1.0 NTU in Quabbin Reservoir in all samples collected by DWSP in 2024.

Table 47. *Seasonal statistics for Turbidity (NTU) in Quabbin Reservoir during 2024 relative to the period of record (2005 – 2023) at DWSP monitoring sites.*

Turbidity

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	9	148	0.21	0.16	0.26	0.27	0.25	0.28	0.32	0.67
202	Mid	9	167	0.20	0.19	0.29	0.28	0.29	0.29	0.36	0.73
202	Deep	9	175	0.22	0.16	0.32	0.26	0.35	0.28	0.52	1.04
206	Surface	9	148	0.20	0.16	0.31	0.28	0.31	0.30	0.52	0.88
206	Mid	9	164	0.21	0.19	0.32	0.31	0.34	0.32	0.42	0.82
206	Deep	9	173	0.20	0.18	0.35	0.31	0.47	0.34	0.88	1.21
Den Hill	Surface	9	144	0.28	0.25	0.46	0.40	0.45	0.42	0.60	0.98
Den Hill	Mid	9	160	0.28	0.24	0.48	0.44	0.45	0.45	0.61	1.13
Den Hill	Deep	9	168	0.25	0.22	0.53	0.46	0.52	0.57	0.69	4.00

As is typical, Den Hill exhibited routinely elevated turbidity relative to other core monitoring locations within the Quabbin Reservoir (Figure 34). This well-established spatial gradient has previously been attributed to local inputs from the East Branch Swift River (DWSP, 2021a). While turbidity was relatively higher at Den Hill than in the other core monitoring sites, this year's turbidity levels were comparable across sites and overall, turbidity remained low at all sites.

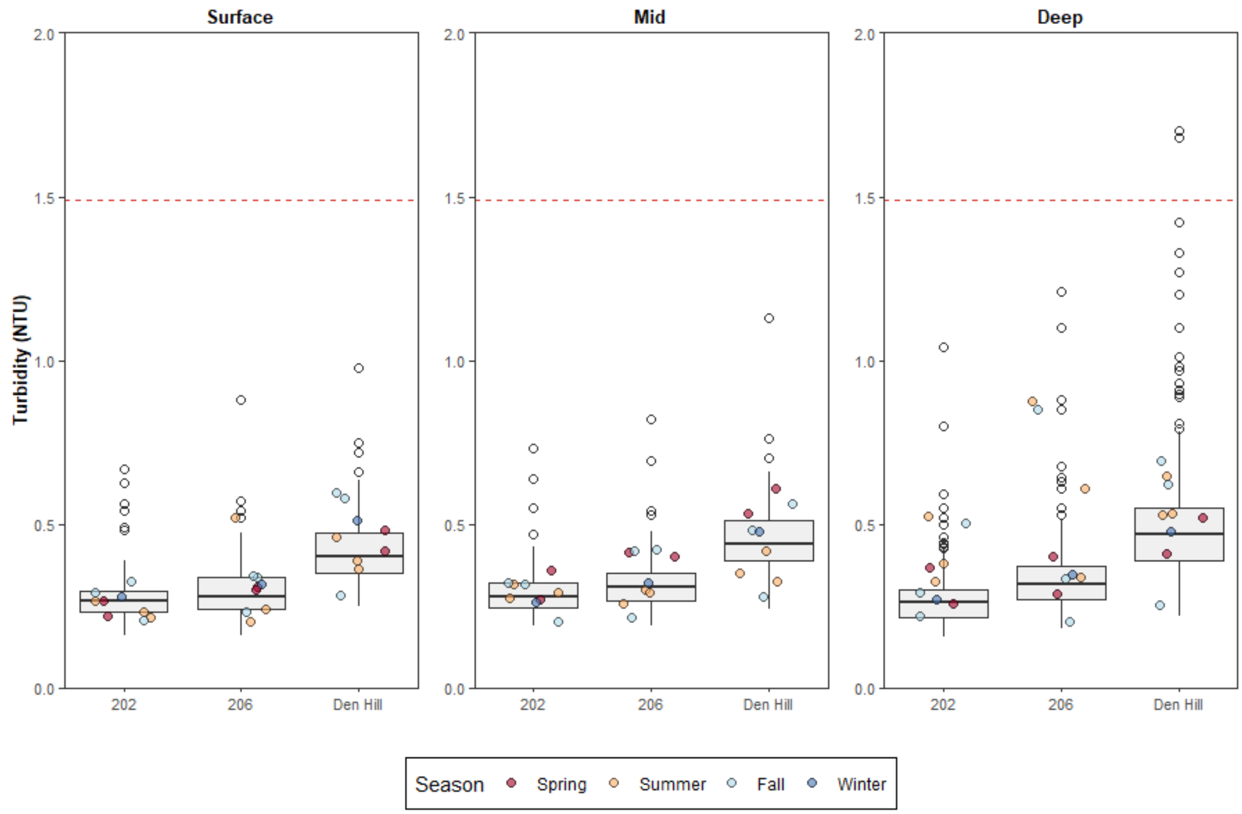


Figure 34. *Boxplots depicting the seasonal and vertical distributions of turbidity in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median. Outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively. The MassDEP 1 NTU standard, which applies to the intake, is marked by the red dashed line in each panel.*

3.3.8 Secchi Disk Depth/Transparency

Simultaneous aided and unaided Secchi disk transparencies were measured in the Quabbin Reservoir in 2024. Aided Secchi disk measurements were made using a standard view scope (4-inch diameter tube, 3-feet long, black on inside with Plexiglas disk on one end) to reduce variability introduced by surface glare and waves. The aided Secchi measurements resulted in greater transparency than unaided. On average, aided transparency was approximately 1.7 m deeper than unaided measurements. The largest difference between aided and unaided measurements was 4.65 m, taken at sampling site 206 on July 24, 2024 (Figure 35). This large difference was most likely due to surface glare. On April 9, 2024 at site 206, there was a 0.05 m difference between transparencies. This was likely due to low waves, which lowered surface glare.

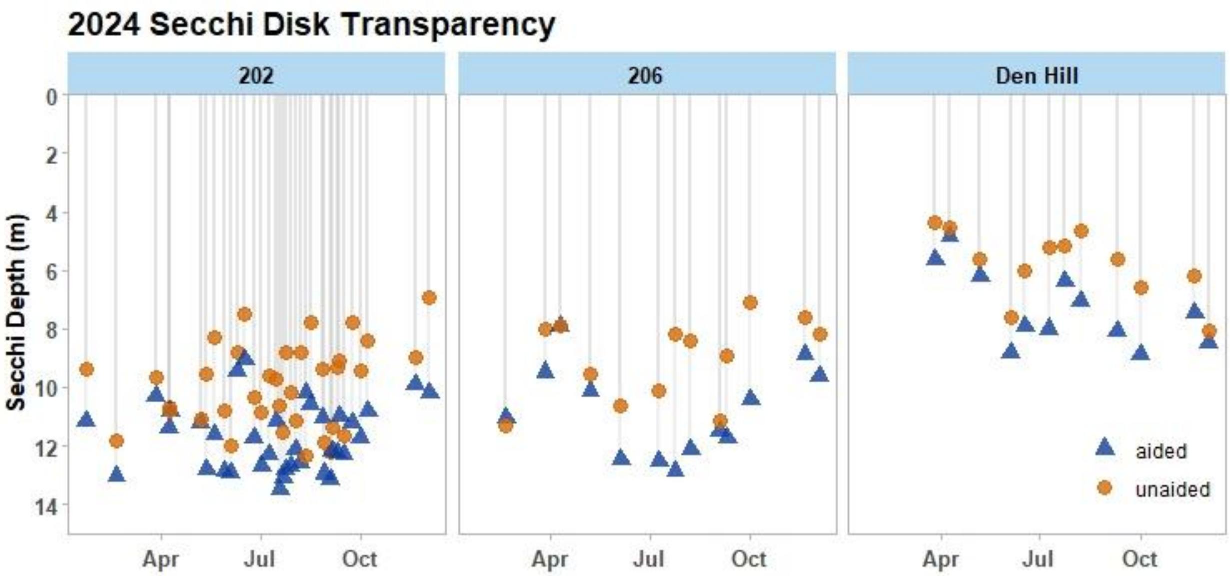


Figure 35. *Secchi disk transparencies measured in 2024 in Quabbin Reservoir at DWSP monitoring sites 202 (maximum depth 46 m), 206 (maximum depth 30.5 m), and Den Hill (maximum depth 22.7 m). Orange circle data points are unaided measurements, and dark blue triangle points are aided, collected using a view scope.*

Water in the Quabbin Reservoir continued to demonstrate exceptional clarity in 2024, with a median aided Secchi disk transparency of 11.7, 11.0, and 7.6-m, and median unaided Secchi of 9.7, 8.4, and 4.3 m at sites 202, 206, and Den Hill, respectively. Secchi disk transparency in Quabbin Reservoir was generally consistent with previous monitoring, mirroring seasonal patterns of phytoplankton dynamics (Worden, 2000; DWSP, 2019a) and turbidity. The minimum Secchi disk transparency observed in 2024 was 4.3 m unaided (March 27, 2024) and 4.8 m aided (April 9, 2024) at monitoring site Den Hill. The maximum Secchi disk transparency was 12.3 m unaided (August 12, 2024) and 13.4 m aided (July 19, 2024) at monitoring site 202.

Transparency at monitoring site Den Hill was characteristically lower than at sites 202 and 206 (Figure 35), reflecting the nearby contribution of large riverine inputs from the East Branch Swift River. The East Branch Swift River is estimated to contribute as much as 9 to 16 percent of the annual inflow to the Quabbin Reservoir (DWSP, 2007). Thus, this inflow may act as a source of color and sediment, reducing transparency and resulting in slightly elevated levels of turbidity within the Quabbin Reservoir during and following high streamflow events, periodically observed at the Den Hill monitoring site due to proximity.

3.3.9 Nutrients

Patterns of nutrient distributions in Quabbin Reservoir in 2024 were generally consistent with those documented previously by Worden (2000) and historical ranges observed in Quabbin Reservoir by DWSP monitoring. Prominent seasonal, spatial, and vertical variations were present, likely due to the interactions of demand by phytoplankton in the epilimnion and metalimnion, the decomposition of organic matter in the hypolimnion, and the timing and extent of terrestrial-derived sources of nutrients delivered via riverine loading to the Quabbin Reservoir.

3.3.9.1 Total Nitrogen (Ammonia-Nitrogen, Nitrate-Nitrogen, and Total Kjeldahl Nitrogen)

Concentrations of ammonia (NH_3-N) and nitrate (NO_3-N) ranged from less than 0.005 to 0.032 mg/L and from less than 0.005 to 0.073 mg/L, respectively in Quabbin Reservoir in 2024. Overall, concentrations of ammonia and nitrate followed the vertical and temporal variation characteristic of historical seasonal ranges for each site (Table 48). Concentrations of ammonia and nitrate were generally elevated in the hypolimnion and at Den Hill relative to other sites. Ammonia was below detection limits (less than 0.005 mg/L) in all samples collected from the epilimnion at site 202 and for the majority of samples collected from the epilimnion at site 206 and Den Hill. As is characteristically observed, ammonia and nitrate concentrations increased in the hypolimnion in the late summer and fall at all sites, likely coincident with decomposition. Following fall turnover in the reservoir, ammonia and nitrate concentrations decreased at each site, homogenizing across depths. Winter concentrations of ammonia and nitrate were comparable to historical medians (Table 48, Figure 37).

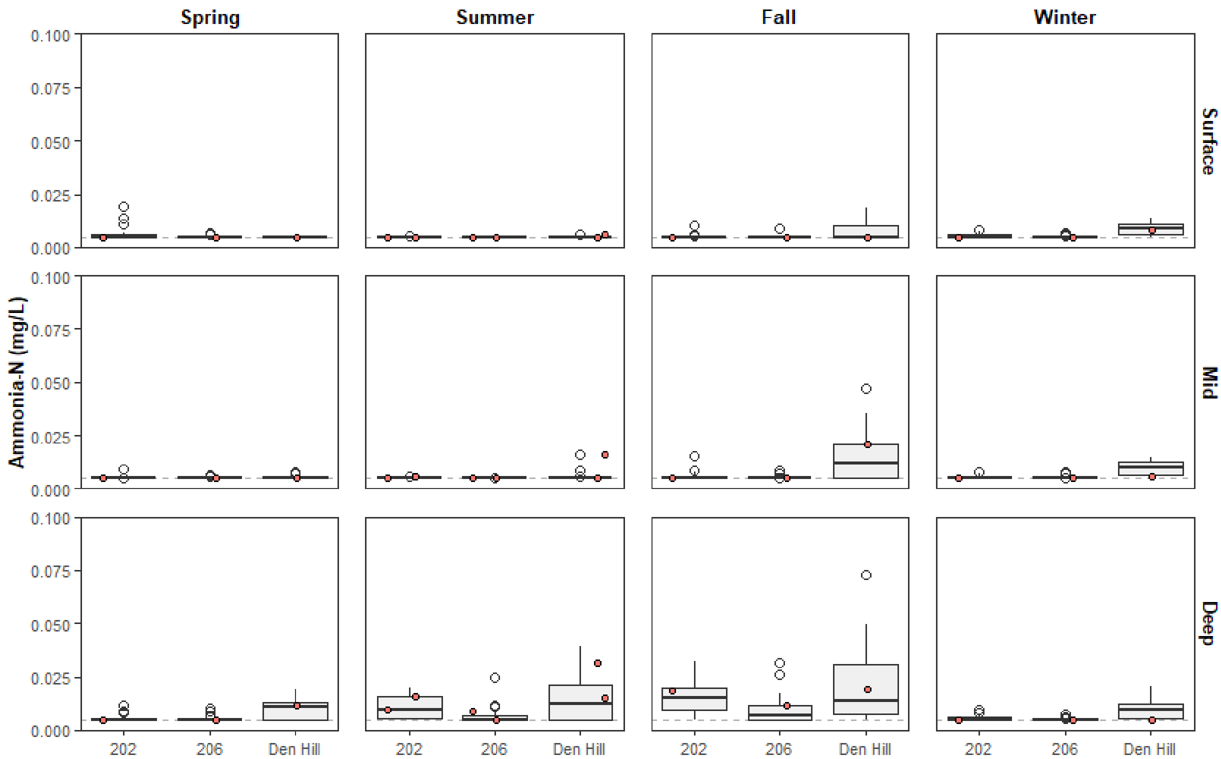


Figure 36. *Boxplots depicting the seasonal and vertical distribution of ammonia in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

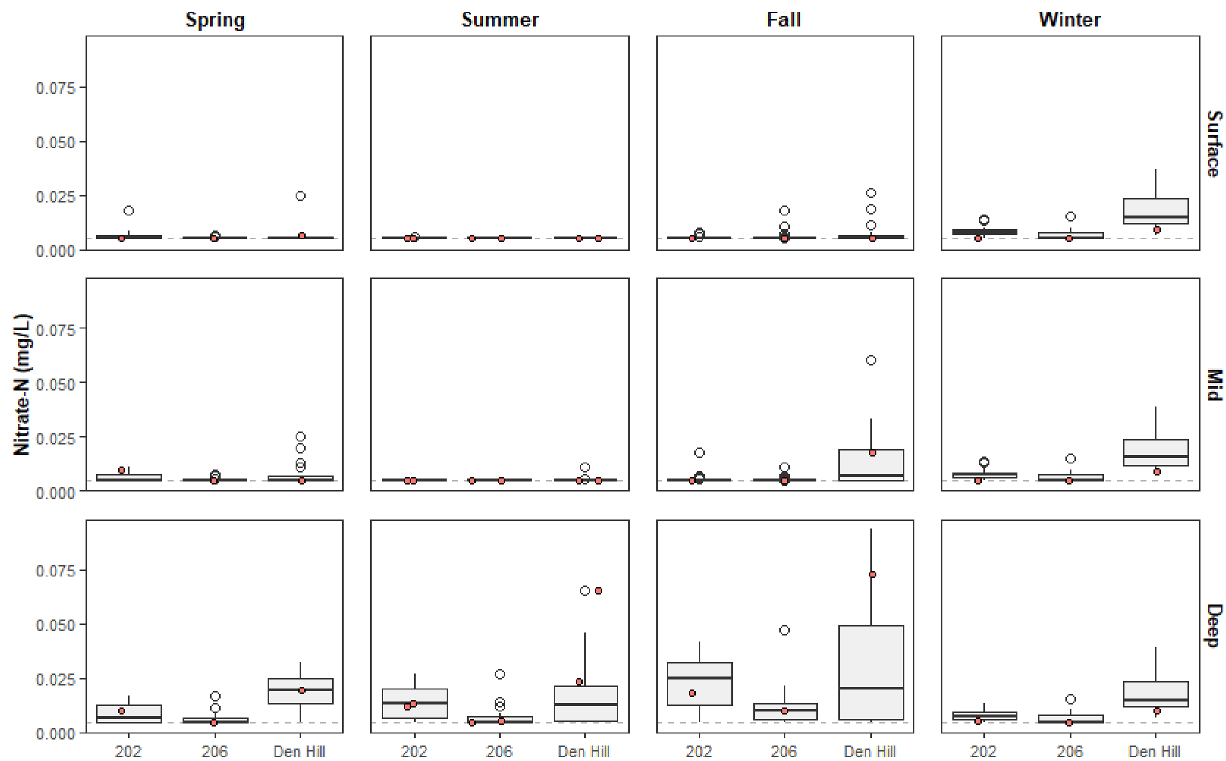


Figure 37. *Boxplots depicting the seasonal and vertical distribution of nitrate in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

Concentrations of TKN in Quabbin Reservoir Core sites ranged from 0.031 to 0.252 mg/L in 2024 (Table 48). TKN concentrations in Quabbin Reservoir exhibited little temporal or spatial variability in 2024 (Figure 38). Overall, most of the TKN concentrations in Quabbin Reservoir approached the historical seasonal medians throughout the water column (Figure 38). The highest TKN concentration observed was 0.252 mg/L from the hypolimnion of 202 (Table 48). Certain TKN results were removed from analysis due to samples being processed outside of the determined holding time; this included spring results for all sites/depths and one summer result from the surface water at site 202. A proportion of the variability in concentrations of TKN observed in 2024, when compared to the historical records, may be attributed to assumptions made during calculations of TKN concentrations for 2020 through 2022 data (e.g., substituting the detection limit of NO_2-N and NO_3-N), or related to differences in sensitivity of different laboratory methods (e.g., the detection limits for TN via Valderrama [1981] were lower than that of EPA 351.2 used previously).

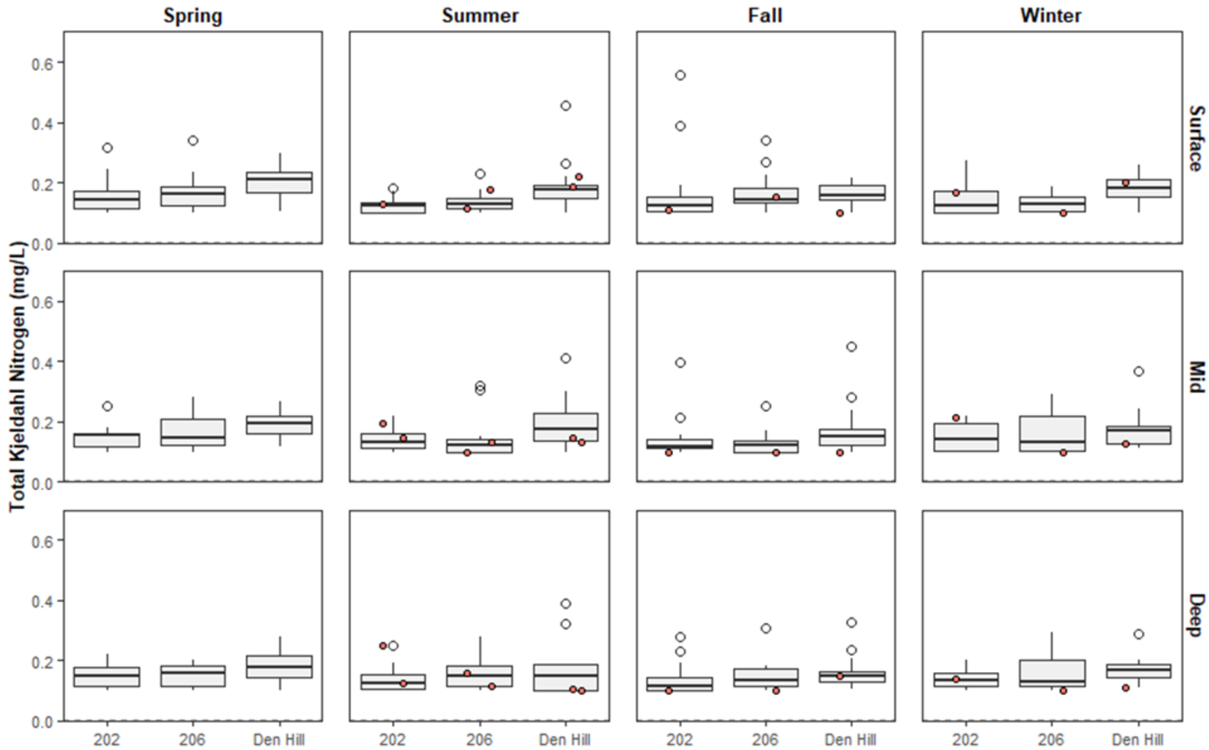


Figure 38. *Boxplots depicting the seasonal and vertical distributions of total Kjeldahl nitrogen (TKN) in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

Table 48. *Descriptive statistics for ammonia, nitrate, and TKN in Quabbin Reservoir during 2024 relative to the period of record (2020 – 2023). Detection limits were less than 0.005 mg/L for ammonia and nitrate and less than 0.100 mg/L for TKN.*

Ammonia-N (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	72	0.005	0.005	0.002	0.002	0.003	0.003	0.005	0.019
202	Mid	5	72	0.005	0.005	0.002	0.003	0.003	0.004	0.005	0.016
202	Deep	5	72	0.005	0.005	0.01	0.008	0.01	0.01	0.018	0.032
206	Surface	5	72	0.005	0.005	0.002	0.003	0.003	0.003	0.005	0.01
206	Mid	5	72	0.005	0.005	0.002	0.002	0.003	0.002	0.005	0.02
206	Deep	5	71	0.005	0.005	0.002	0.004	0.006	0.006	0.012	0.032
Den Hill	Surface	5	70	0.005	0.005	0.002	0.005	0.004	0.006	0.008	0.019
Den Hill	Mid	5	71	0.005	0.005	0.006	0.005	0.01	0.008	0.021	0.047
Den Hill	Deep	5	70	0.005	0.005	0.015	0.011	0.016	0.014	0.032	0.073

Nitrate-N (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	74	0.005	0.005	0.002	0.004	0.002	0.005	0.005	0.018
202	Mid	5	74	0.005	0.005	0.002	0.004	0.004	0.005	0.01	0.018
202	Deep	5	74	0.005	0.005	0.012	0.012	0.012	0.015	0.018	0.042
206	Surface	5	74	0.005	0.005	0.002	0.002	0.002	0.004	0.005	0.018
206	Mid	5	74	0.005	0.005	0.002	0.003	0.002	0.004	0.005	0.015
206	Deep	5	73	0.005	0.005	0.002	0.006	0.005	0.008	0.01	0.047
Den Hill	Surface	5	72	0.005	0.005	0.002	0.004	0.005	0.007	0.009	0.037
Den Hill	Mid	5	72	0.005	0.005	0.002	0.005	0.007	0.01	0.018	0.06
Den Hill	Deep	5	72	0.01	0.005	0.024	0.016	0.038	0.02	0.073	0.094

Total Kjeldahl N (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	3	96	0.099	0.082	0.122	0.122	0.129	0.149	0.167	0.56
202	Mid	4	96	0.09	0.082	0.165	0.13	0.158	0.144	0.214	0.399
202	Deep	4	96	0.077	0.059	0.129	0.122	0.143	0.13	0.252	0.278
206	Surface	4	96	0.09	0.08	0.129	0.133	0.13	0.149	0.178	0.342
206	Mid	4	96	0.09	0.09	0.091	0.131	0.1	0.148	0.131	0.322
206	Deep	4	96	0.085	0.081	0.098	0.137	0.109	0.15	0.158	0.309
Den Hill	Surface	4	92	0.09	0.058	0.187	0.166	0.174	0.177	0.222	0.457
Den Hill	Mid	4	92	0.077	0.082	0.124	0.164	0.117	0.179	0.145	0.449
Den Hill	Deep	4	92	0.031	0.052	0.098	0.151	0.093	0.166	0.15	0.389

3.3.9.2 Total Phosphorus

Vertical and spatial patterns in total phosphorus (TP) concentrations observed in Quabbin Reservoir remained consistent with those previously observed. Concentrations of TP ranged from below the detection limit of less than 0.005 to 0.007 mg/L in 2024 (Table 49). Overall, TP concentrations in Quabbin Reservoir were below or approached the historical seasonal medians throughout the water column, except for one result from the metalimnion of Den Hill (Figure 39). TP concentrations in all 2024 samples remained well below the 10 μg/L threshold for classification as an oligotrophic water body (Carlson, 1977). Concentrations of TP remained low throughout the water column for the entirety of 2024.

Table 49. *Descriptive statistics for total phosphorus (TP) in Quabbin Reservoir during 2024 relative to the period of record (POR). Detection limits for TP in 2024 were less than 0.005 mg/L.*

Total Phosphorus (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	63	0.005	0.005	0.002	0.004	0.002	0.005	0.005	0.01
202	Mid	5	62	0.005	0.005	0.002	0.004	0.003	0.005	0.006	0.014
202	Deep	5	62	0.005	0.005	0.002	0.005	0.002	0.005	0.005	0.01
206	Surface	5	62	0.005	0.005	0.002	0.003	0.002	0.004	0.005	0.01
206	Mid	5	62	0.005	0.005	0.002	0.003	0.002	0.004	0.005	0.015
206	Deep	5	62	0.005	0.005	0.002	0.004	0.002	0.005	0.005	0.01
Den Hill	Surface	5	61	0.005	0.005	0.002	0.006	0.003	0.006	0.007	0.027
Den Hill	Mid	5	61	0.005	0.005	0.002	0.006	0.003	0.006	0.007	0.014
Den Hill	Deep	5	61	0.005	0.005	0.002	0.007	0.004	0.007	0.006	0.014

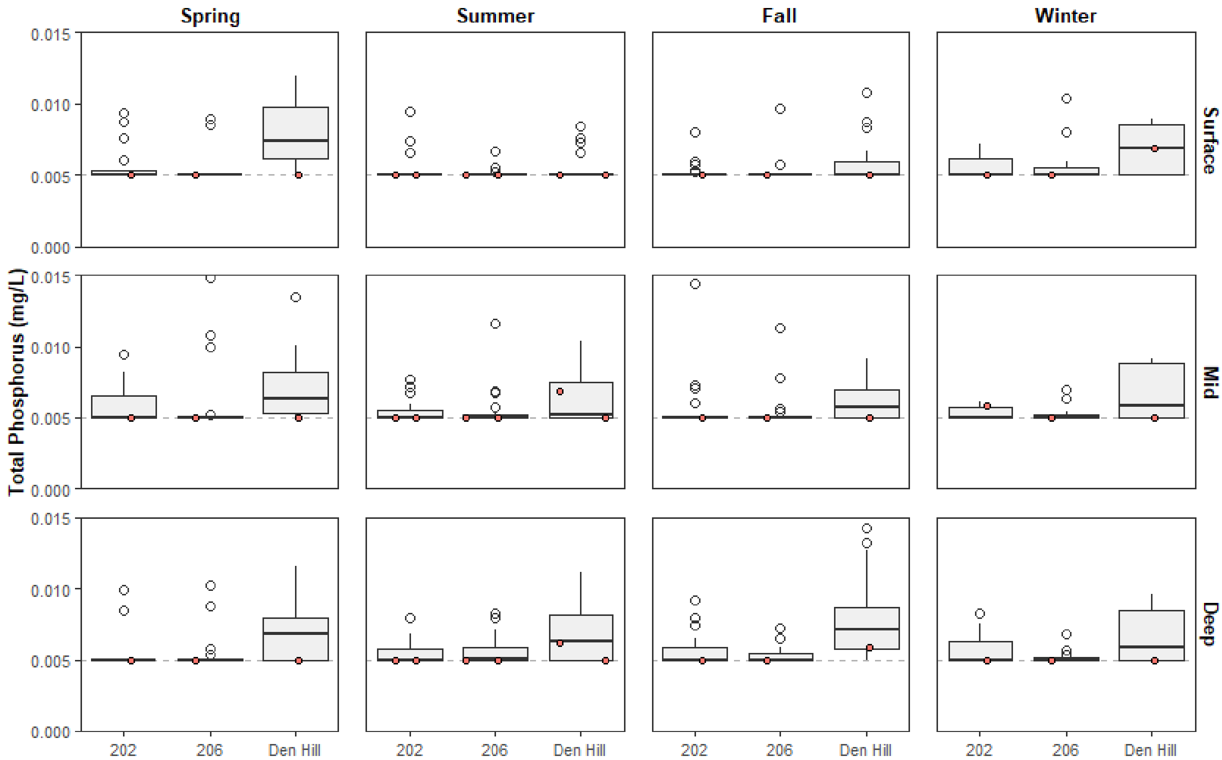


Figure 39. *Boxplots depicting the seasonal and vertical distributions of total phosphorus in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

3.3.9.3 Total Silica

Silica is utilized by phytoplankton, particularly diatoms and chrysophytes, to form their frustules, tests, and scales (Reynolds, 2006). Total silica concentrations in Quabbin Reservoir ranged from 1.50 to 3.95 mg/L in 2024, compared to a range of 1.00 to 3.97 mg/L for the period of record (Table 50). Overall, elevated total silica concentrations were observed in 2024, with the majority of results above historical medians (Figure 40). It has been observed that total silica at 202 and Den Hill, particularly at depth, has been increasing over time (2010 to 2024 - POR).

Concentrations of total silica in the Quabbin Reservoir exhibited spatial and temporal gradients consistent with riverine inputs in the spring, seasonal phytoplankton productivity in the spring and summer, and subsequent endogenous loading from phytoplankton die-offs in late summer and fall. In 2024, total silica concentrations were generally higher in the spring and fall (May and October) and lower in the summer and winter (July and December), consistent with previous results. Elevated concentrations were also observed in the hypolimnion at all sites in August, likely related to die-offs resulting from the *Chrysosphaerella* aggregation (see Section 3.3.10). Similar increases in total silica concentrations have been observed in the fall of other years with

Chrysosphaerella aggregations (2019, 2022, and 2024), suggesting that elevated concentrations at depth are due to the sinking of dead *Chrysosphaerella* colonies. To better understand the presence of silica in the Quabbin Reservoir and its role in *Chrysosphaerella* aggregations, samples will be collected and analyzed for dissolved silica in 2025.

Total silica concentrations were greatest at Den Hill at depth (3.59 to 3.95 mg/L), similar to patterns observed in turbidity, TOC, and UV_{254} across monitoring sites and likely the result of the proximity of Den Hill to the confluence of the East Branch Swift River with the Quabbin Reservoir.

Table 50. *Descriptive statistics for silica in Quabbin Reservoir during 2024 relative to the period of record (2010 - 2023).*

Silica (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	5	74	1.91	1.30	2.09	1.80	2.07	1.81	2.20	2.32
202	Mid	5	74	1.82	1.24	2.10	1.78	2.03	1.80	2.22	2.34
202	Deep	5	76	2.14	1.37	2.56	2.13	2.43	2.12	2.61	2.93
206	Surface	5	74	1.81	1.23	2.03	1.72	1.98	1.71	2.14	2.40
206	Mid	5	75	1.50	1.19	1.71	1.67	1.83	1.67	2.12	2.27
206	Deep	5	75	2.07	1.32	2.19	1.86	2.18	1.87	2.25	2.60
Den Hill	Surface	5	73	1.61	1.25	2.04	1.84	2.12	2.08	2.71	3.75
Den Hill	Mid	5	72	1.82	1.00	2.43	1.87	2.48	2.12	3.40	3.84
Den Hill	Deep	5	72	2.40	1.55	3.86	2.62	3.55	2.62	3.95	3.97

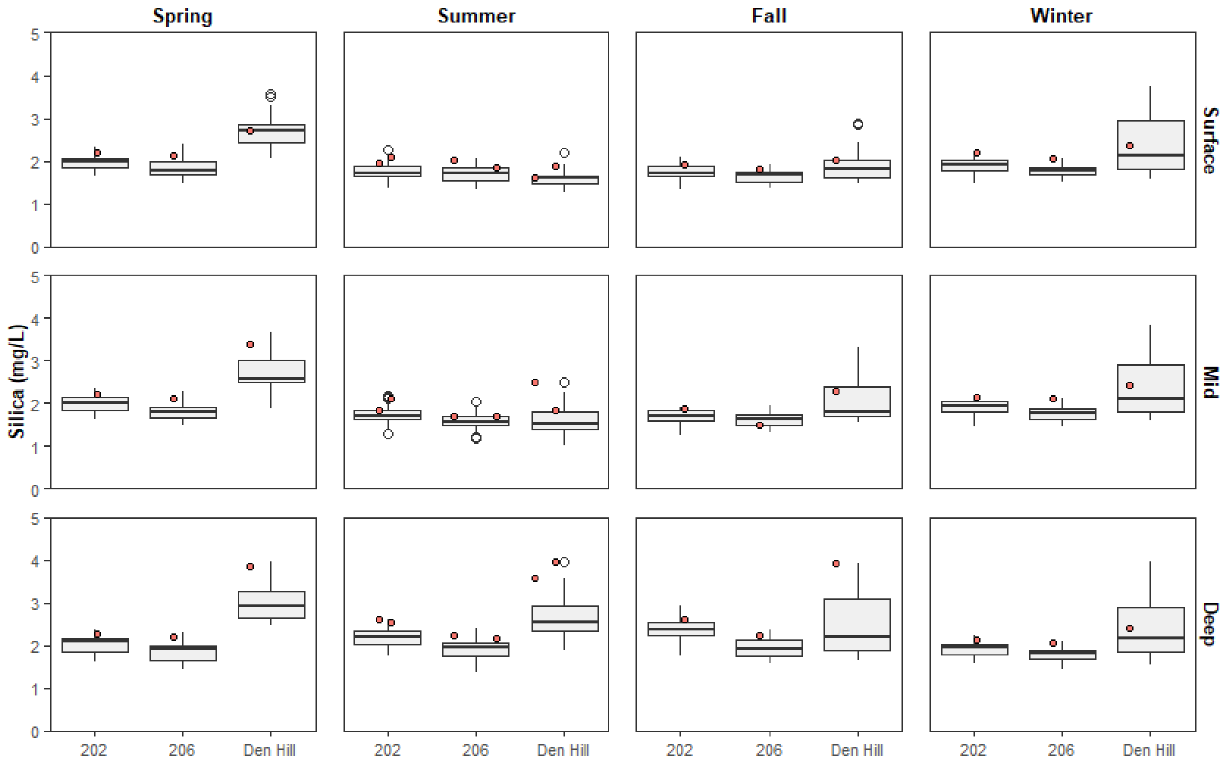


Figure 40. *Boxplots depicting the seasonal and vertical distributions of silica observed in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

3.3.9.4 UV_{254} and Total Organic Carbon

3.3.9.4.1 UV_{254} Absorbance

UV_{254} absorbance in Quabbin Reservoir in 2024 ranged from 0.024 to 0.028 ABU/cm at site 202, from 0.024 to 0.033 ABU/cm at 206, and from 0.040 to 0.091 ABU/cm at Den Hill (Table 51). Annual minimums, medians, and means exceeded the historical measures at all sites, but none of the sites exceeded the historical observed maximums. An increase in monitoring frequency for UV_{254} in Quabbin Reservoir was started in 2020. The higher resolution dataset generated in the previous four years may elucidate new insights regarding intra-annual variability in UV_{254} absorbance in Quabbin Reservoir. This increased sampling frequency may also contribute to the observed annual median results above historical medians.

Table 51. *Descriptive statistics for UV_{254} measured in Core reservoir monitoring sites in the Quabbin Reservoir in 2024 relative to the period of record (2005, 2010-2023).*

UV_{254} (ABU/cm)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	9	78	0.024	0.016	0.026	0.023	0.026	0.023	0.029	0.034
202	Mid	9	78	0.025	0.017	0.030	0.024	0.029	0.024	0.031	0.038
202	Deep	8	78	0.025	0.017	0.027	0.022	0.027	0.023	0.028	0.031
206	Surface	9	78	0.025	0.017	0.027	0.023	0.027	0.024	0.032	0.093
206	Mid	9	78	0.024	0.017	0.030	0.024	0.030	0.024	0.033	0.036
206	Deep	9	78	0.025	0.017	0.029	0.024	0.029	0.024	0.033	0.034
Den Hill	Surface	9	76	0.040	0.023	0.052	0.045	0.057	0.052	0.088	0.122
Den Hill	Mid	9	76	0.040	0.022	0.043	0.040	0.053	0.050	0.090	0.139
Den Hill	Deep	9	76	0.040	0.023	0.062	0.046	0.064	0.052	0.091	0.171

UV_{254} absorbance in the Quabbin Reservoir is impacted by contributions from major tributaries, reservoir circulation, and mixing. Spatial gradients in UV_{254} are largely reflective of localized inputs (e.g., elevated UV_{254} at Den Hill relative to other monitoring sites). Median annual UV_{254} was greatest at Den Hill and displayed little seasonal variation in samples collected from 202 and 206 in 2024 (Figure 41). Similar to last year's pattern, seasonality in UV_{254} absorbance was well established for Den Hill, with higher UV_{254} absorbances during spring. Unlike last year, elevated UV_{254} absorbances were also observed during the summer at all depths in Den Hill, likely attributed to potential increased loading from the East Branch Swift River during high stream flow events in the late summer.

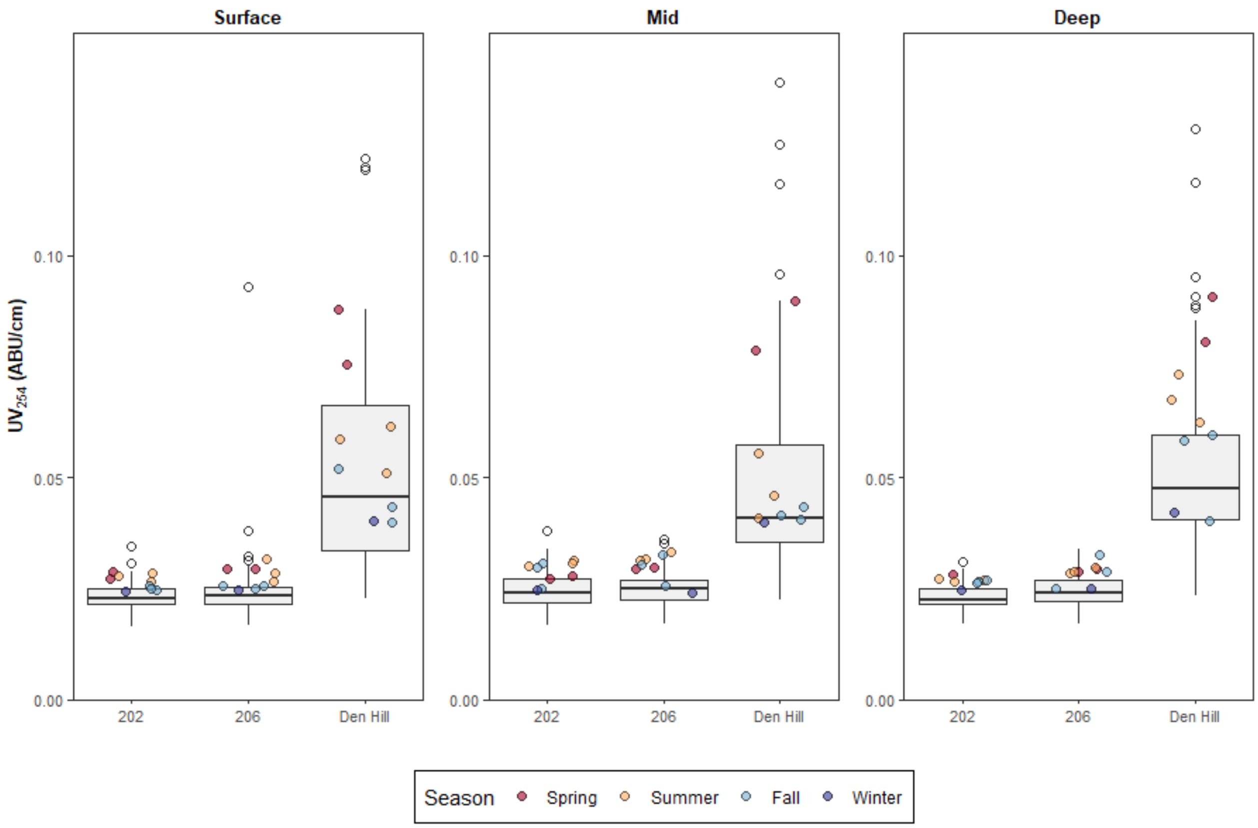


Figure 41. *Boxplots depicting the seasonal and vertical distributions of UV_{254} observed in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

3.3.9.4.2 Total Organic Carbon

Routine monitoring for total organic carbon (TOC) in Quabbin Reservoir began in 2020. TOC concentrations ranged from 1.55 to 2.33 ABU/cm at site 202, from 1.72 to 2.38 ABU/cm at 206, and from 2.01 to 3.22 ABU/cm at Den Hill (Table 52). TOC concentrations in 2024 were lower than those observed in 2023 but comparable to concentrations during monitoring in 2020, 2021, and 2022 and to results generated nearly two decades prior (2 mg/L to 2.7 mg/L; concentrations approached or exceeded 3 mg/L at Den Hill) (Garvey and Tobiason, 2003; DWSP, 2021a). Concentrations of TOC measured in Quabbin Reservoir during 2024 were less than global mean concentrations for deep and north temperate lakes (3.463 mg/L and 5.809 mg/L, respectively) (Chen et al., 2015).

Similar to results from previous years, TOC exhibited little variability with depth or changes in stratification but showed seasonal variation with higher TOC concentrations in the spring (Figure

42). Last year, TOC concentrations showed little seasonal variation due to higher concentrations during the summer and fall compared to observations from 2022. The difference in seasonal TOC variability between 2022, 2023, and 2024, is likely attributed to the difference in riverine inputs during drought conditions (2022 and 2024 – partial drought conditions) and flood conditions (2023) across MA (Raymond and Saiers, 2010; Yoon and Raymond 2012).

Spatial gradients in TOC generally mirrored UV_{254} absorbance – with relative enrichment in samples collected from the Den Hill compared to 202 and 206. However, correlations among these parameters have previously been mixed, with the strongest relationships presented by Den Hill and comparatively poor relationships between UV_{254} and TOC at 202 and 206 (DWSP, 2022).

Table 52. *Descriptive statistics for total organic carbon measured in Core reservoir monitoring sites in the Quabbin Reservoir in 2024 relative to the period of record (2020 - 2024).*

Total Organic Carbon (mg/L)

Location	Season	Count 2024	Count POR	Min 2024	Min POR	Median 2024	Median POR	Mean 2024	Mean POR	Max 2024	Max POR
202	Surface	9	35	1.79	1.89	1.99	2.21	2.05	2.23	2.41	2.68
202	Mid	9	35	1.73	1.74	1.93	2.11	1.97	2.17	2.26	2.79
202	Deep	9	35	1.55	1.60	1.75	1.97	1.85	1.98	2.33	2.42
206	Surface	9	34	1.78	1.82	2.02	2.24	2.04	2.24	2.38	2.66
206	Mid	9	35	1.78	1.84	1.92	2.18	2.00	2.22	2.33	2.69
206	Deep	9	33	1.72	1.66	1.95	2.12	2.00	2.14	2.30	2.58
Den Hill	Surface	9	35	2.10	2.03	2.46	2.51	2.48	2.69	3.16	3.57
Den Hill	Mid	9	35	2.01	1.86	2.20	2.42	2.31	2.52	3.09	3.59
Den Hill	Deep	9	35	2.13	1.92	2.24	2.34	2.42	2.48	3.22	3.83

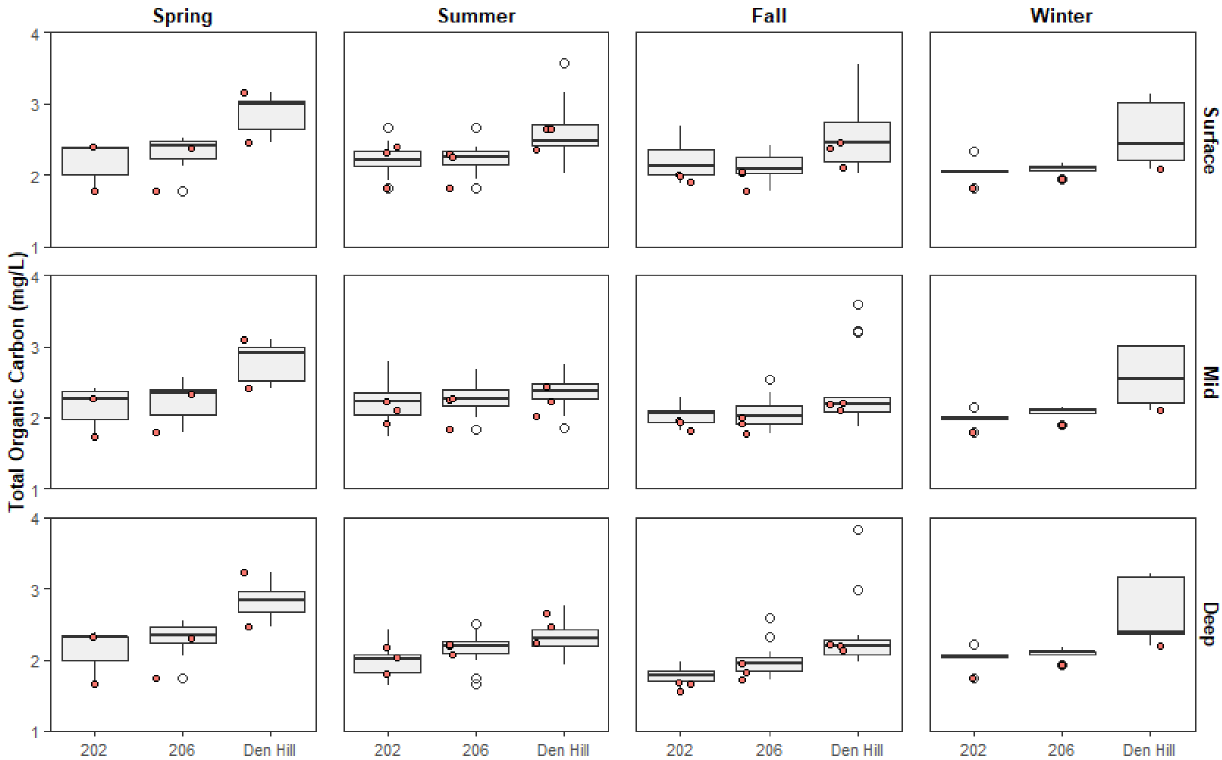


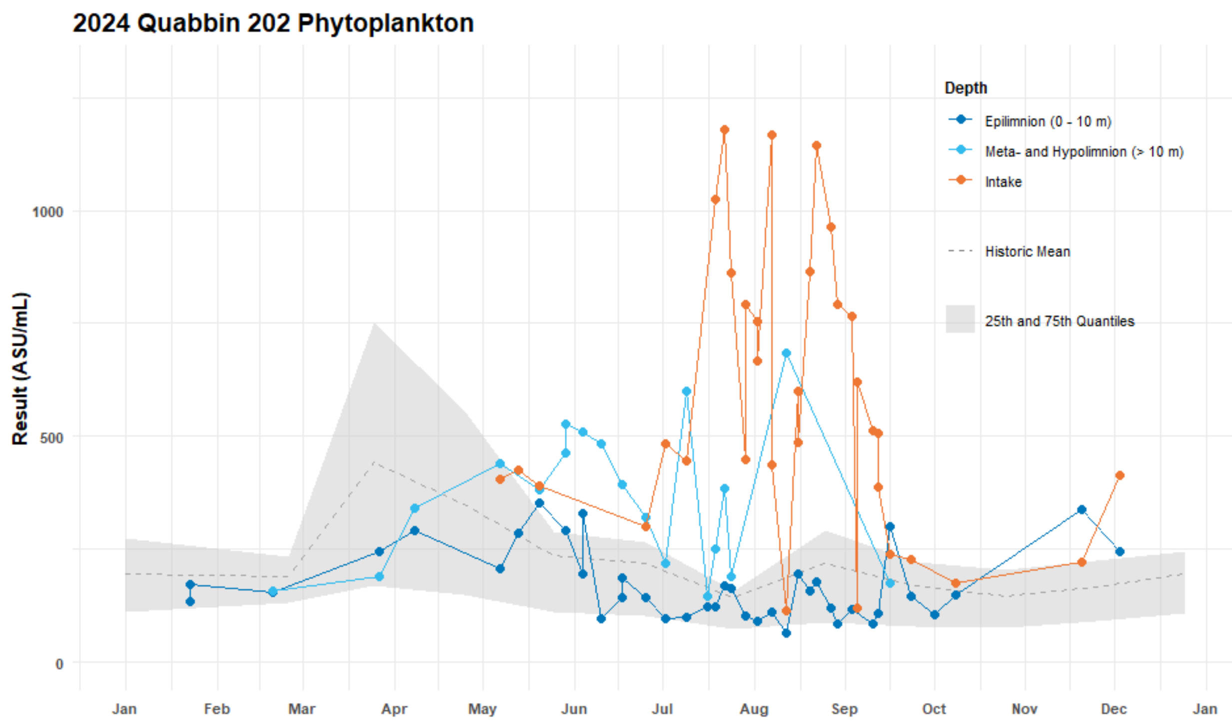
Figure 42. *Boxplots depicting the seasonal and vertical distributions of TOC in Quabbin Reservoir Core sites. Results corresponding to samples collected in 2024 are signified by the colored points. The solid black line represents the historical median, outliers for the period of record are represented by open circles, and the whiskers and box represent 1.5 times the interquartile range, and the 25th and 75th percentiles of all data, respectively.*

3.3.10 Phytoplankton

Samples for phytoplankton enumeration were collected from Quabbin Reservoir core monitoring sites 202, 206, and Den Hill on 36, 14, and 13 days in 2024, respectively. Samples for phytoplankton enumeration were collected from two to three depths, depending on the location: 1) from the epilimnion at 3 m, 2) at the chlorophyll *a* maximum (with simultaneous high dissolved oxygen), typically within the metalimnion, and 3) near intake depths to closely monitor phytoplankton community composition and potential taste and odor impacts. Intake sampling was performed regularly at site 202 to maintain a regular record of phytoplankton densities that directly influence the quality of water flowing into the Winsor Dam Intake (WDI) as part of the CVA system. Occasional sampling at the intake depth was performed (as needed) at site 206 to understand phytoplankton densities entering the Quabbin Aqueduct at Shaft 12 and subsequently transported to Wachusett Reservoir (see Figure 1).

In 2024, samples were collected for routine monitoring at site 202 monthly from January to April and then again from October to December. During the growing season (May through September) samples were collected weekly at site 202. At sites 206 and Den Hill, samples were collected monthly (weather and ice conditions permitting) year-round starting in February at site 206, and in March for Den Hill. Under special circumstances (e.g., exceedance of alert levels, see Table 53) sampling frequency of phytoplankton was increased, and additional samples were collected based on *in-situ* readings of chlorophyll *a* and dissolved oxygen. Sampling frequency was increased to twice per week at site 202 between July 9 to September 16 in response to consistent exceedance of the *Chrysosphaerella* alert level during this period. At sites 206 and Den Hill, sampling frequency was increased to twice per month during July in response to the *Chrysosphaerella* alert level exceedance on July 9, 2024.

Elevated phytoplankton levels were observed in 2024 at all sites. These high phytoplankton levels were mainly attributed to a *Chrysosphaerella* aggregation detected across reservoir sites. Maximum total phytoplankton densities in 2024 were 1180 ASU/mL at site 202 observed on July 22 at 18 m, 1197 ASU/mL at site 206 observed on August 7 at 16 m, and 1628 ASU/mL at site Den Hill observed on July 9 at 13 m (Figure 43 and Figure 45). While the *Chrysosphaerella* aggregation was first observed at 13 m at all sites on July 9, the duration and density of this aggregation varied by site. Higher densities were observed at Den Hill, followed by 206 and then 202, but duration was longer at 202 than at the other two sites. The aggregation lasted around 10 weeks at site 202, 9 weeks at site 206, and 7 weeks at site Den Hill. Drinking water quality during the summer of 2024 was impacted due to taste and odor compounds produced by the high levels of *Chrysosphaerella*.



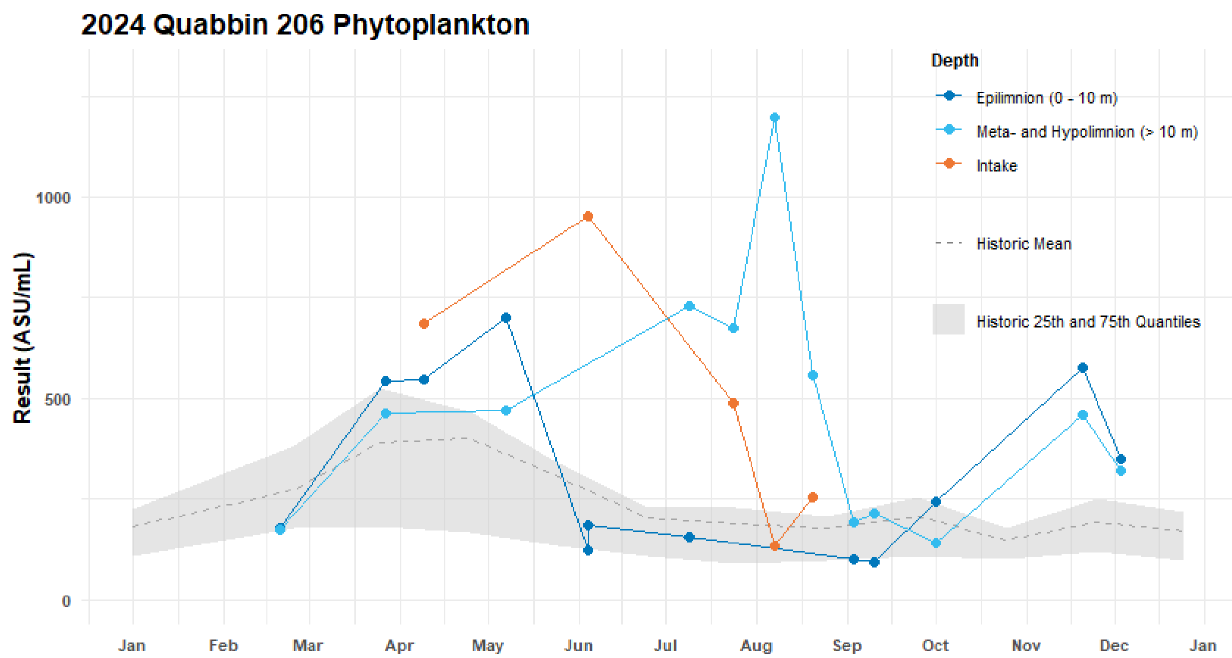


Figure 43. *Total phytoplankton densities during 2024 from sampling sites 202 (top) and 206 (bottom). Sample classification (epilimnion or meta- and hypolimnion) based on depth as defined by summer temperature profiles. The average for historical data covering 2007-2023 is indicated by the dashed line, with 25th and 75th quantiles represented as gray bands, corresponding to all sample depths.*

Aside from the elevated levels in the summer driven by the *Chrysosphaerella* aggregation, the community composition patterns in 2024 were similar to previous years. As is typically observed in Quabbin Reservoir, spring samples from all sites were dominated by diatoms, with the highest densities corresponding to *Asterionella* and *Tabellaria*. Following increased stability of stratification in late June, phytoplankton diversity increased following a slight decline in total densities (Figure 43). This is likely explained by a depletion of available nutrients limiting growth, and increasing competition, resulting in a shift in community composition (Cole and Weihe, 2016). Community composition shifted from diatom dominance driven mainly by *Asterionella*, to a greater variety (albeit at lower densities) of chlorophytes, chrysophytes, and cyanophytes for a short period in the summer (Figure 44). Unlike 2023, where levels remained low for the remainder of the summer, a sudden increase in total phytoplankton densities was observed on July 9, 2024, driven by chrysophytes, specifically *Chrysosphaerella,* at all sites (Figure 44, Figure 46). The community composition at site 202 and 206 remained chrysophyte dominated until September, while a shift in community composition at site Den Hill was observed earlier (Figure 46). By late August, the community composition at Den Hill was dominated by cyanobacteria throughout the water column and by October, samples from all sites were dominated by cyanobacteria (Figure 46). It is typical to observe cyanobacteria dominance during the late summer and fall due to these organisms' heightened performance in warm water compared to other phytoplankton (Whitton, 2012).

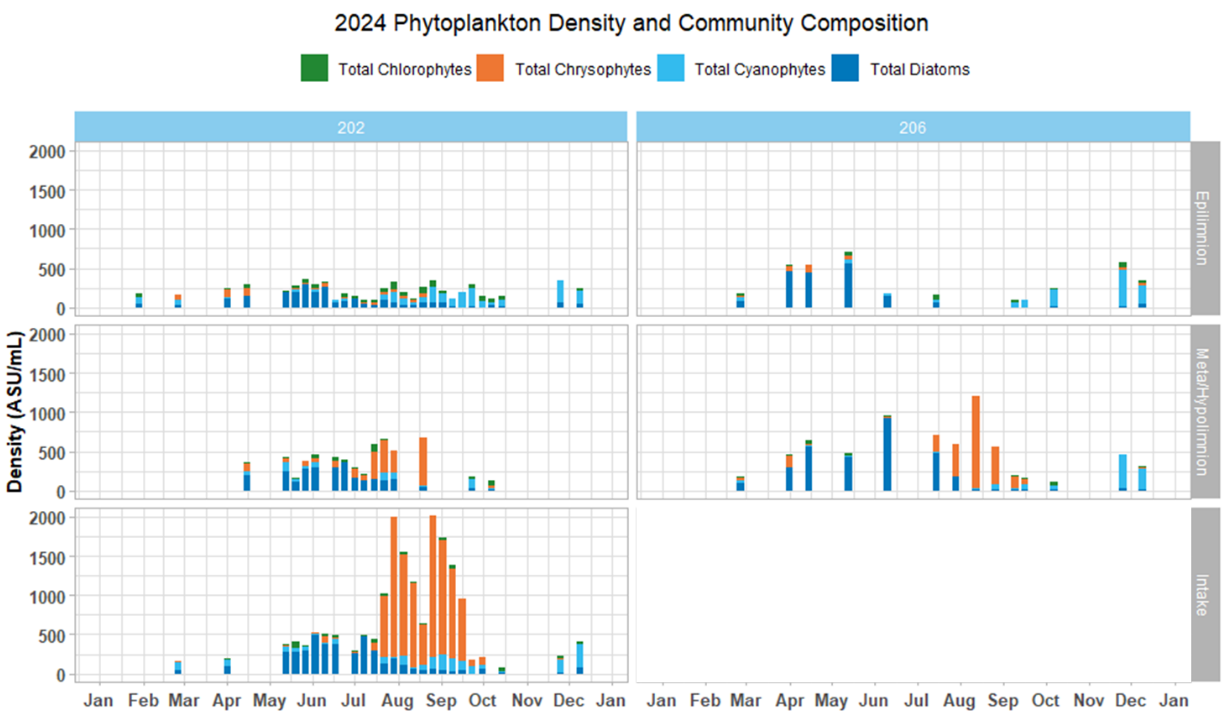


Figure 44. *Phytoplankton community composition, observed in 2024 from the epilimnion and meta/hypolimnion at sampling sites 202 and 206 and at the intake depth for site 202.*

Densities at different sampling depths exhibited similar patterns across sites. The epilimnion samples typically had lower densities than samples collected from the metalimnion and hypolimnion. This was particularly true during the summer period of elevated densities (*Chrysosphaerella* aggregation) previously discussed, which did not affect the epilimnion total densities. Total densities in the epilimnion of site 202 remained below the historical mean for most of the year, except for levels above the historic mean during the winter. Densities at the epilimnion of sites 206 and Den Hill showed more seasonal variability, with high spring densities, followed by low densities in the summer, and increased densities again the winter. Total densities in the meta and hypolimnion of all sites were impacted by the *Chrysosphaerella* aggregation (Figure 43 and Figure 45). The aggregation started at 13 m at all sites but as summer progressed and the thermocline deepened so did the aggregation. On average, the 2024 *Chrysosphaerella* aggregation was observed between 17 m and 18 m at site 202. While the aggregation shifted a couple meters up or down in the water column, the extent of the aggregation was always less than 2 meters in height.

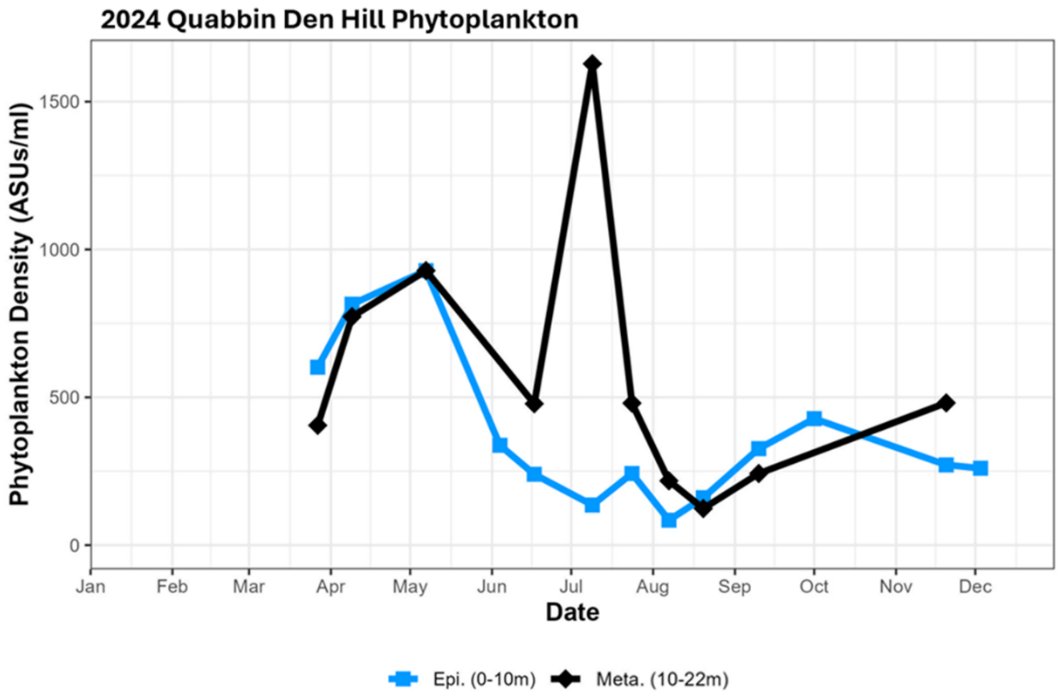


Figure 45. *Total phytoplankton densities during 2024 from sampling site Den Hill. Sample classification (epilimnion or metalimnion) based on depth as defined by summer temperature profiles. Samples collected from the epilimnion are shown in blue and samples collected from the metalimnion are shown in black. Due to ice conditions on the reservoir, site Den Hill was not sampled until March 27, 2024.*

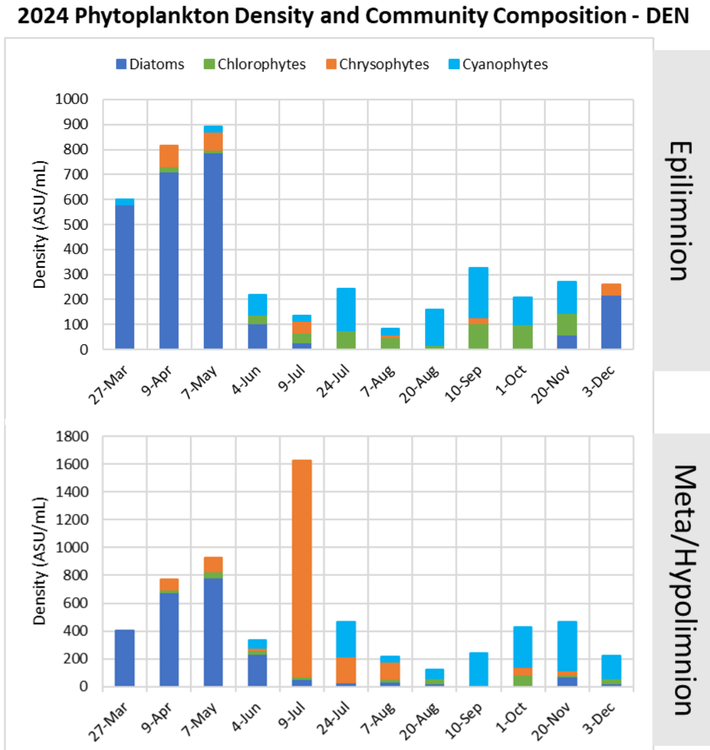


Figure 46. *Phytoplankton community composition, observed in 2024 from the epilimnion and meta/hypolimnion at sampling site Den Hill.*

Overall total densities and changes in community composition were consistent with trends observed in the Quabbin Reservoir over the last six years. An increase in chrysophytes, particularly *Chrysosphaerella*, during the summer has been observed since 2019 (0).

Over the last eight years, monitoring methodology has been modified to better capture phytoplankton aggregations. Prior to 2019, sample depths were selected primarily based on the temperature and dissolved oxygen profiles. Routine profiling of chlorophyll *a* began in 2016 to better inform the selection of sample collection depths for phytoplankton enumeration, supplementing temperature and dissolved oxygen profiles. However, the official change in sample depth selection occurred in 2019, when depths with maximum chlorophyll *a* concentrations began to be specifically targeted for sample collection. This change in field procedures should be considered when interpreting historical patterns of phytoplankton abundance in Quabbin Reservoir, as the sampling focus is now directly driven by chlorophyll *a* values, often resulting in collection of higher phytoplankton densities.

3.3.10.1 Taste and Odor Taxa

Chrysophyte blooms are responsible for nuisance taste and odor properties of water (Lin, 1977; Watson and Jüttner, 2019), oftentimes resulting in reports of undesirable aesthetic characteristics of finished water, such as a "fishy" or "cucumber" taste and odor (Sandgren et al., 1995; Paterson et al., 2004). Chrysophytes have been routinely detected throughout the water column in the Quabbin Reservoir (Worden, 2000; DWSP, 2019a). Chrysophyte densities have been elevated in three of the past six years (2019, 2022, 2024), driven by metalimnetic aggregations.

Several taxa are closely monitored by DWSP to detect potential production of undesirable tastes and odors or cyanotoxin impacts to the drinking water supply. Density thresholds for early monitoring and treatment consideration levels have been set for four chrysophytes and one cyanobacteria taxa (Table 53).

Table 53. *Alert levels for taxa of concern*

Nuisance Organism Class	Nuisance Organism Genus	Quabbin Reservoir Alert Levels (ASU/mL)
Cyanophyte	*Dolichospermum*	15
Chrysophyte	*Synura*	10
Chrysophyte	*Chrysosphaerella*	100
Chrysophyte	*Uroglenopsis*	200
Chrysophyte	*Dinobryon*	200

In 2024, all taxa of concern were observed. *Chrysosphaerella* exceeded the 100 ASU/mL alert level 29 times, and high densities were observed at all sites. The *Chrysosphaerella* aggregation lasted 10 weeks at site 202, nine weeks at site 206, and seven weeks at Den Hill. *Dinobryon* exceeded the 200 ASU/mL alert level twice, once at site 202 and the other at Den Hill. *Synura* exceeded the 10 ASU/mL alert level five times, and high densities were observed at all sites. *Dolichospermum* exceeded the 15 ASU/mL once at site 206. *Uroglenopsis* was observed at all sites but always below the 200 ASU/mL alert level (Figure 47). Due to the exceedance of the alert levels, primarily *Chrysosphaerella*, monitoring frequency was increased from weekly to twice per week at site 202, and from monthly to twice per month at sites 206 and Den Hill to track *Chrysosphaerella* levels. Increased monitoring frequency remained until levels fell below the established alert level. Return to normal monitoring frequency occurred after August 20 for Den Hill, September 3 for site 206, and September 12 for site 202.

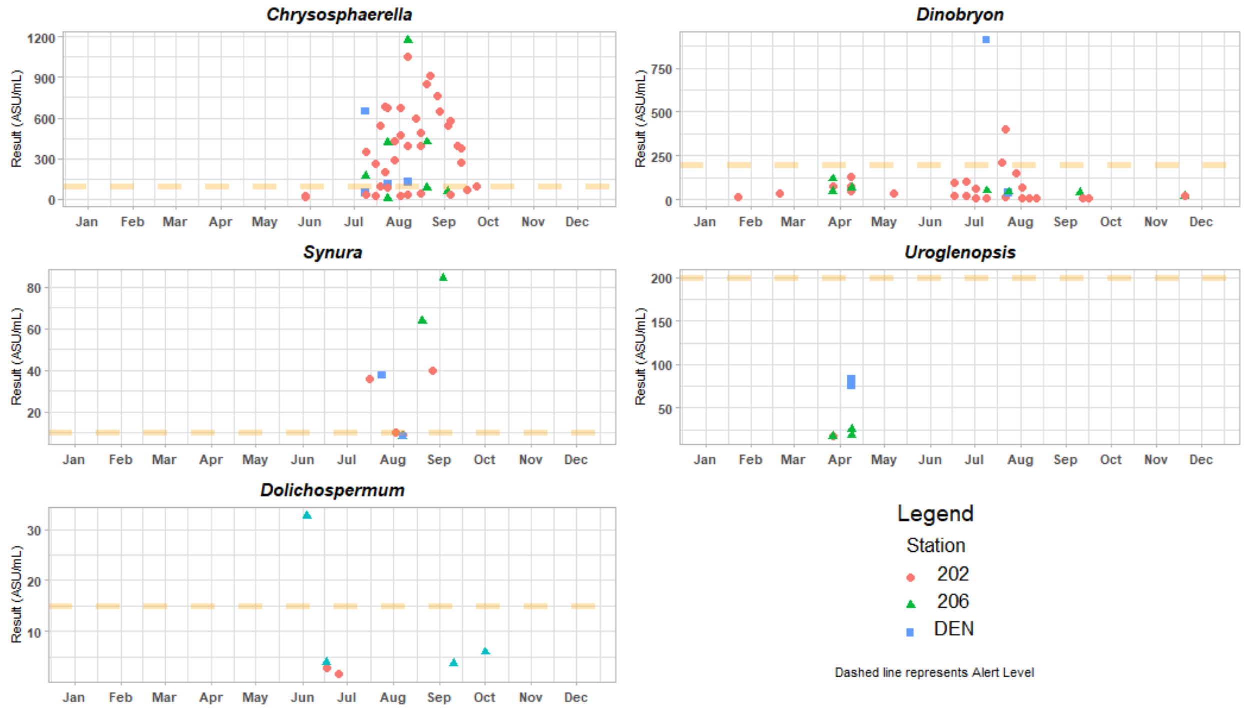


Figure 47. *Occurrence of phytoplankton taxa of concern at Quabbin sampling sites 202, 206, and Den Hill (DEN) during 2024. Dashed line represents the established alert levels specific to each taxa. Lack of occurrence indicates that taxa were not observed during regular monitoring.*

3.4 Aquatic Invasive Species Monitoring and Management

Aquatic invasive species (AIS) include macrophytes, phytoplankton, zooplankton and larger fauna (primarily from the Mollusca phylum). Introduction of AIS may have adverse impacts on water quality including changes in water color and increases in turbidity, phytoplankton growth, and concentrations of trihalomethane (THM) precursors (Gettys et al., 2009). These increases result from the function of these plants as nutrient "pumps" extracting nutrients from sediment and releasing them into the water column, primarily as dissolved and particulate organic matter (Gettys et al., 2009). Invasive macrophyte species are known to aggressively displace native vegetation and grow to nuisance densities, while invasive zooplankton and fauna outcompete native species and disrupt aquatic food webs, thus altering water quality. AIS can be introduced and transported within watersheds via human or wildlife pathways including, but not limited to, aquarium releases, recreational activity (e.g., fishing and boating equipment), waterfowl movements, and downstream flow.

Portions of Quabbin Reservoir and select ponds within the Quabbin Reservoir and Ware River Watersheds are periodically surveyed for the presence of AIS by DWSP staff and by MWRA contractors. Several AIS have been documented through these efforts, in some cases initiating a management response (DWSP, 2020a). Early detection of AIS, education, and participation from the public is critical for successful prevention of new or increased AIS infestations. Management of AIS in Quabbin Reservoir Watershed and Ware River Watershed is primarily based on prevention programs. The following sections of this report provide details of observed AIS presence in the reservoir and watersheds during the 2024 survey season and documents the prevention and management programs currently in place within the watersheds.

3.4.1 Invasive Aquatic Macrophyte Monitoring and Distribution

Aquatic macrophyte surveys are conducted during the growing season and have been performed periodically since 1998 and on a regular basis since 2006 and 2010 in the Quabbin Reservoir and Ware River Watersheds, respectively. Shoreline assessments entail visual observations of the littoral zone via kayak, small boat, or on foot depending on water level. Some water bodies are surveyed annually, while others are surveyed every five years on a rotating schedule based on the Environmental Quality Assessment (EQA) District where the water body is located. Routine monitoring prioritizes water bodies with ramps suitable for launching trailered boats, as this type of activity increases the risk of AIS spread (Rothlisberger et al., 2011). Within the past 10 years, 46 different watershed ponds (including the Reservoir's holding ponds, Prescott Peninsula ponds, and the Ware River itself) across the two watersheds were surveyed either annually or within the EQA schedule.

The following sections summarize the distribution of invasive aquatic macrophytes in the reservoir, the Quabbin Reservoir Watershed, and Ware River Watershed (Table 54). In 2024, three waterbodies were surveyed for aquatic macrophytes in the Quabbin Reservoir Watershed. In addition to these ponds, the reservoir's Boat Launch Areas 1, 2, and 3, and the two holding ponds (O'Loughlin and Pottapaug Ponds) were also surveyed. A total of seven water bodies were surveyed in the Ware River Watershed in 2024. The 2024 EQA Districts were the Quabbin Reservation and East Branch Ware, with four surveyed ponds within these districts. Other waterbodies were within the Burnshirt, Canesto, and Natty, Coldbrook and Longmeadow, East Branch Swift, Fever Brook, Quabbin Northwest, and West Branch Ware districts. In addition, two waterbodies surveyed were located outside of the watersheds but were included in survey efforts due to their proximity to the Quabbin Reservoir.

Table 54. *Aquatic invasive species observed in the Quabbin Reservoir, Quabbin Reservoir Watershed, and Ware River Watershed since the beginning of the AIS program in 2010. Quabbin Reservoir includes O'Loughlin and Pottapaug holding ponds. *No observations made within recent years (2019-2024).*

Scientific Name	Common Name	Quabbin Reservoir	Quabbin Reservoir Watershed	Ware River Watershed
Cabomba caroliniana	Fanwort	-	x*	x
Iris pseudacorus	Yellow Flag Iris	x	x	x
Lythrum salicaria	Purple Loosetrife	x	x	x
Myosotis scorpioides	True Forget-me-not	x*	x	x
Myriophyllum heterophyllum	Variable Leaf Milfoil	x	x	x
Najas minor	Brittle Naiad	x*	-	-
Potamogeton crispus	Curly-leaf Pond Weed	-	-	x
Phragmites australis	Common Reed	x	x	x
Rorrippa microphyllum	One Row Yellowcress	x*	x*	x*
Trapa natans	Water Chestnut	-	-	x
Utricularia inflata	Swollen Bladderwort	x	-	x*
Cipangopaludina chinensis	Chinese Mystery Snail	x	x	x

3.4.1.1 Contracted Aquatic Macrophyte Surveys

Since 2013, MWRA contractors have conducted annual point-intercept surveys of DWSP/MWRA source and emergency reservoirs. Additionally, this year MWRA contractors surveyed Pottapaug Pond and O'Loughlin Pond for *Utricularia inflata* (swollen bladderwort) and removed plants via hand harvesting to manage populations. MWRA contracted with TRC for both the annual macrophyte survey and *U. inflata* management efforts.

Myriophyllum heterophyllum (variable leaf milfoil) was the only submersed AIS observed in the Quabbin Reservoir and Ware River Watersheds during the Annual Macrophyte Survey. Emergent invasives are not specifically included in the contractor point-intercept surveys, but the continued presence of *Phragmites australis* in the Quabbin Reservoir was noted. The extent and density of *M. heterophyllum* in Quabbin Reservoir decreased slightly compared to 2023 (observed at 6% of surveyed points; TRC, 2025).

3.4.1.2 Cabomba caroliniana

Cabomba caroliniana (fanwort) originates from the southeastern United States (Texas to Virginia) and was introduced outside its range through the aquarium plant trade, where it then spread via dumping and cultivation (Bickel, 2015; Bickel, 2017; Schooler et al., 2009). *C. caroliniana* reproduces via fragmentation, allowing it to spread quickly and outcompete native species.

Unmanaged, this species will form dense mats at the water's surface, crowding out other plants and creating hazards for recreationists (Schooler et al., 2009). The long stems impede boats and can get tangled in propellers, paddles, and fishing lines. In addition, swimmers can also become entangled (Schooler et al., 2009). Like other mat-forming AIS, *C. caroliniana* can alter water quality and native composition by nutrient loading and decreasing available dissolved oxygen. Methods of control for this species attempt to limit fragmentation by using chemical treatments, drawdowns, biological control, or manual removal.

Although not present in the Quabbin Reservoir, *C. caroliniana* has been found in both watersheds with the first instance reported in Queen Lake (Phillipston, MA) in 2010. Since then, this species has been detected in several other waterbodies within the watersheds. No new infestations were found during the 2024 survey season (Table 55).

In both Queen Lake and Demond Pond where *C. caroliniana* has been observed, and where a local lake association is present, management efforts have relied on chemical treatments to control this AIS. Although undetectable in the 2022 survey, populations at Queen Lake were observed again at low densities in the 2024 survey. This may indicate that, like Demond Pond, Queen Lake *C. caroliniana* populations regularly rebound following treatment, and may require annual control efforts to prevent further spread. In other waterbodies with no management efforts, *C. caroliniana* has spread throughout the waterbody, in some cases becoming the dominant plant, growing in dense and widespread beds.

Table 55. *Waterbodies with Cabomba caroliniana present during the 2024 AIS survey with survey dates and date of first observation.*

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Demond Pond	Rutland	Ware River	07/18/2024	09/07/2017
Long Pond	Rutland	Ware River	08/15/2024	08/06/2021
Queen Lake	Phillipston	Ware River	06/20/2024	07/30/2010

3.4.1.3 Myriophyllum heterophyllum

Myriophyllum heterophyllum (variable-leaf milfoil) is the most frequently encountered submersed AIS in the watersheds. Although native to the southeastern United States, *M. heterophyllum* is considered invasive in the northeastern states (Bailey, 2007). This species mainly spreads via seeds and fragmentation, where stem pieces with at least one node can regrow into a viable plant (Bailey, 2007; Gross et al., 2020; Halstead et al., 2003). As a result, this species can colonize and outcompete native species within a short period of time, making prevention and rapid response crucial to its management. Unfortunately, *M. heterophyllum* can grow undetected until it is already well-established (Halstead et al., 2003), resulting in higher management costs and effort. When left unchecked, this species creates dense mats throughout the water column, creating boating hazards (clogging propellers and fishing lines), swimming hazards, and decreasing native species' diversity (Bailey, 2007; Halstead et al., 2003). In addition, large amounts of decaying plant matter increase nutrient loading (phosphorus and nitrogen) which reduces dissolved oxygen levels that other species (namely fish) require (Halstead et al., 2003). Due to fragmentation, removal efforts seek to keep the plant intact by utilizing either diver assisted suction harvesting (DASH), herbicide treatments, or covering with benthic barriers.

M. heterophyllum is well distributed in portions of Quabbin Reservoir, with established populations at Boat Launch Areas 2 and 3 and the holding ponds (O'Loughlin and Pottapaug). In addition, *M. heterophyllum* is well established in the Ware River, most notably at (and upstream of) the Shaft 8 intake. Due to the aggressive nature of this species, it is abundant and widely distributed in the waterbodies where it has become established. No new infestations were detected in the 2024 DWSP-EQ surveys.

Management of *M. heterophyllum* is conducted annually by DCR contractors above and below the Ware River Shaft 8 intake. This year, the macrophyte survey was conducted by TRC, with removal efforts by DRG (see Section 3.4.2 for more information). In addition, the Asnacomet "Comet" Pond Lake Association has been working with DCR-Lakes and Ponds since 2018, when *M. heterophyllum* was discovered, to manage plants. With initial financial support from DWSP, management efforts have included hand-harvesting and diver-assisted suction harvesting (DASH). DCR-Lakes and Ponds staff, in conjunction with contractors, revisited Asnacomet Pond in 2024 to continue harvesting efforts. In June, DASH resumed along the northern and western shorelines. Across two days, more than 60 pounds of *M. heterophyllum* was removed from these areas. Contractors suggest ongoing management, one harvest day per month between May and September, to maintain low densities.

Table 56: *Waterbodies with Myriophyllum heterophyllum present during the 2024 AIS survey with survey dates and date of first observation.*

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Boat Area 2 Shoreline	New Salem	Quabbin Reservoir	06/28/2024	2006
Boat Area 3 Shoreline	Petersham	Quabbin Reservoir	08/01/2024	2006
Brigham Pond	Hubbardston	Ware River	09/17/2024	10/14/2010
Demond Pond	Rutland	Ware River	07/18/2024	08/13/2010
Lake Mattawa	Orange	Quabbin Reservoir	07/29/2024	07/20/2001
Long Pond	Rutland	Ware River	08/15/2024	08/13/2010
O'Loughlin Pond	New Salem	Quabbin Reservoir	08/13/2024	2006
Pottapaug Pond	Hardwick	Quabbin Reservoir	08/30/2024	2006
Ware River	Barre	Ware River	07/26/2024	07/08/2016
WhiteHall Pond	Rutland	Ware River	06/11/2024	10/14/2010

3.4.1.4 Najas minor

Najas minor (brittle naiad) was introduced to North America in the early 20th century from its native range of Eurasia and northern Africa (Wentz and Stuckey, 1971; Les et al., 2015; Volk, 2019). Although the exact method of introduction is unknown, its spread has been attributed to cultivation escapes and waterfowl food propagation programs (Les et al., 2015). Spreading mainly via seed dispersal (Les et al., 2015; Volk, 2019), *N. minor* has been documented throughout much of the eastern United States. Waterfowl and recreational equipment assist in *N. minor*'s dispersal, as the small and inconspicuous seeds remain viable after consumption and can cling to the outside of boats, trailers, and other equipment that come in contact with water (Volk, 2019). Although fragmentation itself does not produce separate viable plants, the fragments carry seeds that are then dispersed throughout the waterbody (Volk, 2019). Similar to other mat-forming AIS, *N. minor* can displace native plants, and impacts recreational activities such as swimming, boating, and fishing (Les et al., 2015; Volk, 2019).

N. minor was first documented by contractors in 2014 at O'Loughlin Pond. DWSP hypothesize that *N. minor* seeds were introduced into the pond via avian passage, as birds are known to feed on the indistinguishable native *Najas gracillima* seeds (Martin and Uhler 1939; Reynolds et al., 2015). The *N. minor* infestation in O'Loughlin Pond was quickly harvested using DASH and has not been observed since. This invasive has not been found elsewhere in the Quabbin Reservoir Watershed, or in the Ware River Watershed.

3.4.1.5 Potamogeton crispus

Potamogeton crispus (curly-leaf pondweed) was first observed in Philadelphia in the 1840s, and is native to Eurasia, Africa, and Australia (Bolduan et al., 1994; Zhou et al., 2017). By the 1860s, *P. crispus* was abundant within the Lehigh River in Pennsylvania and Delaware, and by the 1880s had spread to Massachusetts and New York (Bolduan et al., 1994). The spread of this species seems to be associated with fish hatchery activity, as early reports from several states were either found in fish hatchery ponds or waters associated with them (Bolduan et al., 1994). Unlike other plant species that remain dormant in winter, *P. crispus* acts like a winter annual, continuing to grow during the winter season (Bolduan et al., 1994; Johnson et al., 2012; Zhou et al., 2017). This species reproduces via rhizomes and turions, which sprout in the fall and grow rapidly in the early spring, senescing and depositing turions in the sediment by midsummer (Bolduan et al., 1994; Johnson et al., 2012; Zhou et al., 2017). Although this plants' impact on native macrophytes is still being researched, it has been found to impact phosphorus (Owens et al., 2007), nitrogen, and other heavy metals (Zhou et al., 2017), acting as a nutrient loader once this species has senesced.

P. crispus was first identified in 2013 at Whitehall Pond, a waterbody located within Rutland State Park and owned by DCR. Fortunately, this species has not been observed elsewhere within either watershed. As Whitehall Pond has a DCR-managed beach, management and treatment is overseen by DCR Lakes and Ponds. Beginning in 2013, management of *P. crispus* has included mechanical and hand harvesting, as well as chemical control. These treatment actions have reduced *P. crispus* densities, however some plants are still present – most likely from turions sprouting after treatment occurred. The 2024 macrophyte survey found no new infestations of *P. crispus*. Dense populations were observed at Whitehall Pond, indicating that this species may regularly rebound following chemical treatment (Table 57).

Table 57. *Waterbodies with Potamogeton crispus present during the 2024 AIS survey with survey dates and date of first observation*.

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Whitehall Pond	Rutland	Ware River	6/11/2024	08/06/2013

3.4.1.6 *Trapa natans*

Trapa natans (water chestnut) has a wide native distribution, ranging from Eurasia to Africa (Mikulyuk and Nault, 2009; Walusiak et al., 2024), and was first observed in Massachusetts in the late 1890s (Burk et al., 1976, USFWS, 2018). By the 1940s, *T. natans* was well established along the Sudbury River, and in 1974 covered "several hundred square feet" near the intersection of Stony Brook and Route 116 in South Hadley (Burk et al., 1976). Unlike other AIS mentioned in this section, *T. natans* is a floating-leaf aquatic species, and reproduces mainly via seeds, often referred to as "chestnuts". Each chestnut can produce 10-15 rosettes, and each rosette can produce up to 20 chestnuts (USFWS, 2018), which drop down into the sediment to overwinter (O'Neill, 2006). These chestnuts then sprout in the spring but may remain dormant in the substrate for up to 12 years before sprouting (O'Neill, 2006; Phartyal et al., 2018). Rosettes may also detach from their stems and float to another area via wind or currents, resulting in a new infestation (Groth et al., 1996; O'Neill, 2006; USFWS, 2018). This reproductive strategy (i.e., many seeds with a long viability window) allows *T. natans* to outcompete native species, and results in exponential population growth (Burk et al., 1976; USFWS, 2018).

As a floating plant, *T. natans* can cover the majority of the water surface when conditions are right, intercepting most of the available sunlight (USFWS, 2018; Walusiak et al., 2024). This AIS can drastically impact the native ecosystem, outcompeting native macrophytes for sunlight and nutrients, thus decreasing habitat suitability for associated flora and fauna such as algae, zooplankton, ducks, and other waterfowl (USFWS, 2018; Walusiak et al., 2024). Additionally, *T. natans* impedes many recreational activities. Waterways become unnavigable, fishing lines can become tangled, and the chestnuts' sharp spines can cause puncture wounds when stepped on (USFWS, 2018; Walusiak et al., 2024). These spines also act as a vector for spread by clinging to boats, recreational gear, and fur or feathers (Mikulyuk and Nault, 2009; O'Neill, 2006).

T. natans was observed for the first time in the Ware River watershed during the 2024 DCR-DWSP survey at Brigham Pond (Table 58). Brigham Pond was last surveyed in 2021, with no *T. natans* detected, suggesting that this infestation is still in the early stages. In response to this discovery, DCR-DWSP staff were able to remove an estimated 60 gallons of plant material the same day as the survey. Management efforts during early infestation stages are critical in preventing this species from taking over an area, and should be considered as an ongoing management effort for DCR-DWSP staff. To date, no other populations have been observed by DCR staff within either the Quabbin Reservoir or Ware River watersheds.

Table 58. *Waterbodies with Trapa natans present during the 2024 AIS survey with survey dates and date of first observation.*

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Brigham Pond	Hubbardston	Ware River	09/17/2024	09/17/2024

3.4.1.7 *Phragmites australis*

Phragmites australis (common reed) is the most widely distributed emergent AIS in the Reservoir and the watersheds. Unlike other AIS, not all *P. australis* are invasive. This species has three distinct subspecies (ssp.) – ssp. *americanus* (native), ssp. *berlandieri* (native), and ssp. *australis* (invasive) (Lambert et al., 2010; Hazelton et al., 2014). Here-after, *P.* australis is referring to the invasive subspecies. *P. australis* is native to Europe, and has spread to most of the U.S., occupying areas where the native subspecies inhabit and areas where they do not (Lambert et al., 2010). This AIS can spread via seed, but the main method is clonal propagation via rhizomes and stolons (Meyerson et al., 2000; Lambert et al., 2010; Hazelton et al., 2014). This allows *P. australis* to spread rapidly once introduced to an area, becoming denser and larger in the following years, and resulting in reductions in native plant biodiversity (Warren et al., 2001), declines in habitat quality for native fauna (Able and Hagan, 2003), and disruptions to natural nutrient cycling (Meyerson et al., 2000; Hazelton et al., 2014). Although labor intensive, pioneer or small infestations may be eradicated with annual management efforts and should be prioritized before they become dense established stands. Potential management practices include mechanical harvesting (excavation, cutting, hand-pulling, and benthic barriers) and herbicides (Warren et al., 2001; Hazelton et al., 2014). Each method has benefits and drawbacks, and use should be tailored to the area and management plan goals.

P. australis is well established throughout the reservoir, forming dense patches along the shoreline. In addition, '*Phragmites* islands' have formed in some shallow locations of the reservoir where this AIS completely dominates. However, *P. australis* can be difficult to identify at early growth stages, making documentation of spread difficult. Therefore, additional surveys are often required to confirm the identifications. Observations initially made at O'Loughlin Pond during the 2023 DWSP-EQ survey fall into this category and have not been confirmed. No new infestations were found during the 2024 DWSP-EQ survey season (Table 59).

Table 59. *Waterbodies with Phragmites australis present during the 2024 AIS survey with survey dates and date of first observation*.

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Bassett Pond	New Salem	Quabbin Reservoir	06/28/2024	09/06/2013
Boat Area 2 Shoreline	New Salem	Quabbin Reservoir	06/28/2024	1970s
Boat Area 3 Shoreline	Petersham	Quabbin Reservoir	08/01/2024	08/11/2014
Long Pond	Rutland	Ware River	08/15/2024	09/07/2018
O'Loughlin Pond	New Salem	Quabbin Reservoir	08/13/2024	07/11/2023
Pottapaug Pond	Hardwick	Quabbin Reservoir	08/30/2024	1970s

3.4.1.8 Utricularia inflata

Utricularia inflata (swollen bladderwort) is a carnivorous aquatic plant native to much of the southeastern coastline, from Texas and Florida to Delaware (Titus and Grisé, 2009). This AIS has since expanded its range, first observed in the Adirondack Mountains in 1999 (Titus and Grisé, 2009; Urban and Titus, 2010), and now also present in several northeastern states including Massachusetts. *U. inflata* spreads via seeds and fragmentation, where its vegetative propagules separate from the main stem to form an independent plant (Urban and Dwyer, 2016). Unmanaged, this species will form dense mats at the water's surface, creating recreational hazards, disrupting the native food web, and altering water chemistry. Due to its carnivorous nature (Miranda et al., 2021), *U. inflata* competes with native species (such as fish larva/fry) that feed on aquatic insect larva, disrupting the food chain. In addition, due to its mat-forming properties, *U. inflata* can increase light attenuation and cause the extirpation of native species (Urban and Dwyer, 2016).

U. inflata was first documented in the Ware River Watershed and Quabbin Reservoir (Boat Launch Area 2) in 2017. The single plant at BLA2 was removed, and no additional plants have been found there since. Although no observations of *U. inflata* were made between 2019 and 2023 in either watershed, identification of this species when not in bloom is difficult, and it is possible the seasonality of past surveys affected our understanding of its presence and distribution. In May of 2023 this species was observed in the fragment barrier on Pottapaug Pond and later confirmed on O'Loughlin Pond as well. Management efforts have been ongoing since.

DCR-DWSP, in partnership with MWRA, hired contractors to survey and hand remove *U. inflata* on Pottapaug Pond and O'Loughlin Pond during the 2024 season. More information on these management efforts can be found in Section 3.4.3. Several DCR-DWSP surveys were conducted on O'Loughlin Pond in May 2024 to confirm *U. inflata* presence before contractors began their removal efforts.

Table 60. *Waterbodies with Utricularia inflata present during the 2024 AIS survey with survey dates and date of first observation.*

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
O'Loughlin Pond	New Salem	Quabbin Reservoir	05/21/2024	05/21/2024
Pottapaug Pond	Hardwick	Quabbin Reservoir	05/14/2024	05/26/2023

3.4.1.9 Iris pseudacorus

Iris pseudacorus (yellow flag iris) is an invasive species that closely resembles the native blue flag iris when not flowering. Originally introduced as a horticultural plant to North America in the 1900s (Jacobs et al., 2010; Stoneburner et al., 2021), *I. pseudacorus* has spread throughout most of the United States. Although terrestrial in nature, this species is closely tied to wetlands and is often found along shorelines. *I. pseudacorus* spreads via seeds and rhizomes and may experience 'rhizome splitting', resulting in separate plants from the original (Sutherland, 1990; Jacobs et al., 2010; Hayasaka et al., 2018). If left unmanaged, *I. pseudacorus* can alter riparian zones by out-competing native sedges and rushes that support waterfowl and other native species (Jacobs et al., 2010; Hayasaka et al., 2018). It may also create dense stands that impede water flow (Stoneburner et al., 2021).

I. pseudacorus has been documented in the reservoir and within both watersheds (.

Table 61). This species was first documented in Connor Pond (Petersham, MA) in 2013 where it now colonizes large stretches of the western shoreline and has become densely distributed in many small coves. It is hypothesized that this population is the source of plants observed in Pottapaug Pond and at Boat Launch Area 3 from seed pods floating downstream. In 2019, the fragment barrier at Boat Launch Area 3 was repositioned to catch floating seed pods more effectively. No new *I. pseudacorus* infestations were observed during the 2024 DWSP-EQ surveys.

Table 61. *Waterbodies with Iris pseudacorus present during the 2024 AIS survey with survey dates and date of first observation.*

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Asnacomet "Comet" Pond	Hubbardston	Ware River	09/24/2024	06/17/2021
Demond Pond	Rutland	Ware River	07/18/2024	08/17/2017
Pottapaug Pond	Hardwick	Quabbin Reservoir	08/30/2024	2015

3.4.1.10 Lythrum salicaria

Lythrum salicaria (purple loosestrife) originates from Eurasia and was introduced to North America in the early 1800s (Stuckey, 1980; Mullin, 1998; Nagel and Griffin, 2001; Blossey et al., 2001). Since then, it has spread throughout most of the United States, usually inhabiting wetlands, marsh-like, or riparian sites (Mullin, 1998; Nagel and Griffin, 2001). *L. salicaria* is a prolific invasive, producing as many as 2.7 million seeds annually, which create long-lived seed banks that require regular maintenance to keep to manageable levels (Nagel and Griffin, 2001; Henne et al., 2005; Mahaney et al., 2006). If left unchecked, *L. salicaria* can disturb the native ecosystem by outcompeting native plants for space (Stuckey, 1980), decreasing food sources for songbirds, and reducing suitable nesting habitat for waterfowl (Mullin, 1998; Henne et al., 2005). Management of this species is usually either mechanical harvesting or chemical treatment (Mullin, 1998; Henne et al., 2005).

L. salicaria was first documented in 2011 in both watersheds. Since then, this invasive species has spread from the initial three waterbodies to almost twenty, with varying degrees of infestation levels (individual plants to small clusters). This plant is difficult to identify when not in bloom, making accurate estimates of its extent throughout the watersheds difficult to attain. Despite this, populations of *L.* salicaria do not appear to be changing rapidly year to year, demonstrating a relatively low threat to water quality. No new infestations were observed during the 2024 DWSP-EQ surveys (Table 62).

Table 62. *Waterbodies with Lythrum salicaria present during the 2024 AIS survey with survey dates and date of first observation.*

Waterbody Name	Town	Watershed	Last Obs.	First Obs.
Boat Area 3 Shoreline	Petersham	Quabbin Reservoir	08/01/2024	08/24/2022
Cloverdale Pond	Rutland	Ware River	07/23/2024	08/30/2011
Demond Pond	Rutland	Ware River	07/18/2024	08/06/2013
Lake Mattawa	Orange	Quabbin Reservoir	07/29/2024	07/19/2011
Long Pond	Rutland	Ware River	08/15/2024	08/19/2013
Pottapaug Pond	Hardwick	Quabbin Reservoir	08/30/2024	08/20/2011

3.4.1.11 Myosotis scorpioides

Myositis scorpioides (true forget-me-not) is native to Eurasia, and although not considered a true aquatic plant, it does inhabit wet disturbed shorelines. Now found throughout the United States, *M. scorpioides* has naturalized in many areas, but has remained a potential invasive within the New England states. Scientific research regarding this species is sparse, resulting in a relatively unknown impact to water quality and native wetland vegetation. As a result, any populations observed during DWSP-EQ surveys are monitored and removed as needed. When not blooming, *M. scorpioides* can be difficult to identify, which may account for variations in observed populations from year-to-year. This species spreads via seed production and through an extensive and shallow root system. To effectively manage for this species, continuous removal efforts before plants seed would be required.

M. scorpioides was first observed in the Quabbin Reservoir Watershed in 2012, along the shoreline of BLA2 and at Gaston Pond in Barre. Since then, it has been observed in several other ponds within both watersheds. Observations have been variable however, and some populations have not been observed in several years. No *M. scorpioides* were observed during the 2024 DCR-DWSP survey season.

3.4.1.12 Rorippa microphylla

Rorippa microphylla (one row yellowcress), also known as *Nasturtium microphyllum*, is native to Europe and has spread to much of the world due to its popularity as a salad green (GoBotany, 2024). This species is considered invasive in Connecticut but not in Massachusetts. Although a closely related species, *Rorippa amphibia* (water yellowcress), is on the Massachusetts prohibited plant list, *R. microphylla* remains absent (MDAR, 2023). Due to a lack of scientific literature on this species, observations of this non-native should be closely monitored to determine its effect on native species.

R. microphylla is present in both watersheds. It was first observed in the Quabbin Reservoir (BLA2) in 2013 and the Ware River Watershed in 2014. When not flowering, this species can be difficult to identify, and closely resembles other native and state listed species. As a result, *R. microphylla* observations are not consistent, highlighting the importance of marking population locations for subsequent survey efforts. No *R. microphylla* were observed during the 2024 DCR-DWSP survey season.

3.4.2 Invasive Aquatic Fauna Monitoring and Distribution

Visual surveys for *Cipangopaludina chinensis* (Chinese mystery snail) and adult *Dreissena polymorpha* (zebra mussels) are performed alongside aquatic macrophyte surveys. Net tows for invasive zooplankton and the larval stages of *D. polymorpha* in the reservoir began in 2009. The following sections summarize the presence and absence of potential invasive aquatic fauna threats in the Quabbin and Ware River Watersheds.

3.4.2.1 Dreissena polymorpha

Dreissena polymorpha (zebra mussels) were discovered in Massachusetts in 2009, leading to the development and adoption of the Quabbin Boat Decontamination Program (Section 3.4.3). Since then, it has been determined that the low pH and calcium levels found in the Quabbin Reservoir (Section 3.3.5) make it unsuitable for *D. polymorpha* reproduction and growth. As a result, it is unlikely to find fully mature *D. polymorpha* in the reservoir. Despite this, plankton net tows are scanned for the immature larval stages of *D. polymorpha*. To date, no immature larval stages have been found in the reservoir.

3.4.2.2 Invasive Zooplankton

The potential invasive zooplankton of concern are *Bythotrephes longimanus* (spiny waterflea) and *Cercopagis pengoi* (fishhook waterflea). In 2024 oblique tows were collected every other month from May to October near the Boat Launch Areas (BLAs) and scanned for their presence. As of 2024, neither species has been documented in the Quabbin Reservoir.

3.4.3 AIS Management and Boat Decontamination Programs

Aquatic invasive species (AIS) management within the Quabbin Reservoir and Ware River Watersheds is currently limited to two projects: *Myriophyllum heterophyllum* removal on the Ware River, and *Utricularia inflata* removal on the O'Loughlin and Pottapaug holding ponds. Funding from MWRA supports both management projects.

The DWSP Quabbin Reservoir/Ware River Region runs several prevention programs designed to limit the spread of AIS throughout the watersheds. These programs include the Quabbin Boat Seal Program for anglers on the Quabbin Reservoir and two self-certification programs within the Ware River Watershed. The Quabbin Boat Decontamination program was initiated in 2009. The Self-Certification programs began in 2010.

3.4.3.1 Ware River Management of Myriophyllum heterophyllum

Annual management of *M. heterophyllum* has occurred since 2016 in the basin above the Shaft 8 intake along the Ware River and in sections above the railroad and Route 122 bridges along the Ware River. Despite these efforts, *M. heterophyllum* remains an issue for water operations due to plant fragmentation. Control methods are currently restricted to physical removal of plants and drawdowns. Winter drawdowns may lessen the labor necessary to reduce *M. heterophyllum* in this area; however, the hard freezes required for this to be effective are not consistent or predictable. In addition, the population of *M. heterophyllum* upstream of the Shaft 8 intake continues to repopulate the area.

M. heterophyllum upstream of Route 122 maintained similar distribution to the previous year, covering about 4.3 acres, with an additional small area (0.17 acres) noted along the eastern shoreline (TRC, 2024b). Davey Resource Group was contracted by MWRA to physically remove plants for the seventh consecutive year. The 2024 harvest yielded a 48% reduction in total gallons removed compared to the previous year, most likely due to increased search time due to plant sparsity (Davey Resource Group Inc., 2024). Downstream of Route 122 saw a decrease of 69% in gallons removed and upstream saw an increase of 20%. This difference is most likely due to an increased amount of time spent above the Route 122 bridge (Davey Resource Group Inc., 2024). Depopulating the entire river above Route 122 would be impractical, daunting, and extremely expensive. This is an ongoing issue with no foreseeable permanent solution. For this reason, the focus is to keep the basin above the intake as free of *M. heterophyllum* as is feasible.

3.4.3.2 Quabbin Holding Ponds – Management of Utricularia inflata

Since its discovery in 2023, removal efforts have been ongoing at the Quabbin holding ponds: O'Loughlin Pond and Pottapaug Pond. Removal efforts in 2023 were initially conducted by DCR-DWSP and a MWRA contractor but were limited due to early plant senescence. A contractor (TRC) was hired through MWRA for the 2024 growing season of *U. inflata* (May-July).

Management on Pottapaug and O'Loughlin was conducted in three stages in 2024: an initial growth survey, a point-intercept survey, and removal. The initial growth survey was conducted on May 22 to determine the growing period of *U. inflata*, as this species is a relatively new invasive to the northeastern states. Following this, a point-intercept survey was conducted on both holding ponds. A total of 656 survey points were visited (511 points on Pottapaug and 145 points on O'Loughlin). Of the 511 points on Pottapaug, 169 points had sparse coverage, 26 had moderate coverage, and 10 had dense coverage. Of the 145 points on O'Loughlin, 19 points had sparse coverage, most with only one plant found (TRC, 2024a).

Subsequent removal efforts began June 3 and continued until July 3, mainly targeting areas on Pottapaug Pond closest to Boat Launch Area 3 and the inlet to Quabbin Reservoir. A total of 21 harvest days were conducted on Pottapaug Pond, resulting in the removal of 1,527 gallons of *U. inflata* (TRC, 2024a). In contrast, only three removal days occurred on O'Loughlin Pond, resulting in approximately one gallon of *U. inflata* removed.

3.4.3.3 Quabbin Boat Decontamination Program

The Quabbin Boat Decontamination program was initiated in 2009 to mitigate the risk of AIS introduction into the reservoir through recreational boat fishing. The Quabbin Reservoir is a popular destination for anglers as the system hosts both cold and warm water fish species. DCR provides rental boats for anglers to use on the Quabbin Reservoir, however many people prefer to use their own boats. Though some anglers exclusively fish at the Quabbin Reservoir, many others fish at a variety of locations across New England within a season. This provides a potential pathway for the interchange of AIS between bodies of water.

The Quabbin Boat Decontamination Program was developed to prevent the spread of AIS, which includes plants (variable-leaf milfoil, Eurasian milfoil, hydrilla, etc.), zooplankton (spiny and fish-hook water flea), and invertebrates (zebra mussels and Chinese mystery snails). Many invasive species are very well adapted to endure harsh conditions, such as periods of desiccation. Plants can spread via small seeds and small plant fragments. Zooplankton and zebra mussels are microscopic during certain life stages and can persist inside boat motors for long periods of time. The boat inspection and decontamination programs required by DWSP serve to limit the introduction of these invasive species into the Quabbin Reservoir.

The Quabbin Boat Decontamination Program consists of two options for recreational boaters to clean their boats: warm-weather decontamination (WWD) and cold-weather quarantine (CWQ). WWD events occurred over 15 dates in 2024 throughout the fishing season, and the cold-weather quarantine program occurred over five dates in 2024 after the fishing season had closed. Samples of biological substances collected off boats inspected during either the WWD or CWQ programs were identified whenever possible.

During WWD, before vessel inspection and decontamination, boaters are asked where the vessel was last launched to determine potential AIS threats (i.e., a vessel last launched at Lake Winnipesaukee may be harboring *B. longimanus* or *T. natans*, both of which are not present in the Quabbin Reservoir). Afterwards, DCR-DWSP staff inspect all parts of the boat (including hulls, all through-hull fittings, live wells, bilge, downriggers, anchors, lines, and trolling motors) in addition to the boat trailers (including rollers and bunks). If the vessel passes inspection, the motor is then flushed with hot water (140 °F) until the water runs out of the motor for 10 seconds at the same temperature. The vessel, including hulls, live wells, bilge, anchors, trailer, and fishing gear (such as poles and nets), are then washed with high pressure hot water. Any organisms that may be present in the motor or on the vessel should be killed by this process. While this program requires payment from anglers, it enables them to fish outside of the Quabbin Reservoir, then return following the completion of a decontamination event. This significantly reduces the risk of AIS introduction from other waterbodies without restricting anglers to exclusively fish at the Quabbin Reservoir.

Unlike WWD, CWQ requires no fee. Boats are tagged at the beginning of the winter season, ensuring they remain on trailers for around four months. At least three consecutive days below 32°F, or 46 days with an average low temperature of 30 °F is required to cause desiccation or cold thermal death for any potential AIS (McMahon et al., 1993). The 2023-2024 winter season (October-April) had seven consecutive days below 32°F, and a 46-day average low of 25°F.

In 2024, 117 boats were inspected and decontaminated through the WWD program. This is lower than the previous five-year average (168 WWDs from 2019-2023). Eighty-one boats were inspected and sealed through the CWQ program in 2024. This is lower than the previous five-year average (85 CWQs from 2019-2023). In 2024, around 38% of boaters used the WWD for the first time, and around 14% of boaters used the CWQ for the first time.

Public perception of the boat decontamination programs has improved since their inception. While the programs initially met some resistance, many anglers are now grateful for the opportunity to safely recreate between the Quabbin Reservoir and other waterbodies. This is likely due to a region-wide effort from state and local officials as well as pond associations, to educate anglers on the risks of AIS. Participation in boat inspections and cleaning programs is now standard practice at many recreational waterbodies in, and outside of, Massachusetts. Though the public is becoming more aware of AIS, continued education is crucial. Many boaters remain unaware of the span of AIS beyond zebra mussels and common invasive plant species. This demonstrates the importance of continued education efforts to keep anglers engaged to ensure the Quabbin Reservoir remains free of new AIS infestations.

3.4.3.4 Boat Ramp Monitoring and Self-Certification Programs

The Boat Ramp Monitoring and Self-Certification Program was established in 2010 to reduce the spread of AIS in ponds that allow boaters in the Ware River Watershed. The program was implemented in 2010 utilizing two full-time seasonal positions to educate boaters and inspect watercraft. Since then, a self-certification boat inspection process has been in place to streamline the program while reducing DWSP staff resources. Efforts are focused on Asnacomet Pond in Hubbardston and Long Pond in Rutland due to the high volume of boaters utilizing these waterbodies.

Self-certification forms are prominently displayed at Comet and Long Ponds in boxes on the kiosks near each boat ramp, along with signage directing boaters to self-certify their watercraft as free of AIS before launching. Kiosks, signs, and forms were updated in 2021 to make the program clear and information accessible. Forms include questions about where the boat was last used, how long it was out of the water, how they cleaned their boats and with what, and if they are aware of any AIS in the location they previously boated. These questions provide information for management purposes, in addition to encouraging boaters to take responsibility for understanding the risk of AIS in their recreational water bodies.

Boaters are asked to display the completed forms on their car dashboard. Parking areas at both ponds are periodically checked through the boating season to monitor for compliance with the program. Vehicles/boaters not displaying a completed form are given instructions, and a blank form.

Cabomba caroliniana (fanwort) was first identified in 2021 during an annual macrophyte survey at Long Pond, a DCR-owned pond that utilizes self-certification. Fragments of *C. caroliniana* were found near the boat launch, and a dense patch had formed in the cove between the boat launch and road. The size of individual plants, and the spread of the patch indicate this invasive plant had been present in Long Pond for over a year before discovery. Due to the location of the infestation in the water body, it is very likely it was introduced by boaters. This AIS introduction highlights the importance of the self-certification process and presents an example of the consequences that follow noncompliance.

4 Conclusions and Next Steps

Monitoring results generated by DWSP in 2024 documented the continued high quality of water in the Quabbin Reservoir and its tributaries. The requirements of the filtration avoidance criteria under the SWTR were satisfied for the entirety of 2024. Increased sampling intervals for parameters of particular interest (e.g., nutrients, organics) has allowed DWSP to develop a better understanding of the range of variability across sites and across seasons for these analytes and better characterize patterns under different meteorological and hydrological contexts (e.g., drought season of 2024 compared to high rainfall and streamflow year of 2023). Water quality monitoring continues to assess and document water quality in the Quabbin Reservoir and Ware River Watersheds and ensure continued fulfillment of the requirements stipulated by the SWTR.

DWSP sampling plans will continue to be developed in coordination with MWRA and UMass partners to best adapt to emerging water quality concerns.

4.1 Meteorology and Hydrology

In 2024, the NOAA weather stations in the Quabbin Reservoir and Ware River watersheds showed warming trends when compared to historical records. Warming in 2024 wasn't as extreme as what was observed the previous year; however, 2024 has shown a more consistent warming pattern throughout the year than 2023. The most notable fluctuations were observed in the Ware River watershed, with mean monthly maximums exceeding historical means by an average of 5°C during winter months. Despite these variations, daily median temperatures generally remained within historical ranges, although occasional outliers were observed, particularly in winter and spring. Even though March was a record setting month for rainfall, cumulative annual precipitation was below historical averages across all monitoring stations, with annual deficits ranging from 2.8% to 13.3% below long-term means. The persistent lack of precipitation contributed to progressively worsening drought conditions throughout 2024, culminating in 100% of Massachusetts experiencing drought by year-end, with many regions in severe to extreme drought conditions. Snow monitoring in the Quabbin Reservoir watershed indicated below-average total annual snowfall as compared to historical records, with snowfall totals for 2024 falling within the lower 25th percentile.

Streamflow in the Quabbin Reservoir and Ware River watersheds was highly variable throughout 2024, mirroring the year's uneven precipitation. The year began with unusually high flows in January and March, particularly at Ware River at Gibbs Crossing where flows exceeded historical averages by over 500 cfs. As drought conditions intensified from spring through fall, streamflow declined across monitoring stations, with West Branch Swift River recording September flows at only about 16% of its historical average. Despite the lack of water, daily minimum flows remained above historical critical levels, and streamflow began recovering in the final months of the year as precipitation increased.

These findings highlight the dynamic nature of climate, precipitation, and hydrological responses in the Northeast, with notable variations observed across seasons and watersheds. They also reflect the impact of climate change on weather patterns in the Northeast, with 2024 meteorological and hydrological data from the Quabbin Reservoir and Ware River watersheds exhibiting broad variability when compared to historical observations. Studies in the region suggest that further impacts to climate in the Northeast will result in less predictable and increasingly extreme meteorological trends, and these trends will be reflected in more frequent high magnitude streamflow events (Demaria et al., 2016; Siddique et al., 2020; Young and Young, 2021). Continued monitoring, and the potential expansion of monitoring networks in both the Quabbin and Ware River watersheds, is recommended in order to better understand and adapt to future changes.

4.2 Tributary Water Quality

Results generated from routine monitoring of tributaries in Quabbin Reservoir and Ware River Watersheds in 2024 were largely consistent with historical data and met drinking water quality standards. Water quality patterns in tributaries of these two watersheds reflected the distinct differences in seasonal rainfall and streamflow observed in 2024. The high early winter and spring streamflow, spatially variable summer thunderstorms and corresponding high intensity rainfall, and prolonged fall drought followed by rain-on-snow rewetting conditions lead to distinct patterns in seasonal sediment and nutrient export.

While turbidity values were higher than average across sites due to the extreme and varying hydrology of the year, results were largely within historical ranges. Similarly, summer UV_{254} observations were elevated relative to the period of record across sampling locations in both watersheds, attributed to consistent high discharge simultaneous to timing of peak biological productivity in the watershed. The prolonged fall drought and diminished streamflow lead to a marked decline in both mean UV_{254} levels and TOC concentrations throughout the watersheds. Results from the high-discharge event of December 30, 2024 (rain-on-snow) following this fall drought period included numerous record high winter maximum results across numerous analytes (e.g., total phosphorous, TOC, turbidity), highlighting the influence of seasonal drought and flood cycles, as well as discrete flood events, on water quality patterns and transport dynamics. The increased temporal resolution of routine nutrient monitoring into 2024 (from quarterly to biweekly) continued to reveal more detailed dynamics of terrestrial aquatic N-cycling than previously documented, including the influences of seasonal drought and re-wetting on the varied nutrient patterns seen across streams of these watersheds. Results from bacterial analysis were largely within normal historical ranges in 2024. Annual geometric mean *E. coli* values were mostly on the lower end of historical ranges, with most monitored EQA sampling locations showing a lower annual geometric mean compared to previous monitoring cycles. Monitoring results of water quality parameters in Quabbin Reservoir Watershed and Ware River Watershed in 2024 were consistent with historical data, did not suggest the presence of any new substantial point-source contributions, and ultimately demonstrated continued adherence to drinking water quality standards.

4.3 Reservoir Water Quality

Results of routine water quality profiles collected in Quabbin Reservoir in 2024 were comparable to historical data and indicated that the timing of turnover and stratification occurred in line with prior seasons. In addition, profile data captured the impact of high stream flows on site Den Hill, resulting in low dissolved oxygen and elevated UV_{254} levels. Profile data also served to guide phytoplankton sampling. Phytoplankton densities observed in 2024 were higher than those in 2023. However, changes in phytoplankton community composition in 2024 were consistent with patterns observed in prior years. The elevated phytoplankton levels in 2024 were primarily attributed to a *Chrysosphaerella* aggregation, which reached levels similar to those seen during the 2019 and 2022 events and resulted in taste and odor impacts on water quality. Water quality monitoring showed that nutrient (TP, TKN, ammonia, and nitrate) levels have not increased over the period of record and that the observed low nutrient levels still characterized the Quabbin Reservoir as an oligotrophic water body (Carlson, 1977). Due to the low nutrient concentrations and the inconsistent pattern of phytoplankton aggregations observed in the last 6 years, it is believed that the high levels of *Chrysosphaerella* observed some years were not influenced by nutrients but by other hydrological and climatic drivers (such as temperature, possible silica, and precipitation/high riverine flows). Years with observed aggregations (2019, 2022, and 2024) experienced drought conditions (or partial drought conditions) while years without aggregations experienced consistent flood conditions. The impact of drought and flood conditions on phytoplankton aggregations will continue to be studied by DWSP staff and will be discussed in future reports. For example, to better understand the role of silica availability in the water column and uptake by chrysophytes (algal group containing most of the taxa of concern for the Quabbin Reservoir) dissolved silica will be added to the 2025 monthly reservoir monitoring.

4.4 Aquatic Invasive Species Monitoring and Management

Continued prevention efforts and monitoring of current and potential invaders are the main priority of the AIS Program at Quabbin. Changes in environmental factors due to climate change, which previously prevented certain species from establishing in New England, has led to an increase in invasive species' spread throughout the region. With the integration of digital data collection and GPS, information about AIS spread within waterbodies in the Quabbin and Ware River Watersheds will help aid future prevention, education, and management efforts.

Overall, AIS observations during the DWSP-EQ 2024 surveys remained similar to previous years with a few notable exceptions. *Utricularia inflata* was confirmed on O'Loughlin Pond and emphasized the need for early-season surveys on high priority waterbodies within the Quabbin and Ware River watersheds. It is recommended that these twice-yearly surveys continue on the holding ponds and on the Ware River upstream of the Shaft 8 Intake to detect early-season species such as *U. inflata* and *Potamogeton crispus*. Management of *U. inflata* on the holding ponds should continue, to reduce potential spread into the Quabbin Reservoir. In addition, reservoir areas adjacent to the holding ponds should be surveyed to confirm presence/absence of this species.

Trapa natans was also observed for the first time within the Ware River watershed on Brigham Pond. Although not a source waterbody, the presence of new AIS in either watershed is a cause of concern as it may spread to our source waters. Surveys of EQA ponds should continue as scheduling and staffing allows, and management actions should be taken, when able, to mitigate the risk to our source waters.

4.5 Proposed Quabbin Reservoir and Ware River Watershed Monitoring Programs for 2025

The water quality sampling plan for the Quabbin Reservoir and Ware River Watersheds is reviewed and modified annually to direct focus to different sub-basins within the watersheds, investigate new areas/analytes based on emerging water quality concerns, and adapt to changing conditions (including but not limited to changes in land use/land cover and/or climate-driven hydrometeorological changes). Planned changes to 2025 monitoring programs are detailed below.

4.5.1 Tributary Monitoring

The 2025 sampling plan retains the long-term Core sites in both watersheds and replaces the sites used to support Environmental Quality Assessment (EQA) efforts in Quabbin Reservoir and Ware River Watersheds. The Quabbin Reservoir Watershed tributary monitoring program includes seven Core sites and up to seven EQA sites. In 2025, DCR will continue to sample every two weeks in the Quabbin Reservoir Watershed, discontinue monitoring at EQA sites monitored in 2024 (211A-1, 211B-X) and begin monitoring at four EQA sites located in the East Branch Swift sanitary district (216C, 216D, 216G, 216I-X). All Core sites will remain. The same suite of analytes and sample frequency is planned for this watershed (Table 5). EQA reporting for the East Branch Swift sanitary district is planned for 2026.

The Ware River Watershed tributary monitoring program includes six Core sites and up to six EQA sites. DCR will continue to sample every two weeks at Core sites, discontinue monitoring at the EQA sites monitored in 2023 (108A, 108B, 108C, 117) and begin monitoring at four EQA sites (105, 119, 110, 121M) located in the Coldbrook-Longmeadow sanitary district in 2025. Monitoring at site 101 will remain consistent with that of tributaries in the Quabbin Reservoir Watershed. Nutrient (NO_3-N, NH_3-N, TKN, and TP) monitoring will continue at a quarterly sampling interval in the remaining monitoring tributaries in the Ware River Watershed in 2025. All other analyses will remain unchanged from 2024 (Table 5).

4.5.2 Reservoir Monitoring

Monthly Quabbin Reservoir monitoring at Core sites (202, 206, and Den Hill) will be conducted by DWSP from March through December 2025, weather and reservoir conditions permitting. This monitoring will include analyses for turbidity, total and fecal coliform, *E. coli,* TOC, UV_{254}, and extracted chlorophyll *a*. Quarterly Quabbin Reservoir monitoring will be conducted in May, July, October, and December. In addition to the monthly analytes, quarterly monitoring will include alkalinity, Na, Cl, and nutrients (NO_3-N, NH_3-N, TKN, TP, and Si). Routine monitoring for phytoplankton will be performed by DWSP weekly at site 202 during the growing season (May 1 through September 30, 2024), monthly at site 202 outside of the growing season, and monthly at sites 206 and Den Hill. *In situ* profiles of temperature, pH, specific conductance, dissolved oxygen, turbidity, chlorophyll *a*, and phycocyanin will be collected at each monitoring site within the Quabbin Reservoir and used to determine appropriate sample collection depth and inform controls on phytoplankton dynamics in Quabbin Reservoir.

Two modifications to DWSP monitoring efforts in Quabbin Reservoir Watershed or Ware River Watershed are anticipated for 2025. Sample collection and analysis for dissolved silica will be added to the monthly Quabbin Reservoir monitoring to better understand the role of dissolved silica on chrysophyte aggregations. The second modification to the 2025 monitoring efforts will be to extend the Quabbin Reservoir monitoring period to start in March instead of April, ice-cover conditions permitting. Changes to the DWSP water quality monitoring program introduced in 2025 may aid in future management decisions and help to better elucidate potential controls on productivity and algal dynamics in Quabbin Reservoir.

4.5.3 Aquatic Invasive Species Monitoring and Management

Every year, DWSP monitors select ponds for AIS in addition to contractors hired by MWRA who survey the Quabbin Reservoir, holding ponds, and the Ware River around the Shaft 8 intake. For the 2025 survey season, nine waterbodies are planned for DWSP surveys. This includes the two holding ponds, three boat launch areas, and the west arm of the Quabbin Reservoir (Table 63).

DCR-DWSP has conducted periodic AIS surveys of the Quabbin Reservoir but has been limited to the West Arm and Boat Launch Areas. MWRA contractors have also conducted annual surveys of the Reservoir, but these are limited to specified points and do not cover the full extent of the Quabbin Reservoir's littoral zone. To prioritize the protection of our source waters and collect a more comprehensive overview of AIS in the area, Quabbin littoral areas will be separated into five zones for DWSP to survey on a rotating basis (i.e., surveying one zone every five years). In 2025, Zone 1 will be surveyed (see Appendix 6.3). This zone covers the west arm down to the Winsor Dam and boat cove.

Table 63. *Proposed AIS monitoring schedule for CY2025*

Quabbin Reservoir Watershed

Water Body Name	Location	Type	Last Survey Year	To Be Surveyed by
Quabbin Reservoir	New Salem, Petersham, Hardwick	Annual	2024	TRC
Quabbin Reservoir, West Arm (Zone 1)	Pelham, New Salem	Annual	2024	TRC and DWSP
Quabbin Reservoir, Boat Launch Area 1	Belchertown	Annual	2024	TRC and DWSP
Quabbin Reservoir, Boat Launch Area 2	New Salem	Annual	2024	TRC and DWSP
Quabbin Reservoir, Boat Launch Area 3	Petersham	Annual	2024	TRC and DWSP
O'Loughlin Pond	New Salem	Annual	2024	TRC and DWSP
Pottapaug Pond	Hardwick	Annual	2024	TRC and DWSP

Ware River Watershed

Water Body Name	Location	Type	Last Survey Year	To Be Surveyed by
Ware River, Upstream of Shaft 8	Barre	Annual	2024	TRC and DWSP
Ware River, Upstream of Boat Launch	Barre	Annual	2017	DWSP
Brigham Pond	Hubbardston	Annual	2024	DWSP
Long Pond	Rutland	Annual	2024	DWSP

Management of *Utricularia inflata* at the Pottapaug and O'Loughlin holding ponds will continue in the CY2025 season by DWSP staff and MWRA contractors (please refer to Table 64 for a breakdown of responsibilities and overall schedule). An initial point-intercept survey will be conducted on reservoir areas adjacent to Boat Launch Area 3 to confirm presence, extent of infestation, and density. As time allows, point-intercept surveys will also be conducted on Pottapaug Pond and O'Loughlin Pond. During harvesting efforts, contractors will be required to provide periodic updates, noting amount harvested and harvest locations through email and a DCR Survey 123 form. Upon receipt of the final draft report, DCR will work with MWRA to determine next management steps.

Table 64. *Proposed timeline for contractor hire, Utricularia inflata surveys, harvest efforts, and reporting.*

Month	Task
February	MWRA - Call for Proposals
March	MWRA - Award Bid
May	DWSP - Silt Fence Disposal Site Set-up
May	DWSP - Plant Growth Survey
May	Contractor - Point-intercept Surveys
May - June	Contractor - Plant Removal
June - July	Contractor - to Submit Draft Report
August	Contractor - to Submit Final Report

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6 Appendices

6.1 Appendix A. 2024 Watershed Monitoring Parameters

Table A1: *Water quality parameters, and associated analytical methods, monitored by DWSP in surface water in the Quabbin Reservoir Watershed and Ware River Watershed in 2024. Monitoring for select parameters in Quabbin Reservoir or tributary monitoring locations is indicated by an "X" in columns R and T, respectively. Precipitation and air temperature measurements were recorded from meteorological stations maintained by DWSP and NOAA. Discharge measurements were recorded from stream gages maintained by USGS. Adapted from DWSP, 2021c.*

Parameter Name	Units	Sampling Group	Analysis Location(s)	Analysis Method	R	T
Air Temperature	Deg-F	Meteorological	Field-Sensor	-	-	-
Ammonia-nitrogen	mg/L	Nutrients	MWRA Lab	EPA 350.1, 353.2	X	X
Alkalinity	mg/L $CaCO_3$	Nutrients	MWRA Lab	SM 2320 B	X	X
Blue Green Algae	ug/L	Field parameter	Field-Sensor	*In situ* Fluorometry	X	
Blue Green Algae RFU	RFU	Field parameter	Field-Sensor	*In situ* Fluorometry	-	-
Chloride	mg/L	Nutrients	MWRA Lab	EPA 300.0	X	X
Chlorophyll	ug/L	Field parameter	Field-Sensor	*In situ* Fluorometry	X	-
Chlorophyll RFU	RFU	Field parameter	Field-Sensor	*In situ* Fluorometry	-	-
Chlorophyll volts	volts	Field parameter	Field-Sensor	*In situ* Fluorometry	-	-
Discharge	cfs	Field Parameter	Field-Sensor	-		X
Dissolved Oxygen	mg/L	Field Parameter	Field-Sensor	SM 4500-O G-2001	X	X
E. coli	MPN/100 mL	Bacteria	MWRA Lab	9223B 20th Edition (Enzyme Substrate Procedure)	X	X
Mean UV_{254}	ABU/cm	Nutrients	MWRA Lab	SM 5910B 19th edition	X	X
Nitrate-nitrogen	mg/L	Nutrients	MWRA Lab	EPA 350.1, 353.2	X	X
Nitrite-nitrogen	mg/L	Nutrients	MWRA Lab	EPA 350.1, 353.2	X	X
Oxygen Saturation	percent	Field parameter	Field-Sensor	SM 4500-O G-2001	X	X
pH	S.U.	Field parameter	Field-Sensor	SM4500-H+ B-2000	X	X
Precipitation	in	Meteorological	Field-Sensor (USGS/NOAA)	N/A	-	-
Secchi Depth	ft	Field parameter	Field-Sensor	N/A	X	
Silica	µg/L	Nutrients	MWRA Lab	EPA 200.7	-	-
Sodium	µg/L	Nutrients	MWRA Lab	EPA 200.7	-	-
Specific Conductance	µS/cm	Field parameter	Field-Sensor	SM 2510 B-1997	X	X
Staff Gage Height	ft	Field parameter	Field-Sensor	Pressure Transducer/ Visual staff plate reading	-	X
Total Coliform	MPN/100 mL	Bacteria	MWRA Lab	9223B 20th Edition	X	X
Total Kjeldahl Nitrogen	mg/L	Nutrients	MWRA Lab	EPA 351.2	X	X
Total Nitrogen	mg/L	Nutrients	MWRA Lab	Calculated	-	-
Total Organic Carbon	mg/L	Nutrients	MWRA Lab	SM 5310 B	-	-

Parameter Name	Units	Sampling Group	Analysis Location(s)	Analysis Method	R	T
Total Phosphorus	µg/mL	Nutrients	MWRA Lab	EPA 365.1	X	X
Total Suspended Solids	mg/L	Nutrients	MWRA Lab	SM2540	-	-
Turbidity FNU	FNU	Field parameter	Field-Sensor	ISO7027	-	-
Turbidity NTU	NTU	Bacteria	DWSP Lab, USGS	EPA 180.1	X	X
Water Depth	m	Field Parameter	Field-Sensor	N/A	X	-
Water Temperature	Deg-C	Field Parameter	Field-Sensor, USGS	SM 2550 B-2000	X	X

6.2 Appendix B. DWSP Investigation into bacterial sources at Boat Cove Brook, 2024

E. coli was elevated above the period of record normal levels (25th to 75th percentile) in routine samples collected in Boat Cove Brook throughout the 2024 sampling year (Figure B1). Elevated results in 2024 occurred both in the summer and during unseasonably warm weather in December, coinciding with rainfall events. The annual maximum *E. coli* level observed at this location in 2024 (1530 MPN/100 mL) was attributed to the July 16 2.64" rainfall event. Elevated *E. coli* in surface waters following precipitation events may be attributed to episodic flushing from upland sources, as concentrations typically return to baseline levels with decreasing streamflow. Persistent elevated levels of *E. coli* in the absence of hydrological events may indicate a potential wildlife presence in the near stream contributing areas.

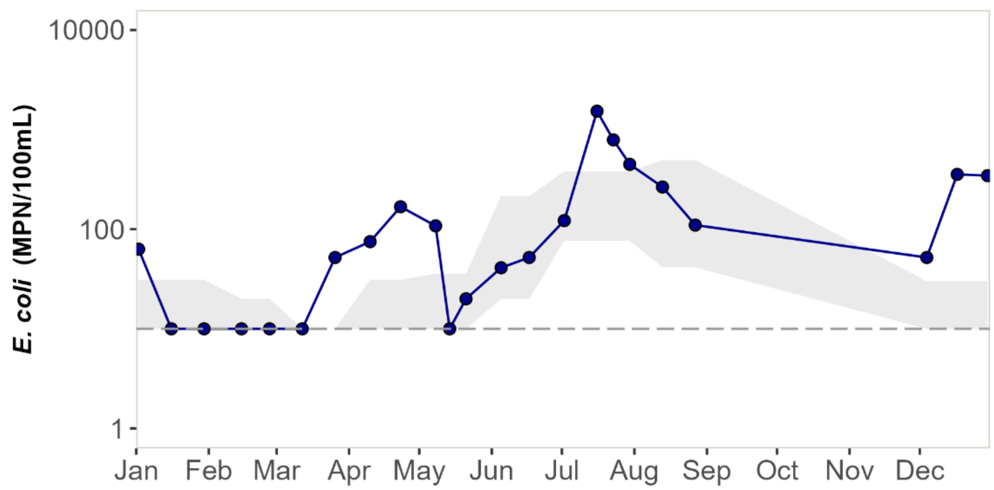
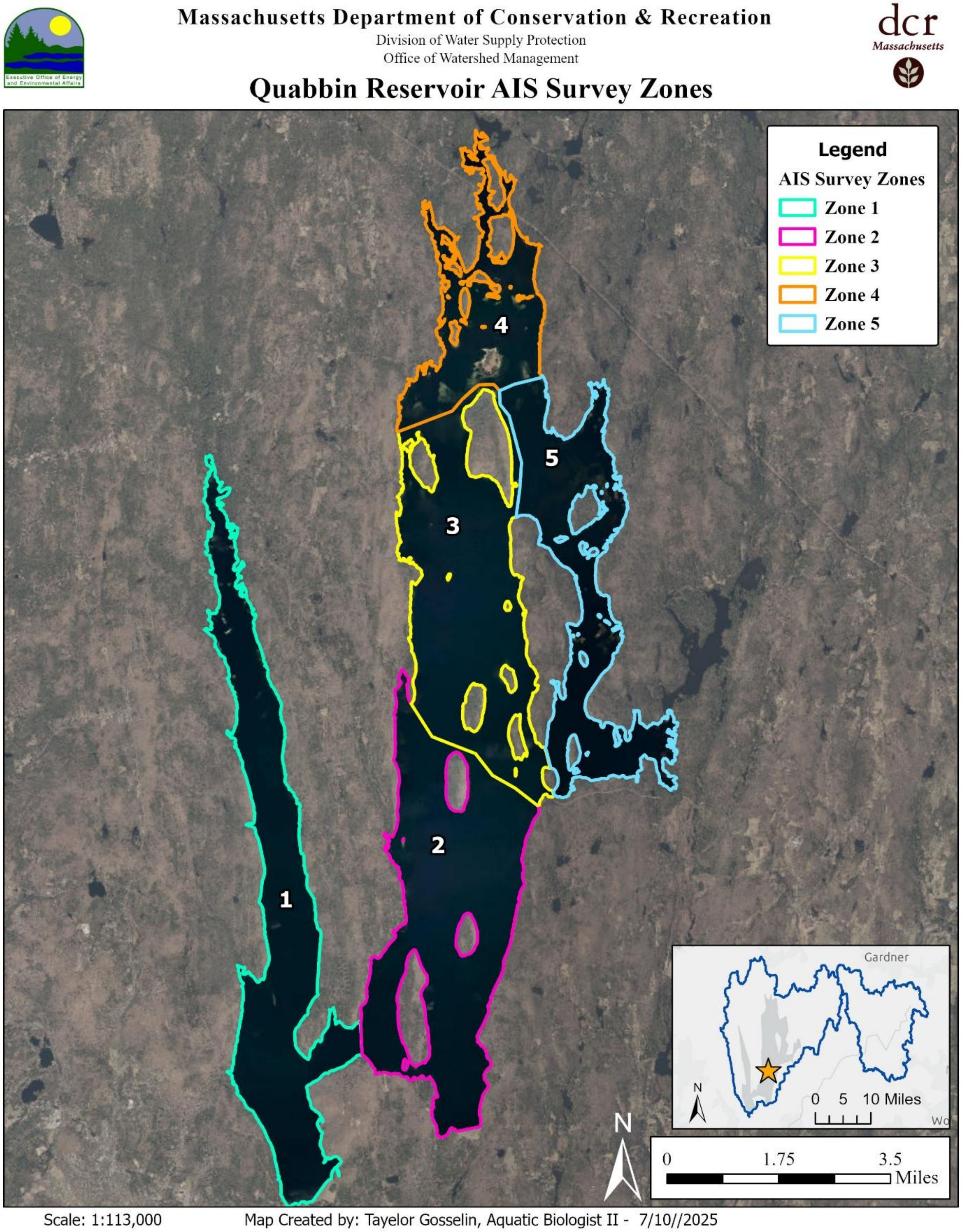


Figure B1. *Time series of E. coli measured in Boat Cove Brook tributary during 2024. Lower gray line indicates the laboratory detection limit (10 MPN/100 mL). Shaded band signifies period of record monthly 25th to 75th percentile values*.

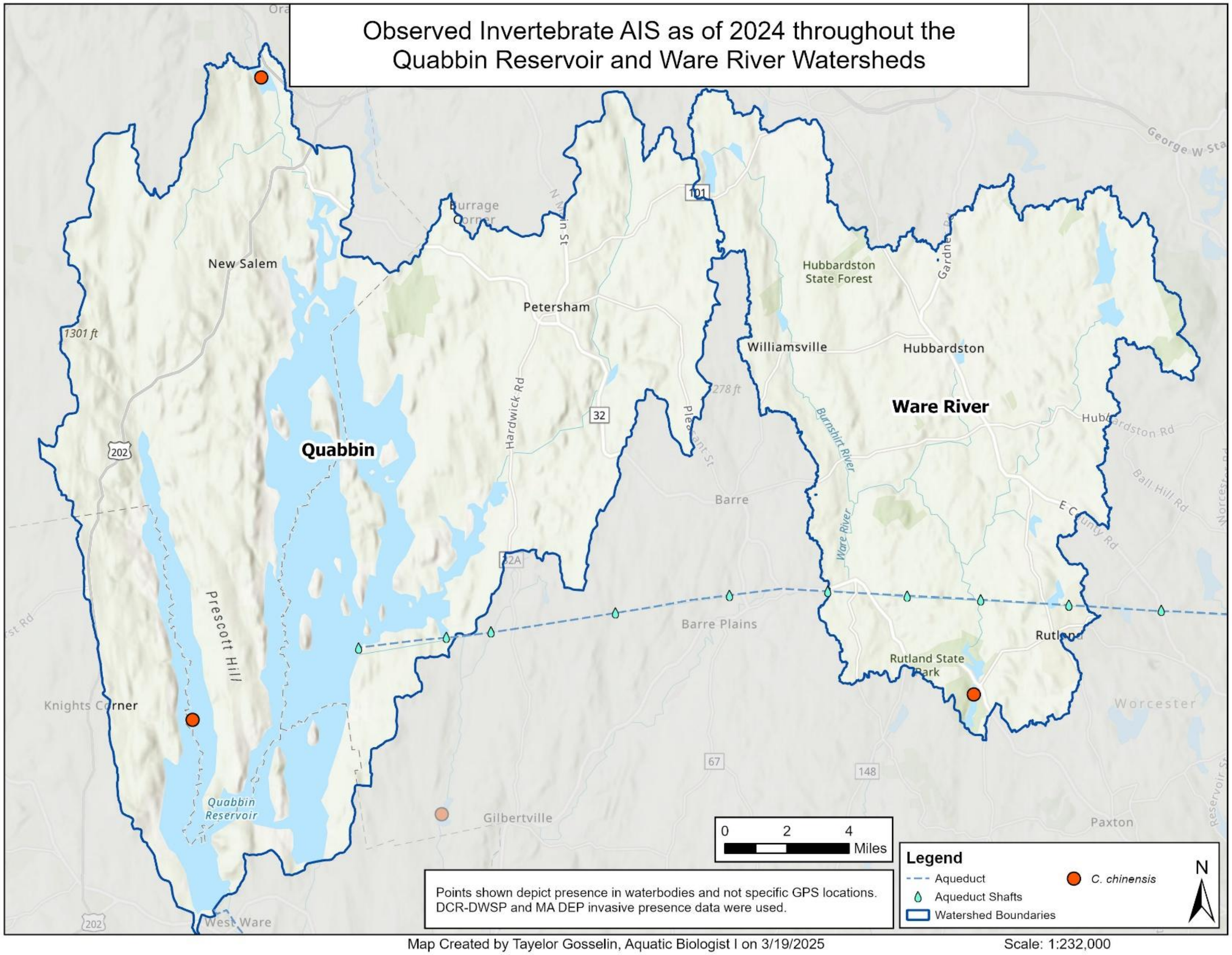
The 2024 Boat Cove Brook *E. coli* results align with the overall pattern in *E. coli* for the period of record with low *E. coli* in the winter to begin the year, an increase as temperatures and flows rise in the spring, elevated levels in the summer as the flow in Boat Cove Brook decreases and bacteria is flushed into the stream during rain events, before dropping in the fall heading into winter. In 2024, Boat Cove Brook completely dried up and samples could not be collected between August 27 and December 4. Once sampling resumed, the two samples most elevated above the period of record normal range were observed on December 17 and December 30. Both samples were collected during unseasonably warm weather (50°F on 12/17, 56°F on 12/30) with rain events (0.28" on 12/17, 0.65" on 12/30).

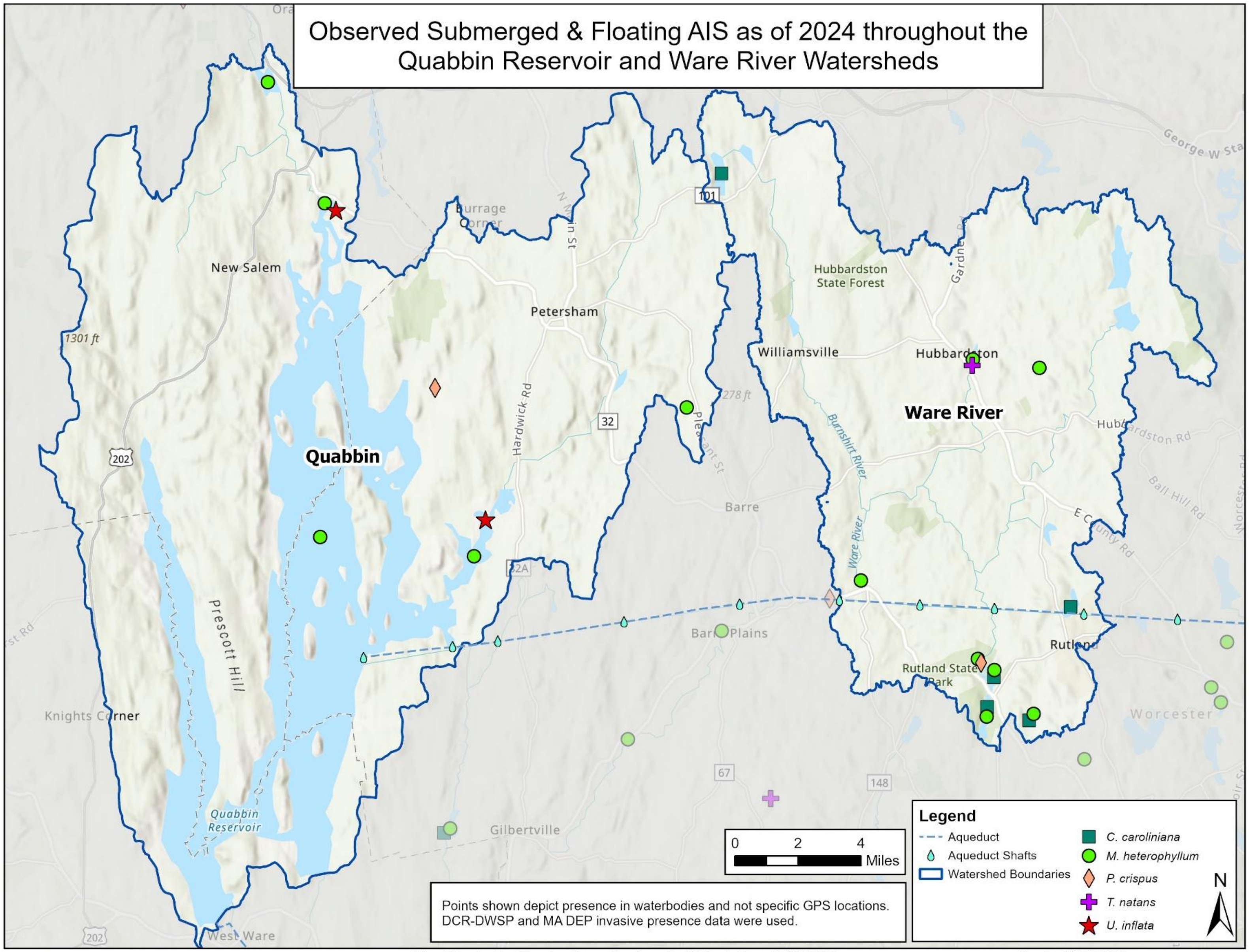
The Boat Cove Brook subbasin has been the subject of repeated surveys and investigations in recent years due to the elevated levels of *E. coli* observed. Signs of wildlife have been documented as a likely contributor of *E. coli* flushing into the stream (DWSP, 2018a; DWSP, 2023a; DWSP, 2024a). In 2024, the Boat Cove Brook catchment was subject to further investigations for an Environmental Quality Assessment report related to its history and ecology. The main issue impacting the area was its use as a borrow pit to build the Windsor Dam. This altered the catchment's hydrology and severely impacted the ability of the ecosystem to naturally filter water due to the removal of the surface soils. The examination of Boat Cove Brook catchment will be further expanded upon in the 2025 Quabbin Reservation Environmental Quality Assessment report.

6.3 Appendix C. Quabbin Reservoir AIS Survey Zones



6.4 Appendix D. Quabbin Reservoir and Ware River Watershed AIS Presence Maps





Map Created by Tayelor Gosselin, Aquatic Biologist I on 3/19/2025

Scale: 1:232,000