Water Quality Report: 2024

Wachusett Reservoir Watershed

Quinapoxet River Circular Dam – Mussel Relocation on September 10, 2024 – Jamie Carr (2024)

July 2025

Massachusetts Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management
Wachusett Reservoir Watershed

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Abstract

The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management manages Wachusett Reservoir and lands within the Watershed to assure the availability of safe drinking water to present and future generations. The Division's Environmental Quality Section implements a comprehensive water quality and hydrologic monitoring program to screen for potential pollutants, measure the effectiveness of watershed management programs, better understand the responses of the Reservoir to a variety of physical, chemical, and biological inputs, assess the ecological health of the Reservoir and the Watershed system, and demonstrate compliance with state and federal water quality standards. As part of this program, Environmental Quality Section staff perform field work, manage and interpret water quality data, and prepare reports of findings. This report is a summary and discussion of water quality monitoring methods and results from water quality and hydrological monitoring activities carried out by the Division in the Wachusett Reservoir Watershed during 2024. This annual water quality report is intended to meet the needs of watershed managers, the interested public, and others whose decisions must reflect water quality considerations.

Monitoring of tributaries and the Reservoir is a proactive measure aimed at identifying trends and potential problems that may require additional investigation or corrective action. In 2024, Wachusett Reservoir water quality satisfied the requirements of the Filtration Avoidance Criteria established under the United States Environmental Protection Agency Surface Water Treatment Rule.

Despite a near normal precipitation total for 2024, rainfall distribution throughout the year was heavily skewed towards the first half of the year, leading to a drastic swing in hydrologic conditions – from very wet to very dry. Stream flows and groundwater levels remained unseasonably high until May, but then quickly dropped to below normal levels and remained below normal through the second half of 2024, as drought conditions persisted. Overall, 2024 was a warm year (0.72 °C above the long-term mean annual temperature) with July being the warmest since 1998. These factors provide important context for the interpretation of water quality results discussed in this year's report.

Compliance with state surface water quality standards among the tributaries varied, with minor exceedances attributed to higher solute loads measured during storm events, wildlife, and/or natural attributes of the landscape. Substantial loading of dissolved salts to the tributaries and Reservoir has continued, though ion concentrations and salt loads were lower in 2024 than in recent years. Turbidity levels were slightly elevated throughout the Watershed in 2024, but mostly within historical ranges. As in prior years, bacteria concentrations in the tributaries were frequently elevated during the warmer months of 2024, but did not lead to violations of Surface Water Treatment Rule standards for raw drinking water pathogens. A few tributaries experienced seasonal or episodic elevated bacteria concentrations, above typical background concentrations, which have previously either been investigated and documented in prior Annual Water Quality Reports or are discussed in this report.

Overall, the results of the Wachusett Watershed tributary monitoring programs were consistent with historical data and demonstrate continued adherence to high drinking water quality and aquatic life use standards. The more urbanized subbasins within the Watershed continue to experience chronically high chloride concentrations and periodic episodes of elevated bacteria concentrations. Water temperatures rose above the MassDEP recommended threshold for coldwater fishery resources at several monitoring locations, for cumulative durations between 9 and 106 days.

Results of reservoir monitoring align with those observed in the Watershed. Reservoir monitoring focuses on two areas of water quality; physical and chemical parameters such as temperature, clarity, and

nutrients, and biological conditions including phytoplankton density and composition, invasive aquatic plants, and fish populations. Elevated alkalinity and UV_{254} values and elevated concentrations of silica were observed at several reservoir sites in 2024. These higher values can be attributed to record precipitation events which transported nutrients from the Watershed into the Reservoir in 2023 and early 2024. Although drought conditions in the later portion of 2024 resulted in overall lower contributions of native watershed water and a higher portion of Quabbin water transferred to the Wachusett basin, previously transported nutrients were sequestered in the hypolimnion resulting in some elevated results, especially during stratification.

Patterns typical of oligotrophic water bodies were observed in the phytoplankton population which remains dominated by diatoms and/or chrysophytes for much of the year. Organisms that can produce undesirable tastes and odors were only briefly present above internally defined thresholds and cyanobacteria concentrations remained below levels of concern. No new invasive species were detected in the Reservoir in 2024, and management activities continue to reduce known populations.

The appendices to this report include tributary hydrographs (Appendix A: Continuous Data Hydrographs) and a list of applicable water quality criteria/standards or thresholds of interest (Appendix B: Water Quality Standards and Criteria). Previously compiled background information and historical context for monitoring parameters are included in Appendix C: Watershed Monitoring Parameters and Historical Context to assist in the interpretation of water quality results and serve as a reference for the reader. Quality assurance and quality control (QA/QC) efforts for 2024 are summarized in Appendix D: Quality Assurance and Appendix E: Quality Control. Some of the ancillary data presented in this report have been compiled with the help of outside agencies (e.g., U.S. Geological Survey) and other workgroups within Division of Water Supply Protection whose efforts are acknowledged below.

Plain Language Summary

Water used by people and businesses in metro-Boston comes from the Quabbin and Wachusett Reservoirs and the Ware River. Streams, rivers, and groundwater that flow into these water bodies are monitored for quality and quantity by the DCR Division of Water Supply Protection. Certain water quality standards set by federal and state regulations must be met annually. This report summarizes the monitoring methods and results for 2024, which satisfy these requirements and continue to ensure availability of safe drinking water to present and future generations.

CITATION

Division of Water Supply Protection. (2025). Water Quality Report: 2024 Wachusett Reservoir Watershed. Massachusetts Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management. West Boylston, MA.

Acknowledgements

This report was prepared by the Environmental Quality Section of the Office of Watershed Management, Wachusett/Sudbury Region. Daniel Crocker, Environmental Analyst IV, and Joy Trahan-Liptak, Aquatic Biologist III, were the primary authors. The authors acknowledge the following for their contributions to this report:

Caroline Anderson, Seasonal Aquatic Biologist I/Environmental Analyst II for analyzing zooplankton samples; for watershed field work and sampling and carrying out the hydrologic and groundwater monitoring programs; Writing, analysis, map production, and review of this report.

Jamie Carr, EQ Section head, for leading the Water Quality Monitoring team and Chloride/Conductivity Working Group and providing report review and comments.

Travis Drury, Environmental Analyst II [currently EAIII at Quabbin/Ware region], for watershed field work and sampling, and carrying out the hydrologic and groundwater monitoring programs.

Kelley Freda, Regional Director of the Wachusett/Sudbury Region, for providing program leadership and report review and comments.

Nick Ferry, Environmental Analyst II, for watershed field work and sampling.

Derek Liimatainen, Assistant Regional Director of the Wachusett/Sudbury Region, whose staff helps maintain access to sampling sites and maintains boats that are critical for reservoir sampling.

Max Nyquist, Aquatic Biologist II, for field work, monitoring for potential invasive species, leading the Phragmites management program, and collecting water quality data and phytoplankton collection, analysis, and reporting; writing, analysis, and review for this report.

Erica Poisson, DWSP GIS Director, for providing Geographical Information System data, maps, and support.

Jason Stolarski, Aquatic Biologist at MassWildlife, for leading the Lake Trout monitoring program.

John Scannell, Director of the Division of Water Supply Protection, for providing program leadership and report review and comments.

Josh Sjogren, Environmental Analyst II, for field investigations and sampling assistance.

Joel Zimmerman, DWSP Watershed Planning Coordinator, for assistance in final report production.

The Massachusetts Water Resources Authority (MWRA), whose laboratory staff conducted nutrient, pathogen, and bacteriological analyses and contributed to the management of laboratory data and sample bottle preparation.

Matt Walsh and Caulin Lauzon of MWRA, who provided water system data from MWRA facilities.

The University of Massachusetts, Amherst – Department of Civil and Environmental Engineering faculty and graduate students, for collaboration and research leading to a better understanding and management of the DWSP-MWRA water supply system.

The U.S. Geological Survey, who, through a cooperative agreement established with DWSP, provided tributary flow and precipitation data included in this report.

Table of Contents

Figures and Tables

Figures

Tables

Abbreviations

The following abbreviations are used in this report:

AIS	Aquatic Invasive Species
BCB	Boston City Base
Cl	Chloride
CFR	Coldwater Fish Resources
CWTP	Carroll Water Treatment Plant
DBP	Disinfection Byproducts
DCR	Massachusetts Department of Conservation and Recreation
DWSP	Department of Conservation and Recreation, Division of Water Supply Protection
D.O.	Dissolved Oxygen
EPA	U.S. Environmental Protection Agency
EQ	Environmental Quality
E. coli	*Escherichia coli*
EWM	Eurasian Water-milfoil (*Myriophyllum spicatum*)
LTF	Long-term Forestry [Monitoring]
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MCL	Maximum Contaminant Level
MWRA	Massachusetts Water Resources Authority
N/A	Not Applicable
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
OWM	Office of Watershed Management
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
SMCL	Secondary Maximum Contaminant Level
SOP	Standard Operating Procedure
STF	Short-term Forestry [Monitoring]
STV	Statistical Threshold Value
SWE	Snow Water Equivalent
SWTR	Surface Water Treatment Rule
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
THM	Trihalomethane
TSS	Total Suspended Solids
UMass	University of Massachusetts
USGS	U.S. Geological Survey
VWM	Variable Water-milfoil (*Myriophyllum heterophyllum*)
WFR	Warmwater Fish Resources

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. Mean UV_{254} results are reported as the amount of ultraviolet light at a 254 nm wavelength that can 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:

Abbreviation	**Unit of Measurement**
ABU/cm	Absorbance units per centimeter of path length
ASU/mL	Areal standard units per milliliter
BG	Billion Gallons
cfs	Cubic feet per second
CFU	Colony-forming unit (equivalent to MPN)
°C	Degrees Celsius
ft	Feet
FNU	Formazin Nephelometric Units
in	Inches
µS/cm	Microsiemens per centimeter
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
UV_{254}	Ultraviolet Absorbance at 254 Nanometers
S.U.	Standard Units (pH)

1 Introduction

The Department of Conservation and Recreation (DCR), Division of Water Supply Protection (DWSP), Office of Watershed Management (OWM[1]) manages and maintains a system of watersheds and reservoirs to provide raw water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.7 million people and thousands of industrial users in 53 Massachusetts communities. The active watershed system includes the Quabbin Reservoir, Ware River, and Wachusett Watersheds. Quabbin Reservoir, Ware River, and Wachusett Reservoir are interconnected by a series of aqueducts (Figure 1). Sudbury Watershed, containing Sudbury and Foss Reservoirs, is also part of this system, however it was taken out of regular service in 1978 and is maintained as part of the MWRA emergency backup water supply[2].

The U.S. Environmental Protection Agency (EPA) introduced the Federal Surface Water Treatment Rule (SWTR) in 1989[3], followed by the Interim Enhanced Surface Water Treatment Rule (IESWTR) in 1998[4], to ensure that public water supply systems that use surface water, or groundwater under direct influence of surface water, provide safeguards against the contamination of water by viruses and bacteria. These 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. DWSP and MWRA have maintained a joint waiver for the filtration requirement of the SWTR since 1998 and work together to manage the water supply watersheds in fulfillment of the waiver[5].

DWSP monitors the quality and quantity of source water within watershed aquifers, reservoirs, and tributaries, whereas MWRA is responsible for monitoring water quality upon withdrawal from the Reservoirs and throughout the treatment and distribution processes[6]. DWSP water quality sampling and field inspections help identify 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, turbidity, and nutrients in the Reservoirs and tributaries provides an indication of sanitary quality of water sources, promoting security of water resources and public health. Monitoring is also conducted by DWSP staff to better understand the responses of the Reservoirs and tributaries to a variety of physical, chemical, and biological drivers, and to assess the ecological health of these water resources. A long-term record of water quality statistics 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 annual summary is intended to meet the needs of watershed managers, the interested public, and others whose decisions must reflect water quality considerations. The following pages summarize and discuss water quality monitoring methods, results, and major findings from all water quality and hydrologic monitoring activities carried out by DWSP in the Wachusett Reservoir Watershed and Reservoir during 2024. Additionally, some background information is included for context and programmatic status

[1] In most instances in this document DWSP is used to refer to DWSP-OWM-Wachusett/Sudbury Region

[2] Massachusetts Water Resources Authority [MWRA], 2014

[3] National Primary Drinking Water Regulations: Surface Water Treatment Rule (SWTR) - 40 CFR Part 141, Subpart H, 1989

[4] National Primary Drinking Water Regulations: Interim Enhanced SWTR (IESWTR) - 40 CFR Part 141, Subpart P, 1998

[5] Massachusetts Department of Conservation and Recreation [MassDCR] & MWRA, 2004

[6] Ibid

updates are provided to document changes in monitoring programs. Data generated from water quality monitoring in 2024 and prior years are available upon request.

The remainder of Section 1 provides an overview of the water quality regulations applicable to the water resources of the Wachusett Reservoir Watershed (hereafter also referred to as Wachusett Watershed or the Watershed), summarizes DWSP goals and objectives with respect to its water quality monitoring programs and includes an overview of the MWRA water supply system and Wachusett Reservoir Watershed. Section 2 presents methods for water quality monitoring programs in 2024, including an overview of monitoring locations, the parameters monitored and their manner of analysis, documentation of statistical methods and data management tools utilized, and a summary of quality assurance and control measures. Section 3 presents results for all Wachusett Watershed monitoring programs. Conclusions and recommendations are offered in Section 4, where significant findings are discussed and any proposed changes to Wachusett Watershed and Wachusett Reservoir water quality monitoring programs are presented. References are listed in Section 5 and additional information and data are provided in the appendices.

1.1 Public Water Supply System Regulations

Water quality criteria in the SWTR 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. There are two standards for turbidity levels at source water intakes. The SWTR requires that turbidity levels at the intake are always below 5.0 NTU[7]. Massachusetts Department of Environmental Protection (MassDEP) regulations require that turbidity levels at the point of consumption for all public drinking water always remain below 1.0 NTU[8]. Authority to enforce the SWTR has been delegated to MassDEP.

All waters within the Wachusett Watershed are designated as Class A Public Water Supply[9] and thereby are considered Outstanding Resource Waters for the purposes of water quality protection[10]. Massachusetts has developed numerical Class A water quality criteria for several parameters. These are presented in Appendix B: Water Quality Standards and Criteria along with the SWTR standards. Narrative criteria for Class A waters also exist for some parameters, including nutrients:

> *Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site-specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00.*[11]

There are other standards that apply to various elements and compounds in public drinking water supplies, such as arsenic, polychlorinated biphenyls (PCBs), haloacetic acids[12] and per- and polyfluoroalkyl substances (PFAS)[13]. The required monitoring for these substances at different stages in the system (i.e.,

[7] National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule, 2003
[8] Massachusetts Drinking Water Regulations, 2020a
[9] Massachusetts Surface Water Quality Standards, 2022f
[10] Ibid
[11] Massachusetts Surface Water Quality Standards, 2022d
[12] MWRA, 2012
[13] MWRA, 2023

after treatment, after disinfection, and point of consumption) is conducted by MWRA. Separate reports are produced by MWRA that detail the monitoring results and compliance for those parameters, therefore they are not discussed as part of this report[14].

1.2 DWSP Monitoring Program Goal and Objectives

MWRA, as an unfiltered public water supplier, is required to have a watershed protection program intended to promote and preserve high quality source water by using a range of methods and strategies that ultimately control the release, transport, and fate of pollutants in the Watersheds. A primary function of DWSP is to design and implement this watershed protection program for the MWRA-DWSP water supply system. Since 1991, DWSP has written periodic Watershed Protection Plans (WPP), which provide a systematic approach to evaluate potential water quality threats and develop programs that eliminate or minimize those threats. The current WPP was written in 2023 and covers fiscal years 2024 – 2028[15]. The broadly defined goal for water quality/quantity monitoring programs is:

> *Conduct tributary and reservoir sampling. Identify short-term water quality problems and maintain the historical record for long-term trend analyses. Use data analyses and assessments in management decisions.*

The data obtained from water quality and hydrologic monitoring programs are used to assess current water quality conditions, establish ranges of values for parameters considered normal or typical, screen for excursions from normal ranges, alert staff to potential contamination events, and assess watershed trends. Shorter term studies may be conducted to evaluate specific issues. These programs are re-evaluated with each iteration of the WPP to ensure that they are providing the breadth and depth of information necessary to evaluate the performance of DWSP water quality control programs. Specific water quality and hydrologic monitoring activities are also reviewed and updated by DWSP staff each year to incorporate new information or additional methods used to evaluate DWSP watershed protection programs. Efforts that do not yield useful information are modified or discontinued. Any programmatic changes that are recommended for water quality and hydrologic monitoring will be discussed in this and any future annual water quality reports. These data and information provide a meaningful foundation to inform management decisions to minimize or eliminate water quality threats.

The specific objectives of the water quality and hydrologic monitoring programs in Wachusett Watershed are directly related to the broader WPP goal listed above. These objectives are as follows:

- Maintain long-term water quality data and statistics.
- Document compliance with the EPA's SWTR requirements and criteria consistent with filtration avoidance.
- Identify streams and water bodies that do not meet water quality standards and initiate specific control measures to mitigate or eliminate pollution sources.
- Conduct proactive surveillance of water quality trends to identify emerging issues and support ongoing assessments of threats to water quality.
- Document quality assurance and quality control (QA/QC) metrics in annual water quality reports.

[14] MWRA, n.d.
[15] Division of Water Supply Protection [DWSP], 2023f

To meet these objectives, DWSP monitoring programs will continue to evolve as necessary by responding to emergent and high priority threats to water quality, making use of the best available scientific information, and implementing new tools and technologies. It is important to note that monitoring is just one element of a much larger watershed protection program carried out by DWSP. The achievement of water supply protection goals, including specific water quality targets, is dependent upon the coordinated implementation of each of DWSP's many watershed protection programs. For example, the 1992 Watershed Protection Act gives DWSP the authority to regulate certain land uses and activities that take place within critical areas of the Watershed to protect drinking water quality[16].

Coordination will continue with DCR's Office of Climate Resilience on climate related planning and project implementation. DWSP is partnering with Tighe and Bond via EEA Resilient Mass Project funding to complete a comprehensive DWSP-wide Climate Change Vulnerability Assessment that incorporates climate related impacts to important natural resources. DWSP will strive to utilize data collected internally as well as state level data to identify current impacts and assess projected future impacts. Staff will continue to monitor and evaluate climate change research and scientific literature, data, and recommendations.

1.3 MWRA System and Wachusett Watershed Overview

The Quabbin Aqueduct connects, from west to east, Quabbin Reservoir, the Ware River Watershed, and Wachusett Reservoir to provide drinking water to 53 communities in central and eastern Massachusetts. Quabbin Reservoir is the largest of the sources, with a capacity of 412 billion gallons (BG). Wachusett Reservoir holds 65 BG at full capacity (Table 1). The emergency backup Sudbury and Foss Reservoirs hold another 7.7 BG, combined[17].

[16] Watershed Protection, 2017
[17] MWRA, 2021a

Table 1: a) General Information on the Wachusett Reservoir, b) Wachusett Reservoir Watershed

Other protected lands include property identified by MassGIS as Open Space protected in perpetuity less DWSP, fee lands, and WPRs (WPR = Watershed Preservation Restriction, similar to a Conservation Restriction). Acreage may vary from previous years due to increased accuracy of MassGIS data. DWSP Controlled Area includes Watershed Preservation Restrictions.

a) Wachusett Reservoir General Information

Description	Quantity	Units
Capacity	65.7	Billion gallons
Surface Area at Full Capacity	4,147	Acres
Length of Shoreline	37	Miles
Maximum Depth	122	Feet
Mean Depth	49	Feet
Surface Elevation, at Full Capacity	395	Feet, relative to Boston City Base
Typical Operational Elevation	390.5	Feet, relative to Boston City Base

b) Wachusett Reservoir Watershed General Information[18]

Description	Quantity	Units	% Total Watershed or Land Area
Watershed Area	74,909	Acres	100%
Land Area	70,876	Acres	94.6%
Forest Area	47,142	Acres	67.0%
Forested + Non-forested Wetland	5,442	Acres	7.7%
DWSP Controlled Area	20,400	Acres	28.8%
Other Protected Area	12,263	Acres	17.2%

Water from Quabbin Reservoir is transferred to Wachusett Reservoir via the Quabbin Aqueduct Intake at Shaft 12, which outlets into the Quinapoxet River at Shaft 1 just upstream of the Quinapoxet Basin (Figure 1). Quabbin Reservoir water is also transferred directly to three western Massachusetts communities daily via the Chicopee Valley Aqueduct from the Winsor Dam Intake. Water from the Ware River may be used to supplement Quabbin Reservoir when water is diverted into the Quabbin Aqueduct at Shaft 8 in Barre, MA and delivered to Quabbin Reservoir via gravity flow. Ware River water enters the Quabbin 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 on diversions.

Water from the Wachusett Reservoir is withdrawn at the Cosgrove Intake in Clinton, MA and transferred to the John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough, MA via the Cosgrove or Wachusett Aqueduct. The treated water leaves the plant through the MetroWest Water Supply Tunnel and the Hultman Aqueduct where it enters the storage and distribution system and is ultimately delivered to greater Boston and MetroWest communities and businesses.

The Wachusett Reservoir Watershed is in central Massachusetts, east of the Ware River and north of Worcester, and covers 117 square miles (74,909 acres), predominantly west of the Reservoir. The headwaters of the Watershed (Stillwater and Quinapoxet River basins) are situated within the Worcester/Monadnock Plateau portion of the Northeastern Highlands ecoregion. This ecoregion (58g) is described as a “rolling plateau, with hills and monadnocks, numerous ponds, lakes, and reservoirs;

[18] DWSP, 2016

moderate gradient streams with bedrock, boulder, cobble, gravel, and sandy substrates"[19]. The eastern portion of the Watershed, including the Reservoir, lies within the Gulf of Maine Coastal Plain portion of the Northeastern Coastal Zone ecoregion. This ecoregion (59h) is defined as having rolling plains and hills with glacial drumlins, ponds, small lakes, and wetlands. Streams and large rivers have low to moderate gradients with sand, gravel, boulder, and bedrock substrates[20].

The Watershed landscape is spread across 12 towns, but lies predominantly in the towns of Boylston, Holden, Princeton, Rutland, Sterling, and West Boylston. The Stillwater and Quinapoxet Rivers are the largest tributaries to Wachusett Reservoir, collecting and delivering water draining from more than 80% of the Watershed land area. Approximately two-thirds of Watershed lands are forested, and DWSP owns or controls 20,400 acres (28.8%) of Watershed area for water supply protection purposes (Table 1b). Including the Reservoir, DWSP owns or controls 32.6% of the entire Watershed area, with an additional 17.2% protected by other government agencies and non-government organizations. Approximately 19% of Watershed lands are developed (residential, commercial, industrial/other land cover) while 4.4% is in agriculture. Additional information regarding land use and ownership in the Wachusett Reservoir Watershed is presented in the *Watershed Protection Plan FY24 – 28*[21] and the *2017 Land Management Plan*[22].

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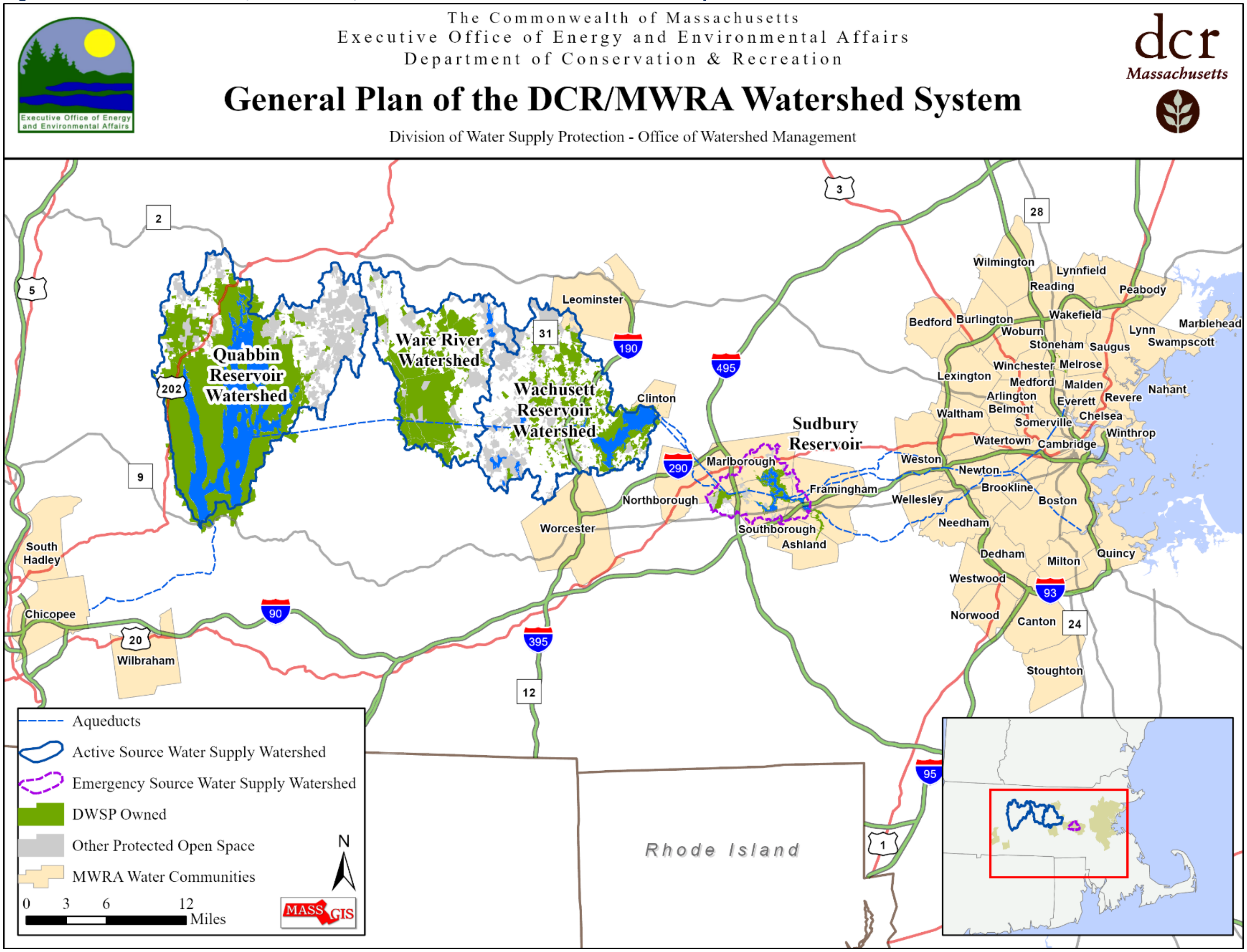
[19] Griffith et al., 2009
[20] Ibid
[21] DWSP, 2023g
[22] DWSP, 2018a

Figure 1: Quabbin Reservoir, Ware River, and Wachusett Reservoir Watershed System



2 Methods

This section provides an overview of how each element of DWSP water quality and hydrologic monitoring was carried out during 2024, including what parameters were sampled, their monitoring frequency and locations, and methods of analysis. Additional details and information about equipment and techniques used during monitoring activities can be found in standard operating procedures (SOPs) that have been developed for each monitoring activity. These SOPs are available upon request.

2.1 Monitoring Programs

DWSP water quality and hydrologic monitoring programs are reviewed annually and updated as necessary to meet changing priorities and public health concerns, as well as to incorporate newly developed analytical methods and revised regulatory requirements. DWSP monitoring activities can be grouped into three broad categories:

1. Water quality sampling: Water samples are collected and then analyzed in a laboratory.
2. *In situ* field measurements: Sensors are placed in water bodies briefly or for extended periods of time and take direct measurements of physical/chemical characteristics of the water; direct observations or measurements are made by field personnel.
3. External monitoring: Additional research and monitoring activities are conducted by other agencies and organizations related to water quality and hydrology within the Wachusett Watershed, with DWSP funding and direction.

2.1.1 Wachusett Watershed Monitoring Locations

DWSP staff collected routine water quality samples from seven groundwater wells, 20 tributary monitoring stations, and 27 stations on Wachusett Reservoir in 2024. These sampling locations (stations) are described in Table 2 (tributaries), Table 3 (reservoir) and Table 5 (groundwater). Figure 2 and Figure 3 maps show all routine monitoring locations within the Wachusett Watershed.

Tributary sampling locations are established on all major streams and rivers that flow into Wachusett Reservoir. To capture water quality and quantity data representing as much of the Watershed as possible, monitoring stations were positioned at the furthest downstream locations that were practical or convenient for sample collection (Figure 2). These stations, listed as *Primary* sampling locations in Table 2, are where stream discharge is monitored, and routine nutrient samples are collected. *Secondary* tributary stations are situated at upstream locations or on smaller tributaries to the major streams and rivers. Some sampling locations were established in areas where historical water quality problems were observed, on pristine streams to serve as reference sites, or to divide large drainage areas into smaller units. Twice monthly turbidity and bacteria sampling is conducted at all *Primary* and *Secondary* monitoring stations. Field parameters (water temperature, pH, dissolved oxygen, specific conductance) are measured during all routine tributary monitoring visits. Although it is not a natural tributary, Shaft 1 (Quabbin Transfer) is routinely sampled for nutrients because it comprises a large percentage of total surface water inflows to the Reservoir. There are two monitoring locations that were established in 2013 for a long-term forestry study.

Wachusett Reservoir sample locations include primary stations at which phytoplankton and water quality profiles are routinely collected and stations at which nutrients are collected quarterly from three depths. Details on these locations and selection thereof can be found in the SOPs for each type of sampling. General characteristics of each Reservoir sampling location are presented in Table 3. Bacteria sampling is conducted at 23 surface locations situated along transect lines covering the Wachusett Reservoir basins east of Rt. 140 (Figure 3).

Figure 2: Hydrology, Subbasins, and Water Quality Monitoring Locations for Calendar Year 2024 in the Wachusett Reservoir Watershed

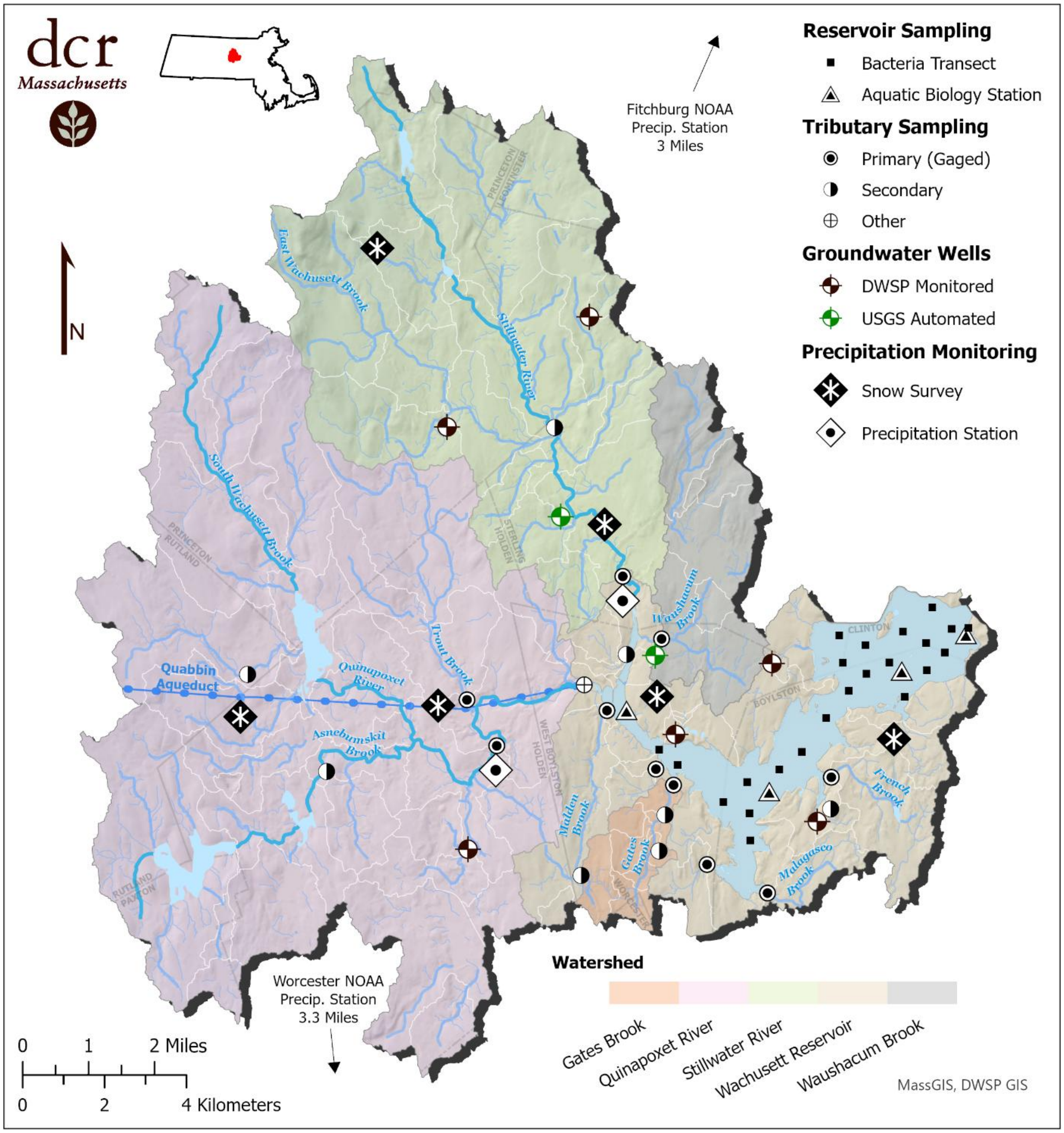


Table 2: Wachusett Tributary Sampling Locations, 2024

Location	Description	Sampling Category
Asnebumskit Brook (Princeton) - M102	Downstream of Princeton St. near post office, Holden	Secondary
Boylston Brook - MD70	Upstream of Rt. 70, Boylston	Secondary
Cook Brook - Wyoming - MD11	Wyoming Dr., Holden	Secondary
East Wachusett Brook (140) - MD89	Downstream of Rt. 140, Sterling	Secondary
French Brook - MD01	Downstream of Rt. 70, Boylston	Primary
Gates Brook 1 - MD04	Downstream of bridge inside Gate 25, West Boylston	Primary
Gates Brook 4 - MD73	Upstream of Pierce St., West Boylston	Secondary
Holden Forestry - FHLN	Off Mason Rd. inside Gate H-21, Holden	Long-term Forestry
Jordan Farm Brook - MD12	Upstream of Rt. 68, Rutland	Secondary
Malagasco Brook - MD02	Downstream of W. Temple St. Extension, Boylston	Primary
Malden Brook - MD06	Upstream of Thomas St., West Boylston	Primary
Muddy Brook - MD03	Upstream of Rt. 140, West Boylston	Primary
Oakdale Brook - MD80	Downstream of Waushacum St. and East of Rt. 140, West Boylston	Secondary
Princeton Forestry - FPRN	Off Rt. 31 near Krashes Field, Princeton	Long-term Forestry
Quinapoxet River (Canada Mills) - MD69	Upstream of River St. bridge (Canada Mills), Holden	Primary
Scarlett Brook (DS W.M.) - MD81	Behind Walmart above confluence with Gates Brook, West Boylston	Secondary
Shaft 1 (Quabbin Transfer) - MDS1	MWRA Shaft 1 outlet off River St., West Boylston	Other
Stillwater River - Muddy Pond Rd - MD07	Downstream of Muddy Pond Rd., Sterling	Primary
Trout Brook - M110	Downstream of Manning St., Holden	Primary
Waushacum Brook (Prescott) - MD83	Upstream of Prescott St., West Boylston	Primary
West Boylston Brook - MD05	Upstream of access road inside Gate 25, West Boylston	Primary

Figure 3: Wachusett Reservoir Sampling Locations

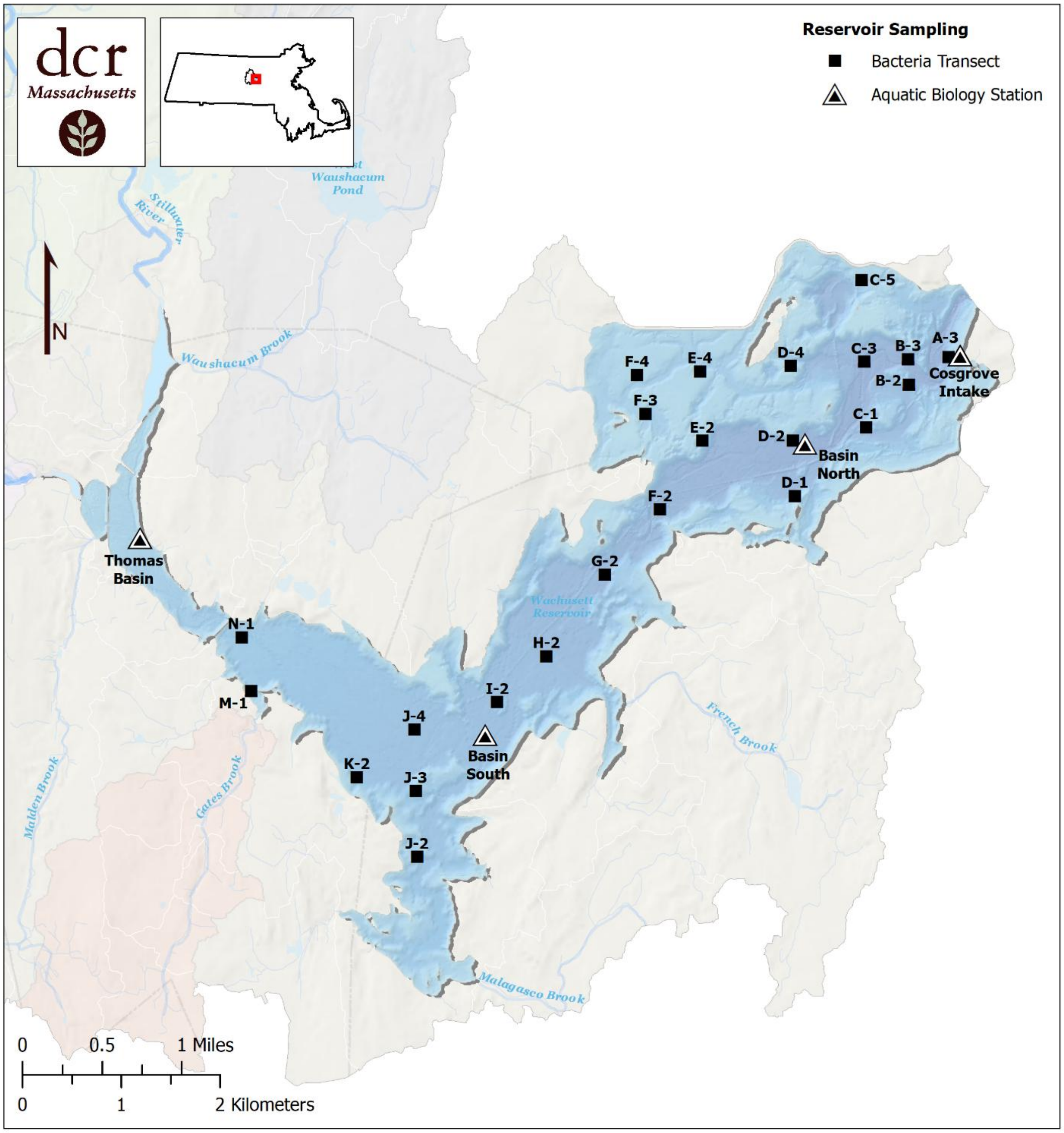


Table 3: Wachusett Reservoir Sampling Locations
Depth is at normal operating elevation of 390.5 Boston City Base (BCB).

Station (Id)	Location Description	Approximate Depth (m)	Frequency: Plankton/profile	Frequency: Nutrients
Cosgrove Intake (CI3409)	Adjacent to Cosgrove Intake, samples collected from the building catwalk	18	Weekly	N/A
Basin North (BN3417)	Mid reservoir near Cunningham Ledge	30	Weekly	Seasonally
Basin South (BS3412)	Mid reservoir near Scar Hill Bluffs	27	Occasionally	Seasonally
Thomas Basin (TB3727)	Thomas Basin at approximate intersection of Quabbin interflow/Quinapoxet River and Stillwater River	10	Occasionally	Seasonally

2.1.2 Meteorologic and Hydrologic Monitoring

2.1.2.1 Precipitation and Air Temperature

DWSP monitors precipitation and uses this information to provide context for the water quality and hydrological conditions observed in the tributaries, groundwater, and Reservoir. The type, amount, intensity, frequency, and spatial distribution of precipitation (or snowmelt) across the landscape are the dominant drivers of the water quality and hydrologic dynamics. It is important for DWSP to consider this hydrological context when interpreting water quality results, comparing interannual variability, or evaluating trends.

DWSP contracts with the U.S. Geological Survey (USGS) New England Water Science Center out of Northborough, MA for precipitation monitoring at two locations: the Stillwater River – MD07 (USGS 01095220) and the Quinapoxet River – MD69 (USGS 01095375) (Table 4). The National Oceanographic and Atmospheric Association (NOAA) monitors precipitation at two locations situated a few miles outside of the Wachusett Watershed to the south in Worcester (NOAA USW00094746) and to the north in Fitchburg (NOAA USW00004780) (Figure 4). DWSP acquires daily precipitation totals from both NOAA and USGS servers using Application Programming Interfaces (APIs) and automated scripts. There are several other entities monitoring meteorological parameters in the Wachusett Watershed, however the USGS and NOAA have more rigorous quality controls for data products than any other source of local meteorological data, so these four stations are used for calculating average watershed precipitation.

Table 4: Wachusett Watershed Meteorological Stations

Station Name	Owner	Gage Number	Period of Record	Data Collected
Worcester	NOAA	USW00094746	1892 - Present	Precipitation, Air temperature
Fitchburg	NOAA	USW00004780	1998-04-01 - Present	Precipitation, Air temperature
Stillwater	USGS	01095220 (MD07)	2000-06-01 - Present	Precipitation
Quinapoxet	USGS	01095375 (MD69)	2012-10-01 - Present	Precipitation
Waushacum Brook	DWSP	MD83	2017-08-03 - 2023-11-03	Air temperature
West Boylston Brook	DWSP	MD05	2023-11-03 - Present	Air temperature
Princeton Forestry	DWSP	FPRN	2017-01-03 - Present	Air temperature

Since 1985, the Wachusett Watershed average annual precipitation is 47.3 inches, with a historical low of 35.4 inches (2001) and high of 64.4 inches (2023). Average monthly precipitation ranges from 2.97 inches (February) to 4.76 inches (October). Large precipitation events (> 2 inches) typically occur several times per year, usually related to localized summertime thunderstorms or larger tropical storms and hurricanes that track the eastern coast of the USA after originating in and around the equatorial North Atlantic Ocean (e.g., Gulf of Mexico, Caribbean Sea). These events often cause noteworthy responses in stream flows and solute loads and can lead to a series of cascading ecological responses in aquatic environments. Likewise, drought conditions can lead to adverse ecological consequences as some solutes can become concentrated and aquatic habitat can become diminished or degraded.

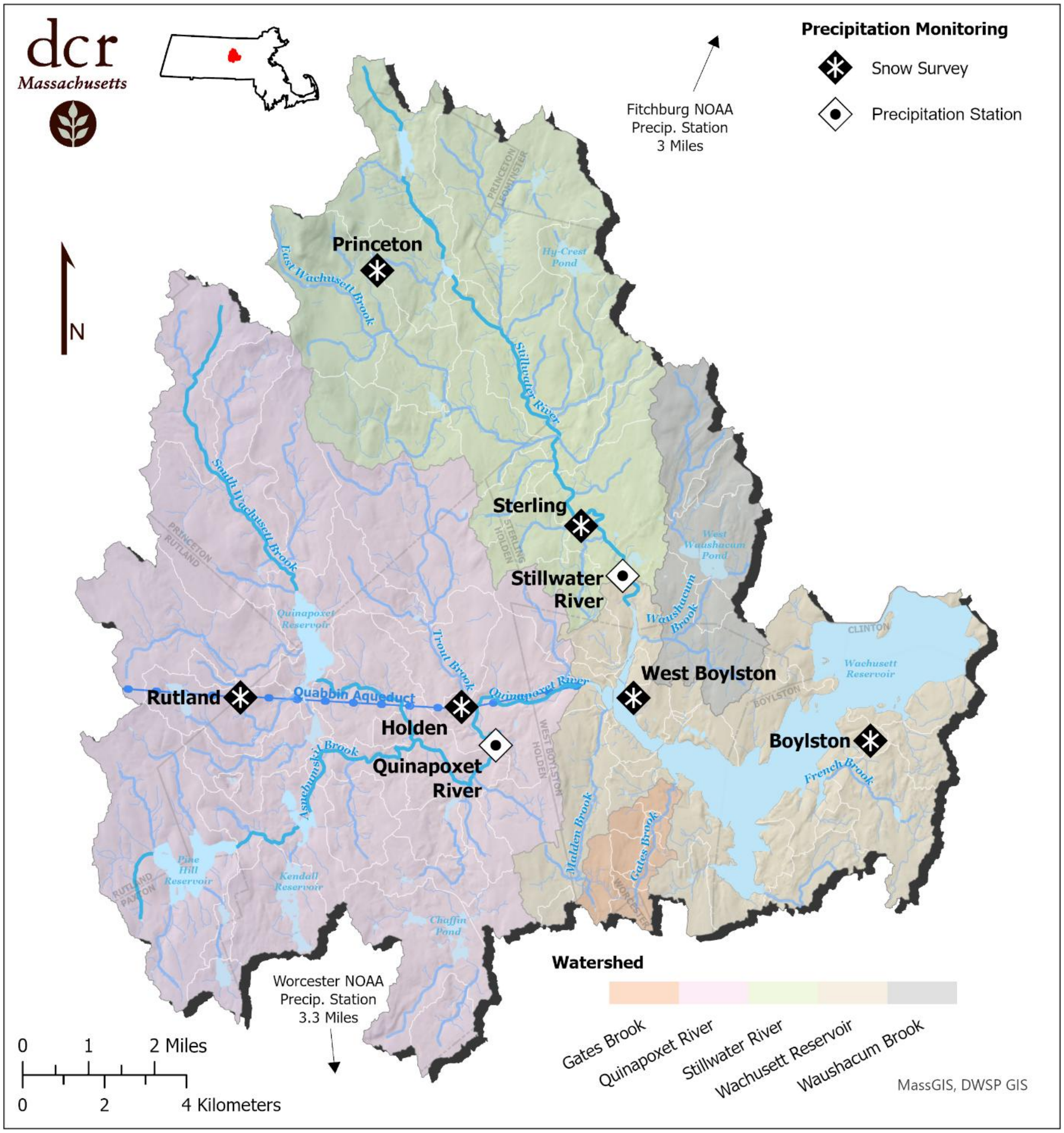
Effectively managing Wachusett Reservoir water storage volume requires an accurate prediction of water inputs to the Reservoir which are derived from new precipitation and/or melting of past precipitation stored in the snowpack. Therefore, DWSP carries out a snowpack monitoring program to track the water content of the snowpack and document any changes resulting from melt, evaporation, and sublimation, so that future water inputs to the Reservoir can be modeled and estimated.

Wachusett Reservoir Watershed snowpack is measured weekly throughout the winter unless there is not enough snow to obtain reliable measurements. DWSP measures snowpack at six locations (Figure 4) with varied altitudes, aspects, and cover types to capture the variability of snowpack across the Watershed. At each location five snow core samples are taken, the depth of the snow is recorded, and each core is weighed to determine its snow water equivalent (SWE) (see Section 3.1.1.2 for results). These measurements are averaged by location and then reported to the NOAA National Operational Hydrologic Remote Sensing Center (NOHRSC). NOHRSC uses these data along with other weather conditions and forecasts to predict near-term changes to river flows and provide flood threat information to the public. MWRA uses watershed snowpack measurements to predict future inputs to the Reservoir from melt water.

Air temperature is a meteorological parameter which has important implications for both water quality and the seasonal timing of water inputs to the Reservoir. Air temperatures determine if precipitation falls in liquid or frozen form. It is therefore a key factor in winter snowpack development and controls its subsequent melt. Heat exchange over time between the atmosphere and water at various stages of the water cycle (both gain and loss) drives seasonal water temperature fluctuations in both tributaries and the Wachusett Reservoir. Water temperature plays a significant role in aquatic ecology (see Appendix C: Watershed Monitoring Parameters and Historical Context), and seasonal ice formation on the Reservoir (see Section 3.4.1).

Daily air temperature statistics are recorded by NOAA at the precipitation stations discussed earlier in this section. Additionally, DWSP has two atmospheric sensors recording air pressure and temperature at 15-minute intervals. These stations and their periods of record are listed in Table 4.

Figure 4: Active Precipitation Monitoring Stations in the Wachusett Reservoir Watershed



2.1.2.2 Hydrologic Monitoring

Streamflow

Monitoring of stage (water level) and discharge (flow) has been conducted at primary tributary sampling locations for more than two decades using both manual and automated methods. The USGS was responsible for the development and maintenance of stage-discharge relationships at these locations and continues to operate three stations (Quinapoxet River – 01095375, Stillwater River – 01095220, and Gates Brook – 01095434) using continuous monitoring technologies. Continuous data (15-minute increments) from the Stillwater and Quinapoxet Rivers have been collected since 1994 and 1996, respectively. Stage data from Gates Brook were collected manually from 1994 until December 2011 when the station was upgraded with new sensors and equipment to collect stage, temperature, and conductivity data at 10-minute increments. All data and details about USGS monitoring methods and equipment for these stations can be found on the National Water Data for the Nation (WDFN) website[23]. Responsibility for streamflow monitoring on the other primary tributaries was transferred to DWSP towards the end of 2011.

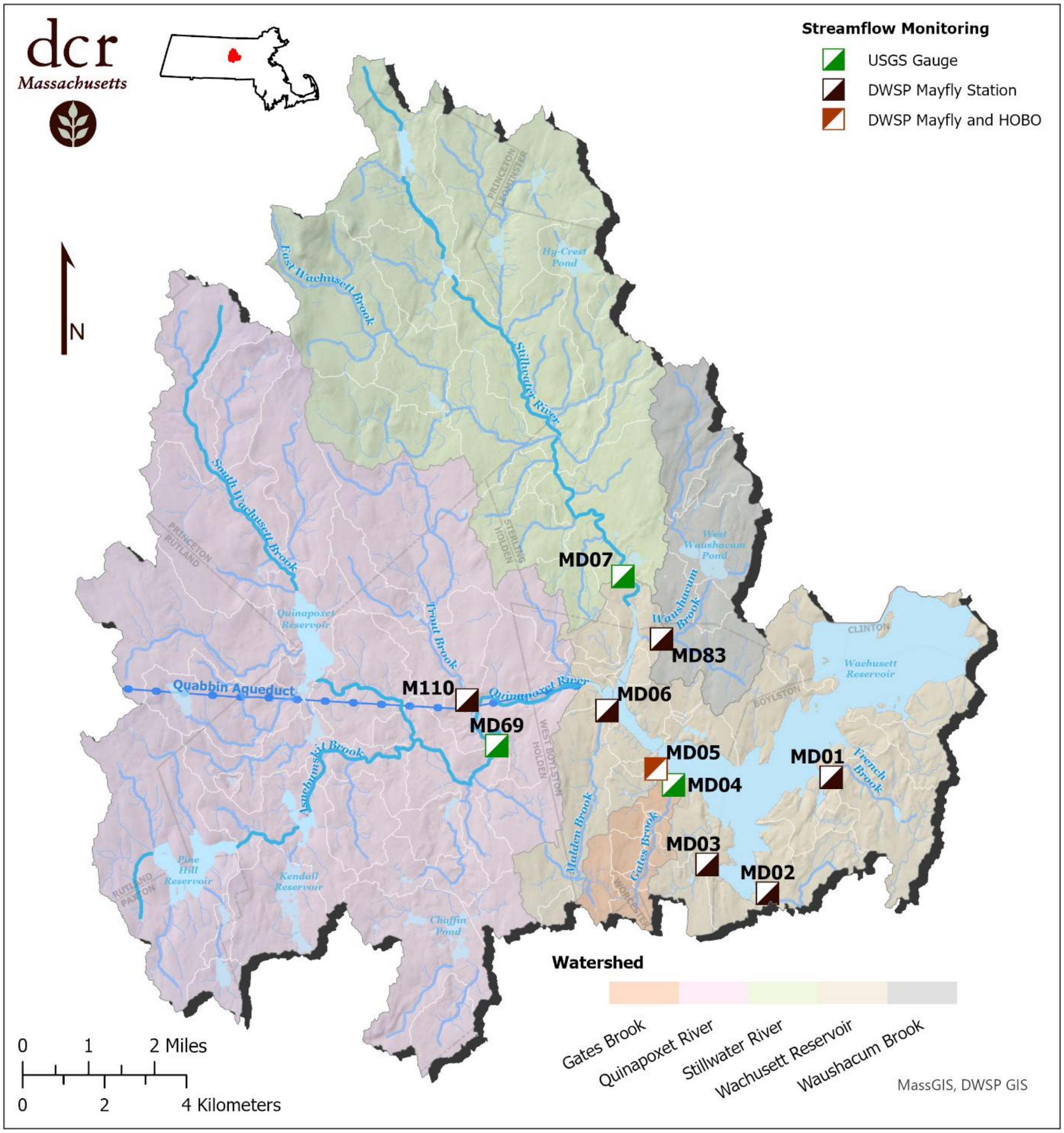
At the seven DWSP flow monitoring stations (Figure 5) visual observations of stream depth (stage) is recorded from staff plates during all sampling visits (typically three times per month). Manual stage measurements were supplemented by continuous depth recordings using HOBO water level data loggers starting in 2013. Unfortunately, data management issues have prevented reliable use of HOBO data prior to 2017. Additionally, prior to 2017, HOBO devices were removed from streams in winter months due to concerns over freezing. This issue was resolved in late 2017 and HOBO devices are now in service year-round.

New real-time monitoring instrumentation was added to the Waushacum Brook monitoring station in 2019 to pilot a viable replacement for aging Onset HOBO dataloggers. The equipment utilizes a Mayfly datalogger[24], which allows for the connection of several types of water quality probes, as well as cellular transmission of data to a cloud-based data storage server with built-in visualization tools. Data for this station can be viewed publicly[25]. Due to the increased interest in collecting additional specific conductance/Cl data this pilot station was outfitted with a Hydros21 CTD sensor manufactured by Meter Group, Inc., which measures specific conductance, water temperature, and water depth. This pilot project was determined to be successful and Mayfly units were deployed at five additional monitoring locations in December 2021. One final Mayfly station was installed at Trout Brook in 2023. Additional details about continuous stream flow monitoring are provided in the DWSP *SOP for the Monitoring of Continuous Stream Flow*[26].

Reliable stage-discharge relationships (ratings) allow the use of easily acquired stream depths to quickly estimate discharge. Direct flow measurements (discharge measurements) at a range of depths are usually performed several times during the year using a Sontek FlowTracker handheld acoustic doppler velocimeter. A rating equation is calculated after enough discharge measurements are obtained at a tributary, which is subsequently used to derive discharge as a function of stage. Additional details about stream discharge measurements are provided in the DWSP *SOP for the Monitoring of Stream Discharge*[27].

[23] United States Geological Survey [USGS], 2025c
[24] Ensign et al., 2019
[25] DWSP, 2025b
[26] DWSP, 2023c
[27] DWSP, 2021c

Figure 5: Streamflow Monitoring Locations in Wachusett Reservoir Watershed



Reservoir Elevation

Wachusett Reservoir elevation is controlled by MWRA, which manages aqueduct transfers and outflows to maintain a water surface elevation within the normal operating band between 390 and 391.5 ft when the Reservoir surface is not completely frozen over. During full ice over conditions the normal operating band lower elevation is reduced to 388 ft to accommodate large inputs from snow melt in the early spring. Water from Quabbin Reservoir is typically transferred to Wachusett Reservoir during the months of increased water demand (summer – fall), and/or as necessary to keep the Reservoir within its normal operational elevation in conjunction with drinking water withdrawals and other releases. Occasionally there are deviations in elevation due to large storm events or planned drawdowns. DWSP relies on reservoir elevation data collected by MWRA, which are available in real-time (15-minute increments), but typically presented as daily average elevation.

Groundwater Levels

Groundwater resources are important to the management of Wachusett Reservoir and tributaries due to base flow contributions to the tributaries and direct inflow to the Reservoir. Research by USGS hydrologists in the Housatonic River Basin in Berkshire County, Massachusetts found that base flow contributions represented 55 to 80 percent of total annual streamflow[28]. Base flow contributions in Wachusett Watershed streams are likely to be of comparable proportions due to similar surficial geology. Long-term measurement of the depth to groundwater throughout various Wachusett Watershed aquifers can yield useful information about seasonal and interannual fluctuations in groundwater storage.

In 2024, DWSP continued its groundwater quality monitoring program that began in 2019 to collect additional specific conductance/Cl data in response to observed increases in tributary specific conductance in the Wachusett Watershed (Figure 6). Water levels are measured as part of this groundwater monitoring effort. A total of seven wells are sampled by DWSP, six of which were previously monitored by USGS and have historical water level data. An eighth well (MDW8, USGS Code: 422201071530201) was sampled from 2019 to 2022 but was discontinued before 2023 sampling began because the narrow diameter prevented the collection of the full suite of parameters collected in other wells. The periods of historical data and other summary information about the wells sampled in 2024 by DWSP and USGS are presented in Table 5.

Table 5: Wachusett Groundwater Well Information

DWSP Code	Well Name	USGS Code	Type	Depth Below Ground Surface (ft)	Elevation (ft)	USGS Period of Record
MDW1	Holden - Wachusett St	422102071501401	Dug	10.09	670	1995 – 2002
MDW2	Boylston - Rt 70	422125071440101	Augered	12.53	475	1995 – 2002
MDW3	West Boylston - Gate 27	N/A	Augered	15.13	403	N/A
MDW4	West Boylston - Rt 110	422334071444201	Augered	31.26	525	1995 – 2002
MDW5	Sterling - Justice Hill Rd	422805071480801	Dug	19.52	710	1947 – 2015
MDW6	Princeton - Rt 62	422636071503601	Augered	20.73	695	1995 – 2002
MDW7	Sterling - Rt 140	422520071483001	Augered	26.91	505	1995 – present
WSW26	West Boylston - Prescott St	422341071464901	Augered	16.80	485	2012 – present

Manual measurements of depth to groundwater to the nearest one-hundredth inch were made with a Geoteck KECK water level meter, which is calibrated by USGS every two years. USGS maintains automated groundwater observations in the Sterling - Rt 140[29] and West Boylston - Prescott St[30] wells, which record

[28] Bent, 1999
[29] USGS, 2025a
[30] USGS, 2025b

groundwater levels every 15 minutes. Additional details about groundwater level monitoring are provided in the DWSP *SOP for the Monitoring of Groundwater (WATWEL)*[31].

2.1.3 Groundwater Quality Monitoring

Groundwater quality can differ drastically between and within groundwater aquifers. This water resource is a major component of the Wachusett Watershed water budget. DWSP groundwater quality monitoring began in 2019 with specific conductance, temperature, and chloride data collection (Figure 6). MWRA assigned the project code "WATWEL" for groundwater parameters requiring laboratory analysis. This list of parameters was expanded for one year, from May 2021 to April 2022, to include concentrations of alkalinity, sulfate, fluoride, bromide, calcium, magnesium, sodium, and nitrate. In April 2022, DWSP began using a flow cell, which enables the collection of data with a YSI ProQuatro probe. Groundwater quality parameters collected from April 2022 through 2024 include specific conductance, temperature, pH, and dissolved oxygen.

Prior to sample collection, groundwater wells were purged at a constant flow rate using a submersible pump until temperature and specific conductance readings stabilized over three consecutive five-minute intervals. This method[32] ensures the samples were representative of the surrounding groundwater. Two wells (Holden – Wachusett St and Sterling – Justice Hill Rd) are dug wells and therefore unable to be fully purged due to the large volumes of water they contain. Additional details about groundwater quality monitoring are provided in the DWSP *SOP for the Monitoring of Groundwater (WATWE*L)[33].

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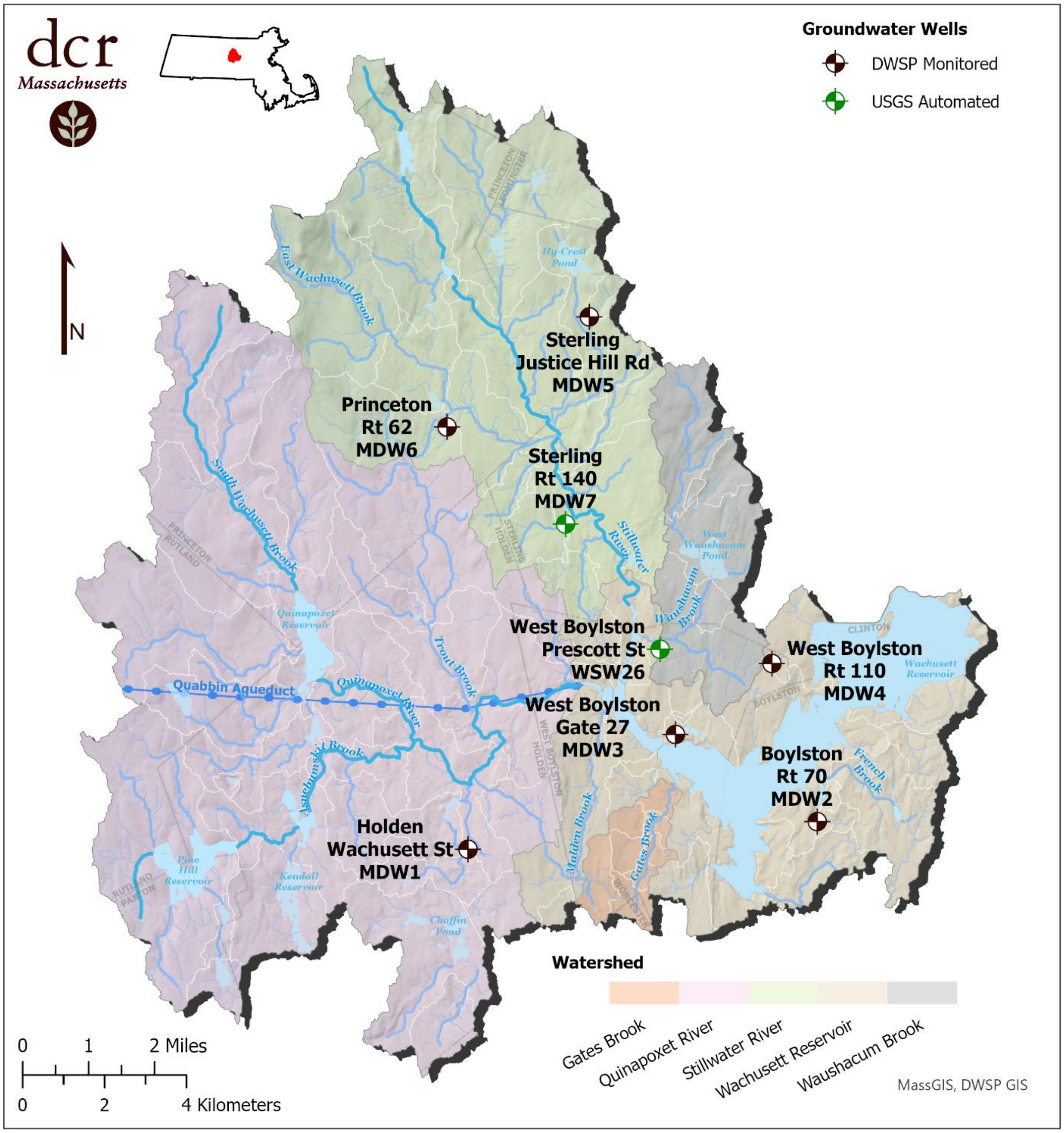
31 DWSP, 2021b
32 United States Environmental Protection Agency [USEPA], 2017
33 DWSP, 2021b

Figure 6: DWSP Groundwater Monitoring Wells in Wachusett Reservoir Watershed
Well MDW7 was converted into an automated well by USGS in November 2022.



2.1.4 Tributary Monitoring

The principle tributary monitoring programs are divided into two groups: 1) Routine tributary monitoring for bacteria and turbidity (MWRA project code WATTRB) and 2) Nutrient and total suspended solids (TSS) monitoring (MWRA project code WATMDC, referred to as 'nutrient monitoring'). Other tributary monitoring occurs at the two long-term forestry (LTF) project study locations (MWRA project code WATBMP) (Figure 7). *In situ* measurements for physiochemical parameters (field parameters) are also taken in conjunction with all tributary monitoring visits. Field parameters are measured with a YSI

ProQuatro multi-sensor meter and include water temperature (°C), specific conductance (µS/cm), dissolved oxygen (mg/L), and hydrogen ion activity (pH) (S.U.). Stage is recorded at the ten primary tributary monitoring locations (Table 2) so that parameter concentrations/values have corresponding flow data to aid in interpretation of results and allow for solute loading estimates to be calculated.

2.1.4.1 Routine Tributary Monitoring

In 2024, routine water quality samples for bacteria, turbidity, and field parameters were collected from 18 locations on 17 tributaries. Each tributary location was visited twice per month throughout the entire year (Table 2 – Primary and Secondary). Discrete water samples were collected for analysis of *Escherichia coli* (*E. coli*) and measurement of turbidity. All *E. coli* samples were delivered to the MWRA Southborough lab for analysis within six hours of sample collection. Turbidity samples were analyzed in the field using a HACH 2100Q portable turbidimeter or in the lab with a HACH 2100N laboratory turbidimeter. Samples were occasionally collected from additional locations to investigate water quality problems discovered during environmental assessments or investigations. Follow-up samples were sometimes collected after detecting elevated bacteria concentrations to determine if bacteria sources were persisting. Additional details about routine tributary monitoring are provided in the DWSP *SOP for the Monitoring of Tributary Bacteria and Turbidity (WATTRB)*[34].

2.1.4.2 Nutrient Monitoring

In 2024, routine nutrient monitoring was conducted monthly at 10 tributary monitoring stations, typically during the second week of the month. The parameters for this project include: alkalinity[35], ammonia-nitrogen (NH_3-N), chloride (Cl), mean UV absorbance at 254 nm (henceforth referred to as UV_{254} for simplicity), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), total phosphorus (TP), and total suspended solids (TSS). All samples were analyzed at the MWRA lab on Deer Island in Winthrop, MA. Nutrient measurement units are all mg/L except for UV_{254}, which is reported in ABU/cm, and TP which was converted from mg/L to µg/L due to its low concentrations. Since the Quabbin Transfer comprises such a significant volume of water to Wachusett Reservoir, Shaft 1 is sampled for nutrients as well, usually monthly (when flowing). All primary tributaries were sampled 12 times for nutrients in 2024. The Quabbin Transfer was sampled six times in 2024 (May – October, December). Results from all tributary sampling programs are discussed in Section 3.2. Additional details about how nutrient samples are collected are provided in the DWSP *SOP for the Monitoring of Tributary Nutrients (WATMDC)*[36].

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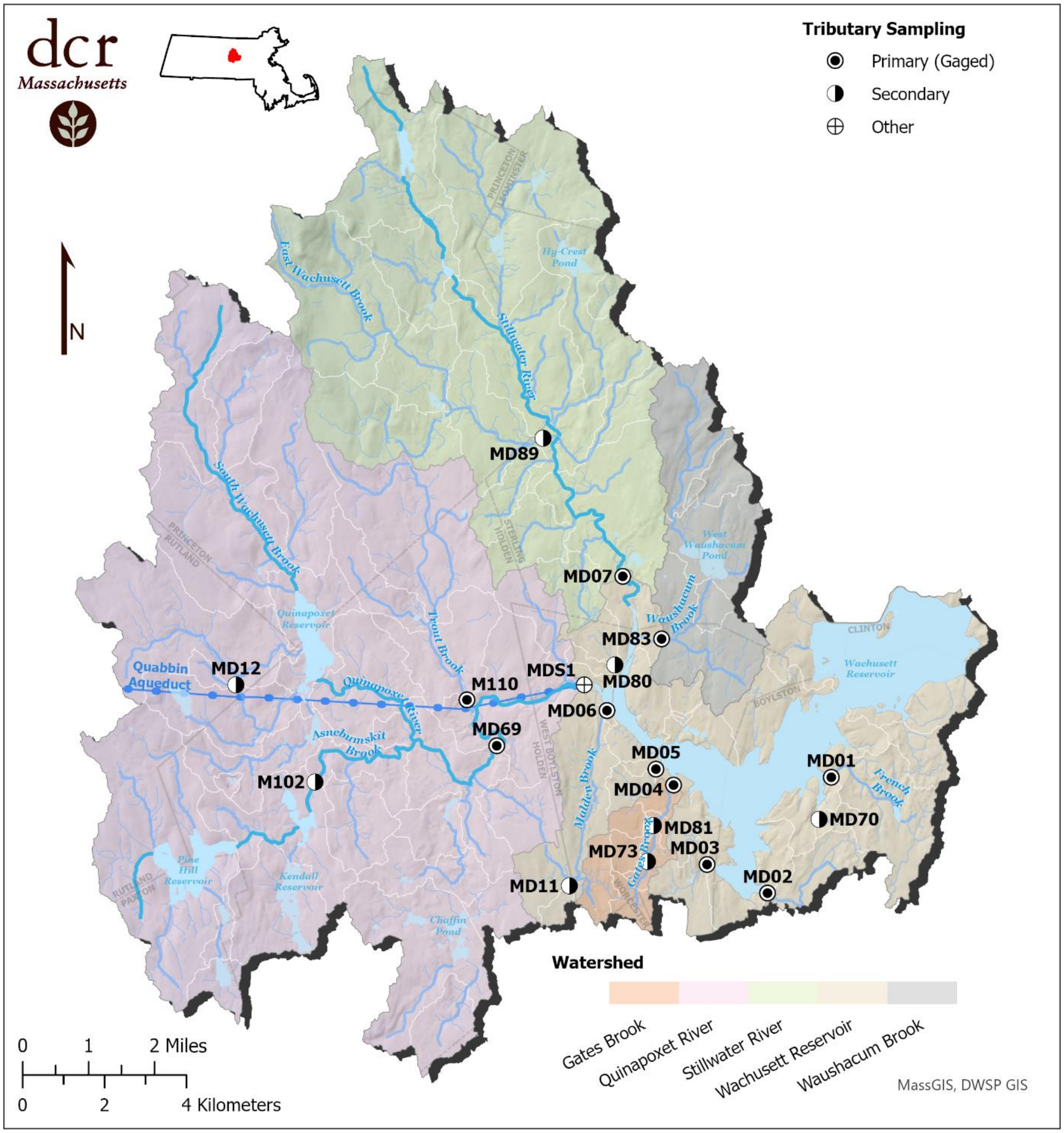
[34] DWSP, 2023e
[35] Alkalinity sampling was resumed at all primary tributary locations in September 2020
[36] DWSP, 2023d

Table 6: 2024 Tributary Monitoring Program Components

Sample counts with a single asterisk are analyzed for multiple parameters at the MWRA lab at Deer Island.

Program Name	MWRA Project Code	Parameters	Sampling Frequency	Sample Locations	# Samples/ Measurements Collected in 2024
Nutrients	WATMDC	NH_3-N, NO_2-N, NO_3-N, TKN, TP, TSS, TOC, UV_{254}, Cl, Alkalinity	Monthly	Primary, Other	127*
Bacteria and Turbidity	WATTRB (Only for bacteria)	*E. coli*, turbidity	Twice per Month	Primary, Secondary	421 (*E. coli*) 421 (turbidity)
Field Parameters (physical and chemical)	N/A	Water temperature, dissolved oxygen, pH, specific conductance	1-3 times per month/location in conjunction with WATMDC and WATTRB projects	Primary, Secondary, Other	2,188
Field Parameters (hydrology)	N/A	Stage	3 or more times per month	Primary	360
Long-term Forestry	WATBMP	NH_3-N, NO_2-N, NO_3-N, TKN, TP, TSS, TOC, UV_{254} + Field Parameters	Monthly dry weather /Quarterly Storms	LTF	2 (dry weather)* 12 (storm)*

Figure 7: Tributary Sampling Locations in the Wachusett Reservoir Watershed



2.1.5 Reservoir Monitoring

Monitoring of Wachusett Reservoir includes collection of *in situ* measurements, collection and analysis of water samples for plankton, nutrients, and bacteria, as well as collection or observation of other flora and fauna inhabiting the Reservoir (Table 7). Details of each program are provided below.

When the Reservoir is thermally stratified and water is being transferred from Quabbin Reservoir, an interflow is established between Shaft 1 and the Cosgrove Intake. This interflow layer is comprised of a higher percentage of water from Quabbin Reservoir, indicated by lower specific conductance values, than those of native Wachusett Watershed water. The timing and duration of the interflow has important implications on water quality entering the system. Therefore, tracking the progress of this layer is an important component of reservoir monitoring. More details can be found in this section and in Sections C-8 and C-12.

Table 7: 2024 Reservoir Monitoring Program Components

Sample counts with a single asterisk are analyzed for multiple parameters at the MWRA lab at Deer Island.

Program Name	MWRA Project Code	Parameter or Analysis	Typical Sampling Frequency	Sample Locations	# Samples Collected in 2024
Profiles	N/A	Water temperature, specific conductance, chlorophyll *a*, phycocyanin, dissolved oxygen, pH	Weekly (May – Sept), biweekly (Oct – April)	Primary: BN3417, CI3409, Secondary: BS3412, TB3427, other	48
Phytoplankton	N/A	Phytoplankton density	Weekly (May – Sept), biweekly (Oct – April)	Primary: BN3417, CI3409, Secondary: BS3412, TB3427, other	119
Nutrients	MDCMTH	Alkalinity, NH_3-N, NO_3-N, Silica, TKN, TP, UV_{254}	Seasonally (4x)	BN3417, BS3412, TB3427	36*
Bacteria	WATTRN	*E. coli*	Monthly (minimum)	23 transect stations	288
Macrophytes	N/A	Species present, location, density	Throughout growing season	Entire reservoir	N/A
Zooplankton	N/A	Population screening	Quarterly (4x)	BN3417, BS3412, TB3427	48
Salvelinus namaycush (Lake Trout)	N/A	Species, length, weight	Multiple sample trips during fall spawn	Entire reservoir – spawning locations	See Section 3.4.10

2.1.5.1 Water Quality Profiles

DWSP staff routinely record water column profiles in Wachusett Reservoir using a YSI EXO2 multi-parameter sonde for the following parameters: temperature, specific conductance, dissolved oxygen concentration, percent oxygen saturation, chlorophyll *a*, phycocyanin, turbidity, and pH. Data are recorded with a handheld display connected to the sonde with a 33-meter cable, starting at the surface. Measurements are recorded at 0.5 to 1-meter intervals or more frequently, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column. Detailed procedures are contained in the DWSP *SOP for Collection of Reservoir Profiles*[37].

[37] DWSP, 2020b

A total of 43 profiles were collected from four locations in 2024. These included 12 profiles collected in conjunction with reservoir nutrient monitoring.

Three remote sensing profiling buoys have been deployed annually by MWRA starting in 2016. In 2024 these buoys corresponded to DWSP routine sampling sites at Basin South and Basin North. An additional profiling buoy was placed outside of Cosgrove Intake. Profiles are collected with YSI EXO2 sondes identical to those used by DWSP. The profilers automatically run every 6 hours (12am, 6am, 12pm, and 6pm) and collect data at 1-m increments. The data can be remotely viewed shortly after collection via the MWRA Operations Management Monitoring System (OMMS) website. Results are used by DWSP to augment the routine profile/plankton 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 allow 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.

2.1.5.2 Nutrient Monitoring

Sampling for assessment of nutrient dynamics was conducted in May at the onset of stratification, July in the middle of the stratification, near the end of the stratification period in October, and following turnover in November. These samples were collected at three routine locations: Basin North (BN3417), Basin South (BS3412), and Thomas Basin (TB3427) (Figure 3). Grab samples were collected from three depths representative of specific stratification layers during the stratified period and from the surface, middle, and bottom of the water column during periods of isothermy. These collections resulted in a total of 252 nutrient samples which were analyzed by MWRA staff at the Deer Island Central Laboratory for the following: NH3-N, NO3-N, TKN, Silica, TP, and UV_{254}. Details of the sampling protocol are provided in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics[38] and in the DWSP *SOP for Collection of Reservoir Nutrients*[39].

2.1.5.3 Bacteria Monitoring

Bacteria transect samples (*E. coli*) are collected routinely (at least monthly) during ice-free conditions at 23 fixed surface locations on the Reservoir (Figure 3). These samples are collected to document the relationship between seasonal bacteria variability and visiting populations of gulls, ducks, geese, cormorants, and swans. Samples are collected at higher frequencies (up to weekly) during periods when waterfowl are present in higher numbers and the bird harassment program is active. All samples are by the MWRA lab in Southborough, MA. MWRA has designated project code "WATTRN" for Wachusett Reservoir bacteria sampling.

2.1.5.4 Phytoplankton Monitoring

Routine monitoring for phytoplankton follows a seasonal schedule with samples collected every other week from October through April and at least once per week from May through September. Sampling frequency may intensify in response to increases in density of specific phytoplankton genera (see Section C-18, Table C-1), or decrease when conditions such as ice cover physically prevent sampling. Monitoring by DWSP staff takes place at either Basin North (BN3417) or at the Cosgrove Intake Facility (CI3409) with additional locations sampled as necessary to characterize the phytoplankton community present throughout the Reservoir (Figure 3). Grab samples are typically collected from at least two depths

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[38] Worden & Pistrang, 2003
[39] DWSP, 2020a

including an epilimnion sample at 3 m and (during stratification) a metalimnion sample. The exact depth of the latter is typically selected based on results of a water column profile collected in conjunction with phytoplankton sample collection. Chlorophyll *a* data obtained from the Reservoir profile are typically used to select the discrete metalimnion sample depths, typically corresponding to depths where chlorophyll *a* values are highest. More information on sampling protocols and details of phytoplankton sample collection and enumeration may be found in the following DWSP SOPs: *SOP for Collection of Reservoir Profiles*[40], *Phytoplankton Collection and Reporting*[41] and *Microscopic Enumeration of Phytoplankton*[42].

In 2024, phytoplankton monitoring was carried out on 40 days, resulting in 119 individual samples. Twenty-four of these samples were analyzed solely for taxa of concern (see Section C-18, Table C-1); the entire phytoplankton community was assessed in the remainder.

2.1.5.5 Zooplankton Monitoring

Quarterly collection of zooplankton samples was conducted in conjunction with nutrient sampling as described above. A total of 48 samples were field preserved with 70% ethanol. Entire water column samples collected during each sample event from each site were scanned by DWSP aquatic biologists for invasive species, specifically *Bythotrephes longimanus* (spiny waterflea) and *Cercopagis pengoi* (fishhook waterflea). Details of zooplankton sample collection are documented in the DWSP *SOP: Collection of Reservoir Zooplankton*[43].

2.1.5.6 Macrophyte Monitoring

Frequent assessments of the aquatic vegetation community in and around Wachusett Reservoir are made as part of the invasive macrophyte control program. Monitoring takes place throughout the growing season, typically May through October, and may include visual surveys conducted via boat, in-water assessments via snorkeling, and collection of vegetation biovolume data with boat-based sonar. Related activities undertaken by DWSP staff include maintenance of floating fragment barriers; inspection of boats and other vessels deployed to the Reservoir by contractors, emergency personnel, and others; oversight of aquatic invasive species (AIS) management programs in collaboration with MWRA: and management of *Phragmites australis* along the Reservoir shoreline. The *P. australis* management program takes place from June through October and involves physical and mechanical methods of control, coupled with photographic documentation of management progress.

Surveys in 2024 were conducted in support of ongoing management programs including physical AIS management in the Reservoir and management programs in local pond systems: Clamshell Pond in Clinton, and the Lily Ponds in West Boylston.

2.1.5.7 Fish Monitoring

DWSP and MassWildlife staff conduct annual surveys for *Salvelinus namaycush* (Lake Trout) as part of an ongoing mark and recapture study. The annual *S. namaycush* mark and recapture study capitalizes on spawning behavior to target *S. namaycush* that move into shallow gravel and cobble substrate spawning areas at night after the water temperature has reached approximately 12 °C (55 °F), typically in October. Gillnets are set in these spawning areas for 30-45 minutes. Captured fish are weighed, measured, injected

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[40] DWSP, 2020b
[41] DWSP, 2020d
[42] DWSP, 2018b
[43] DWSP, 2020c

with a passive integrated transponder (PIT) tag, and marked by clipping the adipose fin before being released. The length and weight data collected during this study are used to develop a length-weight relationship for the Wachusett *S. namaycush* population. When a *S. namaycush* with a clipped adipose fin is recaptured, the PIT tag is scanned to identify the individual fish, which is then measured, weighed, and released. The changes in weight and length collected from recaptured fish help develop growth rates and track conditions for the Wachusett population.

Surveys for *Osmerus mordax* (Rainbow Smelt) spawning activity are often carried out in early spring by DWSP Aquatic Biologists as *O. mordax* are considered an important prey species for *S. namaycush*, however, surveys were not completed in 2024[44].

2.1.6 Additional Watershed Monitoring and Special Studies

In addition to routine monitoring of Wachusett Reservoir and its tributaries, DWSP staff conduct several special investigations. These studies vary in duration and depth of scope, but include storm sampling, monitoring of potential short-term and long-term water quality changes following forest management activities, and evaluation of spatial and temporal trends in specific conductance and Cl concentrations of waters impacted by roadway de-icing practices. Additional monitoring or water quality investigations may arise from recommendations in Environmental Quality Assessments or updates to the Watershed Protection Plan.

2.1.6.1 Long-term Forestry Monitoring

Forest management operations, when conducted with proper management practices, should not have significant short or long-term effects on water quality. Monitoring of harvest operations and water quality is conducted to ensure water quality standards are maintained on DWSP lands. Short-term monitoring focuses on direct water quality impacts that can occur during logging, while long-term monitoring involves evaluating water quality parameters as the forest regenerates following logging operations. Currently, long-term forestry water quality monitoring is being conducted in support of an ongoing internal study.

Two locations in the Wachusett Reservoir Watershed have been established for long-term monitoring of the potential impacts of timber harvesting on water quality. This project involves collection of water quality and flow data downstream of a timber lot that will be sold and harvested and downstream of a second lot (control) that will not be harvested. Monitoring for this study will span a period of at least ten years, with at least five years of sampling occurring both pre- and post-harvest. Nine years of pre-harvest data, beginning November 2013, have now been collected and data summary and comparison between the control and test lots will be presented in a preliminary report. The study includes monthly dry weather discrete grab sampling and quarterly storm event monitoring using automatic samplers. Parameters monitored in this study include flow, pH, water temperature, dissolved oxygen, TSS, TOC, NH_3-N, NO_3-N, NO_2-N, and TP. Methods for sample collection are the same as for these parameters on other tributaries. Additional details for this program are provided in the DWSP *SOP for Long-term Forestry Monitoring (WATBMP)*[45].

2.1.6.2 Storm Sampling

Storm sampling on primary tributaries has been conducted in past years to supplement routine monthly nutrient sampling and provide detailed information about the variability of solute concentrations during

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[44] Stolarski, 2019.
[45] DWSP, 2021a

storm events. Since 2000, over 67 storm events have been sampled, usually at 2–4 locations per storm. Storm sampling is now only considered for extreme precipitation events (2 or more inches of rain) to support UMass modelling efforts. No storms were sampled in 2024. A separate storm sampling report will be produced providing a detailed summary and analysis of the 46 storms that were sampled at routine water quality stations. Additional information about the storm sampling program is provided in the DWSP *SOP for Storm Sampling*[46].

2.1.6.3 Stormwater Basins

Monitoring of the stormwater basins located on either side of the Route 12/140 causeway was initiated in summer 2019. Baseline vegetation data were collected along shoreline transects of each forebay and within the constructed wetlands. Water temperature, pH, dissolved oxygen, and specific conductance were recorded with a YSI multi-sensor meter at inlet and outlet locations of each forebay at least monthly from July through December. Photographic documentation of vegetation and water level was also recorded using a customized ESRI Field Maps application. These data will be used to assess changes which may occur in water quality and vegetative composition because of inputs to the basins from road runoff and to estimate the effect these containment systems have on reducing inputs to the Reservoir. Frequent monitoring in these areas also serves to identify pioneer infestations of invasive species including *P. australis* (common reed) and *Lythrum salicaria* (purple loosestrife) and the presence of other organisms which often inhabit standing water areas and may present a threat to the function of the basins, water quality, and/or public health, such as cyanobacteria, mosquitoes, and *Branta canadensis* (Canada geese).

2.1.6.4 Environmental Quality Assessments

DWSP conducts annual Environmental Quality Assessments (EQA) of a single sanitary district in Wachusett Watershed to assess potential sources of contamination. Each of five separate sanitary districts is comprehensively evaluated by DWSP once every five years. The 2024 EQA report focused on the Waushacum sanitary district. Targeted sampling may be conducted relating to specific recommendations concerning known or suspected water quality issues identified in EQA reports.

2.2 2024 Watershed Monitoring Parameters

In 2024, 25 distinct physical, chemical, and biological parameters were monitored across all water quality and hydrologic monitoring programs throughout the Wachusett Reservoir Watershed (Table 8). Most parameters were selected because they either directly affect water quality or can indicate potential water quality issues.

Criteria or regulatory standards exist for many of these parameters for aquatic life protection, drinking water supply, and/or recreational contact. For some parameters which do not have specific regulatory standards, results are compared to the EPA Ecoregional Nutrient Criteria for Rivers and Streams, when applicable. All relevant regulatory and guidance thresholds for these parameters are listed in Table B-1 in Appendix B: Water Quality Standards and Criteria. Scientific background information and historical context in relation to the Wachusett Watershed is also provided in Appendix C: Watershed Monitoring Parameters and Historical Context to help readers better understand the discussion of water quality and hydrologic monitoring results. Monitoring results for 2024 are presented and discussed in Section 3.

[46] DWSP, 2021d

Table 8: 2024 Monitoring Parameters

The analysis location column indicates whether the parameter is measured directly in the field or if a water sample is collected and analyzed in a laboratory. Laboratory or field-based methods of analysis are listed under the method column. The water type where each parameter was measured is indicated in the last three columns, where R = reservoir, T = tributary, and G = groundwater. Precipitation and air temperature measurements are recorded from four specific land-based locations and are considered watershed-wide parameters.

Parameter Name	Units	Sampling Group	Analysis Location	Analysis Method	R	T	G
Air Temperature	Deg-C	Meteorological	Field-Sensor	N/A	N/A	N/A	N/A
Ammonia-nitrogen	mg/L	Nutrients	MWRA Lab	EPA 350.1, 353.2	X	X	N/A
Alkalinity	mg/L (as $CaCO_3$)	Nutrients	MWRA Lab	SM 2320 B	X	X	N/A
Blue Green Algae	µg/L	Field parameter	Field-Sensor	*In situ* Fluorometry	X	N/A	N/A
Blue Green Algae RFU	RFU	Field parameter	Field-Sensor	*In situ* Fluorometry	X	N/A	N/A
Chloride	mg/L	Nutrients	MWRA Lab	EPA 300.0	N/A	X	N/A
Chlorophyll	µg/L	Field parameter	Field-Sensor	*In situ* Fluorometry	X	N/A	N/A
Chlorophyll RFU	RFU	Field parameter	Field-Sensor	*In situ* Fluorometry	X	N/A	N/A
Chlorophyll volts	volts	Field parameter	Field-Sensor	*In situ* Fluorometry	X	N/A	N/A
Depth to Water	ft	Field parameter	Field-Sensor	*SOP for Groundwater*	N/A	N/A	X
Discharge	cfs	Field parameter	Field Sensor/ Calculated	Calculated from stage-discharge rating curve	N/A	X	N/A
Dissolved Oxygen	mg/L	Field parameter	Field-Sensor	SM 4500-O G-2001	X	X	X
E. coli	MPN/100 mL	Bacteria	MWRA Lab	9223B 20th Edition (Enzyme Substrate	X	X	N/A
Mean UV_{254}	ABU/cm	Nutrients	MWRA Lab	SM 5910B 19th	X	X	N/A
Nitrate-nitrogen	mg/L	Nutrients	MWRA Lab	EPA 350.1, 353.2	X	X	N/A
Nitrite-nitrogen	mg/L	Nutrients	MWRA Lab	EPA 350.1, 353.2	X	X	N/A
Oxygen Saturation	%	Field parameter	Field-Sensor	SM 4500-O G-2001	X	N/A	N/A
pH	S.U.	Field parameter	Field-Sensor	SM4500-H+ B-2000	X	X	X
Precipitation	in	Meteorological	Field-Sensor	(USGS/NOAA)	N/A	N/A	N/A
Secchi Depth	ft	Field parameter	Field-Sensor	SOP for Secchi	X	N/A	N/A
Specific Conductance	µS/cm	Field parameter	Field-Sensor	SM 2510 B-1997	X	X	X
Staff Gage Height	ft	Field parameter	Field-Sensor	Pressure Transducer/ Visual staff plate	N/A	X	N/A
Total Kjeldahl	mg/L	Nutrients	MWRA Lab	EPA 351.2	X	X	N/A
Total Nitrogen	mg/L	Nutrients	MWRA Lab	Calculated	N/A	X	N/A
Total Organic Carbon	mg/L	Nutrients	MWRA Lab	SM 5310 B	N/A	X	N/A
Total Phosphorus	µg/mL	Nutrients	MWRA Lab	EPA 365.1	X	X	N/A
Total Suspended	mg/L	Nutrients	MWRA Lab	SM2540	N/A	X	N/A
Turbidity FNU	FNU	Field parameter	Field-Sensor	ISO7027	X	N/A	N/A
Turbidity NTU	NTU	Bacteria	Field-Sensor	EPA 180.1	N/A	X	N/A
Water Depth	m	Field parameter	Field-Sensor	N/A	X	N/A	N/A
Water Temperature	Deg-C	Field parameter	Field-Sensor, USGS	SM 2550 B-2000	X	X	X

[47] DWSP, 2023f

2.3 Statistical Methods and Data Management

All numerical calculations and related graphics were generated using the R programming language[48] and preserved in scripts, which document the exact steps that were utilized to produce the results presented. This provides an additional level of transparency and will improve efficiency and consistency in the writing of future annual water quality reports. Graphics were produced with the ggplot2 package[49]. All seasonal statistics presented in this report, apart from reservoir nutrients (see Section 3.4.7), use the following date cutoffs to determine season:

- December 1 (start of meteorological winter)
- March 1 (start of meteorological spring)
- June 1 (start of meteorological summer)
- September 1 (start of meteorological autumn)

In 2021, DWSP changed how left-censored laboratory results (values that were below lower detection limit thresholds) were stored and analyzed. Previously, left-censored results were recalculated as one-half the detection limit and statistics were calculated using these values. All left-censored results are now stored to be equal to the detection limit, however, statistical methods have been improved to handle the uncertainty associated with censored results. Right-censored laboratory results (values above the upper quantification limit) are assigned a value equal to the limit (this did not change). All censored results are flagged as such in the database.

Annual report statistics (mean, median, geometric mean) are now calculated using methods depending on the prevalence of non-detects within each data grouping. Logic has been embedded in R scripts so that when fewer than four values are detected in a data group, the left-censored results (except for *E. coli*) are set to one-half the detection limit value and the normal statistic is calculated using base R functions. However, when there are four or more uncensored values in a data group, statistics are calculated using functions from the NADA package[50]. A parametric method, Maximum Likelihood Estimation (MLE), is used to compute bacteria geometric means. A non-parametric method, Regression on Order Statistics (ROS), is used with non-bacteria data to calculate means and medians. This change in statistical methods has caused some slight differences from the statistics that were reported in prior annual reports (for some parameters). For parameters where data groupings had no censored results, the statistics will not differ between the 2021 and future reports and prior annual reports.

Water quality, precipitation, and streamflow data generated since 1985 are stored in a Microsoft SQL Server database, maintained by DWSP-EQ. The Watershed system data Visualization Environment (WAVE) is a custom R/Shiny[51] application developed as a collaborative effort between individuals from the Department of Civil and Environmental Engineering at UMass Amherst and DWSP. WAVE serves as a portal to visualize and review data within the database. Data generated from water quality monitoring in 2024, and prior years are available upon request.

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[48] R Core Team, 2019
[49] Wickham, 2016
[50] Lee, 2020
[51] Chang et al., 2019

2.4 Quality Assurance and Quality Control

Over the last several years, QA/QC protocols have been incorporated into many aspects of water quality and hydrological monitoring in the Wachusett Reservoir Watershed. Since 2018, and prior to any formalized SOPs, automated data quality and other screening checks were embedded into data processing scripts. In 2019, the first detailed description of monitoring programs was written, which became the precursor for individual monitoring program SOPs. Between 2020 and 2023, formal SOPs were developed to cover most routine water quality and hydrological monitoring programs. An internal monthly QA/QC report was developed in 2022, which summarized equipment calibration results, pre-sampling calibration verification checks, and potential data outliers that may need to be reviewed by staff. In 2023, field duplicates and blanks were added to the routine tributary monitoring programs and field and lab audits were conducted to ensure that established SOPs are being adhered to by DCR staff. A summary of field blanks and duplicate results was incorporated into the monthly QA/QC report, indicating if any parameter was outside of the acceptable range. The first Wachusett Watershed Quality Assurance Project Plan (QAPP) for water quality and hydrological monitoring programs was completed in June of 2023[52], which serves as the umbrella document for all SOPs and QA/QC procedures.

The implementation of the QAPP and recent modifications to SOPs have resulted in more efficient data processing and field procedures as well as better data quality control and reliability. In particular, the addition of field blanks and duplicates has improved the detection of data anomalies which may have otherwise gone unnoticed. A full summary of QA/QC efforts for 2024 are provided in Appendix D: Quality Assurance and Appendix E: Quality Control.

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[52] DWSP, 2023b

3 Results

This section presents the results of DWSP routine monitoring programs in Wachusett Watershed for 2024, including the Reservoir, tributaries, and groundwater. In the tributaries, DWSP staff collected 421 turbidity samples along with 2,188 physiochemical measurements (548 water temperature, 548 specific conductance, 546 dissolved oxygen and 546 pH) in the field at tributary stations and Shaft 1. Staff collected 119 phytoplankton samples from the Reservoir and 48 water column profiles (temperature, specific conductance, dissolved oxygen, percent oxygen saturation, chlorophyll a, phycocyanin, and pH). A total of 709 bacteria samples were collected and delivered to the MWRA Southborough laboratory for *E. coli* analysis (421 from tributaries and 288 from the Reservoir), and 1,521 samples (1,269 tributary, 252 reservoir) were collected and shipped to the MWRA Deer Island laboratory for a total of 2,230 analyses of nutrients and other parameters; these numbers do not include special studies, QC samples, or non-routine samples. Daily climate statistics for the Wachusett Watershed were calculated using records from NOAA, USGS, and DWSP monitoring stations. Daily streamflow statistics were calculated from DCR stream gaging stations or obtained from three USGS monitoring stations. Daily Quabbin Transfer totals were provided by MWRA. DWSP staff measured watershed snowpack on seven occasions during 2024.

3.1 Meteorologic and Hydrologic Conditions

Climatic patterns (precipitation and temperature) are the primary drivers of the hydrologic cycle and have important implications for water supply and water quality due to their influence on water availability and biochemical processes. There is often a response in both hydrologic conditions and water quality when local climatic conditions deviate from "normal" for a prolonged period (e.g. drought) or after short and intense weather events. Thus, it is important to compare water quality results to antecedent hydrological and climate conditions to determine if there is a causal link, or if other factors may be responsible for the water quality response.

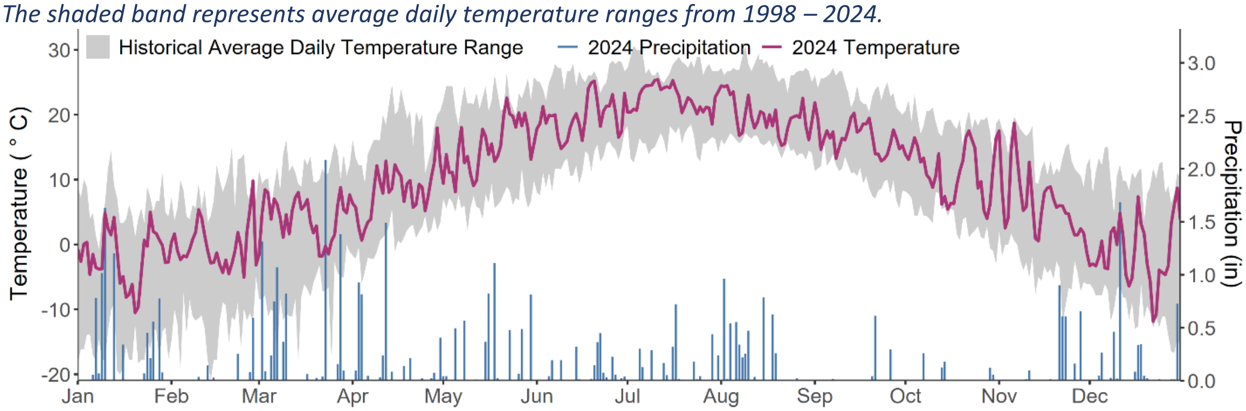
3.1.1 Meteorologic Conditions

3.1.1.1 Air Temperature

The mean annual temperature in the Wachusett Watershed (average of all stations) for 2024 was 10.02 °C, which is 0.72 °C above the historical annual mean temperature (since 1998). Average daily air temperatures for 2024 ranged from -11.8 °C (December 22) to 25.4 °C (July 11) (Figure 8). The lowest daily minimum temperature (average of all stations) observed in 2024 was -17.62 °C on December 23, while the highest daily maximum temperature was 34.27 °C on June 20.

Figure 8: Climatograph of Daily Mean Temperatures and Daily Precipitation Totals for Wachusett Watershed from January 1 through December 31, 2024

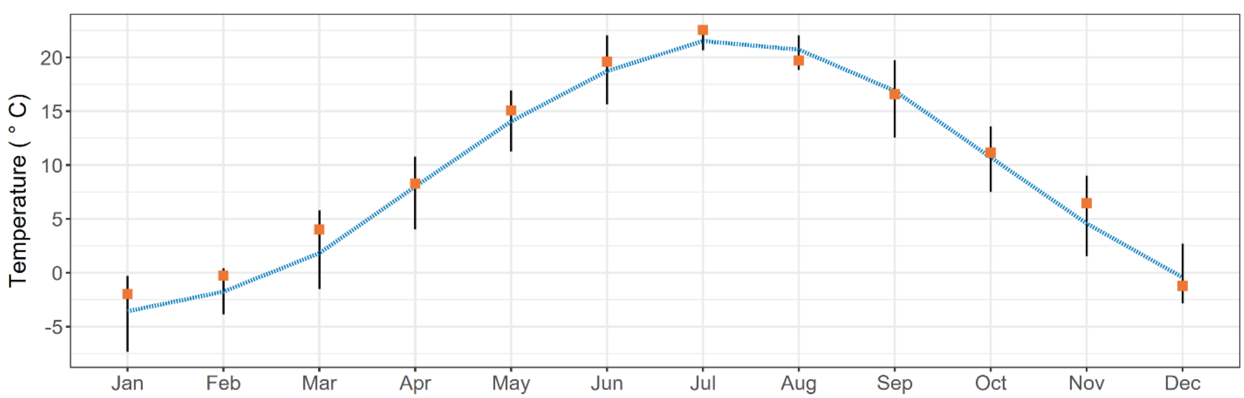
The shaded band represents average daily temperature ranges from 1998 – 2024.



All monthly average temperatures were within historical ranges, except for July, which was the warmest July in the period of record (since 1998). Nine months in 2024 experienced above average temperatures and three below (Figure 9).

Figure 9: Wachusett Reservoir Watershed Monthly Mean Temperatures in 2024

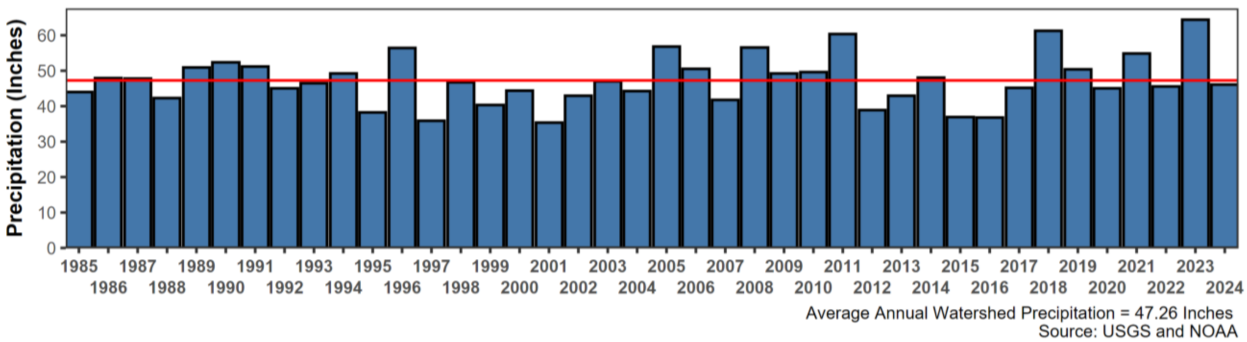
Monthly mean temperatures for 2024 (orange squares) are shown in relation to the long-term average monthly temperatures (blue dashed line). The vertical black lines indicate the range of monthly mean temperatures over the period of record, which began in 1998.



3.1.1.2 Precipitation

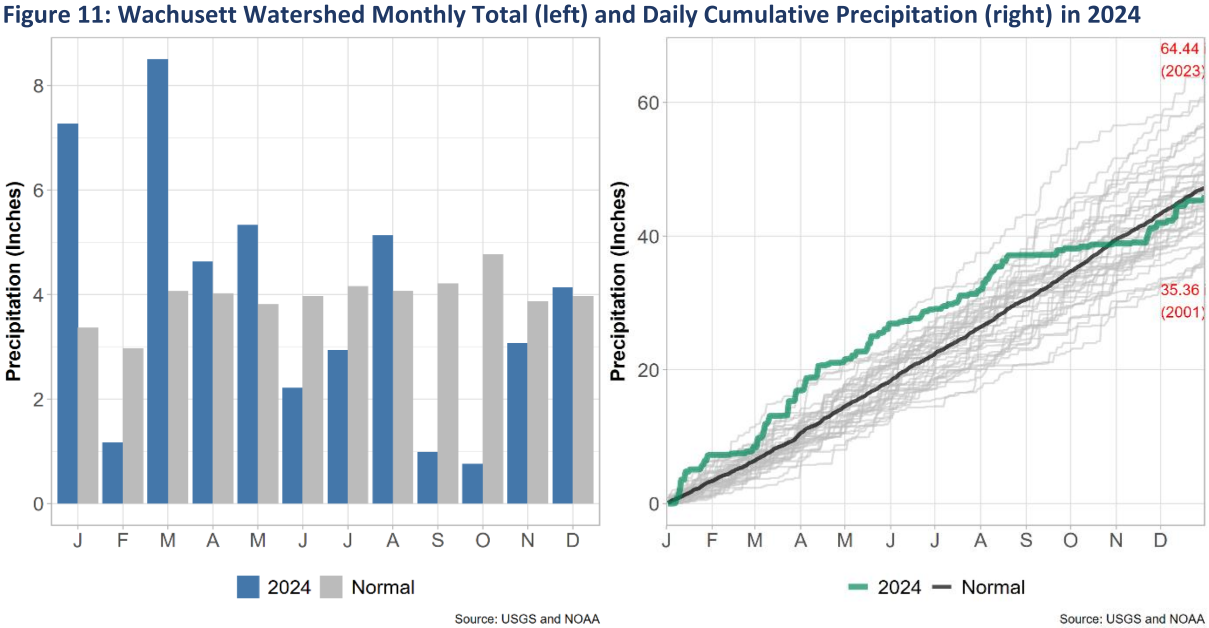
Annual precipitation for the Wachusett Watershed in 2024 (46.11 inches) was slightly below the long-term annual average (47.26 inches; POR = 1985 - 2024), resulting in a calendar year departure of -1.15 inches (Figure 10). Despite a near average precipitation total for 2024, rainfall distribution throughout the year was heavily skewed towards the first half of the year, leading to a drastic swing in hydrologic conditions – from very wet to very dry.

Figure 10: Annual Precipitation for Wachusett Watershed, 1985 to 2024
The red line indicates the long-term average annual total precipitation.



Calendar year cumulative precipitation remained well above normal (average) from May until mid-August. During the three-month period between August 20 – November 20, there was only 1.9 inches of precipitation, which is 10.7 inches below the historical average for this period of the year. Precipitation returned to normal in December, however the significant cumulative precipitation deficit through the fall resulted in widespread drought conditions that would take many months to recover from (Figure 11). Mild drought (Level 1) was declared for the Central Region of MA on October 11, 2024. By November 7, the Central Region Drought Status was increased to Critical Drought (Level 3), where it remained until being downgraded back to Level 2 effective December 1, 2024[53]. March was the wettest month of 2024 (8.5 inches), whereas October was the driest (0.76 inches) (Table 9). Small and medium storms were numerous throughout 2024, with 10 days receiving one inch or more precipitation, 23 days between 0.5 and 1.0 inches, and 23 days between 0.2 and 0.5 inches. Noteworthy storms in 2024 occurred January 9-10 (2.65 inches - rain on snow event), March 23 (2.08 inches), and December 11 (2.36 inches).

Figure 11: Wachusett Watershed Monthly Total (left) and Daily Cumulative Precipitation (right) in 2024



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[53] MA Drought Management Taskforce, 2024

Table 9: Monthly Total Precipitation in 2024 and Statistics for the Period of Record, 1985 to 2024

The annual normal (average) precipitation is not the same as the sum of average monthly precipitation.

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation (in)	7.27	1.16	8.5	4.63	5.33	2.21	2.94	5.13	0.98	0.76	3.07	4.13	46.11
Normal (in)	3.36	2.97	4.06	4.02	3.93	3.97	4.16	4.07	4.21	4.76	3.87	3.97	47.26
Departure (in)	3.91	-1.81	4.44	0.61	1.40	-1.76	-1.22	1.06	-3.23	-4.00	-0.80	0.16	-1.15

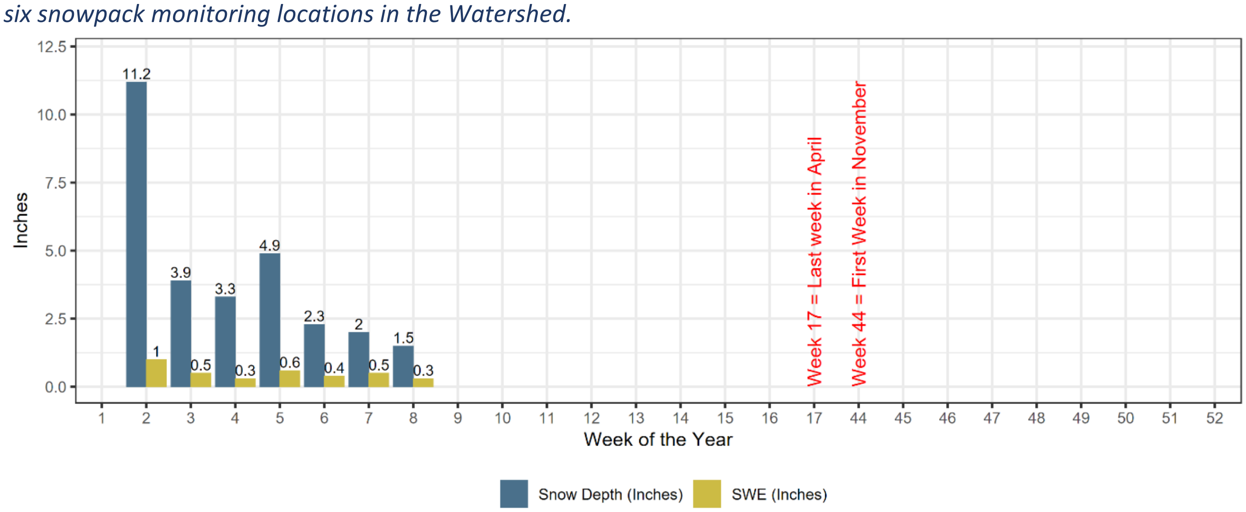
Snow

The snowpack measurement results for calendar year 2024 are presented below (Figure 12). The weekly results do not account for all snow accumulation that occurred during the season as it is a weekly snapshot of the snow depth and snow-water-equivalent (SWE) over time, represented as the average of measurements across all snowpack monitoring locations in the Watershed. Between measurements there can be losses due to sublimation/melt, gains due to additional frozen precipitation, or periods of both gain and loss.

The first measurable snowpack in 2024 occurred after a storm on January 6-7. The Watershed average snow depth totaled 11.2 inches, and the snow-water-equivalent (SWE) was 1.0 inch. Warm temperatures (up to 13.9 °C) and over two inches of rain reduced the snowpack after the first week to an average of 3.9 inches. Generally, snow depths slowly decreased throughout January until a snowstorm on January 28-29 increased watershed average snowpack to 4.9 inches. Snowpack declined through February, becoming too thin to measure after the February 20 survey. More detailed information was recorded in snowpack reports that were produced for the weeks that a snowpack survey was conducted.

Figure 12: Snowpack Measurements in 2024

SWE = Snow-water-equivalent. Snow depth and SWE are presented as the average of the measurements across the six snowpack monitoring locations in the Watershed.

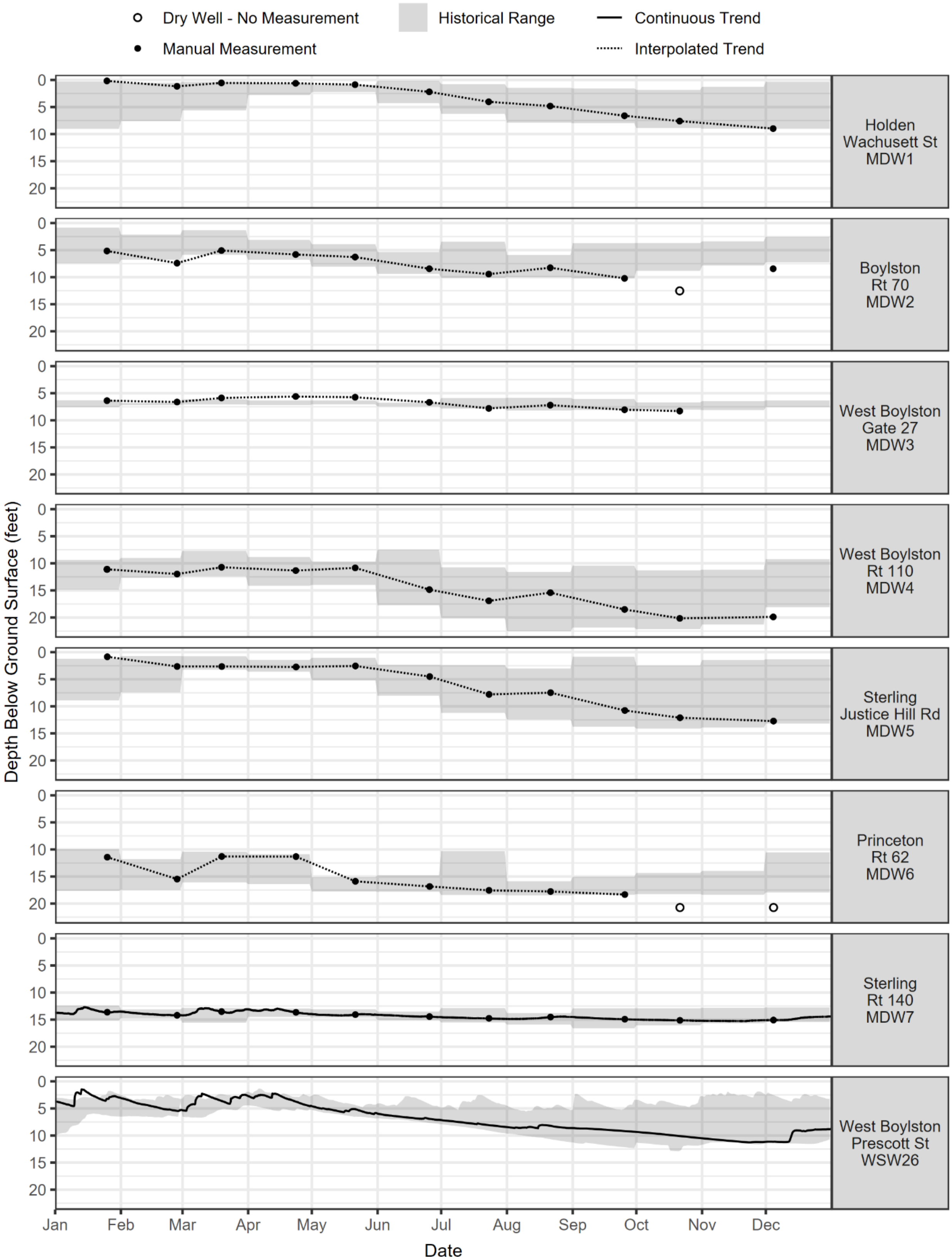


3.1.2 Groundwater Levels

Groundwater levels in 2024 varied throughout the year, following the same hydrological patterns presented in Section 3.1, above. During the 2024 sampling period, the Boylston – Rt. 70 well was dry in October and the Princeton – Rt. 62 well was dry in October and December. Groundwater measurements were not collected in November. For December, the West Boylston – Gate 27 well was not sampled, instead a nearby well was sampled but not included in the analysis.

Water levels are presented in comparison with monthly historical ranges for all wells except West Boylston – Prescott St., which has daily historical ranges presented due to the availability of nine years of automated water level measurements by USGS (Figure 13). When compared with these historical ranges, groundwater levels can be indicative of drought or excess saturation water in the Watershed. In 2024, excluding any dry well measurements and only using manual measurements, Sterling – Justice Hill Rd. experienced the greatest change in depth below ground surface, with a difference of 11.9 ft between January 25 (0.8 ft) and December 4 (12.7 ft). Generally speaking, most wells followed this pattern of declining water levels as the year progressed (Figure 13). Multiple wells indicated aquifer levels that were at lower elevations towards the end of the year (relative to ground surface) than historical levels, including Holden – Wachusett St., Boylston – Rt. 70, West Boylston – Gate 27, and West Boylston – Rt. 110. Wells that were not outside of their historical ranges were close to the furthest depths below ground surface in the period of record. These record low groundwater elevations reflected the local drought conditions during the fall months of 2024.

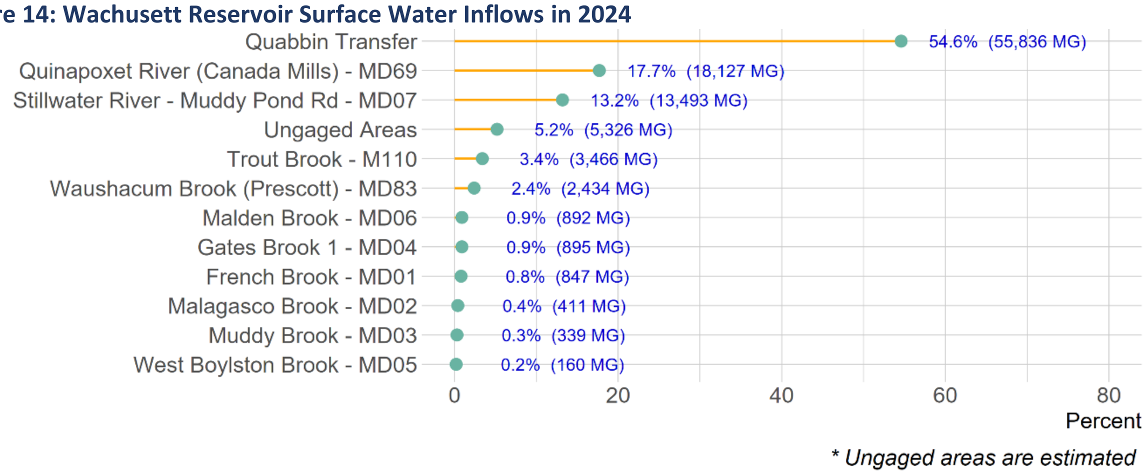
Figure 13: Wachusett Groundwater Depth Measurements in 2024 with Historical Ranges for Comparison



3.1.3 Streamflows, Quabbin Transfer and Withdrawals

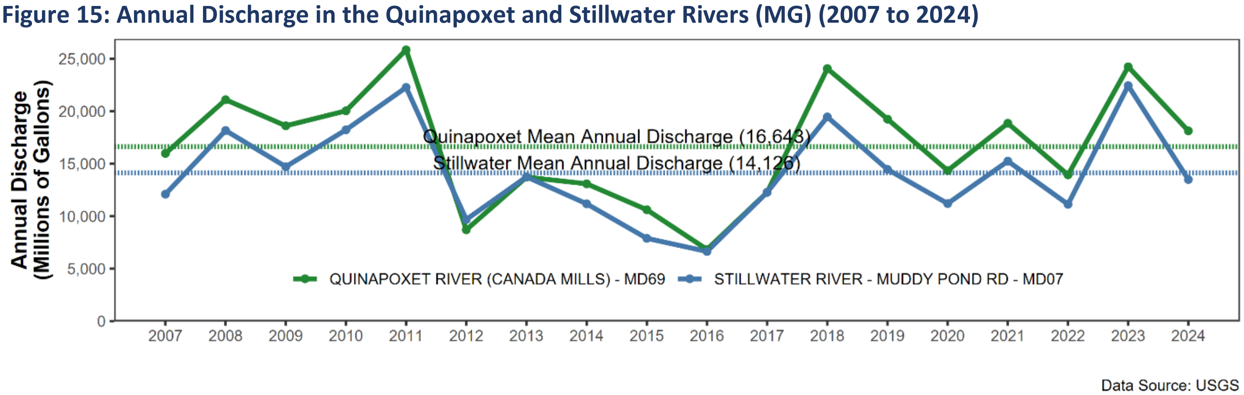
2024 was a year of hydrologic extremes in the Wachusett tributaries, with streamflows (discharge) responding to the seasonal patterns in precipitation and groundwater levels discussed above. The total surface water inflow to Wachusett Reservoir in 2024 was estimated to be 102.2 BG; about 17.3 BG less than in 2023. Water transfers from the Quabbin Reservoir comprised 54.6% of the total surface water inflow in 2024, which is only about 3.9 billion gallons more than in 2023, but an 8% greater share of the total annual surface water inflows to Wachusett Reservoir. About 31% of surface water inputs came from the Quinapoxet and Stillwater Rivers, while about 14.5% was contributed by the smaller tributaries and ungaged areas (Figure 14).

Figure 14: Wachusett Reservoir Surface Water Inflows in 2024



Total annual discharges for the Quinapoxet and Stillwater Rivers for 2024 were 8.9% above and 4.5% below the historical average, respectively (Figure 15).

Figure 15: Annual Discharge in the Quinapoxet and Stillwater Rivers (MG) (2007 to 2024)



Daily mean discharge rates for 2024 in the smaller tributaries ranged from < 0.01 cfs at Waushacum and French Brooks to 145 cfs at Trout Brook. The maximum instantaneous discharges at these tributaries ranged from 15.26 cfs at West Boylston Brook to 218 cfs at Trout Brook (Table 10).

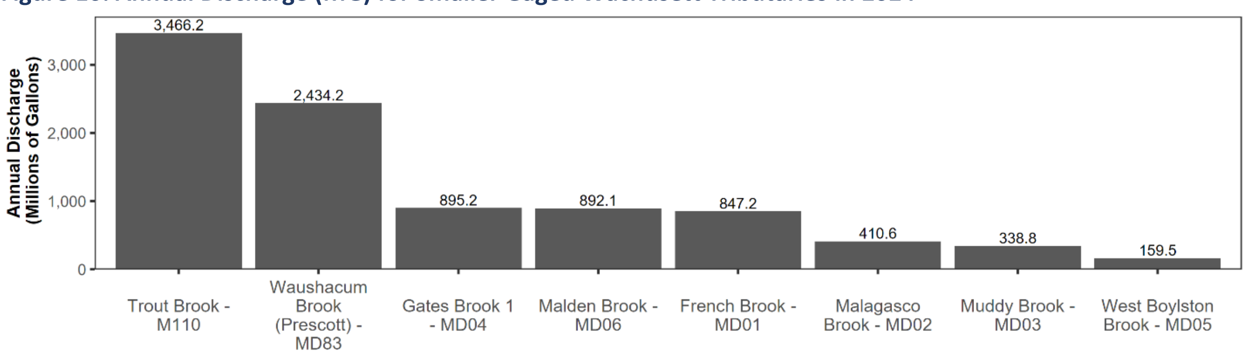
Table 10: 2024 Discharge Statistics for Wachusett Reservoir Tributaries

Cumulative annual discharge from Ungaged Areas was estimated and other discharge statistics are not applicable.

Location	Min Daily Mean Discharge (CFS)	Avg Daily Mean Discharge (CFS)	Max Daily Mean Discharge (CFS)	2024 Peak Inst. Discharge (CFS)	Min Month Volume (MG)	Avg Month Volume (MG)	Max Month Volume (MG)	2024 Total Volume (MG)
French Brook - MD01	<0.01	3.57	84.11	119.8	0.6	70.6	258.0	847.2
Gates Brook 1 - MD04	0.48	3.78	37.30	69.4	10.8	74.6	179.6	895.3
Malagasco Brook - MD02	0.02	1.73	15.15	18.6	1.9	34.2	104.8	410.6
Malden Brook - MD06	0.04	3.78	17.99	26.7	8.3	74.3	186.7	892.1
Muddy Brook - MD03	0.04	1.43	12.99	18.5	3.1	28.2	77.1	338.8
Quinapoxet River - MD69	1.54	76.63	670.00	881.0	54.5	1,510.7	4,688.4	18,126.8
Stillwater River - MD07	1.61	57.04	542.00	812.0	55.3	1,124.4	3,390.1	13,492.6
Trout Brook - M110	0.11	14.62	144.94	218.2	7.2	288.9	870.9	3,466.2
Waushacum Brook - MD83	<0.01	10.28	68.39	85.0	1.2	202.9	636.9	2,434.2
West Boylston Brook - MD05	0.02	0.67	8.81	15.26	0.8	13.3	40.5	159.5
Ungaged Areas	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5,326.1
Quabbin Transfer	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55,836.4

Cumulative annual discharges for the smaller tributaries are presented in Figure 16. Trout Brook contributed the largest water volume to Wachusett Reservoir of the smaller tributaries with 3,466 MG (~3.4 %), while Waushacum Brook contributed 2,434 MG (~2.4%) of surface water inflow to the Reservoir. The other gaged small tributaries collectively contributed less than 4% of the surface water inflows to Wachusett Reservoir. Non-gaged areas contributed an estimated 5.2% of the total inflows.

Figure 16: Annual Discharge (MG) for Smaller Gaged Wachusett Tributaries in 2024



Discharges in the streams and rivers of Wachusett Watershed are typically highest in the late winter and early spring (March – April) due to snowmelt and the thawing of frozen soils. Discharges decline through the growing season as evapotranspiration rates increase, reaching their lowest levels by July or August. As the growing season wanes through the fall and evapotranspiration rates decline, discharges start to increase once again. This seasonal pattern is illustrated by the normal discharges for the Quinapoxet River (Figure 17) and Stillwater River (Figure 18). The seasonal hydrologic patterns typical of Wachusett Watershed were amplified by the swing from very wet conditions early in the year, to drought conditions later in the year. Spring discharges were much higher than normal but then dropped to record low levels by late summer and through the fall. Discharges did begin to pick up again by December, but this seasonal increase was much later and much less than in years with normal fall precipitation. Most intermittent streams (Boylston Brook, Jordan Farm Brook, and others that are not monitored) dried up starting late summer into late fall. Even some smaller perennial streams (e.g. Cook Brook – MD11) that do not typically dry up, went dry for a short period of time due to the critical drought.

In 2024, monthly tributary discharges followed their typical seasonal patterns, except that winter discharges in February decreased due to low precipitation and freezing conditions and the usual increases in discharges starting in the fall were very muted due to regional drought conditions referenced in Section 3.1.1.2.

Figure 17: Monthly Discharge in the Quinapoxet River (MG) 2024

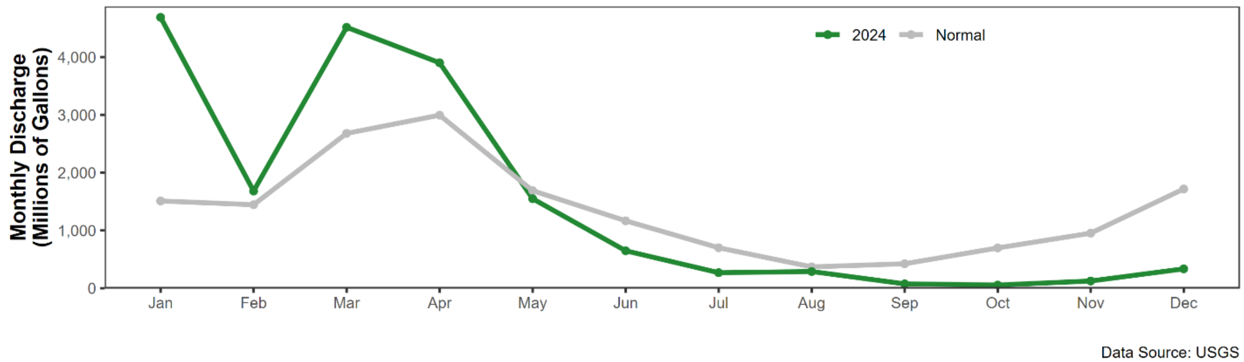
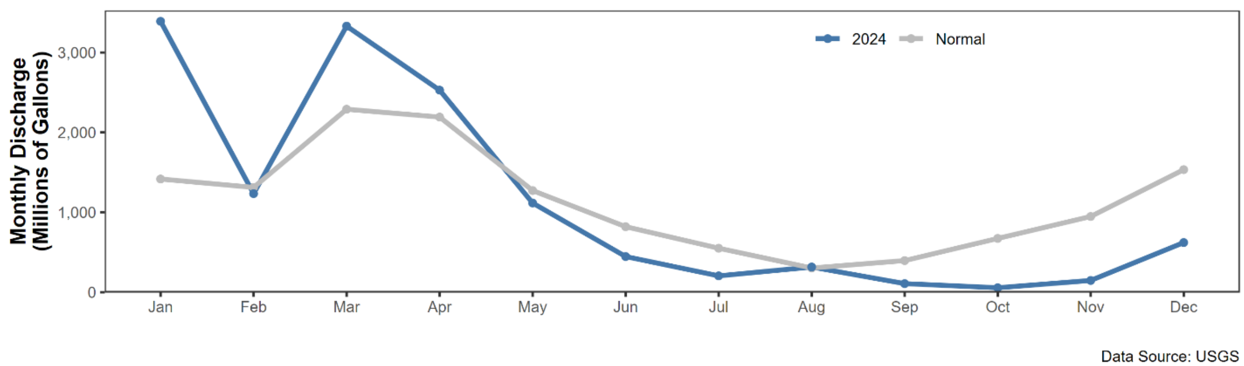
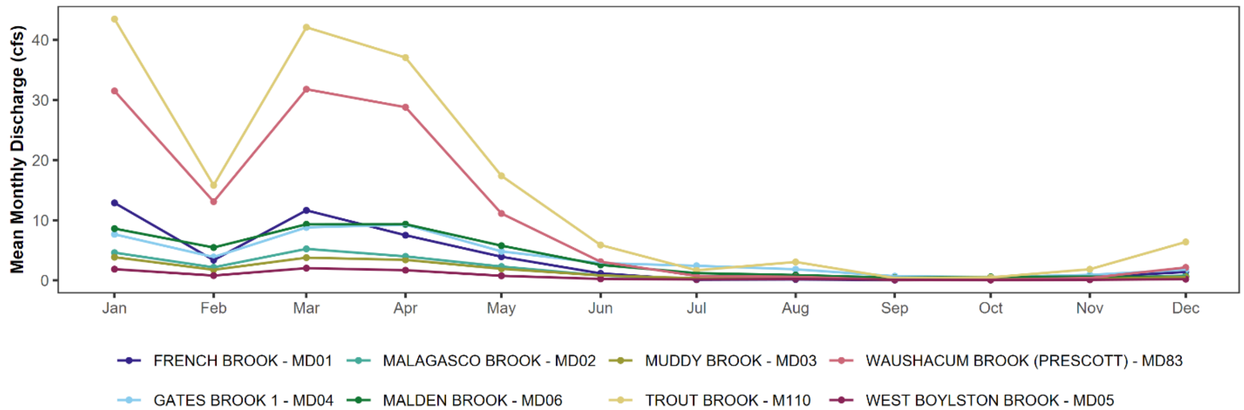


Figure 18: Monthly Discharge in the Stillwater River (MG) 2024



Cumulative monthly discharges in the Quinapoxet River (Figure 17) and Stillwater River (Figure 18) for 2024 followed the same pattern as the smaller tributaries (Figure 19), with predominantly above normal discharge through April followed by a fairly sharp decline between April and June. The highest monthly cumulative discharge for both rivers was in January, with discharges more than double the historical averages (normal) for this month. Complete hydrographs for all flow monitored tributaries are provided in Appendix A.

Figure 19: Mean Monthly Discharge in Smaller Wachusett Tributaries (CFS) in 2024



In 2024, the Quabbin Transfer was incrementally ramped up to 300 MGD during the first half of May and remained on through the end of October, when it was shut off to accommodate construction activities for the removal of the Quinapoxet Dam, immediately upstream of Shaft 1. The transfer was turned back on in early December to bring additional water to the Wachusett Reservoir, which was quickly declining in water elevation due to the prolonged drought and resultant lack of recharge from tributary inflow. The transfer was on for a total of 201 days, delivering a total volume of 55.8 BG to Wachusett Reservoir at an average transfer rate of 277.8 MGD (Figure 20). This is equivalent to 85.9% of Wachusett Reservoir capacity (65 BG) and is 9,924 MG more than the average transfer volume between 2005 and 2023 (45,912 MG) (Figure 21). Wachusett Reservoir elevation remained within or slightly above its operating band for most of 2024. After the Quabbin Transfer was shut off in late October, the water level declined rapidly and was below the normal operating band (390 ft) by mid-November. The reservoir elevation peaked at 392.05 ft on January 14, while its lowest point in 2024 was 387.42 ft on December 9.

Figure 20: 2024 Daily Wachusett Reservoir Water Elevation and Daily Quabbin Transfer Rate

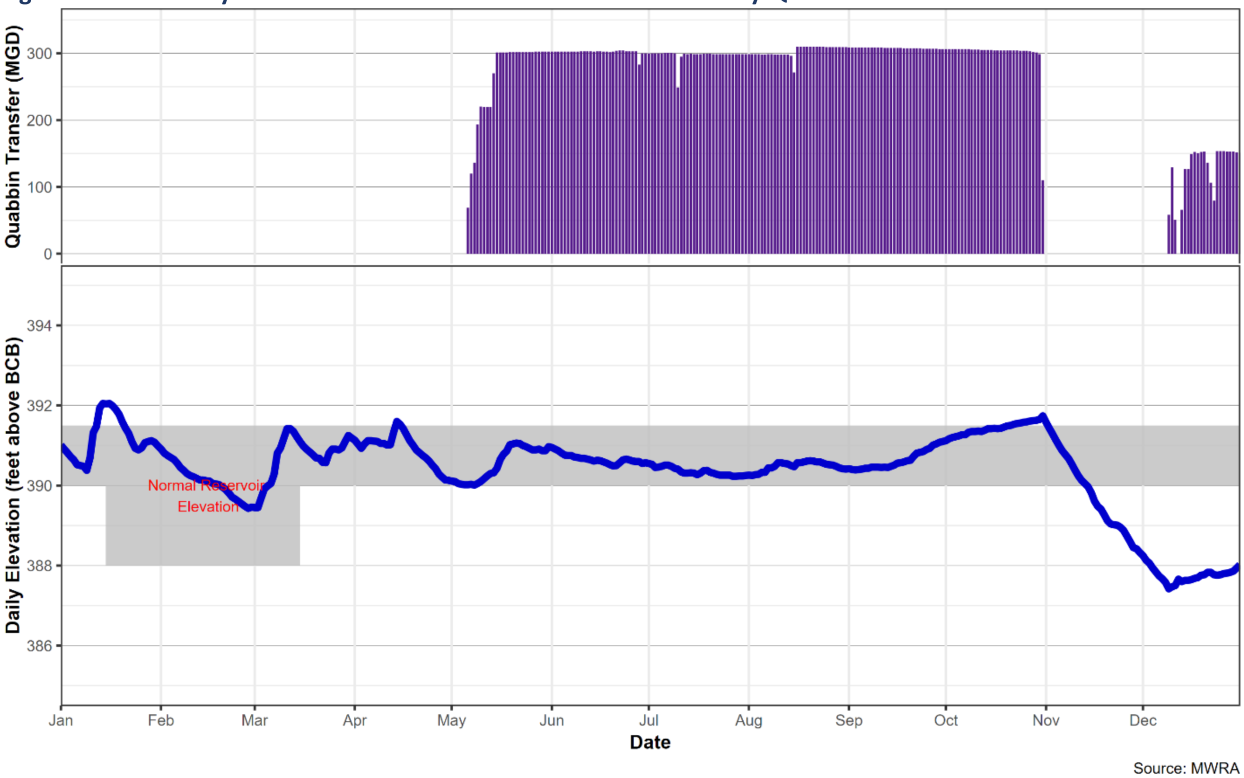
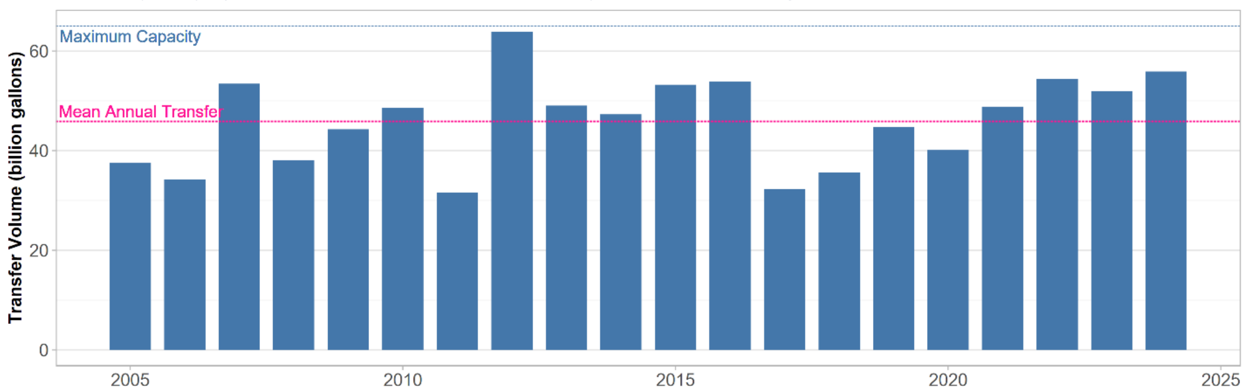


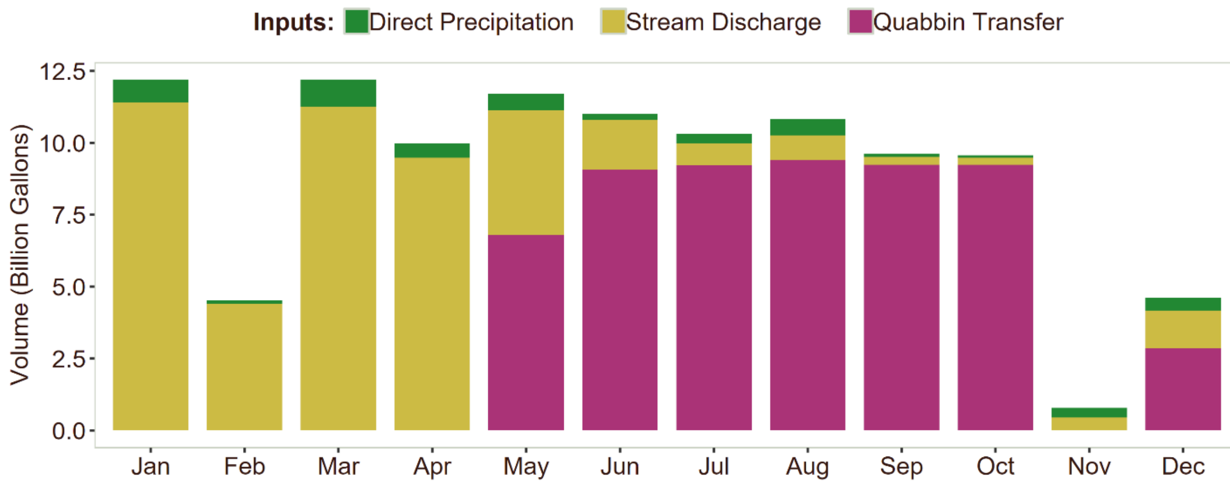
Figure 21: Annual Volume of Quabbin Transfer to Wachusett Reservoir

Maximum capacity of Wachusett Reservoir indicated by line at 65 billion gallons.



Wachusett Reservoir withdrawals by MWRA during 2024 were just under 74 BG, which was only 0.41 BG more than the mean annual total withdrawal since 2014. Fortunately, the surplus water from the end of 2023 into the first few months of 2024 kept the Reservoir at the top of the normal operating band through mid-April (391.5 ft). The Quabbin Transfer typically comprises more than 50% of water inputs to Wachusett Reservoir from June through November, however due to the drought conditions during the second half of 2024, the Quabbin Transfer accounted for more than 90% of water inputs to the Wachusett Reservoir during these months (Figure 22). This drastic shift in proportions of native Wachusett water to Quabbin Transfer water entering the Wachusett Reservoir has short-term, seasonal, and likely long-term impacts on reservoir water quality and algal dynamics. This will be further discussed in Section 3.4.

Figure 22: Monthly Water Inputs to Wachusett Reservoir (Billion Gallons) in 2024



3.2 Tributary Monitoring

3.2.1 Water Temperature and Dissolved Oxygen

Tributary water temperature and dissolved oxygen conditions for 2024 are presented below. Records for these parameters prior to 2020 are not included in this analysis due to failure to meet current QC standards for approval. Interannual variation and statistics will be presented once a sufficient record of reliable data has been accumulated.

In 2024, water temperature in Wachusett Watershed tributaries ranged from 0 °C at East Wachusett Brook and Trout Brook to 27.5 °C at French Brook. At the 10 monitoring locations where temperature sensors were installed, the 7-day mean maximum temperature (purple points) is shown for comparison to the MassDEP 20 °C coldwater fish resources (CFR) (Figure 23) and 28.3 °C warmwater fish resource (WFR) (

Figure 24) limits[54]. For the CFR tributaries with temperature sensors, all monitoring locations exceeded the 20 °C limit on at least one day over the summer (Table 11). It is likely that the other three CFR tributaries without temperature sensors also exceeded the 20 °C threshold over multiple days in 2024. Based on continuous sensor data (where available) two tributaries (French Brook and Waushacum Brook) exceeded the WFR threshold during 2024 (Figure 23). While there is no regulatory limit or guidance for drinking water supply temperatures, colder waters are preferred for healthy fish communities and because many solutes (e.g., trace metals) are less soluble and biological productivity (algae, *E. coli*) is slower, which generally helps reduce the likelihood of taste, odor, and other sanitary issues.

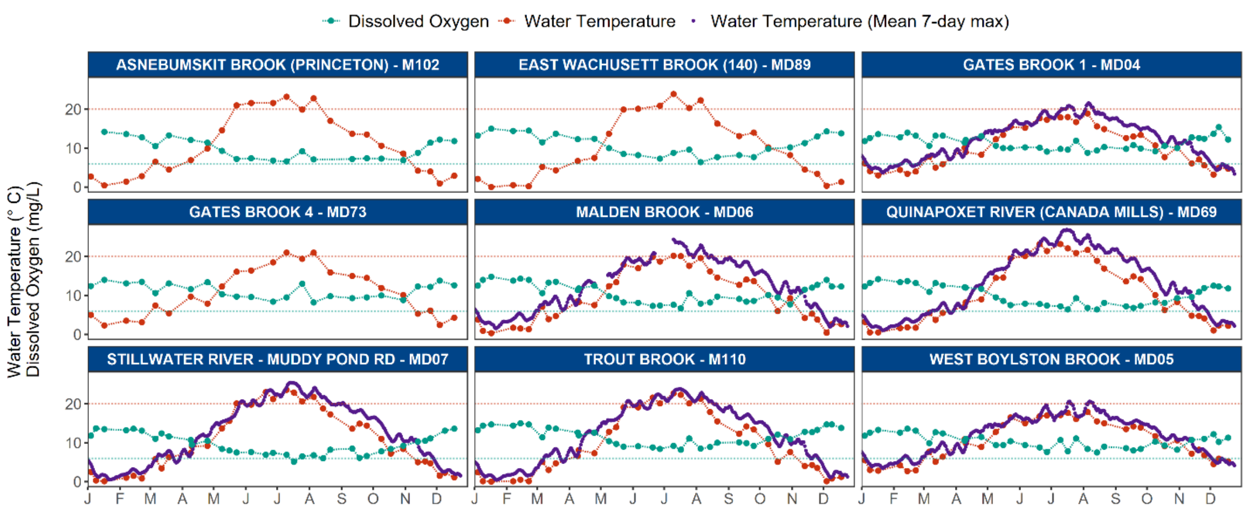
Table 11: Coldwater Fish Resource Tributaries that Exceeded the MassDEP Water Temperature Recommended Limit of 20 °C (mean 7-day maximum temperature) in 2024

Data with an asterisk is incomplete due to sensor malfunction.

Monitoring Location	Days Exceeded
Gates Brook 1 - MD04	19
Malden Brook – MD06	38*
Quinapoxet River (Canada Mills) - MD69	106
Stillwater River - Muddy Pond Rd - MD07	81
Trout Brook - M110	69
West Boylston Brook - MD05	9

Figure 23: Water Temperature and Dissolved Oxygen for Wachusett Tributaries Designated as Coldwater Fish Resources (CFR)

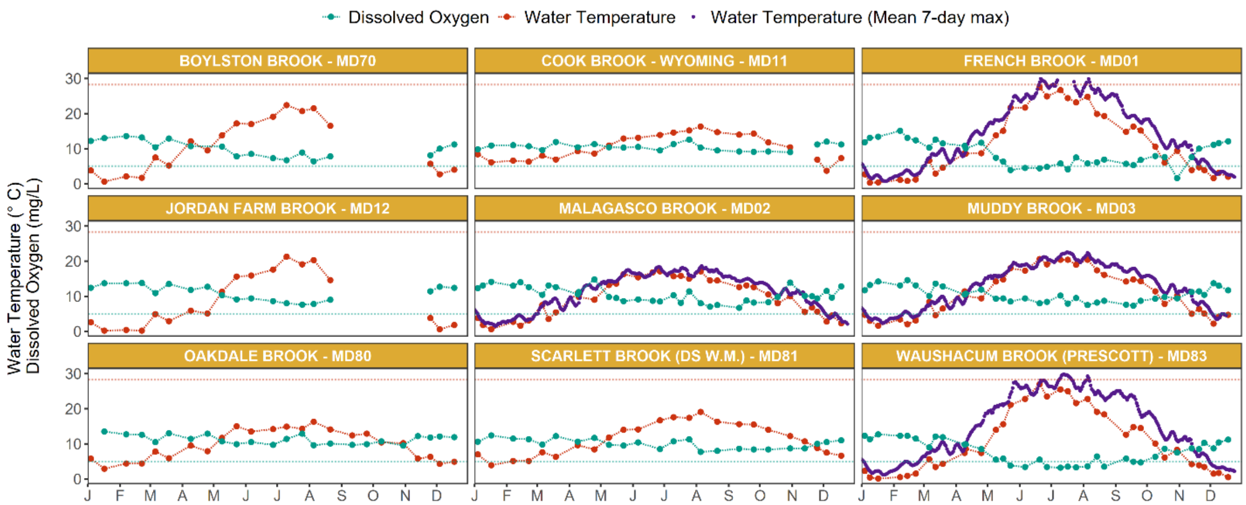
The red horizontal line represents the upper temperature limit for CFR waters (20 °C), while the blue horizontal line represents the lower recommended dissolved oxygen concentration for CFR waters (6.0 mg/L). Red and blue points are grab measurements; Purple points represent the mean 7-day maximum temperature from deployed sensors.



[54] Massachusetts Surface Water Quality Standards, 2022f

Figure 24: Water Temperature and Dissolved Oxygen for Wachusett Tributaries designated as Warmwater Fish Resources (WFR)

The red horizontal line represents the upper temperature limit for WFR waters (28.3 C), while the blue horizontal line represents the lower recommended dissolved oxygen concentration for WFR waters (5.0 mg/L). Red and blue points are grab measurements; Purple points represent the mean 7-day maximum temperature from deployed sensors.



Dissolved oxygen (D.O.) concentrations in 2024 were generally inversely correlated with water temperatures, with the highest concentrations observed during the winter months when water was cold and lowest concentrations observed during the summer months when water was warm. D.O. ranged from a low of 1.6 mg/L at French Brook to a high of 15.4 mg/L, also at Waushacum Brook[55]. The MassDEP aquatic life criteria for D.O. (minimum of 6.0 mg/L) was met at all CFR monitoring locations except for the Stillwater River, which fell below this threshold during 1 day in July (Figure 23). At WFR monitoring locations, D.O. fell below the MassDEP aquatic life threshold (5.0 mg/L) at French Brook (six visits) and Waushacum Brook (10 visits). This is common for these tributaries during the summer months due to the large and shallow wetland areas upstream of the monitoring locations.

There are no drinking water standards for D.O., however this parameter is important for regulating many biogeochemical processes that do have ecological importance, which ultimately affect the suitability of water as a drinking water source. Waters with higher D.O. are preferred because they are typically colder and less stagnant, which helps to reduce problematic concentrations of bacteria and algal growth. Low dissolved oxygen is also an indicator of eutrophication, which is undesirable for source waters.

3.2.2 Alkalinity and pH

Alkalinity monitoring in Wachusett tributaries was previously conducted between 2000 and 2012 and then resumed at all primary tributary monitoring locations in September of 2020 to better understand the cause of increasing alkalinity observed in Wachusett Reservoir in recent years.

In 2024, and in the earlier monitoring period, alkalinity concentrations in the tributaries (as calcium carbonate ($CaCO_3$)) correspond well with the underlying bedrock carbonate content. A band of calcpelite,

[55] Although sensor calibration was confirmed prior to sampling, the recommended dissolved oxygen sensor maintenance schedule was not followed in 2021 and early on in 2022, casting greater uncertainty about results above 15 mg/L.

which is composed of 15 – 45% carbonate minerals[56], stretches across the Wachusett Watershed through Gates Brook, West Boylston Brook, and Waushacum Brook subbasins. These three tributaries have the highest 2020 – 2024 mean and median alkalinity concentrations in the Wachusett Watershed. Another narrow swath of calcpelite runs under the eastern half of Wachusett Reservoir and the shoreline in Boylston, however this is situated mostly downgradient from monitoring locations on Malagasco, French and Boylston Brooks. Granite and metamorphic rocks, which have little to no carbonic content, comprise most of the bedrock throughout the rest of the Watershed. Accordingly, streams draining those areas have lower alkalinity since the groundwater is largely free of carbonic minerals originating from the bedrock.

Compared to the 2000 – 2012 period, the latest four years of alkalinity data, including 2024, show slight increases in mean alkalinity (0.23 – 3.77 mg/L) at most tributaries, except for Muddy Brook (Table 12). For 2024, mean annual alkalinity values were the highest in the period 2020 – 2024 at every tributary except for Waushacum and Trout Brooks and the Quinapoxet and Stillwater Rivers. Alkalinity concentrations in 2024 ranged from 5.44 mg/L at Trout Brook to 46.24 mg/L at Gates Brook.

There are no drinking water criteria for alkalinity, however the EPA recommends a minimum concentration of 20 mg/L for the protection of aquatic life. Data from 2020 – 2024 suggest that most Wachusett tributaries fall below this minimum alkalinity requirement to protect aquatic life. As more data are collected it will become possible to draw stronger conclusions about how alkalinity has changed over the years and whether the tributaries exhibit any seasonal variability or statistically significant trends.

Table 12: Wachusett Tributary Alkalinity (mg/L) 2000 – 2012 Compared to 2020 – 2024 Results

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

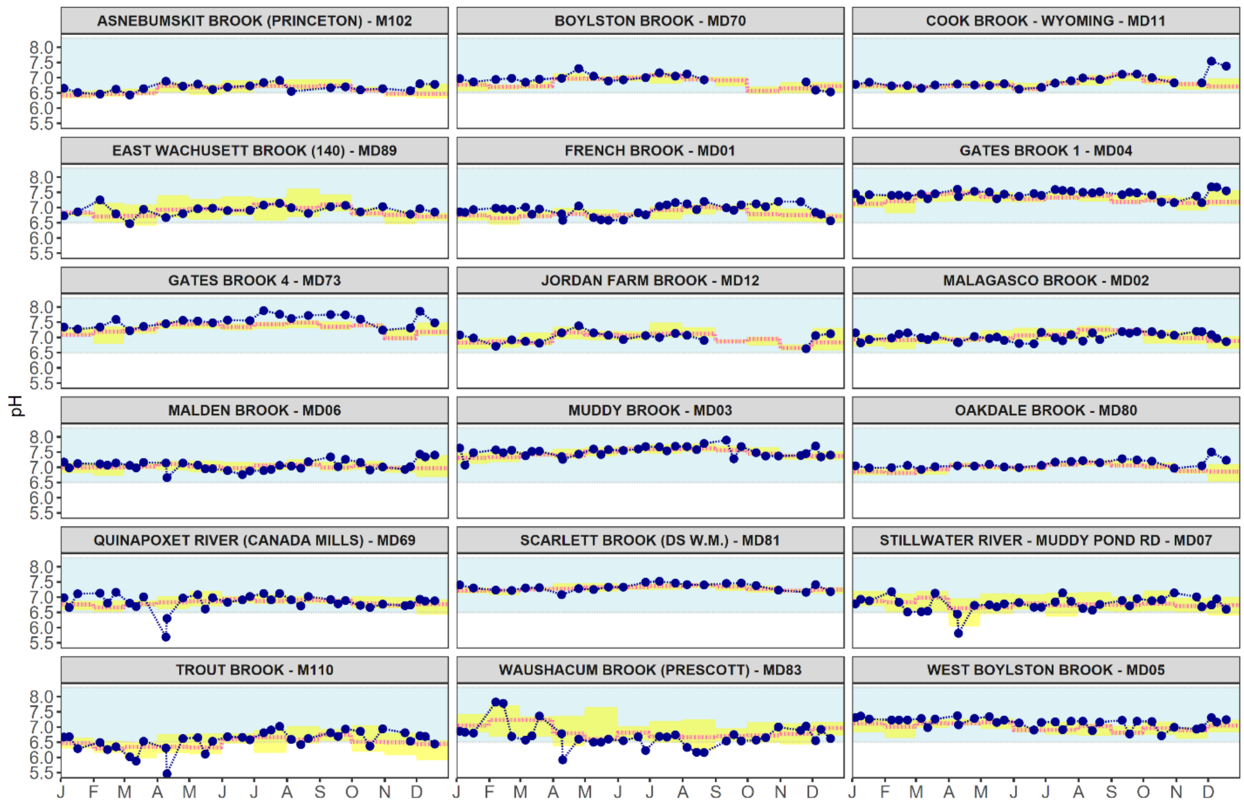
Sample Location	# Samples 2000-2012	# Samples 2020-2024	Mean 2000-2012	Mean 2020-2024	Median 2000-2012	Median 2020-2024
Cook Brook -Wyoming - MD11	61	N/A	30.85	N/A	30.80	N/A
French Brook - MD01	71	52	13.32	16.75	10.80	12.60
Gates Brook 1 - MD04	77	52	43.64	43.87	44.90	43.90
Jordan Farm Brook - MD12	48	N/A	16.88	N/A	15.50	N/A
Malagasco Brook - MD02	78	52	11.63	11.93	11.10	12.20
Malden Brook - MD06	65	52	20.37	21.10	22.00	21.25
Muddy Brook - MD03	78	52	21.66	20.41	22.55	20.40
Quinapoxet River (Canada Mills) - MD69	138	51	8.36	10.75	7.96	9.96
Rocky Brook (E Branch) - MD13	48	N/A	1.48	N/A	0.56	N/A
Shaft 1 (Quabbin Transfer) - MDS1	N/A	20	N/A	4.54	N/A	4.06
Stillwater River - Muddy Pond Rd - MD07	138	52	7.94	10.99	6.85	8.89
Trout Brook - M110	N/A	47	N/A	4.64	N/A	4.36
Waushacum Brook (Prescott) - MD83	N/A	52	N/A	31.68	N/A	28.05
West Boylston Brook - MD05	78	52	31.63	35.40	32.80	34.30

[56] Grady & Mullaney, 1998

Across all tributary monitoring locations, pH values in 2024 ranged from 5.46 at the Stillwater River to 7.89 at Muddy Brook (Figure 25). Tributary pH values below the recommended range (6.5 – 8.3)[57] are common in Wachusett Watershed and were observed at the following six monitoring locations at least once in 2024: Asnebumskit Brook, East Wachusett Brook, Trout Brook, Waushacum Brook, and the Quinapoxet and Stillwater Rivers. In 2024, seasonal variation in pH levels across monitoring locations generally followed historical patterns. Several tributaries showed an increase in pH late in the year, after precipitation picked back up after three months of very dry conditions (Figure 25).

Figure 25: 2024 Results for pH in Wachusett Tributaries

The blue band represents the MassDEP Class A Surface Water standard range for pH, 6.5 – 8.3 SU. The yellow ribbon represents the 25th -75th percentile historical range by month. The pink dashed line is the monthly historical median.



The extent and magnitude of different anthropogenic and geogenic influences on Wachusett tributary chemistry has not yet been researched, however, DWSP will be investigating those influences as part of its goal to better understand the sources and ramifications of freshwater salinization observed in the Watershed. Long-term trends in Wachusett pH will be compared with regional trends once a sufficient data record is established.

3.2.3 Specific Conductance and Chloride

In 2024, tributary specific conductance ranged from 42 µS/cm at East Wachusett Brook to 1,233 µS/cm at Gates Brook 4. Values of less than 100 µS/cm were recorded in 91% of all samples from Trout Brook (33

[57] Massachusetts Surface Water Quality Standards, 2022f

of 36), 33% of samples at East Wachusett Brook (8 of 24), 11% of samples at the Stillwater River (4 of 36), and 10% of samples at Jordan Farm Brook (2 or 19). This represents 8.7% of all specific conductance samples from Wachusett tributaries during 2024. Measurements greater than 904 µS/cm, the proxy chronic Cl toxicity threshold[58], were recorded in 5.7% of all samples from 2024. For individual tributaries, this threshold was exceeded in 63% of samples from Gates Brook 4 (MD73), 5.6% of samples from Gates Brook 1 (MD04), and 39% of samples from West Boylston Brook. Extremely high specific conductance values (>1,800 µS/cm) were not observed in the grab samples during 2024.

At seven monitoring locations, mean annual specific conductance for 2024 was slightly higher than in 2023 (within 30 µS/cm). Malagasco Brook experienced the largest increase in mean annual specific conductance from 2023 (60 µS/cm), increasing to 412 µS/cm. The other 10 monitoring locations had lower mean specific conductance in 2024 compared to the previous year – eight of which had their lowest mean annual specific conductivity value in the last 10 years. High frequency specific conductance data (where available) was also used to calculate annual means, and the results were very similar to the grab data, which consisted of only 24-36 measurements, depending on the location. This is discussed in further detail below, in Section 3.2.3.1.

Table 13: Annual Mean Specific Conductance (µS/cm) in Wachusett Tributaries

The last column (2024) represents annual mean specific conductance values calculated from high frequency sensors at USGS and Mayfly water quality stations. Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.*

Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2024*
Asnebumskit Brook - M102	254	336	279	249	267	243	195	254	205	209	N/A
Boylston Brook - MD70	579	542	594	686	661	679	546	611	530	531	N/A
Cook Brook -Wyoming - MD11	475	526	640	624	524	489	478	609	543	394	N/A
East Wachusett Brook - MD89	166	174	171	151	169	180	140	164	124	118	N/A
French Brook - MD01	321	447	364	302	318	347	250	298	252	244	244
Gates Brook 1 - MD04	942	1,081	1,272	1,202	1,154	1,075	940	1,027	883	736	809
Gates Brook 4 - MD73	1,276	1,371	1,696	1,558	1,451	1,253	1,149	1,437	1,131	958	N/A
Jordan Farm Brook - MD12	124	181	175	183	193	169	178	187	196	160	N/A
Malagasco Brook - MD02	447	473	450	439	525	558	345	444	331	391	412
Malden Brook - MD06	288	334	364	370	371	382	311	340	308	279	282
Muddy Brook - MD03	273	320	344	335	340	351	296	350	303	275	298
Oakdale Brook - MD80	872	982	1,136	1,166	989	878	954	870	827	575	N/A
Quinapoxet River - MD69	255	304	296	253	261	268	211	291	228	257	259
Scarlett Brook (DS W.M.) - MD81	635	620	771	747	897	632	487	692	550	577	N/A
Stillwater River - MD07	182	213	170	164	174	200	152	197	133	156	156
Trout Brook - M110	74	86	96	92	87	86	82	99	80	81	114
Waushacum Brook - MD83	339	396	420	391	408	421	334	375	332	353	358
West Boylston Brook - MD05	1,137	1,227	1,700	1,280	1,266	1,221	901	1,131	796	706	754

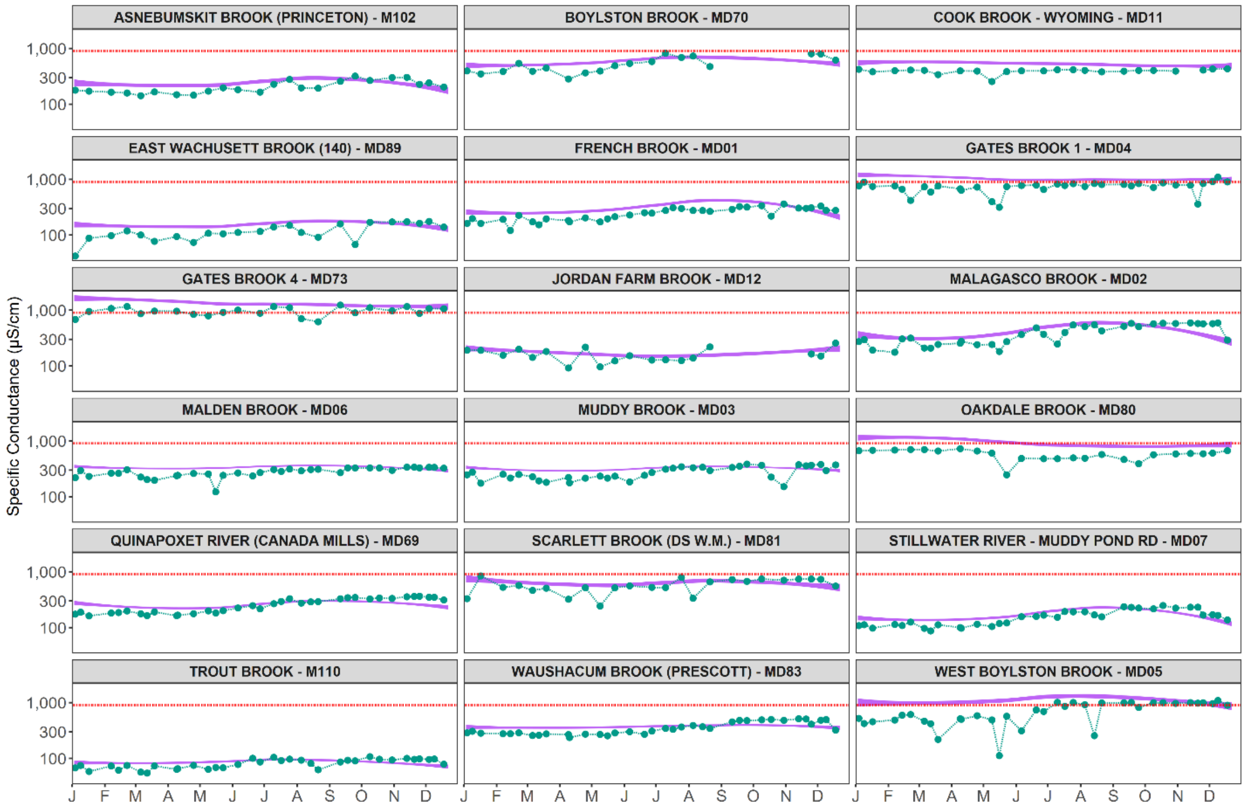
Seasonal patterns of specific conductance in 2024 were influenced by surplus precipitation during the early months of the year followed by extremely dry conditions in the late summer and fall. Most tributaries exhibited lower than normal specific conductivity values until September (Figure 26). Values increased through the late summer and fall months as stream chemistry became more reflective of baseflow (groundwater) due to the lack of precipitation. For 2024, only Gates Brook 4 had a mean annual specific

[58] MassDEP, 2022

conductivity above the chronic chloride toxicity threshold (904 µS/cm), which indicates possible negative impacts to aquatic life (Table 13).

Figure 26: Specific Conductance Measurements at Wachusett Tributaries

The green points show specific conductance results for 2024, with the purple band representing a LOESS smooth function 95% confidence interval for the period 2015-2023. The red dotted line is the MassDEP proxy chronic Cl toxicity threshold of 904 µS/cm.



Roadway deicing products (primarily rock salt) are the dominant source of dissolved ions detected in Wachusett tributaries. As expected, the more developed subbasins with more roads have a higher need for roadway deicing during the winter months, therefore they are experiencing the greatest increases in specific conductance. This topic is discussed in greater detail in a publication by UMass researchers[59].

3.2.3.1 Specific Conductance at USGS and Mayfly Monitoring Stations

High frequency specific conductance data available from the three USGS monitoring stations and the seven Mayfly monitoring stations (DWSP) capture more of the variability of specific conductance throughout the year, which is not reflected in the grab measurements collected two or three times per month. In subbasins that are more impacted by historical and current road salt applications (West Boylston, Gates, Malagasco Brooks), the groundwater specific conductance levels are elevated and there is a distinctive pattern visible in the high frequency data (Figure 27). During the cold months, runoff (rain or snowmelt) is often laden with dissolved road salt which causes rapid spikes in specific conductance. In-stream specific conductance returns to baseline levels when overland runoff stops and baseflow becomes

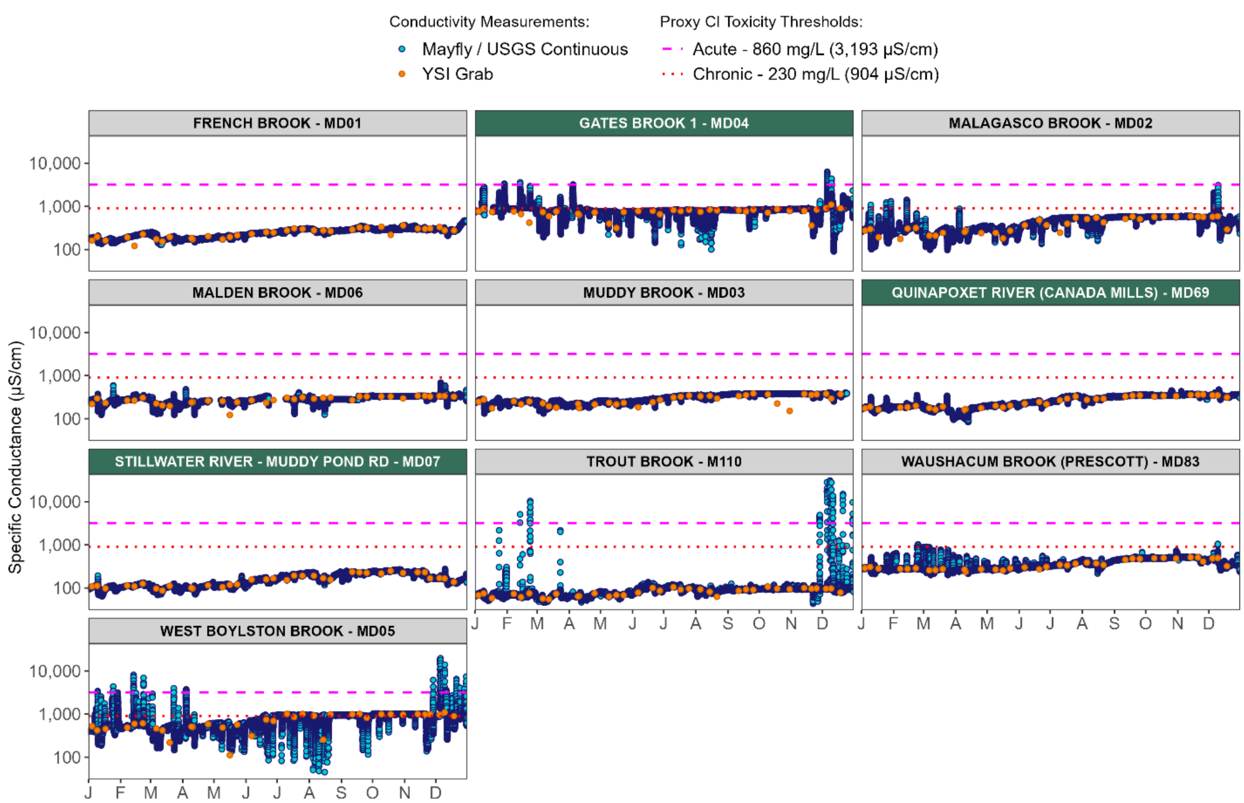
[59] Soper, 2021

dominant again. In the warm months, after the de-icing season is over, roadway runoff is not carrying dissolved salts from de-icing agents and the specific conductivity can be extremely low in comparison to the baseflow (e.g. Gates Brook, West Boylston Brook). These periods are visible in the high frequency data as rapid declines in specific conductance caused by dilution, with levels returning to baseline conditions as runoff stops. This pattern is less prominent in subbasins that are less impacted by roadway salt applications (French, Trout, Waushacum Brooks).

Annual mean specific conductance values calculated from high frequency data were remarkably similar to the annual mean values calculated from the grab data (Table 13). The largest discrepancy was observed at Trout Brook, where several conductivity spikes were recorded by the Mayfly sensor during the snow season, which reached as high as 30,000 µS/cm. The validity of these spikes was confirmed with field verification during a stormwater run-off event immediately after road salt application. There is a stormwater outfall just below the Mayfly sensor in Trout Brook which creates a pocket of salt-laden stormwater that surrounds the Mayfly sensor during periods of runoff. This phenomenon became more pronounced during times of ice accumulation in the stream channel, which restricted water movement and mixing within the vicinity of the Mayfly sensor. As in prior years, the grab samples failed to capture the extremes in specific conductivity on the tributaries. Unfortunately, many of these documented spikes in specific conductance exceeded the 860 mg/L (chloride) acute toxicity threshold for aquatic life (using the proxy specific conductance threshold of 3,193 µS/cm)

Figure 27: Mayfly and USGS Station Conductivity Measurements with YSI Grabs in 2024

The panel labels with a green background are the USGS Monitoring Stations. Gaps in continuous data indicate missing data.



3.2.3.2 Chloride

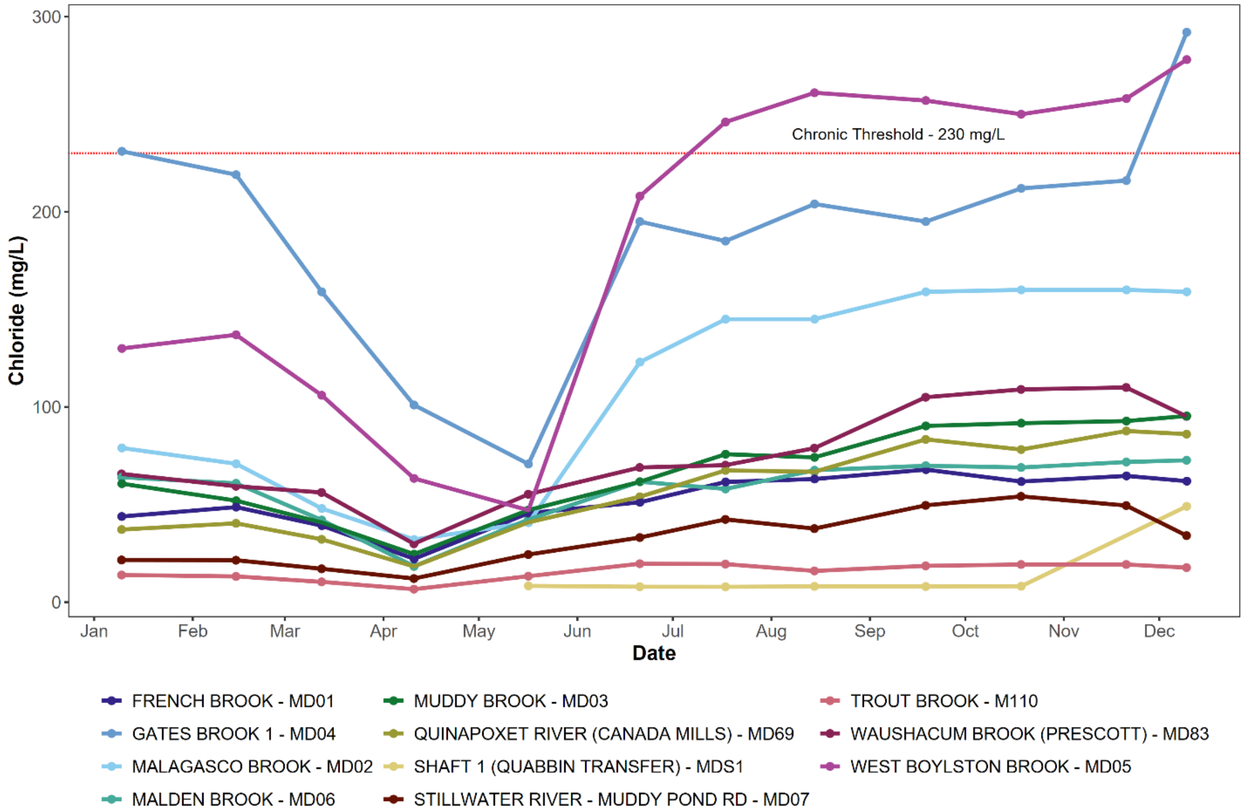
Individual chloride (Cl) concentrations in 2024 ranged from 7.0 mg/L at Trout Brook to 292 mg/L at Gates Brook. Mean Cl concentrations were lower than 2023 concentrations at six Wachusett tributary monitoring locations. Malagasco Brook was the only tributary with a substantial increase in mean annual chloride between 2023 and 2024 (80 to 110 mg/L) (Table 14). Mean annual chloride was lower in 2024 compared to 2023 and the five-year average. As in 2023, Gates Brook 1 had the highest mean annual Cl concentration (190 mg/L) while West Boylston Brook had the second highest concentration (187 mg/L). Trout Brook and the Stillwater River continued to have the lowest concentrations at 16 and 33 mg/L, respectively. These statistics, although comprised of only 12 samples per monitoring location each year, do follow similar patterns reflected by the high frequency specific conductivity statistics, but only when aggregated by longer durations of time. As illustrated by Figure 27, the full range of concentrations is not reflected in the monthly grab data. Therefore, the actual short-term variability in chloride must be inferred through the high frequency specific conductance measurements.

Although Cl is not monitored at a frequency high enough to detect exceedances of the EPA aquatic life criteria, it is probable that both Gates Brook 1 and West Boylston Brook exceeded the chronic threshold for aquatic life (230 mg/L 4-day average) for portions of 2024, and the acute threshold (860 mg/L 1-day average) several times a year after roadway deicing. The five-year mean Cl concentrations at West Boylston and Gates Brooks are about the same as the MassDEP secondary maximum contaminant level (SMCL) for Cl (250 mg/L). However, this SMCL only applies to finished drinking water for public systems. These two tributaries are not directly used for drinking water and contribute less than 2% of the total inflow to Wachusett Reservoir; the overall Wachusett Reservoir Cl concentration is well below this threshold. Still, Cl concentrations at Gates Brook 1 and West Boylston Brook are detrimental to aquatic life and contribute to the overall load of dissolved salts to the Wachusett Reservoir, which has undesirable consequences for drinking water treatment processes.

Table 14: Chloride Concentration (mg/L) Summary for Wachusett Tributaries in 2024

Sample Location	Count	Minimum (mg/L)	Median mg/L)	Maximum (mg/L)	Mean (mg/L)	2020 - 2024 Mean (mg/L)
French Brook - MD01	12	22	56	68	53	64
Gates Brook 1 - MD04	12	71	200	292	190	248
Malagasco Brook - MD02	12	32	134	160	110	110
Malden Brook - MD06	12	18	63	73	58	75
Muddy Brook - MD03	12	25	68	95	67	75
Quinapoxet River (Canada Mills) - MD69	12	18	60	88	58	56
Shaft 1 (Quabbin Transfer) - MDS1	7	8	8	49	14	9
Stillwater River - Muddy Pond Rd - MD07	12	12	34	54	33	37
Trout Brook - M110	12	7	17	20	16	19
Waushacum Brook (Prescott) - MD83	12	30	70	110	75	81
West Boylston Brook - MD05	12	47	227	278	187	267

Figure 28: Chloride Concentrations in the Wachusett Tributaries During 2024



A discussion of other work completed in 2024 related to Cl and conductivity is provided in Section 3.2.9.2. Chloride monitoring in groundwater is discussed in Section 3.3.

3.2.3.3 Salt Loading

The current Watershed Protection Plan (FY24 – 28) includes a multi-prong approach to reduce road salt applications in the Watershed, which should ultimately lead to less salt loading to the tributaries and reservoir. In addition to tracking salt applications by municipalities, MassDOT, and others, DWSP has expanded its chloride/specific conductance monitoring with the installation of Mayfly monitoring stations that measure water temperature, water depth, and specific conductance at 15-minute intervals. Combined with the three USGS stations, DWSP now collects high frequency specific conductance measurements from all 10 primary tributaries, representing about 90-95% of surface water inflows to the Wachusett Reservoir (not including the Quabbin Transfer).

From year to year, watershed salt application amounts (inputs) will vary with winter weather severity, and salt loads in the tributaries (output) will vary with the timing and magnitude of precipitation, runoff, changes to aquifer storage, and baseflow contributions to streams. Over the long-term, DWSP's goal is to track the success of salt reduction programs by documenting decreasing salt application rates (inputs), followed by decreasing salt loading rates (outputs). As this program is newly developed, the period of record of information and data is insufficient to analyze any input/output trends. Until sufficient data are available for trend analysis, annual reports will focus on documenting the year-to-year variability.

For each tributary, a linear regression was performed on coincident specific conductance and chloride grab samples. The regression equations and high frequency specific conductance measurements were then used to derive time-series chloride concentrations at each tributary in 15-minute intervals. Chloride concentrations and associated flow rates, in cubic feet per second, were used to calculate a daily chloride load for each tributary. This daily load of chloride was then used to estimate a daily salt load, assuming that nearly all the chloride present in tributaries comes from dissolved road salt (NaCl). Annual salt loads, shown in Table 15 below, were computed by summing the daily loads for each year.

Table 15: Salt Load Estimates (tons) for Wachusett Tributaries, 2022-2024

Location	2022	2023	2024	% Change from 2023	2022-2024 Average
West Boylston Brook - MD05	236	192	133	-31%	187
Muddy Brook - MD03	145	239	127	-47%	170
Malagasco Brook - MD02	164	327	169	-48%	220
Trout Brook - M110	282	482	349	-28%	371
French Brook - MD01	340	577	234	-59%	384
Malden Brook - MD06	373	599	346	-42%	439
Waushacum Brook (Prescott) - MD83	948	1,629	1,047	-36%	1,208
Gates Brook 1 - MD04	1,339	1,734	1,160	-33%	1,411
Stillwater River - Muddy Pond Rd - MD07	2,224	3,558	2,012	-43%	2,598
Quinapoxet River (Canada Mills) - MD69	4,823	7,139	4,532	-37%	5,498
WACHUSETT TRIBUTARY TOTAL	**10,874**	**16,476**	**10,110**	**-39%**	**12,487**

Compared with 2023, there was a 39% decrease in salt loads in the tributaries for 2024, with all tributaries showing a substantial decrease in salt load (Table 15). The salt loads for 2024 were very similar to the 2022 loads, which received comparable annual rainfall (45.56 and 46.11 inches, respectively).

3.2.4 Turbidity

Turbidity results in Wachusett tributaries in 2024 ranged from 0.22 NTU at West Boylston Brook to 113 NTU at Muddy Brook. There were 27 samples with turbidity levels of 5.0 NTU or higher, which were predominantly collected from Muddy Brook (12 samples), where elevated concentrations of fine particulate matter are historically persistent and naturally occurring. The remaining turbidity results above 5.0 NTU were collected during low flow conditions where shallow stream depths often result in turbidity samples that contain bed load sediments.

2024 annual median turbidity was higher than the 2015 – 2023 median at all sampling locations, and at 11 monitoring locations, near or above the 75th percentile. Annual median turbidity values ranged from 0.6 NTU at East Wachusett Brook to 5.4 NTU in Muddy Brook (Table 16). Median turbidity levels were 0.6 NTU higher (on average) during or after wet weather conditions (> 0.2 inches of rainfall within 24 hours of sample) (Table 17).

Section 3 Boxplots Explained:

1) Lower whisker = smallest observation greater than or equal to lower hinge – 1.5*IQR
2) 25% quantile (lower hinge)
3) Median, 50% quantile
4) 75% quantile (upper hinge)
5) Upper whisker = largest observation less than or equal to upper hinge + 1.5 * IQR
6) Outliers = single observations above upper whisker or below lower whisker
7) Individual sample results (green circle points)
8) Annual median result (red square point)

Note: IQR = Interquartile Range (where 50% of observations fall; 25th –75th percentile)

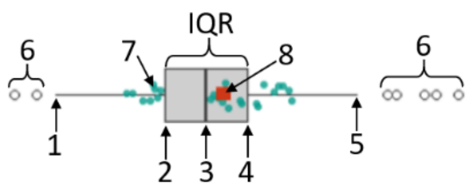
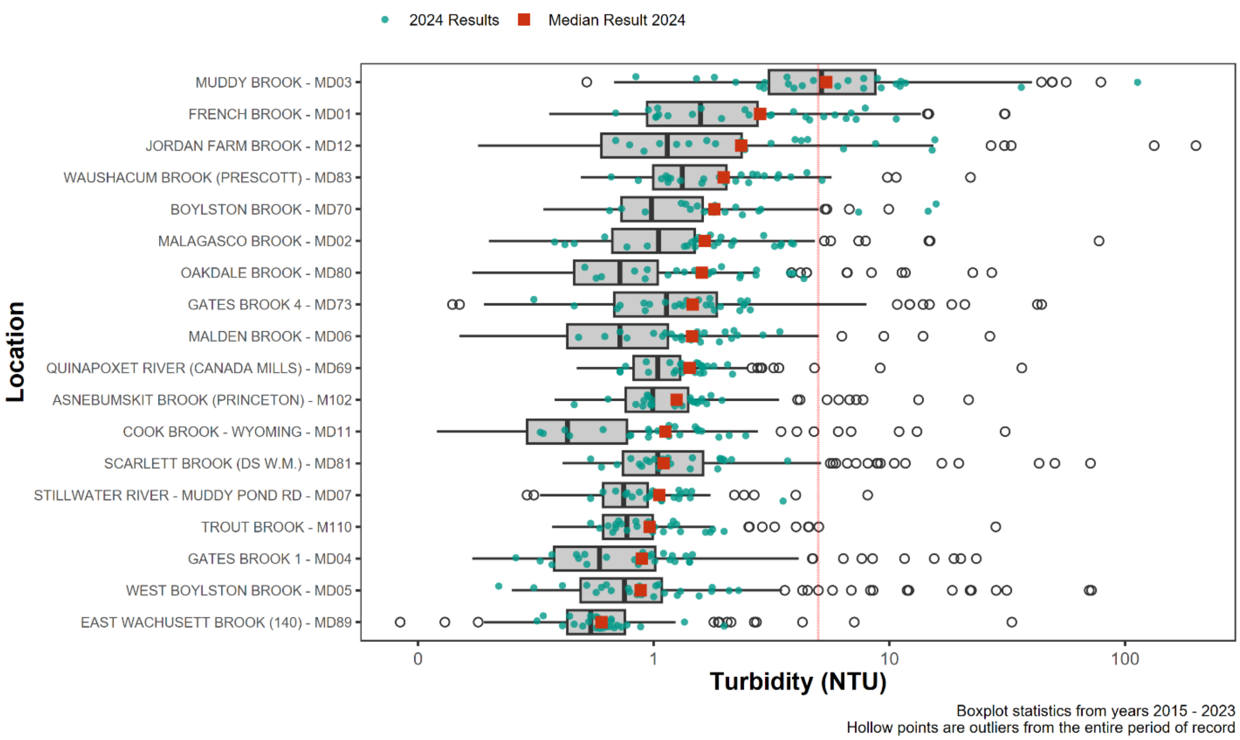


Figure 29: 2024 Turbidity Levels with 2015 – 2023 Statistics

The red vertical line is at 5.0 NTU, the SWTR raw water regulated limit at drinking water intakes.



Annual mean turbidity in 2024 ranged from 0.67 NTU at East Wachusett Brook to 11.5 NTU at Muddy Brook, with mean turbidities higher than in 2023 at every tributary except Gates, Malagasco, Scarlett, and West Boylston Brooks (Table 16). Apart from Boylston Brook, which experienced its highest annual mean turbidity in the last ten years (3.4 NTU), all annual mean values were within historically observed ranges.

Table 16: Annual Mean Turbidity at Wachusett Tributaries (NTU)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Asnebumskit Brook (Princeton) - M102	1.47	1.14	1.63	1.07	1.12	1.16	1.49	2.92	0.85	1.22
Boylston Brook - MD70	0.98	0.92	1.06	1.13	1.44	1.09	1.92	2.24	1.66	3.42
Cook Brook -Wyoming - MD11	0.63	0.28	1.75	0.55	0.42	0.91	1.38	1.82	1.09	1.14
East Wachusett Brook (140) - MD89	0.60	0.47	0.86	0.65	0.57	0.54	0.92	2.14	0.65	0.67
French Brook - MD01	2.16	1.93	1.56	1.73	2.55	6.86	2.08	3.73	2.03	3.61
Gates Brook 1 - MD04	0.53	0.57	1.16	1.23	0.85	1.00	2.38	2.61	1.22	0.86
Gates Brook 4 - MD73	0.91	0.89	2.73	1.88	1.68	1.63	2.90	4.65	2.24	1.51
Jordan Farm Brook - MD12	1.61	0.51	1.68	2.22	2.44	1.65	8.43	15.16	2.58	4.13
Malagasco Brook - MD02	0.90	0.82	1.13	1.27	1.21	1.08	2.32	5.71	1.92	1.87
Malden Brook - MD06	0.84	0.52	0.75	0.95	0.96	0.96	1.48	2.73	1.48	1.54
Muddy Brook - MD03	5.46	5.48	9.12	6.86	6.83	5.36	7.92	11.53	8.72	11.50
Oakdale Brook - MD80	0.63	0.43	2.12	1.18	0.79	1.28	1.31	2.68	1.15	1.82
Quinapoxet River (Canada Mills) - MD69	1.09	1.00	1.01	1.11	1.17	1.14	1.48	3.12	1.29	1.39
Scarlett Brook (DS W.M) - MD81	1.05	1.38	3.65	1.91	2.24	1.17	1.71	5.12	1.69	1.35
Stillwater River - Muddy Pond Rd - MD07	0.76	0.75	0.70	0.80	0.83	0.86	0.97	1.36	0.86	1.13
Trout Brook - M110	1.22	0.60	0.76	0.81	0.90	0.97	1.15	2.27	0.85	1.04
Waushacum Brook (Prescott) - MD83	1.29	2.04	1.74	1.67	1.63	2.09	1.21	3.11	1.02	2.22
West Boylston Brook - MD05	0.86	1.09	3.59	2.22	1.27	1.29	1.98	4.35	1.15	1.01

Table 17: Turbidity Statistics in Wachusett Tributaries for 2024 (NTU)

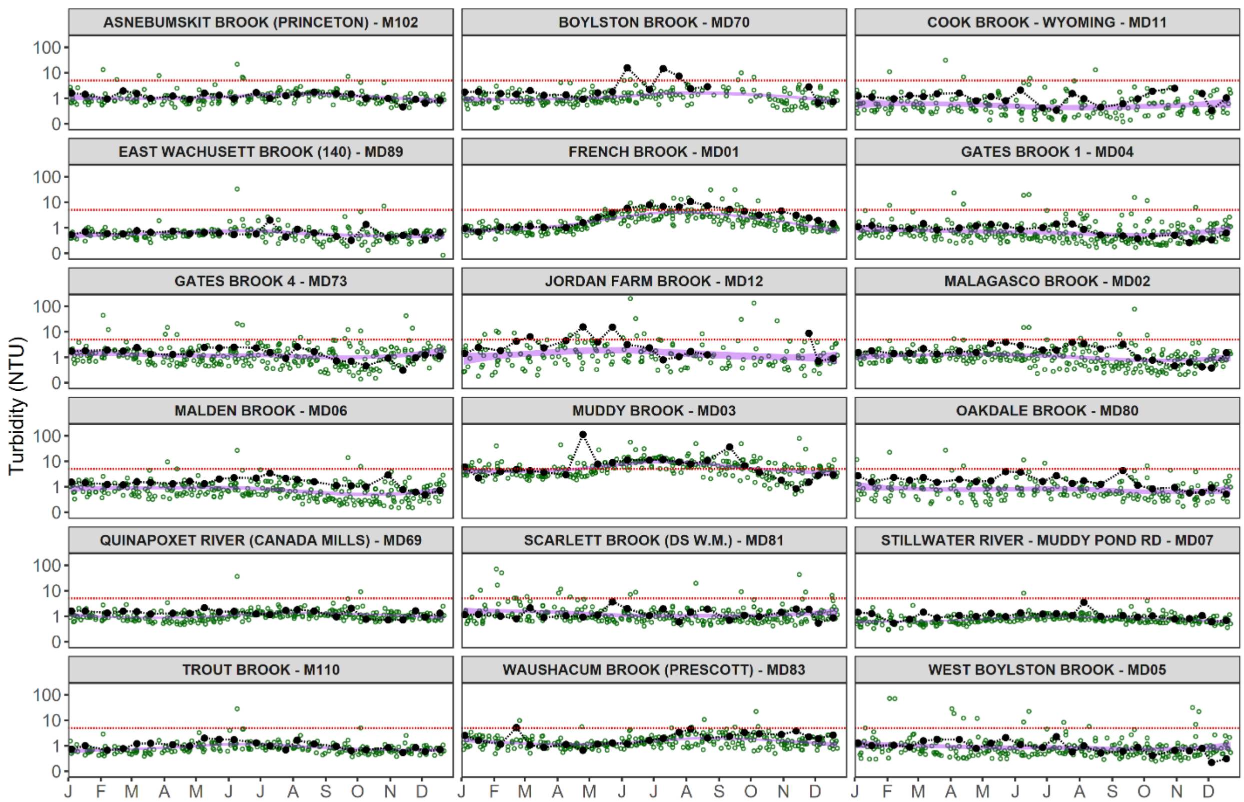
Wet weather samples were collected soon after or during precipitation events of 0.2 inches or more.

Sample Location	Minimum	Maximum	Annual Median	Dry Median	Wet Median
Asnebumskit Brook (Princeton) - M102	0.46	1.95	1.25	0.98	1.43
Boylston Brook - MD70	0.65	15.80	1.81	1.48	2.01
Cook Brook -Wyoming - MD11	0.33	2.46	1.12	1.26	1.04
East Wachusett Brook (140) - MD89	0.32	1.99	0.60	0.57	0.66
French Brook - MD01	0.69	10.70	2.83	2.44	3.92
Gates Brook 1 - MD04	0.26	1.46	0.89	0.52	1.17
Gates Brook 4 - MD73	0.31	2.57	1.46	1.23	2.34
Jordan Farm Brook - MD12	0.69	15.60	2.35	2.09	2.44
Malagasco Brook - MD02	0.38	3.92	1.65	1.39	2.19
Malden Brook - MD06	0.48	3.43	1.46	1.24	1.90
Muddy Brook - MD03	0.84	113.00	5.40	3.94	7.79
Oakdale Brook - MD80	0.51	4.34	1.60	1.35	1.73
Quinapoxet River (Canada Mills) - MD69	0.72	2.16	1.42	1.31	1.52
Scarlett Brook (DS W. M.) - MD81	0.54	3.70	1.10	1.01	1.46
Stillwater River - Muddy Pond Rd - MD07	0.54	3.54	1.06	0.98	1.28
Trout Brook - M110	0.54	1.99	0.96	0.77	1.30
Waushacum Brook (Prescott) - MD83	0.66	5.18	1.98	2.35	1.60
West Boylston Brook - MD05	0.22	2.29	0.88	0.78	1.11
All Wachusett Tributaries (mean)	**0.51**	**10.89**	**1.66**	**1.43**	**2.05**

Figure 30 shows the variability in turbidity by location for 2024 compared to the prior nine years. At nine of the sampling locations, turbidity values were normal and close to historical seasonal levels. Nine other sampling locations experienced higher than normal turbidity for much of the year, especially in the summer and early fall months when streamflow was very low. Muddy Brook experienced two turbidity spikes related to rain events which affected watershed aggregate turbidity statistics for the year. One of these spikes was 113 NTU, which is two orders of magnitude higher than typical watershed stream turbidities. Jordan Farm Brook experienced higher than normal turbidity levels during the spring months, however elevated turbidity on this tributary is usually the result of agricultural operations within the drainage area.

Figure 30: Turbidity Results at Wachusett Tributaries

The black points show turbidity results for 2024, while the hollow green points show results from years 2015 – 2023, with the purple band representing a LOESS smooth function 95% confidence interval for the same period. The horizontal red dashed line is the SWTR threshold of 5.0 NTU.



The standard for turbidity is 5.0 NTU at drinking water intakes under the SWTR and 1.0 NTU at the point of consumption under MassDEP regulations. While these standards are not directly applicable to tributary waters, they can be used as reference points in evaluating the turbidity results. Turbidity levels observed in 2024 were generally very low for moving surface waters and indicative of excellent water quality, predominantly below the 5.0 NTU intake standard (Figure 29). Differences observed between tributaries reflect variations in subbasin land cover, topography, surficial geology, land disturbances from development, agriculture, and other factors. The overall mean turbidity for Wachusett tributaries for 2024 was 2.30 NTU and the median was 1.66 NTU. Turbidity observed at Wachusett Reservoir raw water intake and points of consumption, where the standards apply, is monitored by MWRA and compliance reports are sent to MassDEP regularly.

3.2.5 Total Suspended Solids

Total suspended solids (TSS) in Wachusett tributaries ranged from less than 5.0 mg/L (detection limit) to 61.0 mg/L at Muddy Brook. Only 23 of 126 samples contained more than the detection limit, and most of these samples were collected during or shortly after a rain event. While TSS is not typically considered a parameter of concern in Wachusett Reservoir tributaries, storm events can produce TSS measurements in excess of 100 mg/L. Mean TSS concentrations for 2024 were mostly consistent with the previous nine years, with no unidirectional patterns over time (Table 18). Storm events on two days (May 16 and July 17) resulted in high TSS concentrations at several tributaries and influenced annual mean statistics at those locations. If there were three or fewer detected results each year, the results below detection were multiplied by 0.5 prior to the calculation of summary statistics. Since most samples (82%) were below detection limits, the values presented below have a high degree of uncertainty relative to their magnitude.

Table 18: Total Suspended Solids Annual Mean Concentrations in Wachusett Tributaries (mg/L)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	3.02	3.84	3.00	3.92	7.03	12.43	4.87	4.40	3.92	7.90
Gates Brook 1 - MD04	2.48	3.25	2.21	2.56	3.08	3.33	2.50	2.50	9.25	4.04
Malagasco Brook - MD02	2.80	3.10	3.58	2.93	4.25	3.48	3.13	2.50	9.29	6.86
Malden Brook - MD06	4.27	3.13	2.50	2.77	2.82	2.83	2.50	3.88	3.46	3.29
Muddy Brook - MD03	2.50	6.74	11.99	6.12	4.23	7.16	3.29	3.00	4.98	7.99
Quinapoxet River (Canada Mills) - MD69	2.49	3.13	2.50	2.75	2.50	2.50	2.50	2.92	2.83	3.29
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	1.75	2.82	2.45	2.50	2.50	2.50	2.50	2.50
Stillwater River - Muddy Pond Rd - MD07	2.50	3.88	2.43	2.49	2.50	2.71	2.50	2.50	2.50	3.50
Trout Brook - M110	2.91	2.94	2.50	2.92	2.75	2.50	2.50	2.50	2.50	3.68
Waushacum Brook (Prescott) - MD83	2.50	2.89	2.43	5.06	3.00	2.79	3.00	3.17	2.78	3.42
West Boylston Brook - MD05	2.49	2.77	4.33	4.88	2.96	15.96	4.88	2.50	3.63	4.04

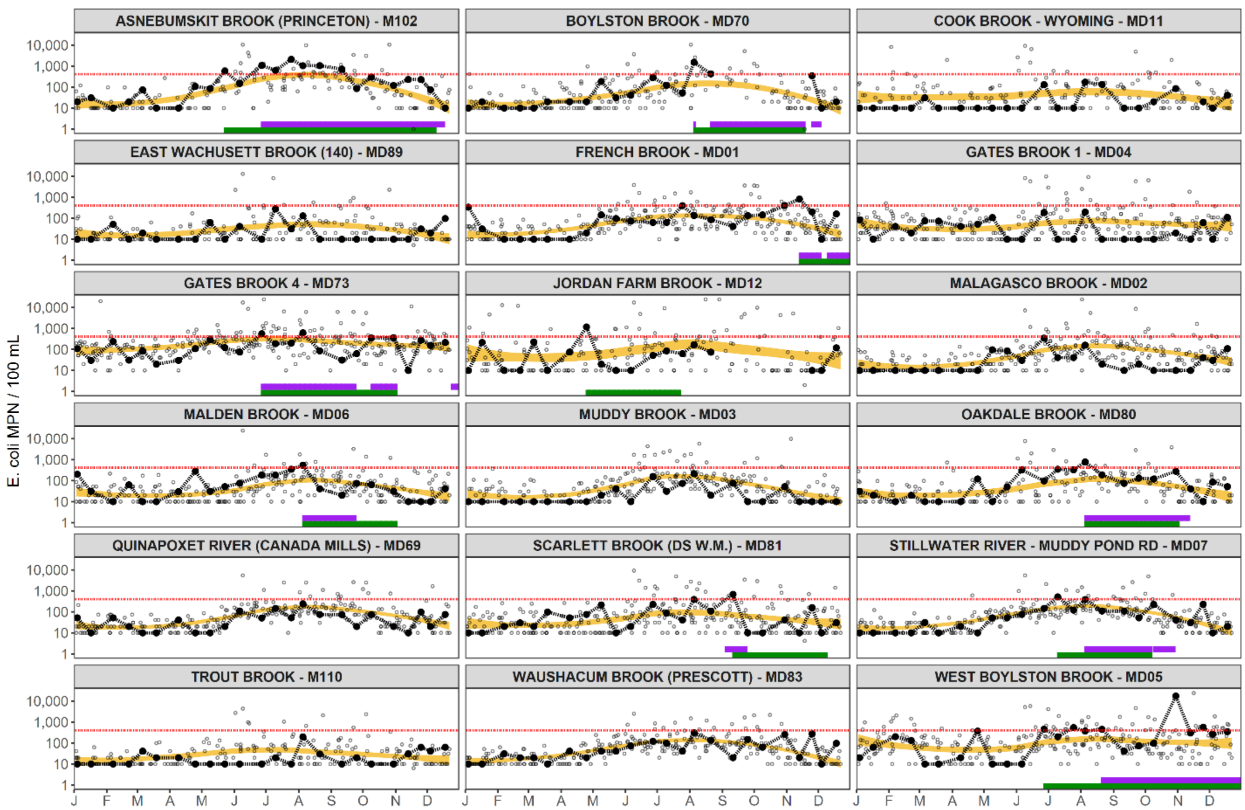
3.2.6 *E. coli* Bacteria in Tributaries

Bacteria samples collected from Wachusett Reservoir tributaries during 2024 contained a wide range of *E. coli* concentrations, from less than the lower detection limit (10 MPN/100 mL) in approximately 19% of all samples, to a high of 17,300 MPN/100 mL at West Boylston Brook on October 30. As in previous years, the higher bacteria concentrations were usually recorded during or following precipitation, however in 2024, some tributaries experienced more frequent elevated bacteria concentrations during dry conditions (French, Jordan Farm, Malden, Waushacum, and West Boylston Brooks). Four of the seven samples that exceeded 1,000 MPN/100 mL in 2024 were collected from Asnebumskit Brook, while the other three occurred at Boylston Brook, Jordan Farm Brook, and West Boylston Brook. Except for Boylston Brook, the tributaries that experienced elevated bacteria concentrations in 2024 have had sustained periods of elevated bacteria that were investigated in 2024 or in prior years.

In 2021, Massachusetts Surface Water Quality Criteria were revised to adopt EPA's 2012 bacteria criteria recommendations, which replaced the EPA recommendations from 1986. These changes updated the single sample maximum threshold of 235 CFU/100 mL for *E. coli,* with a statistical threshold value (STV) of 410 CFU/100 mL, which is not to be exceeded by more than 10% of samples in any 90 day or shorter time period. The geometric mean criteria of 126 CFU/100 mL was not changed, however the time duration for applying the geometric mean changed from a rolling 6-month period to a 90-day, or shorter, period[60]. These standards only apply to Class A/B waters designated for Primary Contact Recreation. The tributaries to Wachusett Reservoir are designated as Drinking Water Supply source waters and primary contact recreation is prohibited by the Watershed Protection Regulations (313 CMR 11.00) and the Massachusetts Drinking Water Regulations (310 CMR 22.20B). Drinking water standards for bacteria are stipulated by the Safe Drinking Water Act and apply to raw water at drinking water supply intakes. This topic is further discussed in Section 3.4.11. Notwithstanding the inapplicability of these standards to Wachusett tributary waters, the bacteria results are compared to these standards in this report for additional context and/or as a benchmark for comparison. For this report, a 90-day duration was used to calculate both the STV and geometric mean statistics.

Figure 31: *E. coli* Concentrations in Wachusett Tributaries in 2024

The black points show E. coli *results for 2024, while the hollow points show results from years 2015 – 2023, with the orange band representing a LOESS smooth function 95% confidence interval for the same period. The red dashed line is the MassDEP Class A surface water quality standard STV: 410 MPN/100 mL. The regions underlined with a purple bar indicate days where the geometric mean surface water quality standard was exceeded, while those underlined with a green bar indicate days where the STV standard was exceeded.*



In 2024, 10 of the 18 Wachusett Watershed tributaries exceeded the MA Class A surface water quality standard STV and/or geometric mean *E. coli* threshold for at least one day (Figure 31 and Table 19). In total, there were only 22 individual results above 410 MPN/100 mL. Surface water quality standard

[60] MassDEP, 2021

exceedances often persist for several weeks to months at a time due to the frequency of sample collection (twice per month) and statistical methodology, which is focused on Primary Contact Recreation (e.g. swimming/boating). Most tributaries exhibit a seasonal increase in bacteria levels during the summer months when there are more favorable physical, chemical, and biological conditions for bacterial growth and survival, of which temperature is a dominant driver. This pattern was evident at most monitoring locations in 2024 (Figure 31).

Table 19: Bacteria (*E. coli*) Surface Water Quality Standard Exceedances during 2024

This standard applies only to Class A/B surface waters designated for Primary Contact Recreation. Exceedances for this standard are not applicable to Wachusett Tributaries, but are presented for context and comparison purposes.

Location	# of Samples	# Results > 410 MPN/100mL	# Days Exceeding STV-90	# Days Exceeding GM-90	# Days Exceeding SWQS	% Days Exceeding SWQS
Asnebumskit Brook - M102	24	7	201	174	209	57
Boylston Brook - MD70	19	2	106	101	115	31
Cook Brook -Wyoming - MD11	23	0	0	0	0	0
East Wachusett Brook - MD89	24	0	0	0	0	0
French Brook - MD01	24	1	49	43	49	13
Gates Brook 1 - MD04	24	0	0	0	0	0
Gates Brook 4 - MD73	24	2	129	123	137	37
Jordan Farm Brook - MD12	19	1	90	0	90	25
Malagasco Brook - MD02	24	0	0	0	0	0
Malden Brook - MD06	24	1	90	51	90	25
Muddy Brook - MD03	24	0	0	0	0	0
Oakdale Brook - MD80	24	1	90	100	100	27
Quinapoxet River - MD69	24	0	0	0	0	0
Scarlett Brook (DS W.M.) - MD81	24	1	90	21	97	27
Stillwater River - MD07	24	1	90	85	111	30
Trout Brook - M110	24	0	0	0	0	0
Waushacum Brook - MD83	24	0	0	0	0	0
West Boylston Brook - MD05	24	5	188	133	188	51

Figure 32: Annual Geometric Mean vs 90-Day Rolling Geometric Mean of *E. coli* for Wachusett Reservoir Tributaries (MPN/100 mL).

The red line indicates the MassDEP Class A surface water quality standard: 126 MPN/100 mL (geometric mean), applicable to the 90-day rolling geometric mean (purple points). The bars represent the annual geometric mean for each year, with the colors indicating different seasons.

For 2024, the annual *E. coli* geometric mean was below 126 MPN/100 mL at all Wachusett tributaries (Table 20). Muddy Brook had the lowest geometric mean (11 MPN/100 mL), whereas Asnebumskit Brook had the highest geometric mean (113 MPN/100 mL). Aside from West Boylston Brook, annual geometric mean concentrations of *E. coli* over the past 5 years do not show any significant (visually) unidirectional trend (Figure 32). The interannual variability in bacteria concentration has multiple drivers, which differ in each of the tributary drainage areas. Low to moderate tributary bacteria concentrations, < 410 MPN/100 mL, will degrade over the long residence time in Wachusett Reservoir and have not led to exceedances of drinking water standards at the intake.

Bacterial source investigations were completed in 2018, 2023 and again in 2024. In 2018, one source of elevated bacteria concentrations was geographically linked to a large population of roosting birds in the Gates Brook 9 subbasin. In 2023, an investigation led to a bacterial source geographically linked with wildlife activity (raccoon/rats) in the stream corridor upstream of Gates Brook 4. This investigation concluded that the animals were likely foraging in dumpsters behind food service businesses along Rt. 12 in West Boylston. Efforts were made to inform the business owners of the issue and remind them of proper management of food waste, which may persuade wildlife to relocate due to lower food availability.

In 2024, persistently elevated bacteria concentrations at Asnebumskit Brook prompted a bacteria source tracking investigation. The location of the bacteria source on Asnebumskit Brook was determined, however the animal source of *E. coli* has yet to be confirmed, despite two rounds of DNA analysis. More information about this investigation is provided in Appendix D: Quality Assurance.

Table 20: Trends in Geometric Mean E. coli *Concentrations (MPN/100 mL)*
Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2021 GEOMETRIC MEAN	2022 GEOMETRIC MEAN	2023 GEOMETRIC MEAN	2024 GEOMETRIC MEAN	5 YEAR GEOMETRIC MEAN	10 YEAR GEOMETRIC MEAN
Asnebumskit Brook - M102	110	106	50	113	86	68
Boylston Brook - MD70	27	19	41	39	28	29
Cook Brook -Wyoming - MD11	44	31	17	12	32	29
East Wachusett Brook - MD89	28	22	16	14	20	20
French Brook - MD01	47	53	27	59	43	46
Gates Brook 1 - MD04	79	56	31	25	47	43
Gates Brook 4 - MD73	284	180	152	108	180	168
Jordan Farm Brook - MD12	42	61	41	28	43	53
Malagasco Brook - MD02	51	47	30	17	35	37
Malden Brook - MD06	38	34	27	41	35	35
Muddy Brook - MD03	20	29	22	11	26	31
Oakdale Brook - MD80	34	45	20	53	38	40
Quinapoxet River - MD69	38	65	36	32	45	48
Scarlett Brook (DS W.M.) - MD81	43	37	29	37	36	36
Stillwater River - MD07	40	49	37	44	46	48
Trout Brook - M110	22	24	30	15	22	22
Waushacum Brook - MD83	52	56	36	46	48	43
West Boylston Brook - MD05	185	127	110	99	127	97

Aside from the Quinapoxet River and West Boylston Brook, wet weather bacteria concentrations during 2024 were higher than dry weather concentrations (Table 21).

Table 21: Wet and Dry Weather *E. coli* Metrics in Wachusett Watershed Tributaries During 2024 (MPN/100 mL)
Wet weather samples were collected soon after or during precipitation events of 0.2 inches or more.

Sample Location	GMEAN DRY	GMEAN WET	% <10 DRY	% <10 WET	% >410 DRY	% >410 WET	COUNT DRY	COUNT WET
Asnebumskit Brook (Princeton) - M102	93	156	6.7	11.1	20.0	44.4	15	9
Boylston Brook - MD70	21	72	30.0	0	10.0	11.1	10	9
Cook Brook -Wyoming - MD11	9	20	50.0	22.2	0	0	14	9
East Wachusett Brook (140) - MD89	10	32	46.7	22.2	0	0	15	9
French Brook - MD01	56	65	13.3	11.1	6.7	0	15	9
Gates Brook 1 - MD04	20	34	13.3	22.2	0	0	15	9
Gates Brook 4 - MD73	83	167	6.7	0	0	22.2	15	9
Jordan Farm Brook - MD12	15	50	40.0	22.2	10.0	0	10	9
Malagasco Brook - MD02	9	57	53.3	0	0	0	15	9
Malden Brook - MD06	32	63	20.0	11.1	0	11.1	15	9
Muddy Brook - MD03	8	19	53.3	33.3	0	0	15	9
Oakdale Brook - MD80	47	65	13.3	11.1	0	11.1	15	9
Quinapoxet River (Canada Mills) - MD69	31	29	6.7	33.3	0	0	15	9
Scarlett Brook (DS W. M) - MD81	32	46	20.0	11.1	6.7	0	15	9
Stillwater River - Muddy Pond Rd - MD07	34	69	0	0	0	11.1	15	9
Trout Brook - M110	14	18	33.3	22.2	0	0	15	9
Waushacum Brook (Prescott) - MD83	39	59	0	0	0	0	15	9
West Boylston Brook - MD05	158	45	6.7	22.2	26.7	11.1	15	9

It is very difficult for tributary waters to meet the MA Surface Water Quality standard for Primary Contact Recreation, and even more so with the updated criteria. There can be dramatic fluctuations in bacteria concentrations due to precipitation events and variable flow conditions, even without human-related sources of contamination, and in pristine and undeveloped watersheds. Even though Wachusett Watershed tributaries are not regulated for Primary Contact Recreation, it is useful to monitor bacteria concentrations, as this has led to the discovery of persistent sanitary issues that may have otherwise gone undetected and it can help differentiate bacteria sources that may be responsible for elevated reservoir bacteria concentrations (e.g. roosting birds, vs storm water runoff). Despite the several wet-weather related spikes, *E coli* concentrations for 2024 continued to indicate good sanitary quality at most Wachusett Reservoir tributaries and during most of the year.

3.2.7 Nutrient Dynamics

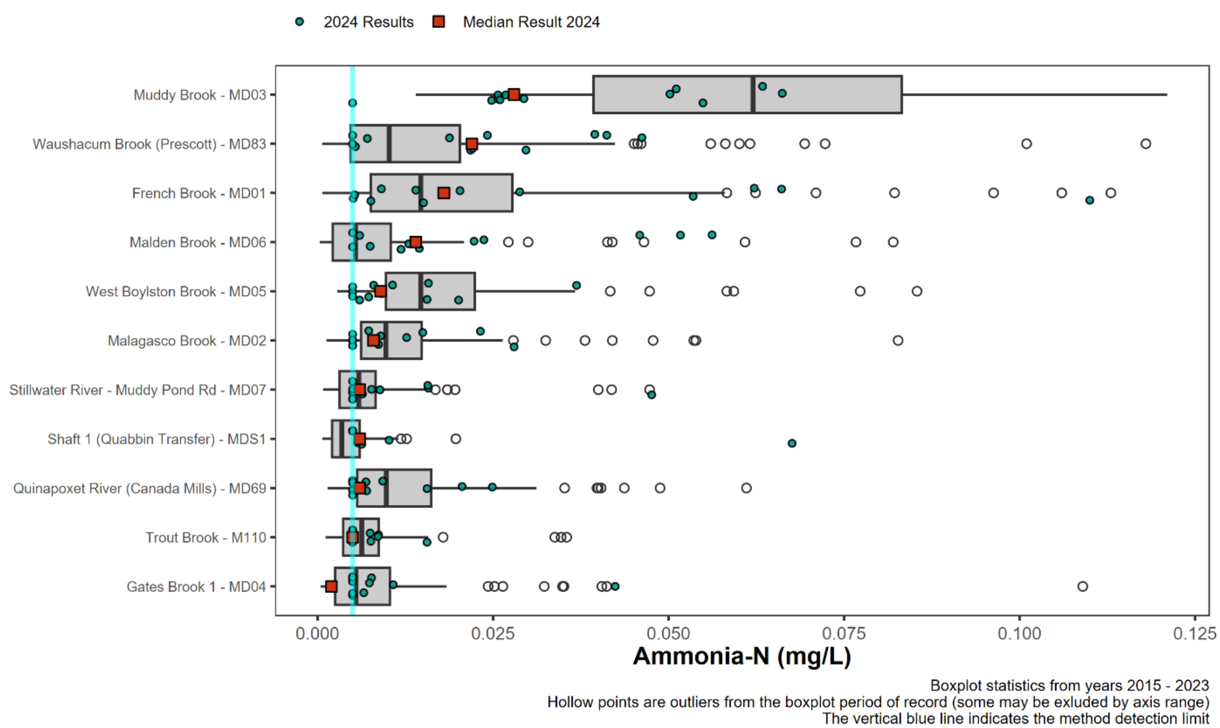
Results for monthly tributary nutrient monitoring in Wachusett tributaries are presented below. Sampling results for Quabbin Transfer water are not discussed but are included in the tables and figures because transfer water is a large percentage of the annual inflow to Wachusett Reservoir and has a significant impact on reservoir nutrient dynamics and overall reservoir water quality.

3.2.7.1 Nitrogen Species (Ammonia-Nitrogen, Nitrate-Nitrogen, Nitrite-Nitrogen, Total Kjeldahl Nitrogen, Total Nitrogen) in Wachusett Reservoir Watershed Tributaries

Ammonia-Nitrogen

In 2024, ammonia-nitrogen (NH_3-N) concentrations were below the limit of detection in 31.5% of samples, while the detected results were mostly within historical 25 – 75th percentile concentrations. There was a higher percentage of results above the detection limit in 2024, along with several outliers greater than the 75th percentile of historical concentrations – most notably at Waushacum Brook and Malden Brook. Muddy Brook continues to have the highest median annual concentration of NH_3-N (Figure 33), however the 2024 median was below the 25th percentile historical concentration. The Muddy Brook sample location is immediately downgradient to a closed landfill in West Boylston, which is a potential source of elevated NH_3-N, although this has yet to be investigated.

Figure 33: 2024 Ammonia-Nitrogen Concentrations with 2015 - 2023 Statistics



Due to the high number of non-detection lab results (<0.005 mg/L) the values presented in Table 22 for NH_3-N have an inherent high level of uncertainty relative to their magnitude. Trout Brook had the lowest annual mean concentration in 2024 (0.006 mg/L), while Muddy Brook had the highest annual mean concentration (0.038 mg/L).

Wachusett tributary NH_3-N concentrations are consistently below the MA acute and chronic aquatic life criteria (17 mg/L and 1.9 mg/L) and below the World Health Organization taste and odor thresholds for drinking water (1.5 mg/L and 1.9 mg/L) by at least one order of magnitude. Thus, NH_3-N does not present a water quality concern for Wachusett tributaries.

Table 22: Ammonia-Nitrogen Annual Mean Concentrations at Wachusett Tributaries (mg/L)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	0.041	0.018	0.012	0.029	0.026	0.201	0.023	0.028	0.013	0.033
Gates Brook 1 - MD04	0.012	0.013	0.008	0.008	0.012	0.006	0.005	0.006	0.009	0.007
Malagasco Brook - MD02	0.028	0.012	0.014	0.011	0.014	0.009	0.014	0.027	0.016	0.010
Malden Brook - MD06	0.016	0.004	0.005	0.012	0.006	0.009	0.008	0.012	0.012	0.022
Muddy Brook - MD03	0.076	0.060	0.078	0.086	0.094	0.055	0.084	0.072	0.069	0.038
Quinapoxet River (Canada Mills) - MD69	0.021	0.011	0.015	0.012	0.011	0.009	0.012	0.014	0.014	0.008
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	0.004	0.003	0.006	0.003	0.008	0.002	0.007	0.013
Stillwater River - Muddy Pond Rd - MD07	0.011	0.007	0.006	0.006	0.005	0.007	0.010	0.007	0.007	0.010
Trout Brook - M110	0.012	0.007	0.008	0.006	0.008	0.007	0.007	0.006	0.007	0.006
Waushacum Brook (Prescott) - MD83	0.023	0.010	0.013	0.011	0.029	0.028	0.017	0.023	0.010	0.022
West Boylston Brook - MD05	0.021	0.016	0.037	0.027	0.034	0.016	0.013	0.013	0.012	0.012

Nitrite-Nitrogen

Nitrite-nitrogen (NO_2-N) is rarely detected in Wachusett Reservoir tributaries, therefore results are not displayed below. In 2024, there was only one NO_2-N concentration above the 0.005 mg/L detection limit: Muddy Brook (0.0068 mg/L) on June 20. The typical tributary NO_2-N concentrations are not a concern for any designated use, however, nitrite's eventual conversion to nitrate in aquatic systems does contribute to the overall nutrient loading of the Wachusett tributaries and Reservoir. All NO_2-N results for 2024 were below the EPA MCL of 1.0 mg/L.

Nitrate-Nitrogen

Annual mean nitrate-nitrogen (NO_3-N) concentrations for 2024 ranged from 0.064 mg/L at Waushacum Brook to 1.14 mg/L at West Boylston Brook (Table 23), with individual measurements from below detection (< 0.005 mg/L) at Waushacum Brook to 1.4 mg/L at West Boylston Brook. The mean annual NO_3-N concentrations in 2024 were higher than in 2023 at all tributaries, except for Waushacum Brook, however concentrations are mostly stable and very close to long-term averages (within 0.1 mg/L). In 2024, Muddy Brook and the Stillwater River had their highest mean annual NO_3-N concentration since 2015, however these records were only 0.03 mg/L higher than their long-term mean concentrations. Annual median NO_3-N concentrations for 2024 were mostly higher than the historical medians from the 2015 – 2023 period (Figure 34), however none were greater than the 75^{th} percentile historical concentration.

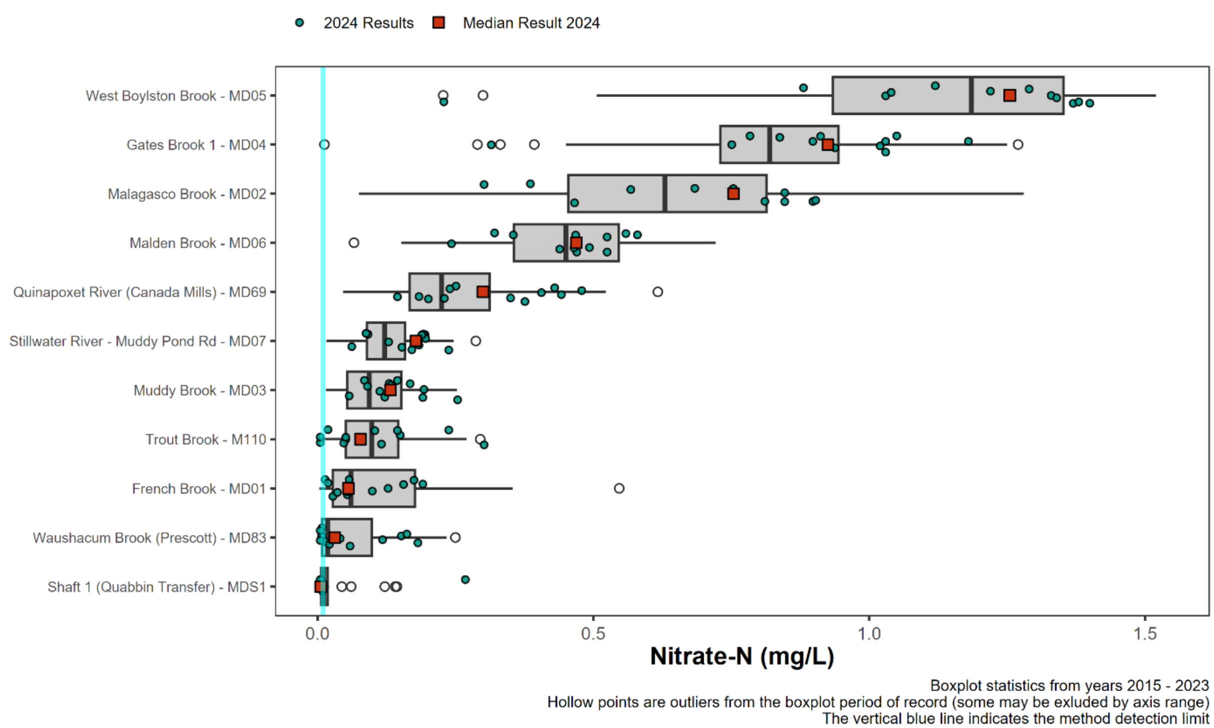
Table 23: Nitrate-Nitrogen Annual Mean Concentrations at Wachusett Tributaries (mg/L)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	0.093	0.153	0.110	0.134	0.119	0.096	0.070	0.078	0.072	0.084
Gates Brook 1 - MD04	0.786	0.762	0.907	0.846	0.886	0.747	0.809	0.801	0.810	0.895
Malagasco Brook - MD02	0.704	0.615	0.684	0.599	0.626	0.619	0.608	0.605	0.491	0.685
Malden Brook - MD06	0.534	0.443	0.488	0.452	0.463	0.424	0.412	0.424	0.373	0.454
Muddy Brook - MD03	0.134	0.139	0.108	0.110	0.095	0.098	0.070	0.125	0.075	0.140
Quinapoxet River (Canada Mills) - MD69	0.291	0.208	0.320	0.239	0.277	0.275	0.186	0.241	0.192	0.311
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	0.020	0.053	0.020	0.010	0.009	0.006	0.011	0.041
Stillwater River - Muddy Pond Rd - MD07	0.155	0.122	0.134	0.108	0.127	0.133	0.124	0.123	0.100	0.157
Trout Brook - M110	0.110	0.101	0.101	0.101	0.097	0.093	0.132	0.125	0.097	0.104
Waushacum Brook (Prescott) - MD83	0.053	0.022	0.030	0.069	0.073	0.059	0.057	0.060	0.068	0.064
West Boylston Brook - MD05	1.250	1.198	1.284	1.069	1.170	1.094	1.115	1.214	0.989	1.136

Most Wachusett tributaries exhibit NO_3-N concentrations reflective of local ecoregional background levels (0.16 – 0.31 mg/L). However, several tributaries continue to have mean NO_3-N concentrations that indicate excessive nutrient loading: West Boylston Brook and Gates Brook 1, which have well documented impacts from urban/suburban development, and Malagasco and Malden Brooks, which are less developed but could be impacted by a higher proportion of agricultural runoff (Malagasco) and potential septic system failures (Malden and Malagasco). While the NO_3-N concentrations at these four tributaries are somewhat elevated, they are still well below the EPA drinking water criteria of 10 mg/L and still low enough that impacts to aquatic life are likely negligible.

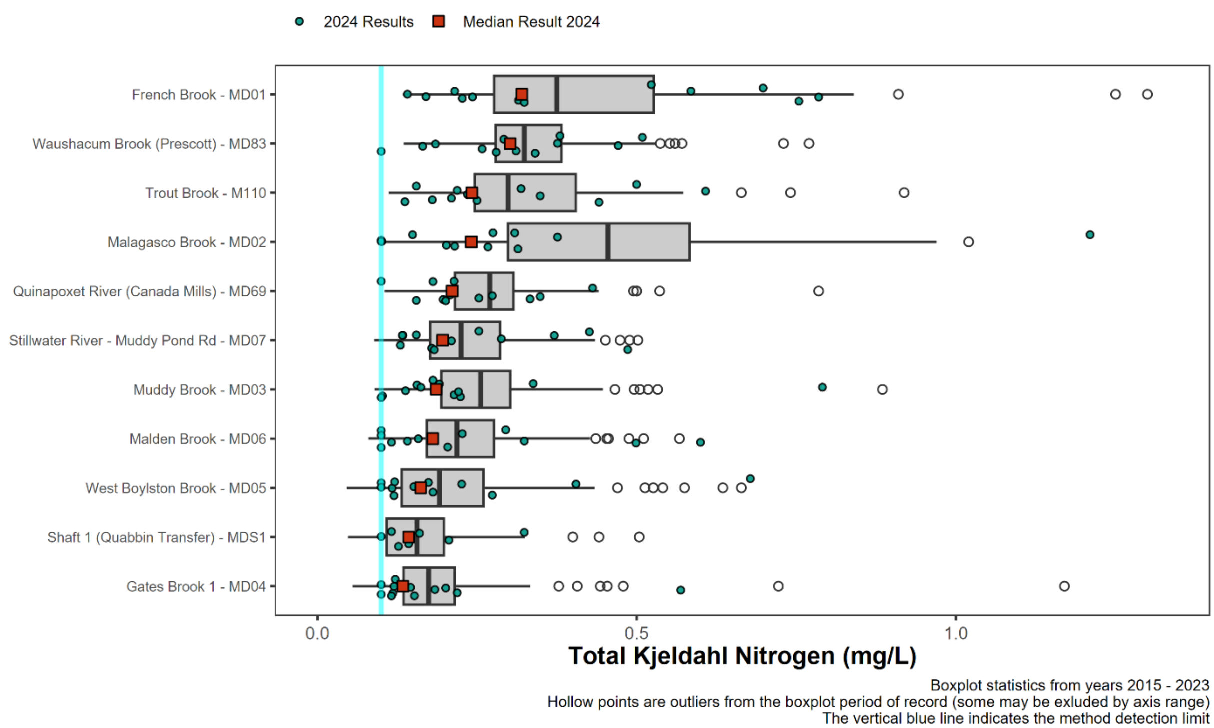
Figure 34: 2024 Nitrate-Nitrogen Concentrations with 2015 - 2023 Statistics



Total Kjeldahl Nitrogen

Annual mean Total Kjeldahl Nitrogen (TKN) concentrations for 2024 ranged from 0.172 mg/L at Gates Brook to 0.295 mg/L at Malagasco Brook, with single sample concentrations ranging from < 0.1 mg/L (detection limit) at Malden Brook to 1.21 mg/L at Malagasco Brook. All 2024 mean annual TKN concentrations were below the long-term average for the previous nine years (2015-2023), except the Stillwater River, which was slightly above. 2024 annual mean TKN concentrations at Malagasco Brook and the Quinapoxet River were the lowest in the period of record. Most individual samples for 2024 fell below the long-term median, with many results falling between the detection limit and the 25th percentile value (Figure 35).

Figure 35: 2024 Total Kjeldahl Nitrogen Concentrations with 2015 - 2023 Statistics



There are no established water quality criteria or standards for TKN, therefore the goal is to maintain local background concentrations in each tributary. TKN concentrations observed in 2024 were generally reflective of local ecoregional background concentrations (0.1 – 0.3 mg/L). The four tributaries with the highest median TKN concentrations (French, Malagasco, Trout, and Waushacum Brooks) frequently contain slightly higher concentrations, between 0.3 and 0.75 mg/L. These four tributaries all have significant proportions of wetlands within their drainage areas, which are highly productive environments where organic compounds containing nitrogen and carbon are constantly breaking down and entering surface waters. Interannual variation is likely driven by variation in seasonal precipitation and runoff patterns. Other reasons for the variation and patterns observed in TKN concentrations have yet to be explored.

Table 24: Total Kjeldahl Nitrogen Annual Mean Concentrations at Wachusett Tributaries (mg/L)
Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	0.391	0.356	0.358	0.480	0.421	0.796	0.419	0.504	0.386	0.415
Gates Brook 1 - MD04	0.158	0.210	0.162	0.163	0.217	0.209	0.216	0.176	0.287	0.172
Malagasco Brook - MD02	0.376	0.344	0.465	0.472	0.389	0.394	0.563	0.479	0.685	0.295
Malden Brook - MD06	0.231	0.222	0.207	0.246	0.198	0.231	0.254	0.251	0.257	0.229
Muddy Brook - MD03	0.252	0.229	0.270	0.267	0.248	0.317	0.291	0.256	0.294	0.232
Quinapoxet River (Canada Mills) - MD69	0.290	0.288	0.246	0.265	0.260	0.258	0.301	0.301	0.280	0.242
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	0.102	0.208	0.190	0.194	0.152	0.158	0.138	0.168
Stillwater River - Muddy Pond Rd - MD07	0.206	0.266	0.228	0.228	0.201	0.227	0.253	0.288	0.259	0.246
Trout Brook - M110	0.257	0.310	0.351	0.345	0.381	0.329	0.360	0.345	0.298	0.300
Waushacum Brook (Prescott) - MD83	0.281	0.361	0.303	0.324	0.338	0.354	0.356	0.426	0.317	0.308
West Boylston Brook - MD05	0.178	0.188	0.175	0.248	0.269	0.376	0.238	0.227	0.234	0.216

Total Nitrogen

Total Nitrogen (TN) concentrations in 2024 ranged from 0.13 mg/L at Waushacum Brook to 1.53 mg/L at West Boylston Brook, with mean annual concentrations for 2024 ranging from 0.38 mg/L at Waushacum Brook to 1.36 mg/L at West Boylston Brook. Except for French Brook in 2020, TN concentrations have been stable at each tributary since 2015. 2024 annual mean concentrations were all within the historical ranges, respectively (Table 25).

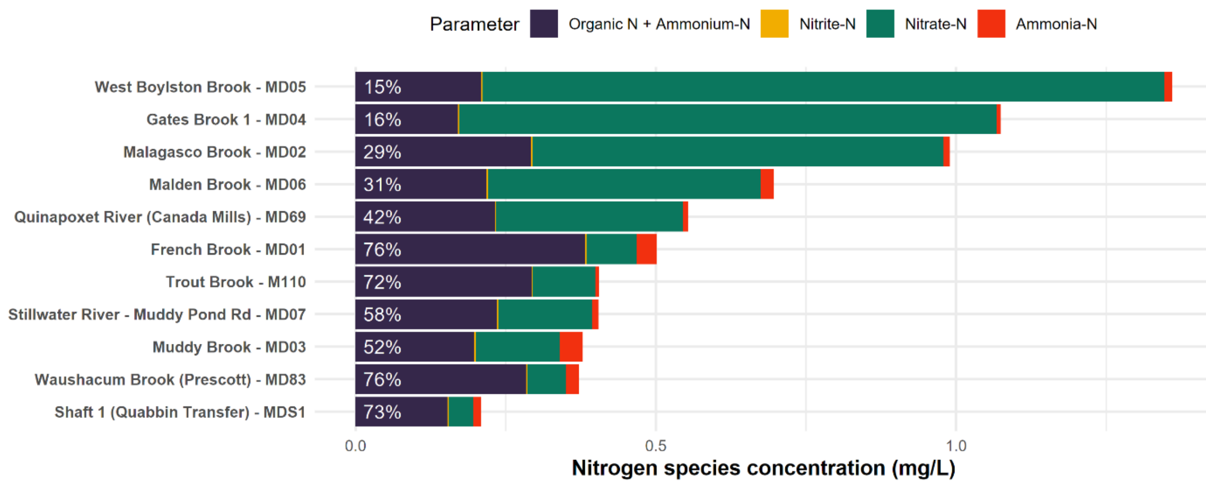
Table 25: Total Nitrogen Mean Annual Concentrations at Wachusett Tributaries (mg/L)
Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	0.488	0.514	0.473	0.619	0.545	0.905	0.494	0.587	0.448	0.504
Gates Brook 1 - MD04	0.952	0.977	1.018	1.014	1.109	0.963	1.030	0.984	1.078	1.079
Malagasco Brook - MD02	1.074	0.966	1.154	1.075	1.020	0.995	1.176	1.089	1.159	0.992
Malden Brook - MD06	0.770	0.670	0.708	0.705	0.666	0.661	0.671	0.680	0.620	0.698
Muddy Brook - MD03	0.391	0.376	0.384	0.382	0.348	0.420	0.366	0.387	0.362	0.380
Quinapoxet River (Canada Mills) - MD69	0.587	0.501	0.571	0.508	0.542	0.539	0.501	0.547	0.468	0.557
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	0.152	0.271	0.217	0.208	0.170	0.189	0.158	0.217
Stillwater River - Muddy Pond Rd - MD07	0.367	0.394	0.367	0.335	0.333	0.366	0.382	0.416	0.358	0.408
Trout Brook - M110	0.448	0.412	0.455	0.452	0.481	0.434	0.497	0.472	0.388	0.408
Waushacum Brook (Prescott) - MD83	0.339	0.388	0.339	0.398	0.416	0.418	0.418	0.491	0.381	0.375
West Boylston Brook - MD05	1.438	1.391	1.472	1.326	1.444	1.452	1.358	1.446	1.192	1.361

Figure 36 shows the relative proportion of all nitrogen species in the Wachusett tributaries, which differ considerably based on the landscape characteristics of each tributary subbasin. Less developed subbasins, such as Trout, French, Malagasco and Waushacum Brooks, usually have higher proportions of organic nitrogen (see discussion of TKN in Appendix C: Watershed Monitoring Parameters and Historical Context) while more developed subbasins, such as West Boylston Brook and Gates Brook, have much lower proportions of organic nitrogen. This phenomenon is a function of the availability of organic nitrogen source material, inorganic nitrogen uptake by plants and phytoplankton, and decomposition rates. On a per unit area basis, less developed subbasins have greater amounts of organic nitrogen within the landscape and more nutrient uptake by plants. The ratios of various nitrogen species play a significant role in aquatic ecology, both in the tributaries and Reservoir, in terms of algal production and bacteria growth and survival.

Figure 36: 2024 Mean Total Nitrogen Concentrations at Wachusett Tributaries

Percentages indicate the organic nitrogen fraction of total nitrogen at each sample location.

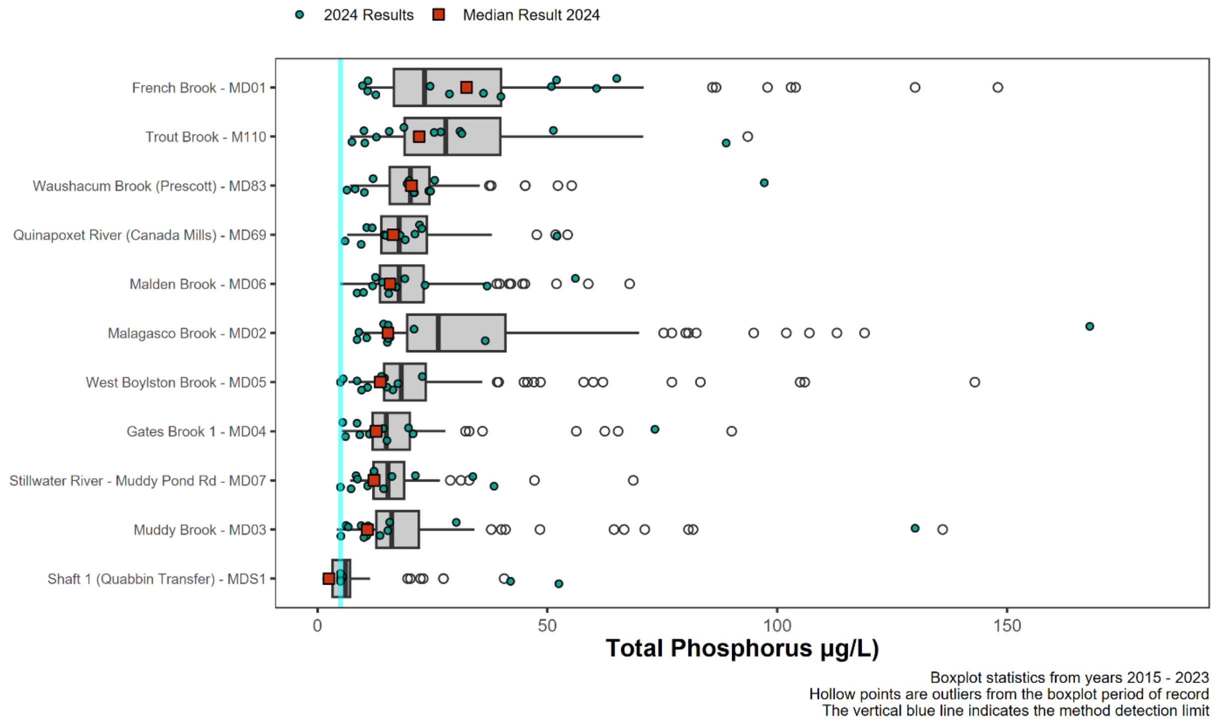


Concentrations of TN within Wachusett tributaries are mostly within the range of ecoregional background concentrations (0.34 – 0.59 mg/L), which are suggested reference conditions for numerical criteria development. West Boylston, Gates and Malagasco Brooks all exceed these concentrations, likely because of either urban/suburban development, golf courses, or agriculture. The Quinapoxet River and Malden and French Brook TN concentrations are also somewhat elevated above naturally occurring background conditions. The Quinapoxet River drainage area is large with many potential nitrogen sources, including significant urban/suburban landscapes and their associated uses. DWSP efforts to reduce nitrogen loads to Wachusett Reservoir should be targeted in the landscapes draining these six tributaries, especially the Quinapoxet River drainage area due to its higher relative loading contribution.

3.2.7.2 Total Phosphorus

Total phosphorus (TP) concentrations measured in Wachusett tributaries during 2024 ranged from < 5.0 µg/L at four tributaries to 168 µg/L at Malagasco Brook (Figure 37). Annual median TP concentrations were below the 2015-2023 median at eight monitoring locations, with the remaining two under the 75th percentile. Annual mean concentrations ranged from 12.8 µg/L at West Boylston Brook to 35.5 µg/L at Waushacum Brook (Table 26). There is very little correlation of TP interannual variability among the tributaries. Half of the tributaries had mean annual TP concentrations higher than in 2023, and half had lower concentrations. Because phosphorus strongly adsorbs to soil particles, higher TP concentrations are typically observed during storm events when soil particles are eroded off the land and carried to tributaries with surface runoff, or during extremely low flows when fine bed load particles can be collected in samples. Both of these conditions were common in 2024, which may explain the outlier results shown in Figure 37. In 2024, there were 13 TP results > 50 µg/L, and these outliers have a significant influence on annual statistics due to the number of samples collected at each tributary each year (n =12).

Figure 37: 2024 Total Phosphorus Concentrations with 2015 – 2023 Statistics



Mean annual TP concentrations in 2024 for most Wachusett tributaries were within typical ecoregional background concentrations (12 – 23 µg/L). Three tributaries (French, Trout, and Malagasco Brooks) have long-term median TP concentrations above 23 µg/L, which could be reflective of local background conditions (high percentage of wetlands), or possibly the result of anthropogenic sources. All these subbasins have on-lot waste disposal systems (septic) on developed parcels. Furthermore, French Brook subbasin contains a golf course which covers 10% of the drainage area and Malagasco Brook contains a nursery operation which covers 8% of its drainage area. The drainage areas to these tributaries should be targeted for nutrient reduction opportunities, specifically evaluating the impacts of septic systems, golf courses, urban stormwater runoff, and agricultural operations on phosphorus concentrations in surface waters. The 2024 flow weighted mean TP concentration for all tributaries plus the Quabbin Transfer was 17.2 µg/L. However, the flow-weighted mean TP concentration of the Wachusett tributaries without the Quabbin Transfer would have been 19.1 µg/L, which is a difference of about 10%.

Table 26: Total Phosphorus Annual Mean Concentrations at Wachusett Tributaries (µg/L)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

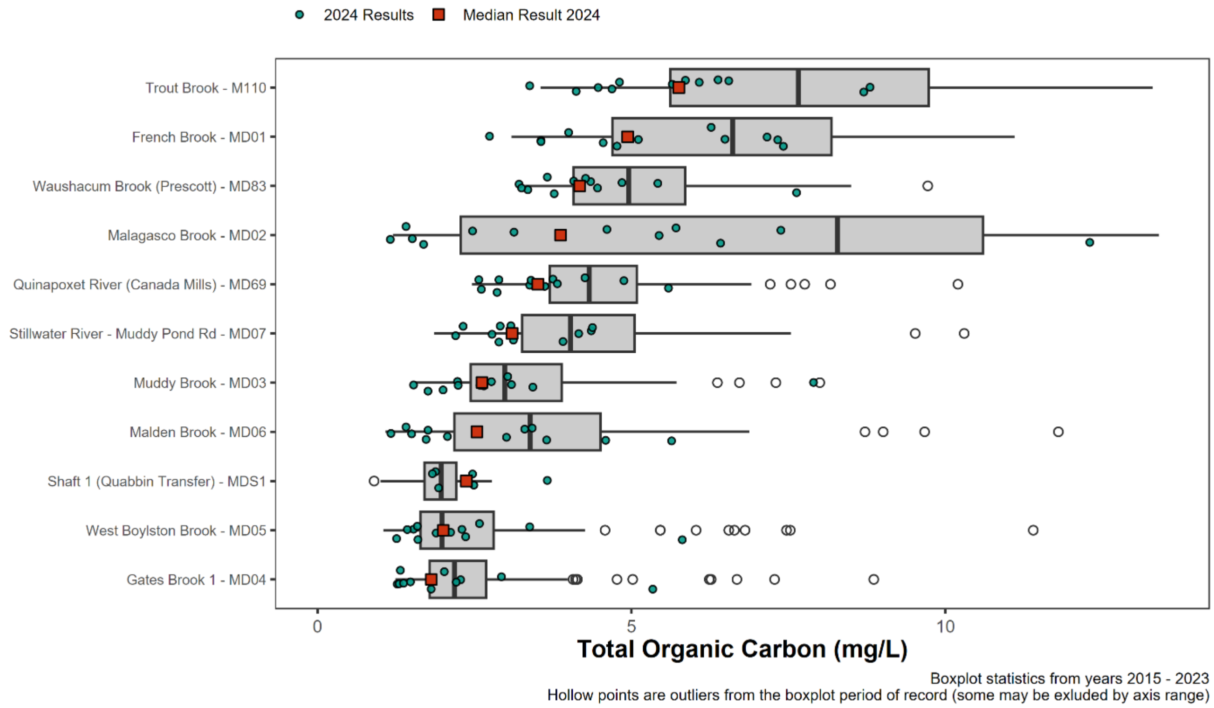
Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook – MD01	32.3	28.7	22.9	26.2	44.3	53.7	25.6	32.6	25.8	33.5
Gates Brook 1 - MD04	14.8	17.3	15.3	18.8	22.9	20.9	15.9	15.2	19.1	17.5
Malagasco Brook - MD02	37.8	25.1	37.3	35.6	30.1	30.2	38.5	29.5	44.4	28.8
Malden Brook - MD06	23.8	19.5	15.6	19.9	17.9	20.6	20.0	20.2	23.4	20.1
Muddy Brook - MD03	18.4	20.1	20.5	20.7	19.3	30.9	18.8	15.2	27.1	22.0
Quinapoxet River (Canada Mills) - MD69	24.0	21.2	17.4	19.0	17.5	22.6	16.7	21.2	17.8	18.6
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	7.8	12.4	7.3	9.7	6.2	6.7	4.1	15.7
Stillwater River - Muddy Pond Rd - MD07	18.9	18.5	14.7	16.0	15.0	18.4	14.6	15.2	18.8	15.7
Trout Brook - M110	50.0	37.6	30.5	29.4	28.9	35.0	27.8	26.3	21.0	27.5
Waushacum Brook (Prescott) - MD83	21.9	26.3	19.8	19.0	20.7	26.5	17.9	22.9	15.7	24.2
West Boylston Brook - MD05	20.5	18.2	19.5	30.8	24.7	32.2	27.0	17.2	28.9	12.8

3.2.7.3 Total Organic Carbon and UV_{254}

In 2024, Total Organic Carbon (TOC) sample concentrations in the Wachusett tributaries ranged from 1.2 mg/L at Malagasco Brook to 12.3 mg/L - also at Malagasco Brook (Figure 38; Table 27). The overall mean concentration for 2024 was 3.7 mg/L, which is 27% lower than the long-term mean concentration since 2015 (5.1 mg/L). Over the 2015 – 2024 period, all tributaries had their lowest annual mean TOC concentration in 2024. Similar to 2023, the highest mean annual TOC concentrations were recorded from Malagasco, Trout, and French Brooks and the lowest concentrations Gates and West Boylston Brooks (Table 27). Most tributaries had median TOC concentrations in 2024 near the 25th percentile from the 2015 – 2023 period of record. West Boylston Brook had a 2024 median TOC concentration close to its historical median (Figure 38).

The 2024 flow-weighted mean TOC concentration for all tributaries and Quabbin Transfer was 2.7 mg/L. Without the Quabbin Transfer, the flow-weighted mean concentration would have been 3.7 mg/L, or 36% higher. The likely source of organic carbon in Malagasco Brook is a headwaters wetland that covers 17% of the subbasin drainage area. The large plant/tree nursery in Malagasco subbasin may be contributing elevated carbon loads in that subbasin, however this also has not yet been investigated or confirmed. French Brook also has a high percentage of wetlands in its drainage area, which are probably a significant carbon source to the stream.

Figure 38: 2024 Total Organic Carbon Concentrations with 2015 - 2023 Statistics



A recent internal analysis of UV_{254} revealed a weak increasing trend at Waushacum Brook and weak decreasing trends in Boylston, French, and Trout Brooks. These trends are strongly influenced by precipitation, which if decoupled from the variation of precipitation, result in no significant increasing trends and two additional significant decreasing trends (Gates Brook 1 and West Boylston Brook). Correlations between UV_{254} levels and TOC are strong, so it is likely that TOC trends are similar. The lower-than-normal TOC concentrations in 2024 can likely be attributed to the extremely dry conditions during the second half of the year and significant flushing from record precipitation during the prior year growing season.

Table 27: Total Organic Carbon Annual Mean Concentrations at Wachusett Tributaries (mg/L)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	5.88	6.06	6.81	7.14	5.51	7.59	6.81	7.11	6.85	5.25
Gates Brook 1 - MD04	1.86	2.34	2.27	2.45	2.46	2.55	2.82	2.53	3.47	2.10
Malagasco Brook - MD02	7.79	8.83	10.82	10.81	7.20	6.80	12.11	9.99	15.25	4.44
Malden Brook - MD06	2.29	3.08	3.50	3.67	2.82	3.50	4.58	3.46	5.15	2.77
Muddy Brook - MD03	2.44	2.93	3.53	3.49	2.73	3.06	4.00	2.98	4.52	2.94
Quinapoxet River (Canada Mills) - MD69	4.11	4.92	4.53	4.73	3.61	3.92	5.33	4.68	5.26	3.64
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	1.89	1.55	1.79	2.04	2.11	2.36	2.36	2.38
Stillwater River - Muddy Pond Rd - MD07	3.89	3.84	4.54	4.79	3.34	3.65	4.64	4.22	5.24	3.27
Trout Brook - M110	9.54	8.50	9.43	9.31	6.51	7.06	7.73	6.58	8.25	5.79
Waushacum Brook (Prescott) - MD83	4.50	4.97	5.36	4.91	4.27	4.98	5.60	6.12	5.78	4.36
West Boylston Brook - MD05	1.76	1.88	2.26	2.71	2.80	3.07	2.73	2.36	3.37	2.32

TOC concentrations between 2 and 4 mg/L are considered low for surface waters, and the 2024 flow-weighted mean TOC concentration of 3.7 mg/L is not a concern for aquatic life. However, this concentration is higher than optimal from a drinking water treatment perspective. Although tributary TOC concentrations are within ranges reflective of typical background concentrations, more research needs to be conducted to determine the sources and controls of natural organic matter that is entering the tributaries. Until those sources and controls are better understood, recommendations for reduction cannot be made. Quabbin water will continue to play an important role in overall TOC concentrations in the Reservoir. The slight upward trend in Shaft 1 TOC concentration may be the dominant driver of any upward trend in TOC observed in the Wachusett Reservoir.

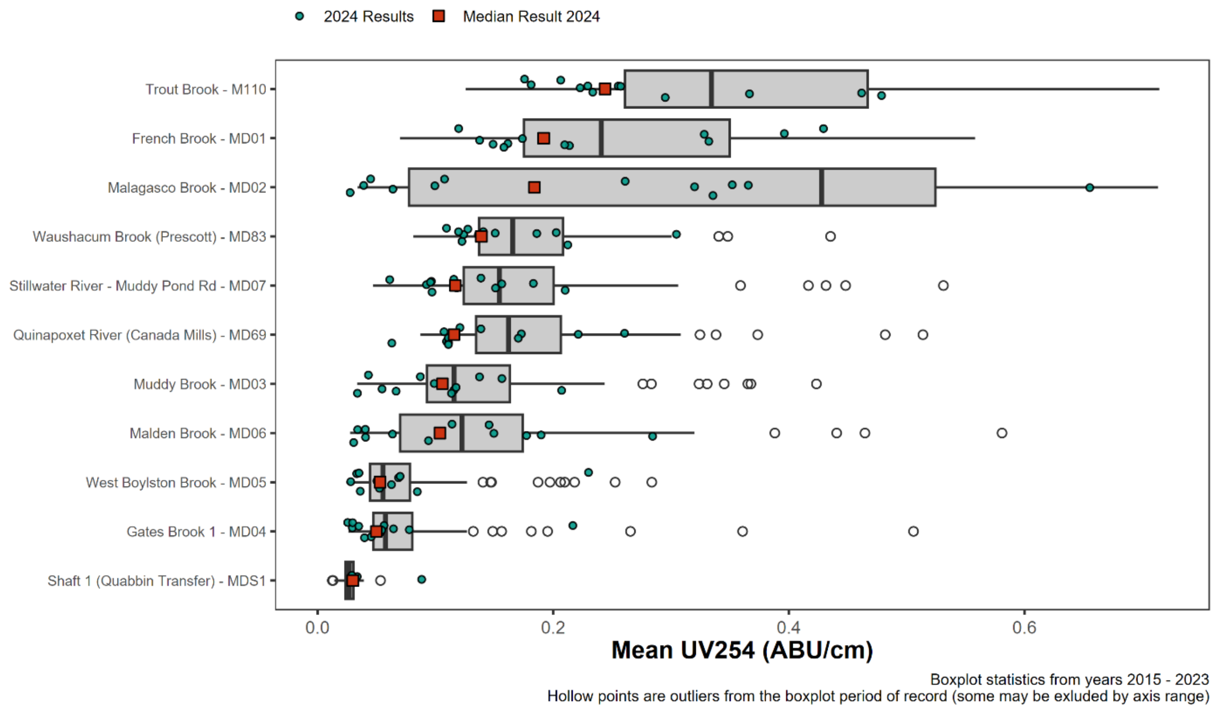
Measurements of UV_{254} absorbance for Wachusett tributaries in 2024 demonstrated variability comparable to TOC concentrations (Figure 39, Table 28). The highest UV_{254} absorbance level was from Malagasco Brook (0.66 ABU/cm) and the lowest was from Gates Brook 1 (0.025 ABU/cm). Mean annual UV_{254} absorbance levels were lower for every tributary in 2024 compared with 2023 (Table 28). Five of ten tributaries had record low annual mean UV_{254} levels for 2024 and annual median levels were below the long-term median at every tributary, with many near or above the 25th percentile historical value (Figure 39).

Table 28: UV_{254} Mean Absorbance at Wachusett Tributaries (ABU/cm)

Table cells are shaded to aid in visually comparing tabular data. Cell colors are based off the relative distance from the high and low values in the shaded region of the table and do not signify those values are below/above any particular threshold.

Sample Location	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
French Brook - MD01	0.23	0.20	0.25	0.31	0.24	0.31	0.31	0.28	0.28	0.23
Gates Brook 1 - MD04	0.05	0.07	0.06	0.08	0.10	0.07	0.08	0.06	0.11	0.06
Malagasco Brook - MD02	0.37	0.30	0.51	0.62	0.38	0.30	0.67	0.51	0.80	0.22
Malden Brook - MD06	0.08	0.10	0.13	0.16	0.12	0.13	0.21	0.12	0.21	0.11
Muddy Brook - MD03	0.10	0.10	0.13	0.15	0.12	0.11	0.22	0.10	0.20	0.10
Quinapoxet River (Canada Mills) - MD69	0.16	0.16	0.20	0.21	0.15	0.15	0.22	0.17	0.20	0.14
Shaft 1 (Quabbin Transfer) - MDS1	N/A	N/A	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04
Stillwater River - Muddy Pond Rd - MD07	0.17	0.13	0.19	0.22	0.14	0.14	0.20	0.14	0.21	0.13
Trout Brook - M110	0.43	0.32	0.44	0.42	0.34	0.33	0.41	0.28	0.38	0.28
Waushacum Brook (Prescott) - MD83	0.15	0.15	0.17	0.19	0.16	0.18	0.21	0.21	0.21	0.16
West Boylston Brook - MD05	0.05	0.06	0.05	0.09	0.08	0.08	0.08	0.06	0.10	0.07

Figure 39: 2024 UV_{254} Absorbance with 2015 - 2023 Statistics



TOC concentrations and UV_{254} absorbance levels observed in 2024 were low compared to historical results, particularly in the latter half of the year. The record high precipitation in 2023 and first quarter of 2024 likely flushed dissolved and particulate carbon from the landscape and soils. The drought during the latter half of 2024 effectively shut off carbon loading in the tributaries from allochthonous sources. Collecting flow targeted and or higher resolution TOC or UV_{254} absorbance data at primary tributary monitoring locations could help provide a better understanding of the factors controlling dissolved organic matter loads[61]. Monthly measurements limit the ability to discern which factors may be responsible for the transport of organic matter through Wachusett subbasins, as deviations from long-term statistics can be heavily influenced by a single sample taken during anomalous hydrologic conditions.

3.2.8 Special Studies and Investigations – Tributaries

3.2.8.1 Long-Term Forestry Water Quality Monitoring

All necessary pre-harvest data has been collected at both study locations, and the experimental lot (Princeton) was put out to bid and sold in 2021. In 2024, the Princeton lot was harvested in September, and monitoring resumed for the post-harvest phase of the study. Unfortunately, due to the drought, the forestry monitoring streams remained dry until December, so only one dry weather and one storm event were sampled in 2024.

[61] Leonard, et. al. 2022

3.2.8.2 Conductivity and Chloride

Since 2018, DWSP's Conductivity/Chloride working group has been meeting quarterly to address the increasing specific conductance observed in the Quabbin and Wachusett Reservoirs and many of their tributaries. In 2024, members of the Chloride/Conductivity working group continued to meet quarterly to discuss progress on tasks and brainstorm possible new initiatives and partnerships. This effort involves staff across all sections of DWSP working on several distinct initiatives within the following categories:

- Education, training and outreach
- Data collection
- Modeling, literature review, partnerships
- Salt reduction grant program
- DWSP salt use
- Interagency Salt Reduction Working Group

Several tasks initiated under this program have now been completed and progress is being made in each category listed above. Additional information about DWSP's watershed system salt reduction efforts[62] is provided on the DCR web page, which includes links to educational videos, signage and brochures. Therefore, the discussion in this report will be limited to water quality monitoring activities conducted in the Wachusett Reservoir Watershed.

Real-time Conductivity Monitoring

Real-time conductivity monitoring has been ongoing for many years at the three USGS stations in Wachusett Watershed. Mayfly monitoring stations have now been installed at the other seven primary monitoring locations: French, Malagasco, Muddy, Malden, Trout, Waushacum and West Boylston Brooks (Figure 40). See Section 2.1.2.2 for background information on Mayfly monitoring stations.

The increased temporal resolution of real-time monitoring (15-minute increments) of specific conductivity captures rapid fluctuations in specific conductivity that are missed by routine sampling programs, which only record discrete specific conductivity measurements three times per month. This information will improve the understanding of the timing and magnitude of chlorides delivered to the tributaries after the application of deicing products on roadways, facilitate accurate calculations of total chloride loads by year, and allow DWSP to monitor for the effectiveness of chloride reduction initiatives over time. The data collected at these stations is summarized in Section 3.2.3.

[62] DWSP, 2025a

Figure 40: Mayfly Station at French Brook

3.2.8.3 Stormwater Basins

Monitoring of the stormwater basins located on either side of the Rt 12/140 causeway has been conducted since July 2019. In 2024, 10 monitoring visits were conducted approximately monthly. These data will be used to track changes in the vegetation within these basins and will assist in determining how well these basins are functioning with respect to reducing chloride loads into the Reservoir.

3.2.8.4 Quinapoxet Dam Removal

In November 2024, the removal of the Quinapoxet Dam in West Boylston, MA proceeded after several years of planning between DCR, MWRA, and the Department of Fish and Game – Division of Ecological Restoration. The dam was constructed in 1905 as part of the original design of Wachusett Reservoir, with the intended purpose of detaining sediment. Rather than investing to maintain this dam for a purpose that is no longer needed, it was decided that the best long-term option was to remove the dam and restore the Quinapoxet River to its natural state. The benefits of this dam removal project include:

- Restoring natural riverine hydrologic processes
- Restoring bordering vegetated wetlands and riverine habitat
- Enabling 35 miles of river accessible to fish
- Eliminating safety concerns related to the deteriorating dam
- Enhancing public access to a popular fishing and recreation area.

Prior to any in-channel work, staff from DWSP, the Division of Ecological Restoration, and volunteers from local universities and other organizations relocated over 1,600 eastern pearlshell mussels (*Margaritifera margaritifera*) from the construction zone to suitable upstream habitat. Conserving this population was important to protect the local ecology of the Quinapoxet River and further support this species in the region, where they are increasingly under threat. The dam removal project included a robust erosion and sediment management plan, with continuous monitoring of turbidity at multiple downstream locations. During the in-channel work, implementation of the erosion and sediment management plan by the contractor was successful in maintaining near-background levels of turbidity for the duration of the project. In order to facilitate the dam removal work, the Quabbin Transfer was shut off about one month earlier than usual, which happened to be at the height of the fall drought. This resulted in a record low volume of water entering the Wachusett Reservoir during the month of November, causing a sharp decline in Reservoir elevation, presented in Figure 20. Riverbank stabilization in the form of tree plantings, live stakes, hydroseeding and root wads have been implemented, and the vegetation is becoming established to provide natural bank stabilization. The dam removal and restoration work will be completed in 2025 and is expected to achieve the aforementioned short and long-term benefits to the river ecosystem and water quality.

3.3 Groundwater Quality Monitoring

Groundwater monitoring continued in 2024 at seven monitoring wells on DWSP property (Figure 6), and the data collected since monitoring began in 2019 have provided preliminary insights on the groundwater quality in Wachusett Watershed aquifers. Results of well monitoring in 2024 continued to show a wide range in specific conductance values within the Wachusett Watershed groundwater (Figure 41). The mean specific conductance in West Boylston – Rt. 110 was more than two orders of magnitude higher than the mean in Sterling – Justice Hill Rd., with values from the other wells between those two extremes (Table 29). Mean specific conductance concentrations in 2024 decreased from 2023 in five of the seven wells while mean values increased in 2024 at West Boylston – Rt. 110 and Princeton – Rt. 62.

Elevated specific conductivity levels in the Wachusett Watershed are assumed to be primarily attributable to the long-term application of deicing road salt, but due to the particularly elevated specific conductance levels in West Boylston – Rt. 110, DWSP launched a supplementary investigation in 2019 to determine additional sources impacting the groundwater at that location. To date, no additional sources of elevated specific conductance have been confirmed, but groundwater quality investigations will continue, as opportunities and resources allow.

The ranges and means of dissolved oxygen and pH are shown in Figure 42 and Figure 43. Comparing the results of 2024 with those of 2023, dissolved oxygen averages increased in the Boylston – Rt. 70 well and decreased in all the other wells, although Sterling – Rt. 140 only decreased by a concentration of 0.05 mg/L. For pH, four of the wells increased in 2024 while three of the wells (West Boylston – Gate 27, West Boylston – Rt. 110, and Princeton – Rt. 62) decreased. The Princeton – Rt. 62 well experienced the greatest change in pH, with a decrease of roughly 0.23 between 2023 and 2024.

Figure 41: Specific Conductance Results in Wachusett Watershed Wells for the Period of Record (2019-2024)

The gray boxplots indicate results from previous years, the yellow boxplot depicts the data from the current report year, and the blue boxplot represents the results combined from the entire period of record (POR). The hollow points are indicative of outliers. The chronic and acute thresholds are surface water criteria for aquatic life, provided here only for comparison.

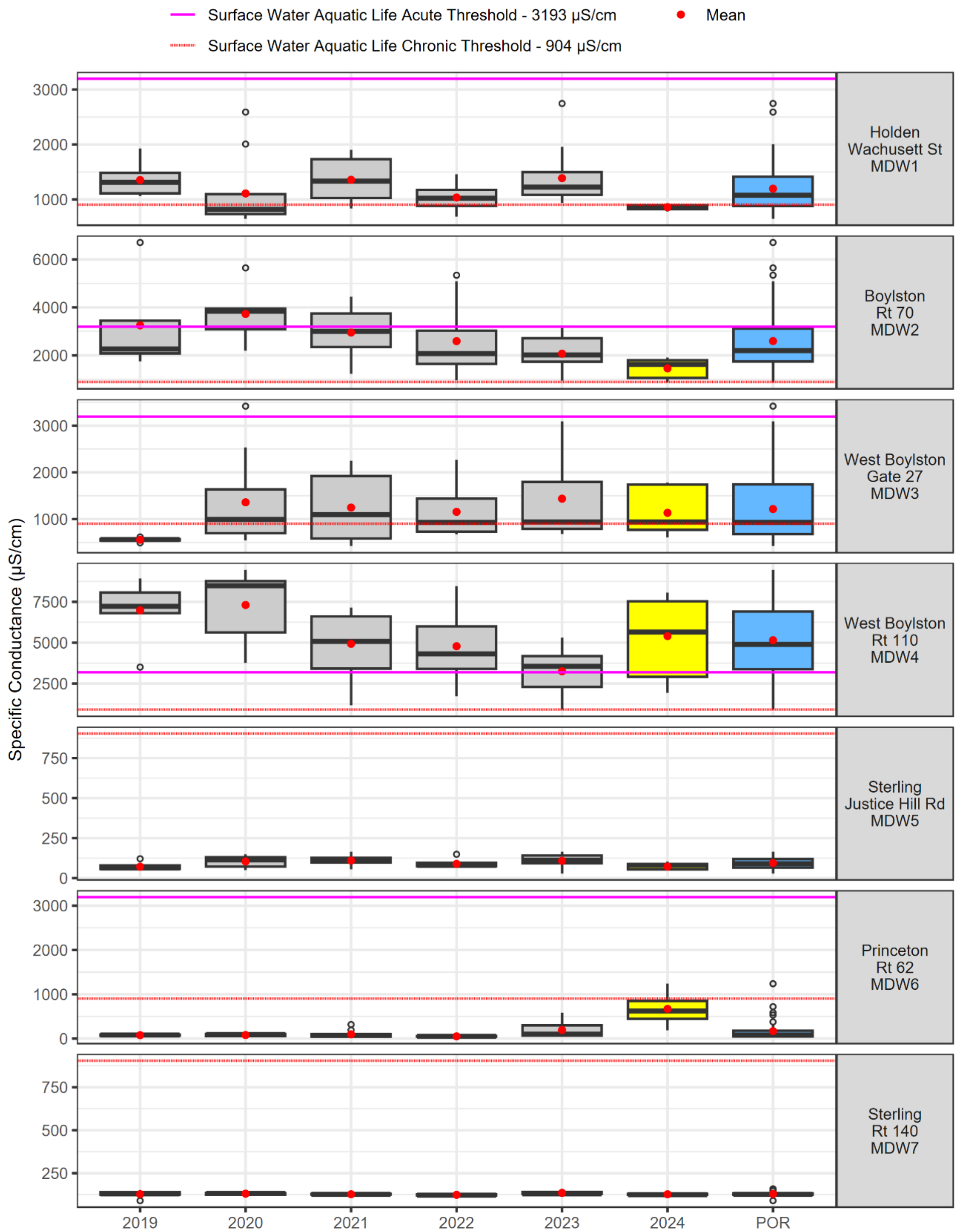


Figure 42: Dissolved Oxygen Results in Wachusett Watershed Wells for the Period of Record (2022-2024)
The gray boxplots indicate results from previous years, the yellow boxplot depicts the data from the current report year, and the blue boxplot represents the results combined from the entire period of record (POR). The hollow points are indicative of outliers.

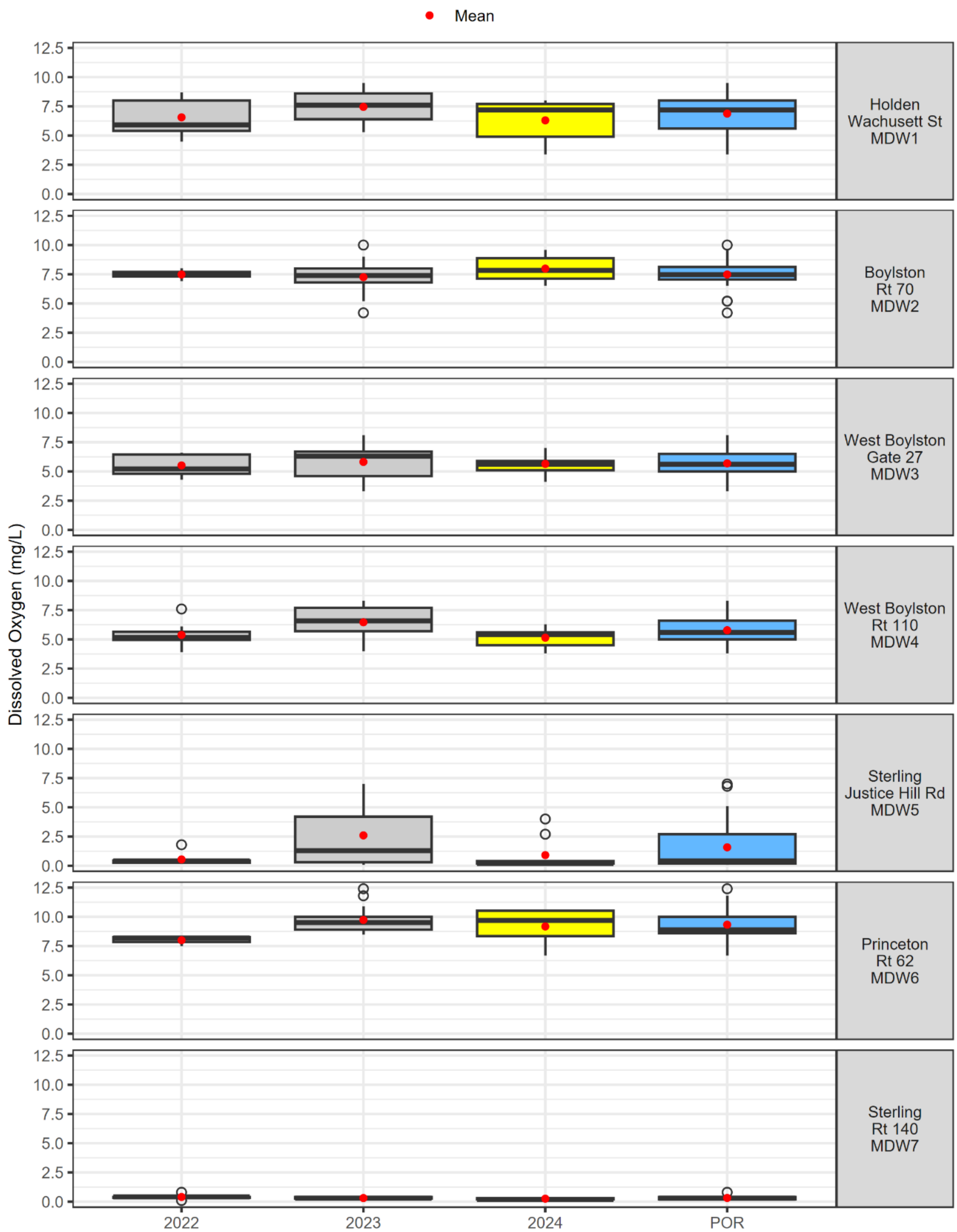


Figure 43: pH Results in Wachusett Watershed Wells for the Period of Record (2022-2024)
The gray boxplots indicate results from previous years, the yellow boxplot depicts the data from the current report year, and the blue boxplot represents the results combined from the entire period of record (POR). The hollow points are indicative of outliers.

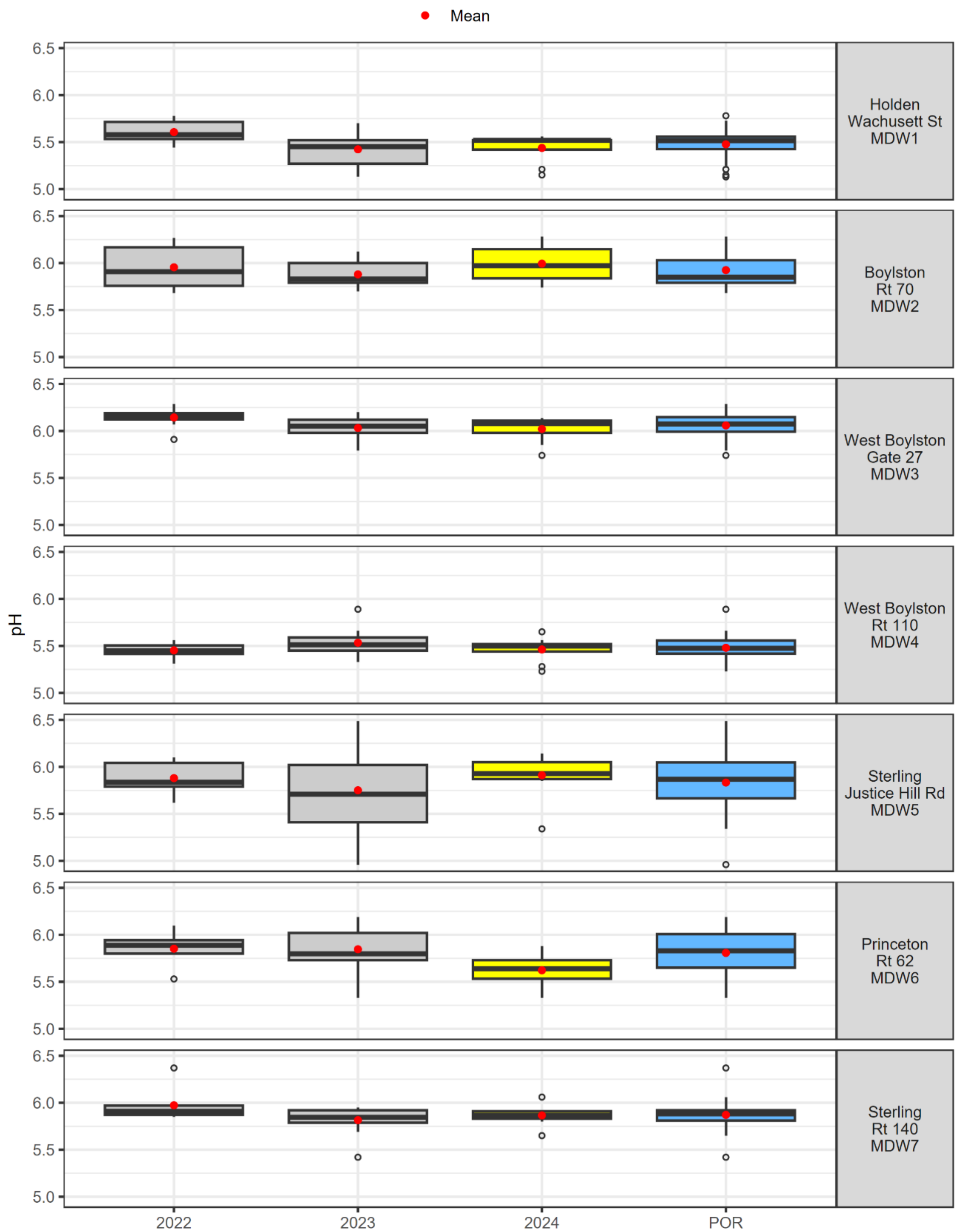


Table 29: Groundwater Monitoring Summary for 2024

The greater-than symbol (>) indicates that the bottom of the well was used as the water depth for calculations when the well was dry. The mean depth below ground surface is likely higher for these values.

Well	Mean Water Depth Below Ground Surface (ft)	Mean Specific Conductance (µS/cm)	Mean Dissolved Oxygen (mg/L)	Mean pH
Sterling – Justice Hill Rd. – MDW5	6.1	72.2	0.9	5.9
Sterling – Rt. 140 – MDW7	14.4	127.3	0.3	5.9
Princeton – Rt. 62. – MDW6	>16.1	669.8	9.2	5.6
Holden – Wachusett St – MDW1	3.4	857.8	6.3	5.4
West Boylston – Gate 27 - MDW3	6.8	1,133.6	5.6	6.0
Boylston – Rt. 70 – MDW2	>7.9	1,459.5	8.0	6.0
West Boylston – Rt. 110 – MDW4	14.7	5,403.6	5.1	5.5

Since the beginning of groundwater quality monitoring in 2019, specific conductance values at each location have varied from year to year. Boylston – Rt. 70, since 2020, has exhibited a decreasing trend in mean specific conductance each year while Princeton – Rt. 62, excluding 2022, has exhibited an increasing trend in mean annual specific conductance over the period of record. The other wells showed no unidirectional trend in mean annual specific conductance. 2024 mean specific conductance was higher than the period of record (POR) mean at West Boylston – Rt. 110 and Princeton – Rt. 62, whereas the 2024 mean was lower than the POR mean at the other five wells. Well monitoring will continue in 2025 to determine if seasonal or long-term trends are present in groundwater specific conductance values.

The wide ranges of specific conductance results in groundwater demonstrate how certain hotspot areas can go undetected when only monitoring surface waters because of the blending of various ground/surface waters from an entire drainage area that occur within tributaries. Unfortunately, there is limited capacity to expand the spatial extent of the groundwater sampling program due to the lack of additional monitoring wells. However, there are other methods that may provide increased spatial resolution of groundwater impairment, such as monitoring baseflow at first order tributaries that are not currently routinely monitored.

3.4 Reservoir Monitoring

In general, results of reservoir monitoring programs followed expected trends and fell within or close to historical values. Notable deviations can be tied to both above average watershed runoff from storm events and a high percentage of water transferred from Quabbin Reservoir. These conditions resulted in improved annual mean Secchi depth, and seasonal site maximums at several locations for silica concentrations and UV_{254}. Details on these and all other water quality and aquatic life monitoring programs are presented below.

Unless otherwise noted, results reported in this section were obtained by DWSP aquatic biologists via hand-held instruments *in situ*, microscopy, or via samples processed by an MWRA lab (see Section 2.1).

3.4.1 Water Temperature

Reservoir temperatures in 2024 supported MassDEP aquatic life use standards for coldwater and warmwater fisheries. Recorded reservoir temperatures ranged from 2.0 °C to 28 °C, the highest recorded temperature since 2018. This value was recorded in July just after the highest average daily air temperature recorded for the year (Section 3.1.1.1).

Ice was present in isolated cove areas and upper basins, but the entire reservoir did not freeze over the winter of 2023 – 2024 (Figure 44). Warming started in April and the presence of a thermocline, as indicated by a 1 °C temperature decrease over one meter in depth, was first recorded on May 13 (Figure 45). Surface temperatures continued to warm, attaining a maximum recorded temperature of 28 °C at Basin North at 0.5 m on July 15. This is the second highest reservoir temperature on record and the highest temperature recorded since 2018. Cooling of the epilimnion started in late September when the combination of cooling air temperatures and wind energy pushed the thermocline deeper. Turnover was detected by remote profiling on November 21 at Basin North and the water column continued to cool for the remainder of the season.

Figure 44: Ice Cover Duration for Wachusett Reservoir for the Period of Record (1992 – 2024)

Ice cover is considered complete when a majority of the north basin is frozen over. Ice may have been present during 'Limited Ice' years, but complete cover was not achieved. Numbers at the end of each line indicate number of days with ice cover.

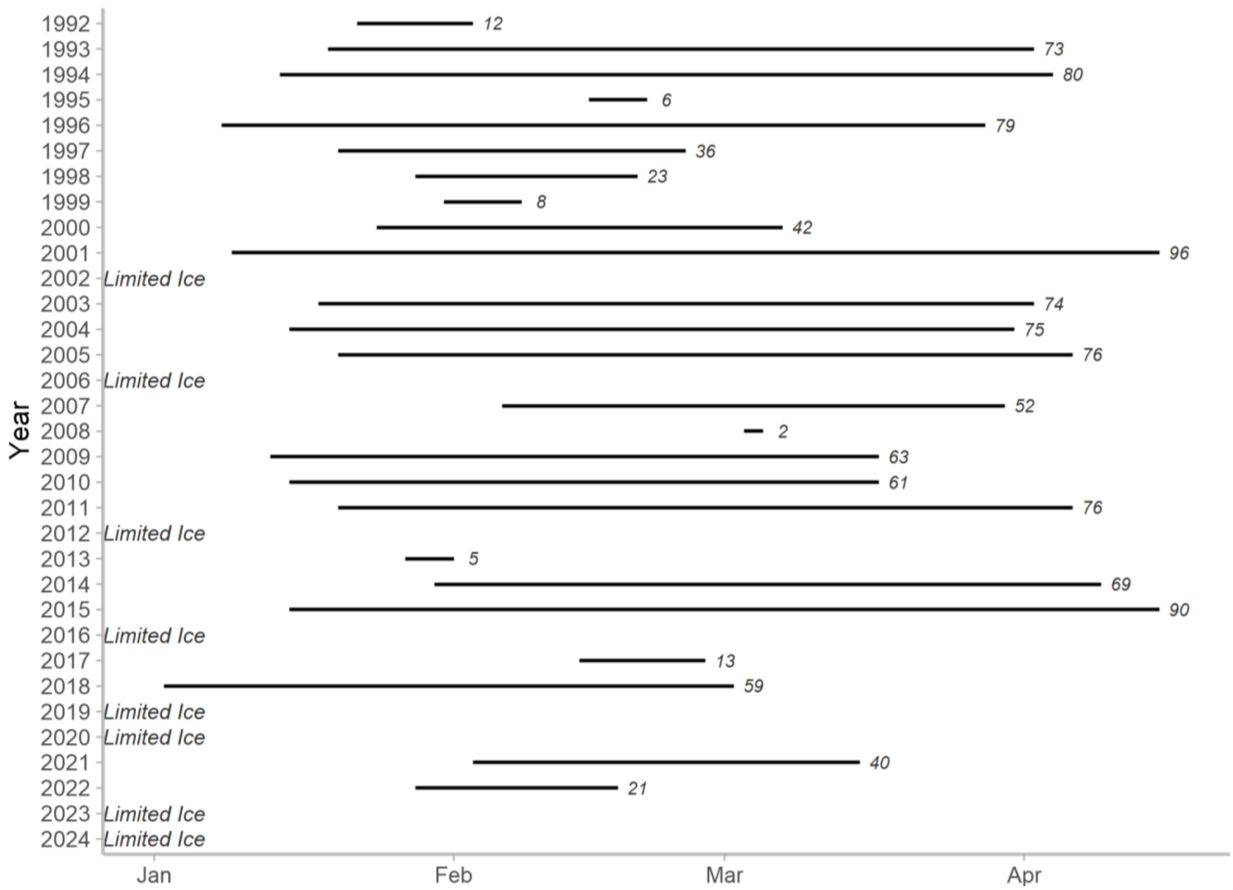
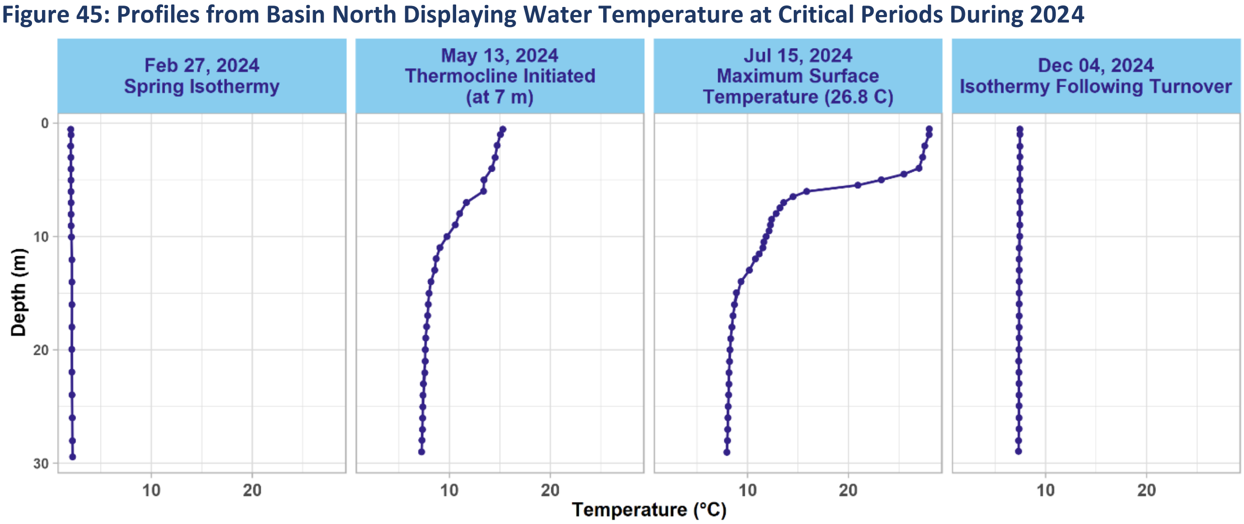
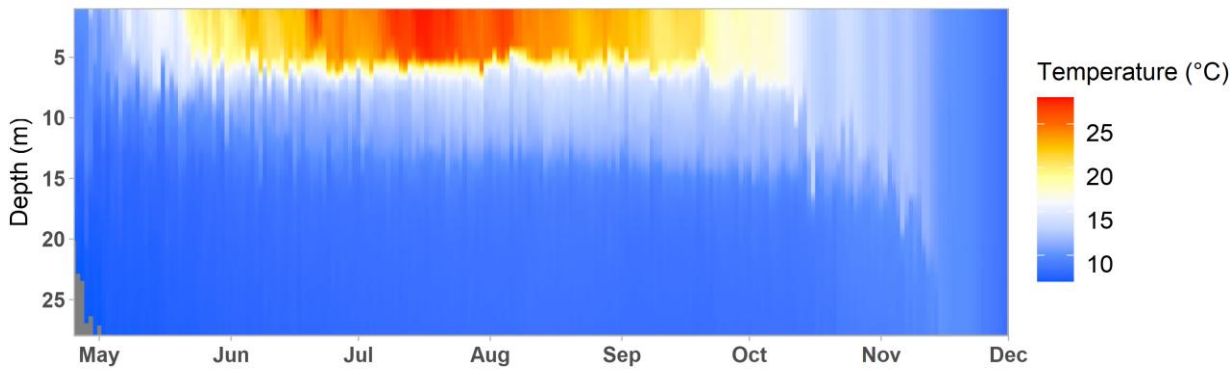


Figure 45: Profiles from Basin North Displaying Water Temperature at Critical Periods During 2024



The high temporal resolution data obtained from MWRA remote sensing buoys provide an opportunity to visualize reservoir temperature changes over the entire season (Figure 46). Cooling of the epilimnion in September was followed by a period of warming and then subsequent cooling until turnover occurred on November 16.

Figure 46: Water Temperature Recorded by Basin North Profiling Buoy May – December 2024
Plot of data recorded daily at 12 pm.

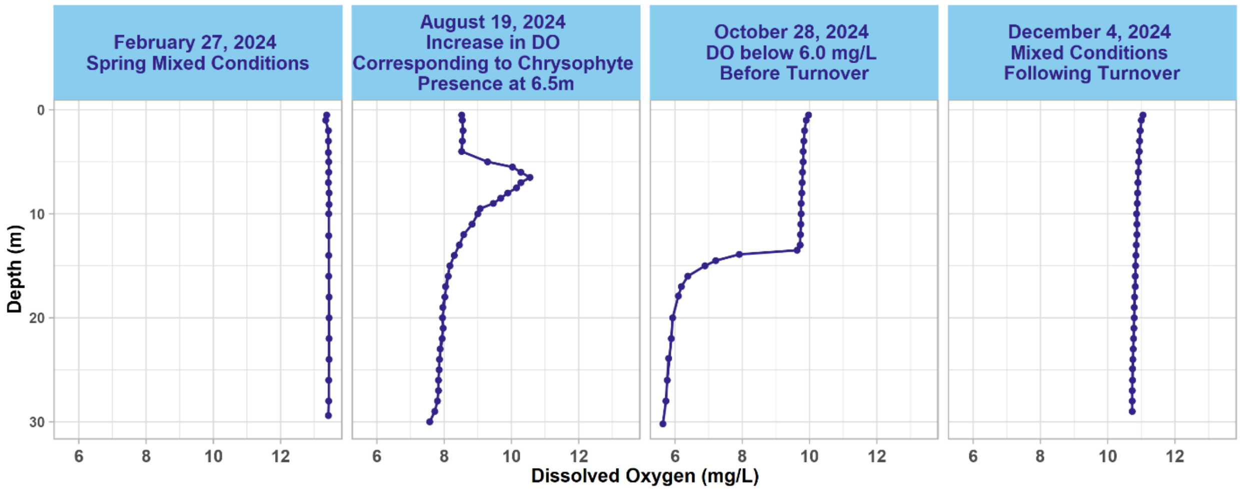


3.4.2 Dissolved Oxygen

Expected patterns in dissolved oxygen were observed throughout the 2024 season. MassDEP aquatic life use criteria of 6.0 mg/L for coldwater communities and 5.0 mg/L for warmwater communities were met for the entire year. Concentrations below 6.0 mg/L were recorded briefly in the hypolimnion in late October prior to turnover but did not fall below 5.64 mg/L based on profiles collected at Basin North (Figure 47).

Cool temperatures, which allow water to hold more oxygen, and isothermic conditions present through the spring season allowed dissolved oxygen to remain above 10 mg/L in the entire water column through mid-May. Stratification then strengthened, isolating water below the thermocline from atmospheric diffusion of oxygen. Dissolved oxygen gradually declined within the hypolimnion, reaching a minimum concentration of 5.64 mg/L at 30 m on October 28. Despite decreased oxygen at depth, the mean dissolved oxygen concentration remained above 8.0 mg/L, maintaining concentrations required to support coldwater species. Once turnover occurred on November 21 (as recorded by MWRA profile buoys), dissolved oxygen was again dispersed through the water column and was approximately 9.3 mg/L from the surface to the bottom on December 4. Elevated dissolved oxygen below the thermocline associated with increased phytoplankton activity occurred in late July and August when *Chrysosphaerella* density was elevated within the interflow around 6.5 m.

Figure 47: Profiles from Basin North Displaying Dissolved Oxygen at Critical Periods During 2024

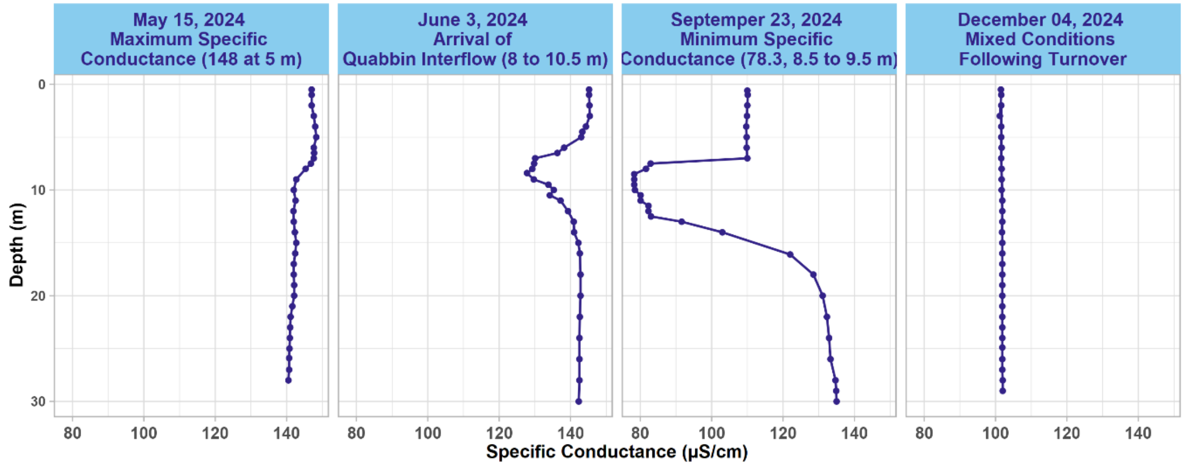


3.4.3 Specific Conductance and Chloride

The annual maximum specific conductance observed at Basin North was significantly lower than observed over the past eight years. Lower than normal inputs from the Wachusett Watershed during the 2024 drought and increased volumes of water transferred from Quabbin Reservoir in recent years (Figure 20) likely contributed to the continued dilution of salts in Wachusett Reservoir. The maximum value of 148.0 µS/cm was recorded at 5 m on May 15. The annual mean was 123 µS/cm. The annual minimum specific conductance of 78.3 µS/cm was recorded between 8.5 and 9.5 m September 23.

Arrival of the Quabbin interflow at Basin North was first observed on May 20 with a decrease in specific conductance detected between 10 and 11.5 m. By June 3, a definitive decrease in specific conductance between 6 and 12 m indicated the establishment of the Quabbin interflow within the Wachusett metalimnion. Following this date, specific conductance within the metalimnion continued to decrease, reaching a minimum of 78.3 µS/cm at 8 through 9.5 m on September 23. On this date, the interflow encompassed approximately 5.5 m between depths of 7.5 m and 13 m. Stratification and the interflow were maintained through the end of September. In early October, decreasing temperatures moved the thermocline lower and the interflow was compressed. Higher conductivity water was mixed deeper into the water column and the interflow was no longer detected as of October 28. Following turnover, specific conductance remained low compared to values observed in recent years due to the high proportion of water transferred from Quabbin in relation to inputs of native Wachusett Watershed water (Figure 48).

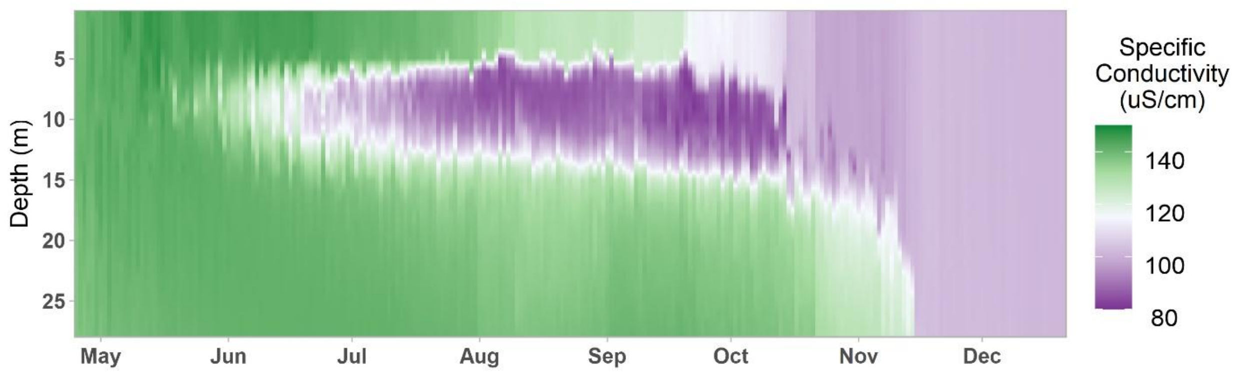
Figure 48: Profiles from Basin North Displaying Specific Conductance at Critical Periods During 2024



Formation of the Quabbin interflow and the stark differences between interflow specific conductance and that of native Wachusett Watershed water throughout the year is shown below using the high-resolution data obtained from the MWRA profiling buoy in Basin North (Figure 49).

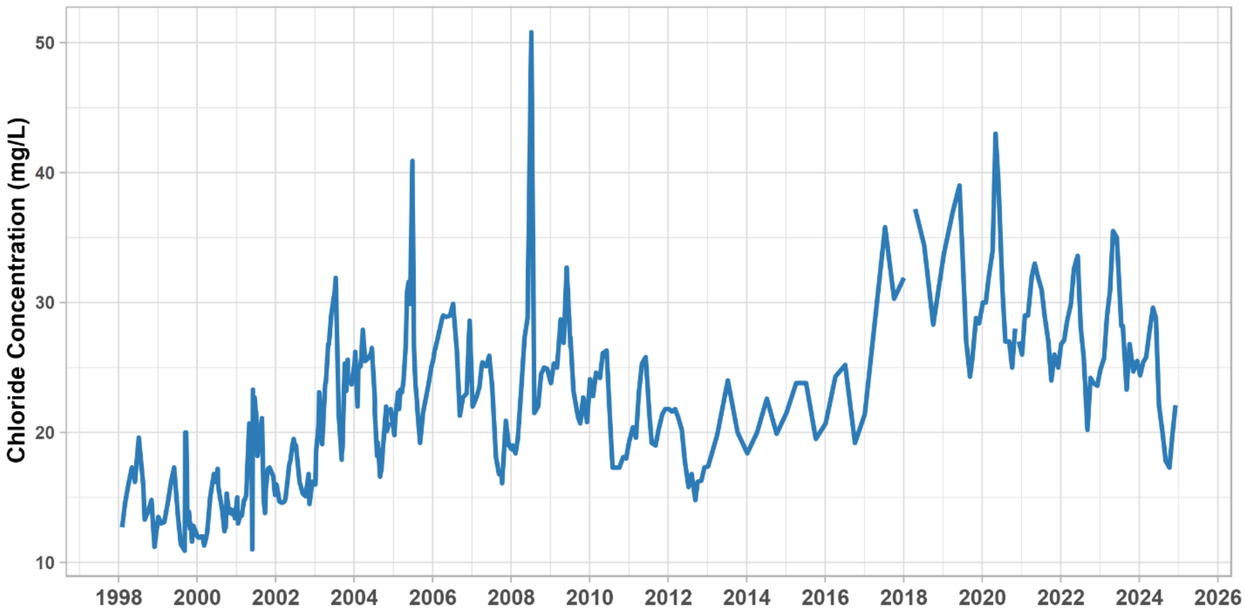
Figure 49: Specific Conductance Recorded by Basin North Profiling Buoy May – December 2024

Plot of data recorded daily at 12 pm. The Quabbin interflow layer is visible in the range of 80 to 120 µS/cm between mid-June and October.



The 2024 annual average of chloride values recorded at the Carroll Water Treatment Plant (CWTP) was 23.4 mg/L. This value is notably lower than the previous year (28.1 mg/L in 2023), and the lowest annual average since 2016. A general declining trend in Wachusett Reservoir chloride values has been observed since 2017 (Figure 50), which corresponds with an increasing trend in the total annual volume of water transferred from the Quabbin Reservoir (Figure 21). A watershed scale chloride reduction program also implemented within this time frame aims to reduce the application of road salts and further understand the fate and transport of chloride within the system.

Figure 50: Wachusett Reservoir Monthly Chloride Concentrations 1998-2024



3.4.4 Turbidity

Turbidity in the Reservoir was measured with sensors installed on the YSI EXO2 sondes used by DWSP and on the remote profiling buoys. The precision of these sensors is 0.3 NTU (Nephelometric Turbidity unit), which is the typical result observed in the Reservoir. Therefore, turbidity values observed *in situ* are used for observational purposes only. Data for regulatory compliance are collected by MWRA at various points throughout the distribution system once water leaves the Reservoir.

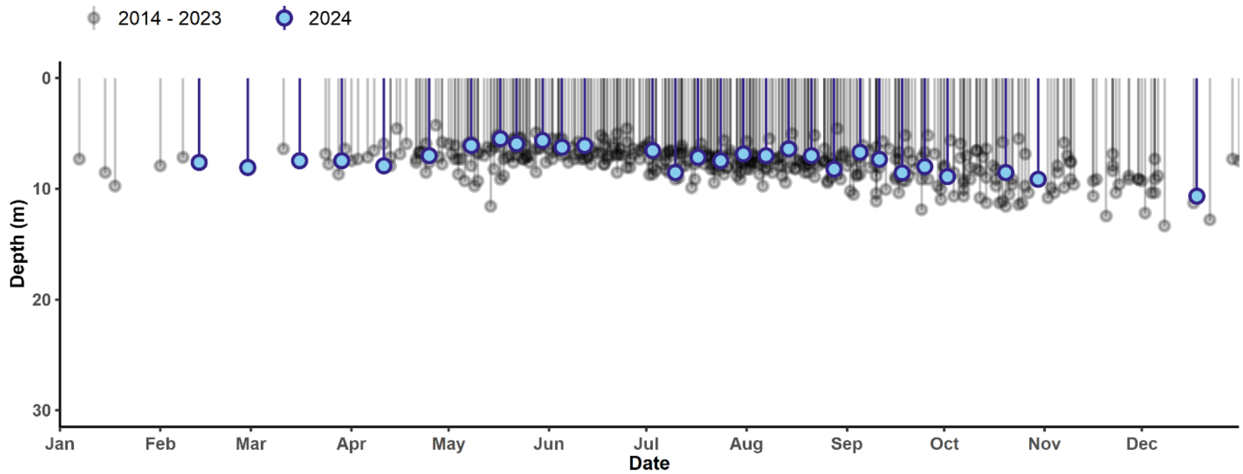
3.4.5 pH

Reservoir pH varies slightly seasonally and vertically through the water column corresponding with changes in photosynthesis and respiration. In 2024, pH ranged from neutral to slightly acidic with a maximum value of 7.69 and minimum value of 5.73. Slight acidity was observed below depths of 9 m from late July through October as phytoplankton senesced and subsequent carbon release occurred at depth.

3.4.6 Secchi Disk Depth/Transparency

Secchi disk depths in 2024 ranged from 5.5 m to 10.7 m. The maximum depth was recorded on December 16 (Figure 51). Transparency decreased in the spring with increasing density of diatoms and spring runoff events. The minimum value of 5.5 m was recorded on May 15, prior to stratification and coincident with the annual maximum specific conductivity value and elevated UV_{254} in the epilimnion due to watershed inputs early in the season. The growing season maximum Secchi depth of 8.5 m was recorded on July 8 during a period of low plankton density (See Section 3.4.8). The annual mean Secchi disk depth of 7.4 m remained greater than the reference range of 4 m to 6.1 m for the Reservoir ecoregion.

Figure 51: 2024 Secchi Disk Transparency at Basin North
The Y-axis shows maximum depth at Basin North of 30m.



3.4.7 Nutrient Dynamics

The patterns of nutrient distribution in 2024 seasonal samples generally followed those documented in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics[63]. These patterns consist most importantly of the following: 1) seasonal and vertical variations with low epilimnetic concentrations in summer resulting from phytoplankton uptake, and conversely, higher concentrations accumulating in the hypolimnion due to microbial decomposition of organic matter in sediment; 2) interannual fluctuations in nutrient concentrations occurring throughout the system as a result of the opposing influences of the Quabbin Transfer and the Wachusett Watershed with temporary lateral and vertical gradients becoming pronounced for nitrate, silica, UV_{254}, and specific conductance downgradient of Thomas Basin and within the interflow, if present.

Drought conditions and the resultant high percentage of Quabbin water present throughout the summer created unique results for 2024. The following characterizes water source conditions for the four nutrient sample dates:

- Spring (May) – The Quabbin transfer had been initiated and could be observed below the thermocline at Thomas Basin with specific conductance values below 100 µS/cm. A small layer of Quabbin water was observed at Basin South at 7m with a specific conductance value around 130 µS/cm. The interflow had not yet arrived at Basin North and specific conductance values were above 140 µS/cm.

- Summer (July) – All surface sites were uninfluenced by the interflow and specific conductance was around 140 µS/cm. The interflow was observed at Thomas Basin mid and deep depths and at the mid depths of Basin South and Basin North. Specific conductance in the epilimnion and hypolimnion were similar (around 140 µS/cm) at Basin South and Basin North.

- Fall (October) – The Quabbin interflow was present at all depths at Thomas Basin with specific conductance below 60 µS/cm. At Basin South and Basin North, the interflow had mixed into the

[63] Worden & Pistrang, 2003

epilimnion and values from the surface to 14m were below 100 µS/cm. Water sequestered in the hypolimnion remained greater than 120 µS/cm but specific conductance had decreased compared to values earlier in the season (from around 140 to 120 µS/cm).

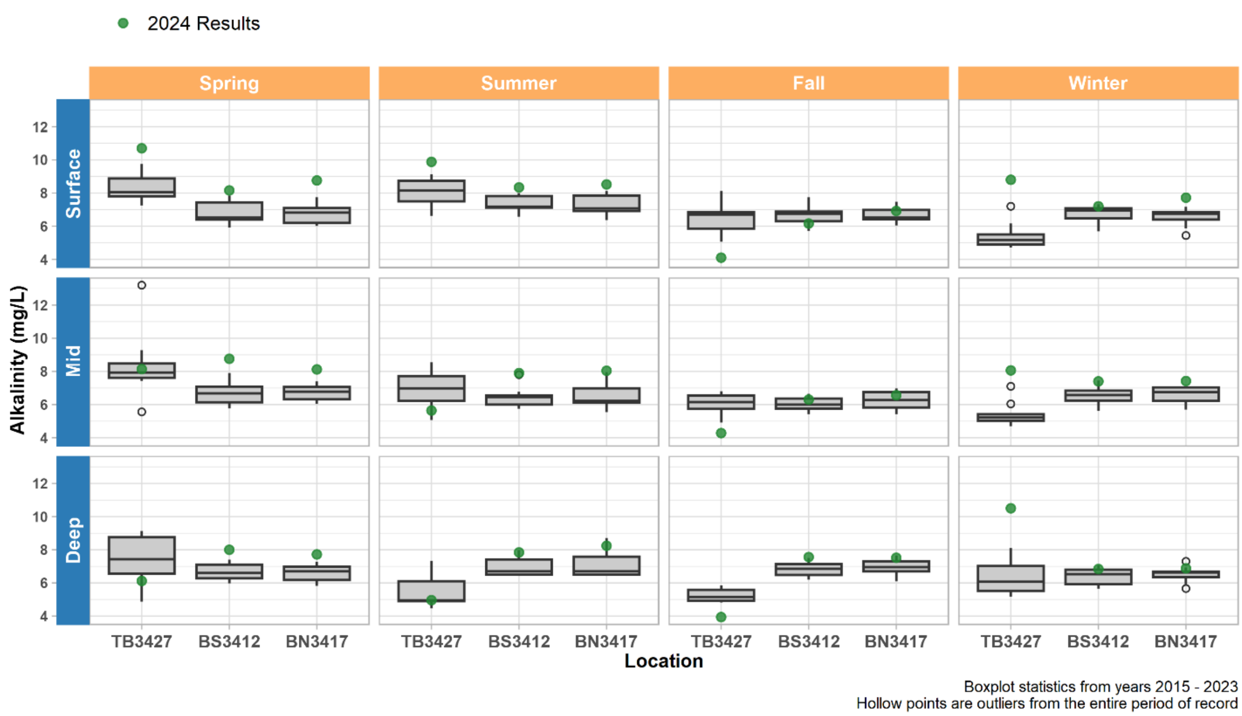
- Winter (December) – The Quabbin Transfer was not running and native watershed water influence was apparent at all depths in Thomas Basin, especially at depths where specific conductance was greater than 180 µS/cm. Specific conductance at Basin South and Basin North were both around 100 µS/cm, indicating a higher-than-normal Quabbin Transfer influence.

3.4.7.1 Alkalinity

As with many analytes, differences in alkalinity across Wachusett Reservoir sites and depths are influenced by the percent of water originating from the Wachusett Watershed versus that transferred from Quabbin Reservoir. Annual maximum alkalinity values typically occur at sites where the primary influence was native Wachusett Watershed water whereas minimum values are typically recorded from locations or times when the Quabbin interflow was the primary source of water.

Mean alkalinity across all sites and depths in 2024 was 7.44 mg/L as $CaCO_3$, slightly higher than the mean recorded for 2023. The annual maximum alkalinity value of 10.7 mg/L as $CaCO_3$ was recorded at the surface in Thomas Basin during the spring and annual minimum of 3.94 mg/L as $CaCO_3$ was recorded at the Thomas Basin deep-depth in the fall. The six lowest values and several minimum values for the period of record were also recorded at Thomas Basin in fall and summer when the Quabbin Transfer was the dominant water source. Alkalinity values greater than historical maximums were observed at several locations at times when a higher percentage of native water, as indicated by specific conductance values higher than 140 µS/cm were dominant. As noted in Section 3.2.2, alkalinity in Wachusett tributaries shows slight increases over the past several years and investigations into seasonality are forthcoming.

Figure 52: 2024 Alkalinity as $CaCO_3$ in Wachusett Reservoir with 2015 - 2023 Statistics

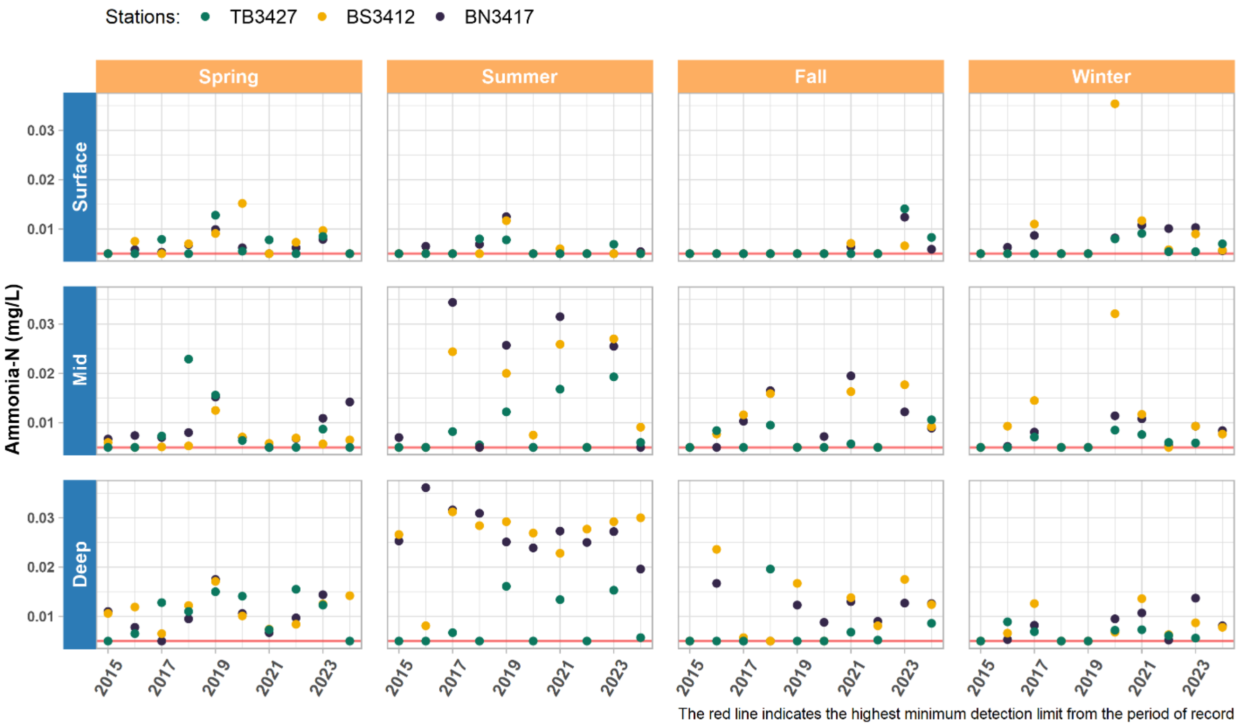


3.4.7.2 Nitrogen Species (Ammonia-Nitrogen, Nitrate-Nitrogen, and Total Kjeldahl Nitrogen)

Ammonia-Nitrogen

In 2024, overall ammonia-nitrogen (NH_3-N) results were within historic ranges. Ammonia-nitrogen levels within the Reservoir remained low, with all values below regulatory thresholds. Typical patterns were observed with the highest values present at mid and deep sample depths during the summer and fall when ammonia builds in the hypolimnion (Figure 53).

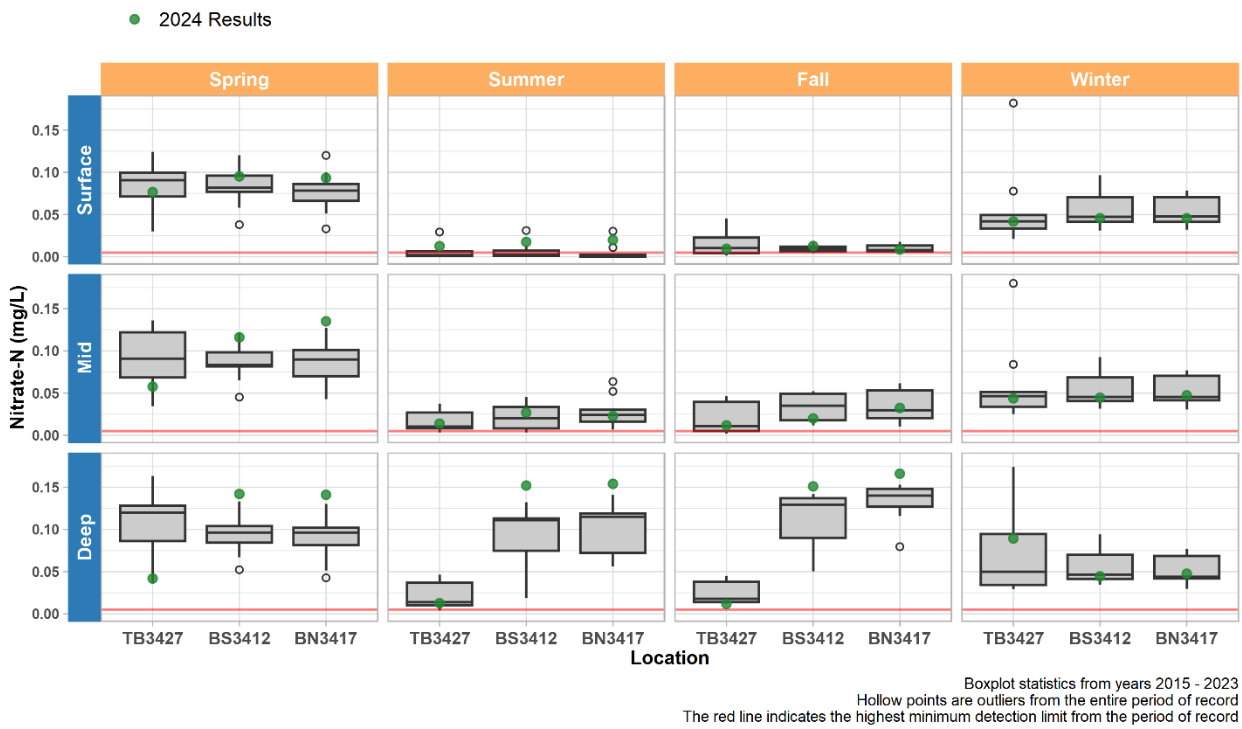
Figure 53: 2015 – 2024 Ammonia-Nitrogen in Wachusett Reservoir



Nitrate-Nitrogen

Annual nitrate-nitrogen (NO_3-N) concentrations were well below the SDWA threshold of 10 mg/L, ranging from 0.009 mg/L to 0.166 mg/L (Figure 54). Highest concentrations are most often observed in the spring and in main basin locations at depth during periods of stratification. This pattern continued in 2024, with spring values at all sites falling between 0.042 and 0.142 mg/L. The highest annual concentrations, between 0.141 and 0.166, were recorded in the hypolimnion during stratification at Basin South and Basin North. Several site maximums were recorded in 2024, aligning with periods of hypolimnetic isolation and a higher percentage of Wachusett Watershed water present at depth in the spring.

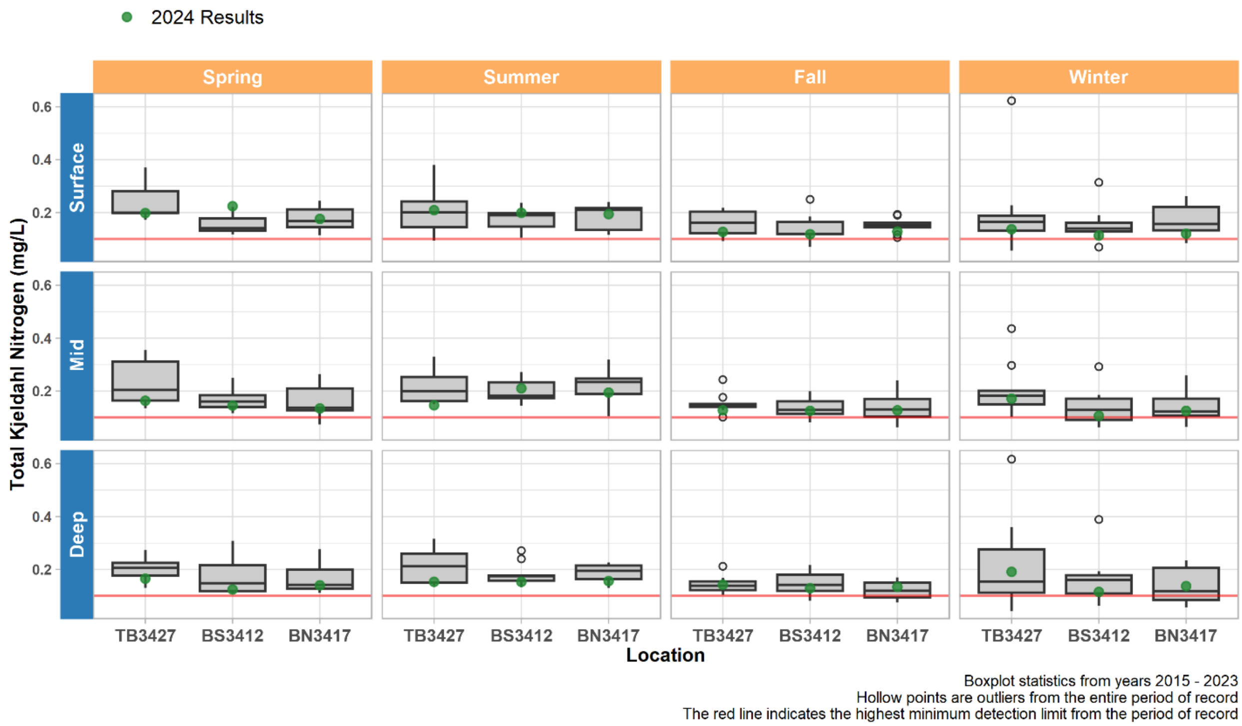
Figure 54: 2024 Nitrate-Nitrogen in Wachusett Reservoir with 2015 - 2023 Statistics



Total Kjeldahl Nitrogen

Concentrations for Total Kjeldahl Nitrogen (TKN) ranged from 0.106 mg/L to 0.224 mg/L (Figure 55), within the historical range. The annual maximum of 0.224 mg/L recorded in the spring at the Basin South surface site also exceeded the depth and seasonal maximum for that site. This value coincided with high specific conductance values for the site and season, indicating a higher percentage of native Wachusett Watershed water present. TKN at this site remained elevated into the summer but fell within the 25th to 75th percentile in the fall.

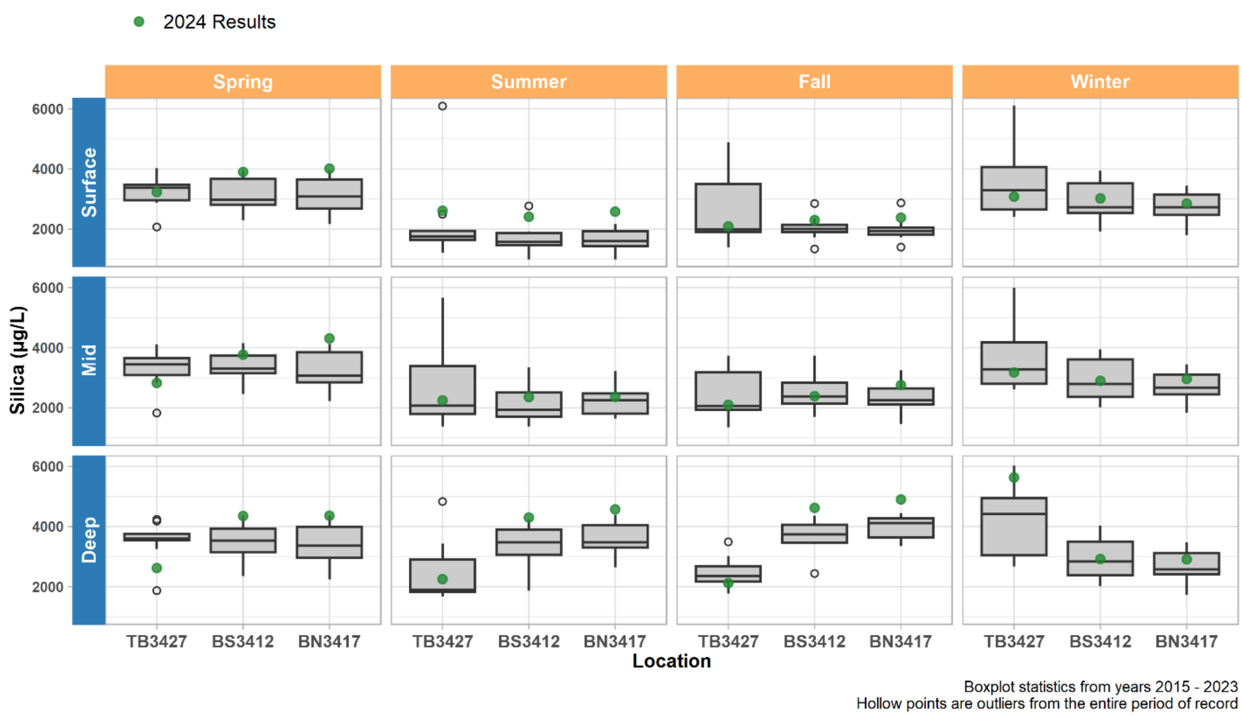
Figure 55: 2024 Total Kjeldahl Nitrogen in Wachusett Reservoir with 2015 - 2023 Statistics



3.4.7.3 Silica

Silica concentrations were between 2,090 and 5,630 µg/L in 2024 (Figure 56). Silica is typically transported to the Reservoir through watershed runoff in spring where it is taken up by diatoms and other organisms requiring this nutrient. This pattern was observed in 2024 data, where most spring values fell within or above the 75th percentile at Basin South and Basin North. Silica was elevated at the surface and at depth in the main basin through the summer and fall, likely due to a higher percentage of native water at the surface and typical sequestration of nutrients in the hypolimnion. Concentrations decreased following turnover and the summer period of primary productivity, but remained above site means at all sites not influenced by the Quabbin interflow.

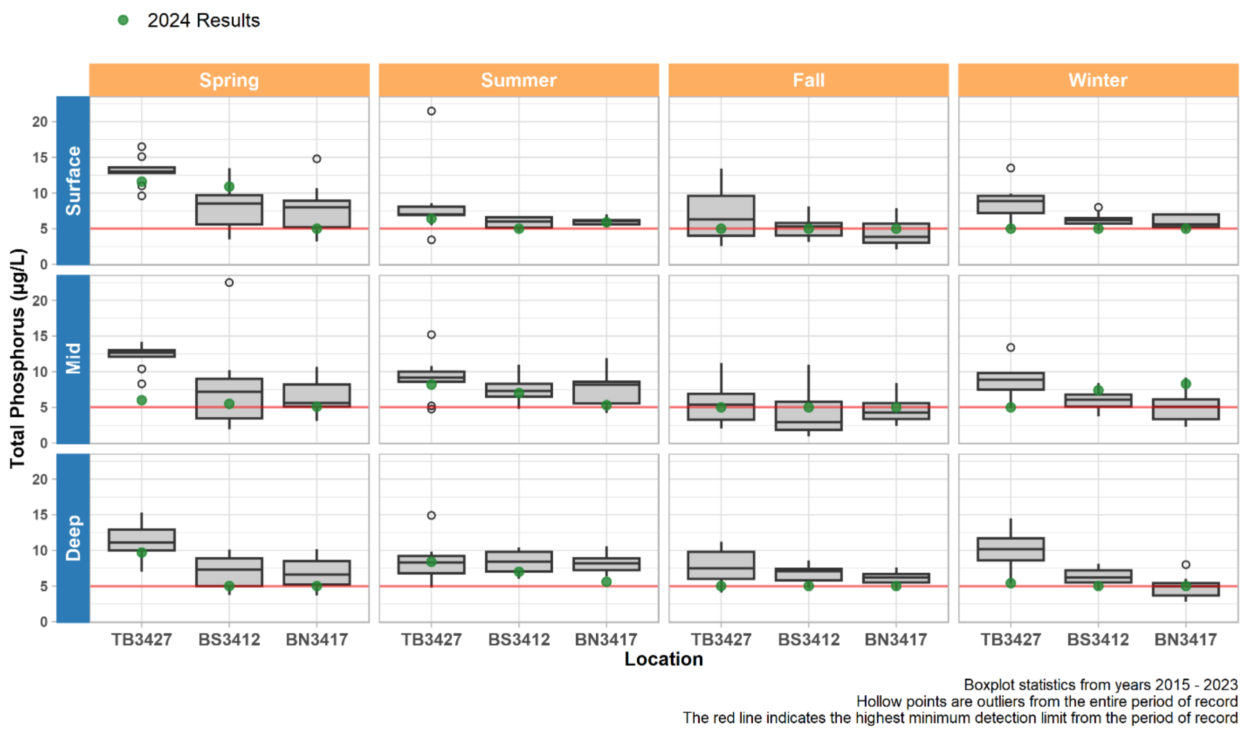
Figure 56: 2024 Silica in Wachusett Reservoir with 2015 - 2023 Statistics



3.4.7.4 Total Phosphorus

Total phosphorus (TP) results for 2024 followed typical spatial and temporal patterns and were within historical ranges. More than half of results were below the detection limit (less than 5 µg/L), and most results (95%) were lower than the 10 µg/L threshold for classification as an oligotrophic water body[64]. Results for spring surface samples at Thomas Basin and Basin South slightly exceeded the oligotrophic threshold but were well within historic ranges (Figure 57). Total phosphorus results for all other sites were within or below the interquartile range.

Figure 57: 2024 Total Phosphorus in Wachusett Reservoir with 2015 - 2023 Statistics



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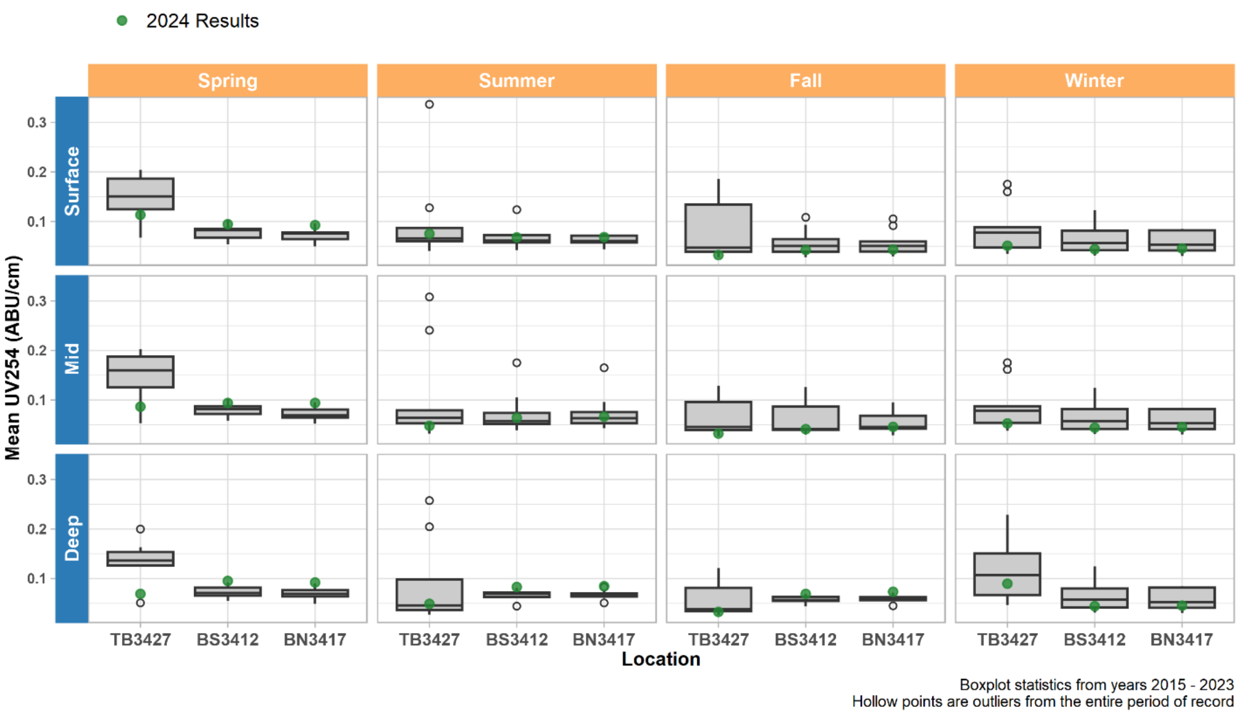
[64] Carlson, 1977

3.4.7.5 UV Absorbance

In contrast to 2023, measurements of UV_{254} were within historical ranges for much of 2024, ranging from 0.032 to 0.113 ABU/cm (Figure 58). Seasonal site and depth records were recorded at five locations where values are typically low. These elevated values correspond with periods when higher specific conductivity water was present at depth at Basin South and Basin North starting in the spring and continuing through the season until turnover. High organic inputs resulting from recent years of wet weather events were likely sequestered in the hypolimnion, contributing to residual elevated UV_{254} in 2024 (also see section 3.2.7.3 for discussion on specific conductance and UV_{254} in the tributaries). Otherwise, the strong influence of the Quabbin Transfer in 2024 led to most values falling below historical medians in the upper portions of the water column and in Thomas Basin.

Figure 58: 2024 Wachusett Reservoir UV_{254} with 2015 - 2023 Statistics



3.4.8 Phytoplankton

A total of 119 phytoplankton samples were collected and analyzed on 40 days during the 2024 season. Ice-free conditions allowed regular collection of samples every other week through the winter, from January to May. Weekly sampling took place from May until October when productivity slowed and sampling every other week resumed through December 31. As in the previous several years, spring diatom densities were low in 2024 compared to the period of record. *Uroglenopsis*, a taxa of special concern due to taste and odor formation, exceeded the alert level once, triggering one day of extra sampling. Otherwise, the routine sample schedule was adhered to for the duration of the year (Figure 61).

The pattern of succession observed in 2024 followed the seasonal changes in phytoplankton community composition and density typically observed in the Wachusett Reservoir. Community composition by group is displayed in Figure 60.

Figure 59: 2024 Wachusett Reservoir Phytoplankton Totals

Epilimnion range is 2 – 5 m, metalimnion range is 5 – 15 m.

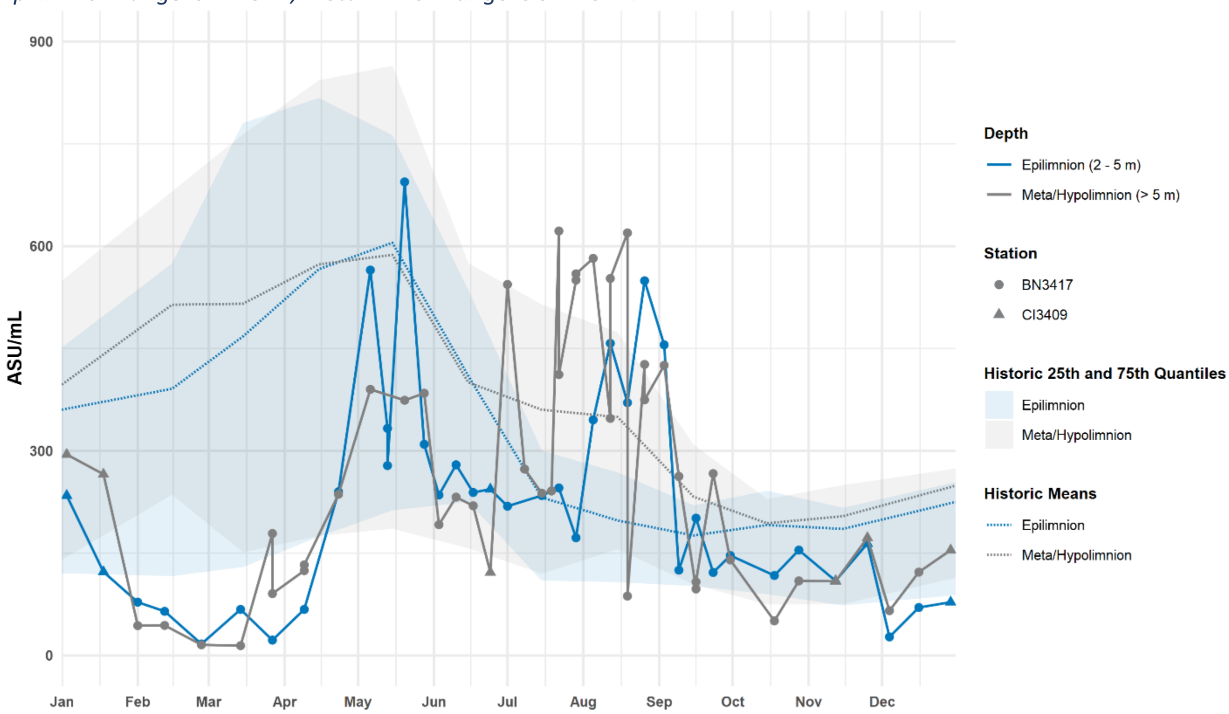
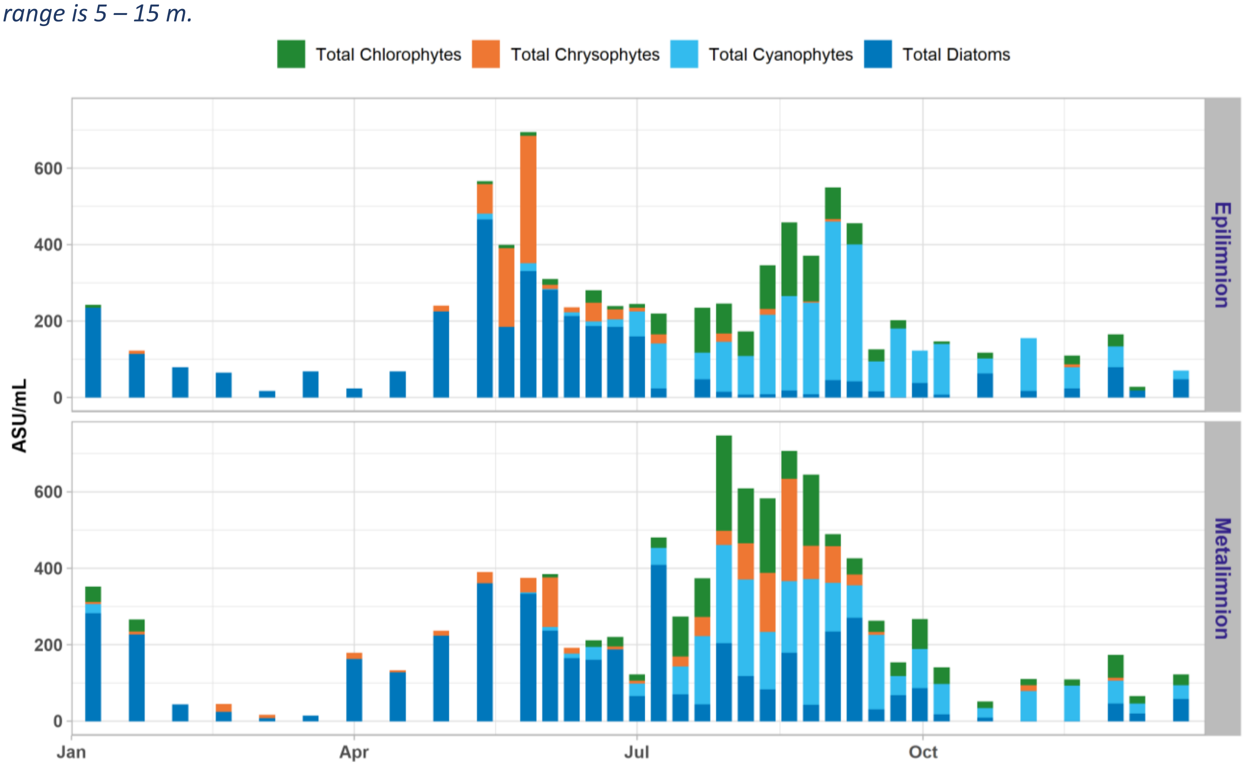


Figure 60: 2024 Phytoplankton Community Composition

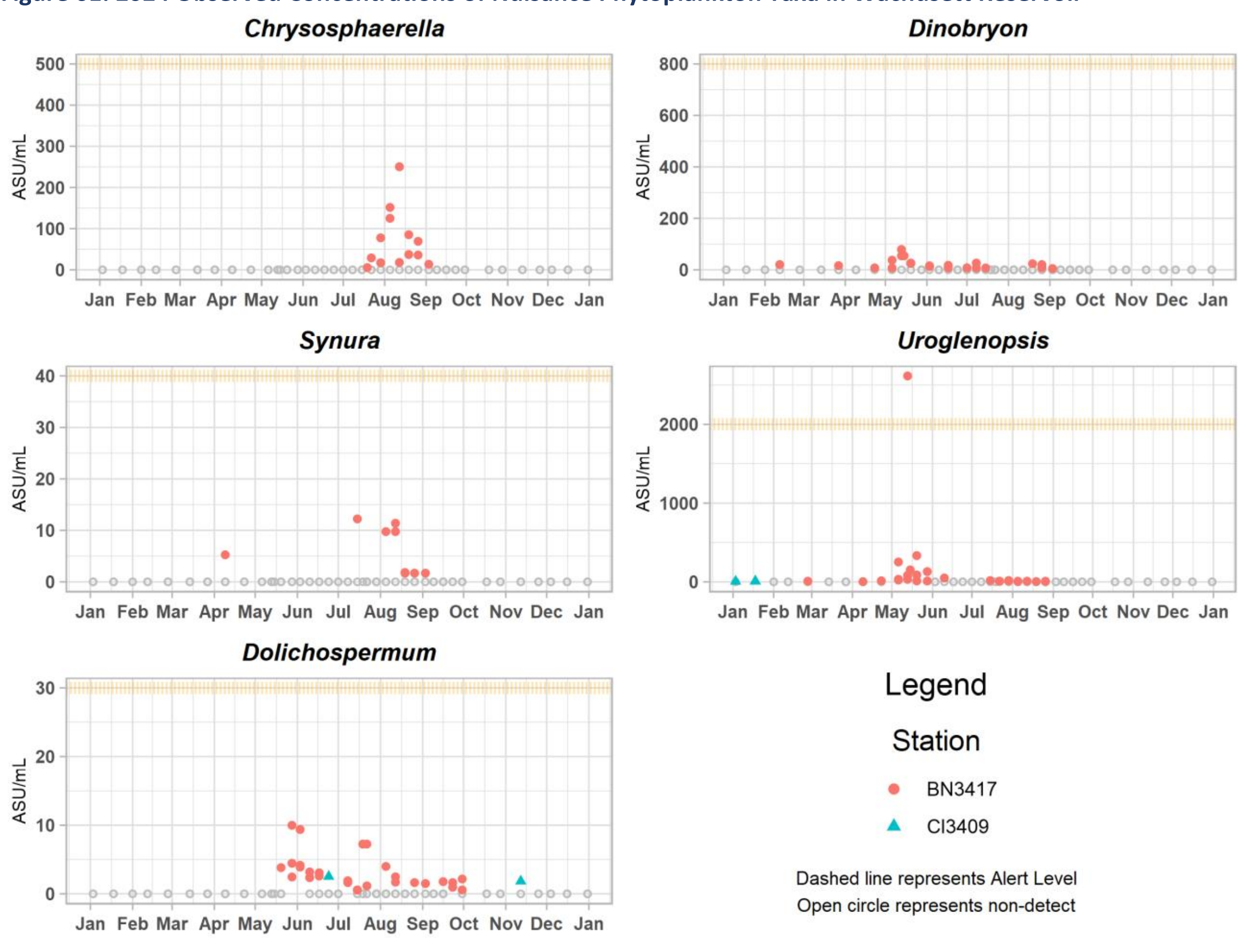
Reported as weekly maximums for Basin North and/or Cosgrove Intake. Epilimnion range is 2 – 5 m, metalimnion range is 5 – 15 m.



Diatoms dominated the phytoplankton community in the Spring and low total densities below 300 ASU/mL were recorded from January through early May. *Uroglenopsis* then rapidly increased in density in the upper epilimnion. Concentrations for this taxa were below alert levels except for a sample collected and analyzed solely for *Uroglenopsis* at 0.5 m on May 13. The *Uroglenopsis* concentration at this location was 2,614 ASU/mL which is the maximum density recorded in any samples for the year (Figure 61, note that other figures in this section omit this outlier value recorded at the surface). Concentrations at 3 m and deeper on the same day were less than 85 ASU/mL and *Uroglenopsis* concentrations recorded for the remainder of the season were well below the alert level of 2,000 ASU/mL. No water quality issues were reported as a result of this brief, isolated, event.

The annual maximum phytoplankton density for samples where the entire community was enumerated occurred on May 20 at 3 m with a density of 694 ASU/mL. On this day, the phytoplankton community was comprised of 48% diatoms, 48% *Uroglenopsis*, 3% cyanobacteria, and 1% chlorophytes. Total concentrations decreased through June and rose above 600 ASU/mL in the metalimnion in late July. This increase was driven by a combination of cyanophytes and *Chrysosphaerella* as well as occasional elevated levels of chlorophytes through August. Concentrations remained above 500 ASU/mL through August with high diversity in observed taxa. Late August brought a typical increase in cyanophytes in the epilimnion with *Aphanothece* and *Gomphosphaeria* common. In late September, total concentrations fell and remained below 200 ASU/mL at all depths for the remainder of the year.

Figure 61: 2024 Observed Concentrations of Nuisance Phytoplankton Taxa in Wachusett Reservoir



No aggregations of cyanobacteria or taste and odor taxa were recorded in 2024. Cyanobacteria concentrations were slightly higher than those observed in recent years but did not exceed alert levels or historic maximums. Cyanobacteria densities between 200 and 414 ASU/mL were maintained from late July through early September. The maximum total cyanobacteria density of 414 ASU/mL was recorded from Basin North 3 m on August 26. *Aphanothece* was the dominant taxa on this date with a density of 203 ASU/mL.

3.4.9 Zooplankton

A total of 48 zooplankton samples were collected in conjunction with the 2024 quarterly nutrient sampling program. A subset of these samples – at least one sample from the full water column tows for each station and date – were scanned for invasive species. No invasive species were detected during these analyses, and none have been recorded in the Reservoir to date.

3.4.10 Fish

Monitoring programs in 2024 included the *Salvelinus namaycush* (Lake Trout) mark-recapture study and electrofishing two major tributaries. DWSP staff assisted MassWildlife with electrofishing surveys of the Stillwater River and Gates Brook on September 23 and 25, respectively. The surveys target *Salmo salar* (Atlantic Salmon) and *Salvelinus fontinalis* (Eastern Brook Trout). The following species were recorded at Stillwater River: *S. salar, S. fontinalis, Catostomus commersoni* (White Sucker), *Semotilus corporalis* (Fallfish), *Ameiurus natalis* (Yellow Bullhead), *Luxillus cornutus* (Common Shiner), *Micropterus salmoides* (Largemouth Bass), *Etheostoma olmstedi* (Tesselated Darter), *Rhinicthys cataractae* (Longnose Dace), *Rhinichthys atratulus* (Blacknose Dace), *Esox niger* (Chain Pickerel), and *Lepmois macrochirus* (Bluegill).

The Wachusett Reservoir *S. namaycush* mark-recapture study continued in 2024. This annual study began in 2014, when MassWildlife and DWSP partnered to investigate the status, life history, and sustainable yield of the Wachusett Reservoir *S. namaycush* population. This study is similar to the ongoing effort at Quabbin Reservoir.

S. namaycush are an important coldwater predator in the Wachusett Reservoir food web and are the most popular game fish for anglers. As more information on the *S. namaycush* population is collected, DWSP and MassWildlife will be able to evaluate both the effects of angling pressure and the susceptibility to climate change [65].

To date, 1,266 *S. namaycush* have been captured during fall sampling efforts between 2014 and 2024, and 998 of these individuals have been assigned a unique ID, tagged, and released (Figure 62). From 2014-2024, there have been 77 recapture events of 69 individually tagged fish, six of which have been recaptured at least twice. In 2024, there were 12 recapture events, 103 fish that had not been previously caught were tagged, and 120 fish were caught in total. Five fish were caught but not tagged due to mortality or inability to insert a tag. The data collected contribute to the development of the length-weight relationship for the Wachusett *S. namaycush* population. The 2024 mean weight and mean length are greater than the mean length and weight recorded in 2023 (Table 30).

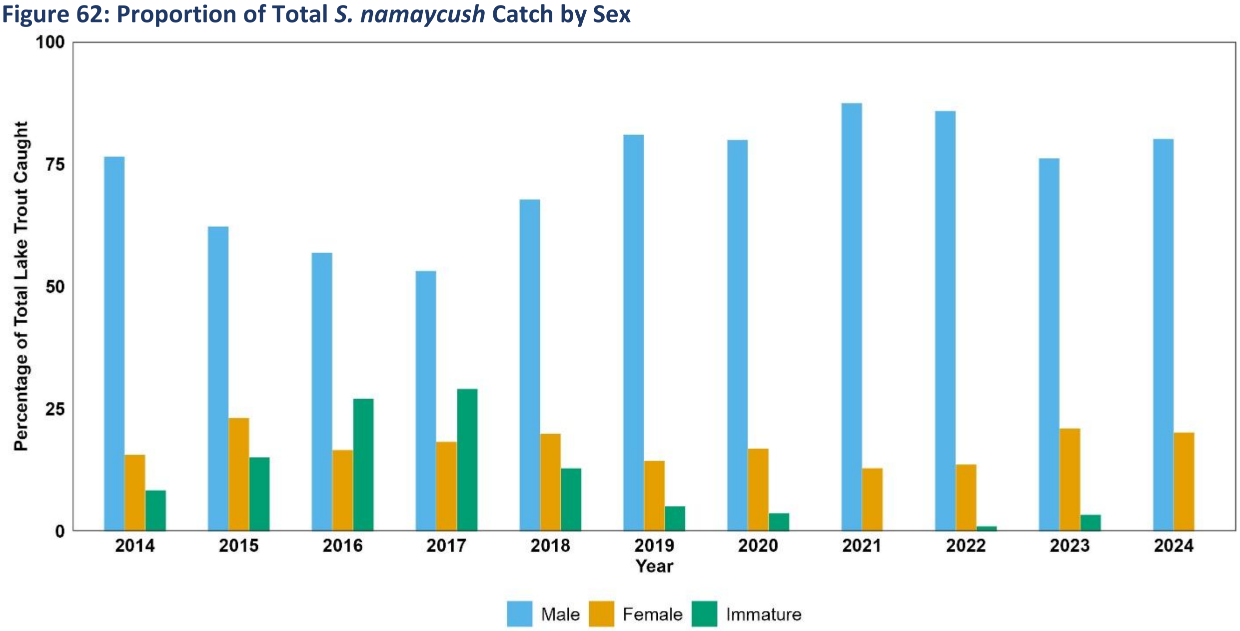
[65] Thill, 2014

Table 30: *S. namaycush* Annual Caught and Tagged Results

Year	Caught	Tagged	Recapture	Caught Mean Weight (g)	Caught Mean Length (mm)	Not Tagged
2014	110	100	2	1,974	582	6
2015	161	137	10	1,427	547	14
2016	67	56	4	1,312	553	7
2017	83	66	10	1,016	515	7
2018	71	59	6	1,402	541	6
2019	162	142	8	1,422	538	12
2020	114	N/A	N/A	1,367	540	114
2021	134	123	7	1,172	535	4
2022	119	105	9	1,282	533	5
2023	125	107	9	1,057	515	9
2024	120	103	12	1,198	522	5
Total	1,266	998	77	1,332	538	191

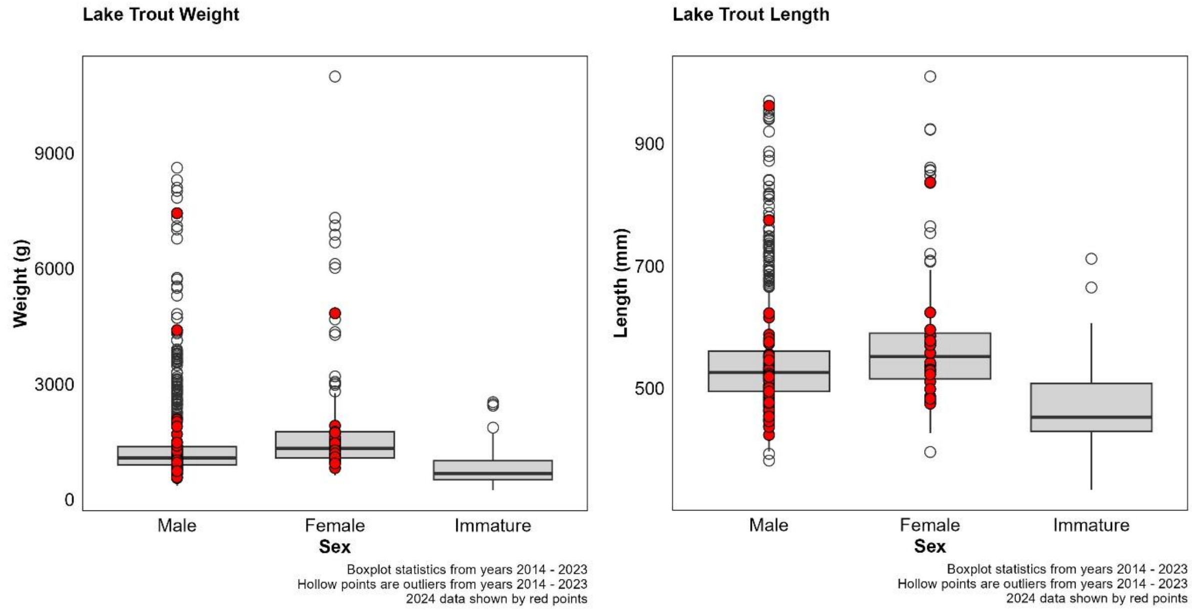
In 2024, 80% of *S. namaycush* captured in Wachusett Reservoir were males and 20% were females. The proportions of the total catch in 2024 were consistent with the results of previous years (Figure 62). Results show that reservoir females are often larger and heavier at capture than males (Figure 63). Evidence suggests that male *S. namaycush* are caught more frequently in gill nets set during the spawn because they spend more time on the spawning grounds searching for females [66]. Studies have also shown that females spend less time on the spawning grounds searching for a mate and thus are less likely to be captured in gill nets[67].

Figure 62: Proportion of Total *S. namaycush* Catch by Sex



[66] Binder et al., 2016
[67] Binder et al., 2014

Figure 63: Wachusett *S. namaycush* Length (left) and Weight (right)



3.4.11 Bacteria

In 2024, *E. coli* samples were collected monthly at 23 transect points in Wachusett (Table 31). Elevated *E. coli* concentrations were most common during the winter months at transects points south of the narrows (transects G – N) and near Crescent and Cemetery Islands (transects E4 – F4) (Figure 3). The highest bacteria levels observed at transect location A3, which is closest to the Cosgrove Intake, were on January 11 (10 MPN/100 mL) and August 15 (4 MPN/100 mL). Harassment was able to restrict the roosting bird populations to the southern parts of the Reservoir, as evidenced by the predominantly lower bacteria results observed in Basin North (transects A - F), even during colder months when birds were most numerous. All reservoir bacteria transect results for 2024 are provided in Table 31.

Table 31: Reservoir Bacteria Transect Results for 2024 – *E. coli* (MPN/100 mL); Sampled at 0.1 – 0.3 m
Result values of 1 were below the method detection limit, which was 1 MPN/100 mL.

Date	A3 (Cosgrove)	B2	B3	C1	C3	C5	D1	D2	D4	E2	E4	F2	F3	F4	G2	H2	I2	J2	J3	J4	K2	M1	N1
Jan 11	10	1	4	1	4	5	4	1	2	3	1	1	22	3	3	1	2	2	1	8	1	10	14
Feb 12	1	2	1	1	1	1	1	1	3	2	1	1	3	1	8	6	1	1	4	5	5	3	2
Mar 14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6	3	1	3	4	3	1	1	3
Apr 02	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6	8	9	3	4
May 17	1	1	1	2	3	1	6	1	5	1	3	1	10	1	1	1	1	1	1	1	1	19	3
Jun 13	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jul 18	1	1	1	1	1	2	3	1	1	1	1	1	2	9	1	1	1	3	1	2	1	9	4
Aug 15	4	1	1	6	1	1	4	2	2	2	4	1	12	1	1	1	1	1	1	1	1	1	1
Sep 20	1	1	1	1	2	1	1	1	1	1	1	10	2	1	1	1	3	1	9	4	4	3	1
Oct 23	1	1	1	1	1	2	2	1	1	2	1	2	2	1	1	1	1	1	6	1	1	1	1
Nov 22	1	3	1	2	2	3	1	3	1	3	1	6	1	1	2	8	16	5	19	21	34	34	9
Dec 16	1	2	2	3	1	3	2	2	1	10	16	2	9	1	1	4	12	4	22	50	24	4	6

Bacteria samples were collected seven days per week by MWRA staff from Carroll Water Treatment Plant (CWTP) at Walnut Hill in Marlborough to demonstrate regulatory compliance. The SDWA regulations for drinking water require that a minimum of ninety percent of all source water samples (in any six-month period) contain less than 20 MPN/100 mL fecal coliform. All 366 samples from CWTP analyzed in 2024 were below the standard, with a maximum concentration of 6 MPN/100 mL on two days: January 11 and October 27. Most samples (67%) did not contain any detectable bacteria. DWSP has put considerable time and effort into implementing a rigorous bird harassment program, and the results from 2024 continued to demonstrate that these efforts are effective at maintaining low numbers of both birds and bacteria.

3.5 Macrophyte Monitoring and Management

Aquatic invasive species (AIS) have serious drinking water quality implications including potential increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. Macrophytes function as nutrient "pumps," extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter. Non-native, invasive species of macrophytes are known to aggressively displace native vegetation and grow to nuisance densities with the aforementioned impairments to water quality. AIS can be transported to the Reservoir system via human or wildlife pathways including, but not limited to, aquarium releases, recreational activity (i.e., fishing and boating equipment), waterfowl movement, and downstream flow. Unless otherwise specified, the non-native species discussed herein have been identified as a threat to water quality and are managed as such.

The *Wachusett Reservoir Aquatic Invasive Species Summary; Historical Update and Ongoing Actions* summarizes the history and threat of AIS in and around Wachusett Reservoir and addresses future actions[68]. It is updated periodically to reflect changes in AIS composition within and in proximity to the Reservoir. A new DWSP-wide AIS Management and Response Plan summarizing current AIS status and how the division is addressing existing populations and planning for new occurrences will be published in 2025.

Table 32. Aquatic Invasive Species in or Near Wachusett Reservoir

Scientific Name	Common Name	Known to be Present in Wachusett Reservoir	Known to be Present in Local Area
Cabomba caroliniana	Fanwort	X	X
Egeria densa	Brazilian elodea	N/A	X
Elatine ambigua	Asian waterwort	X	N/A
Glossostigma cleistanthum	Mudmat	X	N/A
Hydrilla verticillata	Hydrilla	N/A	X
Myriophyllum heterophyllum	Variable leaved water-milfoil (VLM)	X	X
Myriophyllum spicatum	Eurasian water-milfoil (EWM)	X	X
Najas minor	Brittle naiad	N/A	X
Nymphoides peltata	Yellow-floating heart	N/A	X
Phragmites australis	Common reed	X	X
Potamogeton crispus	Curly-leaf pondweed	N/A	X
Trapa natans	Water chestnut	N/A	X
Utricularia inflata	Inflated bladderwort	N/A	X
Pistia stratiotes	Water lettuce	N/A	X

[68] Trahan-Liptak & Carr, 2016

AIS were first recorded in Wachusett Reservoir in the late 1990s and have been actively managed since 2002. Early years of management focused on *Myriophyllum spicatum* (Eurasian water-milfoil) and *Cabomba caroliniana* (fanwort). In recent years, *Myriophyllum heterophyllum* (variable water-milfoil) was added as a target species. Several minute and cryptic AIS, including *Glossostigma cleistanthum* (mudmat) and *Elatine ambigua* (Asian waterwort), have also been documented in the Reservoir and are monitored on a routine basis as part of an overall AIS detection and management program.

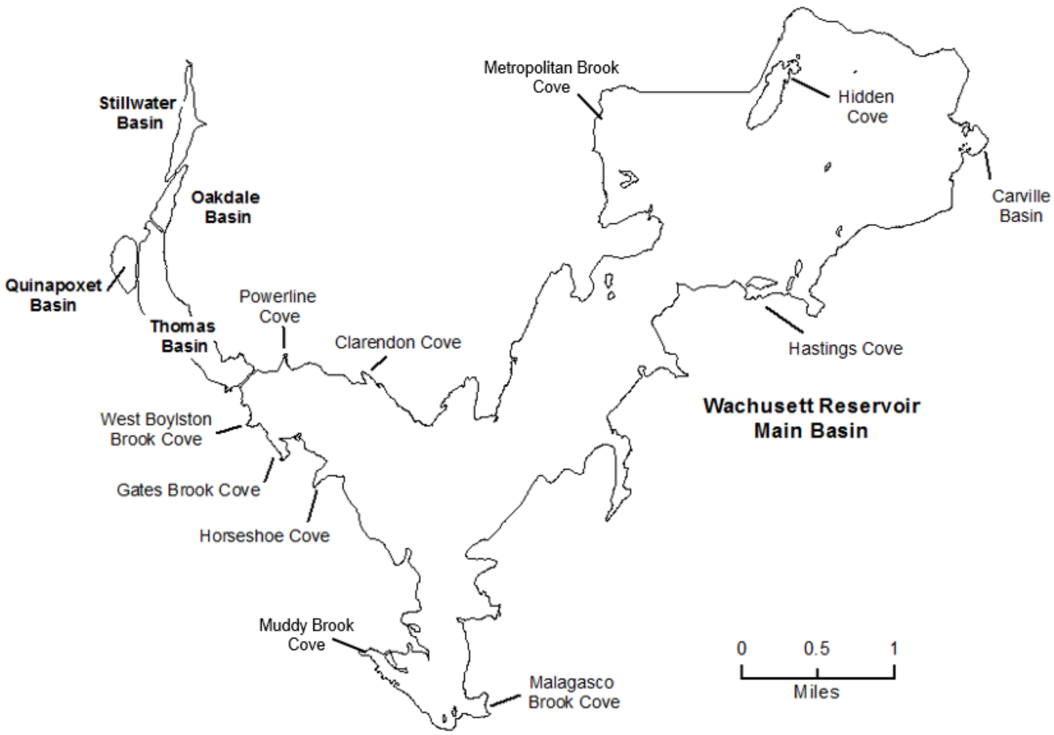
The following sections of this report provide details of AIS management activities undertaken in the Reservoir, elsewhere in the Watershed, and near the Reservoir during 2024 as well as those planned for 2025.

3.5.1 Wachusett Reservoir – Invasive Macrophyte Control Program

M. spicatum was first identified in the Wachusett Reservoir system in August 1999. The plants were initially isolated to Stillwater Basin; however, over the next several years, distribution extended southerly, in the direction of water flow, progressing through Oakdale Basin, into Thomas Basin and the upper coves of the Main Basin west of the Route 12/140 causeway in West Boylston. *C. caroliniana* followed a similar trend, with the initial discovery of the plant in Stillwater Basin in August 2000. The 2001 expansion of *M. spicatum* into Oakdale Basin prompted DWSP and MWRA to design and implement an invasive macrophyte control program. This program was initiated in 2002 and continues to the present.

Removal of *M. spicatum* and *C. caroliniana* via hand-harvesting was initiated in Oakdale Basin in 2002. Despite these efforts, *M. spicatum* and *C. caroliniana* gradually spread throughout Thomas Basin and into several coves of the main basin (Figure 64). As new infestations are identified, these areas are also targeted in annual removal efforts. Diver Assisted Suction Harvesting (DASH) was first implemented in 2012 and has continued as the primary control strategy for dense patches of plant growth. Hand-harvesting is used in areas where target species growth is less dense. An extensive DASH project in Stillwater Basin was initiated in 2013 to reduce the potential for re-infestation from dense growth in this uppermost basin of the Reservoir. Likewise, reservoir-wide management of *Myriophyllum heterophyllum*, including in Quinapoxet Basin, was initiated in 2020 following successful management of this historically present species. Physical control efforts are carried out by MWRA contractors and are supervised, and at times supplemented, by DWSP aquatic biologists. Details of control efforts in past years are provided in previous annual reports.

Figure 64: Locations of 2024 AIS Management and Monitoring in the Wachusett Reservoir System



The main components of this program are as follows:

- Deployment and maintenance of floating fragment barriers
- Physical removal of plants using hand-harvesting and DASH
- Quality assurance checks of select management areas
- Routine scouting within the Reservoir and Watershed by DWSP aquatic biologists to ensure early detection of pioneering infestations
- Immediate removal of pioneer infestations upon detection
- Point-intercept vegetation surveys by independent contractors
- Scouting the entire littoral zone of Wachusett Reservoir every five years (completed in 2012, 2016 and 2021)

Highlights of management in 2024 include the following:

- Plant densities increased and more *M. spicatum* was present in the upper basins (Stillwater, Oakdale and Thomas) than in recent years (Figure 65). Divers reported shifts in substrate and deposition areas following the anomalous 2023 rain events. These disturbed areas are more likely to be colonized by invasive species and will be carefully monitored in the coming years.
- Removal of *M. heterophyllum* continued in all managed areas of the Reservoir. Total plants harvested increased compared to 2023 (Figure 65, Figure 66 and Figure 66).
- A total of approximately 21,900 gallons of biomass were removed from Quinapoxet Basin (Figure 67).
- *C. caroliniana* has not been observed in Quinapoxet Basin since 2018 and *M. spicatum* density remains low with only one plant found in 2024.

Figure 65: *M. spicatum*, *C. caroliniana*, and *M. heterophyllum* Removed from Wachusett Reservoir 2003 to 2024
Plot shows totals removed from Oakdale, Thomas, and Powerline Coves

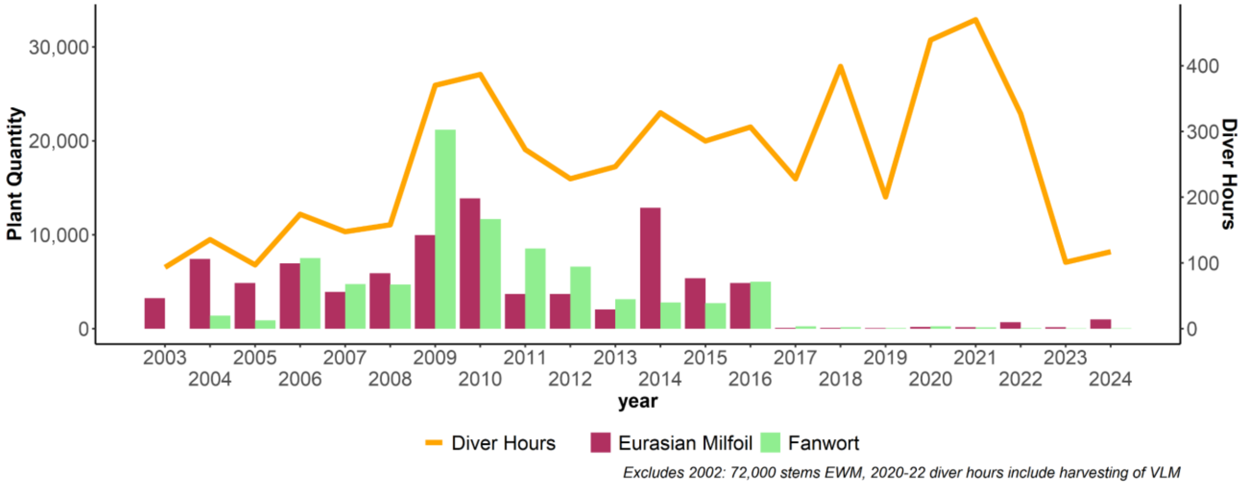


Figure 66: Invasive Species Removed from Wachusett Reservoir 2015 to 2024
Plot shows totals removed from Oakdale, Thomas, and Powerline Coves and includes totals for M. heterophyllum *stems.*

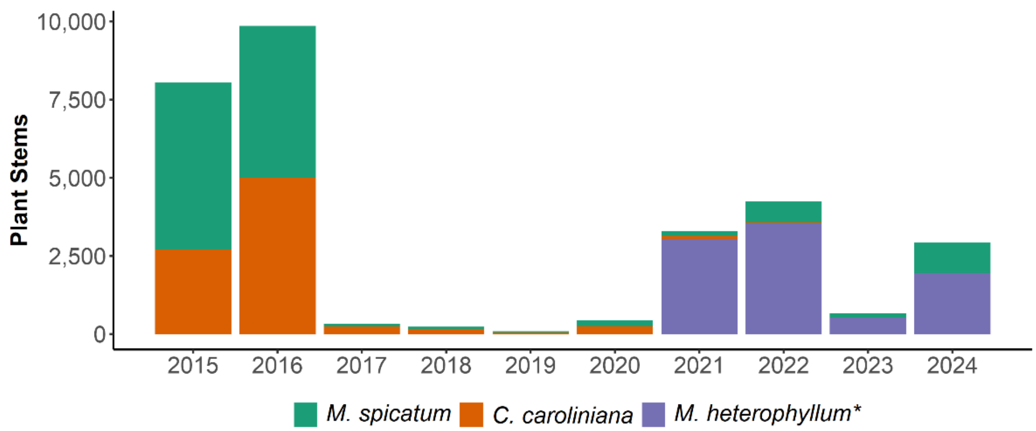
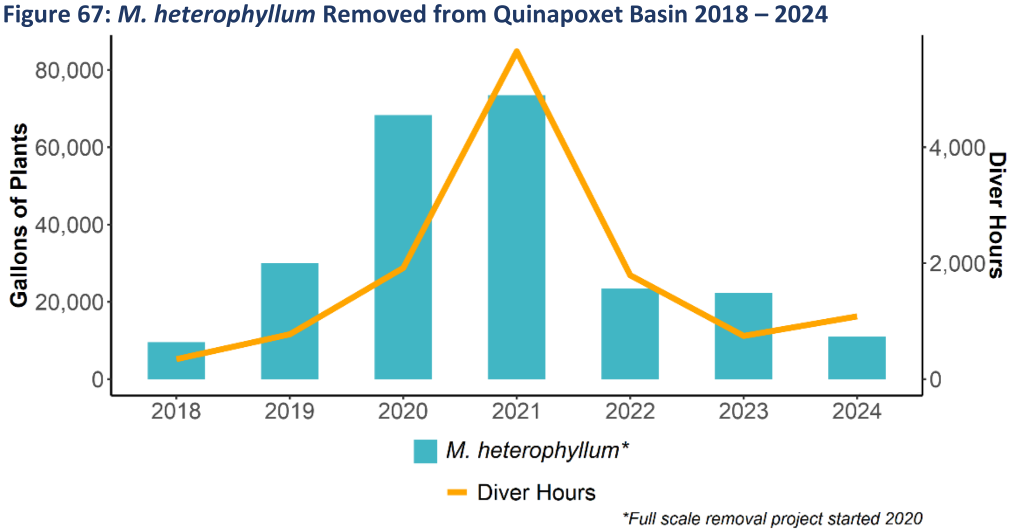


Figure 67: *M. heterophyllum* Removed from Quinapoxet Basin 2018 – 2024



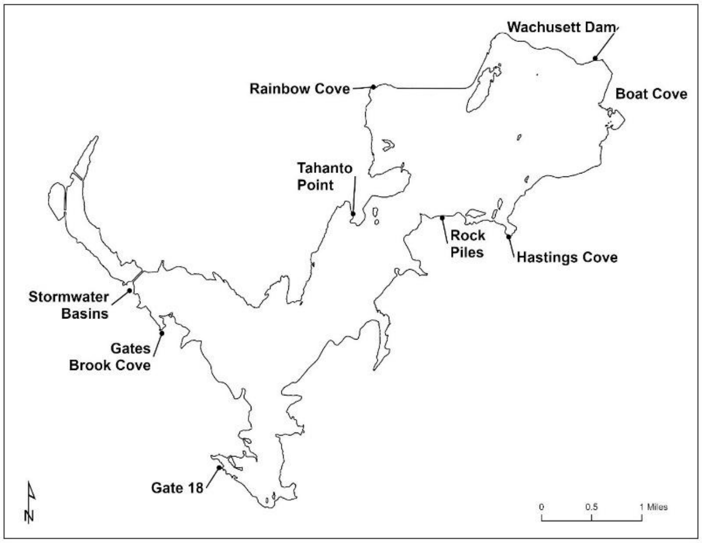
3.5.2 *Phragmites* Management

DWSP EQ staff surveyed for and managed *Phragmites australis* at 20 locations around the Wachusett Reservoir shoreline in 2024 (Table 33, Figure 68). Manual and mechanical removal were the primary management methods used. Management progress was tracked with a series of photographs, taken at the same location before and after each management event. Historical *P. australis* photographs have been preserved in DWSP files and additional background on *P. australis* management at Wachusett Reservoir can be found in prior Annual Water Quality Reports. *P. australis* surveys and management occurred between July and October; the goal of monthly management is to prevent *P. australis* from going to seed and to reduce the above and below ground biomass of all stands. Surveys and management were completed on July 9, August 8, August 27, September 25, and October 4.

Table 33: Shoreline *Phragmites australis* at Wachusett Reservoir

Stand ID	Initial Area (ft^2)	First Documented	2024 Management Method
Boat Cove A	1071	2013	Cutting, Hand pull
Boat Cove B	1640	2013	Cutting
Boat Cove C	316	2013	Cutting, Hand pull
Boat Cove D	50	2022	Cutting
Gates Brook	1314	2014	Cutting
Hastings Cove A	422	2009	Absent
Hastings Cove B	6034	2009	Cutting
Hastings Cove C	1635	2009	Cutting
Hastings Cove D	504	2009	Hand pull
Hastings Cove E	190	2009	Hand pull
Hastings Cove F	146	2009	Absent
Hastings Cove G	NA	2024	Hand pull
The Knob	NA	2022	Cutting, Hand Pull
Rainbow Cove	896	2009	Cutting
Tahanto Point A	860	2016	Absent
Tahanto Point B	511	2016	Hand pull
Storm Water Basins (x3)	19	2017	None
Rock Piles	112	2018	Absent
Dam	6	2018	Absent
Gate 18 Storm Water Basins	10	2021	None

Figure 68: *Phragmites australis* Locations Around Wachusett Reservoir



A new stand was discovered on July 9 just outside of Hastings Cove and was subsequently removed via hand-pulling. Survey and management effort in 2024 returned to a monthly schedule, compared to a reduced schedule in 2023. Overall, the Reservoir stands continued to show diminished regrowth compared to previous years; individual plant height appears to be reduced at most survey locations and plants have not returned to several pioneering locations. As in 2023, Hastings Cove and Rainbow Cove had a higher incidence of individual stems within the terrestrial areas along the shoreline compared to other stands. *P. australis* was not observed at Tahanto Point A, the Wachusett Dam, Rock Piles, and two Hastings Cove locations. The stand at Boat Cove A appears drastically reduced. Surveys and management in 2025 will return to a monthly schedule from June to October.

3.5.3 Wachusett Reservoir – Vegetation Monitoring

MWRA contracted with TRC to carry out point-intercept surveys of DWSP/MWRA source and emergency reservoirs. No new AIS were discovered in Wachusett Reservoir during the 2024 survey and no substantial increases in distribution and density were observed. *Glossostigma cleistanthum* (mudmat) distribution decreased, occurring at 12% of surveyed locations compared to 23% in 2023. TRC reported that low-growing species such as *Eleocharis* species along with *Elodea* species remained the most frequently encountered native aquatic genus in Wachusett Reservoir and macro-algae (*Nitella* spp.) was widely distributed in deeper areas. Overall, TRC reports that aquatic plant cover, density, and biovolume have remained stable over the past several years[69].

3.5.4 Supplemental Invasive Macrophyte Control Activities

Additional activities were conducted in 2024 outside of Wachusett Reservoir in conjunction with the main components of the in-reservoir invasive control program.

3.5.4.1 Management of AIS Outside of Wachusett Reservoir

AIS, including several novel species not found in Wachusett Reservoir have been identified in water bodies close to the Reservoir (Figure 69). Although Clamshell Pond and the South Meadow Pond Complex are

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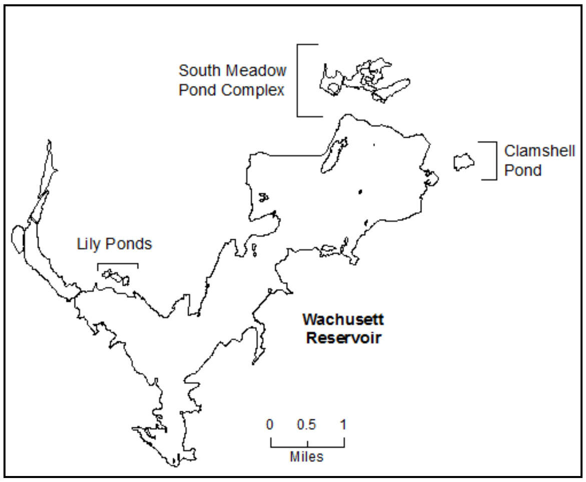
[69] TRC, 2025

outside of the Wachusett Reservoir Watershed, each of these waterways have been identified as potential sources of invasive species due to their proximity to the Reservoir. The potential for transfer of invasive species present in these water bodies to the Reservoir by waterfowl or bait buckets necessitates special management and monitoring efforts. Management and monitoring of these ponds by DWSP is ongoing.

Figure 69: Locations of Local Ponds Managed for AIS



South Meadow Pond Complex

Hydrilla was first discovered in August 2010 in the South Meadow Pond Complex, located just 1,970 feet (600 m) north of Wachusett Reservoir. A rapid response plan was initiated with the first herbicide treatment conducted in fall 2010. Herbicide treatments have continued annually with management of *P. crispus* added to the treatment program upon its discovery in 2015. *Najas minor* was discovered in 2022 and was subsequently added to the treatment program.

Results of treatment are monitored through pre- and post-management surveys conducted by the contractors and DCR and a tuber sampling program conducted by contractors since 2010. Tuber density has decreased such that less than one tuber per square meter is reported annually; however, these tubers continue to produce vegetation, requiring continued annual management. Rigorous surveys and assessments of historic management conducted by DCR contractors in 2023 resulted in a plan for four years of intensive management for the AIS present in South Meadow Pond using a combination of early season contact herbicide treatments to target *P. crispus* and carefully regulated complex-wide systemic treatments targeting *Hydrilla* with incidental control of *N. minor* and *M. heterophyllum* anticipated.

This program was carried out in 2024 with treatment of 4.3 acres of *Potamogeton crispus* with diquat on May 15 and six applications of fluridone to target *Hydrilla* throughout the pond complex. These herbicide applications were guided by monthly vegetation mapping surveys and herbicide residue testing followed by hydrilla tuber sampling in October. *Hydrilla* was observed in Mossy Pond during the 2024 surveys, but no tubers were collected at any sample location. This may indicate that herbicide treatments are successfully reducing the plants' capacity to reproduce, at least at levels where tubers would be detected by sampling methods. *N. minor* and *T. natans* were not encountered during the 2024 season; the former may be incidentally controlled by diquat and fluridone while it is possible the single *T. natans* plant harvested in 2023 was an isolated pioneer, controlled by removal. *Nuphar variegata* was the most commonly encountered native plant species in South Meadow Pond and other floating-leaf species including *Nymphaea odorata* and *Brasenia schreberi* occurred in larger densities in shallow areas of the pond system. Management and surveys will continue in 2025.

Clamshell Pond

DWSP initiated management of *Egeria densa* (Brazilian elodea) and *Trapa natans* (water chestnut) present in Clamshell Pond in 2016. These species had been present in the 25-acre pond, located approximately 1,300 feet (400 m) northeast of Wachusett Reservoir, since at least 2008, but DWSP was not aware of the infestations until records were made available in online databases[70].

E. densa was treated with the contact herbicide diquat in June 2018; it has not been observed in Clamshell Pond in any subsequent surveys. During surveys, DWSP biologists also monitor the *T. natans* population and remove plants, as necessary. In 2024, a total of 31 *T. natans* rosettes were removed from the southernmost cove. The native plant community remains robust with dense submerged vegetation including *Potamogeton robinsii* (Fern-leaf Pondweed) and *P. ampifolius* (Big-leaf Pondweed), and areas of dense floating vegetation including *Brasenia schreberi* (watershield), *Nymphaea odorata* (white water lily), and *Nuphar variegata* (yellow water lily) in shallow areas.

Lily Ponds

Najas minor and *M. spicatum* were identified in the Lily Ponds in 2015. Due to the ponds' locations, approximately 600 feet (180 m) from the Reservoir shoreline, a rapid response plan was initiated in fall 2015 and management has continued annually. *M. spicatum* has not been observed since the initial diquat treatment in 2015. *N. minor* remains in each pond, likely due to a seed bed which persists in the sediment. In 2024, *N. minor* in all three ponds was managed in late June via application of the systemic herbicide fluridone. *N. minor* was not observed in subsequent surveys.

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[70] USGS, 2021

4 Conclusions and Recommendations

4.1 Wachusett Tributary Water Quality

2024 was another year where many water quality and hydrological statistics were skewed either high or low relative to historical means and medians, largely due to a drastic shift in hydrologic conditions. Seasonal hydrological patterns in 2024 were accentuated by above average streamflows and groundwater levels early in the year followed by extremely low levels late in the year and critical drought. Air temperatures were above average during most months of the year and July 2024 was the warmest July since 1998. Significant flushing of the landscape and soils from record precipitation during the 2023 growing season and spring of 2024 resulted in a depletion of hyporheic and terrestrial nutrient and mineral pools, which was ultimately reflected in many of the water quality and chemistry results observed during 2024.

Tributary water temperatures followed typical seasonal patterns, with summertime high temperatures rising above the MassDEP recommended threshold for coldwater species (20 °C) in several tributaries for durations spanning 9 – 106 days (though not necessarily consecutive). Although CFR temperature standards were not met at all monitoring locations, areas of groundwater exfiltration and deeper pools (which are unmonitored) likely provide thermal refuge for temperature sensitive species. All tributaries except for Waushacum and French Brooks remained within the recommended temperature range for warm water species. Dissolved oxygen levels remained in the recommended ranges at all tributaries, except for the Stillwater River (CFR) at one monitoring visit, French Brook (WFR) on six monitoring visits, and Waushacum Brook (WFR) on ten monitoring visits. The summertime low dissolved oxygen in Waushacum Brook is common, and likely due to the large and often stagnant wetland area just upstream of the sample location. The single low dissolved oxygen measured in the Stillwater River was 5.1 mg/L, only 0.9 mg/L below the CFR threshold. To help reduce stress on coldwater species and improve other aspects of tributary water quality, DWSP should continue to actively promote the pre-treatment of stormwater, most importantly through the reduction of direct discharges of stormwater collected from impervious surfaces, and the preservation and expansion of forested stream buffer zones.

Bacteria concentrations in 2024 (*E. coli* geometric means) were variable across Wachusett Reservoir tributaries and generally followed normal seasonal patterns with occasional short-lived spikes. Consistent with previous years, bacteria concentrations were typically higher during periods of wet weather. There were 22 samples that fell above the STV of 410 MPN/100 mL. Gates Brook 4 and West Boylston Brook, which have had episodes of persistently elevated bacteria concentrations in recent years, continue to have relatively higher bacteria concentrations than most other watershed tributaries, but have steadily improved over the last four years. Asnebumskit Brook has had a recurring issue with elevated bacteria concentrations during the summer and fall months. The source of this seasonal bacteria increase was thought to have been roosting pigeons, however a new investigation that began in 2024 found that another source located at Jefferson Mill, downstream of Eagle Lake, was at times the primary driver of elevated bacteria in the brook. Additional sampling was conducted in order to identify the geographic and animal source of this bacteria. Bracket sampling did narrow down the bacteria source to a very specific location, however DNA analysis conducted to identify the source species connected to elevated *E. coli* was inconclusive. More information about this monitoring effort in 2024 is provided in Appendix D, and this investigation will continue until the source can be fully identified or is no longer present.

Median turbidity in all Wachusett tributaries was higher than the long-term (2005-2023) median. The extreme swing in hydrologic conditions (very wet to very dry) resulted in flow conditions that were more frequently very low and very high, which are commonly associated with higher-than-normal turbidity due to shallow water columns causing samples to be collected close to the stream bed, or increased runoff and turbulent flow causing elevated suspended sediment loads. Although there were occasional elevated bacteria and turbidity results during 2024, Wachusett tributary sanitary quality continues to be excellent overall, providing source water that meets all drinking water compliance standards for bacteria and turbidity.

Alkalinity and pH monitoring continued in 2024, with values falling below recommended levels on some tributaries, similar to previous years. Waushacum and Trout Brooks fell below the minimum recommended pH (6.5) more often than other tributaries, which is likely in part due to the peat bogs and wetlands within their respective drainage areas. The seasonal variation in pH mostly followed previously observed patterns at respective tributaries. Mean annual alkalinity for 2024 was highest since 2020 at six tributaries and mean alkalinity over the last five years is slightly higher compared to the 2000-2012 monitoring period, except for Muddy Brook. This increase in alkalinity is beneficial for aquatic life where alkalinity has historically been low (below 20 mg/L), however the geochemical changes that are responsible for these increases are signals of instability, which should be monitored and investigated. Overall, the pH and alkalinity values observed in Wachusett tributaries are reflective of natural conditions and are not a water quality concern for the drinking water supply at this time.

The dilution effect from the precipitation surplus in 2023, which extended into the first half of 2024, resulted in further decreases in specific conductance values going into April and early May. Most tributaries returned to historical levels by September and finished the year slightly above normal. The net result for 2024 was that six tributaries experienced low to moderate increases in mean annual specific conductance, while 12 experienced decreases. Eight tributaries experienced their lowest mean annual conductivity over the last 10 years, including Gates, West Boylston, Oakdale and Scarlett Brooks, which have all struggled with chronically high specific conductivity levels during this period of time. The increased temporal resolution of specific conductance measurements obtained from the Mayfly monitoring stations and USGS stations provided greater insight into the true variability of specific conductance levels in the primary Wachusett tributaries. While the mean annual values of the high-resolution results were similar to the grab results, the grab samples collected 2-3 times per month did not capture the high and low spikes that occurred during runoff events. Salt loads were estimated for the third consecutive year for all primary tributaries. The total annual salt load for Wachusett Watershed in 2024 was just over 10,000 tons, which was approximately 39% lower than in 2023. This load is more comparable to 2022, which had a similar hydrological context.

Routine tributary and groundwater monitoring results for dissolved salts and specific conductance in 2024 continue to be elevated across several Wachusett Watershed subbasins. Chloride concentrations in Gates and West Boylston Brooks continued to be above chronic chloride toxicity threshold during several periods throughout 2024. High temporal resolution specific conductivity data collected from several of the Mayfly and USGS monitoring stations show continued evidence of chloride spikes above the acute toxicity threshold for aquatic life occurring after road salt applications. The newest Mayfly station on Trout Brook was able to capture winter-time runoff events that had extremely high specific conductance levels, which was not previously documented with infrequent grab samples. Unfortunately, this exemplifies that even pristine streams in rural areas can be significantly impacted by a small number of roads that are heavily salted.

Elevated Cl/conductivity in the Wachusett Reservoir and tributaries continues to be a high priority concern for DWSP and is the focus of additional research in collaboration with UMass, ongoing mitigation, and planning efforts at DWSP. The current monitoring for chloride and specific conductivity should continue in tandem with new research findings and mitigation programs.

Routine tributary nutrient monitoring results for 2024 were consistent with historical data and demonstrate continued adherence to drinking water quality standards. Total Nitrogen concentrations have been generally consistent across all primary tributaries since 2015. The fraction of organic forms of nitrogen (TKN and Ammonium-N) in 2024 was lower than in 2023 at all tributaries, whereas the inorganic fraction (Nitrate-N) was higher. The observed concentrations of nitrogen compounds during 2024 continue to be well below regulatory standards and are not sufficiently elevated to be a water quality concern. Annual mean TP concentrations for 2024 were mostly within the ranges observed over the previous nine years, except for West Boylston Brook, which had the lowest annual mean concentration over this time period (12.8 µg /L). 2024 annual TP medians were lower in eight out of the ten primary tributaries. The observed TP concentrations in Wachusett tributaries for 2024 were generally low and mostly within ecoregional background ranges. Three tributaries (French, Trout, and Malagasco Brooks) have long-term median TP concentrations above 23 µg/L, which could be indicative of phosphorus loading above background levels. If time and resources allow, additional assessments could be conducted to determine sources of excess nitrogen in Malagasco and Malden Brooks and phosphorus in French, Malagasco, and Trout Brooks.

In 2024, median TOC concentrations and UV_{254} levels were lower than long-term medians at all tributaries. The overall mean TOC concentration for 2024 was 3.61 mg/L, which is 27% lower than the long-term mean concentration since 2015 (5.06 mg/L). A recent internal trend analysis for UV_{254}, which strongly correlates to TOC concentrations, found that variation in UV_{254} is highly influenced by precipitation patterns. The significant swing from high carbon export rates observed in 2023 to low carbon export rates in 2024 can be directly correlated to the drastic swing in hydrologic conditions during this time – from record wet condition with significant flushing of organic matter from the landscape to critical drought. The long-term trends for UV_{254} in Wachusett tributaries are mixed, with some slightly decreasing and some slightly increasing. The only statistically significant trends were from French, Malagasco, and Trout Brooks, which were all decreasing. However, higher resolution UV_{254} data available for Cosgrove Intake showed a statistically significant and slightly increasing trend. Even though 2024 was a better year in terms of organic loads in raw drinking water from the Wachusett Reservoir, the formation of disinfection byproducts from reactive organic compounds remains a top water treatment concern. DCR staff should continue efforts to better understand the drivers of temporal and spatial variability of carbon loading to Wachusett Watershed tributaries and continue to research management practices or changes to reservoir operations that could help reduce the reactive carbon load to the Wachusett Reservoir.

4.2 Wachusett Reservoir Water Quality

Overall, results of the Wachusett Reservoir monitoring program were consistent with historical data and demonstrated continued adherence to high drinking water quality and aquatic life use standards. The limited number of results which were characterized as elevated or fell above historical site ranges were slightly elevated beyond the 75^{th} percentile, were isolated events, or can be tied to specific factors such as abnormally high rainfall.

Results of routine water quality profiles were comparable to historical trends and continued to provide guidance for phytoplankton sampling, detection of the Quabbin interflow, and stratification. Monitoring results of these conditions were also similar to previous years.

Lower than normal inputs from the Wachusett Watershed during the 2024 drought and increased volumes of water transferred from Quabbin Reservoir in recent years likely contributed to the continued dilution of salts in Wachusett Reservoir. Results for alkalinity, UV_{254}, and silica concentration recorded at Reservoir monitoring locations were elevated at several sites throughout the year. These values largely coincide with relatively high specific conductance values for these sites and timeframes, indicating a higher percentage of native Wachusett water present in these locations. These conditions were especially apparent in the summer when surface waters were influenced by tributary discharge and higher nutrient waters were isolated in the hypolimnion. As is typical, overall concentrations improved following turnover.

4.3 Proposed Wachusett Watershed Monitoring Programs

4.3.1 Hydrological and Climate Monitoring

Continuous monitoring with Mayfly dataloggers and Hydros-21 CTD sensors will continue for 2025 at seven primary tributary monitoring locations: French, Malagasco, Muddy, Malden, Trout, Waushacum and West Boylston Brooks. These stations measure conductivity, temperature, and depth at 15-minute increments with real-time raw data access via the internet. The existing HOBO U20 depth and temperature logger will remain in place at West Boylston Brook (for water depth/discharge only).

Groundwater levels will continue to be manually measured monthly at seven wells. USGS will continue to operate and maintain real-time monitoring stations at the Sterling and West Boylston wells as part of the Climate Response Network.

Snowpack measurements will continue during the winter months as in prior years. Prior to the 2022/2023 snow season, the location of the Boylston snowpack monitoring site was moved closer to the access road parking area on Rt. 70 and given the location ID “BOY70”.

Monitoring Element	Current Program	Proposed Changes
Real-time flow monitoring	10 tributaries (3 by USGS)	No change
Precipitation	2 USGS Stations, 2 NOAA Stations	No change
Snowpack (seasonally)	Weekly, 6 locations	No change
Groundwater levels	Monthly manual, 7 wells	No change

4.3.2 Groundwater Quality Monitoring

Using a flow cell to collect field parameter data, specific conductance, temperature, dissolved oxygen, and pH sampling that began in 2022 will continue in 2025. No samples will be collected for lab analysis under the WATWEL project in 2025. DWSP will continue to seek out additional wells in the Watershed with existing data collected by other organizations or wells that can be added to the routine sampling program.

Monitoring Element	Current Program	Proposed Changes
Groundwater Quality	Monthly – Seven wells for specific conductance, temperature, dissolved oxygen and pH	No change

4.3.3 Tributary Monitoring

Routine tributary monitoring projects (WATMDC and WATTRB) and field parameter collection will continue at the same frequency and with the same parameters as in 2024. Real-time conductivity monitoring will be continued at all primary tributary monitoring locations.

Monitoring Element	Current Program	Proposed Changes
Nutrients, Cl, UV absorbance, TSS, Alkalinity (WATMDC)	Monthly, 10 primary tributaries + Quabbin Transfer (MDS1)	No change
Bacteria and Turbidity (WATTRB)	2x per month, 18 Locations	No change
Field parameters (water temperature, pH, specific conductance, dissolved oxygen, pH, stage)	3x per month in conjunction with other projects	No change
Real-time conductivity monitoring (USGS or DWSP – using Mayfly)	3 USGS Stations, 7 DCR Stations	No change

4.3.4 Special Projects and Other Sampling

4.3.4.1 Long-term Forestry Study

Monitoring long-term effects of water quality at forestry locations resumed in December 2024 after the experimental lot (Princeton) was harvested. Sufficient dry and wet weather data has been collected to establish hydrologic and water quality relationships between the paired watersheds. The completion of a preliminary summary report for the pre-harvest phase is still pending. The post-harvest phase of the study will continue in 2025, and until sufficient data has been collected to complete the study.

Long-term Forestry Monitoring Element	Current Program	Proposed Changes
Nutrients, UV absorbance, TSS (WATBMP)	Monthly dry weather samples and quarterly storm samples at FHLN and FPRN	No change, but resuming after pause
Field parameters (water temperature, pH, specific conductance, dissolved oxygen, pH, stage)	1x per month in conjunction with dry weather samples and high frequency during storm events sampling events	No change, but resuming after pause
Real-time flow and air temperature monitoring (using HOBO)	Flow at FHLN and FPRN, Air temperature at FPRN	No change, but resuming after pause

4.3.4.2 Quabbin Transfer (Shaft 1) Monitoring

Nutrient and field parameter monitoring of Quabbin Transfer water (Shaft 1 - MDS1) will continue in conjunction with routine tributary nutrient monitoring (when flowing). First flush samples will be collected, when possible, to capture water quality impacts that may arise due to prolonged residence times within the aqueduct. This information remains extremely useful in understanding the influence of Quabbin Reservoir water on Wachusett Reservoir water quality.

4.3.4.3 Follow-up Bacteria Monitoring and Microbial Source Tracking

Follow-up samples for bacteria (*E. coli*) at routine sampling locations will be conducted within 48 – 72 hours when a result is higher than a predetermined metric based on historical observations and overall watershed conditions at the time of the sample. Additional locations may be sampled if elevated bacteria levels persist for extended periods of time for unknown reasons. Samples may be sent in for DNA analysis if upstream tracking cannot determine the cause of elevated bacteria levels.

4.3.4.4 Flow Targeted Nutrient Samples

Supplementary nutrient samples may also be collected from routine nutrient monitoring stations when specific flow conditions are present that have been under-sampled in the past.

4.3.4.5 Groundwater Isotope Sampling

Stable isotope sample collection was suspended in 2022 but may resume after a review of the data from existing isotope samples. Previously collected samples are expected to be analyzed during 2025.

4.3.4.6 Tributary Storm Sampling

Storm sampling will remain on hold. Once the accumulated storm sampling data has been analyzed a determination will be made about how best to continue this program. Historical data analysis and future sampling will depend on staff availability.

4.4 Reservoir Monitoring for 2025

Most Wachusett Reservoir monitoring programs which will be conducted again in 2025 have a well-established framework which provide flexibility in response to current environmental conditions. These programs are detailed elsewhere in this report and briefly described below, but overall, no changes are proposed.

Temperature, specific conductance, dissolved oxygen concentration, percent oxygen saturation, chlorophyll *a*, phycocyanin, turbidity, and pH profiles as well as Secchi disk transparency will be measured at Basin North (BN3417) in conjunction with weekly plankton monitoring. More frequent profiles will be collected when necessary to document changing conditions in the Reservoir. Nutrient samples will be collected seasonally at Basin North (BN3417), Basin South (BS3412), and Thomas Basin (TB3427) using standard methodologies described in Section 2 of this report. Quarterly collection of zooplankton for invasive species screening and identification of common zooplankton present in the Reservoir will also continue.

Monitoring and management of AIS within Wachusett Reservoir and in ponds near the Reservoir will continue on an as-needed basis in 2025.

Movement of water and contaminants through the Reservoir remains of significant interest. Sampling of the Reservoir surface will continue regularly. Monthly, twice monthly, or weekly bacterial transect sampling will be completed during ice-free periods to help further understand the effect of avian populations and water movement on fecal bacteria (*E. coli*) levels throughout the Reservoir and fecal coliform levels at Cosgrove Intake.

Monitoring Element	Current Program	Proposed Changes
Reservoir Profiles	Weekly May – Sept. at BN3417 or CI3409	No change
Secchi Disk Depth	Biweekly Oct – April at BN3417 or CI3409	No change
Phytoplankton	Regular phytoplankton sampling will continue; the frequency of additional monitoring for taste and odor taxa to be decided in concert with MWRA based on alert thresholds	No change
Nutrients	Quarterly	No change
Zooplankton	Quarterly	No change
Fish	Fall *S. namaycush* spawn and other seasonal observations as appropriate	No change
Macrophytes	Surveys and contractor monitoring throughout the growing season	No change
Bacteria	At least monthly at 23 locations	No change
Stormwater Basins	Monthly	No change

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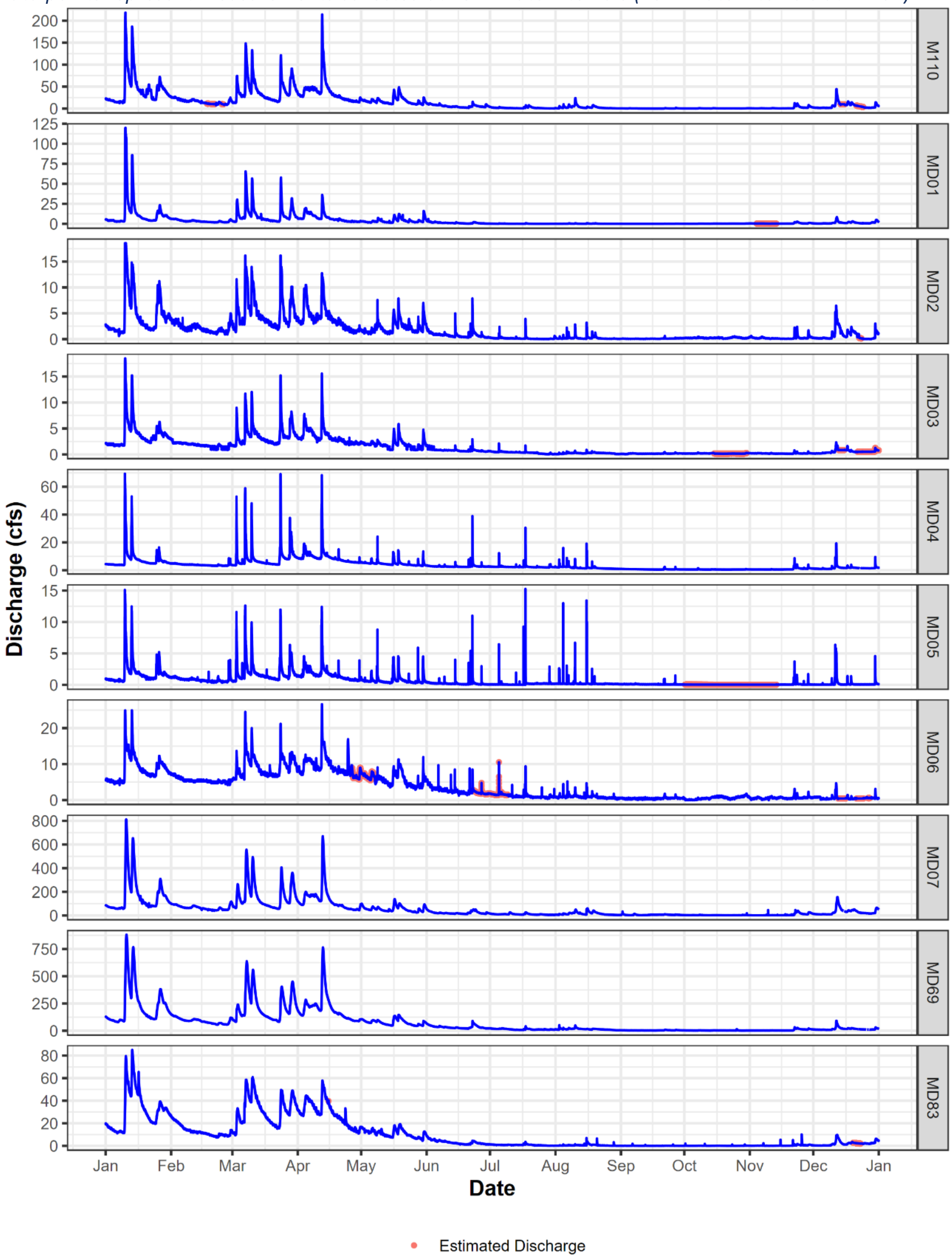
Appendix A: Continuous Data Hydrographs

Figure A-1: Hydrographs for Wachusett Watershed Tributaries During 2024

Data points represent measurements collected at 15-minute intervals (10-minute intervals at MD04).



Appendix B: Water Quality Standards and Criteria

Table B-1: Water Quality Standards/Criteria Applicable to Wachusett Watershed Surface Waters

Parameter	Standard/Criteria	Regulatory reference	Threshold Value	Notes
Alkalinity	Aquatic Life – Freshwater (Chronic)	EPA – Quality Criteria for Water 1986	Minimum 20 mg/L	Except where it is naturally lower; then the criterion cannot be lower than 25% of the natural level
Ammonia-nitrogen	Aquatic Life – Freshwater (Chronic)	EPA - Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater	Maximum 1.9 mg Total Ammonia Nitrogen (TAN)/L (pH 7.0, T = 20 °C)	30-day average; Not to exceed 2.5 times the Criteria Continuous Concentrations (CCC), or 4.8 mg TAN/L (at pH 7, 20 °C), as a 4-day average within the 30-days, more than once in three years on average
Ammonia-nitrogen	Aquatic Life – Freshwater (Acute)	EPA - Aquatic Life Ambient Water Quality Criteria for Ammonia - Freshwater	Maximum 17 mg/L (pH 7.0, T = 20 °C)	1-hr Average; Not to be exceeded more than once in three years on average
Chloride	Drinking Water SMCL	310 CMR 22.07D	Maximum 250 mg/L	Drinking water point of consumption
Chloride	Aquatic Life (Acute)	EPA Ambient Aquatic Life Water Quality Criteria for Chloride	Maximum 860 mg/L	1-hour average once every 3 years (when associated with sodium)
Chloride	Aquatic Life (Chronic)	EPA Ambient Aquatic Life Water Quality Criteria for Chloride	Maximum 230 mg/L	4-day average once every 3 years (when associated with sodium)
Dissolved Oxygen	Coldwater Fisheries (Aquatic Life)	314 CMR 4.05(3)(a)1	Minimum of 6 mg/L	Instantaneous value, background conditions considered
Dissolved Oxygen	Warmwater Fisheries (Aquatic Life)	314 CMR 4.05(3)(a)1	Minimum of 5 mg/L	Instantaneous value, background conditions considered
Escherichia coli (*E. coli*)	Inland waters	MassDEP 314 CMR 314 4.05(5)(f)1	Maximum geometric mean of 126 CFU/100 mL; Maximum 10% samples > 410 CFU/100 mL	Both metrics apply for any 90-day or shorter interval; both must be met
Fecal coliform / Total coliform	Unfiltered Water Supply Intakes	MassDEP 314 CMR 314 4.06(1)(d)1	20 organisms /100 mL OR 90% samples over any 6 months must be < 100 CFU/100 mL	The first criterion applies to fecal coliform and the second criterion applies to total coliform. If both are measured, only the fecal coliform criteria must be met
Nitrate-nitrogen	Drinking Water	EPA SDWA MCL	Maximum of 10 mg/L	Drinking water point of consumption
Nitrite-nitrogen	Drinking Water	EPA SDWA MCL	Maximum of 1 mg/L	Drinking water point of consumption
Nitrate-nitrogen + Nitrite-nitrogen	Ecoregional reference – (Streams/Rivers)	EPA Ambient Water Quality Criteria Recommendations	0.16 – 0.31 mg/L	25^{th} Percentile subecoregion 58 – 25^{th} Percentile subecoregion 59

Parameter	Standard/Criteria	Regulatory reference	Threshold Value	Notes
Nitrate-nitrogen + Nitrite-nitrogen	Ecoregional reference (Lakes/Reservoirs)	EPA Ambient Water Quality Criteria Recommendations	0.014 – 0.05 mg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
pH	Class A Inland Waters	314 CMR 4.05(3)(a)3	6.5 – 8.3 S.U.	Acceptable range but no more than 0.5 units outside of natural background range; No change from background level
Specific Conductance	Aquatic Life Chronic Recommendation	MassDEP CALM 2022	Maximum 904 µS/cm	At 25 °C; Proxy for chloride
Specific Conductance	Aquatic Life Acute Recommendation	MassDEP CALM 2022	Maximum 3,193 µS/cm	At 25 °C; Proxy for chloride
Temperature (Freshwater)	Coldwater Fisheries	314 CMR 4.05(3)(a)2	Maximum of 68 °F (20 °C)	7-day mean-maximum daily temperature unless naturally occurring
Temperature (Freshwater)	Warmwater Fisheries	314 CMR 4.05(3)(a)2	Maximum of 83 °F (28.3 °C)	7-day mean-maximum daily temperature unless naturally occurring
Total Phosphorus	Ecoregional reference – (Streams/Rivers)	EPA Ambient Water Quality Criteria Recommendations	5.00 – 23.75 µg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
Total Phosphorus	Ecoregional reference (Lakes/Reservoirs)	EPA Ambient Water Quality Criteria Recommendations	7.0 – 8.0 µg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
Total Kjeldahl Nitrogen	Ecoregional reference – (Streams/Rivers)	EPA Ambient Water Quality Criteria Recommendations	0.10 – 0.30 mg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
Total Kjeldahl Nitrogen	Ecoregional reference (Lakes/Reservoirs)	EPA Ambient Water Quality Criteria Recommendations	0.33 – 0.43 mg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
Total Nitrogen	Ecoregional reference – (Streams/Rivers)	EPA Ambient Water Quality Criteria Recommendations	0.34 – 0.59 mg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
Total Nitrogen	Ecoregional reference (Lakes/Reservoirs)	EPA Ambient Water Quality Criteria Recommendations	0.27 – 0.40 mg/L	25th Percentile subecoregion 58 – 25th Percentile subecoregion 59
Turbidity	Unfiltered Surface Water Supplies	EPA SWTR MCL	Maximum 5.0 NTU	May not exceed at any time
Turbidity	Unfiltered Surface Water Supplies	310 CMR 22.08(1)	Maximum of 1.0 NTU	Determined by a monthly average rounded to the nearest significant whole number. May only exceed if does not interfere with effective disinfection

Appendix C: Watershed Monitoring Parameters and Historical Context

C-1 Ammonia-Nitrogen

Ammonia is an inorganic form of nitrogen that is usually present in surface water at low background concentrations (less than 0.1 mg/L)[71]. Ammonia is very soluble in water, highly reactive, and can be toxic to aquatic life under certain conditions. Ammonia is converted to nitrate naturally, which depletes water of dissolved oxygen, also negatively impacting aquatic life[72]. In 2013 the U.S. EPA updated its aquatic life ammonia criteria to incorporate findings from more recent studies which demonstrated that aquatic life toxicity is highly dependent on water temperature and pH. The updated criteria also accounted for more sensitive taxa (such as mussels) that were not protected under the previous criteria. At pH of 7 and temperature of 20 °C, the acute criteria for NH_3-N is 17 mg/L (1-hour duration) and the chronic criteria is 1.9 mg/L (30-day average; cannot exceed 2.5 times the chronic criteria (4.8 mg/L) as a 4-day average within the 30-days, more than once in three years on average)[73]. Across the varying temperatures and pH values found in Wachusett Reservoir and the tributaries, the acute criteria ranges from 9.4 – 41 mg/L, while the chronic criteria ranges from 1.2 – 4.5 mg/L. Concentrations of NH_3-N have been below detection (0.005 mg/L) in nearly half of all Wachusett tributary samples taken to date, with a maximum single result of 0.876 mg/L. Ammonia concentrations in the Reservoir have been below detection (0.005 mg/L) in approximately one-third of samples taken to date. The maximum Ammonia concentration recorded in the Reservoir is 0.057 mg/L. There are no drinking water specific action levels or maximum contaminant levels (MCLs) designated by any U.S. statutes, however the World Health Organization guidelines on drinking water quality list odor and taste thresholds of 1.5 and 1.9 mg/L, respectively[74]. Possible sources of NH_3-N in the Wachusett Watershed include septic systems, landfill leachate, agriculture (from fertilizer and livestock), atmospheric deposition, and natural biological processes.

Although the concentrations of NH_3-N that have been observed historically in Wachusett Reservoir Watershed tributaries are well below thresholds of concern, DWSP continues to monitor NH_3-N as a diagnostic tool for detection of contamination from high priority water quality threats (e.g., leaking septic/sewer, agricultural runoff). The current water quality goal for NH_3-N is to maintain local background concentrations.

C-2 Nitrate-Nitrogen

Nitrate-nitrogen (NO_3-N) is an important macro-nutrient for plants and the most abundant inorganic form of nitrogen found in water[75]. Sources of nitrate include runoff from agricultural sites and fertilized lawns, failing on-site septic systems, atmospheric deposition, and some industrial discharges. Background concentrations of NO_3-N + NO_2-N (Nitrite) in rivers and streams of the Wachusett Watershed ecoregions were found to range between 0.1 mg/L and 4.12 mg/L. The 25th percentile values (all seasons) of 0.16 mg/L (ecoregion 58)[76] and 0.31 mg/L (ecoregion 59)[77] are the reference conditions for streams and rivers recommended by the EPA for the development of numerical NO_3-N + NO_2-N criteria for these ecoregions. NO_2-N is usually present in very low concentrations (see Sections 3.2.7.1 and 3.4.7.2), therefore it can be

71 USGS, 1999
72 Mallin et al., 2006
73 USEPA & Tetra Tech Inc, 2013
74 World Health Organization [WHO], 1996
75 USGS, 1999
76 USEPA, 2001a
77 USEPA, 2000

assumed that these background concentrations are primarily composed of NO_3-N. At elevated concentrations, nitrates can cause significant water quality problems including increases in aquatic plant growth, reductions in dissolved oxygen concentrations, changes in plant and animal species composition, and loss of biodiversity[78].

In terms of drinking water quality, consumption of nitrates can become toxic to warm-blooded animals at very high concentrations (10 mg/L or higher), due to conversion to nitrite through reduction (see Sections 3.2.7.1 and 3.4.7.2). The EPA MCL for NO_3-N is 10 mg/L[79]. Several other studies (mostly in Europe) have linked high levels of nitrate consumption, though in some cases below the EPA MCL, to various cancers[80]. However, more research is needed on this topic because high nitrate levels tend to be associated with other contaminants, which can confound the interpretation of study results. Fortunately, NO_3-N concentrations throughout the Wachusett Watershed have remained well below the MCL. The current water quality goal for NO_3-N is to maintain existing local background concentrations.

C-3 Nitrite-Nitrogen

Nitrite-nitrogen (NO_2-N) is a short-lived nitrogen compound that is produced during nitrification/denitrification processes. Sources of nitrite are the same as for nitrate, but it is typically present in surface waters in much lower concentrations. Elevated levels of nitrite have been shown to cause methemoglobinemia in humans, which is a reduction in the ability of blood to transport oxygen to tissues[81], and is particularly lethal to infants[82]. In order to protect human health, the EPA has established the MCL for NO_2-N in drinking water at 1.0 mg/L[83]. Although nitrite concentrations are rarely above the detection limit (0.005 mg/L) in Wachusett tributaries, this parameter continues to be monitored to demonstrate compliance with the MCL and to track nutrient inputs to the Reservoir. The current water quality goal for NO_2-N is to maintain existing local background concentrations, which are well below all thresholds of concern.

C-4 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen plus NH_3-N and ammonium-nitrogen (NH_4-N). It often constitutes a significant proportion of the total nitrogen present in a natural water body (20 – 80% in Wachusett tributaries). Background concentrations of TKN in rivers and streams of the Wachusett Watershed ecoregions were found to range between 0.05 mg/L and 1.45 mg/L. The 25th percentile value (all seasons) of 0.10 mg/L (ecoregion 58)[84] and 0.30 mg/L (ecoregion 59)[85] are the reference conditions for streams and rivers recommended by EPA for the development of numerical TKN criteria for these ecoregions. This fraction of nitrogen is important to account for because it can be converted to other forms of nitrogen through natural processes and can contribute to unwanted plant growth in water bodies. There are no water quality standards for TKN, however this metric includes NH_3-N, which is toxic at low concentrations and has specific regulatory thresholds (see Sections 3.2.7.1 and 3.4.7.2). Sampling for TKN in the Wachusett Reservoir Watershed began in 2015 to account for organic sources of tributary

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[78] Camargo & Alonso, 2006
[79] Safe Drinking Water Act of 1974, 2019
[80] Ward et al., 2018
[81] Ibid
[82] Walton, 1951
[83] Safe Drinking Water Act of 1974, 2019
[84] USEPA, 2001a
[85] USEPA, 2000

nitrogen and allow for a better understanding of nutrient dynamics. The current water quality goal for TKN in streams, rivers, and the Reservoir is to maintain existing local background concentrations.

C-5 Total Nitrogen

Total nitrogen (TN), as measured in water, is the sum of TKN, NO_3-N and NO_2-N. This calculated parameter is important to examine in conjunction with total phosphorus (TP) because the ratio of nitrogen to phosphorus in aqueous systems controls primary production and has important implications for the ecology and drinking water quality of a water body. The dominant forms of nitrogen in surface waters are NO_3-N and organic nitrogen, with much smaller fractions of inorganic NH_3-N and NH_4-N species (See Sections C-1 – C-4).

Massachusetts has only developed numeric water quality criteria for nitrogen for specific water bodies with significant impairments from nutrient over-enrichment. Nitrogen criteria are usually created in conjunction with phosphorus criteria, as they are the two primary causal agents for eutrophication. In absence of water body specific nitrogen criteria for Wachusett Watershed water bodies, only the narrative criteria for nutrients applies – to not '*… cause or contribute to impairment of existing or designated uses'*[86]. Thus, the internal numerical goal for TN in streams and rivers is to maintain naturally occurring local background concentrations. Background concentrations of TN in rivers and streams of the Wachusett Watershed ecoregions were found to range between 0.34 mg/L and 5.57 mg/L. The 25th percentile value (all seasons) of 0.34 mg/L (ecoregion 58)[87] and 0.59 mg/L (ecoregion 59)[88] are the reference conditions for streams and rivers recommended by the EPA for the development of numerical TN criteria for these ecoregions. Long-term (seasonal or annual) TN concentrations above these recommended criteria likely indicate that excess nitrogen is entering waters. Any tributaries exhibiting long-term concentrations above these recommended nitrogen criteria should be examined more closely to determine if any response variables (chlorophyll, macrophytes, turbidity, macroinvertebrates) indicate that water quality impairments are occurring.

C-6 Total Phosphorus

Phosphorus is an important macronutrient and the limiting factor controlling algal productivity in Wachusett Reservoir. Phosphorus is derived from the weathering of rocks and therefore it is naturally present in soils in varying concentrations as orthophosphate (PO_4^{3-}). Plants take up orthophosphate as they grow, which is then returned to the soil in organic compounds via animal waste and the decomposition of plant and animal tissue[89]. Through various human activities, additional phosphorus is released to both soil and water, often in highly concentrated quantities. Many agricultural operations intentionally add phosphorus to soils using chemical fertilizers and/or organic animal waste solids (manure). Concentrated animal feeding operations create large quantities of animal waste that can unintentionally release phosphorus to soils and groundwater when improperly managed. Sewage treatment discharges to streams and septic system effluent leaching to groundwater both usually contain elevated levels of phosphorus. Furthermore, human activities that accelerate erosion processes on the land surface and within streams can increase the release of phosphorus from soils and sediment into water bodies.

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[86] Massachusetts Surface Water Quality Standards, 2022d
[87] USEPA, 2001a
[88] USEPA, 2000
[89] USGS, 2012

Lakes with TP concentrations exceeding 20-30 µg/L may experience nuisance algal growth[90]. Background concentrations of TP in rivers and streams of the Wachusett Watershed ecoregions were found to range between 2 µg/L and 907.5 µg/L. The 25th percentile value (all seasons) of 5 µg/L (ecoregion 58)[91] and 23.75 µg/L (ecoregion 59)[92] are the reference conditions for streams and rivers recommended by the EPA for the development of numerical TP criteria for these ecoregions. Similar to nitrogen, there are no Massachusetts numerical water quality standards for phosphorus for any Wachusett Reservoir Watershed water bodies. However, the narrative water quality criteria do apply as previously described.

In Wachusett tributaries annual mean TP concentrations are historically below 30 µg/L but occasionally are higher for some tributaries. Reservoir concentrations are typically less than 10 µg/L. While elevated TP concentrations pose no direct threat to drinking water quality, they can promote algal blooms in the Reservoir, which can cause taste and odor issues when concentration thresholds for certain species are exceeded or become toxic in the case of specific cyanobacteria. With these concerns in mind, the DWSP goal for TP in streams, rivers, and Wachusett Reservoir is to maintain concentrations as close to naturally occurring local background concentrations as practical.

C-7 Silica

Silica (or Silicon dioxide, SiO_2) is a necessary compound for the cellular function of all living organisms. It is required for protein synthesis in all phytoplankton and is essential for the formation of siliceous skeletons and scales of diatoms and chrysophytes[93]. Silicate minerals are extremely abundant on Earth, comprising much of the material in the Earth's crust. Silica enters aquatic systems through natural weathering processes although export can be accelerated by human activities such as mining, agriculture, and disturbances of terrestrial vegetation which serve as terrestrial silica sinks. Changes in silica abundance in freshwater reservoirs can be observed on a spatial and temporal gradient as water higher in silica enters from tributaries, disperses through the Reservoir, and is subsequently taken up by phytoplankton, particularly diatoms in the spring.

There are no water quality standards for silica, but the element's availability is an important driver of diatom and chrysophyte productivity. These organisms in abundance can cause filter clogging issues and undesirable tastes and odors in drinking water.

C-8 Water Temperature

Temperature is a critical physical property that controls the amount of dissolved oxygen that is available in aquatic environments. As water temperatures increase, the amount of oxygen that can be dissolved in water decreases. Moreover, higher stream temperatures increase the solubility of nutrients, which can contribute to an increase in the growth of filamentous algae and may threaten sensitive aquatic habitats. Due to these aquatic life concerns, MassDEP has set regulatory thresholds for warm and coldwater fisheries. Unless naturally occurring, coldwater fisheries may not exceed 20 °C (68 °F) as a mean of 7-day maximum temperature. Warmwater fisheries may not exceed 28.3 °C (83 °F) as a mean of 7-day maximum temperature[94]. For tributaries, the water quality goal for water temperature is to remain under the

[90] Vollenweider, 1976
[91] USEPA, 2001a
[92] USEPA, 2000
[93] Reynolds, 2006
[94] Massachusetts Surface Water Quality Standards, 2022b

threshold temperatures for cold and warmwater fisheries, depending on their respective fishery designations.

Water temperature regulatory thresholds within the Wachusett Reservoir are also based on MassDEP aquatic life use standards. Although there is no guidance describing how this standard applies to lakes and reservoirs, the presumed goal for coldwater fisheries is to maintain sufficient thermal habitat and refuge for naturally reproducing coldwater communities. Water temperature data collected from discrete water quality profiles are used to monitor thermal habitat at specific locations within the Reservoir. Tracking changes in thermal structure is also an important component of reservoir monitoring as these dynamics affect both biological processes and hydrologic patterns including establishment of the Quabbin interflow. As is typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of stratification structure usually begins in late April or early May when increasing solar radiation and atmospheric warming cause a progressive gain of heat in surficial waters. Stratification is most pronounced during summer when the water column is characterized by three distinct strata: a layer of warm, less dense water occupying the top of the water column (epilimnion), a middle stratum characterized by a thermal gradient or thermocline (metalimnion), and a stratum of cold, dense water at the bottom (hypolimnion). This thermal structure is weakened in fall as heat from the upper portion of the water column is lost to the increasingly cold atmosphere. In late October or early November, the last vestiges of stratification structure are dispersed by wind-driven turbulence and the entire water column is mixed and homogenized in an event known as fall turnover.

C-9 Dissolved Oxygen

Dissolved oxygen dynamics in stream environments may be linked to fluctuations in temperature, rates of streamflow, channel depth, other physical characteristics of the stream channel (e.g., channel slope, morphology, tortuosity), and local hydrology. Depletion of dissolved oxygen in aquatic environments can result from the oxygen requirements of aquatic life, the decomposition of organic matter, and the introduction of oxygen-demanding substances (such as chemical reducing agents). The Massachusetts Class A standard is a minimum of 6.0 mg/L for waters designated as coldwater fisheries and 5.0 mg/L for waters designated as warmwater fisheries. This standard is applied to both the tributaries and the Reservoir.

Dissolved oxygen values in the Reservoir remain near 100% saturation in the epilimnion most of the year due to atmospheric exposure and mixing due to wind-induced turbulence. In contrast, saturation values in the metalimnion and hypolimnion decline progressively due to microbial decomposition and the isolation of these strata from the atmosphere. The supply of oxygen at depth is not replenished until thermal structure dissipates and turnover occurs. The dissolved oxygen concentration in the hypolimnion of Wachusett Reservoir remains sufficient (typically > 6.0 mg/L) to provide suitable habitat for coldwater salmonids such as *Salvelinus namaycush* (Lake Trout) and *Salmo salar* (Landlocked Salmon).

C-10 Alkalinity and pH

The hydrogen ion activity (pH) of a stream is largely a function of the local groundwater hydrogeology and the effectiveness of the stream water in buffering the effects of acid precipitation. pH is an important control on many chemical and biological processes in aquatic environments and can influence the solubility, transport and bioavailability of other substances found in the water[95]. Aquatic life can become

[95] USEPA, 2021

stressed or killed when pH deviates from historical ranges. Low pH can increase corrosion rates of metal drinking water pipes, leaching high concentrations of metals into drinking water and degrading infrastructure.

The Massachusetts Acid Rain Monitoring Project has collected more than 1,610 statewide pH samples across Massachusetts over many years and has found that average surface water pH values increase in the summer and decrease in the winter[96]. This pattern is most prominent in subbasins with granite and metamorphic bedrock because there is low carbonate mineral content to enhance the buffering capacity of streams, which causes stream pH to be more influenced by precipitation and biological processes. Waushacum Brook does not experience this seasonal decline in pH due to its high alkalinity derived from its calcpelite bedrock.

The pH of natural precipitation, unaffected by anthropogenic acidification, ranges between 4.5 and 5.6[97]. During the last five years, the pH of precipitation in central Massachusetts has been approximately 5.1, which is still somewhat influenced by anthropogenic emissions despite significant improvements over the last 30 years[98]. During the growing season, forest vegetation helps buffer the acidity of rainwater and high evapotranspiration rates slow transit times and prevent some of the precipitation from ever reaching the streams[99]. However, during the winter, forest vegetation is primarily dormant and unable to provide acid buffering ecosystem services. Additionally, frozen soils reduce infiltration, and precipitation can more quickly enter the streams without being buffered by any environmental processes. These seasonal patterns, in addition to some minor land use impacts such as the addition of lime to lawns to improve the growth of grasses, drive the seasonal pattern in pH observed in most of the Watershed's streams. While the pH values of Wachusett tributaries are mostly within desired ranges for aquatic life, there is likely some degree of human influenced change to aquatic chemistry due to the weathering of urban landscapes and application of road salt for deicing[100], which may present other threats to aquatic life and degrade overall water quality.

The pH in Wachusett Reservoir is determined ultimately by surface water inputs and the exchange of inorganic carbon between the atmosphere and water (carbon dioxide-bicarbonate-carbonate buffering). Generally, pH values in Wachusett Reservoir are unremarkable, ranging from around neutral (pH = 7) to slightly acidic (pH = 5.5). Patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration, exhibiting only minor fluctuations in the Reservoir. The Class A water quality standard is a range between 6.5 – 8.3 (or no change from background levels). For the Wachusett Reservoir and its tributaries the water quality goal for pH is to maintain compliance with the Class A water quality standards.

Buffering capacity, or the ability of a water body to resist changes in pH from acidic or basic inputs, is quantified by alkalinity as calcium carbonate ($CaCO_3$). Waters in the northeastern U.S. typically have low alkalinity due to the region's lack of carbonate-rich bedrock. Alkalinity may also be influenced by land use within the watershed including agriculture and landscaping which may involve application of lime, weathering of concrete, and use of road deicers. Within a water body, alkalinity can affect photosynthetic activity of algae and other plants. The minimum alkalinity for aquatic life published by EPA is 20 mg/L or

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[96] Godfrey et al., 1996
[97] Turk, 1983
[98] National Atmospheric Deposition Program, 2025
[99] Hornbeck et al., 1977
[100] Kaushal et al., 2020

if lower values are naturally occurring, results cannot be lower than 25% of the natural level[101]. Alkalinity in Wachusett Reservoir is much lower than this threshold. Increases in alkalinity observed over the past 30 years, especially in the last five years, are likely linked to the observed increases in specific conductance caused by regional salinization[102].

C-11 Bacteria

Water bodies naturally contain many microorganisms, most of which are benign. However, there are several harmful intestinal microorganisms (viruses, bacteria, and protozoa) that are sometimes present in water (e.g., *Cryptosporidium*, *Giardia, Salmonella*). Many of these are fecal microorganisms and are known to cause a host of illnesses such as intestinal and urinary tract infections, meningitis, septicemia[103], dysentery, typhoid fever, and cholera[104]. *Escherichia coli* (*E. coli*) is a species in the fecal coliform group, which originates from fecal material of humans and other warm-blooded animals[105]. Some strains of *E. coli* can be deadly, especially for small children or people with weakened immune systems[106]. Studies have found that the presence of *E. coli* is often correlated with the presence of many other pathogenetic microorganisms[107], thus it has been selected as a useful indicator of pathogen contamination in waters. Human exposure to pathogens usually occurs through recreational contact or direct consumption of drinking water that was not adequately disinfected.

Sources of *E. coli* all stem from human or animal wastes: agricultural operations with livestock or that use manure to fertilize crops, treated wastewater, septic systems, urban runoff, land application of biosolids (sludge), pet waste, and wildlife[108]. The only two common *E. coli* sources not applicable to the Wachusett Watershed are biosolids, which are prohibited, and treated wastewater discharges, of which there are none.

Massachusetts Class A surface water quality standards differentiate between bacteria standards for water supply intakes and other Class A waters, which rely on *E. coli* bacteria as the indicator of sanitary quality. The Massachusetts Class A standard for non-intake waters states that the geometric mean of all *E. coli* samples within any 90-day or shorter interval shall not exceed 126 colony-forming-units (CFU) per 100 mL and no more than 10% of all such samples shall exceed 410 CFU/100mL[109]. DWSP prohibits boating, wading, and swimming in Wachusett Reservoir and its tributary waters, however fishing is allowed, and that is probably the only (legal) avenue for public exposure to pathogens from the water supply prior to treatment. Despite there being low risk for pathogen exposure due to recreation, DWSP uses these regulatory thresholds to evaluate the sanitary quality of waters within the Wachusett Watershed. As a major public water supply, regulatory requirements for pathogens at drinking water intakes are much more stringent.

MWRA is required to measure bacteria concentrations in raw water prior to treatment. State and federal regulations specify that fecal coliform concentrations shall not exceed 20 organisms per 100 mL in any six-

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[101] USEPA, 1986b
[102] Kaushal et al., 2005
[103] USGS, n.d.-a
[104] Myers et al., 2014
[105] USEPA, 1986a
[106] USEPA & Tetra Tech Inc., 2013
[107] Myers et al., 2014
[108] Ibid
[109] Massachusetts Surface Water Quality Standards, 2022e

month period[110]. Results for pathogen testing at the intake are briefly discussed Section 3.4.11 and in greater detail in separate reports published by MWRA[111].

C-12 Specific Conductance and Dissolved Salts

Specific conductance is a measure of the ability of water to conduct an electrical current at 25 °C, dependent on the concentrations of various ions in solution[112, 113]. Freshwater systems in Massachusetts naturally contain low levels of mineral salts in solution[114]. Elevated levels of specific conductance and associated dissolved solutes (e.g., sodium, chloride) may stress sensitive biota, threaten ecosystems[115, 116], and degrade drinking water quality[117, 118, 119]. Excess sodium in drinking water may compromise the health of individuals on sodium-restricted diets, such as those with hypertension, and increase the cation-exchange capacity of nearby soils[120], resulting in the mobilization of base cations (e.g., calcium, potassium, magnesium) to streams thereby altering natural biogeochemical cycles. Contamination of drinking water supplies with excess chloride (Cl) may increase the corrosivity of affected waters[121], which can increase the mobilization of lead and copper from older infrastructure. Elevated levels of specific conductance and associated ions in surface water and groundwater may indicate contamination from anthropogenically-derived sources of salts to natural water systems such as septic system effluent, stormwater discharges, agricultural runoff, or road salt runoff from deicing activities[122,123]. In the snowbelt region of the U.S., road salt is the dominant source of chloride to many natural water systems[124, 125, 126].

Sodium chloride is the main component of road salt and brine applied to roads, parking lots and driveways to lower the freezing point of water to prevent ice accumulation on travel surfaces, thereby increasing safety while walking or driving a vehicle. DWSP has documented a long-term increasing trend in specific conductance and the concentration of chloride in surface water in the Wachusett Watershed and Reservoir, and this increase can mostly be attributed to historical road salt application. Since many aquatic organisms are sensitive to increases in Cl, community composition is likely to shift in response[127]. For example, increases in Cl may negatively impact native *Potamogeton* species while facilitating growth of non-native species such as *Phragmites australis* and *Myriophyllum. spicatum*[128].

DWSP has expanded the water quality monitoring program on several fronts and worked with research partners at UMass to learn more about patterns of chloride in the Watershed. Groundwater monitoring

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110 Massachusetts Surface Water Quality Standards, 2022e
111 MWRA, 2021b
112 Granato et al., 2015
113 Rhodes et al., 2001
114 Granato et al., 2015
115 Jackson & Jobbágy, 2005
116 Corsi et al., 2010
117 Kaushal et al., 2005
118 Daley et al., 2009
119 Kelly et al., 2010
120 Kaushal et al., 2017
121 Stets et al., 2018
122 Panno et al., 2006
123 Lautz et al., 2014
124 Kaushal et al., 2005
125 Kelly et al., 2008
126 Mullaney et al., 2009
127 Van Meter & Swan, 2014
128 June-Wells et al., 2013

began in 2019 and currently includes monthly monitoring at seven wells. Results have revealed concerning levels of chlorides at some locations and provided initial information about patterns and sources of chloride in the watershed[129]. Real-time continuous monitoring for specific conductance on primary tributaries enables daily chloride loading estimates to be calculated for more than 90% of the Wachusett Watershed surface water inflow to the Reservoir (See Section 3.2.3.3)

An internal Conductivity/Chloride working group has been meeting quarterly since 2018 to address the increasing specific conductance observed in the Quabbin and Wachusett Reservoirs and many of their tributaries. This effort involves staff across all sections of DWSP working on several distinct initiatives within the following categories:

- Education, training and outreach
- Data collection
- Modeling, literature review, partnerships
- Salt reduction grant program
- DWSP salt use
- Interagency Salt Reduction Working Group

The group will continue to document salt use, evaluate salt loading trends, provide salt reduction grant funding opportunities, and develop and implement other salt reduction strategies.

The EPA established aquatic life criteria for Cl in 1988 at chronic (4-day average) and acute (1-hour average) concentrations of 230 and 860 mg/L, respectively[130]. Neither threshold is to be exceeded more than once every three years. MassDEP has established a linear regression model to derive Cl concentrations from specific conductance values: “Instantaneous exceedances of the acute and chronic Cl criteria are estimated to occur at [specific conductance] readings greater than 3,193 and 904 µS/cm, respectively”[131]. MassDEP also established an Office of Research and Standards Guideline (ORSG) of 20 mg/L sodium in drinking water and a secondary maximum contaminant level (SMCL) for Cl of 250 mg/L[132]. MassDEP does not currently enforce regulatory standards for specific conductance in drinking water.

Within the Reservoir, horizontal and vertical differences in specific conductance are reflective of interactions between native water contributed from the Wachusett Watershed and water transferred from Quabbin Reservoir. For example, average specific conductance values from the largest tributaries to Wachusett Reservoir, the Stillwater and Quinapoxet Rivers, during 2019 were 174 µS/cm and 261 µS/cm, respectively, while the average for water entering via the Quabbin Aqueduct was 49 µS/cm. This difference in specific conductance can be used to track movement of native and Quabbin water through the Wachusett Reservoir. During periods of isothermy, values typically range from 100 to 180 µS/cm depending on the volume of water received from Quabbin Reservoir the previous year. During stratification, the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity generally between 75 and 150 µS/cm.

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[129] DWSP, 2023a
[130] USEPA, 1988
[131] MassDEP, 2022
[132] Massachusetts Drinking Water Regulations, 2020b

C-13 Total Suspended Solids

Total suspended solids (TSS) are the dry weight of particles suspended in a water sample retained by a filter of 2-µm pore size. These particles, both organic and inorganic, may be naturally occurring, the result of human activities, or a combination of these sources. Typically, TSS concentrations are highest during and immediately after storms; overland flow erodes particles from the land surface and carries them into waterways, and as stream velocity and turbulence increase with higher flow rates, sediment deposits on the stream bed and banks can be dislodged and resuspended into the flowing water. Common sources of elevated TSS concentrations are construction sites, agricultural operations, transportation infrastructure, and other areas with high proportions of impervious or disturbed land surfaces. In Massachusetts, and around the U.S., excessive TSS is one of the most prevalent causes of water quality impairment[133, 134].

Depending on particle density, suspended solids may settle out of suspension at different rates and locations as a function of the changing hydraulic and geomorphological conditions between the tributary headwaters and the Reservoir. The concentration and composition of TSS can vary widely across subbasins depending on soils, stream channel geomorphology, land cover types, and changing conditions (e.g., disturbances). These solids provide benthic structure (bed material) and a stock of minerals and nutrients to support aquatic life. Local stream ecology evolved under a "normal" sediment regime, which underpins much of the aquatic habitat and nutrient dynamics at the reach scale[135,136]. When the TSS concentration and composition deviates from "normal" over a sustained period it can be detrimental to aquatic life and cause other water problems. Chronically high TSS concentrations can block light passage in water and absorb solar radiation, which can reduce dissolved oxygen concentrations by inhibiting photosynthesis in plants and by reducing oxygen saturation concentrations due to higher water temperatures[137]. Furthermore, high TSS concentrations can harm fish by clogging gills, reducing visibility so that it is more difficult for fish to find food, and smothering eggs. Suspended solids that settle on the streambed can form thick deposits, reducing fish spawning areas and eliminating habitat for benthic macroinvertebrates. As suspended solids enter Wachusett Reservoir they begin to settle out in coves or along the shoreline, which can negatively affect aquatic life in those places as well as promote invasive or nuisance plant growth by providing nutrient rich substrate.

Fortunately, Wachusett Reservoir is a large enough system that suspended solids rarely reach the intake except in rare instances of soil/debris washing off the shoreline immediately adjacent to the Cosgrove Intake. Nearly all runoff from roadways surrounding Wachusett Reservoir is treated (by passing through stormwater control measures) to reduce TSS prior to being discharged into the Reservoir. Aggregations of phytoplankton, which may contribute to elevated TSS, are likewise rare in the area of the Cosgrove Intake. For drinking water supplies, it is desirable to have low TSS concentrations, as high TSS levels often lead to aesthetic issues (taste/odor), mostly due to organic suspended solids. Although TSS is often cited as the reason for water quality impairments, there are no state or federal standards for TSS in streams since other standards (turbidity, bacteria) are more useful predictors of drinking water quality. However, MassDEP does enforce specific stormwater management standards, which address both water volume and TSS loads from development projects exceeding certain size thresholds[138]. While these regulations

133 Murphy, 2020
134 MassDEP, 2024
135 Southwood, 1977
136 Wohl et al., 2015
137 Murphy, 2007
138 Wetlands Protection, 2014; Water Quality Certification, 2017

have been helpful in mitigating stormwater runoff in recent years, there are many legacy stormwater issues that persist on properties that were developed before the standards were adopted.

TSS concentrations in Wachusett tributaries are below the method detection limit most of the time. Higher TSS concentrations were most often detected during targeted storm sampling, both during and after precipitation and high streamflows. Stormflow TSS in Wachusett tributaries can typically range from 5 – 50 mg/L and can occasionally exceed 100 mg/L during large storm events. The water quality goal for TSS in Wachusett Watershed tributaries is for mean concentrations during dry conditions to remain below detection (< 5.0 mg/L) and for concentrations during wet conditions to remain below 50 mg/L for any single sample.

C-14 Turbidity

Turbidity is another term for water clarity, which is determined by measuring the scatter of light in the water and reported by DWSP in Nephelometric Turbidity Units (NTU)[139]. Any dissolved or suspended particle in water will cause light scatter and increase turbidity. In streams, high turbidity is often associated with storm events, which increase suspended solid concentrations (see Sections C-13 and 3.2.5), as well as concentrations of smaller particles like clay. Reservoir turbidity may be influenced by plankton production, pollen deposits, and shoreline disturbances of organic deposits. Clay particles can also remain suspended in the water column for extended periods because of eroding shorelines or clay laden tributary waters delivered by storm events. For drinking water supplies, the concern over turbidity relates to aesthetics, pathogens, and treatment considerations. The particles that cause turbidity can make water cloudy or have displeasing taste or odor. These particles also promote regrowth of microbes by inhibiting disinfection and providing nutrients and minerals for their reproduction. For these reasons, and its relative ease of measurement, turbidity is a good general water quality indicator.

There are two standards for turbidity levels at drinking water intakes. The SWTR mandates that raw water turbidity levels (at the intake) always remain below 5.0 NTU. MassDEP regulations specify that turbidity levels may exceed 1.0 NTU only if it does not interfere with effective disinfection[140]. Background concentrations of turbidity in rivers and streams of the Wachusett Watershed ecoregions were found to range between 0.28 NTU and 4.33 NTU. The 25th percentile value (all seasons) of 0.8 NTU (ecoregion 58)[141] and 1.68 NTU (ecoregion 59)[142] are the reference conditions for streams and rivers recommended by the EPA for the development of numerical turbidity criteria for these ecoregions. The current water quality goal for turbidity in streams and rivers is to maintain existing local background concentrations.

C-15 Total Organic Carbon

Total organic carbon (TOC) is the sum of all organic carbon in water, both dissolved and particulate (suspended). Organic carbon sources fall into three categories: 1) Terrestrial carbon such as decaying organic matter, proteins, organic acids, and animal waste; 2) Autochthonous sources produced in-stream/reservoir, such as algae; and 3) Anthropogenic sources such as industrial and wastewater discharges, petroleum related pollution, agricultural chemicals, and the accelerated release of natural organic carbon through landscape disturbance. Background TOC concentrations in rivers are typically 1 to

[139] Swenson & Baldwin, 1965
[140] Massachusetts Drinking Water Regulations, 2020c
[141] USEPA, 2001a
[142] USEPA, 2000

10 mg/L, though waters emanating from wetlands or bogs often have much higher natural concentrations of organic carbon[143].

While organic carbon is not a directly regulated drinking water quality parameter, carbon sources are precursors to disinfection byproducts (DBP) called trihalomethanes (THMs) and haloacetic acids, which are regulated at 60 µg/L and 80 µg/L, respectively. If TOC concentrations are above certain reactive thresholds which will cause DBP exceedances, then TOC removal is added to the water treatment process. To meet THM MCLs, water treatment guidelines typically suggest TOC removal when concentrations exceed 2 mg/L in the source water. The water quality goal for TOC in the Wachusett Watershed waters is to maintain background natural concentrations of TOC, preferably below 2 mg/L.

C-16 UV Absorbance

Ultraviolet light absorbance at 254 nm (UV_{254}) is used as a surrogate for the amount and reactivity of natural organic material in source water that is easier to measure than TOC. Measurements of UV_{254} are reported as the amount of ultraviolet light at a 254 nm wavelength that can transmit through a water sample in absorbance units per centimeter of path length (ABU/cm). Higher UV_{254} levels indicate higher organic carbon concentrations, which require increased ozone and chlorine demand for disinfection, which can subsequently increase disinfection byproduct formation. Tributary levels of UV_{254} are influenced by the same variables that are responsible for organic carbon discussed above (Section C-15).

As with TOC, there are no regulatory limits for UV_{254}, however measurements are used to calculate the amount of carbon reduction required in the treatment process to meet the two DBP regulatory standards. After statistical relationships are developed to correlate TOC with UV_{254} for each tributary it is then possible to discontinue TOC sampling and use UV_{254} as a proxy for organic content. Water quality goals for UV_{254} would have to be specific to each tributary based on a statistically significant correlation to TOC concentration. The targeted UV_{254} values would be analogous to local correlative background TOC concentrations, preferably below 2 mg/L. Although there are few management options to address organic carbon loading in streams, DWSP does proactively manage riparian vegetation along the Reservoir shoreline specifically to reduce carbon inputs from leaf litter[144].

C-17 Chlorophyll *a* and Phycocyanin

Plants, algae, and cyanobacteria use pigments to derive light energy for photosynthesis. Chlorophyll *a* is found in all photosynthetic organisms while small amounts of accessory pigments, which transfer energy to chlorophyll *a,* are associated with specific groups of organisms. One such pigment is phycocyanin, a blue light absorbing pigment that is only found in cyanobacteria. These pigments can be measured using *in situ* fluorometers which expose pigments in the water column to light at a specific wavelength and measure the response. This response can be used to estimate the density of algae and cyanobacteria populations. While chlorophyll *a* is used to estimate the overall biomass of the algal community, phycocyanin is used to estimate the proportion of that community comprised of cyanobacteria since this pigment is only produced by those organisms. These pigments measure the biological response to abiotic variables and are most often associated with the nutrients that fuel algal growth.

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[143] Mulholland & Kuenzler, 1979
[144] DWSP, 2018a

There are currently no MA statutory action levels for algal pigments in surface waters, including drinking water sources. The EPA Office of Water does include chlorophyll *a* in its Ambient Water Quality Criteria Recommendations which are specific to the fourteen U.S. nutrient Ecoregions. The reference condition ranges listed for Wachusett Watershed's subecoregions 58 and 59 are 2.1 – 6 µg/L and 1.38 – 2.7 µg/L, respectively[145].

Chlorophyll *a* and phycocyanin data are only collected from reservoir locations at this time. Chlorophyll *a* has been measured in Wachusett Reservoir since 2011 when a fluorometer was added to the HydroLab multiprobe in use at that time. Upon upgrade to the YSI EXO2 probe in 2016, phycocyanin was also added as a routinely measured parameter. On average, measurements for these pigments are low (< 2.7 µg/L); however, periodic increases are observed in association with increases in algal growth. Like the algae increases, increased values are often limited to specific strata rather than spread through the entire water column.

C-18 Phytoplankton

Algae are a large, diverse group of organisms present in nearly every ecosystem from sandy deserts to artic permafrost to freshwater reservoirs[146]. In fresh water they can be planktonic (free-floating) or attached to structures including plants and rocks. Growth of freshwater algae is largely dependent on abiotic factors such as sunlight, temperature, and nutrients present in the water column. Changes in the algae community composition and density can therefore provide early indication of changes in water quality. In drinking water supplies, especially unfiltered systems, monitoring for these organisms can be extremely important, as certain taxa can produce compounds causing undesirable tastes, odors, and in limited cases, toxins. Phytoplankton can proliferate rapidly when ideal conditions are available and routine monitoring is essential for detecting density increases early in the growth phase so that appropriate management actions can be taken. These management options for Wachusett Reservoir include treatment of the algae present in the Reservoir with copper sulfate (the last treatment was in 2014) and adjustments within the treatment system such as increasing the ozone dose.

Phytoplankton undergo seasonal succession, with some genera becoming more or less prevalent throughout the year. In Wachusett Reservoir, phytoplankton follow the typical pattern of a freshwater temperate water body with diatoms most common in the spring followed by a period of decreased productivity where chlorophytes (green algae) typically become more diverse but remain at low density. An increase in chrysophytes (golden-brown algae) is often observed in mid-summer, especially when the Quabbin interflow is well established. An increase in cyanophytes is occasionally observed as these organisms take advantage of warm summer temperatures and nutrient influxes in the fall. Following reservoir turnover, diatoms often undergo a slight increase and remain dominant in the phytoplankton community throughout the winter months.

While the entire phytoplankton community is assessed by DWSP biologists, MWRA and DWSP have established thresholds, also referred to as to 'Alert Levels' for five organisms (Table C-1). These four chrysophyte genera and one cyanobacteria genus have previously attained problematic densities in Wachusett Reservoir and could cause undesirable tastes and odors in the water supply. Once these thresholds are exceeded, monitoring frequency is increased (typically to twice weekly) and action is considered. The joint MWRA-DCR Phytoplankton Action Plan was revised in early 2023 to account for

145 USEPA, 2001b
146 Reynolds, 2006

changes in treatment options and methods of detection. Installation of remote sensing tools allow for near real-time monitoring of water quality and quick response to changing conditions. As climate change influences the region, new water quality concerns such as nutrient pulses, increased water temperature, and changes in phytoplankton communities including increases in cyanobacteria, may arise. The revisions to DCR and MWRA's response plan allow for flexibility in identifying and investigating immediate and future phytoplankton-related water quality concerns.

Table C-1: Alert Levels for Select Phytoplankton Genera

Nuisance Organism Group	Nuisance Organism	Alert Levels (ASU/mL) for taxa densities at routine monitoring sites (BN3417 or CI3409)
Cyanophyte	*Dolichospermum*	30
Chrysophyte	*Synura*	40
Chrysophyte	*Chrysosphaerella*	500
Chrysophyte	*Uroglenopsis*	2,000
Chrysophyte	*Dinobryon*	800

C-19 Zooplankton

Zooplankton are small organisms found in nearly all surface waters and are the most abundant multicellular animal on earth. They maintain a vital role in the ecosystem as grazers, providing a pathway of energy from producers to consumers at higher trophic levels[147, 148]. They are also considered indicators of climate change as they are highly sensitive to changes in temperature and have a life span of less than one year, which means the zooplankton community can rapidly reflect environmental signals as populations change. The distribution of zooplankton, composed mostly of free-floating organisms, is largely affected by local factors of a water body, such as lake area, chemical composition, and predator abundance[149].

The potential invasive zooplankton of most concern are *Bythotrephes longimanus* (spiny waterflea) and *Cercopagis pengoi* (fishhook waterflea). Their native range is Europe and northeast Asia, and Southwest Asia, respectively.

The primary goal of current zooplankton monitoring at Wachusett Reservoir is to identify new occurrences of invasive species as soon as possible. No invasive zooplankton have been found in the Reservoir to date, but these species have colonized all the Great Lakes, the Finger Lakes of New York, and Lake Champlain of Vermont[150]. *B. longimanus* was identified in Lake Winnipesaukee, NH in 2023[151]. During these invasive species assessments, observations of native zooplankton are also made, establishing baseline data that may be used in the future to detect impacts from potential invaders and other environmental changes. Sample collection and scanning for presence of invasive species began in 2014. Samples from 2014 to present are maintained at DWSP offices and may also be assessed for community structure in the future.

[147] Hintz et al., 2019
[148] Richardson, 2008
[149] Havel & Shurin, 2004
[150] USGS, n.d.-b
[151] NH DES, 2023

C-20 Secchi Disk Depth/Transparency

A Secchi disk is a tool used to estimate water clarity and the amount of light penetration in a waterbody. The Secchi disk transparency is the water depth at which a Secchi disk, a round, alternately painted, black and white disk, is barely visible from the surface. This value can be used to estimate the depth of the euphotic zone; this area in which photosynthesis occurs is approximately three times the Secchi disk transparency[152]. In Wachusett Reservoir, Secchi disk transparency is most often affected by phytoplankton dynamics and contributions from the Wachusett Watershed and Quabbin Transfer. Weather patterns and percentage of native Wachusett Watershed water also affect visibility. Secchi disk transparency is recorded in association with Basin North (BN3417) samples and at reservoir nutrient sample locations, following the *SOP for Secchi Measurement*[153]. The reference condition ranges listed for Wachusett Watershed's subecoregions 58 and 59 are 4.0 – 6.1 m and 1.2 – 4.9 m, respectively[154].

[152] Dodson, 2005
[153] DWSP, 2023f
[154] USEPA, 2001b

Appendix D: Quality Assurance

Sample Completeness

As detailed in the Quality Assurance Project Plan (QAPP) for Wachusett Watershed Water Quality Monitoring, sample completeness is an indicator of data quality. This metric is used to evaluate whether an adequate number of samples were collected to meet project objectives. For both laboratory and field parameters, 80-100% of planned samples must be collected to meet DWSP objectives for routine tributary monitoring. The tables below show the number of samples collected and expected by Parameter (Table D-1) and by monitoring location (Table D-2).

Table D-1: Sample Completeness by Parameter

Parameter	Collected	Expected	Percent Complete
Alkalinity	120	120	100%
Ammonia-N	120	120	100%
Chloride	120	120	100%
Discharge	360	360	100%
Dissolved Oxygen	539	552	98%
E. coli	421	432	97%
Mean UV_{254}	120	120	100%
Nitrate-N	120	120	100%
Nitrite-N	120	120	100%
Oxygen Saturation	539	552	98%
pH	539	552	98%
Specific Conductance	541	552	98%
Staff Gauge Height	360	360	100%
Total Kjeldahl Nitrogen	120	120	100%
Total Organic Carbon	120	120	100%
Total Phosphorus	120	120	100%
Total Suspended Solids	120	120	100%
Turbidity NTU	421	432	97%
Water Temperature	541	552	98%

Table D-2: Sample Completeness by Monitoring Location

Location	Collected	Expected	Percent Complete
M102	165	168	98%
M110	420	420	100%
MD01	417	420	99%
MD02	420	420	100%
MD03	420	420	100%
MD04	420	420	100%
MD05	420	420	100%
MD06	420	420	100%
MD07	420	420	100%
MD11	161	168	96%
MD12	133	168	79%
MD69	420	420	100%
MD70	133	168	79%
MD73	168	168	100%
MD80	168	168	100%
MD81	168	168	100%
MD83	420	420	100%
MD89	168	168	100%

Sample completeness was achieved (>80%) for all parameters and at all locations for the 2024 calendar year, except at locations MD12 (Jordan Farm Brook) and MD70 (Boylston Brook), which were dry during the fall drought and could not be sampled. Other reasons for failing to collect 100% of samples include: field personnel errors, laboratory mishaps, samples becoming damaged, contaminated, or lost during transit, equipment malfunction, or data management mistakes. For 2024, cases where the percent complete was below 100 are explained below, by location (Table D-3).

Table D-3: Missing Samples for 2024

Monitoring Location(s)	Reason for missing sample(s) (number of samples)
Jordan Farm - MD12	Dry for 5 monitoring visits between 9/11/2024 and 11/13/2024 Missing 5 sets of field parameters (n=25), 5 Turbidity, and 5 *E. coli*
Boylston Brook – MD70	Dry for 5 monitoring visits between 9/11/2024 and 11/13/2024 Missing 5 sets of field parameters (n=25), 5 Turbidity, and 5 *E. coli*
Cook Brook – MD11	Dry for 1 monitoring visit on 11/13/2024 Missing 1 set of field parameters (n=5), 1 Turbidity, and 1 *E. coli*
Asnebumskit Brook – M102	Field parameters were not logged on YSI on 8/24/2024 and dissolved oxygen, oxygen saturation and pH were lost (n = 3). Temperature and specific conductivity results were preserved on paper field sheets.
French Brook – MD01	Field parameters were not logged on YSI on 11/25/2024 and dissolved oxygen, oxygen saturation and pH were lost (n = 3). Temperature and specific conductivity results were preserved on paper field sheets.

Extra Samples

In 2024, EQ staff collected 76 extra samples throughout the course of the year to investigate potential water quality threats or to confirm the location or persistence of a previously identified water quality issue (Table D-4). The samples were collected in relation to five separate issues.

An elevated bacteria result at Asnebumskit Brook during routine sampling on July 25 resulted in the collection of 37 extra bacteria samples in July, August, September, and November to identify the persistent source of bacteria impacting the brook. Samples were taken upstream near the outlet of Eagle Lake and the Main Street overpass (Figure D-1). Samples near the outflow of Eagle Lake had concentrations near or below the detection limit, which suggested that the source was downstream of Eagle Lake. Elevated bacteria concentrations were not detected until after Asnebumskit Brook passed under Jefferson Mill, just upstream of the Main Street (Rt. 122A) overpass. Additional sampling identified a water-filled stone archway adjacent to Main St. as the source of elevated bacteria. The origin of the water in the stone archway is not yet known, but it was suspected that water could be groundwater exfiltration from underneath the concrete wall along Main St. There could also be a broken sewer line running under Main St., contributing water and bacteria to the stone archway. However, neither of these theories have been confirmed and additional testing will need to be completed in order to identify the exact water source and species responsible for the high *E. coli* concentrations. On two occasions water samples were analyzed for animal DNA markers. The DNA tests did discover genetic markers for swine, bovine, and poultry in the water emanating from stone archway, which were absent from the main channel of Asnebumskit Brook. The bacteria could be from one of those species, or another species that was not tested. If elevated bacteria results return in 2025 this investigation will continue, with an emphasis on ascertaining the source of the water in the stone archway.

Four additional sampling events occurred during 2024. Three bacteria samples were collected on January 3 after a potential septic failure was reported at a Southborough residence located near a stream that flows into the Sudbury Reservoir. The sample results were below the detection limit, and no further action was taken by DCR. On February 28 and April 25, samples were collected due to reports of a strong odor and highly turbid water near Jordan Farm Brook. Bacteria and turbidity samples were collected on each day, as well as field parameters (temperature, dissolved oxygen, oxygen saturation, and pH) on February 28. The high levels of bacteria and turbidity were likely due to agricultural operations (Jordan Farm) within the drainage area. No follow-up sampling was performed after April 25, as values for both turbidity and bacteria returned to normal ranges. Additionally, on April 25, three turbidity samples were collected near Muddy Brook after reports of high turbidity during routine sampling. Turbidity levels decreased and returned to background levels. In September, the tap water at the DCR Watershed Maintenance Headquarters building in Clinton was analyzed for 11 metals after reports of a metallic taste. Results were all within allowable ranges for drinking water.

Figure D-1: 2024 Asnebumskit Brook Follow-up Bacteria Sampling Locations

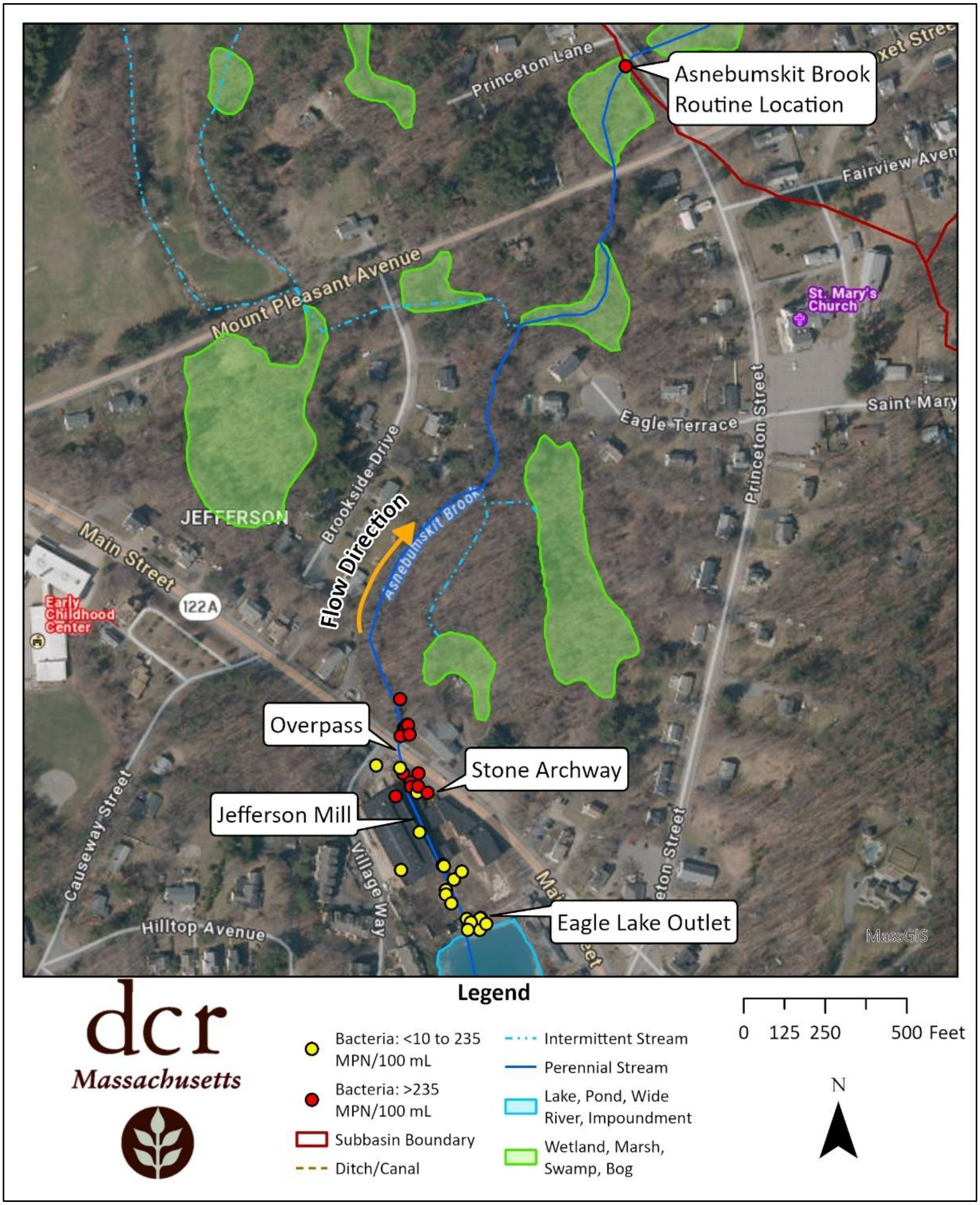


Table D-4: Extra Samples Collected During 2024

Location	Date-Time (ET)	Parameter	Result	Units	Location Description	Latitude (DD)	Longitude (DD)	Sample Notes	EQ File #
MISC	1/3/2024 10:30	*E. coli*	10	MPN/100 mL	Bay Path Lane	42.2874094	-71.5095028	Upstream sample of potential septic failure	EQ2024-002
MISC	1/3/2024 10:45	*E. coli*	10	MPN/100 mL	Woodland Rd.	42.290809	-71.5077493	Downstream of potential septic failure	EQ2024-002
MISC	1/3/2024 11:30	*E. coli*	10	MPN/100 mL	Woodland Rd. downgradient	42.2898055	-71.5079099	Potential septic impacts	EQ2024-002
MD12	2/28/2024 10:40	*E. coli*	426	MPN/100 mL	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:40	Dissolved Oxygen	13.1	mg/L	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:40	Oxygen Saturation	103	%	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:40	pH	7.5	pH	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:40	Specific Conductance	168.1	µS/cm	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:40	Water Temperature	3.8	Deg-C	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:40	Turbidity NTU	166	NTU	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	*E. coli*	249	MPN/100 mL	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	Dissolved Oxygen	12.8	mg/L	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	Oxygen Saturation	101	%	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	pH	7.52	pH	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	Specific Conductance	169	µS/cm	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	Water Temperature	3.8	Deg-C	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MD12	2/28/2024 10:42	Turbidity NTU	169	NTU	Jordan Farm Brook	42.38658094	-71.90564377	N/A	EQ1996-044
MISC	2/28/2024 10:55	*E. coli*	31	MPN/100 mL	Stream parallel to Jordan Farm	42.3824376	-71.9047827	Highly turbid water	EQ1996-044
MISC	2/28/2024 10:55	Dissolved Oxygen	13.3	mg/L	Stream parallel to Jordan Farm	42.3824376	-71.9047827	Sample Type: Turbidity, YSI Parameters	EQ1996-044

Location	Date-Time (ET)	Parameter	Result	Units	Location Description	Latitude (DD)	Longitude (DD)	Sample Notes	EQ File #
MISC	2/28/2024 10:55	pH	7.73	pH	Stream parallel to Jordan Farm	42.3824376	-71.9047827	Sample Type: Turbidity, YSI Parameters	EQ1996-044
MISC	2/28/2024 10:55	Specific Conductance	131	µS/cm	Stream parallel to Jordan Farm	42.3824376	-71.9047827	Sample Type: Turbidity, YSI Parameters	EQ1996-044
MISC	2/28/2024 10:55	Turbidity NTU	31.4	NTU	Stream parallel to Jordan Farm	42.3824376	-71.9047827	Sample Type: Turbidity, YSI Parameters	EQ1996-044
MISC	2/28/2024 10:55	Water Temperature	3.7	Deg-C	Stream parallel to Jordan Farm	42.3824376	-71.9047827	Sample Type: Turbidity, YSI Parameters	EQ1996-044
MISC	4/25/2024 9:10	*E. coli*	173	MPN/100 mL	Near MD12	42.3861	-71.90461	Strong odor and highly turbid sample at MD12, bacteria and turbidity MISC sample collected	EQ1996-044
MISC	4/25/2024 9:10	Turbidity NTU	1.39	NTU	Near MD12	42.3861	-71.90461	Sample Type: Bacteria, turbidity, strong odor and highly turbid sample at MD12	EQ1996-044
MISC	4/25/2024 12:03	Turbidity NTU	6.38	NTU	Muddy Brook, upstream of pond at access road in National Grid right of way	42.34625	-71.76788	High flow at Muddy Brook, investigating possible beaver issues	EQ2024-012
MISC	4/25/2024 12:12	Turbidity NTU	49.3	NTU	Muddy Brook, downstream of National Grid access road at pipe outlet	42.34633	-71.76717	High flow at Muddy Brook, investigating possible beaver issues	EQ2024-012
MISC	4/25/2024 12:30	Turbidity NTU	1.41	NTU	Muddy Brook, upstream of railroad tracks and railroad gutter drain	42.34601	-71.76891	High flow at Muddy Brook, investigating possible beaver issues	EQ2024-012
M102	7/30/2024 10:31	*E. coli*	1210	MPN/100 mL					EQ2024-019
MISC	7/30/2024 10:38	*E. coli*	10	MPN/100 mL	Eagle Lake discharge	42.35999713	-71.88325285	Misc 2 Eagle Lake discharge	EQ2024-019
MISC	7/30/2024 10:47	*E. coli*	2760	MPN/100 mL	Bridge by mill construction	42.36119021	-71.88389971	Misc 3, under bridge, pigeon roost observed	EQ2024-019
MISC	7/30/2024 10:48	*E. coli*	350	MPN/100 mL	Under bridge, pipe discharge	42.36121175	-71.88387136	Blank bottle, pipe discharge from just beyond bridge	EQ2024-019
MISC	8/5/2024 8:59	*E. coli*	31	MPN/100 mL	Outflow of Eagle Lake	42.36001062	-71.88325516	Misc 1	EQ2024-019
MISC	8/5/2024 9:02	*E. coli*	908	MPN/100 mL	Below Main St. overpass/ Asnebumskit Brook	42.36119518	-71.88387127	Misc 2	EQ2024-019
MISC	8/13/2024 8:59	*E. coli*	767	MPN/100 mL	Downstream of Main St. overpass/ Asnebumskit Brook	42.36117478	-71.88389258	Misc 1	EQ2024-019
MISC	8/13/2024 9:00	*E. coli*	836	MPN/100 mL	Upstream of Main St. overpass/ Asnebumskit Brook	42.36076608	-71.88396923	Misc 2	EQ2024-019

Location	Date-Time (ET)	Parameter	Result	Units	Location Description	Latitude (DD)	Longitude (DD)	Sample Notes	EQ File #
MISC	8/15/2024 7:46	*E. coli*	1140	MPN/100 mL	Misc 1, downstream of Rt. 122A on Asnebumskit Brook	42.36136859	-71.88393427	Misc 1	EQ2024-019
MISC	8/15/2024 7:49	*E. coli*	960	MPN/100 mL	Upstream of Rt. 122A in flow next to wall	42.36090881	-71.88390597	Misc 2	EQ2024-019
MISC	8/15/2024 7:56	*E. coli*	10	MPN/100 mL	Outlet of Eagle Lake	42.35993551	-71.88326461	Misc 3	EQ2024-019
MISC	8/21/2024 8:51	*E. coli*	10	MPN/100 mL	Eagle Lake outflow	42.36000844	-71.88326061	Misc 1	EQ2024-019
MISC	8/21/2024 8:57	*E. coli*	1440	MPN/100 mL	Downstream of overpass	42.36113927	-71.88392792	Misc 2	EQ2024-019
MISC	8/21/2024 9:02	*E. coli*	1960	MPN/100 mL	Upstream of overpass, downstream of mill building	42.36083015	-71.88383855	Misc 3	EQ2024-019
MISC	9/11/2024 8:49	*E. coli*	10	MPN/100 mL	Eagle Lake outflow	42.35997412	-71.88321126	Sample Type: Bacteria, Misc 1	EQ2024-019
MISC	9/11/2024 8:54	*E. coli*	1270	MPN/100 mL	Downstream of overpass	42.36120584	-71.88386659	Sample Type: Bacteria, Misc 2	EQ2024-019
MISC	9/11/2024 8:57	*E. coli*	908	MPN/100 mL	Upstream of overpass	42.36085275	-71.88384425	Sample Type: Bacteria, Misc 3	EQ2024-019
MISC	9/18/2024 10:25	Aluminum	8.83	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Cadmium	0.05	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Calcium	4850	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Copper	38.4	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Iron	30.1	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Lead	0.075	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Magnesium	870	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Manganese	0.927	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Nickel	0.692	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A
MISC	9/18/2024 10:25	Silica	2540	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	N/A

Location	Date-Time (ET)	Parameter	Result	Units	Location Description	Latitude (DD)	Longitude (DD)	Sample Notes	EQ File #
MISC	9/18/2024 10:25	Zinc	4.62	ug/L	Clinton WM Headquarters, break room sink	42.40172249	-71.68384436	Sample Type: Metals	
MISC	11/8/2024 10:35	*E. coli*	771	MPN/100 mL	Furthest downstream sample 1	42.36082481	-71.8838391	Sample Type: Bacteria, M1	EQ2024-019
MISC	11/8/2024 10:37	*E. coli*	563	MPN/100 mL	Inside stone arch	42.36090611	-71.88377616	Sample Type: Bacteria, M2	EQ2024-019
MISC	11/8/2024 10:40	*E. coli*	10	MPN/100 mL	Immediately downstream brick building/pillar	42.3607874	-71.88378991	Sample Type: Bacteria, M3	EQ2024-019
MISC	11/8/2024 10:44	*E. coli*	10	MPN/100 mL	Under mill downstream 24-inch pipe over 12-inch pipe	42.36054245	-71.88377145	Sample Type: Bacteria, M4	EQ2024-019
MISC	11/8/2024 10:50	*E. coli*	20	MPN/100 mL	End of wingwall near grinder pump	42.36030762	-71.88392322	Sample Type: Bacteria, M5	EQ2024-019
MISC	11/8/2024 10:55	*E. coli*	10	MPN/100 mL	Daylight upstream mill	42.36024982	-71.8834807	Sample Type: Bacteria, M6	EQ2024-019
MISC	11/8/2024 11:00	*E. coli*	31	MPN/100 mL	In pool at recently wet pipe on river right	42.36033977	-71.883573	Sample Type: Bacteria, M7	EQ2024-019
MISC	11/8/2024 11:02	*E. coli*	10	MPN/100 mL	Just downstream covered concrete slab	42.36030002	-71.88341381	Sample Type: Bacteria, M8	EQ2024-019
MISC	11/8/2024 11:06	*E. coli*	10	MPN/100 mL	Under concrete slab, river right next to third support column	42.36033283	-71.88356551	Sample Type: Bacteria, M9	EQ2024-019
MISC	11/8/2024 11:08	*E. coli*	10	MPN/100 mL	Under concrete slab, main stem between fifth and sixth support	42.36018375	-71.8835493	Sample Type: Bacteria, M10	EQ2024-019
MISC	11/8/2024 11:15	*E. coli*	10	MPN/100 mL	Under concrete slab, river left pool	42.36015599	-71.88354992	Sample Type: Bacteria, M11	EQ2024-019
MISC	11/8/2024 11:20	*E. coli*	10	MPN/100 mL	Pool downstream of dam river left	42.36009913	-71.8835006	Sample Type: Bacteria, M12	EQ2024-019
MISC	11/8/2024 11:22	*E. coli*	10	MPN/100 mL	Outflow Eagle Lake	42.36000342	-71.88337094	Sample Type: Bacteria, M13	EQ2024-019
MISC	11/8/2024 11:24	*E. coli*	10	MPN/100 mL	Eagle Lake top of dam river right	42.35998237	-71.8833401	Sample Type: Bacteria, M14	EQ2024-019
MISC	11/8/2024 11:30	*E. coli*	10	MPN/100 mL	Eagle Lake outflow top of dam middle	42.3599361	-71.88336492	Sample Type: Bacteria, M15	EQ2024-019
MISC	11/20/2024 10:41	*E. coli*	404	MPN/100 mL	Downstream Rt. 122A right wall drainage outlet	42.36114822	-71.88385385	Sample Type: Bacteria, M1	EQ2024-019
MISC	11/20/2024 10:53	*E. coli*	20	MPN/100 mL	Upstream Rt. 122A drainpipe on wall along right bank closest to Rt. 122A, collected from pipe	42.36094043	-71.88393336	Sample Type: Bacteria, M2	EQ2024-019

Location	Date-Time (ET)	Parameter	Result	Units	Location Description	Latitude (DD)	Longitude (DD)	Sample Notes	EQ File #
MISC	11/20/2024 10:57	*E. coli*	318	MPN/100 mL	Downstream of mill complex where the Brook hits the wall along Rt. 122A	42.36082723	-71.8837822	Sample Type: Bacteria, M3	EQ2024-019
MISC	11/20/2024 11:01	*E. coli*	422	MPN/100 mL	Inside the stone arch under the mill building along the wall closest to Rt. 122A	42.36078795	-71.88370243	Sample Type: Bacteria, M4 and DNA sample 1	EQ2024-019
MISC	11/20/2024 11:27	*E. coli*	10	MPN/100 mL	Upstream of fourth pillar under mill, between buildings	42.360958	-71.8841327	Sample Type: Bacteria, M5, and location of second DNA sample	EQ2024-019

Sample Flags and Data Excluded from Analysis

Water quality data are flagged for various reasons during different stages of data review. Some flags are added to records automatically upon import to databases, while others are added manually. Flags are added to records any time results have been altered or any time a result may be influenced by a known factor or condition, which may require further review to determine if the record is reliable or should be excluded from analysis and reporting. If, after a detailed evaluation, sufficient evidence exists to support the determination that a record is likely to be unreliable or inaccurate, then the result will also be given Flag 123 (remove from analysis) in addition to the specific flag that best describes the underlying reason for lacking confidence in the result. Table D-5 lists the records from 2024 that were flagged and removed from analysis. Table D-6 is a summary of all other data that were flagged, where evidence to justify exclusion from analyses was insufficient. Typically, these results were within historical 25th – 75th percentile values for their respective parameter and location.

Table D-5: Flagged data for 2024 that were also censored (removed from analyses with flag code 123)

Sample #	Site	Date-Time ET	Parameter	Result	Units	Comment
109301	M102	1/4/2024 9:00	Dissolved Oxygen	18	mg/L	Likely air bubble caught in sensor
109302	M102	1/4/2024 9:00	Oxygen Saturation	137	%	Likely air bubble caught in sensor
109326	MD80	1/4/2024 10:04	Dissolved Oxygen	23.3	mg/L	Likely air bubble caught in sensor
109327	MD80	1/4/2024 10:04	Oxygen Saturation	190	%	Likely air bubble caught in sensor
110772	MD70	4/25/2024 11:26	Dissolved Oxygen	17.4	mg/L	D.O. above physical limits, probably air bubble in sensor
110773	MD70	4/25/2024 11:26	Oxygen Saturation	153	%	D.O. above physical limits, probably air bubble in sensor
110777	WFD2	4/25/2024 11:27	Dissolved Oxygen	17.4	mg/L	D.O. above physical limits, probably air bubble in sensor
110778	WFD2	4/25/2024 11:27	Oxygen Saturation	153	%	D.O. above physical limits, probably air bubble in sensor
113583	MD83	11/13/2024 8:15	pH	8.4	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113588	MD07	11/13/2024 8:30	pH	8.01	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113593	MD89	11/13/2024 8:42	pH	7.91	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113598	M110	11/13/2024 9:00	pH	7.78	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113603	M102	11/13/2024 9:13	pH	7.41	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113608	MD69	11/13/2024 9:30	pH	7.23	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113613	MD06	11/13/2024 10:00	pH	7.28	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113618	WFD1	11/13/2024 10:01	pH	7.23	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113623	MD80	11/13/2024 10:08	pH	7.18	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113628	MD05	11/13/2024 10:30	pH	7.17	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113633	MD04	11/13/2024 10:40	pH	7.4	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.

Sample #	Site	Date-Time ET	Parameter	Result	Units	Comment
113638	MD81	11/13/2024 10:51	pH	7.43	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113643	MD73	11/13/2024 10:58	pH	7.55	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113648	MD03	11/13/2024 11:15	pH	7.74	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113653	WFD2	11/13/2024 11:26	pH	7.27	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113658	MD02	11/13/2024 11:30	pH	7.34	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113663	MD01	11/13/2024 11:45	pH	7.38	pH	All pH results > 7.0 this day. Calibration seems off; pH sensor was nearing end of life and replaced in Dec.
113696	MD05	11/20/2024 10:45	Dissolved Oxygen	16.42	mg/L	D.O. value too high, likely air bubble trapped in sensor.
113697	MD05	11/20/2024 10:45	Oxygen Saturation	142	%	D.O. value too high, likely air bubble trapped in sensor.
115622	MD07	12/4/2024 9:15	Dissolved Oxygen	16.15	mg/L	Impossible D.O. value. Likely air bubble in YSI.
115623	MD07	12/4/2024 9:15	Oxygen Saturation	145	%	Impossible D.O. value. Likely air bubble in YSI.

Table D-6: Data quality flags in 2024 (not excluded from analysis)

Flag	Parameter	# Samples
103 - Questionable Data (MWRA Code S)	Dissolved Oxygen	2
103 - Questionable Data (MWRA Code S)	Oxygen Saturation	1
103 - Questionable Data (MWRA Code S)	Specific Conductance	8
111 - Above rating curve	Discharge	2
113 - Below rating curve	Discharge	1
116 - Estimated Value (MWRA Code J)	Dissolved Oxygen	1
125 - Sensor calibration issues	pH	17
126 - Analyzed outside hold time (MWRA Code T)	Ammonia-N	3
126 - Analyzed outside hold time (MWRA Code T)	Nitrate-N	3
126 - Analyzed outside hold time (MWRA Code T)	Nitrite-N	3
127 - Sampled with failed duplicate	Ammonia-N	32
127 - Sampled with failed duplicate	Chloride	10
127 - Sampled with failed duplicate	Dissolved Oxygen	196
127 - Sampled with failed duplicate	*E. coli*	88
127 - Sampled with failed duplicate	Oxygen Saturation	83
127 - Sampled with failed duplicate	Total Kjeldahl Nitrogen	31
127 - Sampled with failed duplicate	Total Suspended Solids	11
127 - Sampled with failed duplicate	Turbidity NTU	158
127 - Sampled with failed duplicate	Water Temperature	11
127 - Sampled with failed duplicate	pH	85
128 - Sampled with failed blank	Alkalinity	44
128 - Sampled with failed blank	Ammonia-N	22
128 - Sampled with failed blank	Chloride	11
128 - Sampled with failed blank	Total Organic Carbon	10
129 - QC Duplicate out of range	Ammonia-N	1
129 - QC Duplicate out of range	Chloride	1
129 - QC Duplicate out of range	Dissolved Oxygen	15
129 - QC Duplicate out of range	*E. coli*	5
129 - QC Duplicate out of range	Oxygen Saturation	6
129 - QC Duplicate out of range	Total Kjeldahl Nitrogen	3
129 - QC Duplicate out of range	Total Suspended Solids	1
129 - QC Duplicate out of range	Turbidity NTU	2
129 - QC Duplicate out of range	Water Temperature	1
129 - QC Duplicate out of range	pH	6
130 - QC Blank out of range	Alkalinity	4
130 - QC Blank out of range	Ammonia-N	2
130 - QC Blank out of range	Chloride	1
130 - QC Blank out of range	Total Organic Carbon	1
131 - Equipment error - malfunction or mis-read	Dissolved Oxygen	4
131 - Equipment error - malfunction or mis-read	Oxygen Saturation	4
132 - Abnormal environmental condition	Staff Gauge Height	4

Appendix E: Quality Control

Equipment Calibration

YSI meters are calibrated within seven days of a sampling event to ensure the devices are measuring accurately. If individual probes fail to calibrate, they are cleaned or replaced and then recalibrated until the probe calibration values fall within acceptable ranges. Figure E-1 through Figure E-3 show all of the calibration results for the YSI meters used in 2024. The HACH 2100Q turbidimeter was calibrated monthly in 2024 except for January and August. The recommended calibration frequency for the HACH 2100Q is every three months, however our internal SOP suggests monthly calibrations in order to increase confidence that the meter calibration is still valid (Table E-1).

Figure E-1: YSI Meter pH Calibration Values - 2024

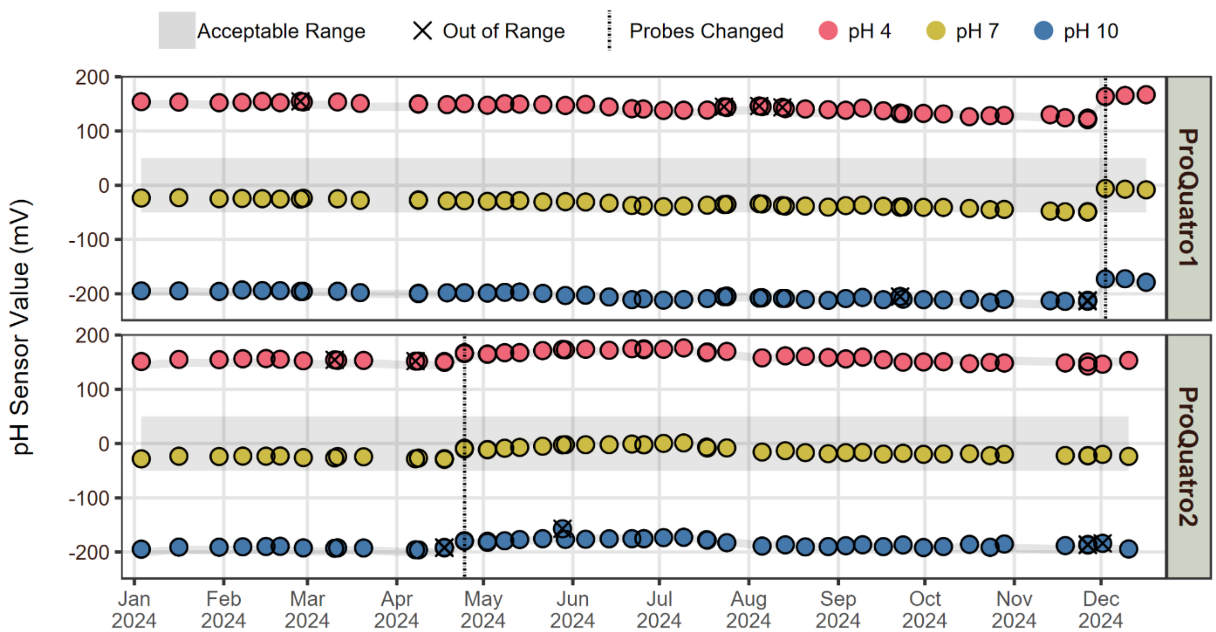


Figure E-2: YSI Meter Dissolved Oxygen Calibration Values - 2024

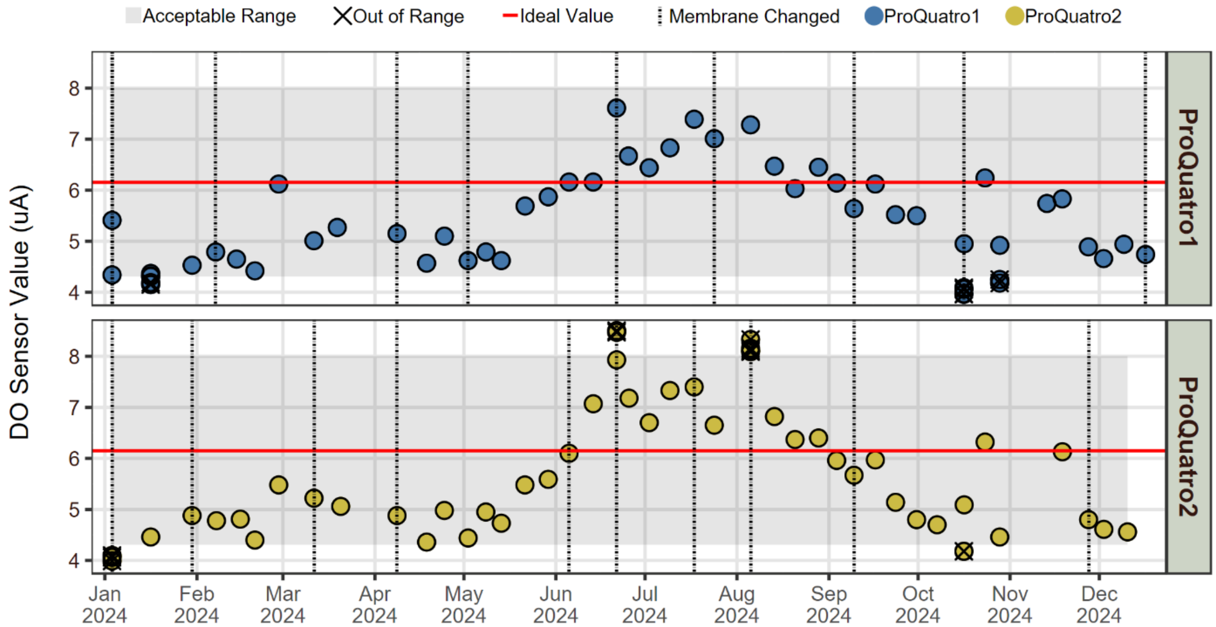


Figure E-3: YSI Meter Conductivity Calibration Values - 2024

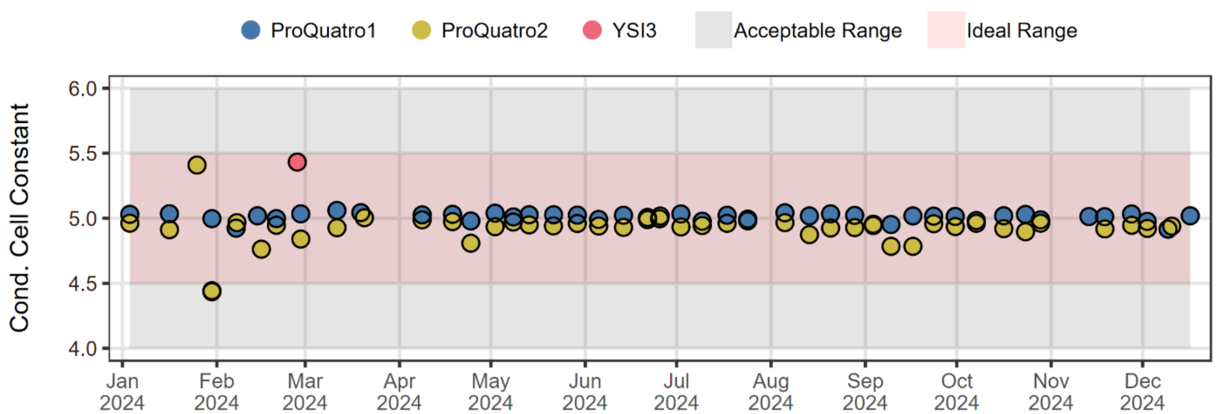
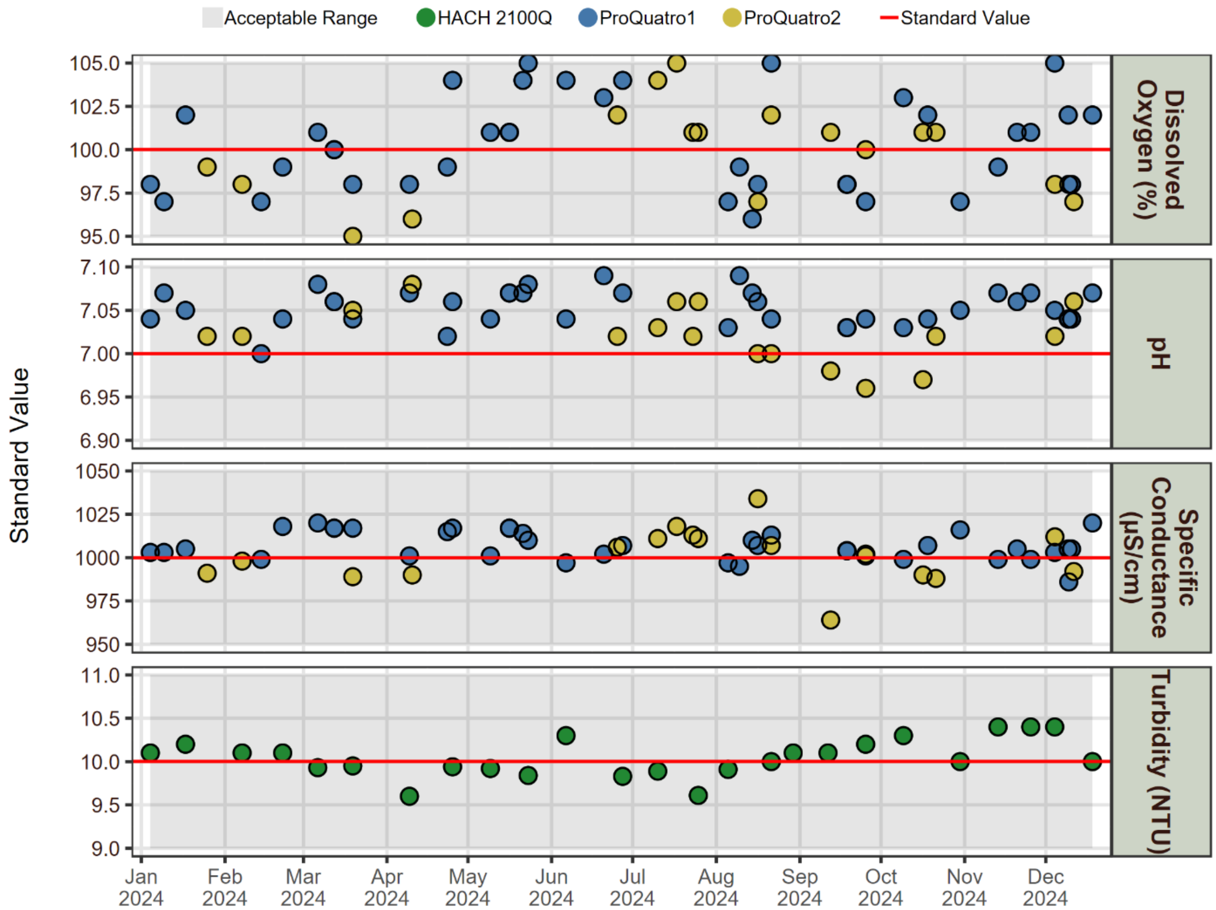


Table E-1: Hach 2100Q Calibration Records for 2024

WACHUSETT TURBIDIMETER CALIBRATION LOG - HACH 2100Q										
YEAR: 2024			Calibration Standards			Calibration Verification*		Quality Control Check		
Date YYYY-MM-DD	Staff	Cuvette #	20 NTU (Enter calibration values below)	100 NTU	800 NTU	Expected Value (NTU)	Result (NTU)	Blank (NTU)	Blank (NTU) New Cuvette	Accuracy Check
2024-02-20	NF	2	20.1	101	801	10.0	9.98	0.08	0.09	0.0016
2024-03-21	NF	2	20	99.4	784	10.0	10.1	0.09	0.09	0.0118
2024-04-18	NF	2	20.1	98.8	773	10.0	10.1	0.09	0.08	0.0018
2024-05-29	NF	2	19.9	97.8	785	10.0	10.8	0.09	0.10	0.0018
2024-06-25	NF	2	20.9	97	765	10.0	9.86	0.11	0.10	0.0022
2024-07-24	NF	2	19.7	96.5	755	10.0	9.79	0.06	0.06	0.0112
2024-09-25	NF	2	20.9	98.7	762	10.0	10.4	0.28	0.27	0.0056
2024-10-28	NF	2	21	98.6	771	10.0	10.8	0.15	0.14	0.0030
2024-11-27	NF	2	20.6	98.2	755	10.0	10.3	0.18	0.18	0.0136
2024-12-16	NF	4	19.4	95.6	754	10.0	10.1	0.06	0.15	*(0.0788)*
*Use 10 NTU Standard to verify calibration										

YSI meters and the HACH 2100Q portable turbidimeter calibrations are checked prior to every use. If any individual probe or meter calibration check falls outside of the acceptable range, the probe/meter will be successfully recalibrated before using in the field. Results for calibration checks in 2024 are displayed in Figure E-4. The failed accuracy check during the December 16, 2024 calibration resulted due to our last cuvette breaking and using another cuvette with some wear or scratches on the glass surface for the duplicate blank sample. The blank value of the field cuvette was within the normal range, therefore calibration of the instrument using this cuvette is assumed to be accurate and comparable to regular calibrations. Impacts to data accuracy in 2024 due to the "noise" introduced by cuvette wear is considered negligible and does not change the interpretation of any turbidity results collected in 2024.

Figure E-4: YSI Meter Pre-Sampling Quality Control Check Values - 2024



Blanks

As detailed in the QAPP for Wachusett Watershed Water Quality Monitoring, sample blanks were collected alongside tributary samples in 2024. During routine tributary sampling, one blank is collected for each parameter per sampling event. A summary of criteria for the evaluation of blanks is shown in Table E-2. A summary of tributary blanks is shown in Table E-3. A visualization of blank results is shown in Figure E-5.

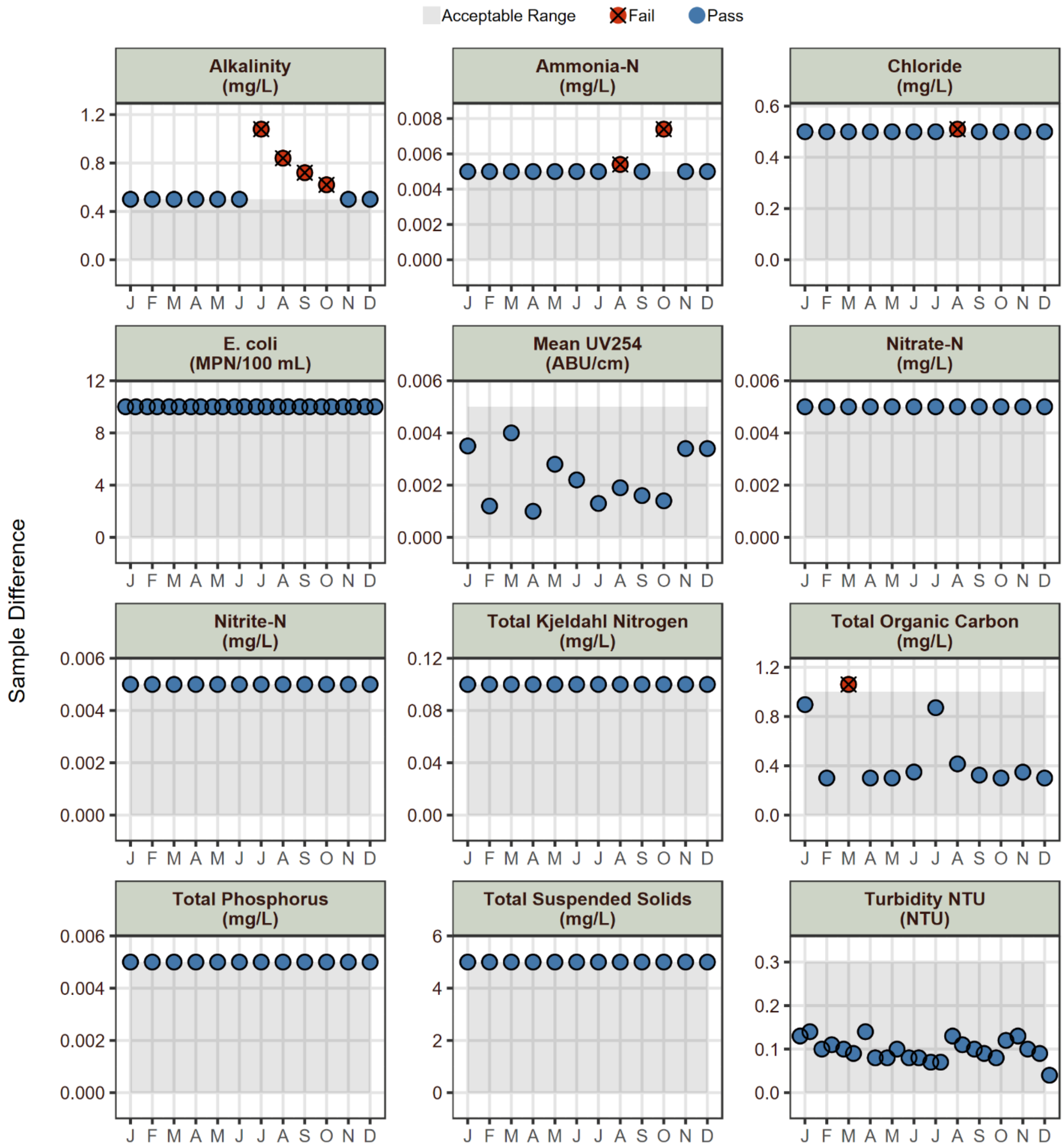
Table E-2: Blank Evaluation Criteria

Parameter	Acceptable Maximum Blank Result	Units
Alkalinity	0.5	mg/L
Ammonia-N	0.005	mg/L
Chloride	0.5	mg/L
E. coli	10	MPN/100 mL
Mean UV_{254}	0.005	ABU/cm
Nitrate-N	0.005	mg/L
Nitrite-N	0.005	mg/L
Total Kjeldahl Nitrogen	0.1	mg/L
Total Organic Carbon	1	mg/L
Total Phosphorus	0.005	mg/L
Total Suspended Solids	2-5	mg/L
Turbidity	0.3	NTU

Table E-3: Tributary Blank Results Summary for 2024

Parameter	Count	Expected	% Complete	Count Pass	Count Fail	% Fail
Alkalinity	12	12	100%	8	4	33%
Ammonia-N	12	12	100%	10	2	17%
Chloride	12	12	100%	11	1	8%
E. coli	24	24	100%	24	0	0%
Mean UV_{254}	12	12	100%	12	0	0%
Nitrate-N	12	12	100%	12	0	0%
Nitrite-N	12	12	100%	12	0	0%
Total Kjeldahl Nitrogen	12	12	100%	12	0	0%
Total Organic Carbon	12	12	100%	11	1	8%
Total Phosphorus	12	12	100%	12	0	0%
Total Suspended Solids	12	12	100%	12	0	0%
Turbidity NTU	24	24	100%	24	0	0%

Figure E-5: Tributary Blank Results for 2024



All failed blank results were flagged with flag 130 (QC Blank out of range) and all associated results of the same parameter on the same day were automatically flagged with flag 128 (Sampled with failed blank). As part of the year end QA/QC process, a detailed review was conducted for sample results of the same parameter and same sample day as the failed blanks. During this review, there was no evidence of sample contamination or another laboratory issue that could have impacted the results of the blank or regular tributary sample. All tributary results on the days of failed blanks were within normal seasonal ranges for the respective parameters. Furthermore, the failed ammonia, chloride, and TOC blank results were marginally over their respective method detection limits. The most likely reason for the failed blanks in 2024 is variable water chemistry of the prepared deionized water used for blank analysis. These failed blank results and associated records (same parameter on the same day) remain flagged in the database and will be used in future analyses, unless flagged for exclusion for a different reason.

Duplicates

As detailed in the QAPP for Wachusett Watershed Water Quality Monitoring, sample duplicates were collected alongside tributary samples in 2024. During routine bacteria and turbidity monitoring, two duplicates are collected for each parameter. One duplicate for each parameter is collected during tributary nutrient sampling. A summary of tributary duplicates is shown in Table E-4. A visualization of duplicate results of parameters collected in the field is shown in Figure E-6 and laboratory analyte duplicates are shown in Figure E-7.

Table E-4: Tributary Duplicate Result Summary for 2024

Parameter	Count	Expected	% Complete	Count Pass	Count Fail	% Fail
Alkalinity	12	12	100%	12	0	0%
Ammonia-N	12	12	100%	9	3	25%
Chloride	12	12	100%	11	1	8%
Dissolved Oxygen	51	60	100%	44	15	25%
E. coli	60	48	100%	43	5	10%
Mean UV_{254}	12	12	100%	12	0	0%
Nitrate-N	12	12	100%	12	0	0%
Nitrite-N	12	12	100%	12	0	0%
Oxygen Saturation	60	60	100%	53	6	10%
pH	60	60	100%	53	6	10%
Specific Conductance	60	60	100%	60	0	0%
Total Kjeldahl Nitrogen	12	12	100%	9	3	25%
Total Organic Carbon	12	12	100%	12	0	0%
Total Phosphorus	12	12	100%	12	0	0%
Total Suspended Solids	12	12	100%	11	1	8%
Turbidity	48	48	100%	38	10	21%
Water Temperature	60	60	100%	59	1	2%

Figure E-6: Tributary Field Parameter Duplicate Results for 2024

Temperature, pH, and dissolved oxygen are shown as the absolute difference of results with < 0.2 acceptable. Oxygen saturation and specific conductance are shown as relative percent difference with < 5 acceptable. Turbidity is shown as relative percent difference with < 30 acceptable.

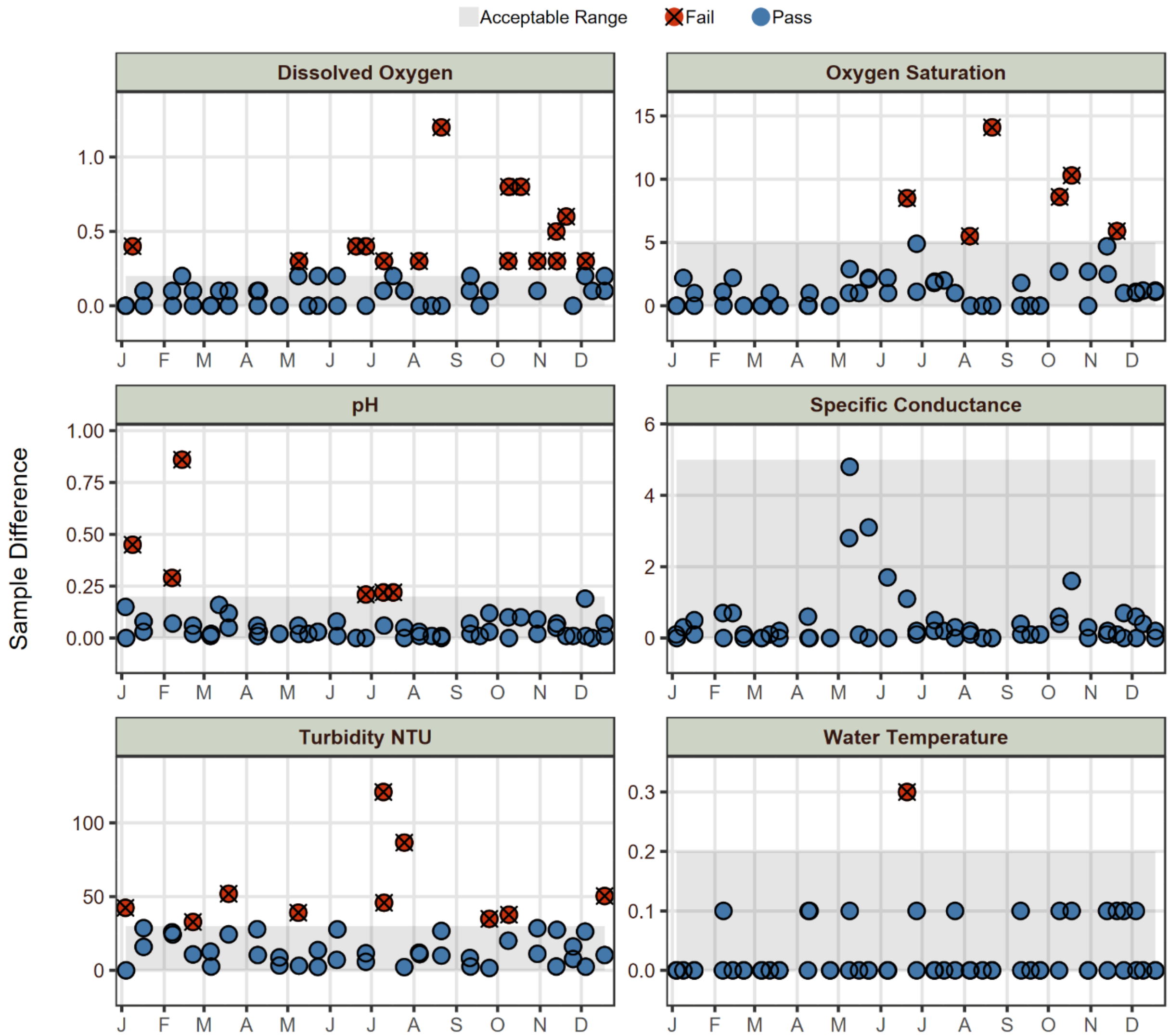
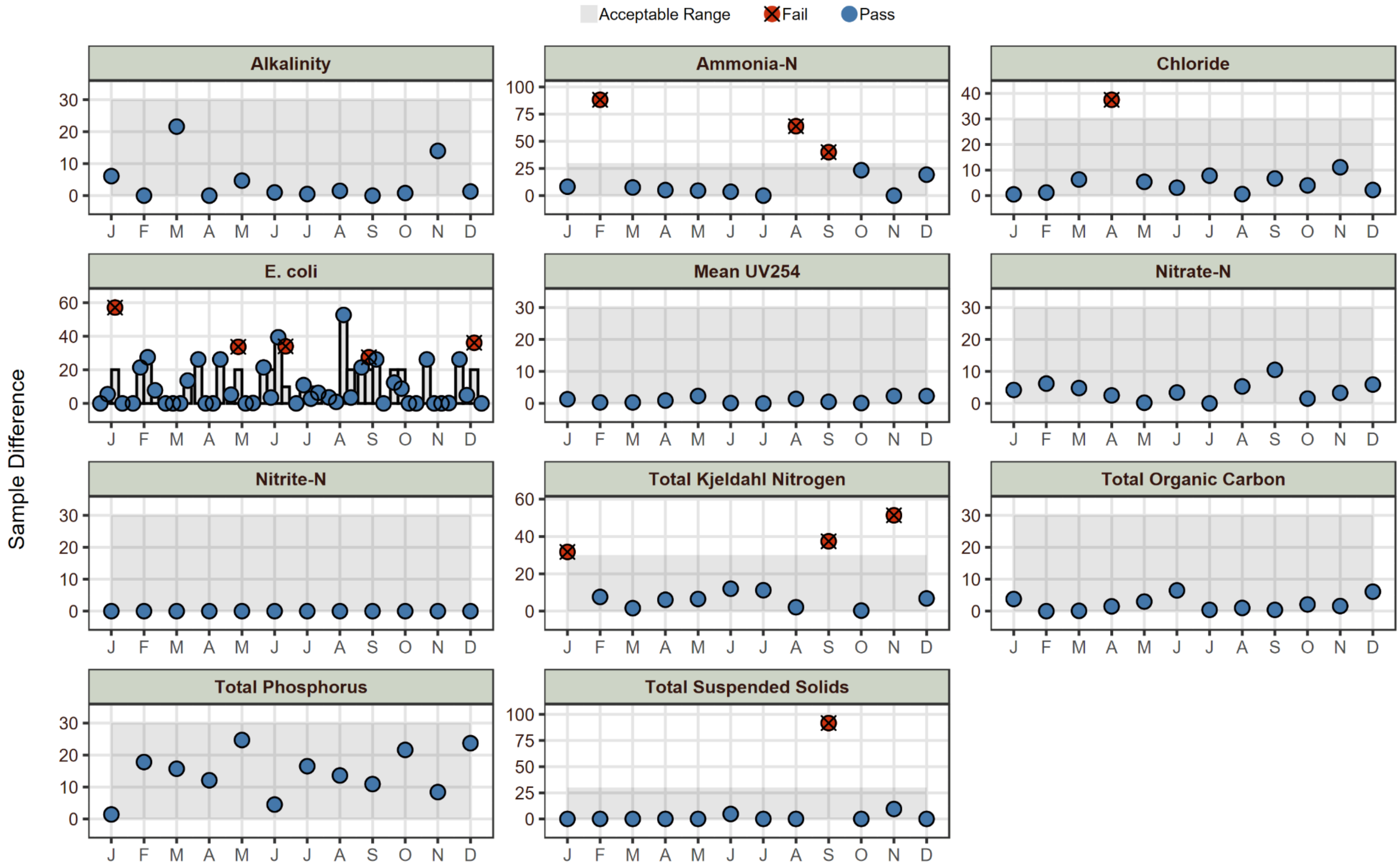


Figure E-7: Tributary Laboratory Analyte Duplicate Results for 2024

E. coli *must be within 50 MPN/100 mL or the relative percent difference of log_{10} values must be < 30 for < 50 MPN, < 20 for 50-500 MPN, < 10 for 500-5000 MPN, or < 5 for > 5000 MPN.*

The remaining parameters are shown as relative percent difference with < 30 acceptable.



All failed duplicate results were flagged with flag 129 (QC Duplicate out of range) and all associated results of the same parameter on the same day were automatically flagged with flag 127 (Sampled with failed duplicate). As part of the year end QA/QC process, a detailed review was conducted for sample results of the same parameter and same sample day as the failed duplicates. This review typically identifies results that are likely to be erroneous or unreliable for reasons that require additional flagging and in certain cases, exclusion from analysis.

For the three failed NH_3-N duplicates, all regular results and their associated duplicates were very low and within ranges typically observed at their respective monitoring locations. No additional data flags were applied to these records based on the failed duplicate results.

There were several duplicate failures for dissolved oxygen (and percent saturation) in 2024. The acceptable difference for dissolved oxygen is only 0.2 mg/L, and most failures were very close to that threshold (0.3 - 0.5 mg/L difference). Only one duplicate sample had an absolute difference over 1 mg/L. Failed dissolved oxygen duplicates are commonly the result of air bubbles being temporarily trapped next to the probe membrane, leading to rapid fluctuations in readings, or natural variability within the stream as water mixes and moves through the sensor. No additional data flags were applied to these records based on the failed duplicate results.

There were five *E. coli* failed duplicates, and three of these were either low concentrations or less than a 100 MPN/100 mL difference. The June 27 failed *E. coli* duplicate at Scarlett Brook was almost an order of magnitude different than the regular sample. This sample location is downstream of the Walmart in West Boylston and is highly impacted by stormwater runoff and is chronically filled with litter and debris. Highly variable bacteria concentrations at this location are common.

The absolute differences for failed duplicates for pH were all within 1.0 S.U. of the regular sample and four out of six samples were within the historical 25^{th} – 75^{th} percentile value for their respective location. This variability could be due to groundwater exfiltration from the stream bed (where the sensor sits while recording pH), longer than usual equilibration times for the pH sensor, or natural variability in stream water chemistry. These results do not indicate any equipment or sampling issues and results are considered representative of the water chemistry of the Wachusett tributaries.

There were three failed duplicates for TKN, which were all at low concentrations with absolute differences between 0.04 and 0.11 mg/L. Although these duplicates failed, the results are reflective of natural variation expected at these tributaries.

Turbidity duplicates failed on ten occasions, which is a failure rate of 21%. All results for regular samples and their duplicates on these occasions were below 5.0 NTU and aside from two samples, absolute differences were within 1.0 NTU. This variability in stream turbidity is expected and all results are representative of the tributary waters sampled. Sample collection and analysis SOPs will be reviewed to determine if there are any procedural changes that could be implemented to reduce the percentage of failed duplicates.

One TSS duplicate sample failed with a 91.7 relative percent difference (RPD). Both the regular sample and the duplicate sample were near the method detection limit and the discrepancy could be in part due to the samples being analyzed at the MWRA lab by different staff on different days. This failed duplicate is anomalous, and the regular result is typical for the tributary sampled (Trout Brook). No additional flags were applied to the regular TSS result on this day.

One chloride duplicate failed on April 10, at Malden Brook, with a RPD of 37.5, but an absolute difference of only 8.5 mg/L. Both the duplicate and regular chloride result on this day were representative of tributary chemistry at Malden Brook during this period of time and the RPD exceeded the failure threshold largely due to the historically low chloride concentrations early in 2024. No additional flags were applied to the regular chloride result on this day.

One water temperature duplicate failed on June 20 at French Brook, with an absolute difference of 0.3 °C. The sample location in French Brook is along a swampy bank where exfiltrated groundwater is frequently mixing with the stream water, creating variable water chemistry and physical conditions. Both the regular sample and duplicate are within typical ranges observed at this location and no additional flags were applied to these records.

All failed duplicates and associated records for 2024 remain flagged in the database and the associated records will be used in future analyses, unless flagged for exclusion based on another rationale.

Field and Laboratory Audits

In order to ensure continued adherence to established procedures as described in the QAPP and relevant SOPs, audits are performed at least on an annual basis for most routine field and laboratory activities. Completed audits from 2024 are listed in the QAPP checklist below (Figure E-8). Upon discovery of a deviation from established procedures, corrective action will be implemented on a case-by-case basis. Minor response actions may be taken immediately to align procedures with those in the relevant SOPs.

For 2024, two lab audits and four field audits were completed. With the exception of the HACH 2100Q turbidimeter calibration audit, all audits were evaluated as either “Good” or “Excellent”. For the HACH 2100Q audit, the procedures were mostly followed, however, during the audit a critical step was not performed, which resulted in the device not actually being calibrated. Fortunately, this device only requires calibration every three months and did not drift significantly during 2024. All turbidimeter calibration pre-checks during 2024 passed, therefore all turbidity results for 2024 can be considered accurate and reliable. All deviations from SOPs were documented on individual audit forms and were determined to be minor - not affecting the quality of the data collected. Staff were immediately notified of any deviation from SOPs and instructed to review specific SOPs when appropriate.

Figure E-8: 2024 QAPP Checklist Indicating Date of Audits and Follow-up Actions

WACHUSETT QAPP CHECKLIST

dcr Massachusetts

Sampling Year: 2024 **QAQC Officer:** Dan Crocker

Field Audits	**Date Complete**
Tributary - WATTRB	12/18/2024
Tributary Nutrients - WATMDC	11/20/2024
Groundwater - WATWEL	10/21/2024
Reservoir Transects - WATTRN	10/23/2024
Discharge Measurements	N/A
Snowpack Measurements	N/A
Reservoir Nutrieints (MDCMTH)	N/A
Reservoir Profiles	N/A
Zooplankton	N/A
Phytoplankton	N/A
Laboratory Audits	**Date Complete**
YSI Pro Quatro calibration	12/16/2024
HACH 2100Q calibration	12/16/2024
Laboratory turbidity analysis (If samples not analysed in the field)	N/A
Audit Follow-up Actions	
Staff informed of deviations from SOPs for projects:	HACH Cal, WATMDC, WATTRB
Staff retrained in techniques for projects:	HACH Cal
Staff re-read SOPs for projects:	
Other:	
Annual Data Checks	**Date Complete**
Data completeness (80-100% of planned measurements)	4/15/2025
Review samples flagged as 127 (sampled alongside failed duplicate)	4/15/2025
Review samples flagged as 128 (sampled alongside failed blank)	4/15/2025

Signatures

Daniel Crocker (signature)

QAQC Officer's Signature

6/13/2025

Date