OARS

FOR THE SUDBURY ASSABET & CONCORD RIVERS

Water Quality Monitoring Program Final Report
2024 Field Season

May 2025

Acknowledgments

OARS wishes to thank our many dedicated volunteers for their work in the field and on our Board and advisory committees. We'd especially like to thank our 2024 water quality and bacteria volunteers: Ken Appel, Roger Beatty, Amanda Brandt, Elissa Brown, Yingyu Chen, Jim Clarke, Dan Cooke, Jason Cunha, April Desclos, Russel Desclos, John Emery, Lisa Fierce, Peter Frick, Brenda Haggerty, Kim Kastens, Matt Liebman, Michal Mueller, Pam Nixon, Steve Pannicci, Glenn Pransky, Terry Snyder, Len Rappoli, Shankara Rao, Liliana Rao, Peter Severance, Alec Steele, Ann Wachur, Sean Walsh, Brooke Warrington, Patrick Thayer, Kate Warwick, and David Winowich.

For scientific review and editorial help, many thanks to Peter Shanahan, Ph.D., P.E., of HydroAnalysis, LLC, OARS Board (retired) and MIT (retired), and Matt Brown and Sarah Kwan of OARS.

We greatly appreciate the support for our water quality sampling program from the towns of Maynard, Concord, Stow, Wayland, Acton, Hudson, and Sudbury. The National Park Service, the Sudbury-Assabet-Concord Wild and Scenic River Stewardship Council, and the Massachusetts Executive Office of Energy and Environmental Affairs provided significant financial support to the monitoring program, for which we are grateful. Bacteria data collection was supported by the Greater Lowell Community Foundation. In-kind services were provided by U.S. Environmental Rental Corporation of Waltham and Nashoba Analytical LLC of Ayer. We also thank the OARS members whose membership dues and donations made this work possible.

Some components of this data collection have been financed with State capital funds from the Massachusetts Department of Environmental Protection (MassDEP) under a Water Quality Monitoring Grant. The contents do not necessarily reflect the views and policies of MassDEP, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

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Available online at: **oars3rivers.org/our-work/river-science/water-quality/water-quality-reports/**

Suggested citation: OARS, 2025, "Water Quality Monitoring Program Final Report: 2024 Field Season", OARS, Concord, MA.

Cover pictures clockwise from top left: sampling in Elizabeth Brook (photo credit A. Brandt), sampling at the Bedford boat ramp (photo credit P. Severance), sampling in Danforth Brook (photo credit B. Warrington), measuring stream flow in Hop Brook (B. Wetherill).

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Executive Summary

This report presents the water quality, streamflow, bacteria, and aquatic plant biomass data OARS collected on the Sudbury, Assabet, and Concord rivers and tributary streams in 2024. It also summarizes and evaluates trends in the data that have become evident for the period of record between 1992 and 2024. The following are the high-level findings for each parameter. The details for each are laid out in the body of the report.

Water Temperature is an important characteristic for aquatic life and is particularly important to watch, considering concerns of global warming. The summer of 2024 was warmer than historic averages and much warmer than 2023. This was evident in river temperatures, which came close to exceeding the Class B warm-water threshold in July in the Concord, Lower Assabet, and Lower Sudbury. An analysis of maximum yearly river temperatures since 1997 shows a clear increase in temperature for the Assabet River and its headwaters.

Conductivity levels in 2024 were generally lower than expected for a dry-weather year, but this was most likely the result of higher-than-average rainfall and flows in the early part of the summer. Hot spots below wastewater treatment plants (WWTPs) and major roads were elevated and clearly distinct from the other sites. Since conductivity in New England is highly correlated with **Chloride**, it is an indicator of road salt pollution. Our long-term conductivity data show a clear and statistically significant upward trend in conductivity for all sections of our rivers. This implies an increasing trend in chloride and is a serious threat to the ecological health of all our waterways. Our conductivity and chloride data also show that the Westborough WWTP is a major source of chloride in the Assabet. We are in the process of studying other WWTPs.

Dissolved Oxygen (DO) continues to show a positive upward trend in the Assabet sites as a result of the WWTP improvements that were made there. In the Lower Sudbury, the trend has been downward, but we have seen reversals in 2022 and 2024. We believe the flooding in preceding years removed organic detritus and reduced biological oxygen demand in the following years. The Hop Brook in Sudbury has consistently had very low DO levels, but the trend is showing improvement. Nashoba Brook below Warner's Pond continues to show a downward trend in DO levels, driven by eutrophication in the pond. We are watching Elizabeth Brook and the Sudbury headwaters, which have chronic low DO and pH levels downstream of large wetlands.

Acidity (pH) readings in 2024 were generally moderate. Trend analysis has shown a clear upward trend in pH in the Assabet River, which is a positive sign of reduced eutrophication and lower levels of aquatic respiration driven by long-term phosphorus reductions. pH readings were noteworthy in four locations: the Hop Brook in Sudbury and the farthest upstream Sudbury site consistently have very low pH related to wetlands, nutrient load, and low DO, the Assabet sites downstream of Ben Smith Dam show consistently high pH probably driven by floating algal growth, and ELZ-004 has had unusually low pH levels for the last five years.

Total Phosphorus (TP) is the primary indicator we watched as improvements were made to the wastewater treatment plants on the Assabet. Trend analysis shows the dramatic reduction in TP through 2012, when the final plant upgrades were implemented. Since 2012, TP mainstem concentrations have been close to the targeted 0.05 mg/l in all mainstem rivers. We still have consistently high TP concentrations in Hop Brook in Sudbury downstream of the Marlborough Easterly WWTP, and two sites, Hop Brook in Northborough and the Fruit Street site at the Sudbury headwater, which both have large wetlands and significant potential developed area runoff, are also showing consistent high phosphorus levels. These are three priority areas for future study. In addition to instream monitoring, we also track direct discharges from WWTPs. While the WWTP phosphorus discharge has been dramatically reduced at all plants, there have been recent issues at the Hudson and Concord WWTPs. The Hudson plant had an equipment failure in 2023, causing it to exceed its permitted TP discharge limits for almost all of 2023 and 2024. The Concord plant exceeded its monthly summer permit limit twice during 2024. OARS is working with MassDEP to address these issues.

Orthophosphate represents the bioavailable portion of total phosphorus. As a percentage of TP, it is trending down in the Assabet, which is a good indicator of WWTP performance. We still see high orthophosphate proportions in Hop Brook downstream of the impoundments that have collected legacy WWTP discharge and in the fall in November when WWTP limits are relaxed, further underscoring the importance of reducing WWTP phosphorus discharge.

Nitrate levels are very high downstream of all WWTPs, and trends show that river concentrations and loads are increasing over time. The WWTPs are the primary source of nitrate in the rivers, and nitrate discharges are currently not regulated. This is a concern for tidal estuaries downstream of our rivers, where nitrogen is the limiting nutrient. Our data show that a significant and increasing load is being passed downstream to the Merrimack River.

Ammonia can be an indicator of industrial spills, municipal wastewater discharges, waste decomposition, and natural nitrogen fixation. It can be toxic to aquatic life, but the levels recorded in our rivers have consistently been well below any toxicity threshold values since permit limits were applied to the WWTPs in 2000. Now, sites downstream of wetlands often have the highest values. Two sites show sporadic ammonia hits that may be worth watching: Marlborough Easterly WWTP and River Meadow Brook. And, in 2024, we noticed a spike in ammonia at the site on the Assabet downstream of the Hudson WWTP. This was caused by the recent operational issues at the Hudson WWTP.

Total Suspended Solids concentrations are usually highest in the Lower Sudbury and Concord rivers, possibly driven by motorized boating that is common in these sections, but these river locations were comparatively less elevated in 2024. Two sites (ABT-237 and NSH-047) exhibited particularly high TSS concentrations common for those sites in low-flow conditions. Our long-term concentration data continue to show an improving trend in all our rivers.

Chlorophyll *a* is a measure of planktonic algae in the water and can be an indicator of eutrophication. High nutrient levels could result in algal blooms. We are measuring chlorophyll *a* only in the Sudbury River. Chlorophyll a concentrations tend to have a strong inverse correlation with summer rainfall, meaning that low rainfall results in high chlorophyll *a* concentrations. Our year-on-year data produce a downward trend line, which is highly skewed by the high chlorophyll *a* levels in 2010. The year 2024 continued this trend, with unusually low chlorophyll levels at all but the most downstream site. We believe the unusually low levels this year are a symptom of the previous year's extremely high flows, which carried available nutrients out of the system.

The **Water Quality Index** is a summary metric that combines many of the parameters listed above. It is used as a primary component of our River Report Card. The index has fluctuated differently for each river, with 2018 representing a favorable point across most river sections. Recent declines in the index have been driven by the negative impact of drought, heavy precipitation, and flooding on phosphorus concentrations and dissolved oxygen in the Lower Sudbury and Concord rivers. In the Assabet, the index has had an upward improving trend, but the Upper Assabet continues to have a very low index value due to the nitrate discharges from the Westborough WWTP.

E. coli bacteria are an indicator of the health safety of the rivers for recreational users. OARS started monitoring the rivers for bacteria in 2019. Bacteria levels in all five years since have generally followed a consistent pattern by site. The Maynard, Ashland, and Lowell sites consistently have concerning bacteria levels, hovering near or above the MassDEP swimming threshold. All three have high levels in dry weather, indicating possible sanitary sewer contamination. We moved the Hudson site closer to downtown this year and found similarly concerning bacteria levels. The Lower Sudbury and Upper Concord sites consistently show very low levels of contamination and are within standards for swimmability. OARS is taking a multi-year approach of conducting intensive source-tracking special studies in the areas with chronic pollution levels: Lowell, Maynard, and Ashland. A study of Ashland was conducted in 2024.

Biomass has been surveyed at three impoundments in the Assabet since 2005 to track progress toward the goal of reducing nuisance biomass. The data show a strong negative correlation between biomass and rainfall, especially for duckweed. There was extremely high rainfall in 2023, which suppressed biomass, but high biomass levels returned in 2024, especially in Ben Smith, which had previously been showing some signs of improvement. Trend analysis shows a mixed picture, with a decreasing trend in the Ben Smith impoundment (except in 2024) and an increasing trend in the Hudson impoundment. Analysis of the plant species surveyed shows that Hudson is dominated by a single species (filamentous green algae). All indications are that the Hudson impoundment is moving toward extreme eutrophication, and we are considering whether this is related to the combined effect of high nitrate concentrations in the Upper Assabet and legacy phosphorus in the sediments.

Water quality reports for 1999–2024 are available on OARS' website (**oars3rivers.org/our-work/river-science/water-quality/water-quality-reports/**). All data are available upon request.

Introduction

OARS is a 501(c)(3) non-profit organization whose mission is to protect, improve, and preserve the Sudbury, Assabet, and Concord rivers and watershed for all people and wildlife. Established in 1986 as the Organization for the Assabet River (OAR) by a group of concerned citizens, OAR added the Sudbury and Concord rivers to its mission in 2011, becoming OARS. Currently, the organization has over 1700 individual and family memberships, a ten-member Board of Directors, and five regular staff, two TerraCorps Service members, plus summer staff. Together with our volunteers and partners, OARS has made significant progress over the past 39 years towards achieving our mission.

The combined Sudbury, Assabet, and Concord (SuAsCo) River watershed comprises about 399 square miles in eastern Massachusetts and is within EPA's Nutrient Ecoregion XIV subregion 59, the Eastern Coastal Plain. The mainstem rivers, particularly the Assabet, have suffered from cultural eutrophication caused by excess nutrients coming from point and non-point sources and from the soft sediments. During the growing season, excess nutrients, phosphorus in particular, have fueled nuisance algal and macrophytic plant growth that interferes with recreational use of the rivers and causes large daily variations in dissolved oxygen concentrations and pH, making poor habitat for aquatic life. When the algae and plants decay, they generate strong sewage-like odors, can dramatically lower dissolved oxygen levels in the water column, and impair the aesthetics and use of the rivers. Invasive aquatic plants are also a problem throughout the watershed. The Sudbury River has a long history of invasive water chestnut (*Trapa natans*), and efforts to remediate this problem have been underway for many years. Significant water chestnut infestations are also common on the Concord River, particularly in the Billerica impoundment, and in sections of the Assabet River downstream of Hudson. Other invasive aquatic plants include Eurasian milfoil, fanwort, and curly leaf pondweed.

Under the federal Clean Water Act (Section 305b), states are required to evaluate the condition of the state's surface and ground waters with respect to their ability to support designated uses (such as fishing and swimming) as defined in each of the state's surface water quality standards. In their 2022 assessment (2022 Integrated List of Waters), Massachusetts Department of Environmental Protection lists all sections of the Assabet and Concord rivers, most sections of the Sudbury River, and many SuAsCo tributaries on the Impaired Waters List as Category 5 ("Waters Requiring a TMDL") for a variety of impairments (MassDEP, 2023). Table 1 provides a list of impairments by waterbody.

Table 1: Category 5 impaired waterways (from 2022 Integrated List of Waters)

Waterbody	Category 5 Impairments
Assabet River (all sections)	Various including: *E. coli*, fecal coliform, macroinvertebrates, fish, algae, eutrophication, odor, phosphorus, trash, DO, and invasives
Concord River (all sections)	Various including: *E. coli*, fecal coliform, mercury, chloride, trash, algae, turbidity, and invasives
Sudbury River (d.s. of Fruit St. bridge)	Various including: mercury, DO, *E. coli*, and macroinvertebrates
Beaver Brook	*E. coli*, DO
Broad Meadow Brook	*E. coli*, DO, macroinvertebrates
Cochituate Brook	*E. coli*, trash, macroinvertebrates, eutrophication
Cold Spring Brook	DO, macroinvertebrates
Coles Brook	*E. coli*, chloride
Eames Brook	macroinvertebrates, odor, algae, trash
Elizabeth (& Assabet) Brook	*E. coli*, macroinvertebrates
Hop Brook in Northborough	macroinvertebrates, chloride
Hop Brook in Sudbury	phosphorus, DO, algae, eutrophication, macroinvertebrates, *E. coli*, turbidity, suspended solids, pH
Nashoba Brook	*E. coli*, temperature, macroinvertebrates
North Brook	Temperature
Pantry Brook	fecal coliform

Waterbody	Category 5 Impairments
Picadilly Brook	temperature, fish
River Meadow Brook	*E. coli*, fecal coliform, temperature, trash, macroinvertebrates, chloride, DO
Whitehall Brook	macroinvertebrates, DO

Nutrient limits were first set for the Assabet River wastewater treatment plants (WWTPs) in 1993, seven years after OAR was established. The EPA and MassDEP set summer discharge concentration limits of 1.0 mg/L for all four plants, and by 2000, all plants reported average summer concentrations below 1.0 mg/L achieved through waste treatment with ferrous sulfate, ferrous chloride, ferric chloride, and/or alum. The *Assabet River Total Maximum Daily Load for Total Phosphorus* study (MassDEP, 2004) was completed in 2004 and confirmed that the majority of the nutrients entering the Assabet were coming from the wastewater treatment plants that discharge treated effluent to the river. In particular, treatment plants were the major source of ortho phosphorus (the bioavailable form of phosphorus). While non-point sources contributed nutrients via stormwater runoff, they contributed significantly less than the point sources. The 2004 study concluded that reductions in nutrient loads from both point and non-point sources would be required to restore the Assabet River to Class B conditions. MassDEP and EPA adopted a two-phased adaptive management plan to reduce phosphorus loads in the Assabet. In Phase 1, lower summertime total phosphorus discharge limits of 0.1 mg/L were required at the four major WWTPs. Also, as a part of Phase 1, ways of limiting nutrient flux from the nutrient-rich sediments that accumulate in the impounded river sections were studied. The *Assabet River, Massachusetts, Sediment and Dam Removal Study* (ACOE, 2010) examined sediment dredging, dam removal, and lower winter phosphorus discharge limits as ways of controlling the annual phosphorus loading from the sediments. The study concluded that: (1) dredging would achieve, at best, short-term improvements; (2) phosphorus discharge from the WWTPs in the winter contributes to the annual phosphorus budget for the Assabet and, therefore, decreased winter phosphorus discharge limits would be another way to control phosphorus loading to the system; and (3) dam removal plus the Phase 1 WWTP phosphorus discharge reductions would almost meet the MassDEP 2004 goal of reducing the sediment phosphorus contribution by 90%, achieving an estimated 80% overall reduction. Upgrades to the four municipal wastewater treatment plants that discharge to the Assabet River were completed as of the spring of 2012: Hudson in September 2009, Maynard in spring 2011, Marlborough Westerly and Westborough in spring 2012. The Marlborough Easterly plant, discharging to the Sudbury River via Hop Brook, finished required upgrades by spring 2015. With the upgrades complete, all the treatment plants currently meet a summer total phosphorus discharge limit of 0.1 mg/L. In Phase 2 of the adaptive management plan, MassDEP and EPA were tasked with jointly deciding what additional phosphorus treatment would be needed for the Assabet to meet water quality standards. In 2023, they took the next step of reducing the winter phosphorus discharge limit from 1.0 mg/L to 0.2 mg/L[1], and as of 2024, Marlborough Easterly's summer discharge limit was set at 0.05 mg/L.

For the nutrient load reductions proposed in the state's TMDL to effectively restore water quality in the mainstem, the existing baseflow in the Assabet and its tributaries must be preserved and augmented if possible. Baseflow, the flow of groundwater into the streams, is particularly critical during the summer and is essential to diluting the effluent discharged to the rivers. The area's water resources are under the strain of an increasing demand for water supply and centralized wastewater treatment, which results in the net loss of water from many sub-basins and reduced baseflow in the mainstem and tributaries. A natural streamflow regime throughout the year is critical to supporting fish and other aquatic life.

Because of these issues, OARS conducts water quality, streamflow, and aquatic plant biomass monitoring on the mainstems and large tributaries of the Sudbury, Assabet, and Concord rivers. Without the support and

[1] Marlborough Westerly's limit is set at 4.8 lb/day, which corresponds to 0.2 mg/L at design flow.

work of its volunteers, OARS would not be able to conduct such an extensive monitoring program. The summer of 2024 was OARS' 33rd consecutive year collecting water quality data, its 20th year assessing aquatic plant biomass in the large impoundments of the Assabet River, and its 6th year collecting *E. coli* fecal-indicator bacteria data. Water quality and bacteria data, collected under the *Quality Assurance Project Plan for OARS' Water Quality and Quantity Monitoring Program* (OARS, 2022), may be used by EPA and DEP in making regulatory decisions. The goals of OARS' monitoring program remain: to understand long-term trends in the condition of the rivers and their tributaries, to provide sound scientific information to evaluate and support regulatory decisions that affect the rivers, and to promote stewardship of the rivers through volunteer participation in the project.

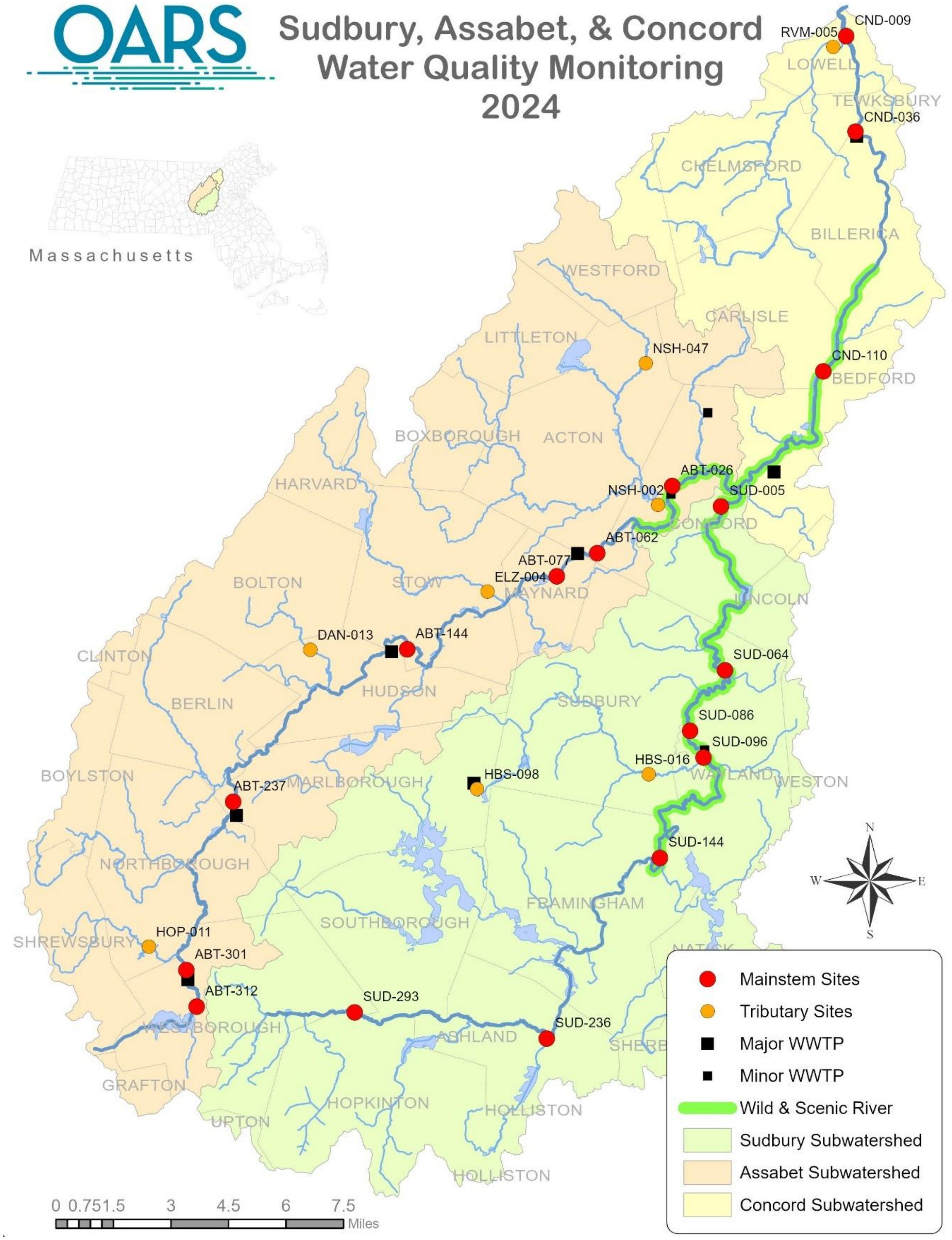


Figure 1: Water Quality Monitoring Sites 2024

Table 2: Water Quality Monitoring Sites 2024

OARS Site #	Waterbody	Site Description	Municipality	SARIS #	Lat/Lon	Sampling Dates			Gauge reading /streamflow*
						June/Jul/ Aug	May/ Sept	Nov/ March	
CND-009	Concord River	Rogers Street	Lowell	46500	42° 38' 09"/ -71° 18' 05"	√	√	√	(USGS Gauge)
CND-036	Concord River	Bristol & Amherst Streets	Billerica	46500	42° 35' 59"/ -71° 17' 49"	√			
CND-110	Concord River	Route 225	Bedford	46500	42° 30' 33"/ -71° 18' 51"	√			
ABT-026	Lower Assabet	Route 2	Concord	46775	42° 27' 57"/ -71° 23' 28"	√	√	√	
ABT-062	Lower Assabet	Route 62 (Canoe access)	Acton	46775	42° 26' 27"/ -71° 25' 46"	√			
ABT-077	Lower Assabet	USGS Maynard Gauge	Maynard	46775	42° 25' 55"/ -71° 26' 59"	√	√	√	(USGS Gauge)
ABT-144	Upper Assabet	Route 62 (Gleasondale)	Stow	46775	42° 24' 16"/ -71° 31' 35"	√			
ABT-237	Upper Assabet	Robin Hill Road	Marlborough	46775	42° 20' 48"/ -71° 36' 53"	√			
ABT-301	Upper Assabet	Route 9	Westborough	46775	42° 16' 59"/ -71° 38' 19"	√	√	√	
ABT-312	Assabet Headwater	Mill Road	Westborough	46775	42° 16' 10"/ -71° 37' 60"	√	√	√	√
SUD-005	Lower Sudbury	Route 62 (Boat House)	Concord	47650	42° 27' 30"/ -71° 21' 59"	√	√	√	
SUD-064	Lower Sudbury	Sherman Bridge Road	Wayland	47650	42° 23' 47"/ -71° 21' 52"	√	√		
SUD-086	Lower Sudbury	River Road	Wayland	47650	42° 22' 26"/ -71° 22' 54"	√	√		
SUD-096	Lower Sudbury	Route 20	Wayland	47650	42° 21' 49"/ -71° 22' 31"	√	√		
SUD-144	Lower Sudbury	Sudbury Landing	Framingham	47650	42° 19' 32"/ -71° 23' 51"	√	√	√	(USGS Gauge)
SUD-236	Upper Sudbury	Chestnut Street	Ashland	47650	42° 15' 27"/ -71° 27' 18"	√			
SUD-293	Upper Sudbury	Fruit Street	Southborough	47650	42° 16' 03"/ -71° 33' 09"	√	√	√	√
DAN-013	Danforth Brook	Route 85	Hudson	47275	42° 24' 14"/ -71° 34' 29"	√	√	√	√
ELZ-004	Elizabeth Brook	White Pond Road	Stow	47125	42° 25' 36"/ -71° 29' 07"	√	√	√	
HOP-011	Hop Brook N'boro	Otis Street	Northborough	47600	42° 21' 26"/ -71° 37' 46"	√	√	√	√
HBS-016	Hop Brook Sudbury	Landham Road	Sudbury	47825	42° 21' 26"/ -71° 24' 11"	√	√	√	
HBS-098	Hop Brook Sudbury	Route 20 Above Hager Pond	Marlborough	47825	42° 21' 03"/ -71° 29' 26"	√			
NSH-002	Nashoba Brook	Commonwealth Ave.	Concord	unnamed	42° 27' 32"/ -71° 23' 50"	√	√	√	√
NSH-047	Nashoba Brook	Wheeler Lane	Acton	46875	42° 30' 43"/ -71° 24' 17"	√	√	√	(USGS Gauge)
RVM-005	River Meadow	Thorndike Street	Lowell	46525	42° 37' 55"/ -71° 18' 32"	√	√	√	√

* USGS Gauge indicates that data is collected from USGS real-time gaging stations via the USGS NWS website. OARS Gages are maintained and read manually by OARS volunteers and staff.

** USGS Gauge at Mill Road, Westborough, is no longer available on the real-time USGS NWS website; gauge is maintained and read by OARS.

√* indicates that site is only monitored for in-situ measurements (no water sample).

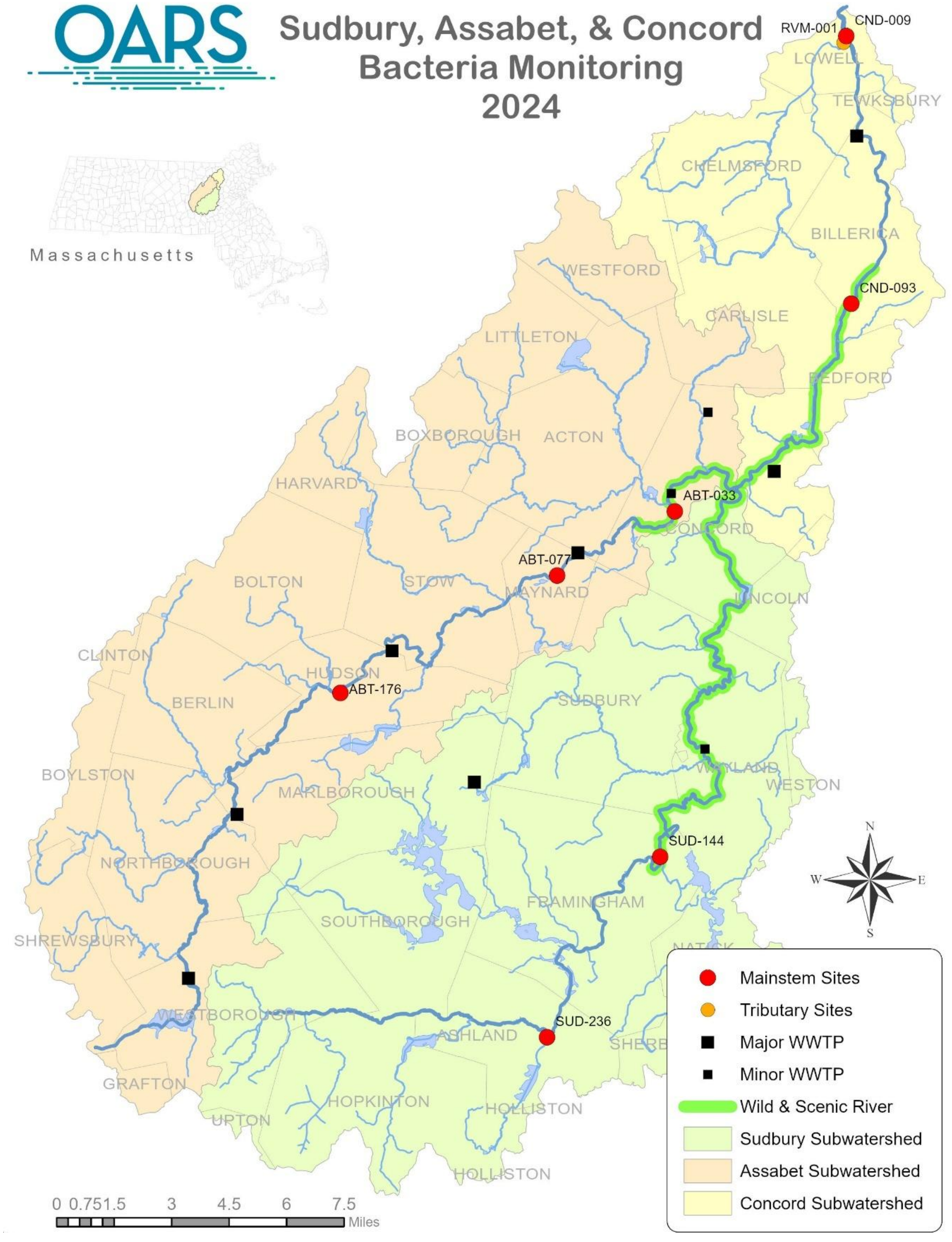


Figure 2: Bacteria Monitoring Sites 2024

Table 3: Bacteria Monitoring Sites 2024

OARS Site #	Waterbody	Description	Municipality	Lat/Lon
ABT-077	Lower Assabet River	USGS Maynard Gauge	Maynard	42° 25' 55"/ -71° 26' 59"
ABT-176	Upper Assabet River	Wheeler Road	Hudson	42° 23' 14"/ -71° 33' 39"
CND-009	Lower Concord River	Rogers Street	Lowell	42° 38' 09"/ -71° 18' 05"
CND-093	Upper Concord River	Concord River at Rt. 4	Billerica	42° 32' 09"/ -71° 17' 57"
RVM-001	River Meadow Brook	645 Lawrence St.	Lowell	42° 37' 60"/ -71° 18' 11"
SUD-144	Lower Sudbury River	Sudbury Landing	Framingham	42° 19' 32"/ -71° 23' 51"
SUD-236	Upper Sudbury River	Chestnut Street	Ashland	42° 15' 27"/ -71° 27' 18"

Water Quality Monitoring

Water Quality Sampling Methods

Trained volunteers and OARS staff monitored water quality at sites throughout the watershed (Figure 1 and Table 2). Each site was assigned a three-letter prefix for the waterbody name plus three numbers designating river miles (to one decimal) above its confluence with the next stream. Water quality monitoring was conducted one Sunday each month in March, May, June, July, August, September, and November. All sites were sampled in June, July, and August. In March, May, September, and November, only selected sites were sampled. From May to September (the growing season), monitoring was conducted between 6:00am and 9:30am to capture the diurnal low in dissolved oxygen readings. In the non-growing season, when dissolved oxygen does not vary dramatically over the day, monitoring was conducted before 12:00pm. Streamflow was either calculated from stage readings of OARS' gages using stage/discharge rating curves developed per the United States Geological Survey (USGS) standards (Rantz, 1982, Smoot, 1968) or recorded from the USGS real-time gauge websites.

Nutrient, chloride, suspended solids, and chlorophyll-*a* samples were taken using bottles supplied by state-certified laboratories under contract with OARS and were stored in the dark on ice during transport from the field to the lab. Samples were delivered to the lab within 26 hours of collection and analyzed within their respective hold-times. Chlorophyll-*a* samples were delivered to the lab within 6 hours of sampling. *In-situ* readings of temperature, dissolved oxygen, pH, and conductivity were taken using multi-function YSI Pro-series or 6-series meters. Pre- and post-calibration was done by OARS staff. To ensure that samples were representative of the bulk flow of the river, bottle samples and meter readings were taken from the main flow of the river at 6–12 inches depth by wading, using a pole, or by lowering the meter from a bridge. Duplicate field samples and distilled water field blanks were taken for 10% of the samples. Table 4 summarizes the parameters measured, laboratory methods, and equipment used. Detailed descriptions of sampling methods and quality control measures are available in the *Quality Assurance Project Plan for OARS' Water Quality and Quantity Monitoring Program* (OARS, 2022).

Table 4: Water Quality Sampling and Analysis Methods 2024

Parameter	Analysis Method #	Equipment Range/ Reporting Limits	Sampling Equipment	Laboratory
Water Temperature	---	-5–45 degrees C	YSI multi-par. sonde	---
pH	---	0–14 units	YSI multi-par. sonde	---
Dissolved oxygen	---	0–50 mg/L	YSI multi-par. sonde	---
Conductivity	---	0–10,000 µS/cm	YSI multi-par. sonde	---
Total Suspended Solids	SM 2540D	5–100 mg/L	bottle	Pace Analytical
Total Phosphorus	SM 4500-P-E	0.01–1 mg/L	bottle	Pace Analytical
Orthophosphate	SM 4500-P-E	0.005–1 mg/L	bottle	Pace Analytical
Nitrate-N	SM 4500-NO3-F	0.1–10 mg/L	bottle	Pace Analytical
Ammonia-N	SM 4500-NH3-BH	0.075–10 mg/L	bottle	Pace Analytical
Chloride	EPA 300.0	1–1000 mg/L	bottle	Pace Analytical
Chlorophyll–*a*	SM 10200-H(3)	2–100 µg/L	bottle	Pace Analytical

Bacteria Sampling Methods

Trained volunteers collected bacteria water samples at seven sites throughout the watershed (Figure 2 and Table 3). The sites were selected with the objective of evaluating recreational areas of the rivers and monitoring populated areas with suspected pollution sources. Bacteria monitoring was conducted two Mondays per month from May to September between 6:00am and 8:00am.

E. coli samples were taken using sterile bottles supplied by the state certified lab under contract with OARS and were stored in the dark on ice during transport from the field to the lab. Samples were delivered to the lab within 6 hours of collection and analyzed within 8 hours of collection. To ensure that samples were representative of the bulk flow of the river, bottle samples were taken from the main flow of the river at 6 inches depth by wading or using a pole. Duplicate field samples and field blanks of sterile water were taken for 10% of the samples. Table 5 below summarizes laboratory methods and equipment used. Detailed descriptions of sampling methods and quality control measures are available in the *Quality Assurance Project Plan for OARS' Water Quality and Quantity Monitoring Program* (OARS, 2022).

Table 5: Bacteria Sampling and Analysis Methods

Parameter	Analysis Method #	Equipment Range/ Reporting Limits	Sampling Equipment	Laboratory
E. coli	SM 9223-B (IDEXX Colilert)	1 MPN/100mL *	bottle	Nashoba Analytical

* MPN = most probable number

Water Quality Review Methods

Water quality measurements were compared with the 2021 Massachusetts Water Quality Standards (MassDEP, 2021) (Table 6). For nutrient concentrations (where the Massachusetts standard is narrative), results were compared with EPA "Gold Book" total phosphorus criteria (EPA, 1986) and with summertime data for Ecoregion XIV subregion 59 (EPA, 2000) (Table 7). All mainstem river sections are designated Class B waters, and all except for the lower Sudbury are Warm Water fisheries. The lower Sudbury has a reduced Aquatic Life designation, which applies Class C dissolved oxygen and temperature criteria. The MA Division of Fisheries and Wildlife lists 33 tributary streams in the basin as Coldwater Fish Resources (CFRs) (MassDFW, 2017). See Appendix V. for water quality designations by river segment and the list of cold-water tributaries.

Table 6: MassDEP Class B Water Quality Standards and Guidance (MassDEP, 2021)

Parameter	Standard / Guidance Class B	Standard / Guidance Class B "Aquatic Life"
Dissolved oxygen	≥ 5.0 mg/l for warm water fisheries ≥ 6.0 mg/l for cold water fisheries	≥ 5.0 mg/l 16 hours of any 24-hour period and ≥ 3.0 mg/l at any time
Temperature	M7DM* <28.3°C and Δ < 2.8°C for warm water fisheries M7DM* <20.0°C and Δ < 1.7°C for cold water fisheries	≤29.4 °C and Δ ≤ 2.8°C
pH	6.5–8.3 and < 0.5 outside the natural background range	
Nutrients	"control cultural eutrophication" / Gold Book** standard TP < 0.05 mg/l for rivers entering a lake or impounded section	
Suspended Solids	"free from floating, suspended and settleable solids in concentrations and combinations that would impair any use assigned to this class"	
Aesthetics	All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.	
E. coli	Primary Contact: Geometric Mean < 126 CFU/100ml and 90% of samples < 410 CFU/100ml Secondary Contact: Geometric Mean < 630 CFU/100ml and 90% of samples < 1260 CFU/100ml	
Chloride	EPA Recommended Criteria*** < 230 mg/L chronic exposure, < 860 mg/L acute exposure.	

* M7DM – Mean of 7-day daily maximum
** EPA, 1986, Gold Book.
*** EPA, 2002, National Recommended Water Quality Criteria.

Table 7: Reference Conditions for Ecoregion XIV (subregion 59) Streams (EPA, 2000)

Nutrient Parameter	25th percentile of summer data	50th percentile of summer data
Total Phosphorus	0.025 mg/L	0.050 mg/L
Orthophosphate	0.010 mg/L	0.025 mg/L
Total Nitrogen	0.44 mg/L	0.74 mg/L
$NO_2 + NO_3$ (as N)	0.34 mg/L	0.43 mg/L
Chlorophyll *a* (Spec A method)	2.00 μg/L *	4.00 μg/L *

* Chlorophyll-*a* data is available only for subregion 63

Long-term Trend Analysis

Summer (June/July/August) trends have been analyzed for most parameters from 1992 to the present (where available). Over the years, the list of actual sites has evolved significantly, so it is important to understand which sites have been added or discontinued over the trend time-period. Sites that are less than 0.1 river miles apart and where there are no significant river changes (e.g., tributaries joining) were considered the same (e.g., ABT-311/ABT-312). Table 8 lists the long-term sites used and their sections.

Table 8: Sites for Trend Analysis

Sections	Sites	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Assbt. Head	ABT-311/ABT-312	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Upper Assabet	ABT-301	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ABT-280					X	X	X	X	X	X	X	X	X	X	X	X	X	X															
	ABT-263/ABT-262								X	X	X																							
	ABT-253/ABT-252								X	X	X																							
	ABT-242	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
	ABT-238/ABT-237	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ABT-220								X	X	X																							
	ABT-196					X	X	X	X	X	X																							
	ABT-182								X	X	X																							
	ABT-159									X	X																							
	ABT-144*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lower Assabet	ABT-077	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ABT-065	X	X	X	X	X	X	X	X																									
	ABT-063/ABT-062								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ABT-047								X	X																								
	ABT-044									X	X																							
	ABT-033	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
	ABT-026	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ABT-010								X	X	X	X	X	X	X	X	X	X	X	X	X	X												
Concord	CND-009													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	CND-036																														X	X	X	X
	CND-045																	X	X	X	X	X	X	X	X	X	X	X	X	X				
	CND-093													X	X	X	X																	
	CND-110																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	CND-161													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Lower Sudbury	SUD-005																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	SUD-064																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	SUD-086																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	SUD-096																					X	X	X	X	X	X	X	X	X	X	X	X	X
	SUD-098																		X	X	X	X												
	SUD-144																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Upper Sudbury	SUD-236																														X	X	X	X
	SUD-293																														X	X	X	X
Hop Brook (Sudbury)	HBS-016																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	HBS-098																														X	X	X	X
Nashoba Brook	NSH-047																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NSH-002											X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
River Meadow Brook	RVM-005													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	RVM-038													X	X	X	X	X	X															
Other Tributary Streams	HOP-011											X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NTH-009											X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
	DAN-013											X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ELZ-004											X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	CLD-030											X	X	X	X	X	X	X	X															
	FTM-012											X	X	X	X	X	X																	
	SPN-003											X	X	X	X	X	X																	

* ABT-144 was moved from above to below the Gleasondale dam in 2000.

River Reaches and Tributaries

For data analysis, the water monitoring sites are divided into sections: (1) Upper Assabet mainstem, (2) Lower Assabet mainstem, (3) Upper Sudbury mainstem, (4) Lower Sudbury mainstem, and (5) Concord mainstem. Tributary sites are analyzed individually. Table 9 lists tributary and mainstem basin characteristics calculated using the USGS's StreamStats program.

Table 9: StreamStats Drainage Basin Statistics

	Statistics at Mouth of River or Tributary[a]				
Mainstem Rivers Headwaters Tributary Streams	Latitude/Longitude at Mouth	Drainage Area (sq.mi.)	Stratified Drift Area (sq.mi.)	% area stratified drift	Slope [b] (%)
Assabet River	42.4652/-71.3596	177.81	73.00	41.1	3.01
Assabet @ Maynard St, Westboro	42.2741/-71.6322	7.16	1.72	24.0	3.67
Hop Brook (Northborough)	42.2887/-71.6449	7.87	2.09	26.6	3.57
Cold Harbor Brook	42.3238/-71.6413	6.86	1.97	28.7	5.01
North Brook	42.3576/-71.6188	16.89	4.12	24.4	4.38
Danforth Brook	42.3897/-71.5666	7.17	2.06	28.7	3.58
Fort Meadow Brook	42.3975/-71.5169	6.25	1.76	28.2	3.77
Elizabeth Brook	42.4217/-71.4776	19.09	6.93	36.3	3.73
Nashoba Brook	42.4592/-71.3942	48.05	19.05	39.7	2.29
Sudbury River	42.4637/-71.3578	162	49.13	30.3	2.52
Sudbury @ Cedar St, Hopkinton	42.2649/-71.5364	20.8	8.51	40.9	3.22
Hop Brook (Sudbury)	42.3627/-71.3733	22.0	14.5	65.9	2.44
Concord River	42.6351/-71.3015	400.0	197.97	49.5	2.63
River Meadow Brook	42.6318/-71.3087	26.32	16.18	61.5	1.91

[a] Calculated using USGS's StreamStats program (**streamstats.usgs.gov/ss/**)
[b] Slope is the mean basin slope calculated from the slope of each grid cell in the designated basin (1:250K DEM).

Precipitation and Streamflow

Precipitation

The precipitation signature in 2024 was dramatically different than the previous year (Figure 3[2]). The previous year 2023 was characterized by average precipitation prior to July and then extreme precipitation for the remainder of the year. The year 2024 was exactly the opposite, beginning with significant precipitation prior to July and rounding out the rest of the year with drought-like conditions. In fact, the last five summers are noteworthy in the way they have alternated from very low precipitation to very high precipitation every year (Figure 4). According to the U.S. Drought Monitor[3], the SuAsCo watershed experienced a "D3" extreme drought in the final months of the year as a result of the lack of precipitation after August (Figure 5). According to the Massachusetts Water Resources Commission, at the end of September 2024, the 3-month Standardized Precipitation Index for Northeast MA was 18%, as opposed to 98% in 2023 (MassDCR, 2024).

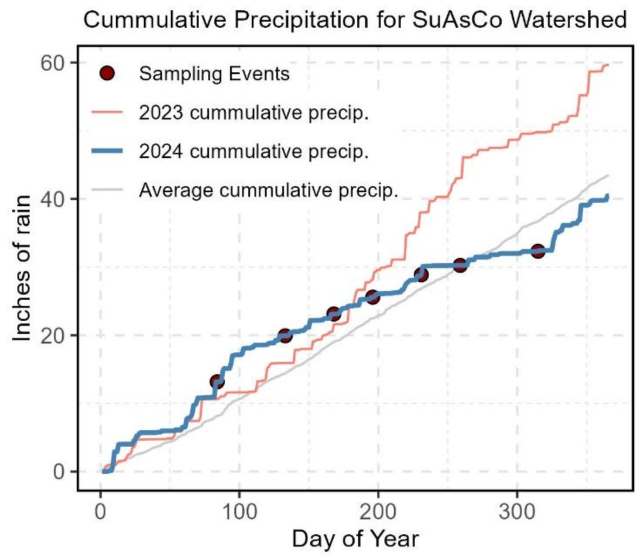


Figure 3: Cumulative precipitation by year[2]

Precipitation plays a significant role in water quality conditions. Precipitation, and the associated increase in stormwater runoff and streamflow tend to be positively correlated in our data with concentrations of total suspended solids and total phosphorus and negatively correlated with nitrate. Samples collected on a rising hydrograph may include "first flush" runoff and the higher load of pollutants associated with the first flush. Sampling events in March and August were both conducted on a rising hydrograph (Figure 6). Sampling events in September and November were particularly impacted by the lack of precipitation and low streamflows. Low streamflows can often result in higher concentrations of contaminants due to the lack of dilution from precipitation.

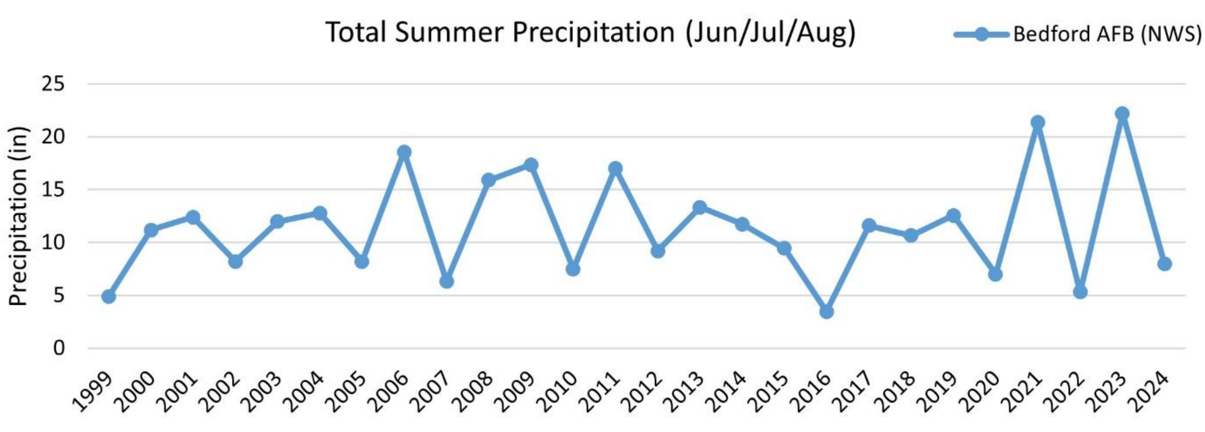


Figure 4: Annual summer precipitation (1999–2024)

[2] Daily rainfall sourced from NWS Bedford Hanscom airfield. **weather.gov/wrh/climate?wfo=box**
[3] **droughtmonitor.unl.edu**

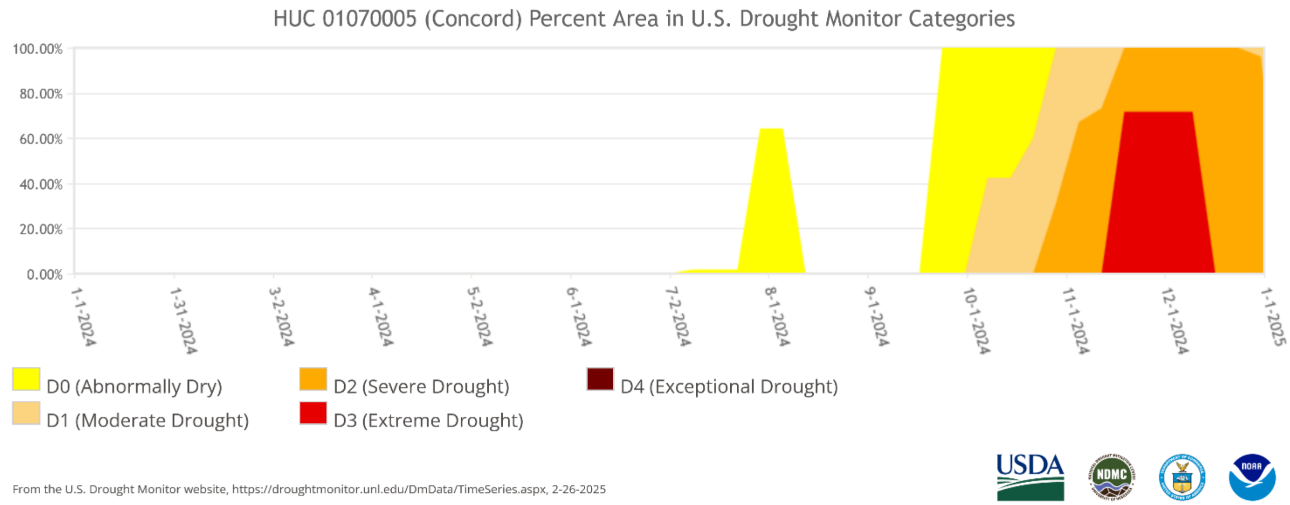


Figure 5: U.S. Drought Monitor status[4] for Concord watershed (HUC 8) 2024

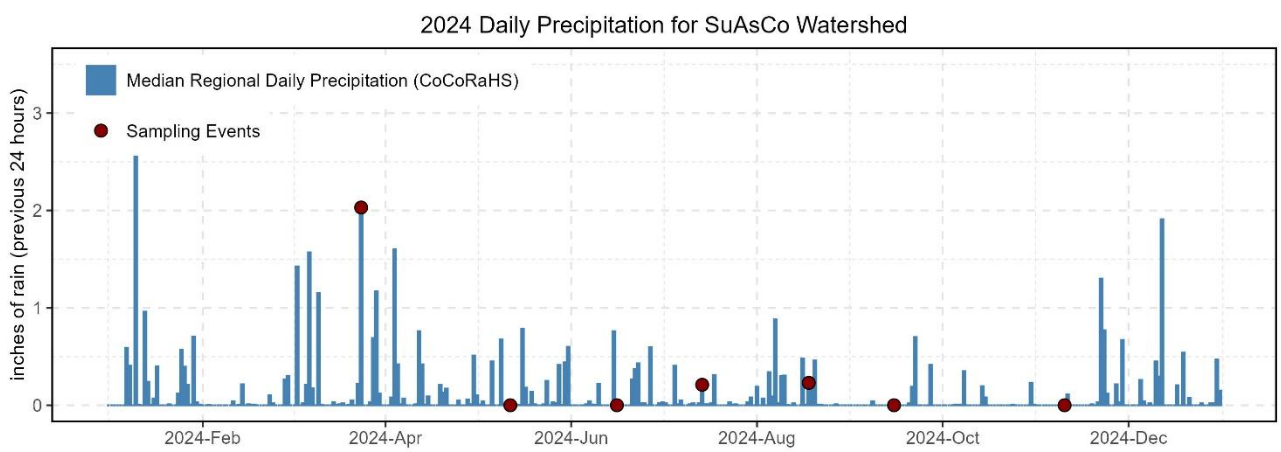


Figure 6: Daily rainfall[5] with sampling dates 2024

[4] Graph from **droughtmonitor.unl.edu/DmData/TimeSeries.aspx**.
[5] Daily rainfall sourced from CoCoRaHS, for box bounded by 42.22852/-71.70227 and 42.51766/-71.31912. **cocorahs.org/ViewData/**

Streamflow

Streamflow in summer 2024 was slightly lower than average, though significantly lower than 2023. Figure 7 shows year-on-year average summer streamflow for the Assabet and Sudbury since 1980. The drought conditions started toward the end of August, so streamflow did not reach very low levels until September. Figure 8 shows mean daily streamflow for 2024 at the Assabet, Sudbury, and Concord river gages compared with the historic mean streamflow for the period of record. Flows were very low for the September and November sampling events. Note that flow at the Sudbury River gauge in Saxonville/Framingham is sometimes affected by reservoir dam manipulations upstream.

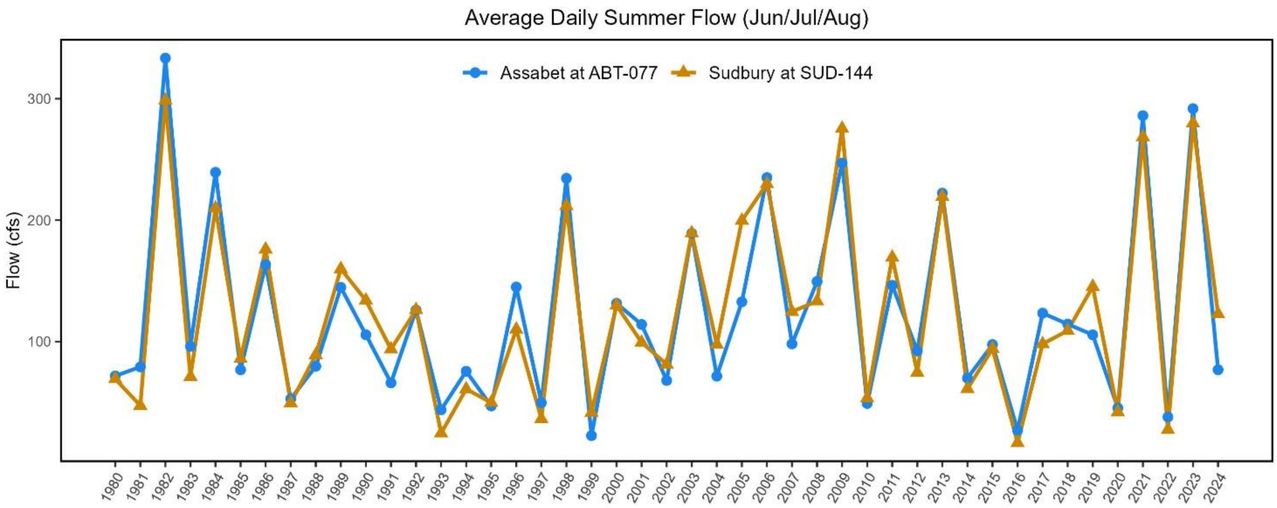


Figure 7: Average summer streamflow[6] (June/July/August)

[6] Flow data sourced from USGS gages in Maynard and Saxonville.

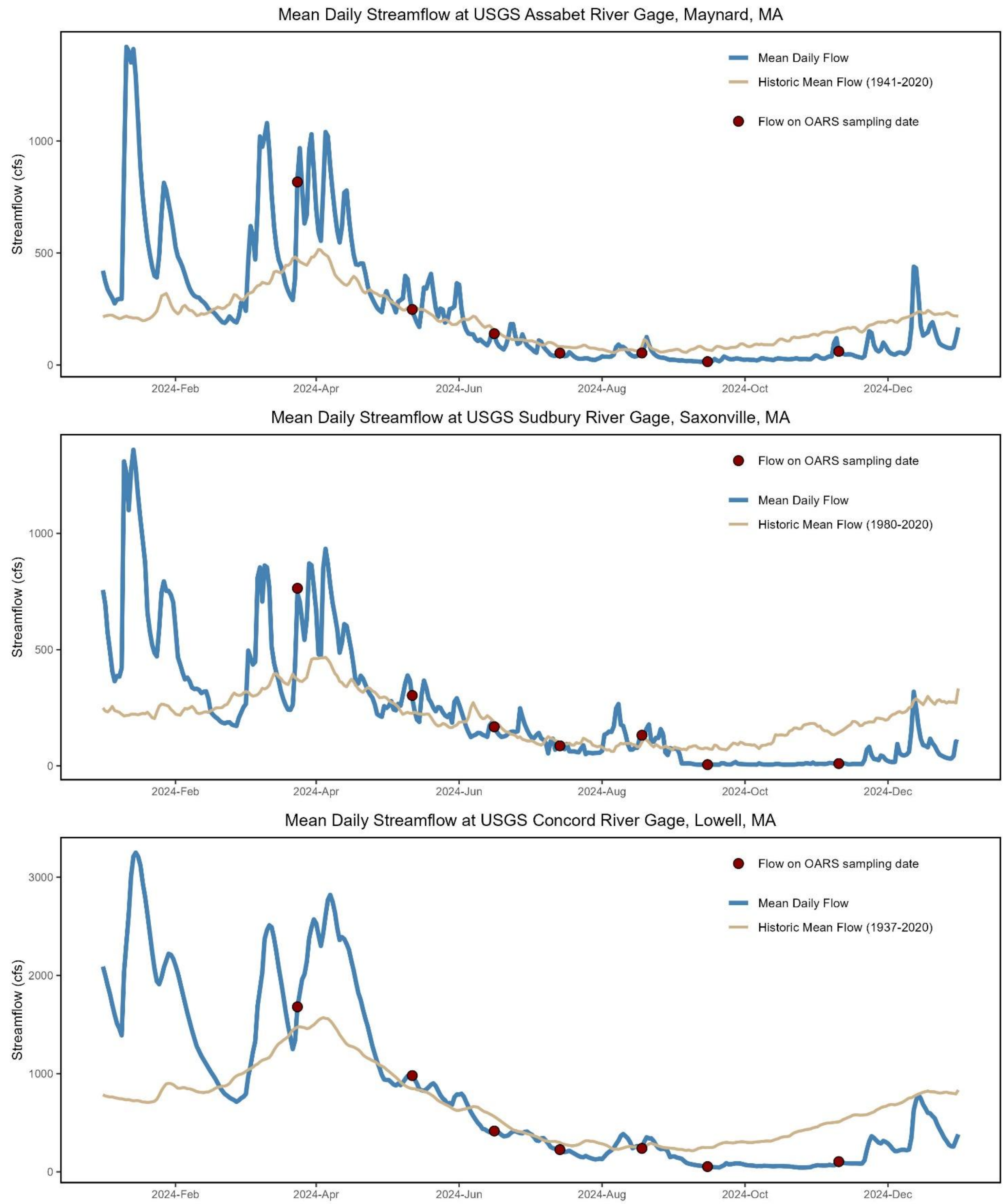


Figure 8: Mean Daily Streamflow by river (2024)

Groundwater

Figure 9 shows 2024 groundwater levels from the USGS monitoring well in Acton[7] compared with historic mean levels. Changes in groundwater level reflect the combination of precipitation and evapotranspiration rates and, in turn, affect baseflow to the streams. Groundwater level fell dramatically in the second half of 2024 as rainfall declined. Due to the timing of the drought in the fall, extremely low groundwater levels have persisted through the winter into March 2025.

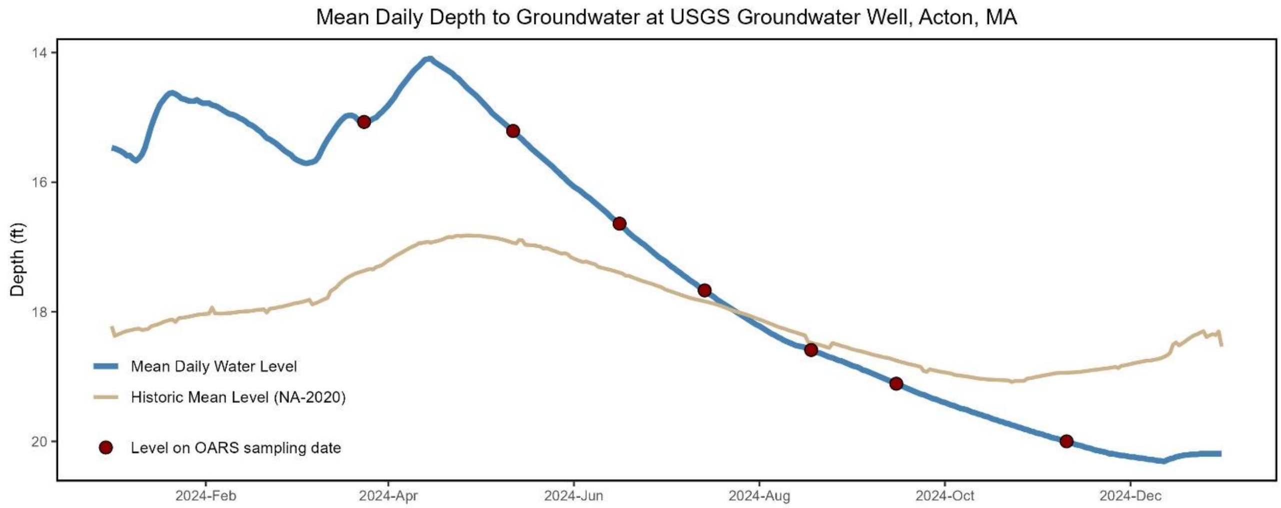


Figure 9: Groundwater Levels (2024, USGS Monitoring Well, Acton, MA)

Wastewater Treatment Plant Discharge

There are eight wastewater treatment plants discharging significant volumes of water into the three rivers (Figure 10). Many of the plants discharge into the upstream most vulnerable sections of the rivers. The largest plant, Westborough, discharges very close to the headwaters of the Assabet River. The third largest plant, Marlborough Easterly, discharges to the headwaters of Hop Brook. Note that wastewater treatment plant discharge correlates with precipitation and groundwater levels due to infiltration by groundwater into the wastewater system.

During low flow times, the discharge of these treatment plants can represent a significant portion of the total flow of the rivers. This is particularly true for the Assabet River. Streamflow measured at the Assabet River gauge in Maynard includes effluent discharges from three of the four municipal wastewater treatment plants on the river (Hudson, Marlborough Westerly, and Westborough). The three treatment plants discharged a combined average of 9.4 cfs to the river from July through September of 2024 (EPA, 2025). This compares with the average flow for this period at the Assabet River gauge of 41 cfs and the minimum flow of 14 cfs. In September 2024, treatment plant discharge constituted almost 62% of the lowest September flow.

[7] USGS 422812071244401 MA-ACW 158 ACTON, MA, **waterdata.usgs.gov/monitoring-location/422812071244401**

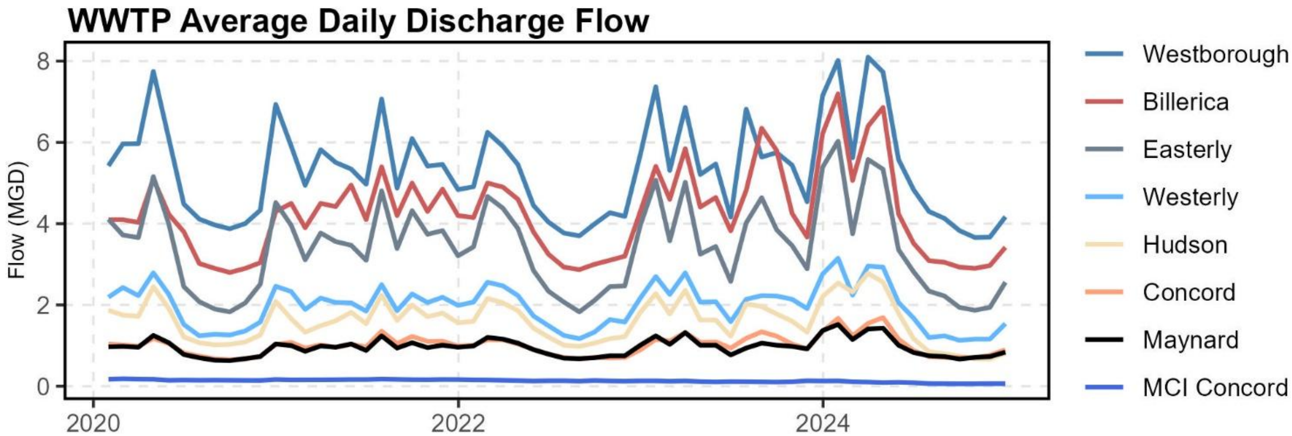


Figure 10: WWTP Discharge Flow (2020–2024)

Water Quality Results

Mainstem statistics for all water quality parameters are provided in tabular form in Appendix I. Raw data are available in Appendix III. Individual parameters are discussed here, with separate discussions by parameter. For each parameter, similar data views are provided: by-site detail for 2024, by-month detail for 2024, year-on-year results for the full monitoring history, and year-on-year load calculations where relevant. Load is the total amount (mass) of a nutrient or pollutant that is carried downstream per day. Since load is based on flow, it naturally incorporates flow. Our load calculations are based on a combination of measured flow at sites with gages and distance-based flow estimates at the sites without gages. Maps and additional graphs are also provided where relevant.

Many of the graphs are boxplot-type graphs because they give a good understanding of the range of the results. In a boxplot graph, the box represents the middle 50% of the data (1^{st} quartile to 3^{rd} quartile, or 25^{th} to 75^{th} percentile), the line in the middle of the box is the median, the lower whisker represents the bottom 25% of the data, and the upper whisker represents the upper 25% of the data. Some of the boxplots show outliers as individual points. Outliers are any points above or below the box by more than 1.5 times the interquartile range. The interquartile range is defined as the range between the 1^{st} quartile and the 3^{rd} quartile (bottom to top of the box).

Water Temperature

Water temperatures at all sites met the Class B warm water fisheries standard (28.3°C) on all the regular testing dates in 2024 (Figure 11 and Figure 12). Temperatures in the Concord, lower Nashoba Brook (NSH-002), and upper Assabet (ABT-312) exceeded the historic 90-percentile range in June and July. The lower Nashoba and upper Assabet sites are both located downstream of large impoundments, which have a warming effect. All tributaries exceeded the cold-water fisheries standard in July (20.0°C). The cold-water standard is the recommended maximum for brook trout (for brown trout, the maximum is 23.9°C). The by-site graph shows how river temperatures tend to increase downstream. In the Assabet, this is confounded by the wastewater treatment plants. The Westborough wastewater treatment plant actually cools the Assabet at ABT-301. The temperature drop at ABT-026 could be due to the influence of Nashoba Brook and the Concord CBI wastewater treatment plant, though this needs to be confirmed.

In year-on-year comparisons of summer temperature data, it is hard to identify trends in temperature, though the Concord River does have an upward trend since 2004 (Figure 13). This could be confounded by the fact that OARS switched to measuring temperature with multi-parameter sondes in 1997. An analysis of maximum temperatures in the Lower Assabet from 1997 shows a much different picture with a visible upward trend in maximum temperatures (Figure 14). The uppermost site in the Assabet (ABT-312) also shows an upward trend in temperatures for the period of record (Figure 15). Air temperature data from the Bedford Hanscom airfield explain why stream temperatures are increasing, showing a nearly three-degree increase in the trend line of average summer air temperature since 1999 (Figure 16).

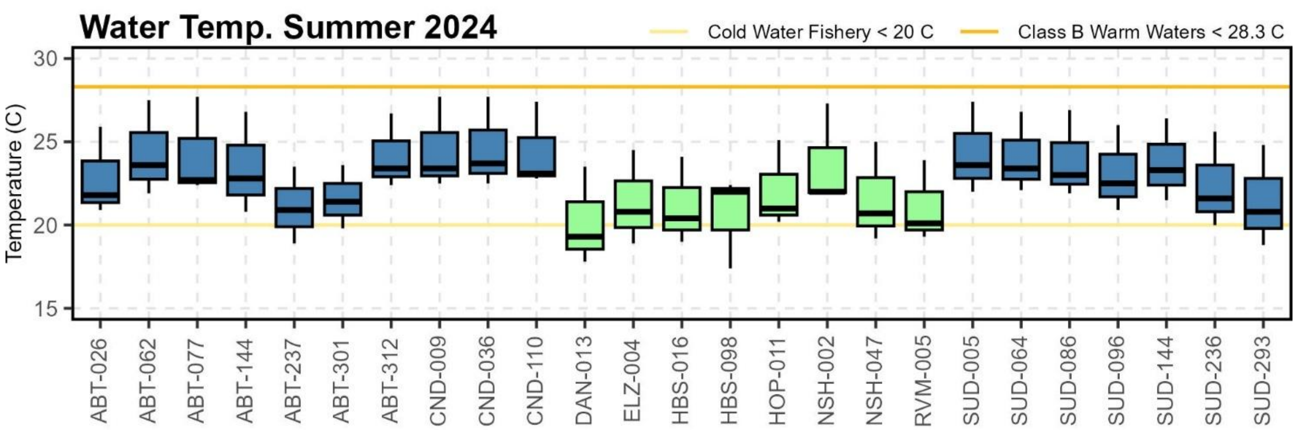


Figure 11: Water temperature by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

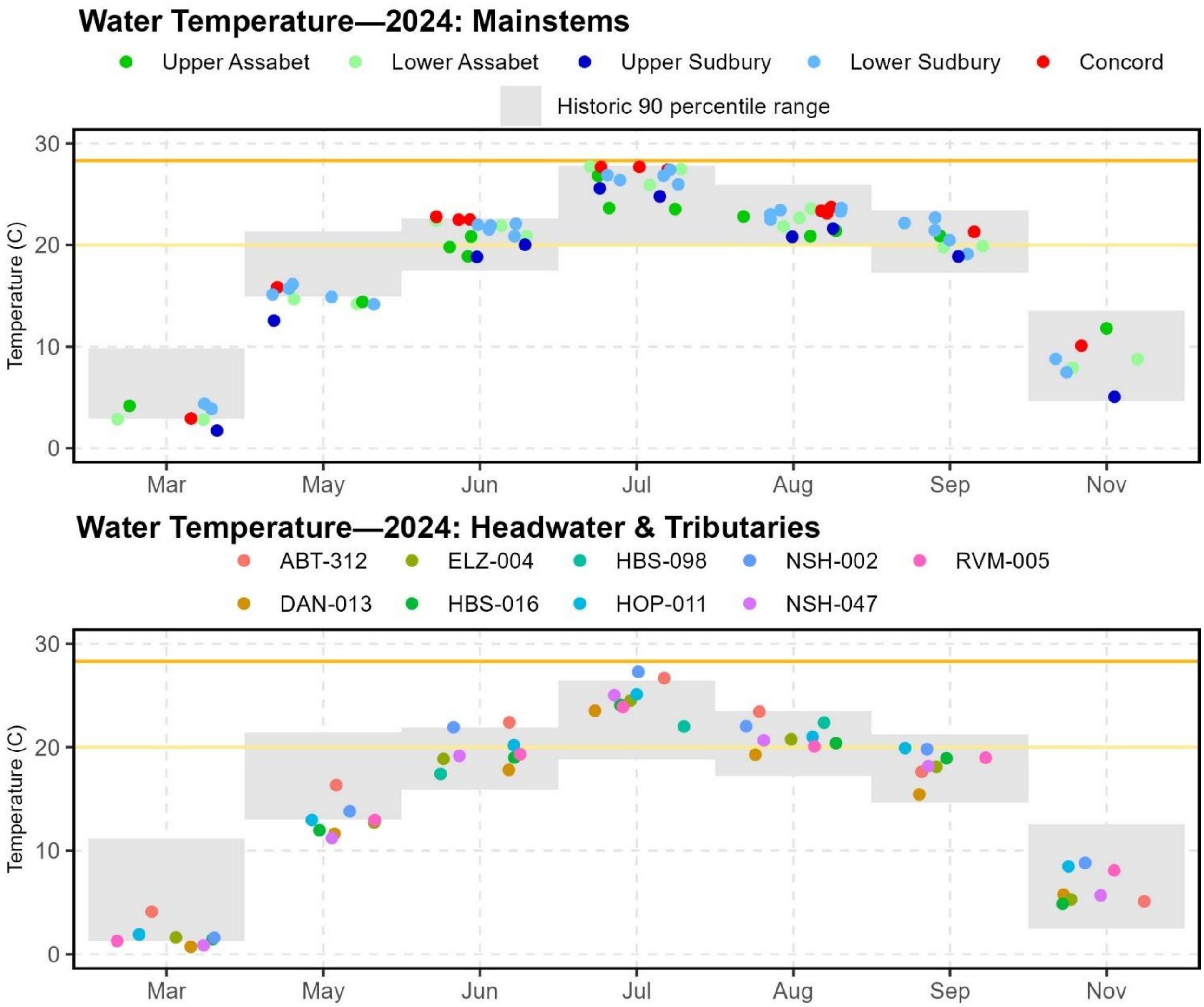


Figure 12: Water temperature by month and site (2024)

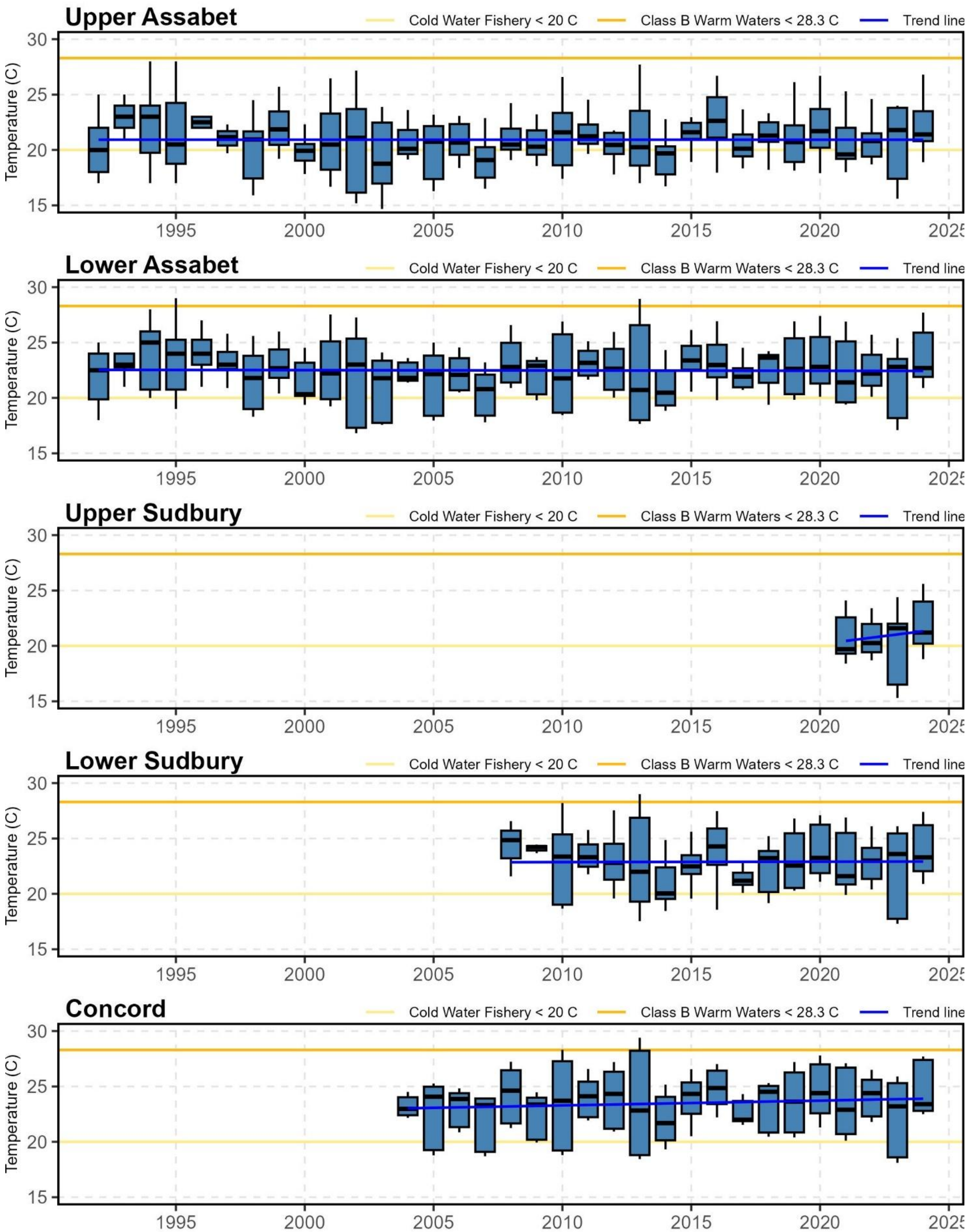


Figure 13: Water temperature by year and section (June/July/August)

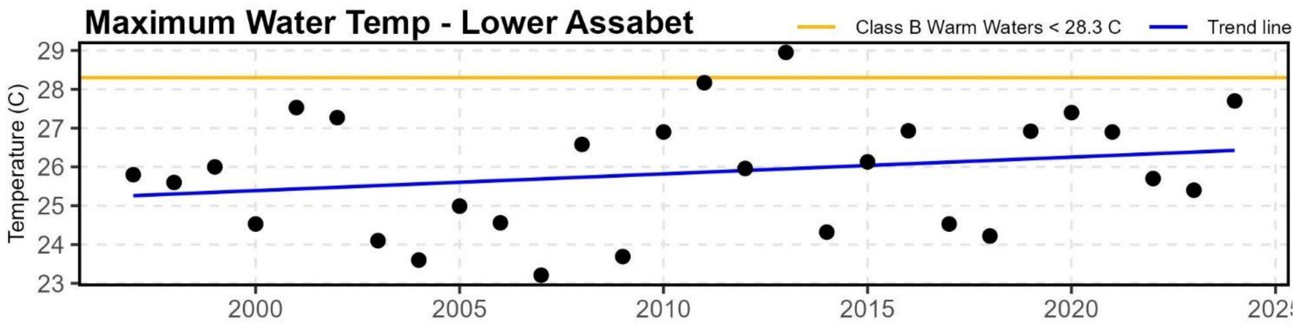


Figure 14: Maximum yearly water temperature—Lower Assabet

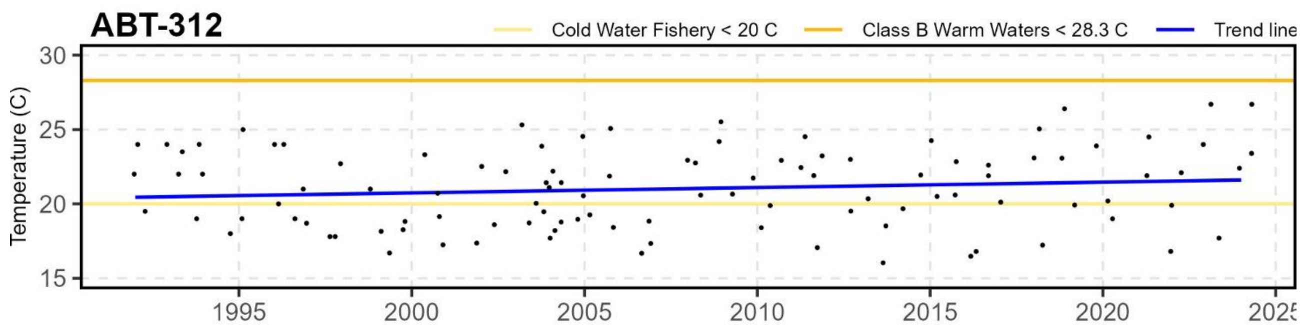


Figure 15: Water temperature trends for selected sites (June/July/August)

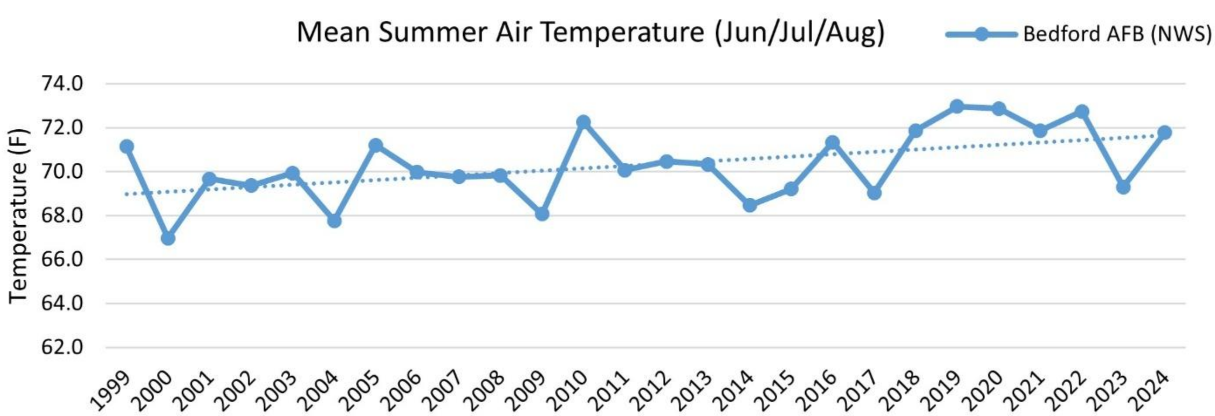


Figure 16: Summer air temperature by year

Conductivity

Conductivity is an indirect indicator of pollutants such as effluent, non-point source runoff (especially road salt), and erosion. A survey of field studies indicated that healthy streams supporting good mixed fisheries have a range between 150 and 500 µS/cm (Ellis, 1944).

Most OARS mainstem sites have been above that range in recent years. In 2024, conductivity was generally lower than would be expected for a dry-weather year. In the last few years, we have seen a pattern of high conductivity in dry years (low dilution) and low conductivity in wet years (high dilution). This year's low levels may be explained by the heavy rainfall and high flows in the first half of 2024, when most road salt would have been carried downstream. The Sudbury and Concord sites were all consistently below 500 µS/cm in 2024, but the Assabet sites were still well above 500 µS/cm due to wastewater treatment plant effluent (Figure 17). Monthly analysis usually shows conductivity increasing later in the summer as flows decrease and salts become more concentrated (Figure 18). This was the case in 2024, especially for the Upper Assabet (below Westborough WWTP) and RVM-005 on River Meadow Brook (downstream of the Lowell highway interchanges). Our monitoring usually highlights high conductivity levels downstream of the WWTPs (ABT-301, ABT-237, ABT-144, HBS-098) and downstream of highways (RVM-005, HOP-011). Two of the headwater and tributary sites (ABT-312 and DAN-013) are consistently within the mixed fishery range. OARS has conducted surveys of other tributaries and shown that conductivity hot spots can be very localized (jumping from 400 to 1400 µS/cm in short distances of the same brook) driven by road and parking-lot runoff.

Year-on-year conductivity analysis shows a clear upward trend for all river sections (Figure 19). The same trend is also evident for sites below the Westborough WWTP (ABT-301) and downstream of major highways (RVM-005, HOP-011) (Figure 20). The years 2021 and 2023 were deviations from the trend due to significantly higher precipitation and flow in those two years, and this had a carryover effect on 2024 due to high early summer flow. The increasing conductivity trend is being noticed throughout New England, and it is believed to be a direct result of road-salt application and its accumulation in groundwater and soils (Daley, 2009; Zuidema, 2018; Evans, 2018). See the section below on chloride for additional discussion about salt pollution.

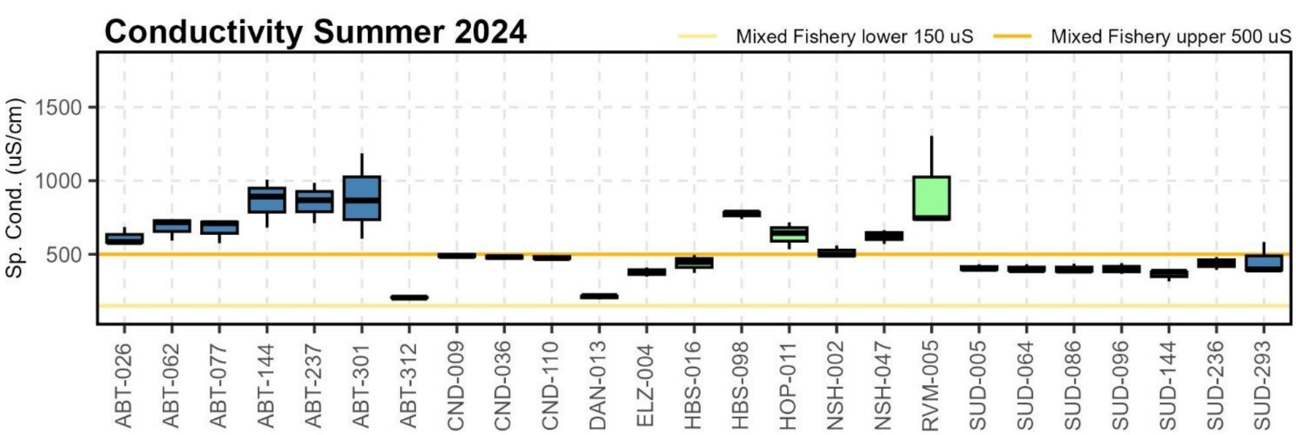


Figure 17: Specific conductance by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

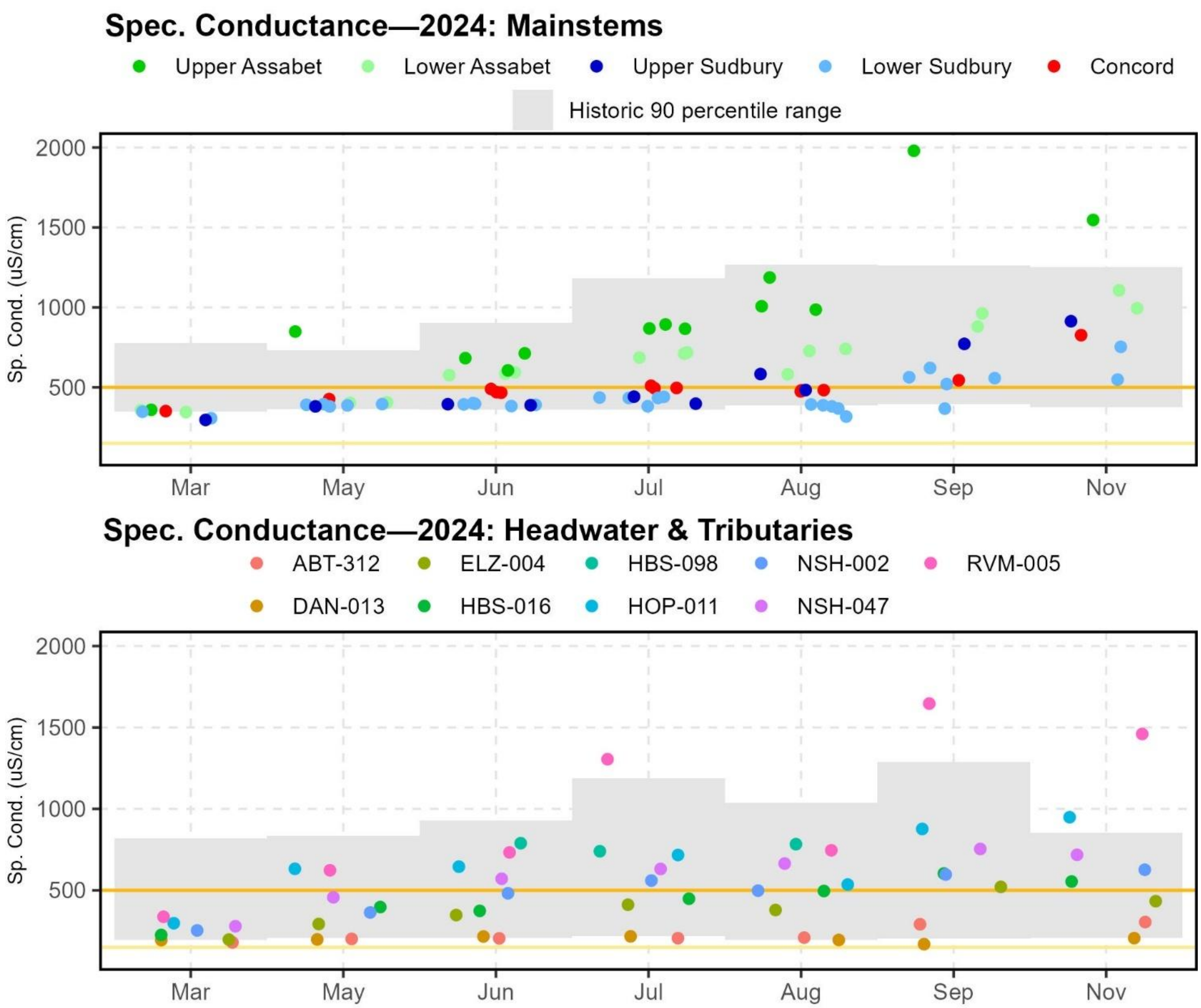


Figure 18: Specific conductance by month and site (2024)

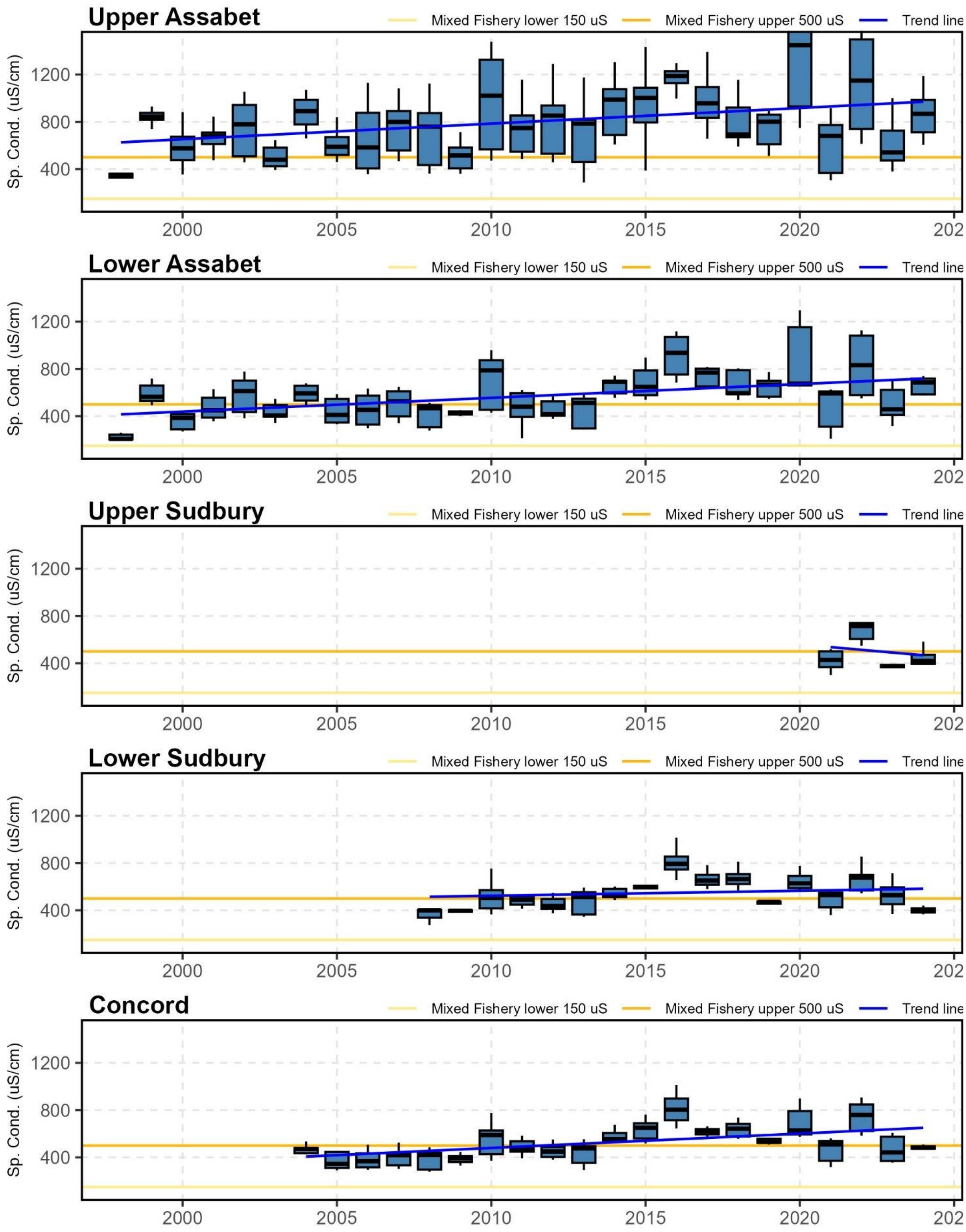


Figure 19: Specific conductance by year and section (June/July/August)

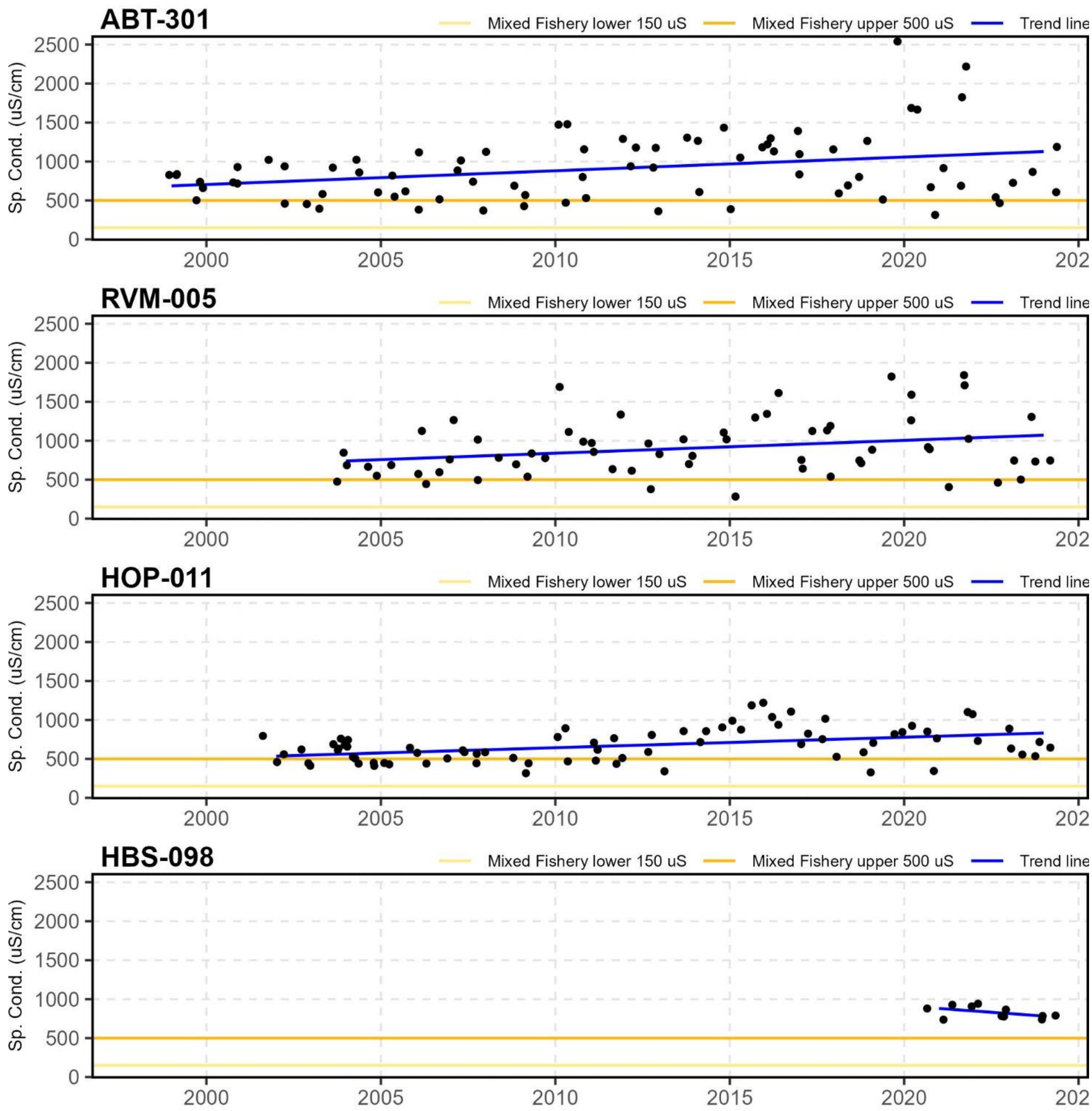


Figure 20: Specific conductance trends for selected sites (June/July/August)

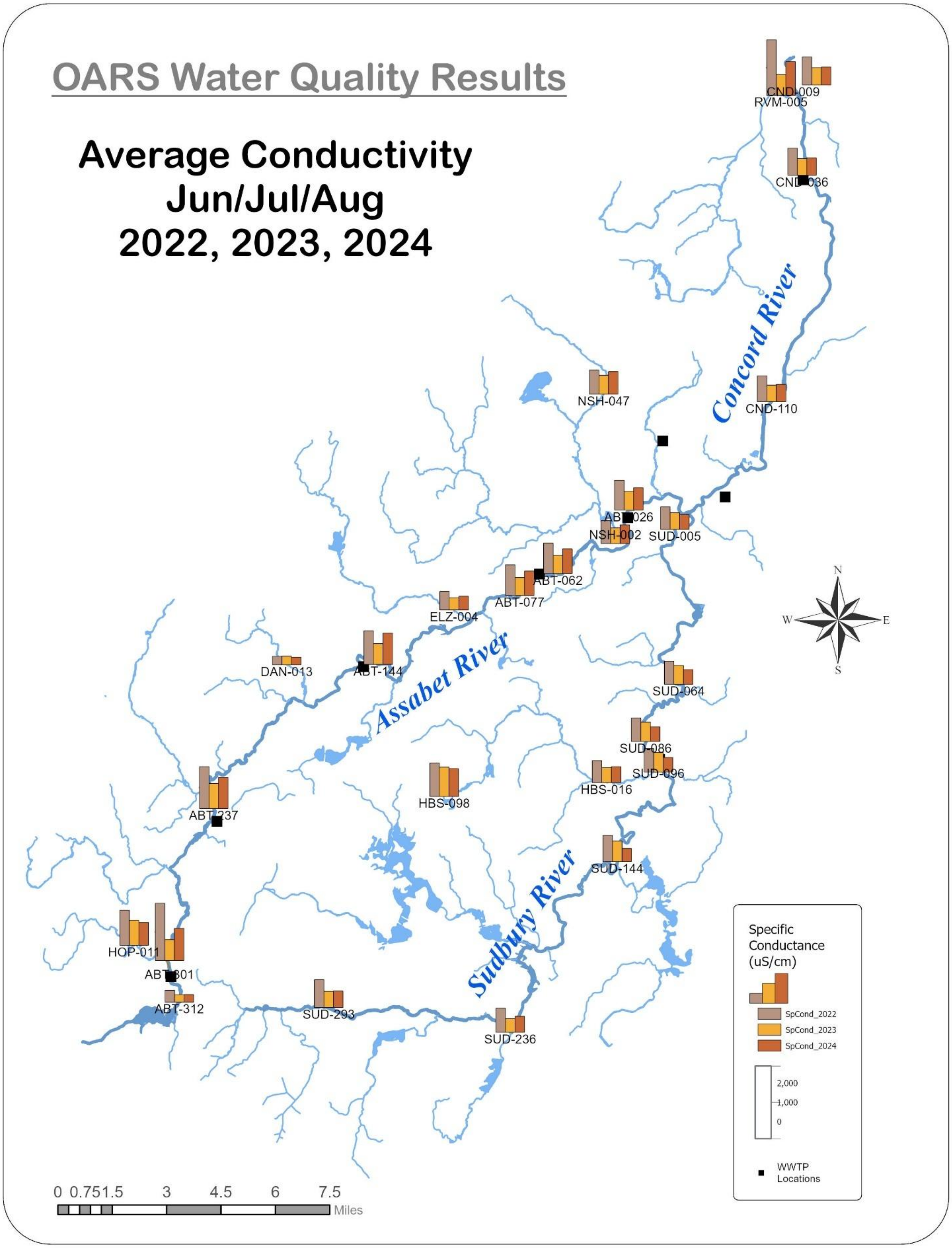


Figure 21: Map of average summer conductivity by site (2022–2024)

Chloride

Chloride is a component of road salt. We started sampling for chloride in 2018 to measure the effect of road salt application on the rivers. The EPA has established a Continuous Concentration Criterion for chloride of 230 mg/L and a short-term Maximum Concentration Criterion of 860 mg/L (EPA, 2002). The EPA's criteria were based on fish tolerances, but recent research has indicated that macroinvertebrate tolerances may be much lower (Moody, 2025). In the New England region, chloride is highly correlated with conductivity because road salt is the dominant source of dissolved ions in the region's fresh water. Figure 22 shows all of OARS' chloride measurements since 2018 compared with conductivity measurements taken at the same time. Our linear regression on the 2018–2020 data has an R^2 value of 0.96 and it lines up very closely with similar regressions conducted by other agencies in our region (Heath, 2011; MassDEP, 2018). This strong correlation allows us to confidently make conclusions about chloride based on easily collectable conductivity measurements. Hence, we tend to focus on conductivity and do not have to sample for chloride separately. The year-on-year summer conductivity graphs above show a clear upward trend in conductivity/chloride for all our rivers (Figure 19). This is a very concerning trend, especially since the estimated chloride for many of these sites is approaching or exceeding the EPA chloride continuous criterion.

In September 2023, we started analyzing for chloride at the site downstream of the Westborough WWTP (ABT-301) because we have noticed very high conductivity there, and MassDEP requires direct chloride results to classify waters downstream of WWTPs as impaired. The results are shown in red in Figure 22. We see the same high degree of correlation with conductivity in the WWTP effluent-dominated waters, though the chloride values tend to be slightly lower than our overall regression line. At this site, 40% of the samples exceeded the continuous criterion limit. In 2025, we will also be sampling for chloride downstream of the Marlborough Easterly WWTP.

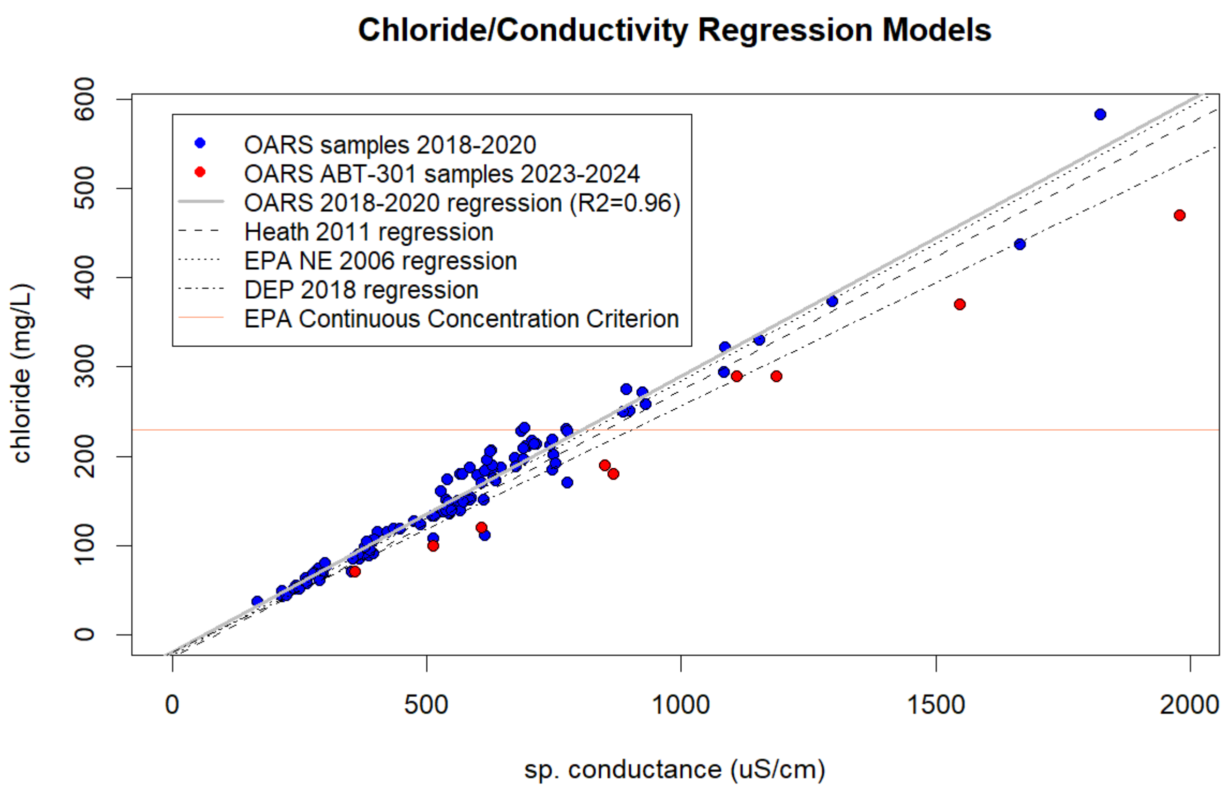


Figure 22: Chloride vs. conductivity, with ABT-301 sample results

Dissolved Oxygen

Dissolved oxygen (DO) concentrations during the growing season are generally lowest between 5am and 8am, after plant and microbial respiration have removed oxygen from the water column overnight. This is the time period we target for sampling. Low minimum DO concentrations and large diurnal variations in DO can indicate eutrophic conditions and violate water quality standards for DO.

In our rivers, DO at the Assabet and Concord river sites is consistently above the minimum water quality standards, but DO at the Lower Sudbury sites tends to hover near or below the Class B standard (>5.0 mg/L) (Figure 23 and Figure 24). The Lower Sudbury is surrounded by large wetland areas, and wetlands naturally have low DO levels due to still water and high respiration. Even though the Lower Sudbury sites were close to this threshold, DO at these sites was significantly higher than in 2023. We have seen a pattern of very low DO during high flow years when the marshlands are flooded and 2023 fit this pattern markedly. The Hop Brook site (HBS-016) consistently has the lowest DO levels due to the combination of wetlands and high nutrient loads coming from upstream. As discussed in the pH section below, low DO levels can coincide with low pH in eutrophic conditions. This was especially evident in 2024 for HBS-016 and the Sudbury headwaters (SUD-293). They both had very low DO and pH levels. The low DO levels in September and November in Danforth Brook (DAN-013) are typical for very low flows at that site.

Year-on-year analysis of dissolved oxygen shows several interesting trends. DO levels in the Assabet River have improved significantly over the period of record (Figure 25). This is especially evident in the improvement from 1999 to 2000, when all four wastewater plants implemented treatment to reduce summer phosphorus discharge concentrations below 1 mg/L. In the Lower Sudbury River, we have been watching a concerning downward trend in DO levels, but levels have rebounded in two of the last three years (2022 and 2024). It is possible that the preceding high flood years washed out accumulated organic detritus, thus reducing biological oxygen demand in the following years. The individual sites we are watching are shown in Figure 26. The Hop Brook site (HBS-016) continues to show a distinct improvement in DO since 2015, the same year upgrades were completed at the upstream Marlborough Easterly WWTP. The Nashoba Brook site (NSH-002) seems to be showing a gradual decline in DO. This site is downstream of Warner's Pond in Concord, which is now in a critical state with excessive aquatic biomass. The town is evaluating what to do to reduce the biomass.

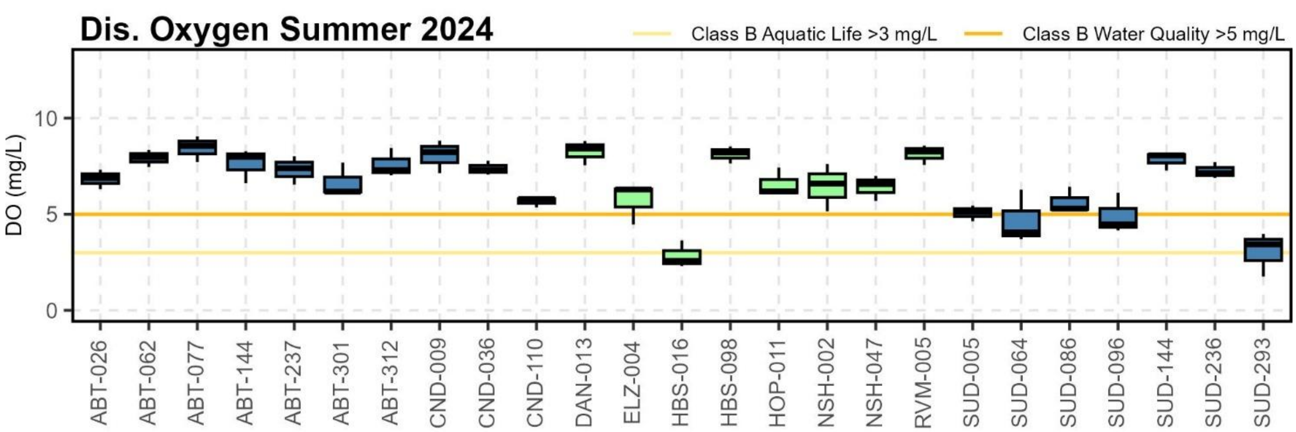
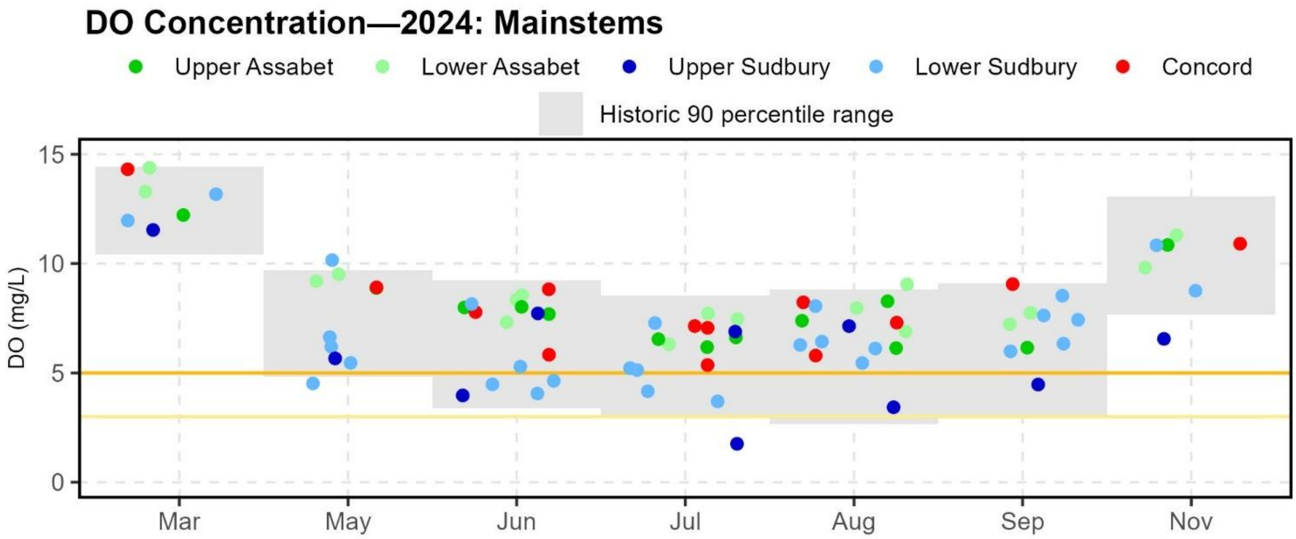


Figure 23: Dissolved Oxygen concentration by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.



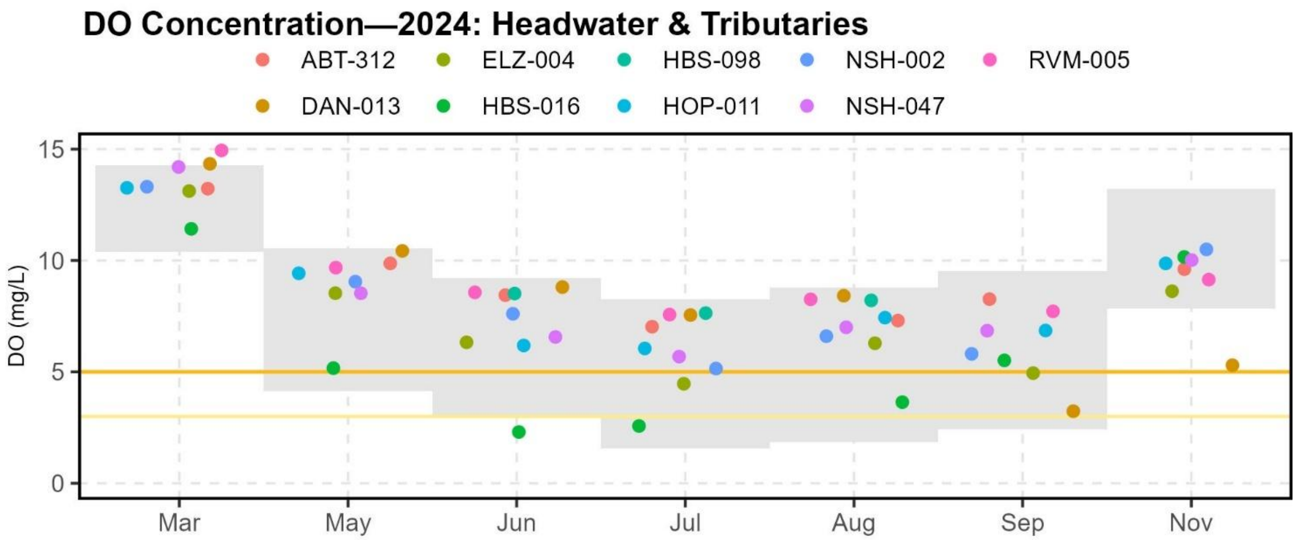


Figure 24: Dissolved Oxygen by month and site (2024)

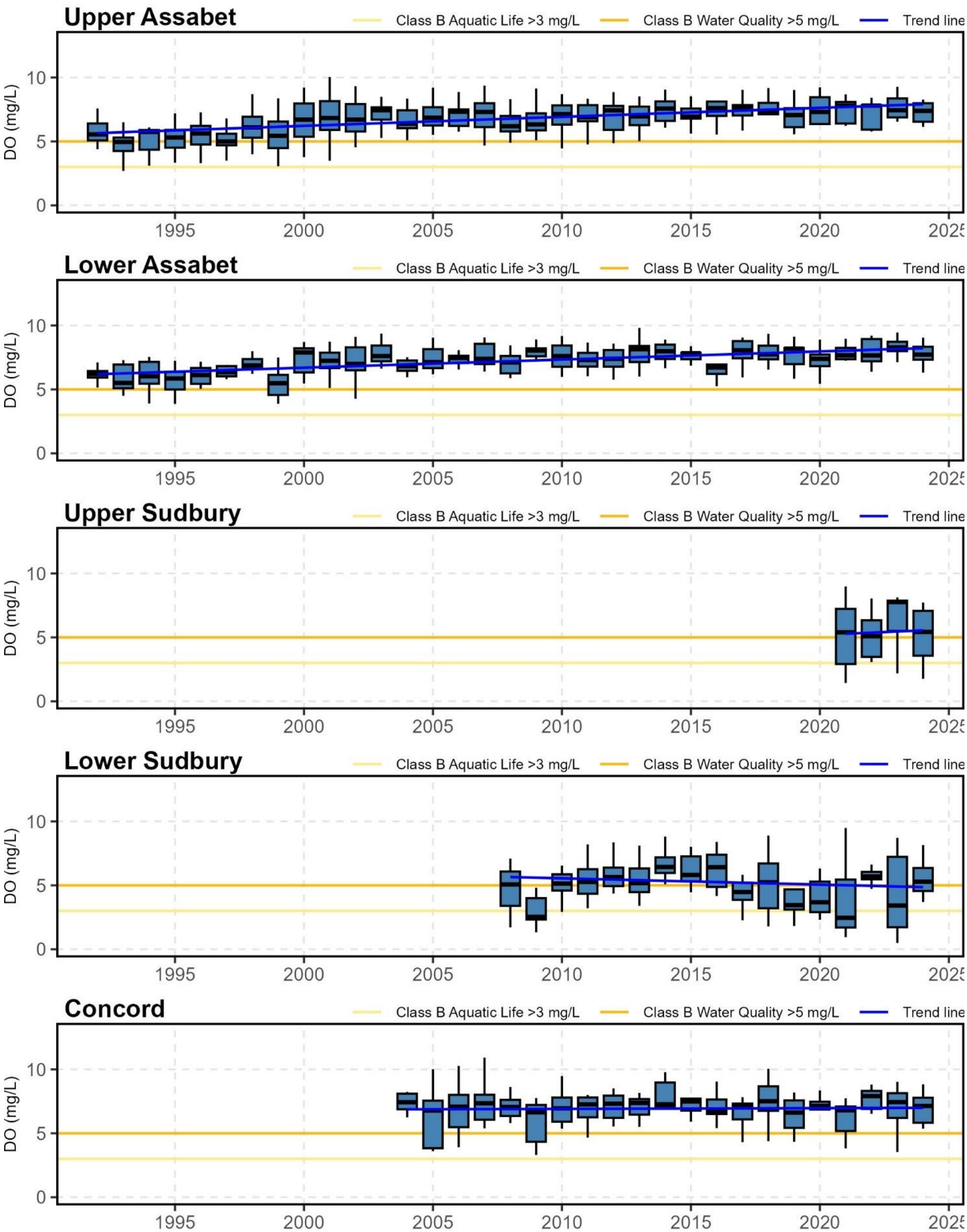


Figure 25: Dissolved Oxygen by year and section (June/July/August)

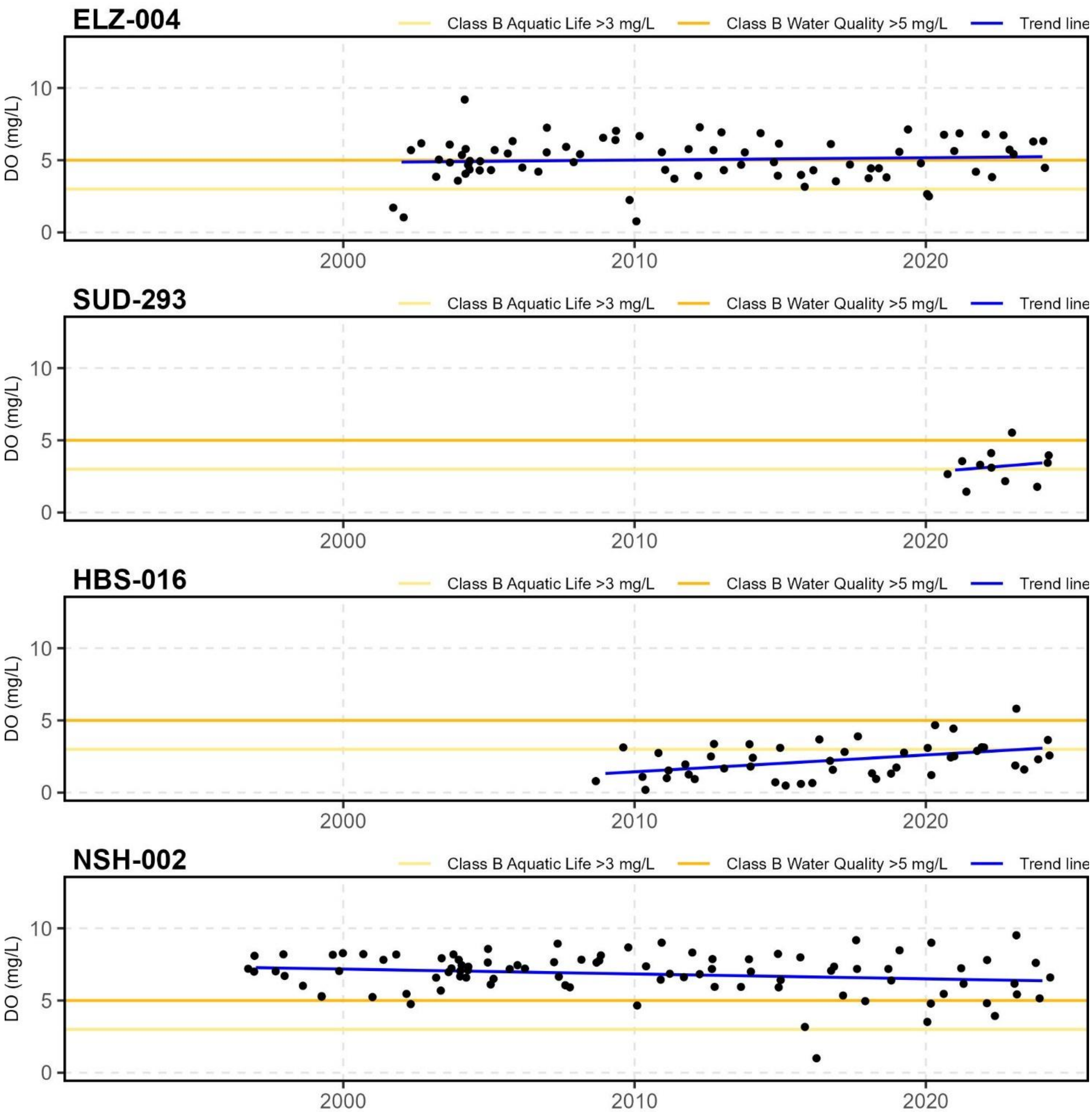


Figure 26: Dissolved Oxygen trends for selected sites (June/July/August)

Acidity (pH)

There are a number of factors that can affect pH. Most rainwater is slightly acidic and can lower pH (increase acidity). WWTP discharge can raise pH (Westborough's average discharge maximum pH is slightly alkaline at 7.6). Carbon dioxide dissolved in water can lower pH, and thus can indicate high levels of respiration or eutrophication, and photosynthesis can raise pH by consuming carbon dioxide.

In 2023, pH levels were moderate, with the exception of HBS-016 and SUD-293 (Figure 27 and Figure 28). Both sites have upstream wetlands with significant opportunities for organic decomposition and very low DO levels, as discussed above in the dissolved oxygen section. For the third year in a row, sites ABT-077 and ABT-062 had higher pH than upstream sites. The time-series view of ABT-077 in Figure 30 shows generally high pH levels since 2012. It is not clear what is driving up the pH at these sites. ABT-077 is downstream of the Ben Smith Impoundment and the Hudson WWTP. The Hudson effluent maximum pH averaged 7.6 in 2024, but there was no spike in August, as was measured in the rivers. ABT-062 is downstream of the Powdermill impoundment and the Maynard WWTP. Maximum effluent pH from Maynard averaged only 7.1. This must have been a result of algal growth in the impoundments. There was a corresponding spike in DO at these two sites in 2024 and in August in particular. See the Biomass section below for a discussion about biomass in the Ben Smith impoundment.

Year-on-year analysis of summer pH shows a visible upward trend in pH for the Assabet River (Figure 29). This is most likely a positive effect of reduced phosphorus in the WWTP discharge. Reducing nutrients can reduce biomass, which would result in less respiration from decomposition, less dissolved carbon dioxide, and a higher pH. This hypothesis is also supported by the corresponding improvement in dissolved oxygen shown above (Figure 25). The individual sites we are watching are shown in Figure 30. For five years in a row, the Elizabeth Brook site (ELZ-004) has had depressed (more acidic) pH levels (Figure 30). This warrants some further study.

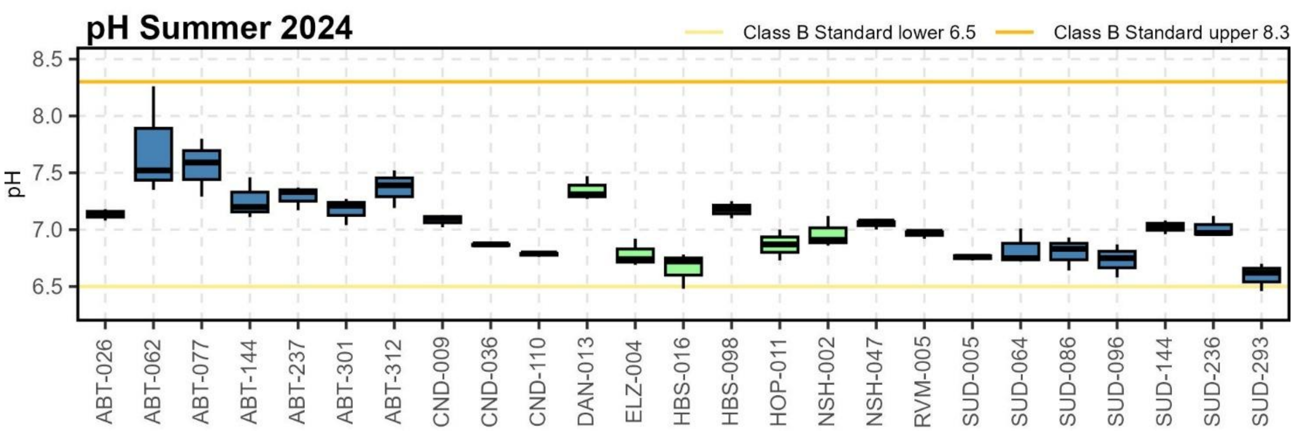


Figure 27: pH by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

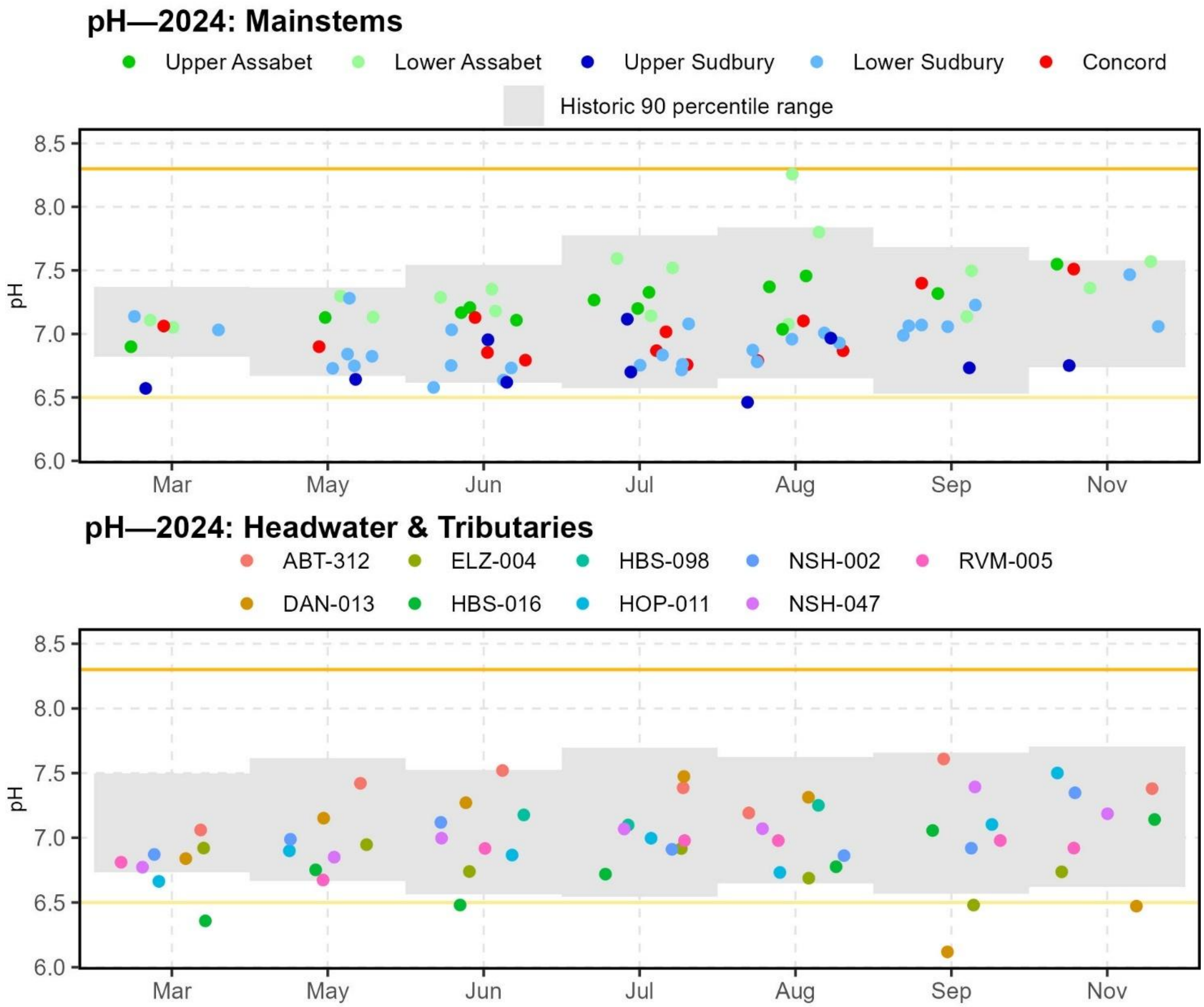


Figure 28: pH by month and site (2024)

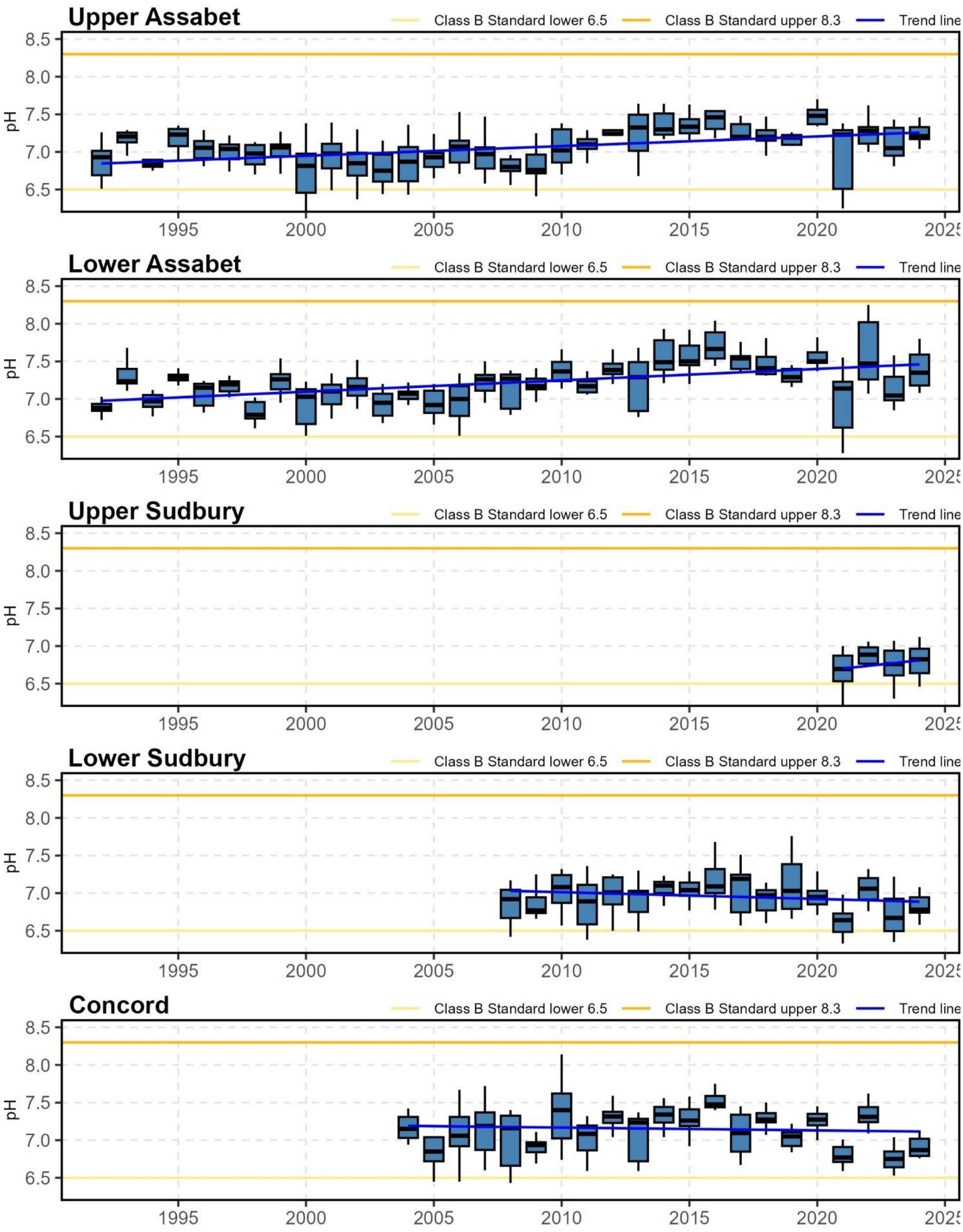


Figure 29: pH by year and section (June/July/August)

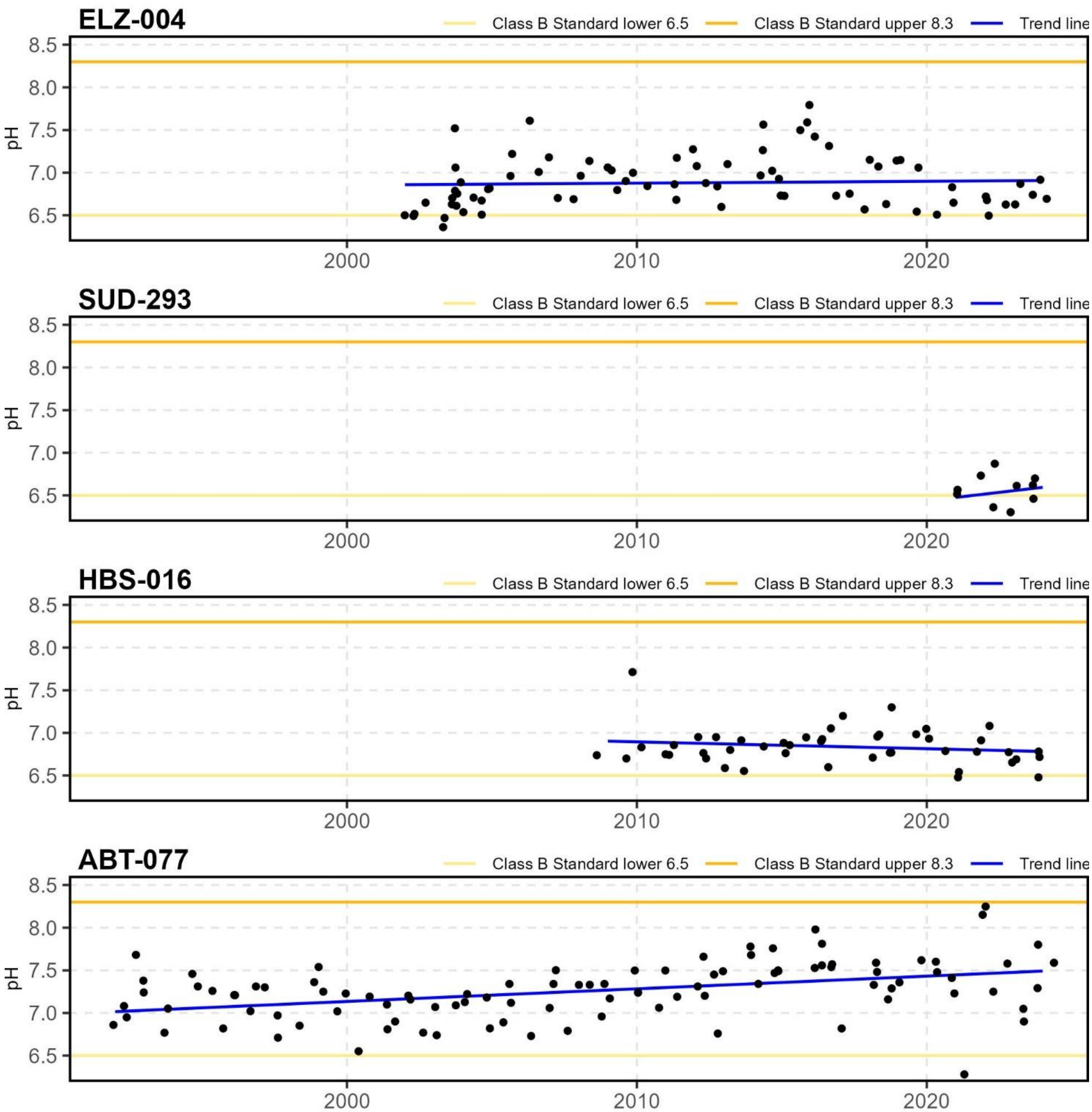


Figure 30: pH trends for selected sites (June/July/August)

Total Phosphorus

Phosphorus is considered the limiting nutrient for primary production in freshwater systems because it is available in much lower proportions per biological need than the other essential nutrients, nitrogen and carbon. For this reason, OARS focuses heavily on phosphorus. A TMDL for phosphorus was established for the Assabet River in 2004 (MassDEP, 2004), and permit limits were set effective 2010 for each of the wastewater treatment plants (WWTPs) to meet the TMDL. Significant reductions in instream phosphorus concentrations have been achieved as a result of these permit limits (Figure 33).

In 2024, Total Phosphorus (TP) concentrations were generally at or below the EPA "Gold Book" recommendation of 0.05 mg/L at most sites (Figure 31 and Figure 32). There is no longer any visible elevation of TP at sites downstream of WWTPs. In 2024, the noteworthy sites were HBS-016, SUD-293, and HOP-011 (also graphed in Figure 35). HBS-016 (Hop Brook in Sudbury) always has the highest TP levels in our watershed. It is in a large wetland and is downstream of four large impoundments that collected phosphorus discharged from the Marlborough Easterly WWTP. OARS is working with the Hop Brook Protection Association to determine what can be done about these impoundments. SUD-293 (Sudbury River headwater) tends to have high TP, low pH, and low DO. It is downstream of a major swamp (Cedar Swamp) and a major highway interchange. We hope to study this in the future. HOP-011 (Hop Brook in Northborough) also has consistently elevated TP levels with a trend upward. It is downstream of a large wetland and impoundment, a highway interchange, a sand quarry, and numerous retail parking lots. This catchment area would be a good opportunity for green stormwater infrastructure.

Year-on-year analysis of TP shows the improvements delivered by the Assabet WWTP upgrades in 2000 and 2012 (Figure 33). *The improvements are significant enough to necessitate a change in the scale for concentration in Figure 33 between the years 2007 and 2008.* Major reductions in phosphorus concentrations have been achieved in the Assabet as a result of the NPDES permits and plant upgrades, and all mainstem rivers now are consistently near the 0.05 mg/L "Gold Book" threshold. Load analysis also shows a declining trend in summertime phosphorus load in the Assabet and Concord rivers (Figure 34). Load is the total amount of phosphorus, measured in kilograms, that is carried downstream in the water per day. It is calculated by multiplying concentration (mass per volume of water) by flow (volume per day). We track flow at many locations on the rivers, and we can estimate flow at the other locations. Load analysis demonstrates how high-flow events, such as those that occurred during 2021 and 2023, can inject quantities of phosphorus into the river system at orders of magnitude greater than periods of normal flow. This phosphorus could settle into the river sediments and feed future eutrophication, or the high flows could carry phosphorus out of the system. The net effect is not clear.

WWTP discharge concentrations and loads are also included for reference (Figure 37, Figure 38, Figure 39, Figure 40). Total Assabet WWTP phosphorus load should have decreased significantly in 2024 because the winter discharge limit for the Westborough WWTP was lowered from 1.0 mg/L to 0.2 mg/L. However, the total load remained above 2022 levels because the Hudson WWTP has been exceeding its limits for the last two years. Hudson had a final clarifier failure in 2023 (caused by COVID staffing issues). OARS is working with the Hudson plant, MassDEP, and the EPA to urgently address this situation. Hudson expects to complete the equipment replacement by May of 2025. The Concord WWTP, which discharges into the Concord River, also exceeded its summer permit limit twice in 2024. OARS has raised a flag about this with MassDEP.

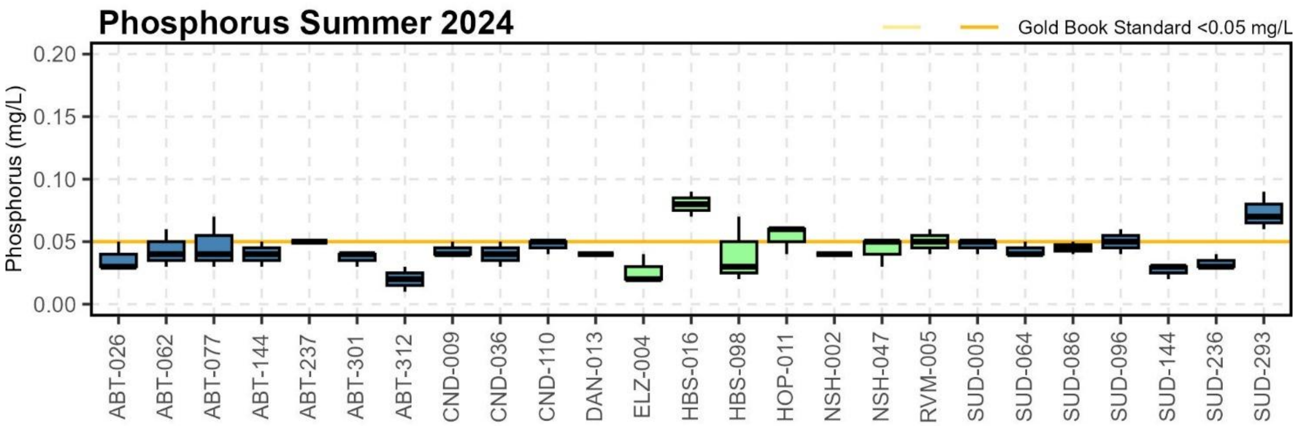


Figure 31: TP concentration by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

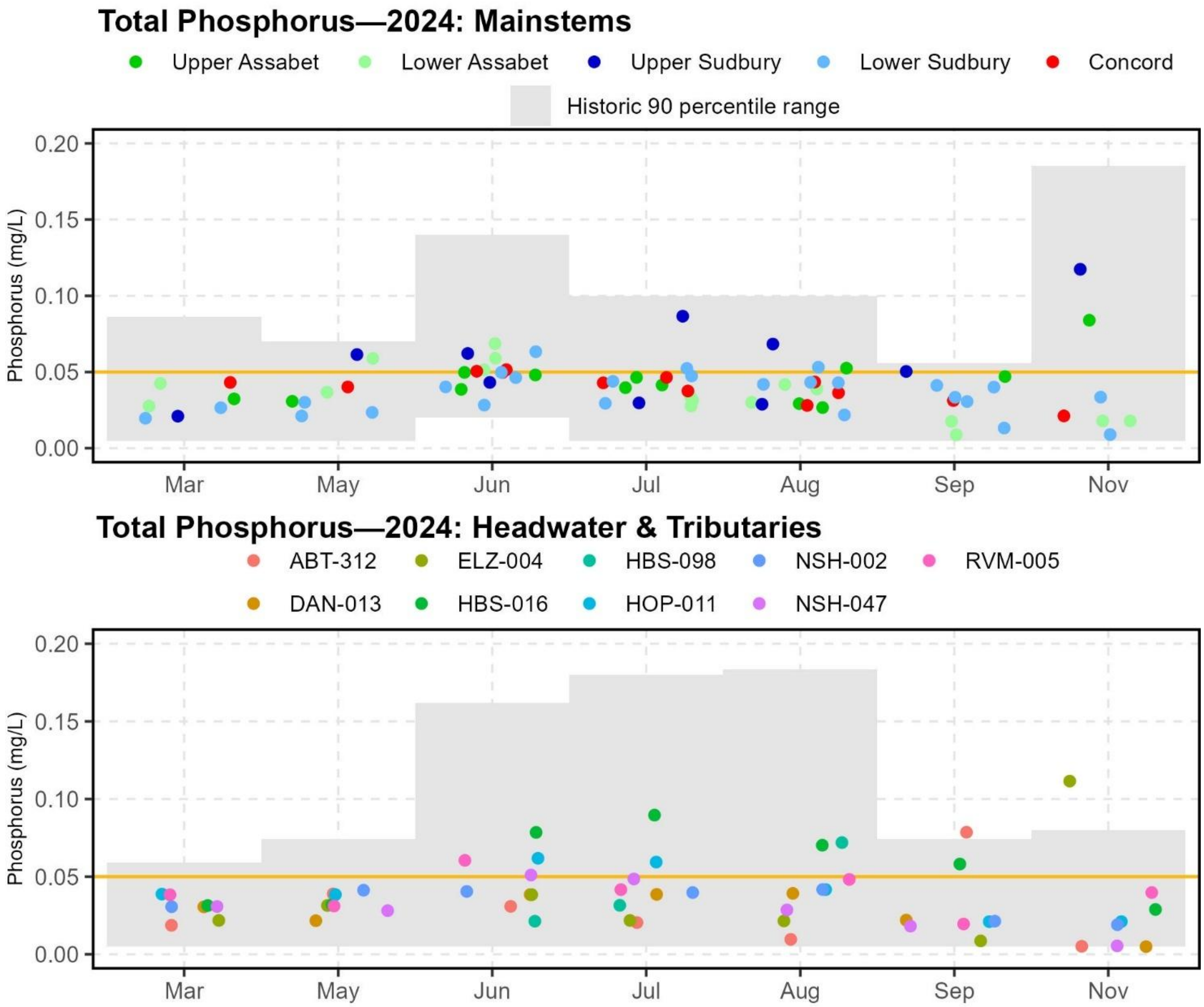


Figure 32: TP concentration by month and site (2024)

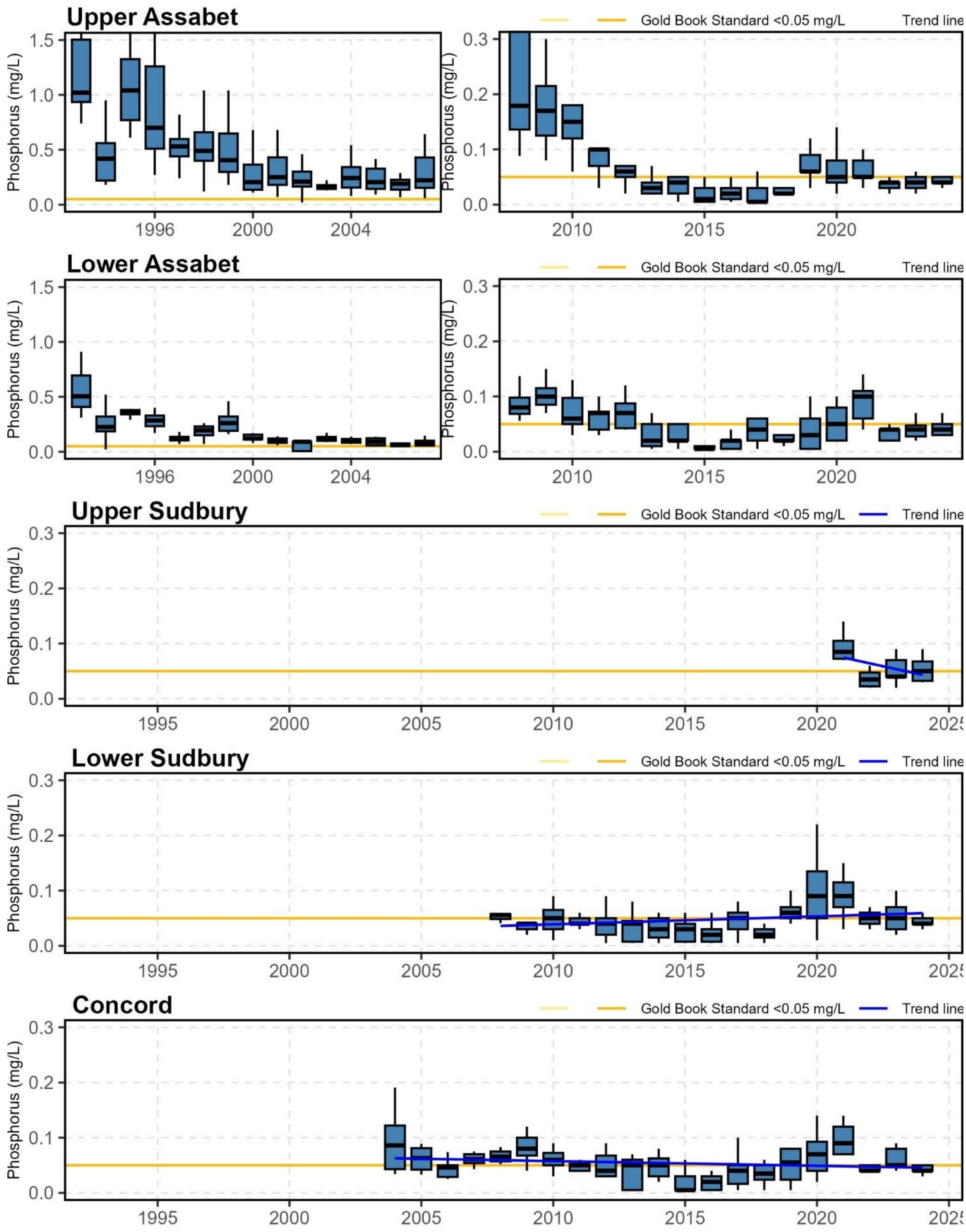


Figure 33: TP concentration by year and section (June/July/August)

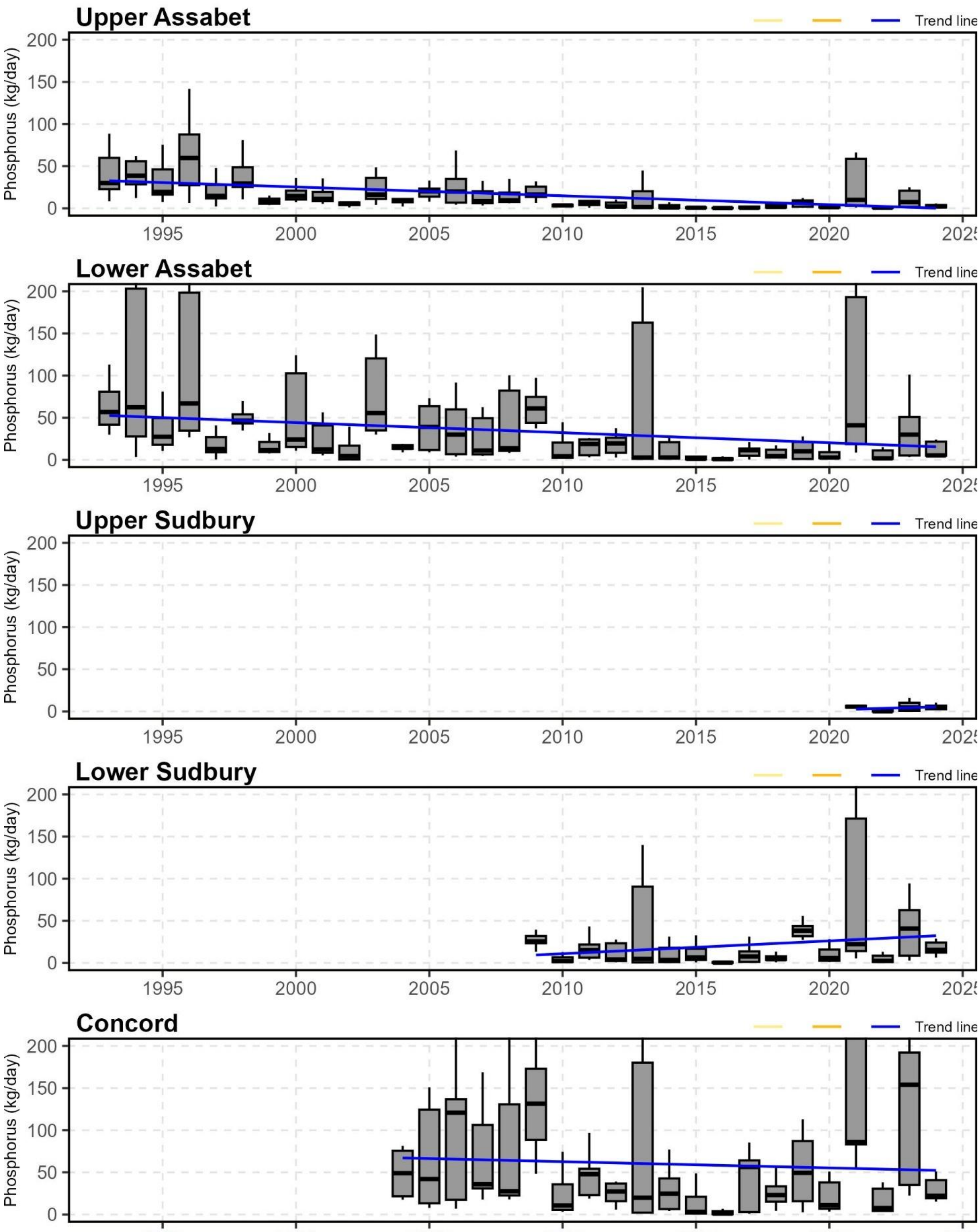


Figure 34: TP estimated load by year and section (June/July/August)

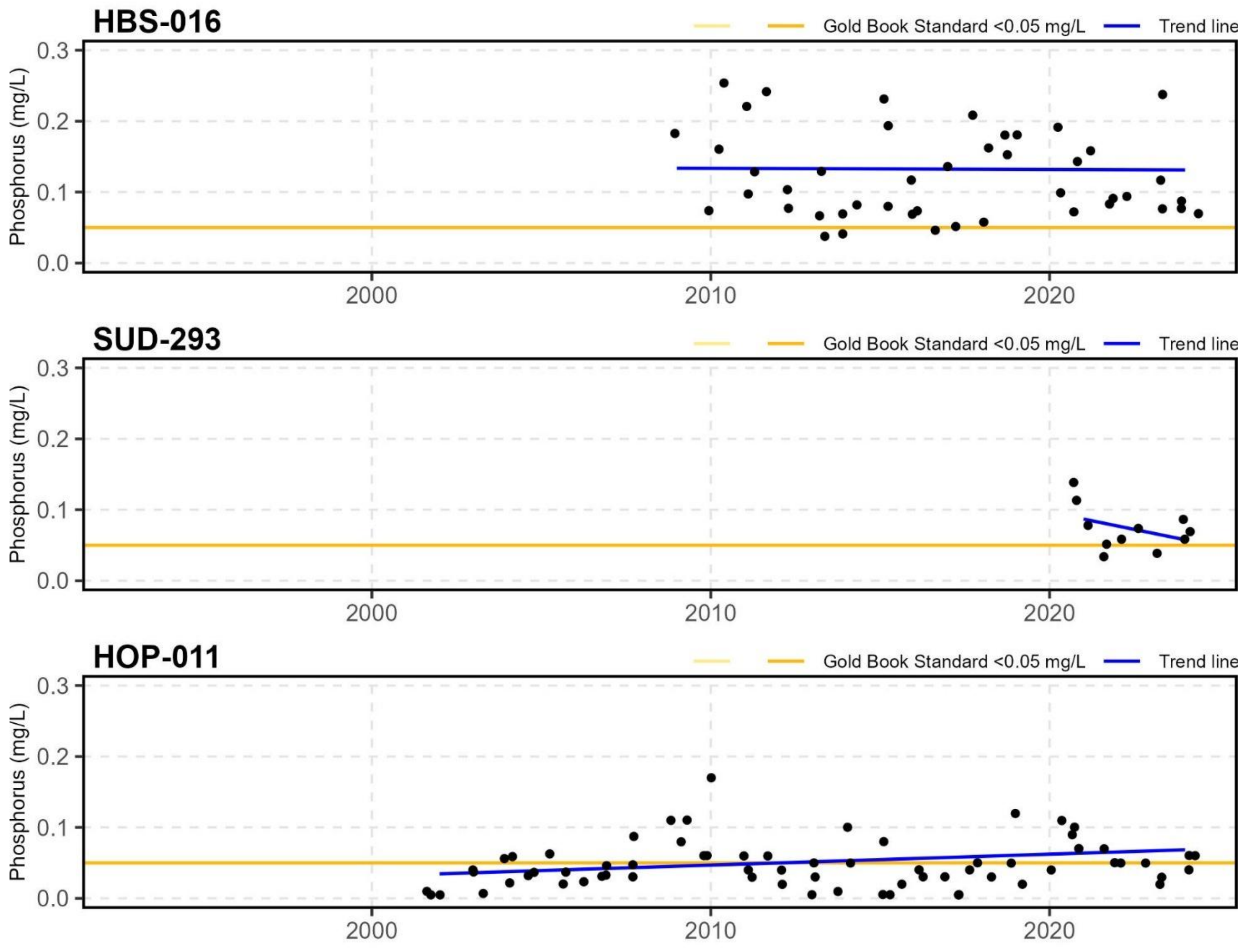


Figure 35: TP concentration trends for selected sites (June/July/August)

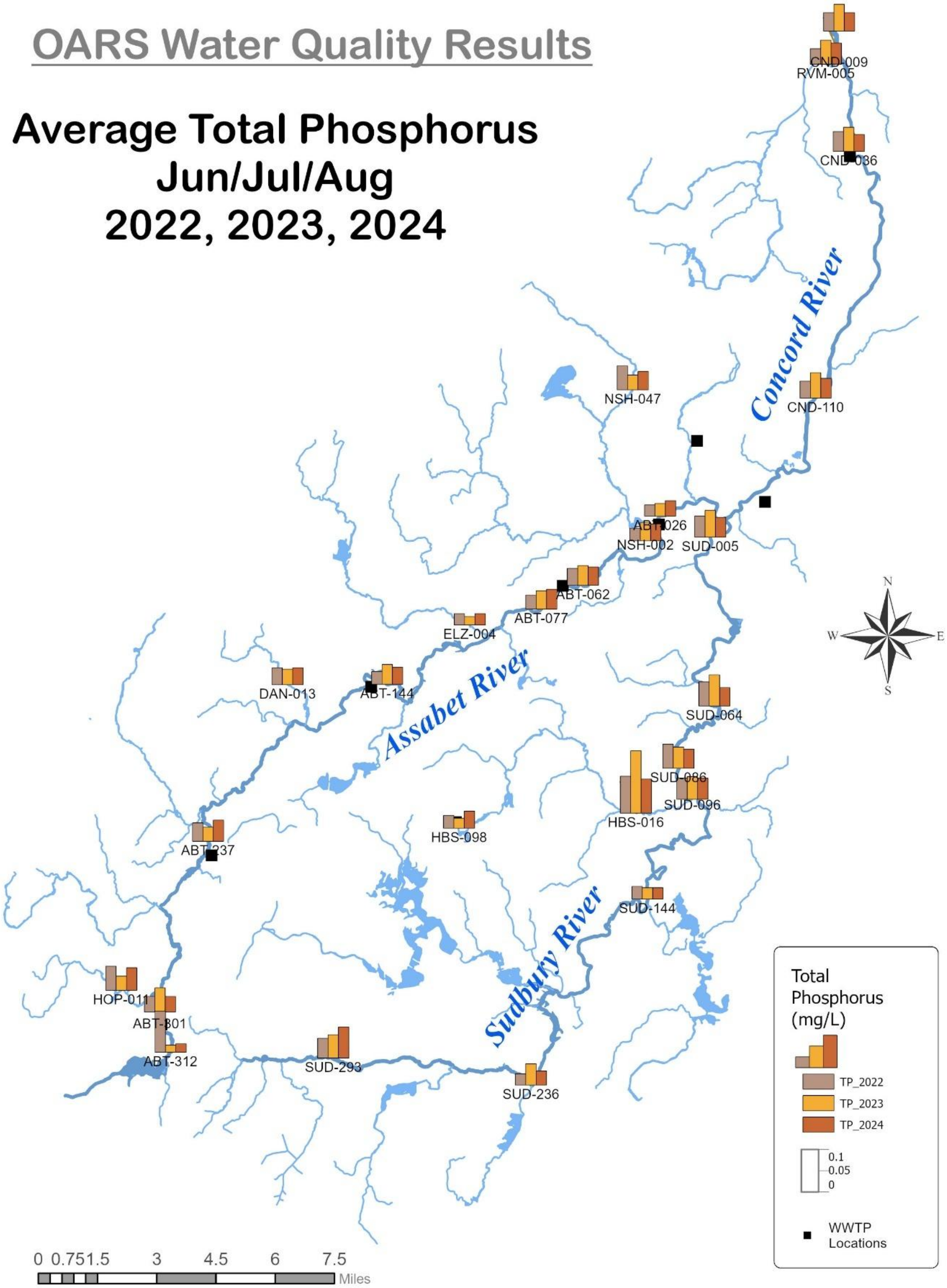


Figure 36: Map of average summer Total Phosphorus by site (2022–2024)

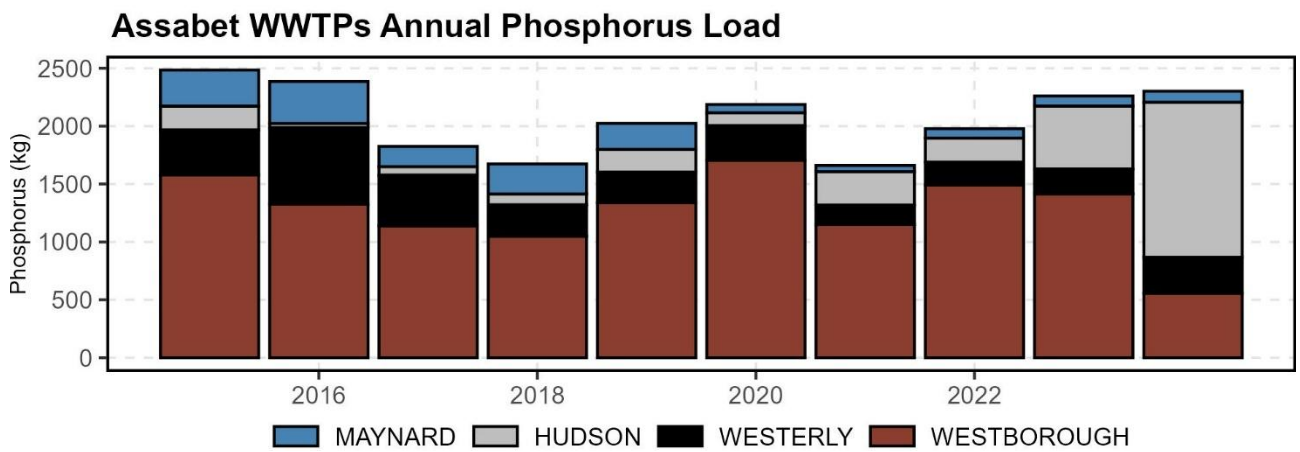


Figure 37: Major Assabet River WWTPs TP discharge (2015–2024)

** Annual discharge is calculated for the water year November through October, to represent discharge relevant for the summer growing season.*

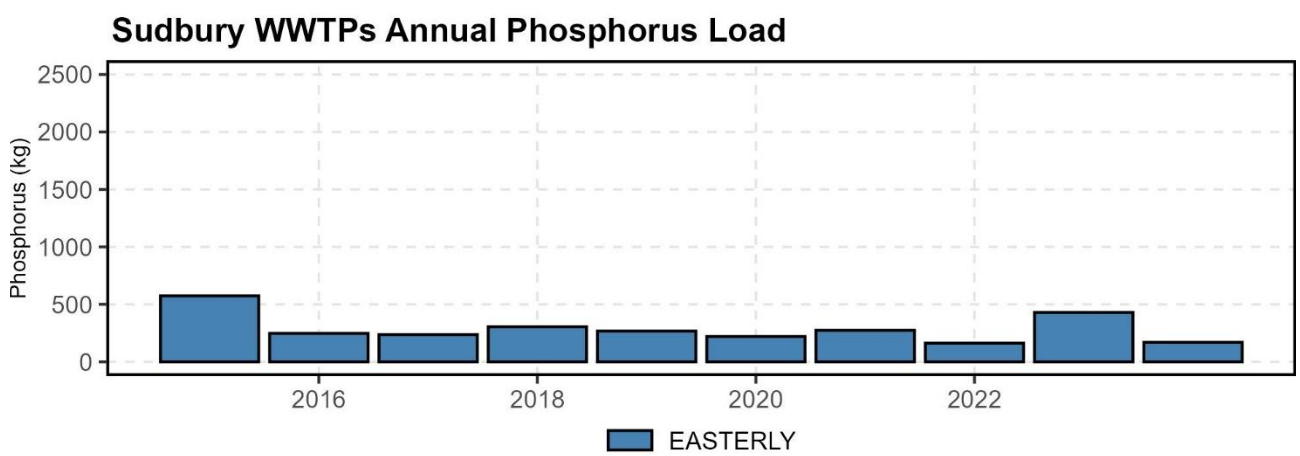


Figure 38: Major Sudbury River WWTP TP discharge (2015–2024)

** Annual discharge is calculated for the water year November through October, to represent discharge relevant for the summer growing season.*

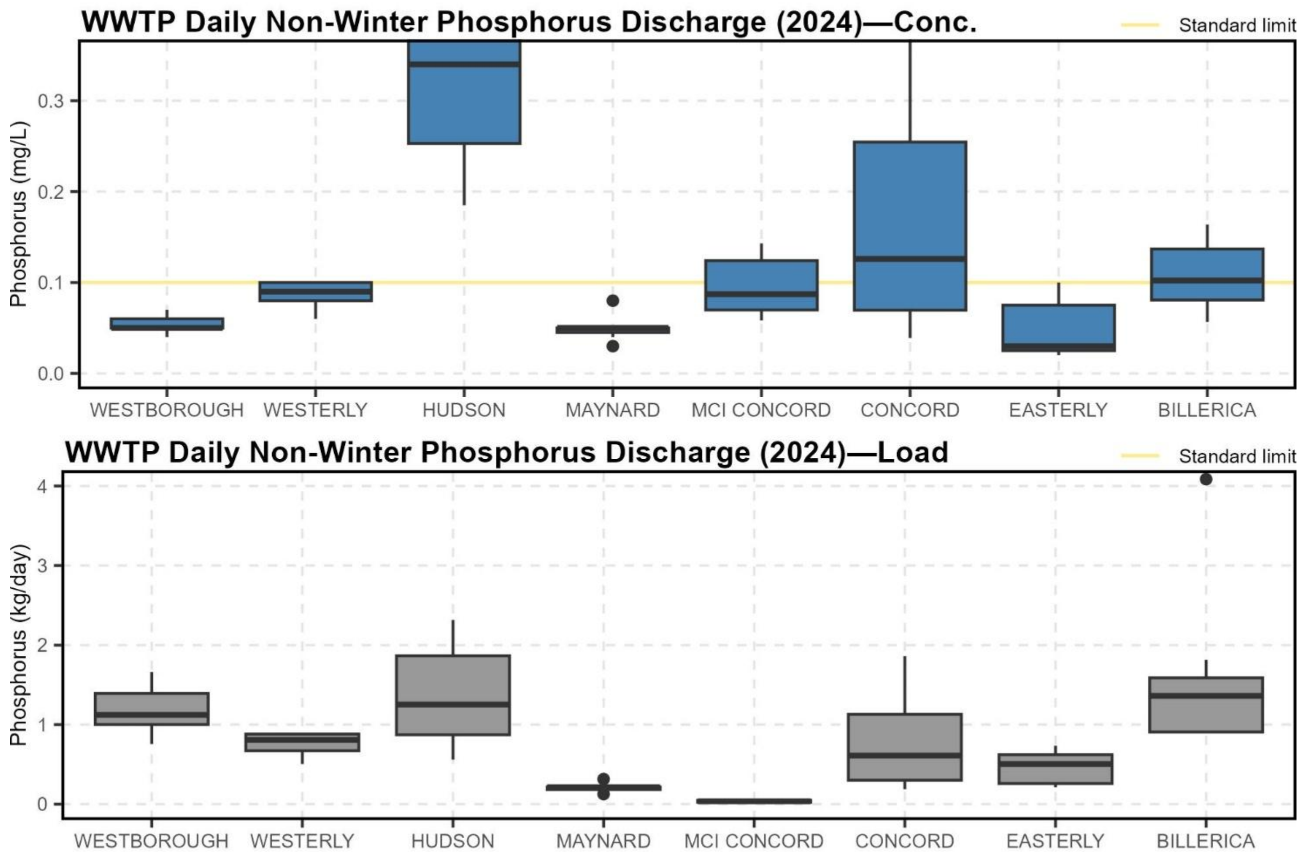


Figure 39: WWTP Daily TP Discharge—summer (2024, Apr–Oct)

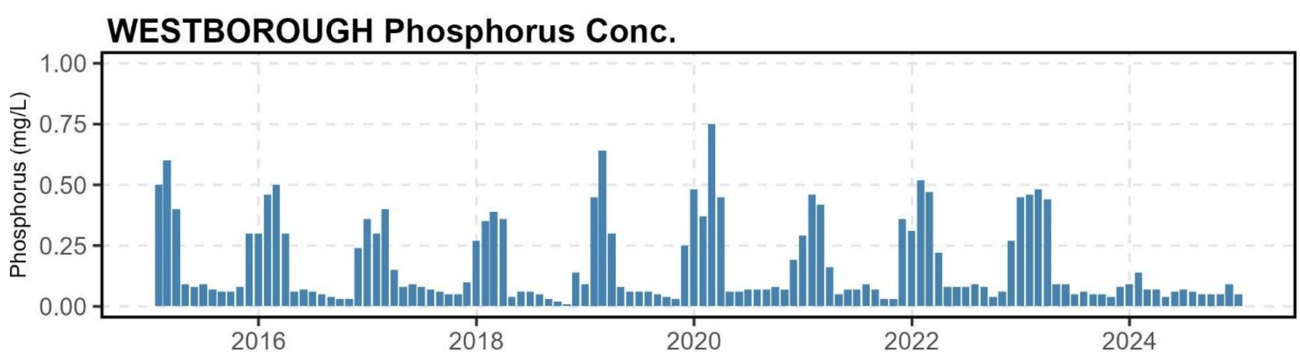


Figure 40: Westborough WWTP TP discharge by month (concentration)

Orthophosphate

Orthophosphate represents the portion of total phosphorus that is bioavailable and in dissolved form in water. It is the inorganic phosphorus that is the main constituent in fertilizers and the main form of phosphorus discharged by wastewater treatment plants.

Analysis of orthophosphate shows that orthophosphate represented from 12% to 58% of TP during the summer in 2024 (Figure 41). This percentage tends to be slightly higher in wet years. Hop Brook in Sudbury (HBS-016), which always has the highest TP levels, had 50% orthophosphate. This site is located in a large wetland and downstream of several impoundments with large quantities of legacy phosphorus in the sediments. A monthly analysis of orthophosphate showed a high proportion in the Upper Assabet in November (Figure 42). The Upper Assabet usually has higher proportions in the winter because the wastewater treatment plants have higher discharge limits in the winter. An analysis of average historical proportions shows how orthophosphate proportions (not absolute values) tend to be highest in the spring in March when dissolved inorganic phosphorus is being washed off the land (Figure 43). Orthophosphate proportions are generally low in the summer and ramp up at the end of the growing season in September. An interesting dynamic is visible in November when orthophosphate proportions are high in our mainstems and very low in tributaries. This may reflect the effect of wastewater treatment plant discharge on the mainstems, and it may also be the result of higher particulate matter proportions in late fall in upstream tributaries.

In the year-on-year analysis, the Assabet plots show clearly how the proportion of TP represented by orthophosphate as well as absolute concentrations of orthophosphate decreased significantly after the WWTP upgrades in 2011 (Figure 44).

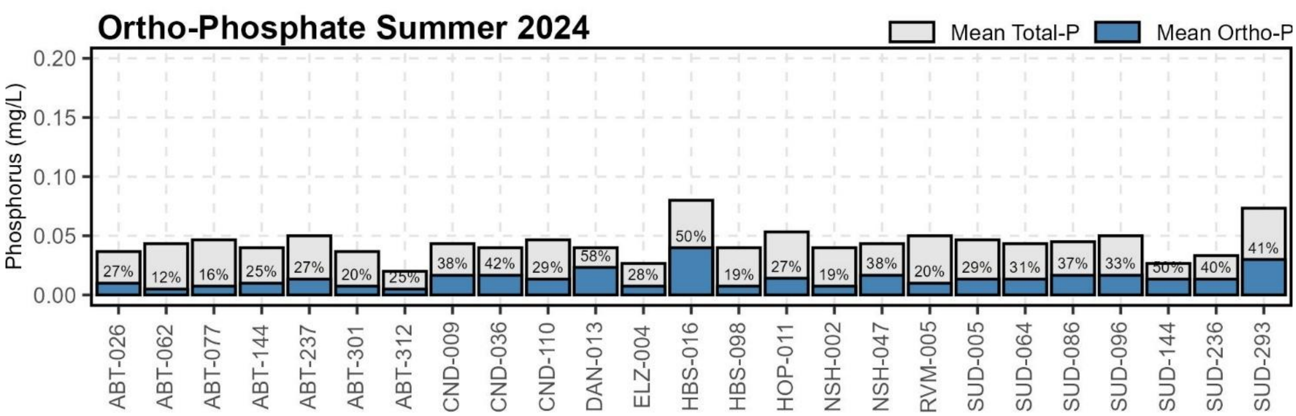


Figure 41: Ortho-P concentration and proportion by site, summer (Jun–Aug 2024)

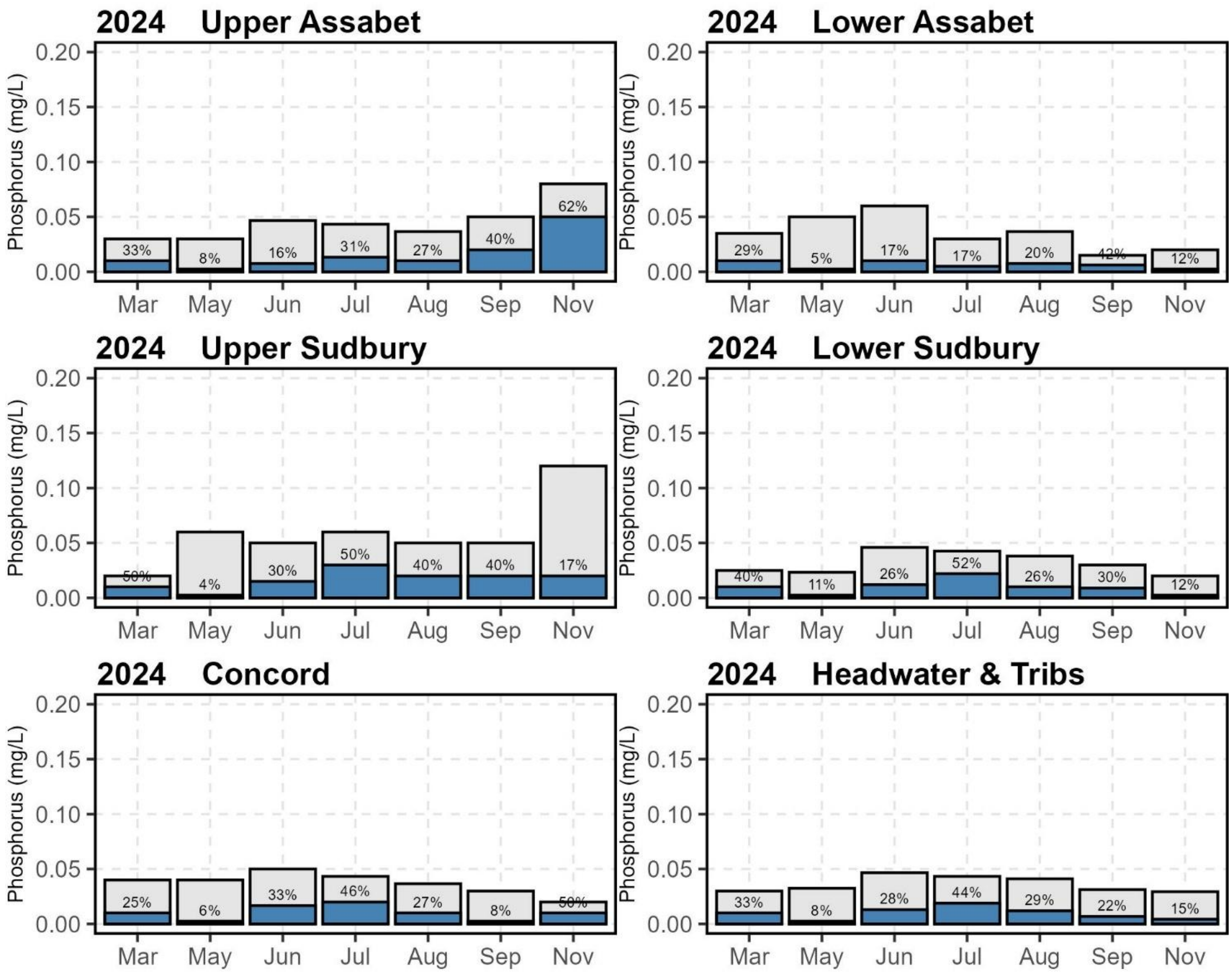


Figure 42: Ortho-P concentration and proportion by month and section (2024, mean)

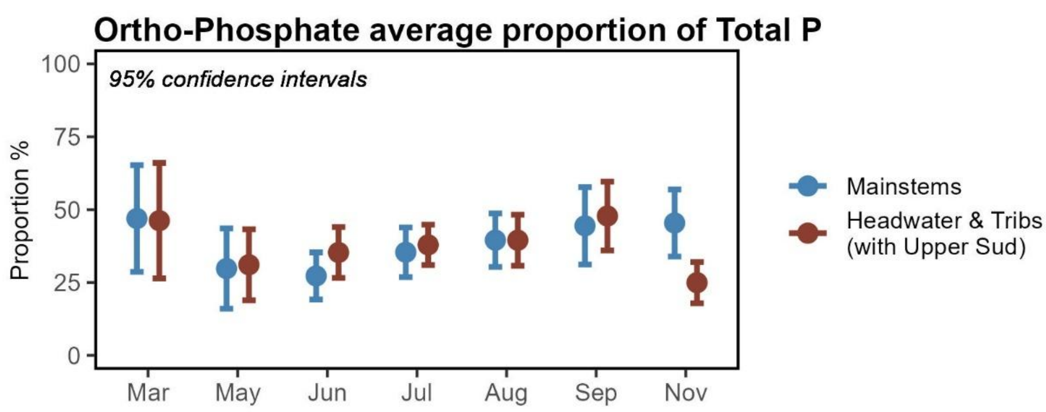


Figure 43: Ortho-P 12-year historical average proportion of Total Phosphorus

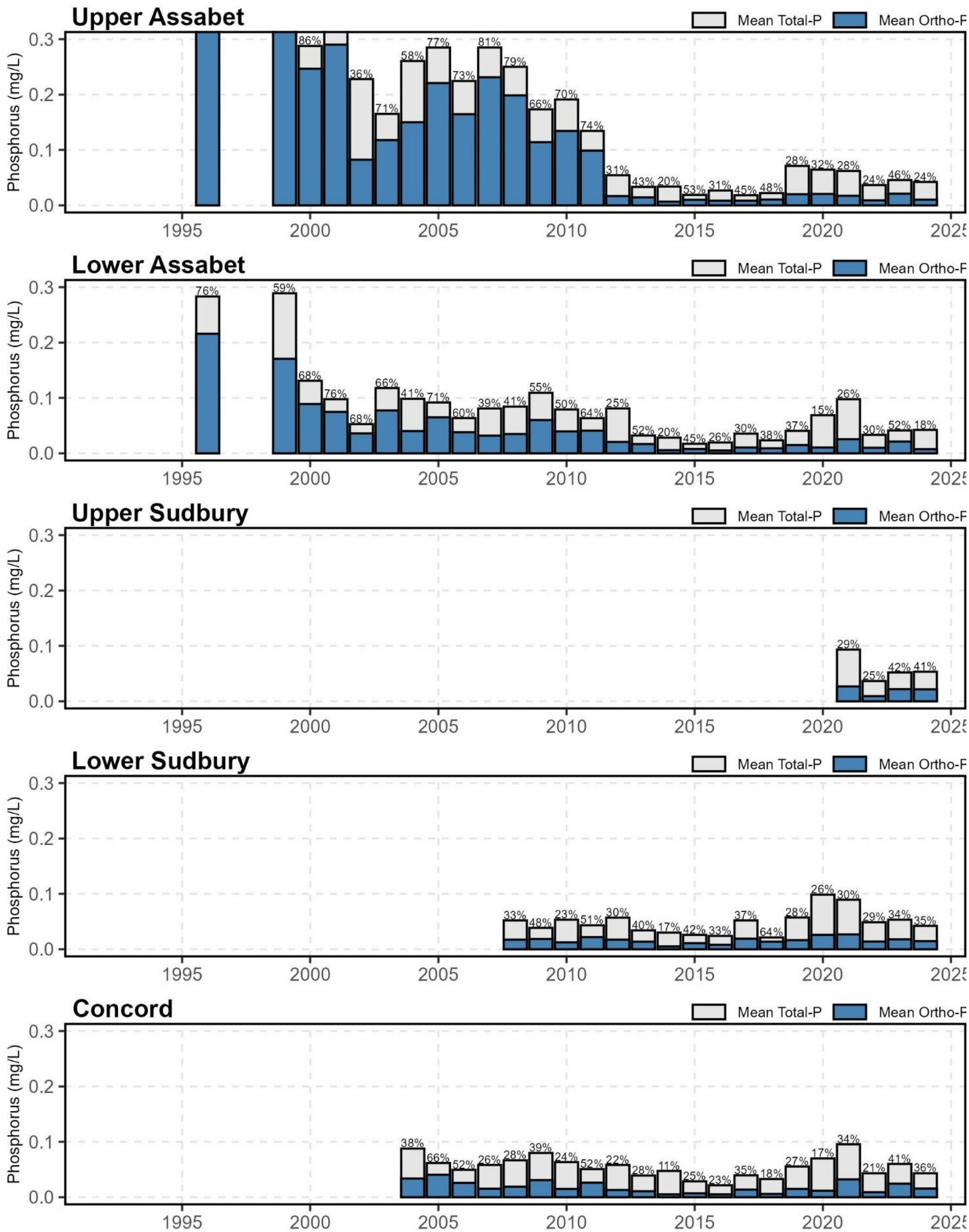


Figure 44: Ortho-P concentration and proportion by year and section (June/July/August)

Nitrate

Nitrate (NO_3) is the secondary nutrient of concern in fresh waters, secondary because it is not the limiting nutrient. However, there are some conditions where this is not the case, such as anoxic bottom waters of impoundments (ENSR, 2001). In anoxic bottom waters, phosphorus can be sourced from the sediments, and atmospheric nitrogen is not available. Plants that derive nutrients from the bottom water, such as filamentous green algae, could thus be limited by nitrate. Additionally, nitrate is the primary nutrient of concern in estuarine environments and it easily flows downstream in dissolved form, so it is critical to track nitrate load flowing downstream.

In our watershed, the WWTPs are the primary source of nitrate. This is confirmed by our 2024 results with the highest concentrations in the Upper Assabet below the Westborough (ABT-301), Westerly (ABT-237), and Hudson (ABT-144) WWTPs (Figure 45). This results in most Assabet sites having concentrations an order of magnitude greater than the Ecoregion reference condition of 0.34 mg/L (for NO_2+NO_3 as N) (EPA, 2000). The Easterly WWTP site on the Sudbury's Hop Brook (HBS-098) has also shown high nitrate levels, but that site was not analyzed for nitrate in 2024. *Note that we changed sampling plans as of 2021 to sample nitrate at fewer sites (river mouths and key Report Card sites) to focus on nitrate being transported to downstream estuaries.* The monthly analysis of nitrate shows higher concentrations in the Assabet and Concord, primarily originating from the Assabet WWTPs, and an increase in the latter parts of the year (Figure 46). The seasonal increase is completely driven by discharge from the Westborough WWTP. Nitrate concentrations at our downstream sampling site (ABT-301) have historically tended to be much higher in September and November than earlier in the year (Figure 47). Westborough nitrate discharge concentrations are generally stable throughout the year, so the in-stream increases must be largely a result of lower flows and less dilution later in the year. However, this does not completely explain the high November levels because the lowest flows tend to be in August and September.

Year-on-year analysis of NO_3 shows what seems to be an increasing trend in concentration and load in the Assabet (Figure 48 and Figure 49). Note that the load from the Upper Assabet WWTPs is also visible flowing downstream in the Lower Assabet and Concord. Nitrate load is not reduced at all with distance downstream, so discharge loads from the Concord to the Merrimack and eventually its estuary are significant (Figure 49). Our data also show very low loads sourced from tributaries and river sections that are not receivers of WWTP discharge (Figure 50).

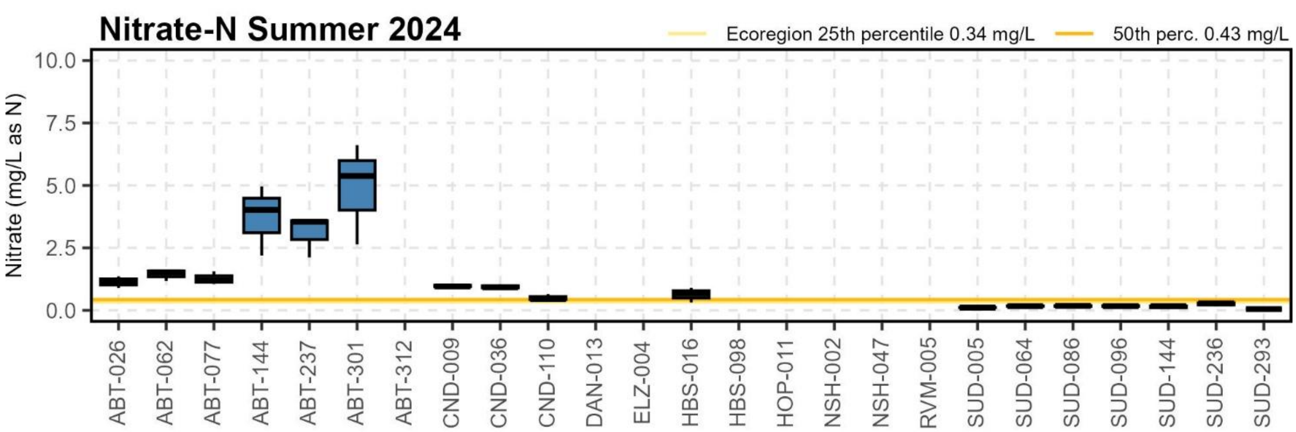


Figure 45: Nitrate concentration by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

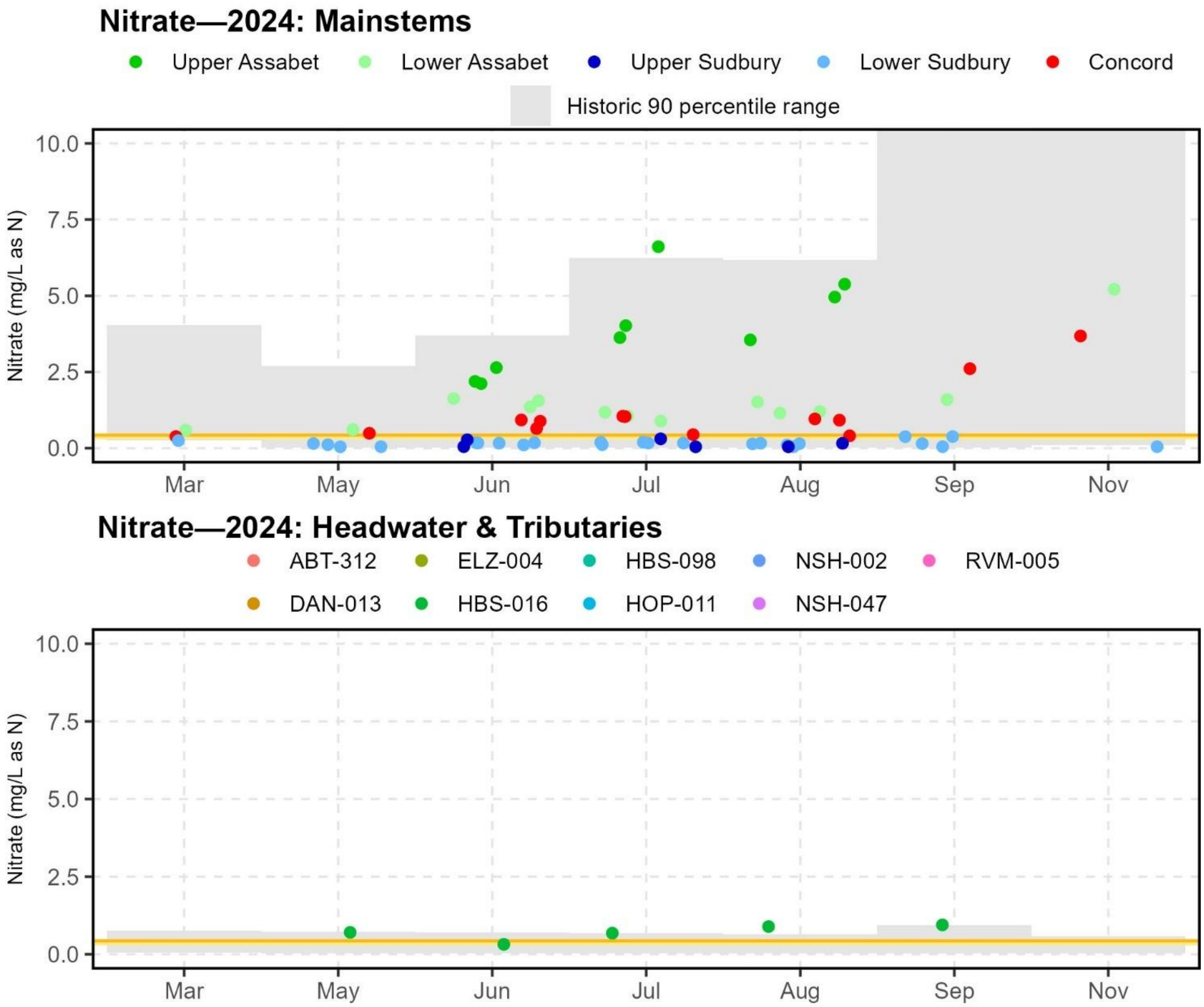


Figure 46: Nitrate concentration by month and site (2024)

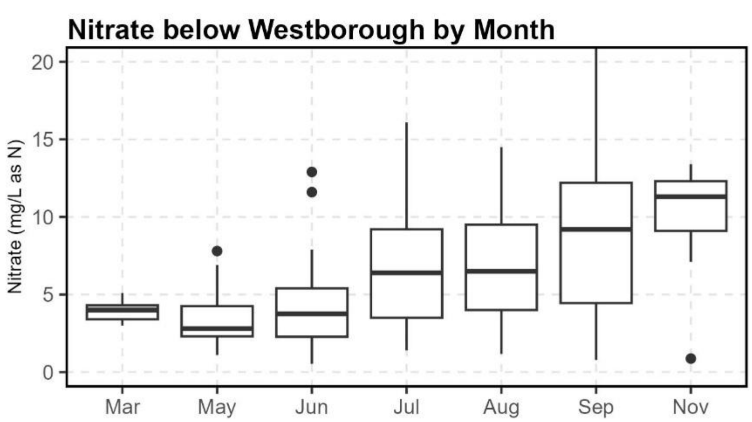


Figure 47: Nitrate concentration by month at ABT-301 below Westborough WWTP (all years)

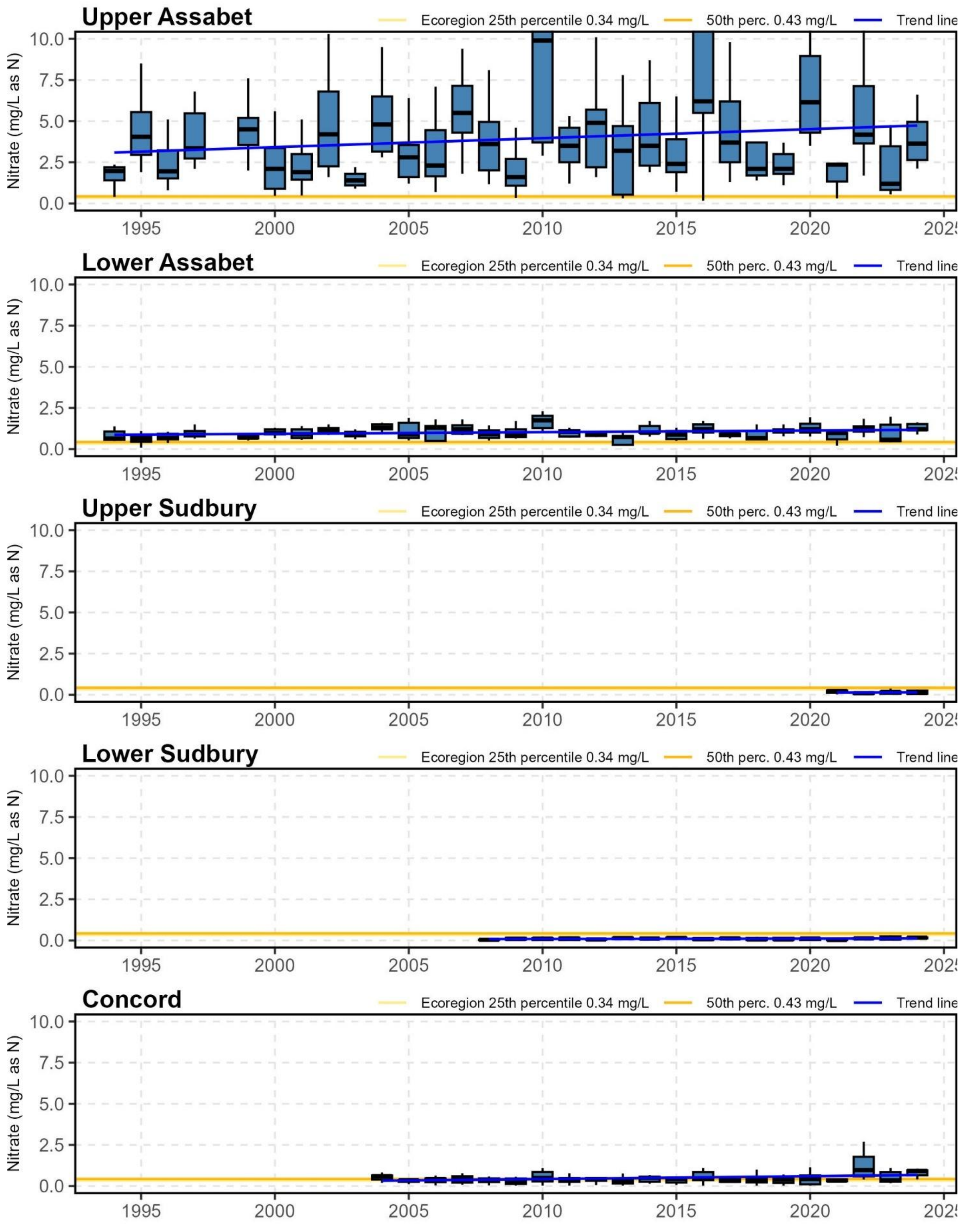


Figure 48: Nitrate concentration by year and section (June/July/August)

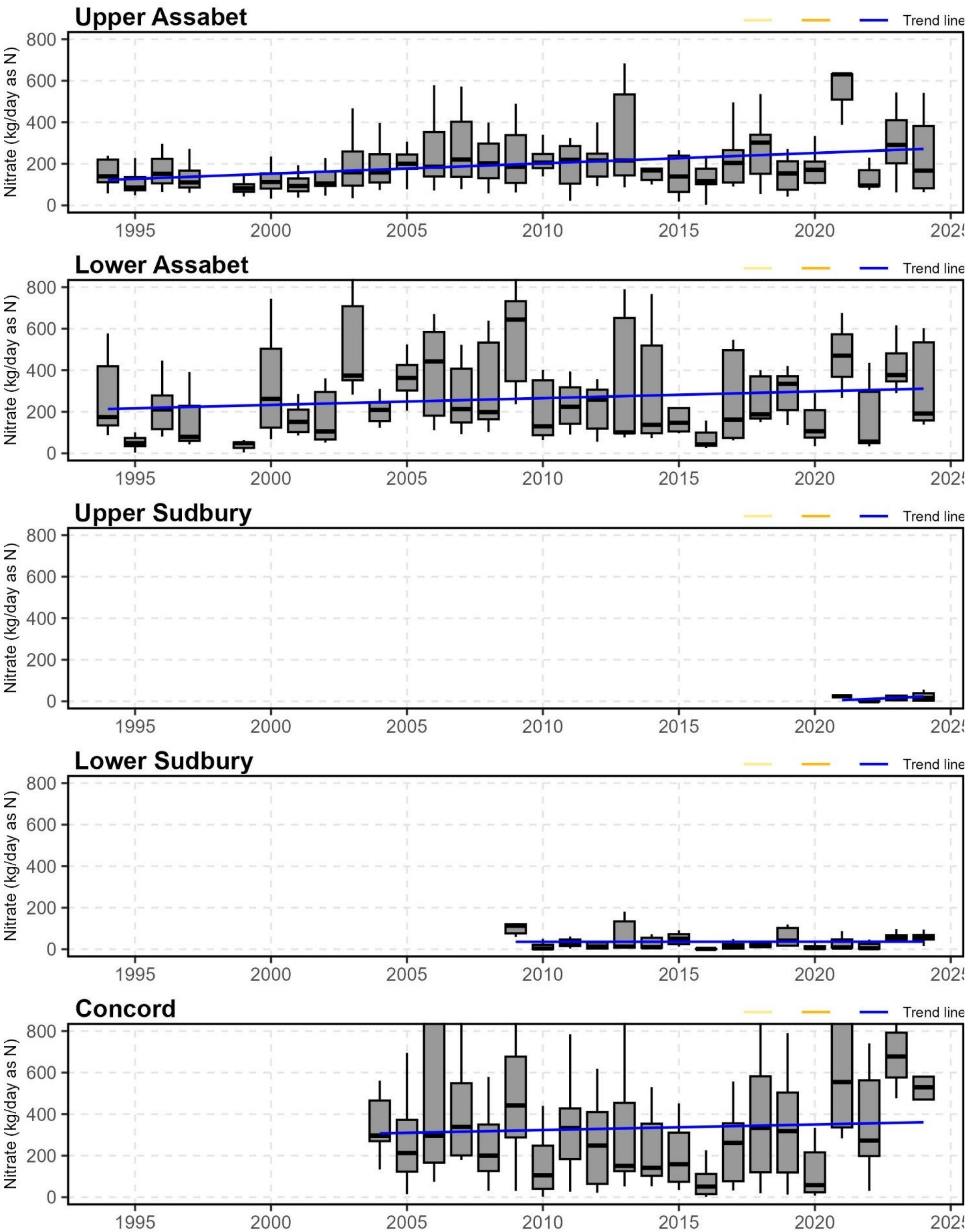


Figure 49: Nitrate estimated load by year and section (June/July/August)

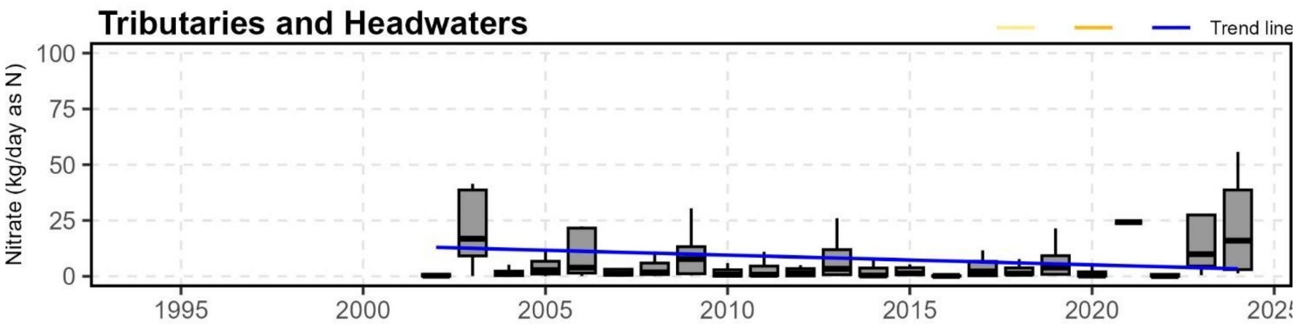


Figure 50: Nitrate estimated load tributaries and headwaters (June/July/August)

Ammonia

Ammonia (NH_3) is a form of nitrogen that can be toxic to aquatic life at high concentrations. Sources of ammonia include industry (from use in a wide range of industrial applications), fertilizer, breakdown of organic waste matter, and natural nitrogen fixation in the environment, and it is produced and excreted by fish. Ammonia maintains an equilibrium in the environment with the ammonium ion (NH_4^+) based on temperature and pH. Un-ionized ammonia (NH_3) is much more toxic than ammonium ion. For our reporting and threshold criteria, we report total ammonia nitrogen (NH_3 and NH_4^+ as N). The toxicity of total ammonia is highly dependent on temperature and pH (more toxic at higher temperature and pH). At pH values of 7.5 (our average maximum value) and water temperatures of 23°C (our average maximum summer temperature), the EPA criteria for ammonia for salmonid fish specify a chronic level of 1.2 mg-N/L and an acute level of 7.2 mg-N/L (EPA, 2013).

In 2024, the maximum summer ammonia concentration we measured was 0.43 mg/L in Elizabeth Brook (ELZ-004), with 84% of samples below 0.1 mg/L, well below concentrations toxic to fish (Figure 51 and Figure 52). Brooks with organic matter decomposition in wetlands tend to have the highest ammonia levels (e.g., ELZ-004, HOP-011, RVM-005, and SUD-293). The ELZ-004 site had the highest value in 2024, and we have seen infrequent, similarly high values at this site in previous years. Two sites below WWTPs showed up in 2024 with elevated ammonia levels (HBS-098 and ABT-144). ABT-144 is downstream of the Hudson WWTP, which has been having operational issues for more than a year. Hudson's discharge ammonia concentrations were well above the permit limit for all of 2024 (Figure 55). OARS is working with Hudson and MassDEP to address this issue.

Year-on-year analysis shows that ammonia levels have been low since 2000, when the first ammonia discharge limits were applied to the WWTPs. Most ammonia measurements have been below the detection limit of 0.1 mg/L since 2012, when the WWTP upgrades were completed (Figure 53). The uptick in ammonia levels in 2017 was the year following the most severe drought in recent history. Only a few sites have had frequent results above the detection limit. The most consistent site with high levels is RVM-005 (River Meadow Brook) (Figure 54).

Daily discharge from the WWTPs is also included for reference (Figure 55). Note that Maynard WWTP has a higher permitted limit than the other plants. There have been two fish kills reported downstream of the Maynard WWTP (2020 and 2023), but Mass DFW has determined that both were due to natural causes related to spring temperature changes. Hudson's recent high discharge concentrations were discussed above.

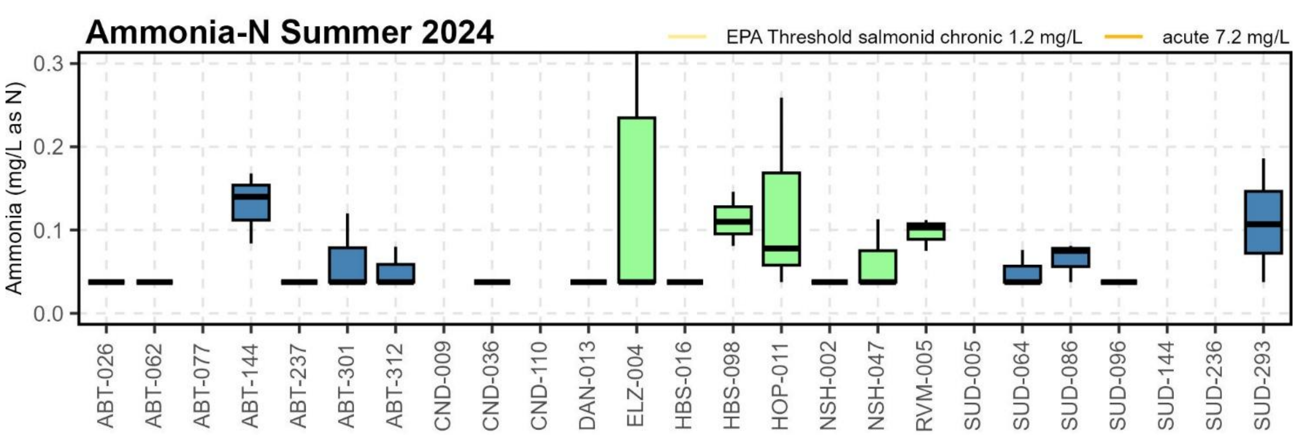


Figure 51: Ammonia concentration by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

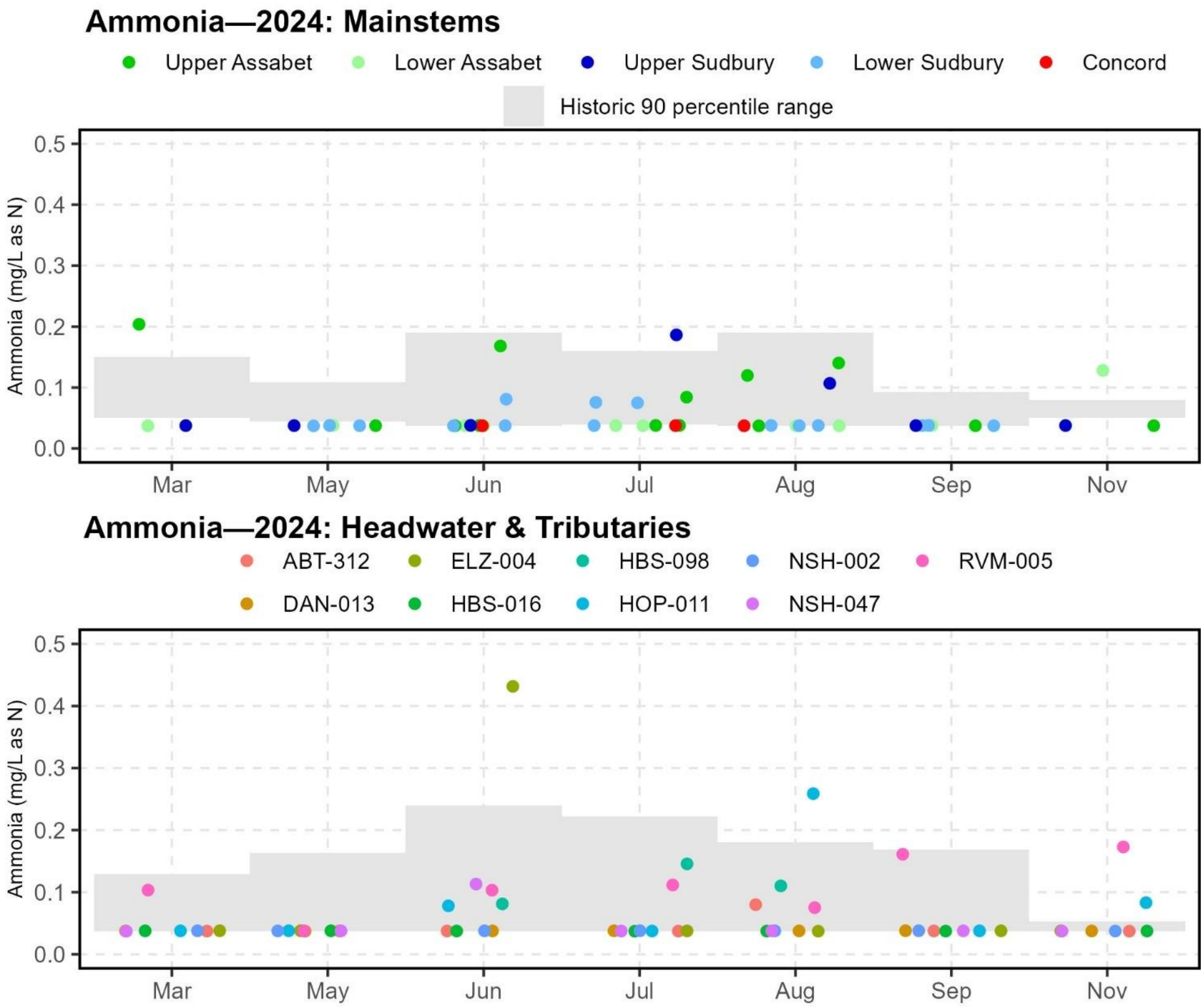


Figure 52: Ammonia concentration by month and site (2024)

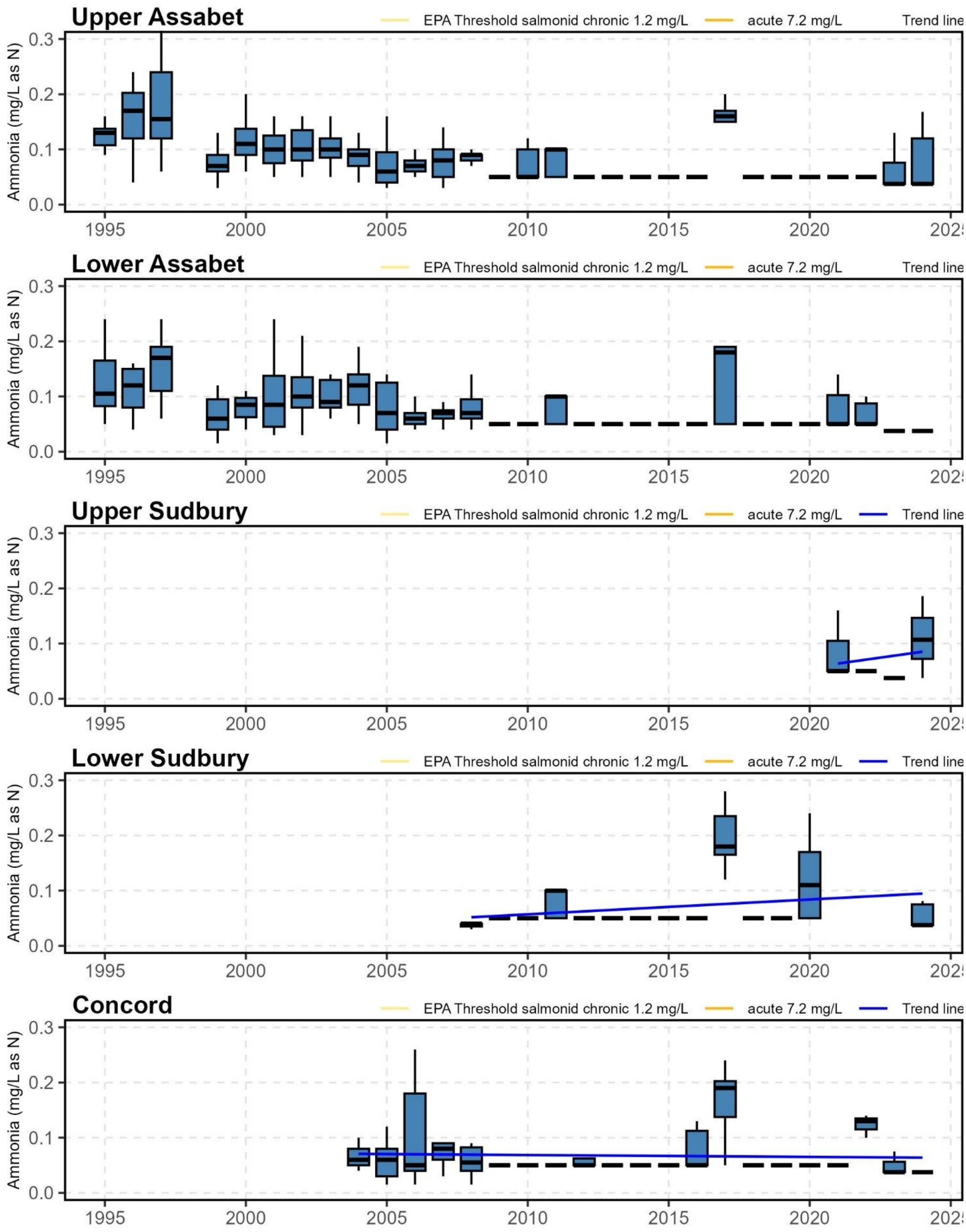


Figure 53: Ammonia concentration by year and section (June/July/August)

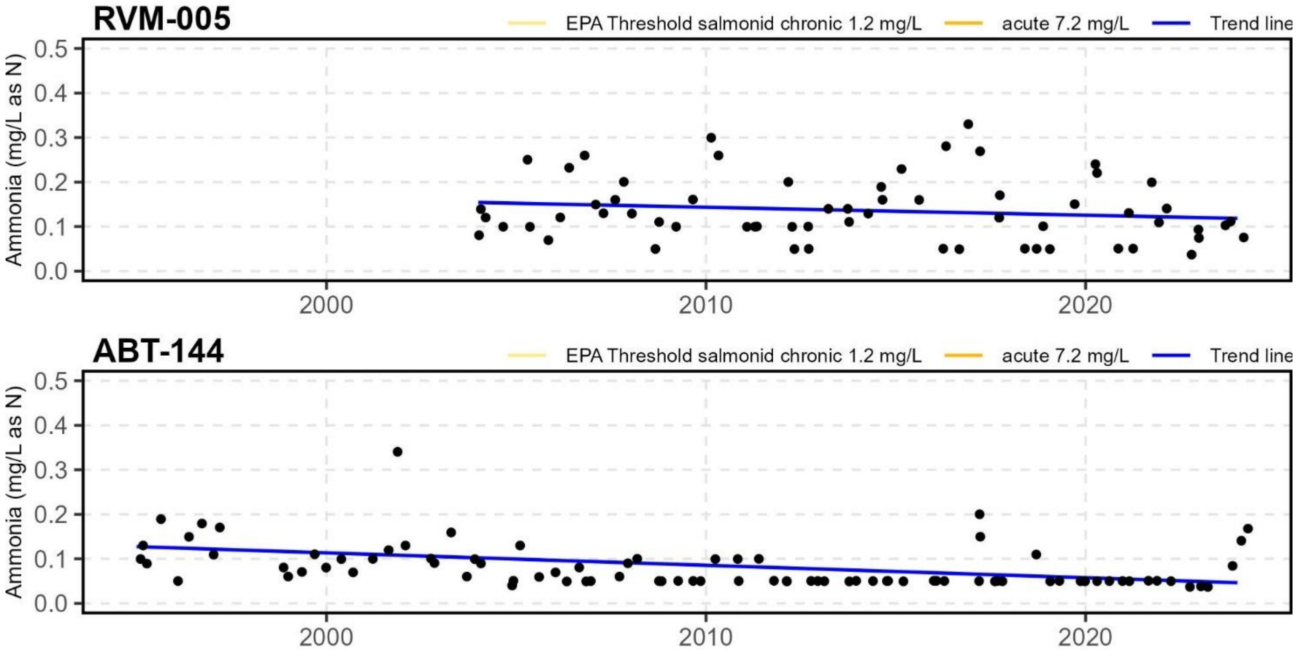


Figure 54: Ammonia concentration trends for selected sites (June/July/August)

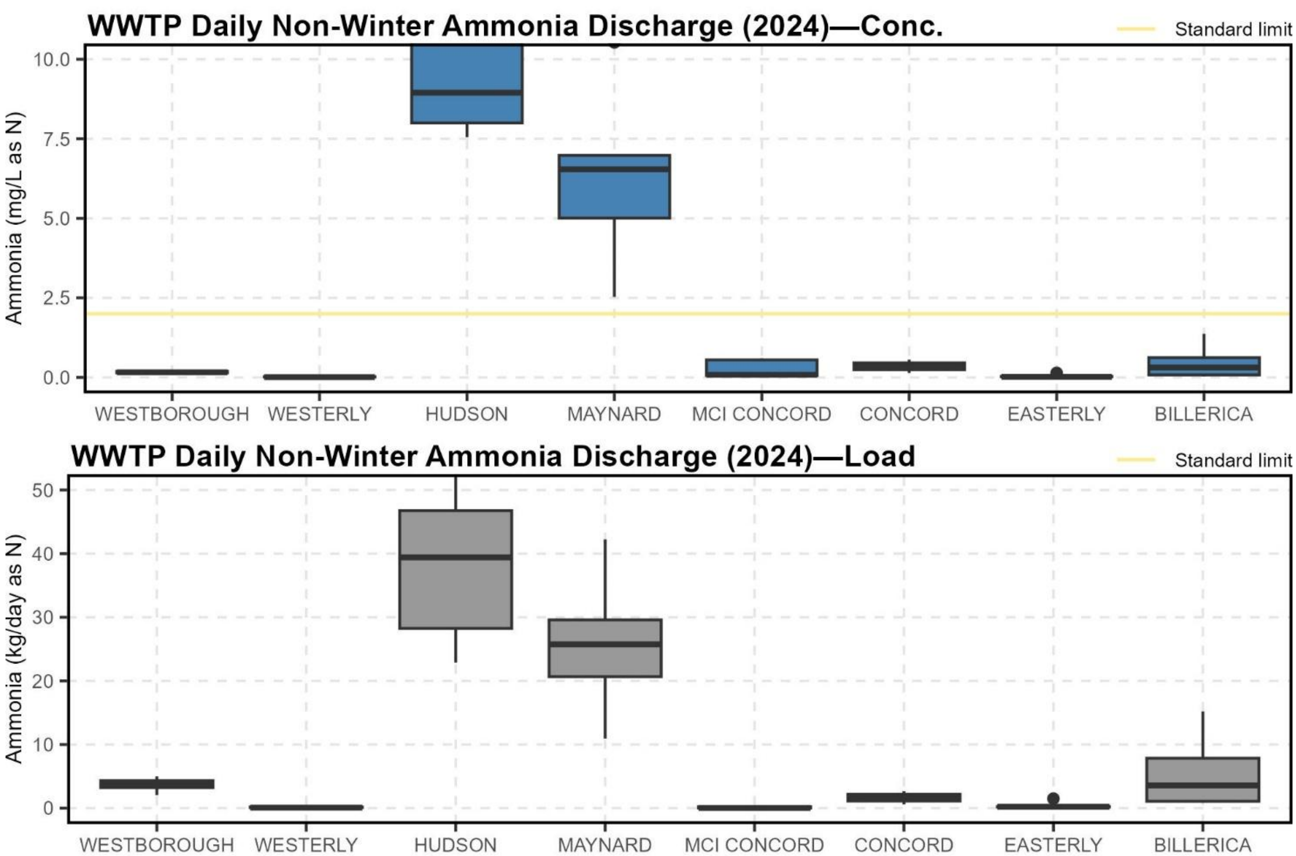


Figure 55: WWTP Daily Ammonia (NH_3 and NH_4^+) Discharge—summer (2024, Apr–Oct)

Total Suspended Solids

Total Suspended Solids (TSS) measures all non-dissolved particulates in the water. High concentrations of TSS can indicate erosion, runoff, live or decaying algae, disturbed sediment, or discharge of sediment-laden water.

In 2024, TSS levels at most sites were generally subdued, but two sites had elevated levels (Figure 56 and Figure 57). The Assabet River site downstream of the Marlborough Easterly WWTP (ABT-237) often has high TSS levels, but it recorded its highest level yet in August during the very low flows. This site is also immediately downstream of the Tyler Retarding Dam, which produces significant turbidity. Also, the Nashoba Brook Wheeler Lane site (NSH-047) recorded very high TSS levels in July. Historically, this is common for this site during low flow periods and is something we should look into to understand. See Figure 60 for time-series data for both sites.

Year-on-year analysis of TSS concentration shows improving trends in all river sections, perhaps due to improved non-point-source pollution controls (Figure 58). It also indicates that the Lower Sudbury and Concord tend to have the highest TSS concentrations. Year-on-year analysis of TSS load shows the effect of precipitation and high flows on total suspended solids load in 2013, 2021, and 2023 (Figure 59). In 2024, concentrations were very low in the Sudbury and Concord, and the load was extremely low in all rivers.

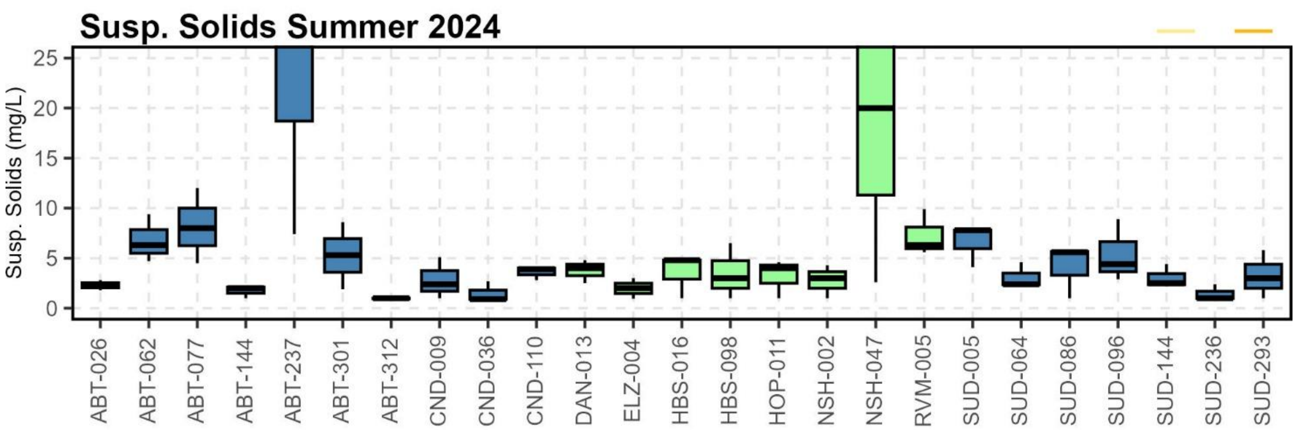


Figure 56: TSS concentration by site, summer (Jun–Aug 2024)

The tributary sites in this by-site chart are grouped together and colored green, from DAN-013 to RVM-005. Mainstem sites are grouped by river and listed in river mile sequence from downstream to upstream.

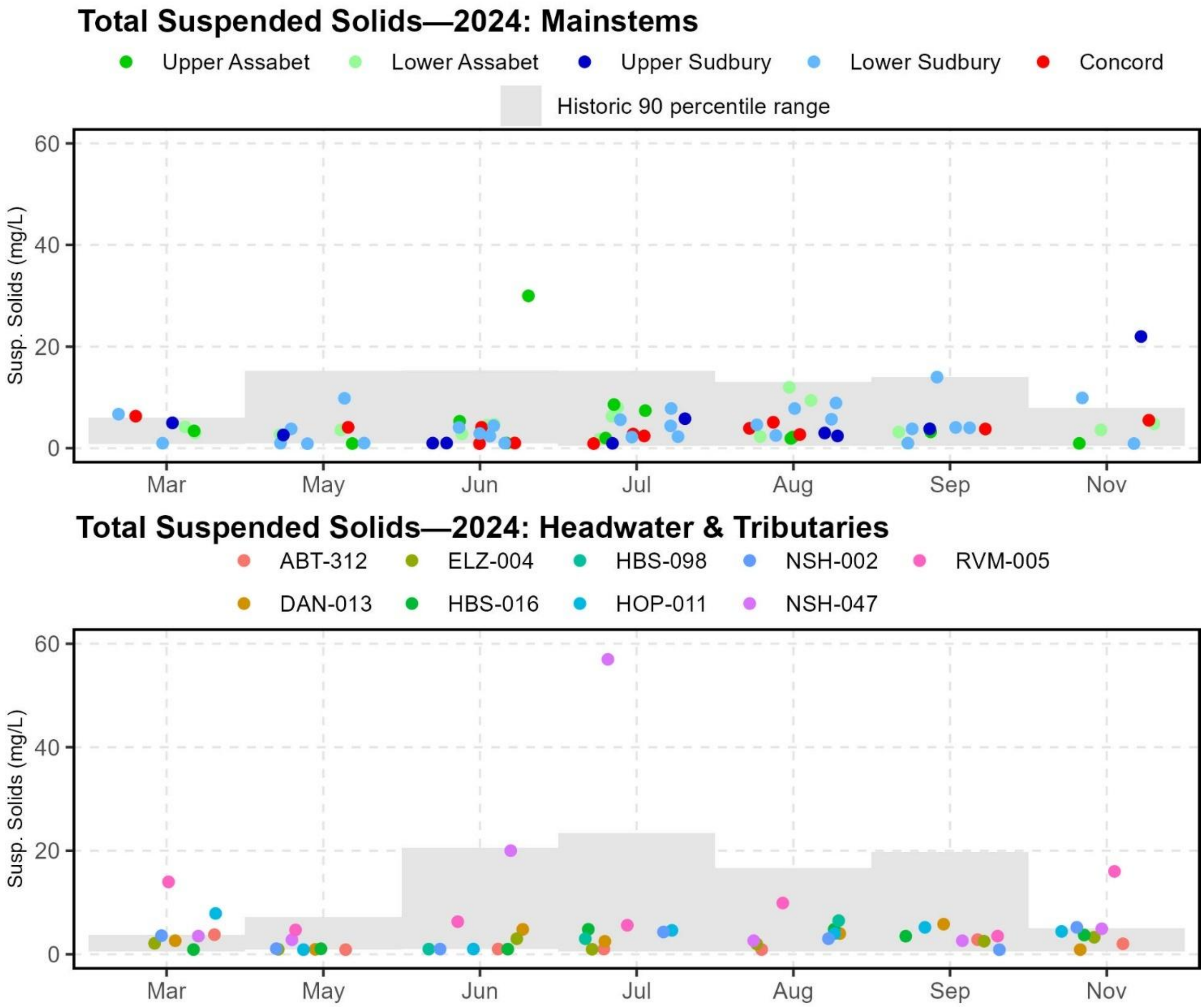


Figure 57: TSS concentration by month and site (2024)

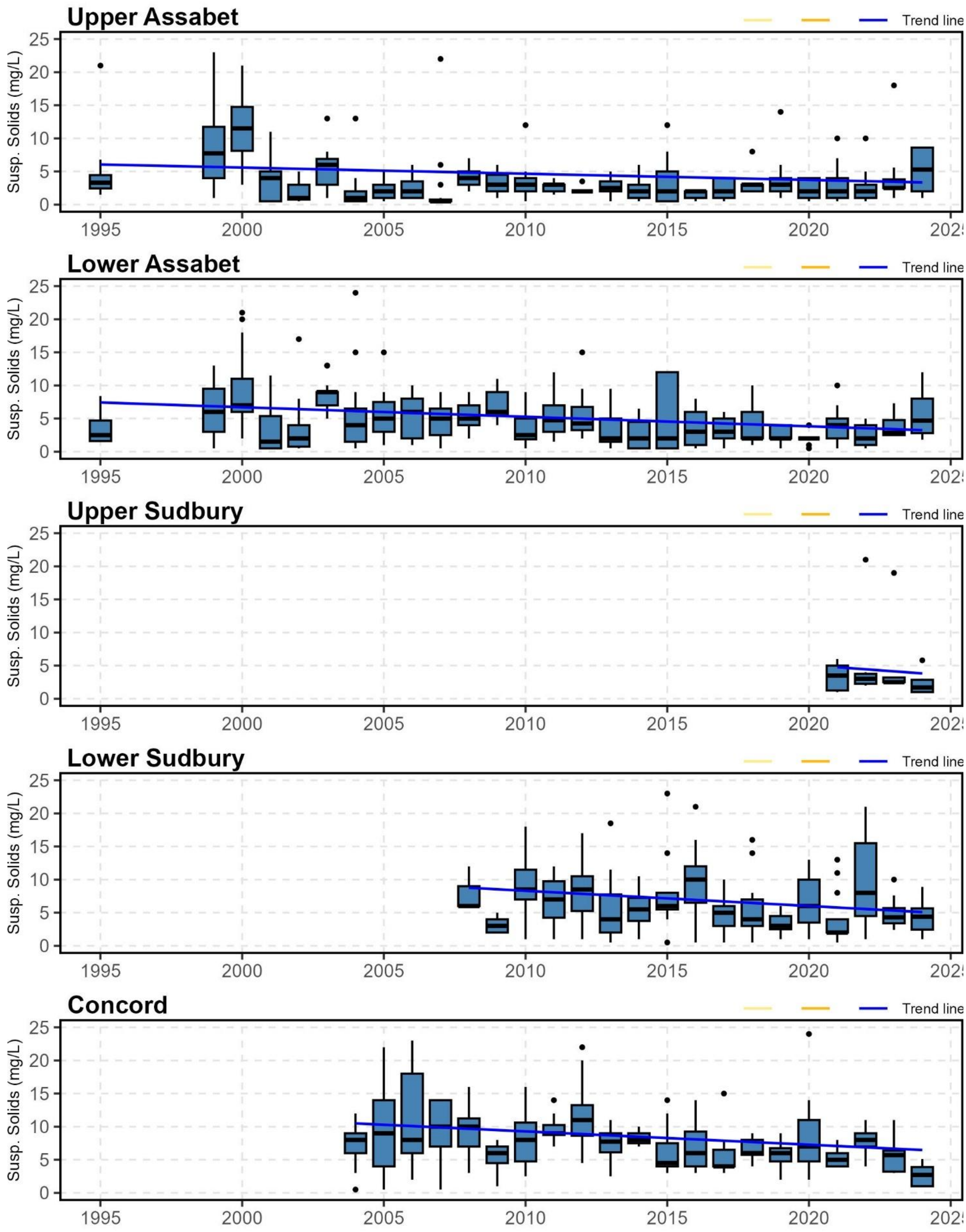


Figure 58: TSS concentration by year and section (June/July/August)

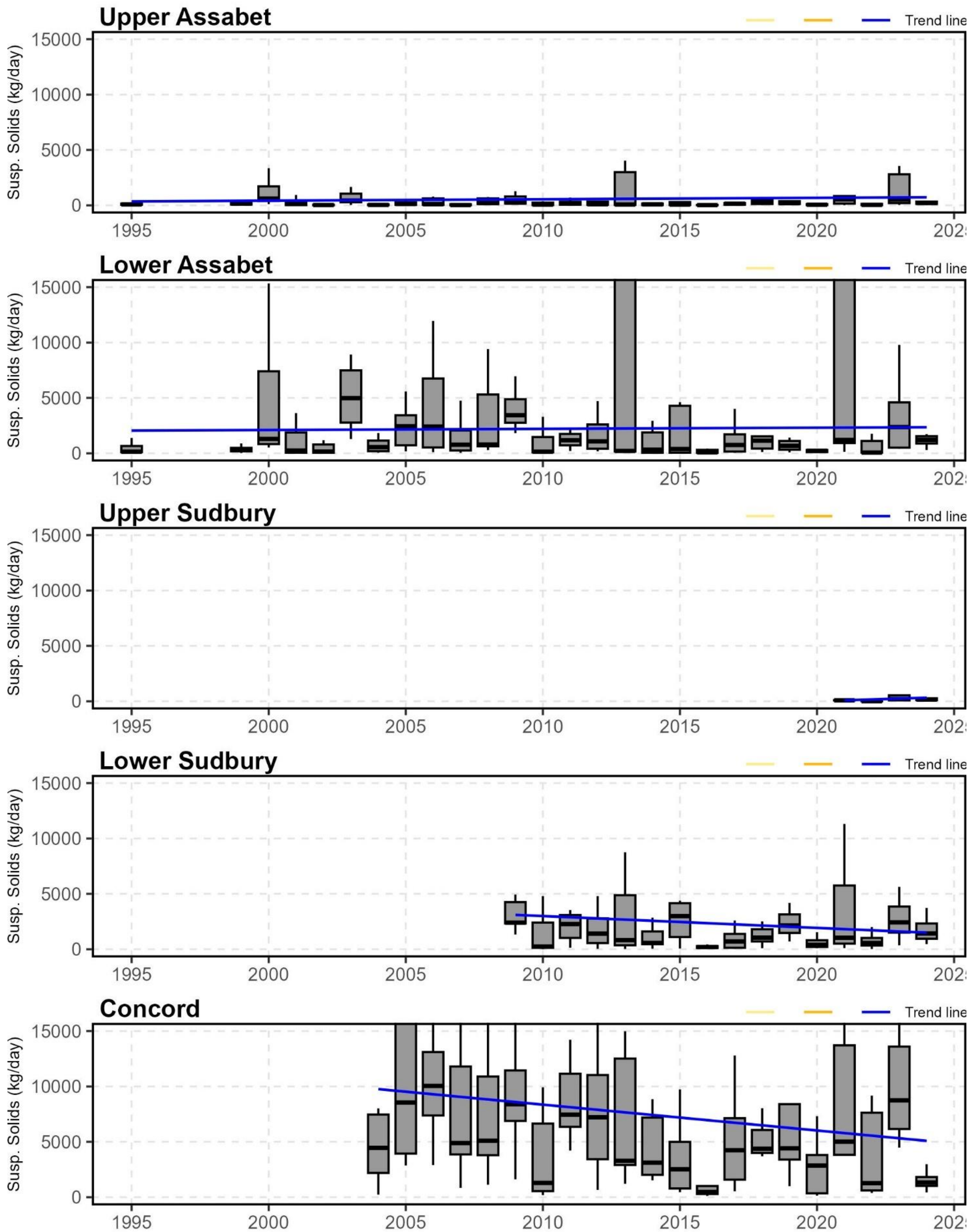


Figure 59: TSS estimated load by year and section (June/July/August)

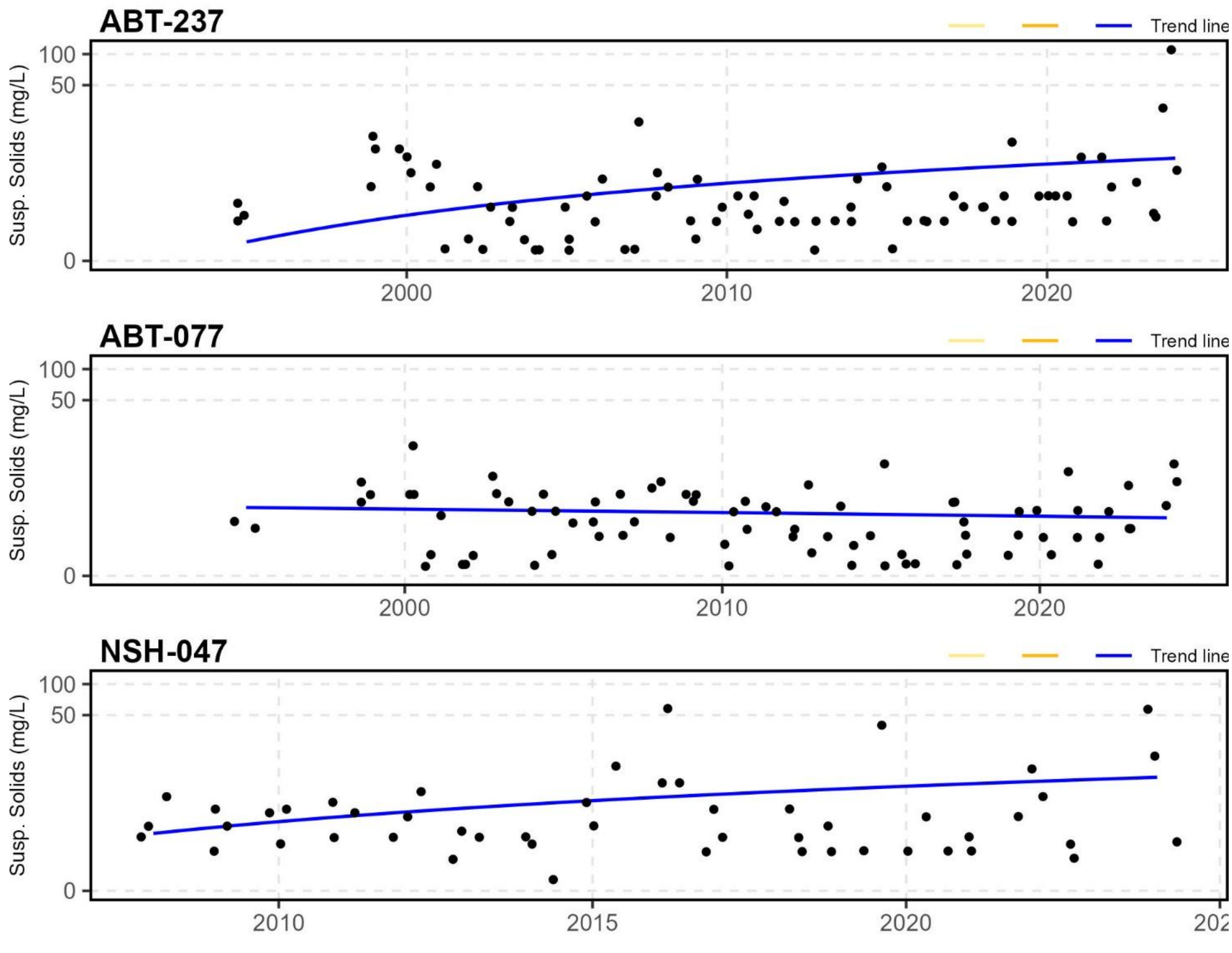


Figure 60: TSS concentration for selected sites (Jun/July/August)

Chlorophyll *a*

Chlorophyll *a* is the principal photosynthetic pigment in algae and vascular plants. Chlorophyll *a* concentration gives an estimate of the biomass of planktonic algae in the river and is an indicator of eutrophication. However, rivers like the Assabet, whose vegetation is dominated by larger rooted and floating aquatic plants, may have low chlorophyll *a* concentrations and still be considered eutrophic. There is no numeric standard for chlorophyll *a* in Massachusetts waters. Results have been compared to the EPA Ecoregion XIV summer reference conditions (25^{th} percentile 2 µg/L, and 50^{th} percentile 4 µg/L). OARS only samples for chlorophyll *a* in the Sudbury River and Hop Brook Sudbury in June, July, and August. The Concord and Assabet rivers are not sampled for chlorophyll *a*.

In 2024, chlorophyll *a* concentrations were mostly lower than normal, below 4 µg/L. However, the farthest downstream site (SUD-005) had results ranging from 7 to 24 µg/L (Figure 61 and Figure 62). Chlorophyll *a* concentrations in the Sudbury tend to increase downstream. This was clearly the case in the 2024 data. By month, chlorophyll *a* concentrations tend to increase from June to August. However, this is not a rule and depends on temperature and flow. There was a slight but not statistically significant increase in August 2024.

Year-on-year analysis of chlorophyll *a* is shown in Figure 63. Chlorophyll *a* concentrations tend to have a strong inverse correlation with summer rainfall, meaning that low rainfall results in high chlorophyll *a* concentrations. Our data produce a downward trend line, which is highly skewed by the high chlorophyll *a* levels in 2010, which seem to be an anomaly. Most samples in 2024 were abnormally low, despite the low rainfall, though there were a few outliers between 7 and 25 µg/L. The low chlorophyll levels may be related to the post-flooding dynamics we also saw in DO, described above.

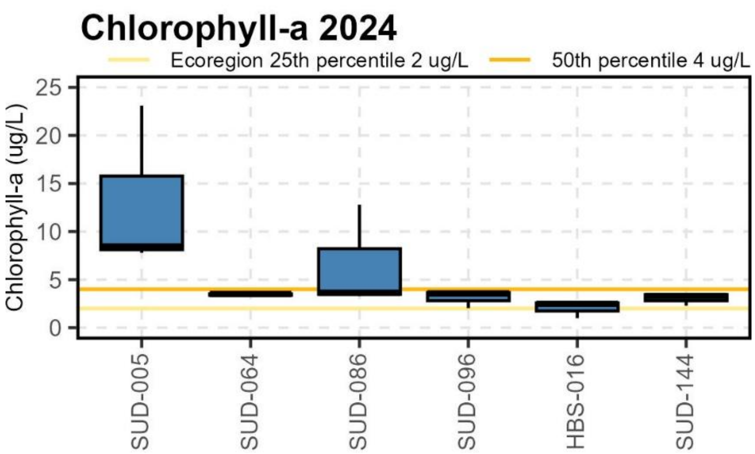


Figure 61: Chlorophyll *a* concentration by site, summer (Jun–Aug 2024)

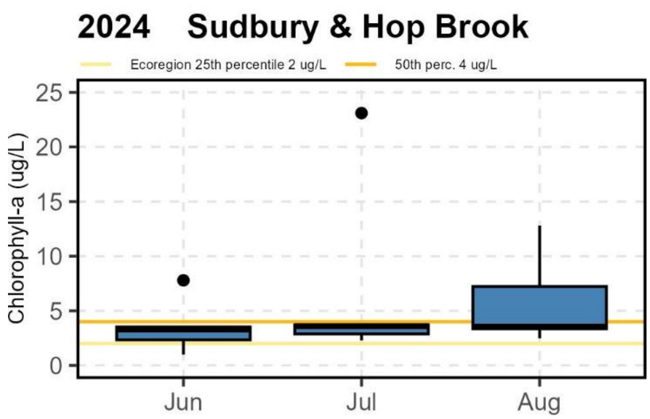


Figure 62: Chlorophyll *a* concentration by month (2024)

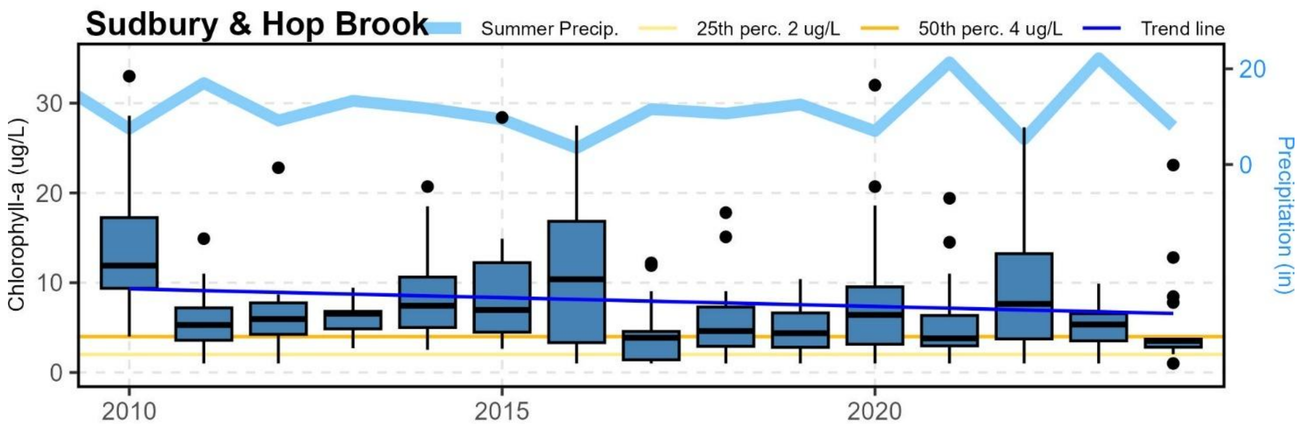


Figure 63: Chlorophyll *a* concentration by year (June/July/August)

Water Quality Index Calculations

The Water Quality Index is used to assess water quality in the mainstems of the Sudbury, Assabet, and Concord rivers. It was developed in 2002 as part of OARS' StreamWatch project in collaboration with the United States Geological Survey, the Massachusetts Division of Fisheries and Wildlife, and Massachusetts Audubon. It was designed to rate summer conditions when the river habitat is most stressed. It is also a major component of the OARS River Report Card[8]. For the Report Card, the index is calculated as a five-year rolling average for samples taken between May 1st and September 30th at 15 mainstem sampling sites. Calculations for the 2024 five-year average are compared with the 2018 five-year average in Table 10 because 2018 was a relatively favorable year for the index and was the first iteration of the River Report Card. The overall index declined over these five years primarily due to the impact of drought and flood cycles. Between 2014 and 2018, there were four years with average precipitation and one drought year. In comparison, between 2020 and 2024, there were two major drought years and two major flood years. Both droughts and floods have adverse impacts on phosphorus and dissolved oxygen.

Year-on-year tracking of the Water Quality Index shows a general downward (worsening) trend since 2018 for the Concord and Sudbury (Figure 64). As mentioned earlier, the index is highly influenced by precipitation and flooding, which affected pollutant concentrations and dissolved oxygen in the Concord and Sudbury. The Upper Assabet's index has historically been especially low due to nitrate concentrations, but it has been improving as a result of TP, DO, and recent NO_3 improvements. We only started computing the index for the Upper Sudbury in 2021.

Table 10: Water Quality Index calculations (2024 vs. 2018)

2014–2018	Nitrate	Total Phosphorus	Total Suspended Solids	Dissolved Oxygen	Temperature	WATER QUALITY INDEX (harmonic mean)
Upper Assabet	18	81	83	79	94	41
Lower Assabet	47	81	77	82	91	70
ASSABET (area weighted)	32	81	80	81	92	55
Upper Sudbury	NA	NA	NA	NA	NA	NA
Lower Sudbury	96	79	65	70	93	76
SUDBURY (area weighted)	96	79	65	70	93	76
Upper Concord	75	77	59	74	87	70
Lower Concord	61	75	60	82	86	68
CONCORD (area weighted)	73	77	59	75	87	70
WATERSHED (area weighted)	64	80	71	75	92	66

2020–2024	Nitrogen	Phosphorus	Suspended Solids	Dissolved Oxygen	Temperature	WATER QUALITY INDEX (harmonic mean)
Upper Assabet	21	61	77	80	92	45
Lower Assabet	47	62	76	85	89	67
ASSABET (area weighted)	34	61	76	82	90	56
Upper Sudbury	92	57	74	50	94	61
Lower Sudbury	95	58	68	59	89	63
SUDBURY (area weighted)	94	58	71	55	91	62
Upper Concord	69	56	62	62	81	62
Lower Concord	58	56	66	83	83	64
CONCORD (area weighted)	68	56	62	64	82	62
WATERSHED (area weighted)	63	59	72	68	90	59

[8] **ecoreportcard.org**

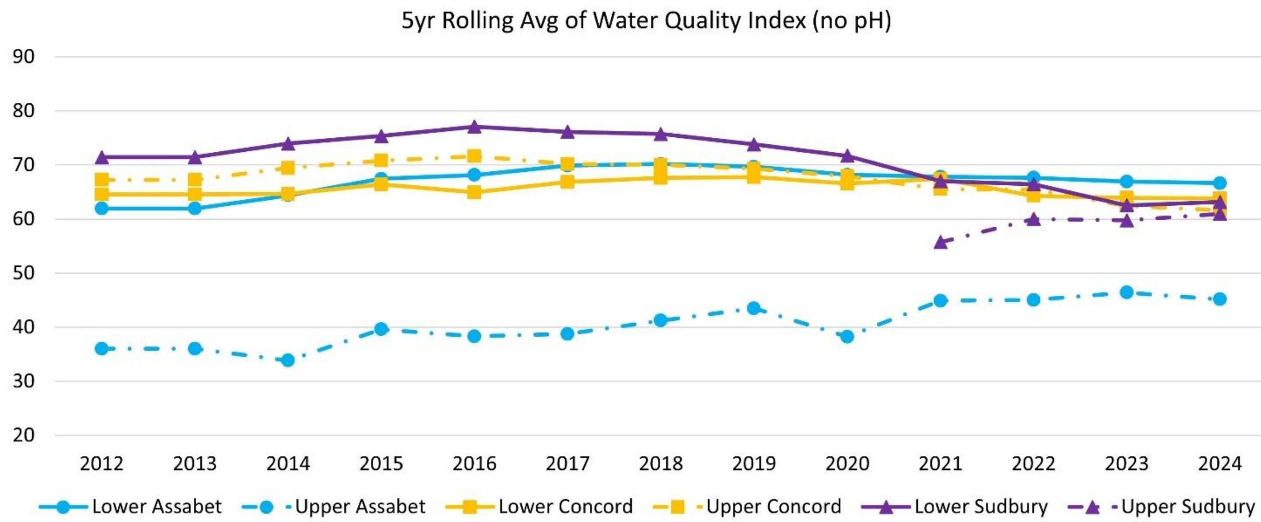


Figure 64: Water Quality Index year-on-year rolling averages (2012–2024)

Bacteria Results

OARS has been monitoring for *Escherichia coli* (*E. coli*) bacteria at six locations in the Assabet, Sudbury, and Concord rivers since 2019. *E. coli* is used as an indicator of fecal contamination in water bodies, and Mass DEP has defined safety threshold values for recreational swimming and boating (MassDEP, 2021, based on EPA, 2012). The swimming threshold for the geometric mean of a series of samples over a 30- to 90-day period is 126 CFU/100 ml[9], and no more than 10% of samples can exceed 410 CFU/100 ml. The Beach Action Value (BAV) for single samples is 235 CFU/100 ml.

In 2024, the sites with the highest and most concerning bacteria levels were consistent with previous years (Figure 65). River Meadow Brook in Lowell and the Maynard site both exceeded the BAV more than 70% of the time. The Concord River in Lowell, the Ashland site, and the Hudson site all exceeded the BAV more than 30% of the time. All five of these sites had seasonal geometric means above 126 CFU/100 ml. They also all had dry-weather bacteria levels exceeding the BAV, which indicates a high probability of sanitary sewer contamination (Figure 66). Please see our 2024 Bacteria Monitoring Results report for more details (OARS, 2024b).

Ashland Bacteria Special Study

In 2024, OARS conducted a special study of bacteria levels below the Union Street bridge in Ashland. As part of the study, OARS conducted bacterial source tracking, environmental DNA analysis, and detergent indication surveys. The study found the municipal storm sewer outfall between 50 Main Street and 98 Main Street to be the primary source of pollution in this section of the river, and it highlighted three other pipes that were worth follow-up. The results were shared with the Ashland Department of Public Works. Please see our white paper "Sudbury River Ashland Bacteria Study—2024" for a detailed summary of the study (OARS, 2025b). Funding for the study was provided by the Greater Lowell Community Foundation.

[9] CFU stands for colony-forming unit and is a standard reporting measure for bacteria. It is functionally interchangeable with MPN (Most Probable Number).

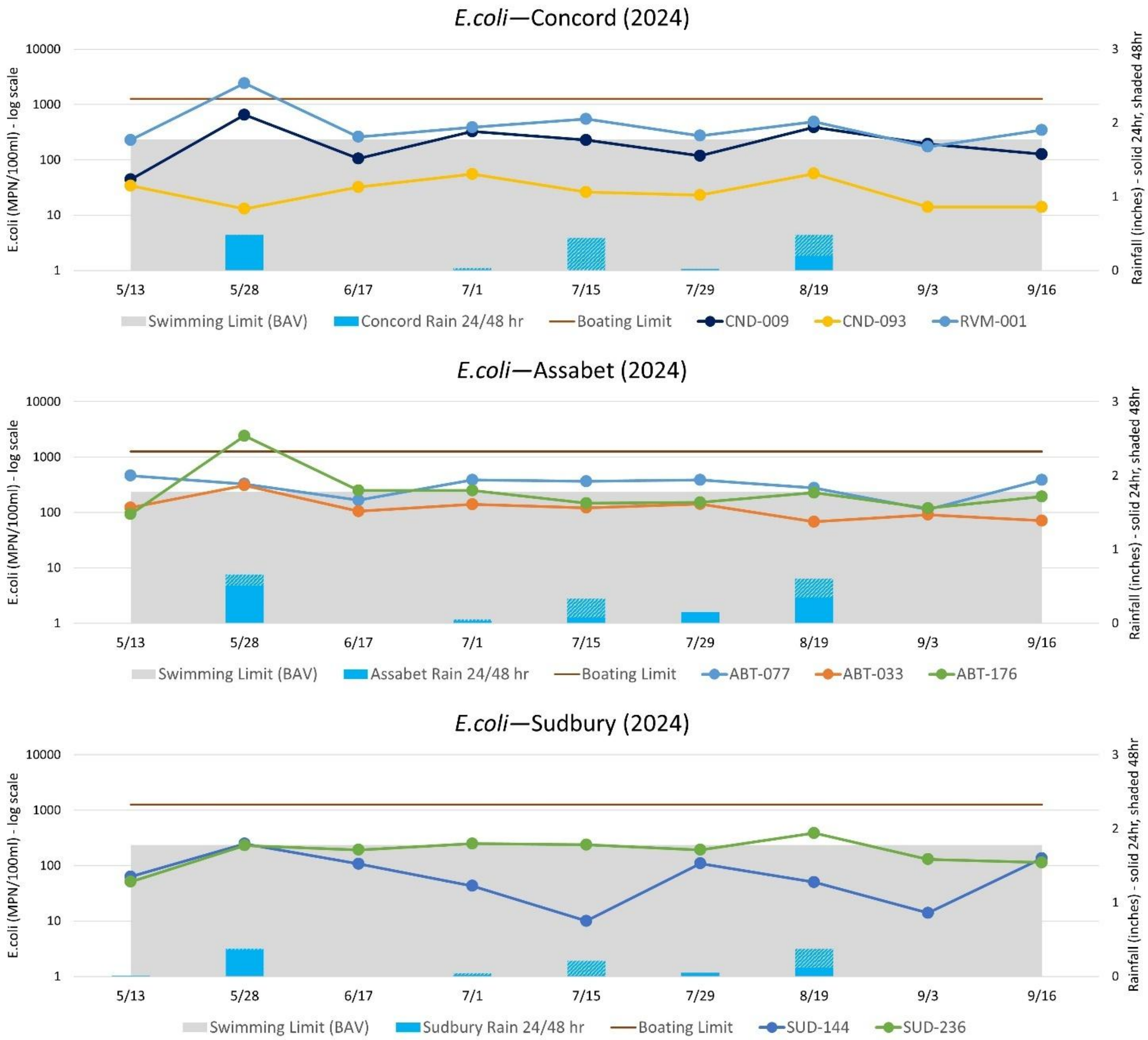


Figure 65: Graphical view of bacteria vs. rainfall (2024)

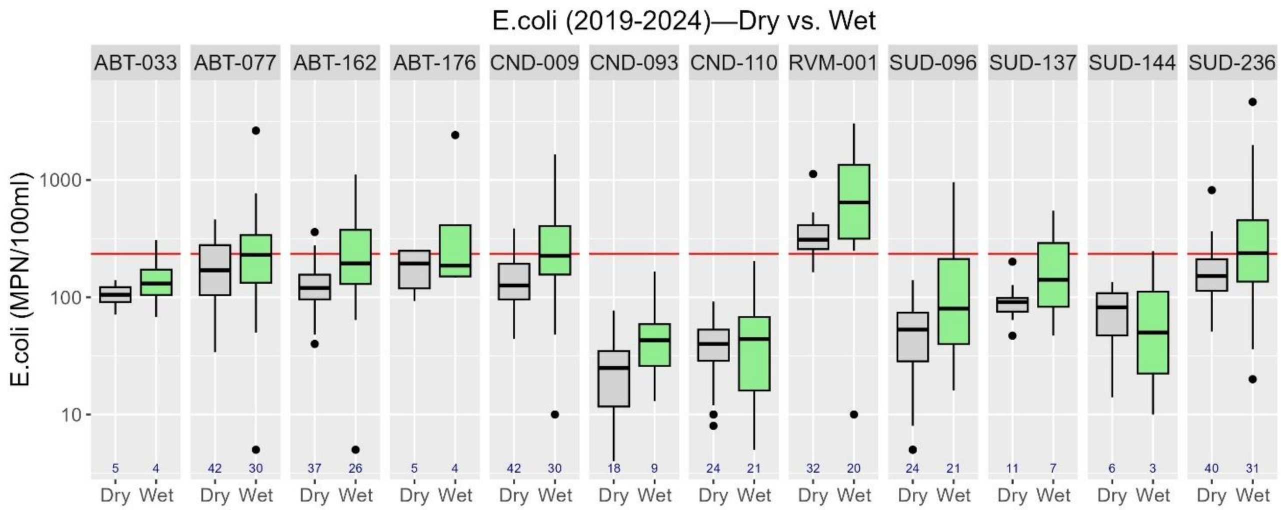


Figure 66: Boxplot analysis of bacteria for wet vs. dry days (2019–2024)

Aquatic Plant Biomass Monitoring

Three large impoundments of the Assabet River have been visually surveyed for aquatic plant biomass between mid-August and early September each year since 2005, following methodology developed by the USGS (Zimmerman et al., 2011). The goals of the ongoing project are to assess the nature and extent of aquatic plant biomass in the major impoundments of the Assabet River and to assess changes in the river's condition and progress in achieving the TMDL goal of reducing biomass by at least 50% from July 1999 values (MassDEP, 2004).

The estimated wet weight[10] of total floating biomass for the Hudson, Gleasondale, and Ben Smith impoundments from 2005 to 2024 is shown in Figure 67. Trend lines for each impoundment are drawn in the graph, showing an upward trend in biomass for Hudson, a downward trend for Ben Smith, and no visible trend for Gleasondale. The previous summer, 2023, was characterized by very heavy precipitation. It was the wettest summer since OARS' biomass surveys began, and biomass in all three impoundments was significantly reduced as a result of the high flows. In 2024, biomass jumped back up to previous levels, especially in Ben Smith. The Hudson impoundment has been choked with biomass for most recent years, with a dominance of filamentous green algae, and this was repeated in 2024. Ben Smith was showing signs of improvement, but in 2024, it returned to earlier high levels. A similar analysis of duckweed (Figure 68) shows the same upward spike for Ben Smith in 2024.

Because aquatic plant growth is strongly affected by precipitation and temperature, correlation coefficients have been calculated between biomass and temperature and biomass and rainfall (Table 11). All three impoundments show an inverse correlation with rainfall, especially Ben Smith. There is a tendency toward a positive correlation with temperature, but only Hudson has a consistently strong positive correlation. Hudson is the shallowest of the three impoundments.

Please see our white paper "OARS Biomass Summary 2024" for a detailed summary of biomass results (OARS, 2024c).

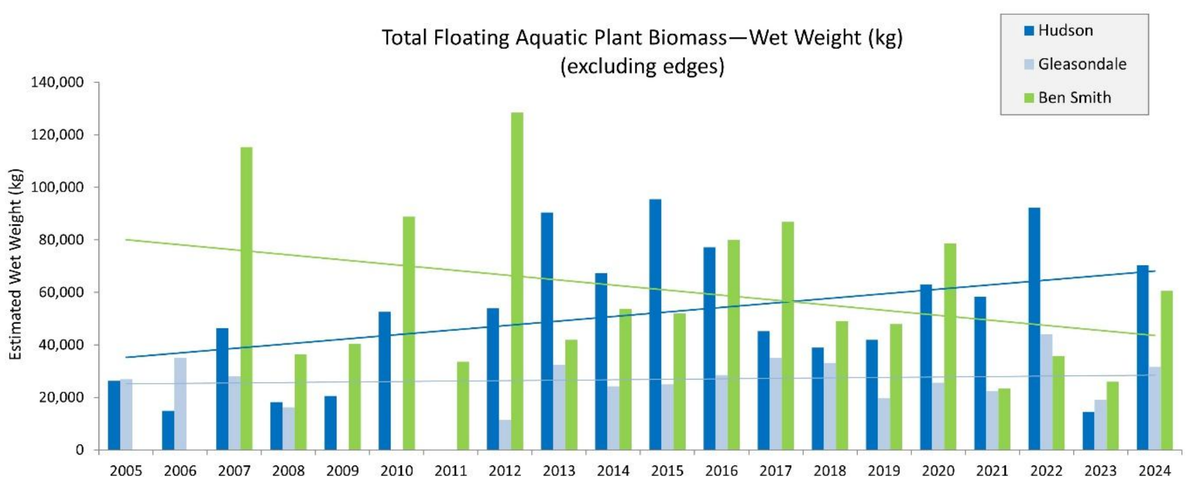


Figure 67: Total floating aquatic plant biomass (2005–2024)

[10] Wet weight estimated based on conversion factors for coverage classes: Class 0 = 0 g/m2; Class 1 = 427 g/m2; Class 2 = 1,186 g/m2; Class 3 = 2,000 g/m2; Class 4 = 2,855 g/m2; Class 5 = 3,782 g/m2. Area * class conversion factor /1,000 = total wet weight in kilograms.

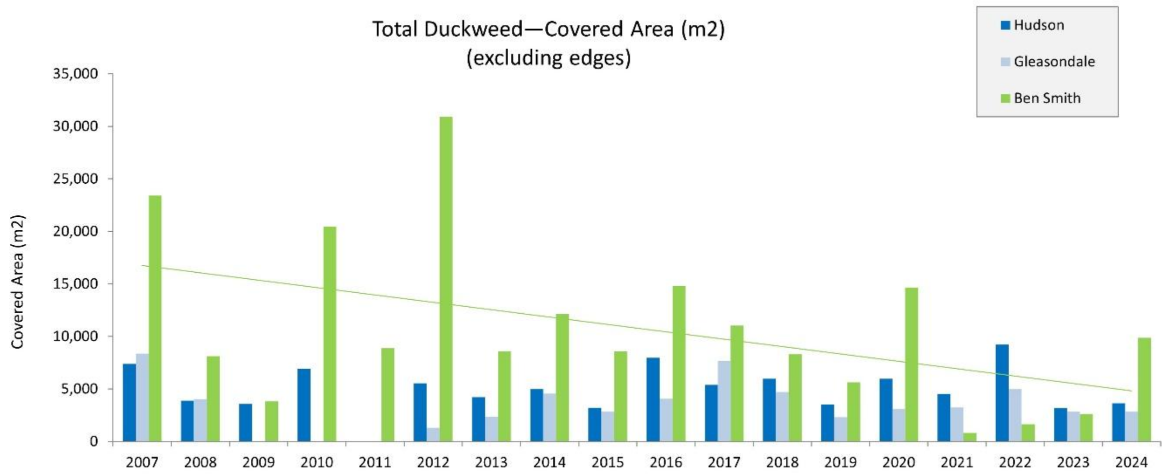


Figure 68: Total duckweed coverage (2007–2024)

Table 11: Pearson Correlation Coefficients—Total Biomass vs Temperature and Rainfall

Pearson Corr.	Hudson	Gleasondale	Ben Smith
Temperature	0.27	0.19	0.03
Precipitation	-0.56	-0.31	-0.64

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Appendix I Mainstem Statistics

2024 Statistics—Mean values (calculated on ½ detection level where sample is Below Detection Limit)

	Reach	# Sites	Temp (°C)	DO % Sat	DO Conc (mg/L)	Cond (µS/cm)	pH	TSS (mg/L)	TP (mg/L)	ortho-P (mg/L)	NO_3-N (mg/L)	NH_3-N (mg/L)	Cl- (mg/L)	Chl (µg/L)
March 24, 2024	Concord	1	2.9	106	14.3	351	7.1	6.3	0.040	0.010	0.38			
	Lower Assabet	2	2.9	103	13.8	352	7.1	3.6	0.035	0.010	0.59	0.04	83	
	Upper Assabet	1	4.2	94	12.2	359	6.9	3.4	0.030	0.010		0.20	71	
	Lower Sudbury	2	4.2	96	12.6	327	7.1	3.9	0.025	0.010	0.25		76	
	Upper Sudbury	1	1.7	83	11.5	296	6.6	5.0	0.020	0.010		0.04		
May 12, 2024	Concord	1	15.8	90	8.9	426	6.9	4.1	0.040	0.003	0.49			
	Lower Assabet	2	14.5	92	9.4	405	7.2	3.2	0.050	0.003	0.61	0.04		
	Upper Assabet	1	14.4	87	8.9	849	7.1	0.9	0.030	0.003		0.04	190	
	Lower Sudbury	5	15.2	66	6.6	389	6.9	3.3	0.023	0.003	0.09	0.04		
	Upper Sudbury	1	12.6	53	5.7	380	6.6	2.6	0.060	0.003		0.04		
June 16, 2024	Concord	3	22.6	87	7.5	475	6.9	2.0	0.050	0.017	0.82	0.04		
	Lower Assabet	3	21.7	92	8.1	585	7.3	4.0	0.060	0.010	1.52	0.04		
	Upper Assabet	3	19.8	87	7.9	667	7.2	12.1	0.047	0.008	2.32	0.08	120	
	Lower Sudbury	5	21.7	61	5.3	393	6.7	3.0	0.046	0.012	0.16	0.05		4.0
	Upper Sudbury	2	19.4	64	5.8	391	6.8	1.0	0.050	0.015	0.17	0.04		
July 14, 2024	Concord	3	27.6	83	6.5	500	6.9	2.0	0.043	0.020	0.85	0.04		
	Lower Assabet	3	27.0	90	7.2	705	7.4	5.4	0.030	0.005	1.04	0.04		
	Upper Assabet	3	24.6	77	6.4	876	7.3	6.0	0.043	0.013	4.75	0.05	180	
	Lower Sudbury	5	26.8	64	5.1	425	6.8	4.5	0.043	0.022	0.17	0.06		7.3
	Upper Sudbury	2	25.2	53	4.3	419	6.9	3.4	0.060	0.030	0.18	0.19		

2024 Statistics—Mean values (calculated on ½ detection level where sample is Below Detection Limit)

	Reach	# Sites	Temp (°C)	DO % Sat	DO Conc (mg/L)	Cond (µS/cm)	pH	TSS (mg/L)	TP (mg/L)	ortho-P (mg/L)	NO_3-N (mg/L)	NH_3-N (mg/L)	Cl- (mg/L)	Chl (µg/L)
August 18, 2024	Concord	3	23.4	84	7.1	479	6.9	3.9	0.037	0.010	0.76	0.04		
	Lower Assabet	3	22.7	93	8.0	683	7.7	7.9	0.037	0.008	1.29	0.04		
	Upper Assabet	3	21.7	83	7.3	1060	7.3	38.0	0.037	0.010	4.63	0.10	290	
	Lower Sudbury	5	21.9	76	6.5	369	6.9	5.9	0.038	0.010	0.12	0.04		6.3
	Upper Sudbury	2	21.2	60	5.3	533	6.7	2.7	0.050	0.020	0.11	0.11		
September 15, 2024	Concord	1	21.3	102	9.1	544	7.4	3.8	0.030	0.003	2.61			
	Lower Assabet	2	19.9	82	7.5	921	7.3	2.1	0.015	0.006	1.60	0.04		
	Upper Assabet	1	20.9	69	6.2	1979	7.3	3.2	0.050	0.020		0.04	470	
	Lower Sudbury	5	21.2	81	7.2	526	7.1	5.4	0.030	0.009	0.24	0.04		
	Upper Sudbury	1	18.9	48	4.5	771	6.7	3.8	0.050	0.020		0.04		
November 10, 2024	Concord	1	10.1	97	10.9	826	7.5	5.5	0.020	0.010	3.68			
	Lower Assabet	2	8.4	90	10.6	1051	7.5	4.2	0.020	0.003	5.21	0.13		
	Upper Assabet	1	11.8	101	10.9	1547	7.6	1.0	0.080	0.050		0.04	370	
	Lower Sudbury	2	8.2	83	9.8	651	7.3	5.4	0.020	0.003	0.05			
	Upper Sudbury	1	5.1	52	6.6	913	6.8	22.0	0.120	0.020		0.04		

Blank = not sampled/not recorded/censored

Appendix II Data Quality Notes

OARS' data quality objectives and data qualifiers are listed below. Full QC details are available in OARS' annual Quality Control Report on request (OARS, 2025).

Data Quality Objectives

Parameter	uom	MDL	UQL	Value Range	Field Duplicate	Lab Duplicate	Field Blank	Lab Blank	Spike/Check Accuracy
Air Temp	deg C	-	-	all	<= 2.0	-	-	-	-
Ammonia	mg/l	0.075	-	all	< 30%	< 20%	BDL	BDL	<= 15%
Chl a	ug/l	2	-	< 15	<= 2	<= 2	BDL	BDL	-
Chl a	ug/l	2	-	>= 15	< 20%	< 20%	BDL	BDL	-
Chloride	mg/l	1	-	all	< 30%	< 20%	BDL	BDL	<= 15%
DO	mg/l	-	-	< 4	< 20%	-	-	-	-
DO	mg/l	-	-	>= 4	< 10%	-	-	-	-
DO saturation	%	-	-	all	-	< 10%	-	<= 5	<= 5
E.coli	MPN/100ml	1	-	< 50	< log30%	< log30%	BDL	BDL	-
E.coli	MPN/100ml	1	-	>= 50	< log20%	< log20%	BDL	BDL	-
E.coli	MPN/100ml	1	-	>= 500	< log10%	< log10%	BDL	BDL	-
E.coli	MPN/100ml	1	-	>= 5000	< log5%	< log5%	BDL	BDL	-
Flow	cfs	-	-	all	-	-	-	-	-
Gauge	ft	-	-	all	<= 0.01	-	-	-	-
Nitrate	mg/l	0.1	-	all	< 30%	< 20%	BDL	BDL	<= 15%
Ortho P	mg/l	0.005	-	< 0.05	<= 0.01	<= 0.01	< 0.01	< 0.01	<= 15%
Ortho P	mg/l	0.005	-	>= 0.05	< 20%	< 20%	< 0.01	< 0.01	<= 15%
pH	-	-	-	all	<= 0.5	<= 0.5	-	-	<= 0.2
Sp Conductance	uS/cm	-	-	< 250	< 30%	< 30%	-	<= 50	<= 50
Sp Conductance	uS/cm	-	-	>= 250	< 20%	< 20%	-	<= 50	<= 50
TP	mg/l	0.01	-	< 0.05	<= 0.01	<= 0.01	BDL	BDL	<= 15%
TP	mg/l	0.01	-	>= 0.05	< 30%	< 20%	BDL	BDL	<= 15%
TSS	mg/l	2	-	<= 3	<= 1	<= 1	BDL	BDL	-
TSS	mg/l	2	-	> 3	< 30%	< 20%	BDL	BDL	-
Water Temp	deg C	-	-	all	<= 1.0	<= 1.0	-	-	<= 1.0

Summary of qualified and censored data:

Parameter	Number of Data Records	Number of Qualified Records	Number of Missed/ Censored Records	% Completeness	Hit/ Miss	Notes
Air Temp	148	0	11	93%		11 measurements not collected due to unavailability of thermometer
Ammonia	107	25		77%	MISS	Qualified all ammonia results between ND and 0.225 mg/L (0.075+0.150) because the lab's tolerance range of 0.150 mg/L is larger than the normal value range for our data.
Chl *a*	18	3		83%	MISS	8/19/24 three samples (HBS-016, SUD-086, SUD-096) held for extended time without ice
Chloride	9	0		100%		
DO	159	1		99%		6/16/24 CND-009 handwritten record and logger record didn't match—used logger record
DO saturation	159	1		99%		6/16/24 CND-009 handwritten record and logger record didn't match—used logger record
E.coli	109	4		96%		7/15/24 SUD-236, SUD-242, SUD-245, SUD-252 temperature of the cooler above 7°C for more than 60 minutes

Parameter	Number of Data Records	Number of Qualified Records	Number of Missed/ Censored Records	% Completeness	Hit/ Miss	Notes
Flow	74	12		84%		DAN-013, NSH-002 qualified all estimates because flow checks differed from flow curve by more than 15%
Gauge	74	1		99%		5/12/24 RVM-005 staff gauge read from a distance and from pictures due to high water
Nitrate	89	0		100%		
Ortho P	159	1		99%		Field duplicate miss. 11/10/24 CND-009 0.11 mg/L duplicate result is an outlier for this site or date. Qualified this record only. Using lower value.
pH	159	1		99%		6/16/24 CND-009 handwritten record and logger record didn't match—used logger record
Sp Conductance	159	0		100%		
TP	167	3	2	97%		5/12/24 SUD-064, SUD-086—censored result due to suspected bottle mix-up 5/12/24 SUD-096—chance of a bottle mix-up but believed to be accurate 7/14/24 SUD-086—qualified due to unusually high value and muddy sample 6/16/24 ABT-237—duplicate miss
TSS	141	7		95%		5/12/24 SUD-064, SUD-086, SUD-096—chance of a bottle mixup but believed to be accurate 6/16/24 ABT-237—duplicate miss 6/16/24 NSH-047—duplicate miss 7/14/24 ABT-301—duplicate miss 9/15/24 SUD-293—duplicate miss
Water Temp	255	0		100%		

Appendix III Water Quality Data

(contact OARS for full data set)

Appendix IV Aquatic Plant Biomass Survey Data

Section	Year	Class 0 Area (m^2) No floating biomass	Class 1 Area (m^2) 1–25% cover	Class 2 Area (m^2) 26–50% cover	Class 3 Area (m^2) 51–75% cover	Class 4 Area (m^2) 76–99% cover	Class 5 Area (m^2) 100% cover
Hudson Impoundment	2005	12881	20779	5782	1764	1655	623
	2006	26376	13221	0	2122	1764	0
	2007	0	21643	8635	12582	623	0
	2008	1954	40907	623	0	0	0
	2009	10676	24186	8621	0	0	0
	2010	7475	22760	0	4038	0	9210
	2011	nr	nr	nr	nr	nr	nr
	2012	3807	11207	18918	4340	1764	3447
	2013	6091	1780	11557	5776	5128	13151
	2014	2582	13686	13625	1764	3204	8622
	2015	0	7871	9299	3204	13691	9418
	2016	3005	11618	10256	4878	1708	12018
	2017	0	22060	16212	1764	0	3447
	2018	623	20526	17802	4533	0	0
	2019	0	22215	16034	1764	3469	0
	2020	0	14895	12379	8781	3982	3447
	2021	0	11583	19884	5210	6807	0
	2022	0	4888	15078	5289	7794	10435
	2023	13460	27805	2218	0	0	0
	2024	8792	13788	2307	2572	4338	11687
Ben Smith Impoundment	2005	nr	nr	nr	nr	nr	nr
	2006	nr	nr	nr	nr	nr	nr
	2007	5364	45609	11985	3732	4204	16431
	2008	15773	68668	715	0	2167	0
	2009	48373	24687	4096	4605	5564	0
	2010	13628	42568	7981	10460	8314	4373
	2011	22162	61505	0	3657	0	0
	2012	14769	20069	14608	15488	14098	8292
	2013	25480	51180	7828	0	0	2835
	2014	7475	56407	22726	0	0	715
	2015	24425	44325	11964	0	6610	0
	2016	0	52585	21321	7052	6366	0
	2017	0	51185	25782	715	3776	5865
	2018	13847	50146	23331	0	0	0
	2019	23643	44693	11252	7736	0	0
	2020	0	52826	22111	9536	0	2852
	2021	32574	54750	0	0	0	0
	2022	20300	59168	7140	0	715	0
	2023	33678	49567	4079	0	0	0
	2024	0	58149	28459	0	715	0
Gle	2005	17488	0	2056	0	539	6062

Section	Year	Class 0 Area (m^2) No floating biomass	Class 1 Area (m^2) 1–25% cover	Class 2 Area (m^2) 26–50% cover	Class 3 Area (m^2) 51–75% cover	Class 4 Area (m^2) 76–99% cover	Class 5 Area (m^2) 100% cover
	2006	11364	3967	1594	0	3667	5554
	2007	0	15481	3918	2907	3839	0
	2008	1775	20295	2307	614	851	304
	2009	nr	nr	nr	nr	nr	nr
	2010	nr	nr	nr	nr	nr	nr
	2011	nr	nr	nr	nr	nr	nr
	2012	18909	3346	1611	0	509	1770
	2013	8913	6714	1873	2307	1360	4980
	2014	6708	11928	1171	3522	0	2817
	2015	6935	6630	4066	4362	0	2278
	2016	5206	11629	3008	851	2488	2963
	2017	1705	10913	4919	2846	3233	2530
	2018	6482	7088	5974	0	2215	4386
	2019	7199	11585	2120	3784	918	539
	2020	2906	15027	1911	2463	2716	1123
	2021	5516	13572	1153	1911	3993	0
	2022	694	9024	3177	5653	3810	3789
	2023	10718	8605	2530	1911	509	1873
	2023	6743	11190	851	304	1662	5395

* Biomass was not assessed in 2011 in Hudson or in 2009/2010/2011 in Gleasondale. In Ben Smith in 2005/2006, the assessment did not include sections upstream of the White Pond Rd. bridge.

Appendix V River and Tributary Classifications

MassDEP SuAsCo river segment classification by water quality criteria (MassDEP, 2021).

River	Section	Designation
Assabet	Headwaters to Westborough Wastewater Treatment Plant	Class B, Warm Water, High Quality Water
Assabet	Westborough Wastewater Treatment Plant to confluence with the Sudbury	Class B, Warm Water
Concord	Confluence of the Assabet and Sudbury to the Billerica drinking water withdrawal	Class B, Warm Water, Treated Water Supply
Concord	Billerica withdrawal to Roger's St. in Lowell	Class B, Warm Water
Concord	Rogers St. to confluence with the Merrimack	Class B, Warm Water, CSO
Sudbury	Headwaters at Cedar Swamp Pond to Fruit St. in Hopkinton	Class B, Warm Water, Outstanding Resource Water
Sudbury	Fruit St. to the outlet of Saxonville Pond in Framingham	Class B, Warm Water, High Quality Water
Sudbury	Saxonville Pond to Hop Brook	Class B, Aquatic Life, High Quality Water
Sudbury	Hop Brook to confluence with the Assabet	Class B, Aquatic Life
Tributaries	Most tributaries	Class B, Cold Water

Massachusetts Division of Fisheries and Wildlife List of Coldwater Fish Resources in the Concord (SuAsCo) basin (MassDFW, 2017). 33 Streams. *Note that MassDEP identifies 27 tributary streams as CFRs in its Sustainable Water Management Initiative viewer (MassDEP, 2012).*

Stream Name	SARIS #
Cranberry Brook	8247885
Danforth Brook	8247275
Flagg Brook	8247225
Great Brook	8247175
Hayward Brook	8248000
Hog Brook	8247325
Hop Brook (1)	8247600
Hop Brook (2)	8247825
Howard Brook	8247525
Jackstraw Brook	8248475
Landham (Allowance) Brook	8247900
Nagog Brook	8246900
North Brook	8247375
Nourse Brook	8247627
Piccadilly Brook	8248450
Pine Brook	8247950
Rawson Hill Brook	8247575
Run Brook	8247875
Second Division Brook	8247075
Sheepsfall Brook	8247250
UNT to A-1 Site (2)	8247628
UNT to Assabet River	8247260
UNT to Cranberry Brook	8247886
UNT to Great Brook	8247180
UNT to Hog Brook (Fosgate Brook)	8247327
UNT to Hop Brook	8247879
UNT to Hop Brook (2, 1; Trout Brook)	8247830
UNT to Hop Brook (2, 3)	8247855
UNT to Nashoba Brook	8246876
UNT to North Brook	8247435
UNT to Nourse Brook	8248530
UNT to Pine Brook	8247965
UNT to Second Division Brook	8247076
Wrack Meadow Brook	8247440