OARS

FOR THE SUDBURY ASSABET & CONCORD RIVERS

Water Quality Monitoring Program Final Report: 2023 Field Season

May 2024

Acknowledgments

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Available online at: **http://www.oars3rivers.org/river/waterquality/reports**

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Cover pictures clockwise from top left: volunteer training on the Assabet River (B. Wetherill); turtles sunbathing in Northborough (H. Conkerton); collecting samples on the Sudbury River (Y. Chen); enjoying the view on the Sudbury River (E. Brown).

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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 2023. It also summarizes and evaluates trends in the data that have become evident for the period of record between 1992 and 2023. Following are the high-level findings for each parameter. The details for each are laid out in the body of the report.

The year 2023 was noteworthy as a very wet year, with precipitation, flows, and groundwater levels all well above average—the most precipitation in the past 20+ years. This factor had a major effect on almost all the parameters monitored and is in contrast with the previous year which was extremely dry.

Water Temperature is an important characteristic for aquatic life and is particularly important to watch considering concerns of global warming. In 2023, water temperatures were heavily influenced by precipitation and flow. Warm rainwater raised temperatures in all streams, but high flows reduced overheating by reducing the residency time of water in impoundments. Our year-on-year river water temperature measurements have not yet revealed a long-term warming trend because cool inflowing groundwater moderates stream and river temperatures and because we recorded several warm years in the early 1990s at the beginning of our time-series.

Conductivity levels were much lower in 2023 than in previous years due to the dilution from heavy rainfall and high flows. Hot spots below waste water treatment plants (WWTPs) and major roads were still relatively higher than other sites but subdued due to rainfall. 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.

Dissolved Oxygen (DO) continues to show a positive upward trend in the Assabet sites as a result of the WWTP improvements that have been made there. In the Lower Sudbury the trend has been downward, despite higher levels during the 2022 drought. In 2023, extremely low DO levels (< 1 mg/L) were measured in the Lower Sudbury for several months during heavy flooding. The Hop Brook in Sudbury has consistently had very low DO levels, but its trend is showing improvement. Nashoba Brook below Warner's Pond has a clear 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 2023 were generally reduced (more acidic) due to the heavy rainfall. Trend analysis has shown a clear upward trend in pH in the Assabet River, which may be a positive sign of reduced eutrophication and lower levels of aquatic respiration driven by long-term phosphorus reductions. pH readings were noteworthy in three locations: the lower Sudbury sites had extremely low pH values below Class B standards driven by rainfall and decomposition in flooded floodplains, SUD-293 showed similar results, and ELZ-004 has had unusually low pH levels for the last four years.

Total Phosphorus (TP) is the primary indicator that 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. We still have consistently high TP concentrations in Hop Brook downstream of the Marlborough Easterly WWTP, and we are seeing a potential trend over the last five years of increasing TP concentrations in the Lower Sudbury and Concord rivers. Analysis of TP loads highlights the major role of wet weather events on the amount of phosphorus passing through the river system. Wet years 2023, 2021, and 2013 showed very large TP loads in all river sections. While the WWTP phosphorus discharge has been dramatically reduced at all plants, there has been a recent issue at the Hudson WWTP. The Hudson plant exceeded its permitted TP discharge limits four months in 2022 and eight months in 2023, resulting in total summer phosphorus loads that were about twice as high in 2023 as the permit allows. OARS is working to get this issue addressed.

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. However, our data also show that stormwater can deliver especially high ratios of orthophosphate to total phosphorus. This would mean that tackling stormwater can have a big impact on bioavailable phosphorus.

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, and our data show that a significant 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. A few sites show sporadic ammonia hits that may be worth watching: Marlborough Easterly WWTP, Hop Brook in Sudbury, and River Meadow Brook.

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 2023 due to high flows. Heavy rainfall and flows resulted in very high suspended solids loads carried downstream, but those loads were diluted in the high flows, resulting in lower concentrations than in previous years. Our long-term concentration data 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* in only the Sudbury River. Our year-on-year chlorophyll *a* data show a fairly strong downward trend for all sites combined. The year 2023 continued this trend, but this year's low chlorophyll *a* levels were most likely a result of the heavy precipitation and flows that limited growing conditions for algae.

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 trend, but the Upper Assabet tends to fluctuate dramatically 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 levels of bacteria, hovering near or above the MassDEP swimming threshold. All three have high levels in dry weather, indicating possible sanitary sewer contamination. The Hudson site fluctuates at or below the swimming threshold. 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 Maynard was conducted in 2023.

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, and the extreme rainfall in 2023 kept biomass levels down. Trend analysis shows a mixed picture, with a decrease in biomass in the Ben Smith impoundment and a noticeable increase in biomass 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 1999–2022 are available on OARS' website (**http://www.oars3rivers.org/river/waterquality/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, their tributaries and watersheds, for public recreation, water supply, and wildlife habitat. 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 900 individual and family memberships, an eleven-member Board of Directors, and five regular staff plus summer staff. Together with our volunteers and partners, OARS has made significant progress over the past 38 years towards achieving our mission.

The combined Sudbury, Assabet, and Concord 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, fuel 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 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, invasives
Concord River (all sections)	Various including: *E. coli*, fecal coliform, mercury, chloride, trash, algae, turbidity, invasives
Sudbury River (d.s. of Fruit St. bridge)	Various including: mercury, DO, *E. coli*, 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 (e.g., stormwater) contributed nutrients, 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 which 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 Hop Brook tributary to the Sudbury River, 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 and a winter limit of 1.0 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. As of 2023, they have taken the next step of reducing the winter phosphorus discharge limit to 0.2 mg/L, and a new NPDES winter phosphorus limit has been set for all plants (Marlborough Westerly's limit is set at 4.8 lb/day, which corresponds to 0.2 mg/L at design flow).

For the nutrient load reductions proposed in the state's TMDL to be effective in restoring 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 water resources of the area 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 (i.e., range, duration, and timing of streamflow) 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 work of its volunteers, OARS would not be able to conduct such an extensive monitoring program. The summer of 2023 was OARS' 32^{nd} consecutive year collecting data at mainstem Assabet River sites, its 22^{nd} year collecting data at tributary sites, its 20^{th} year collecting data at mainstem Concord River sites, its 15^{th} year collecting Sudbury River data, its 19^{th} year assessing aquatic plant biomass in the large impoundments of the Assabet River, and its 5^{th} 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.

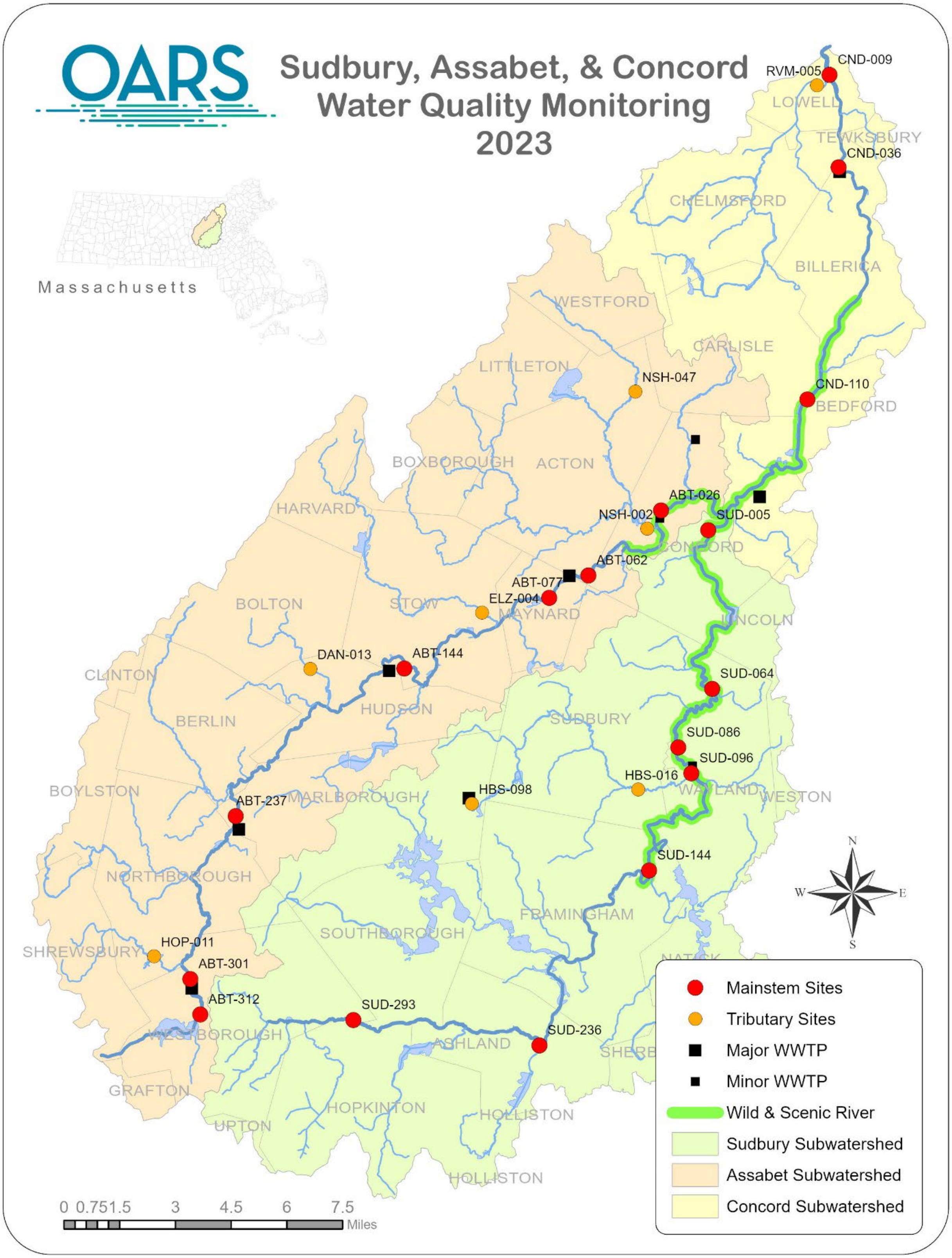

Figure 1: Water Quality Monitoring Sites 2023

Table 2: Water Quality Monitoring Sites 2023

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 gauges 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.

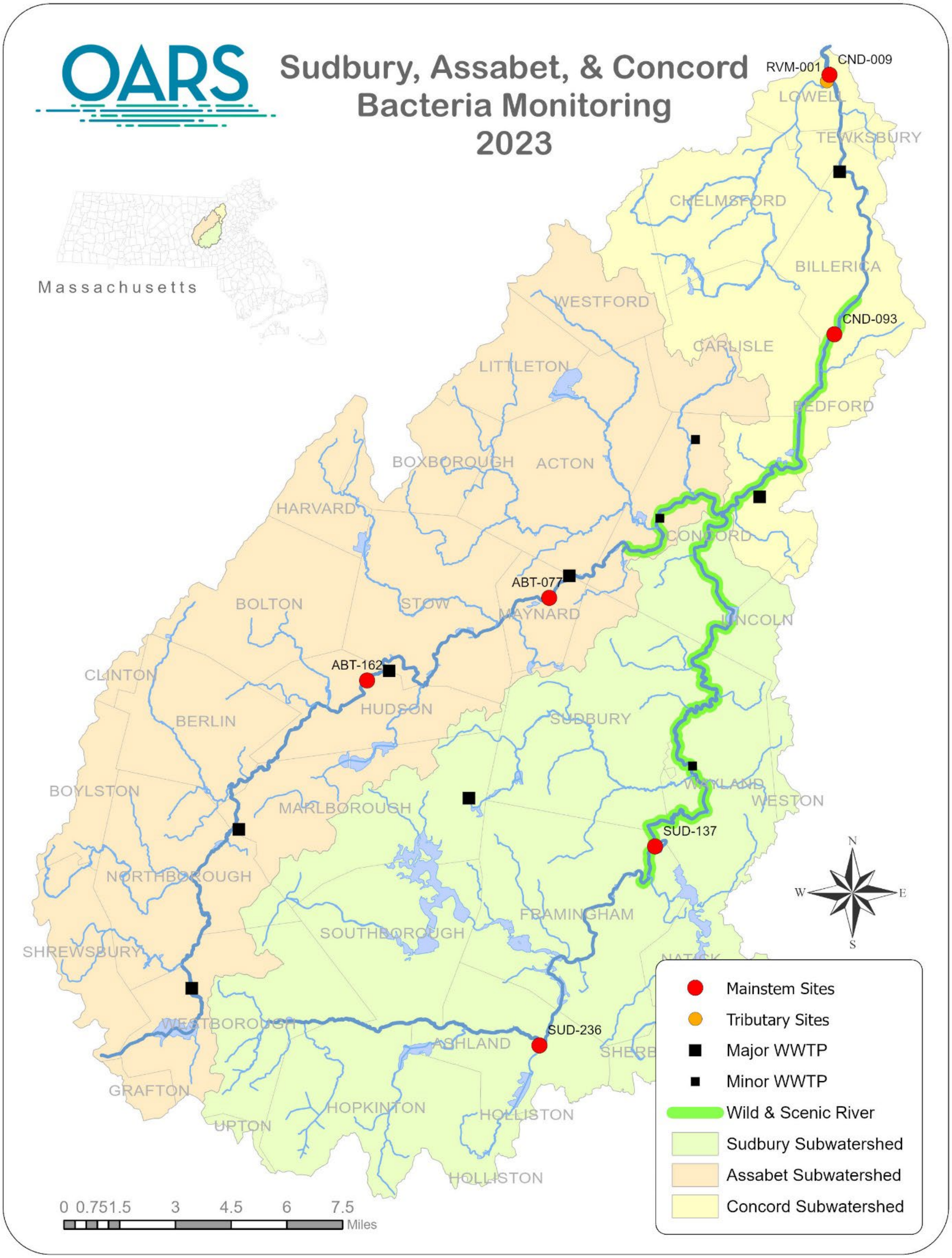

Figure 2: Bacteria Monitoring Sites 2023

Table 3: Bacteria Monitoring Sites 2023

OARS Site #	Waterbody	Description	Municipality	Lat/Lon
ABT-077	Lower Assabet River	USGS Maynard gauge	Maynard	42° 25' 55"/ -71° 26' 59"
ABT-162	Upper Assabet River	Cox Street	Hudson	42° 23' 59"/ -71° 32' 46"
CND-009	Lower Concord River	Rogers Street	Lowell	42° 38' 09"/ -71° 18' 05"
CND-093	Upper Concord River	Concord River at Rte 4	Billerica	42° 32' 09"/ -71° 17' 57"
RVM-001	River Meadow Brook	645 Lawrence St.	Lowell	42° 37' 60"/ -71° 18' 11"
SUD-137	Lower Sudbury River	Little Farms Rd	Framingham	42° 20' 06"/ -71° 23' 40"
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 9:00am, 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' gauges 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 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 2023

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	Alpha Analytical
Total Phosphorus	SM 4500-P-E	0.01–1 mg/L	bottle	Alpha Analytical
Orthophosphate	SM 4500-P-E	0.005–1 mg/L	bottle	Alpha Analytical
Nitrate-N	SM 4500-NO3-F	0.1–10 mg/L	bottle	Alpha Analytical
Ammonia-N	SM 4500-NH3-BH	0.075–10 mg/L	bottle	Alpha Analytical
Chloride	EPA 300.0	1–1000 mg/L	bottle	Alpha Analytical
Chlorophyll—*a*	SM 10200-H(3)	2–100 µg/L	bottle	Alpha Analytical

Bacteria Sampling Methods

Trained volunteers collected bacteria water samples at seven sites throughout the watershed (Figure 2 and Table 3). OARS selected the sites based on the MassDEP 303d list of river segments impaired by bacteria (MassDEP, 2023) and current OARS water quality monitoring sites.

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). All mainstem river sections are designated Class B waters, and all except for the upper Sudbury are Warm Water fisheries (Table 8). The MA Division of Fisheries and Wildlife lists 33 tributary streams in the basin as Coldwater Fishery Resources (CFRs) (MassDFW, 2017) (Appendix V). 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).

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
NO2 + NO3 (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

Table 8: MassDEP River Segment Water Quality Designations

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

River	Section	Designation
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

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 9 lists the long-term sites used and their sections.

Table 9: 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
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
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
	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
	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
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
	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
	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
	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
	CND-036																														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
	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
	SUD-064																		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
	SUD-096																					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
Upper Sudbury	SUD-236																														X	X	X
	SUD-293																														X	X	X
Hop Brook (Sudbury)	HBS-016																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	HBS-098																														X	X	X
Nashoba Brook	NSH-047																	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
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
	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
	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
	ELZ-004											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, (5) Concord mainstem. Tributary sites are analyzed individually. Table 10 lists tributary and mainstem basin characteristics calculated using USGS's StreamStats program.

Table 10: 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 (**https://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

The year 2023 differed dramatically in precipitation from the previous year (Figure 3 and Figure 4). The summer of 2022 was characterized by substantially lower precipitation than normal, and the summer of 2023 had the highest precipitation since record keeping started in 1999. In fact, the last four years are noteworthy in the way they have alternated from very low precipitation to very high precipitation every year.

According to the U.S. Drought Monitor[1], the SuAsCo watershed experienced a "D0" minor dry period in April and May of 2023, but the rest of the season was very wet (Figure 5). According to the Massachusetts Water Resources Commission, at the end of September, 2023, the 9-month Standardized Precipitation Index for Northeast MA was 98%, as opposed to 13% in 2022 (MassDCR, 2023).

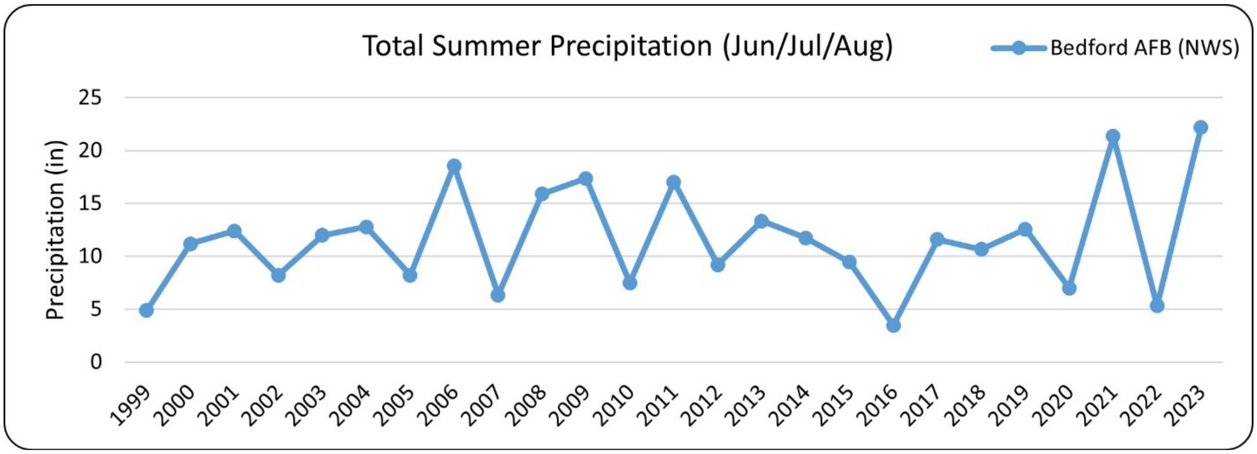

Figure 3: Annual summer precipitation (1999-2023)

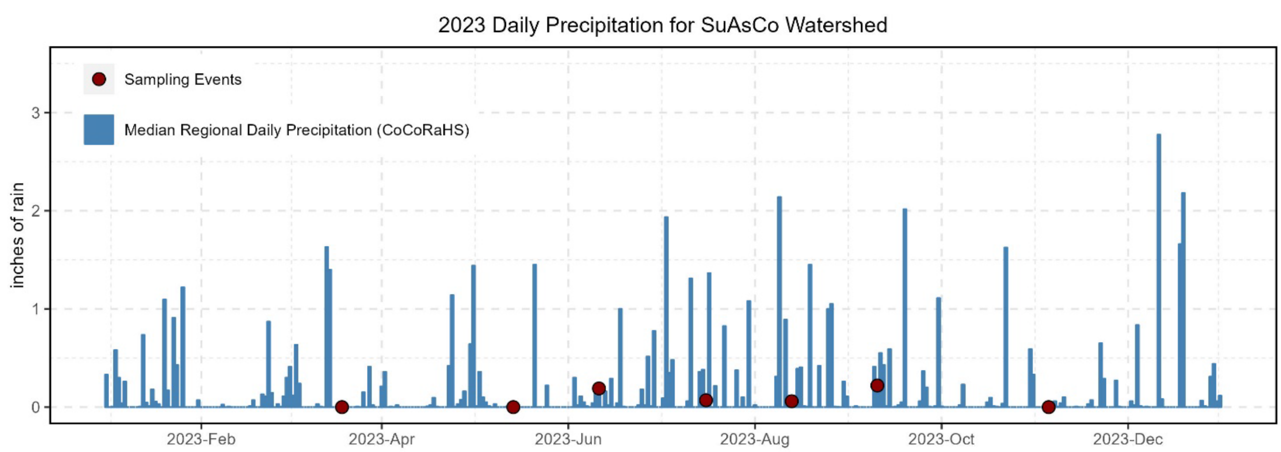

Figure 4: Daily rainfall with sampling dates 2023

Daily rainfall sourced from CoCoRaHS, for box bounded by 42.22852/-71.70227 and 42.51766/-71.31912.
https://www.cocorahs.org/ViewData/

[1] **https://droughtmonitor.unl.edu**

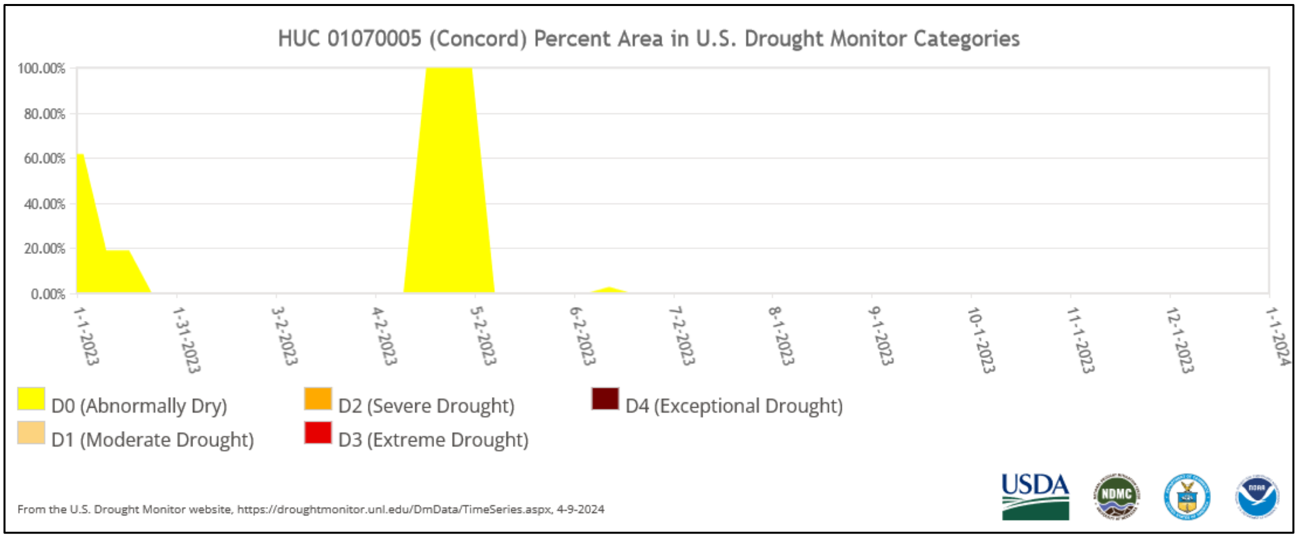

Figure 5: U.S. Drought Monitor status for Concord watershed (HUC 8) 2023

*Graph from **https://droughtmonitor.unl.edu/DmData/TimeSeries.aspx**.*

As a direct result of the high precipitation, streamflow in 2023 was also extremely high. Figure 6 shows year-on-year average summer streamflow for the Assabet and Sudbury since 1980. The summer of 2023 had the second highest streamflow over this period, while the previous year (2022) had one of the lowest streamflows for the period. Figure 7 shows mean daily streamflow for 2023 at the Assabet, Sudbury, and Concord River gauges compared with the historic mean streamflow for the period of record. In 2023, streamflow for all rivers was well above average from the beginning of July through the end of November. However, flows were below average during the May and June sampling events.

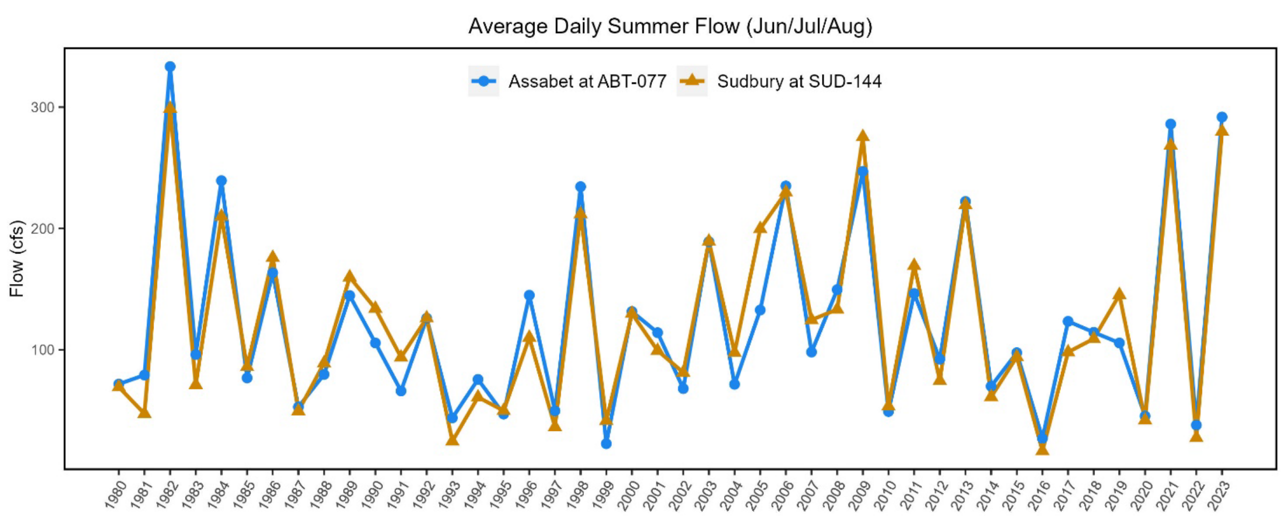

Figure 6: Average summer streamflow (June/July/August)

Flow data sourced from USGS gauges in Maynard and Saxonville.

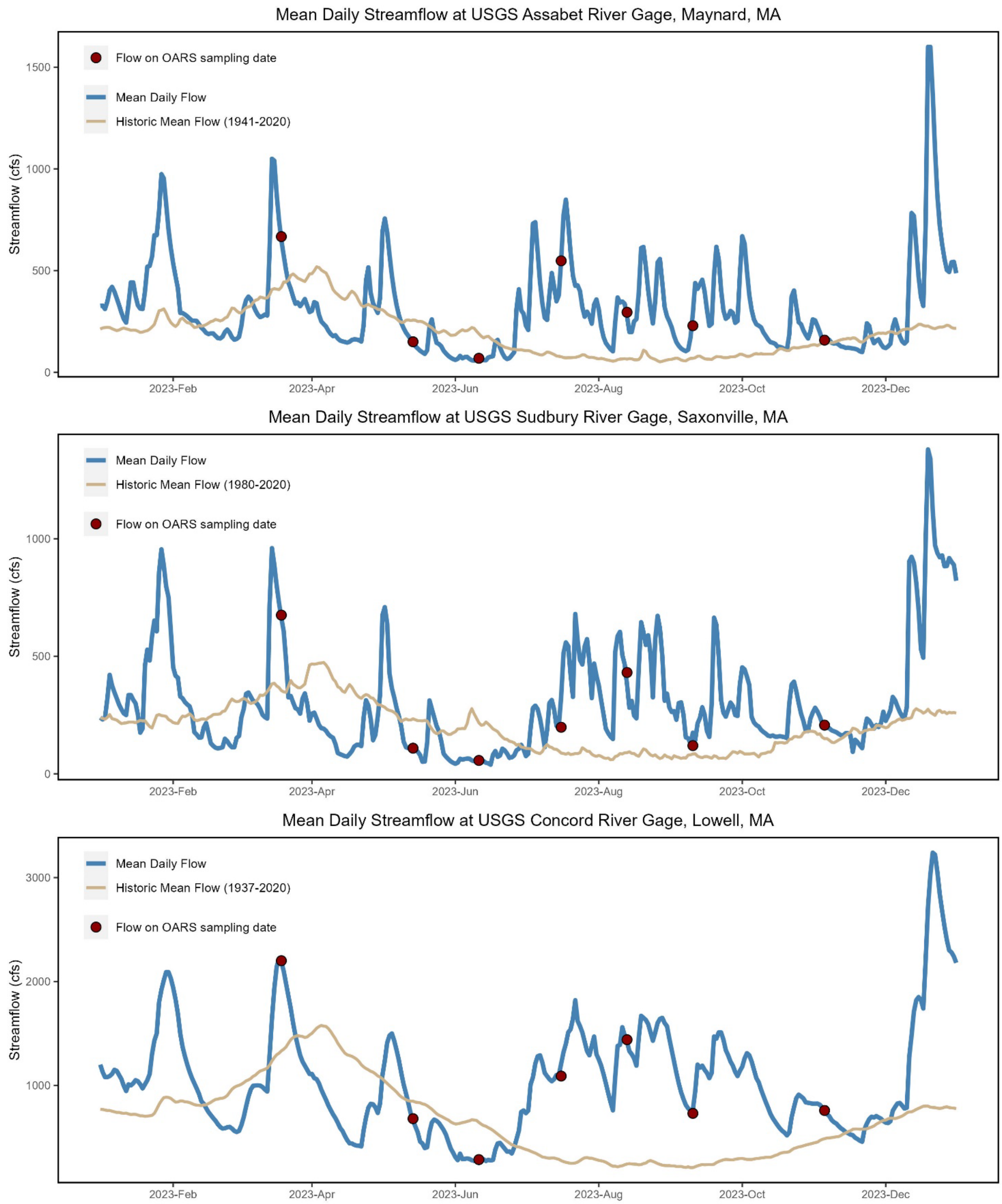

Figure 7: Mean Daily Streamflow by river (2023)

Figure 8 shows groundwater levels in 2023 compared with historic mean levels from the USGS monitoring well in Acton (USGS 422812071244401 MA-ACW 158 ACTON, MA). Groundwater levels tracked the major precipitation trends with well-above-average levels in the second half of 2023. Changes in groundwater levels reflect the combination of precipitation and evapotranspiration rates and, in turn, affect baseflow to the streams.

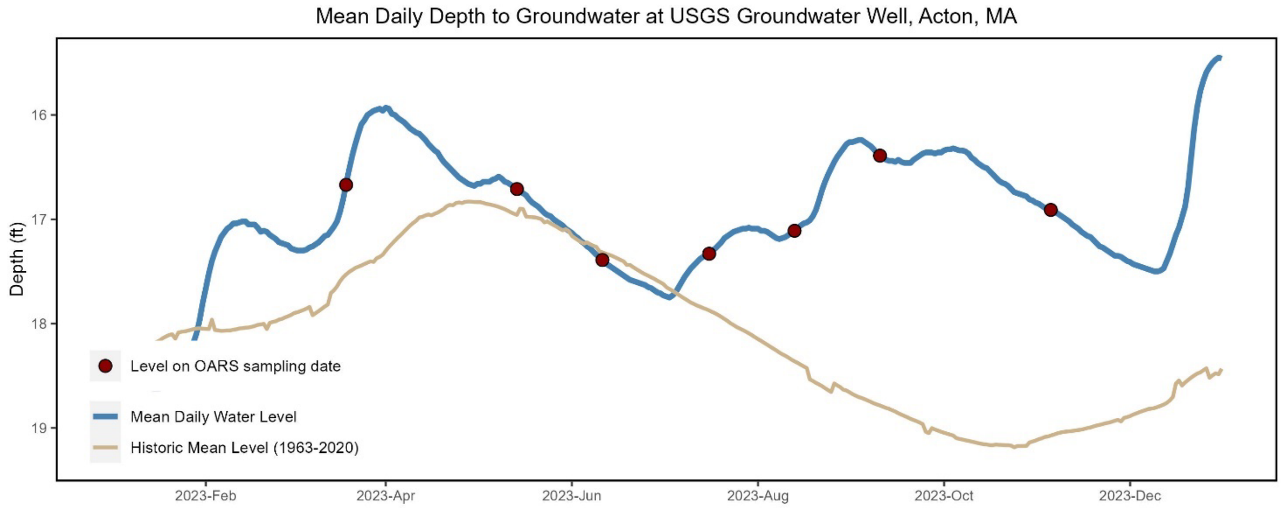

Figure 8: Groundwater Levels (2023, USGS Monitoring Well, Acton, MA)

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. For the purposes of this analysis, sampling dates were classified by visual inspection of the hydrograph of the nearest available real-time USGS stream gauge as rising, falling, or flat hydrograph (Table 11). Samples collected on a rising hydrograph may include "first flush" runoff and the higher load of pollutants associated with the first flush. Sampling events that were preceded by more than 0.1 inches of rain in the previous 48 hours (the standard definition of a "wet" weather sampling) are highlighted. Note that flow at the Sudbury River gauge in Saxonville/Framingham is sometimes affected by reservoir dam manipulations upstream.

Table 11: Hydrograph and Precipitation Summary for Water Quality Sampling 2023

	Hydrograph at USGS gauge			Precipitation (inches)
Sampling Date	Assabet River at Maynard	Sudbury at Framingham	Concord at Lowell	Previous 48 hours
Mar 19, 2023	Falling	Falling	Falling	0
May 14, 2023	Falling	Falling	Falling	< 0.01
Jun 11, 2023	Flat	Flat	Flat	0.35
Jul 16, 2023	Rising	Flat	Rising	0.45
Aug 13, 2023	Falling	Falling	Falling	0.06
Sep 10, 2023	Rising	Flat	Flat	0.63
Nov 5, 2023	Falling	Falling	Falling	0

<u>Wastewater Treatment Plant Discharge</u>
There are eight wastewater treatment plants discharging significant volumes of water into the three rivers (Figure 9)[2]. 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 13.7 cfs to the river from May through September in 2023 (EPA, 2024). This compares with the average flow for this period at the Assabet River gauge of 283 cfs and the minimum flow of 58 cfs. Since summer 2023 was a very rainy season, this year's treatment plant discharge never constituted a large portion of the total river flow, but in some years it has made up the majority of the flow. In August 2022, treatment plant discharge constituted almost 100% of the total flow.

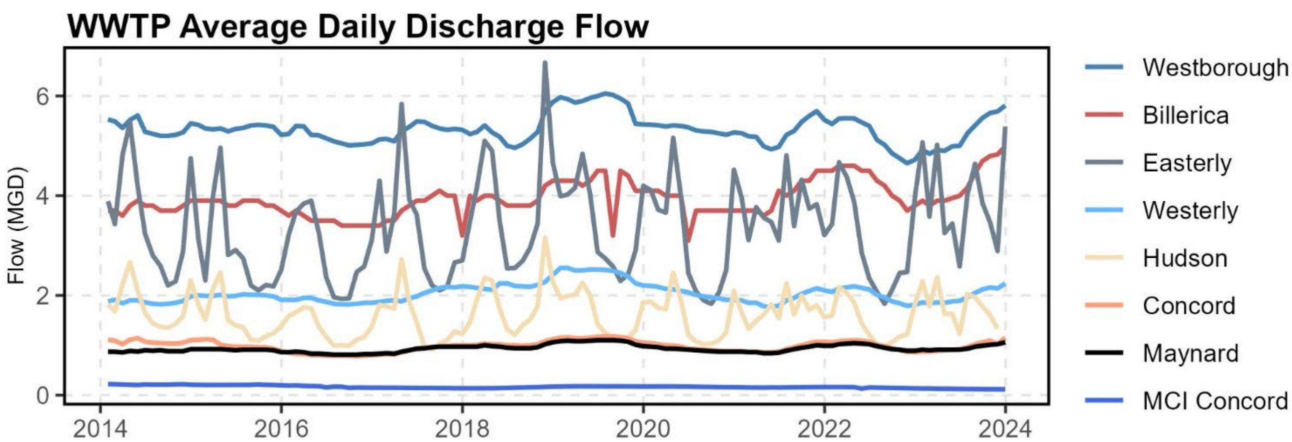

Figure 9: WWTP Discharge Flow (2014-2023)

[2] Note that we believe there is an issue with the EPA Discharge Monitoring Report that provides this discharge flow data. It appears that Marlborough Westerly, Concord, Maynard, and MCI may be reporting a 12-month rolling average flow instead of a monthly average flow. We are working with the EPA to get the monthly average flow data.

Water Quality Results

Mainstem statistics for all water quality parameters are provided in tabular form in Appendix I. Raw data is 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 2023, by-month detail for 2023, 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 gauges and distance-based flow estimates at the sites without gauges. 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 (1st quartile to 3rd quartile, or 25th to 75th 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 that are above or below the box by more than 1.5 times the interquartile range. The interquartile range is defined as the range between the 1st quartile and the 3rd 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 2023 (Figure 10 and Figure 11). Heavy rain and high flows in the warmest months kept temperatures below the warm water fisheries threshold, but the warm rainwater also counteracted groundwater influence in July, August, and September causing all tributary and river samples to exceed the cold water fisheries standard (20.0°C). The cold water standard is the recommended maximum for brook trout (23.9°C for brown trout). Inter-site temperature differences were less significant than in previous years, also due to the heavy flow.

Year-on-year comparisons of temperature data show very little statistical change in water temperatures for the period of record (Figure 12 and Figure 13). Trend lines are level for all sections and tributaries. It is worth noting that ABT-312 has often had low water temperatures during low flow years (2007, 2016, 2022), implying influence of a cold-water spring. Site NSH-002 is unusual compared with other sites in that temperatures did not increase during the 2023 high flows.

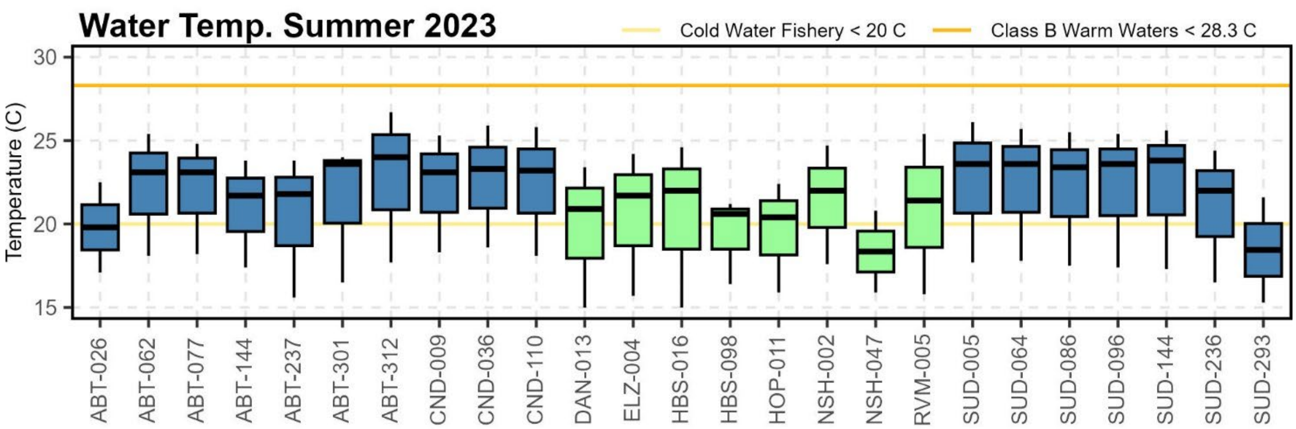

Figure 10: Water temperature by site, summer (Jun-Aug 2023)

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. Sites ABT-026, NSH-047, and SUD-293 are low because they were not sampled in July (due to a major storm).

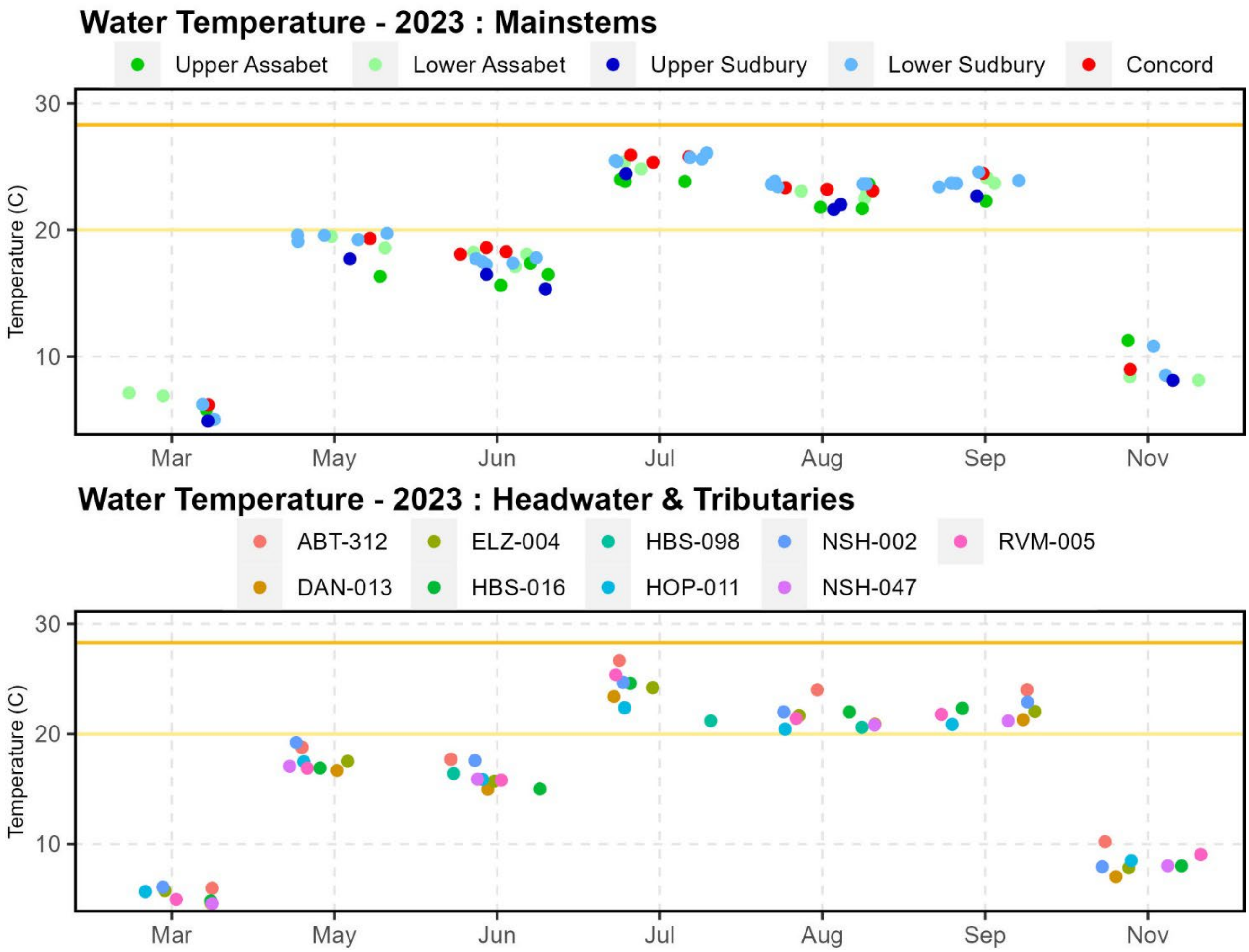

Figure 11: Water temperature by month and site (2023)

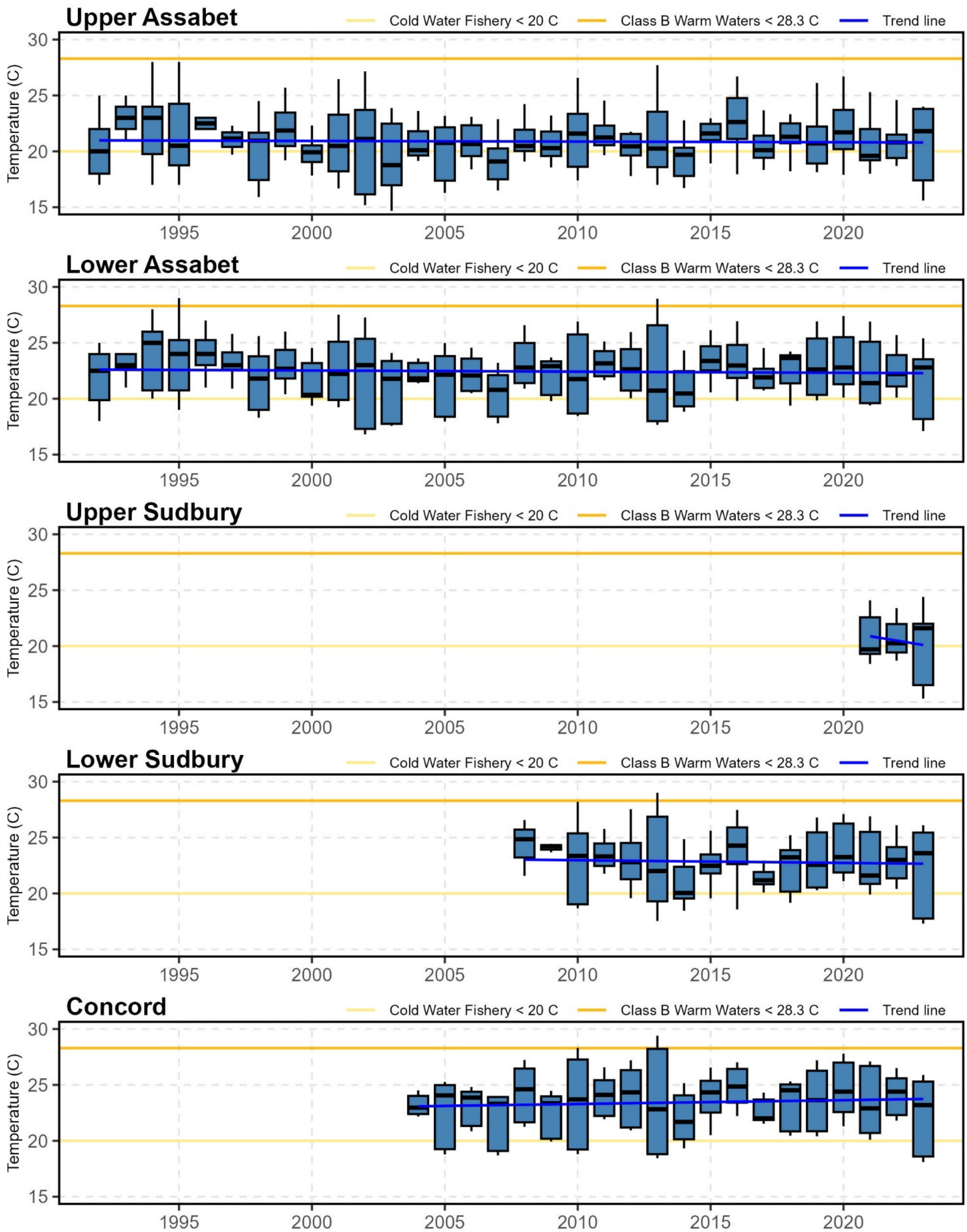

Figure 12: Water temperature by year and section (June/July/August)

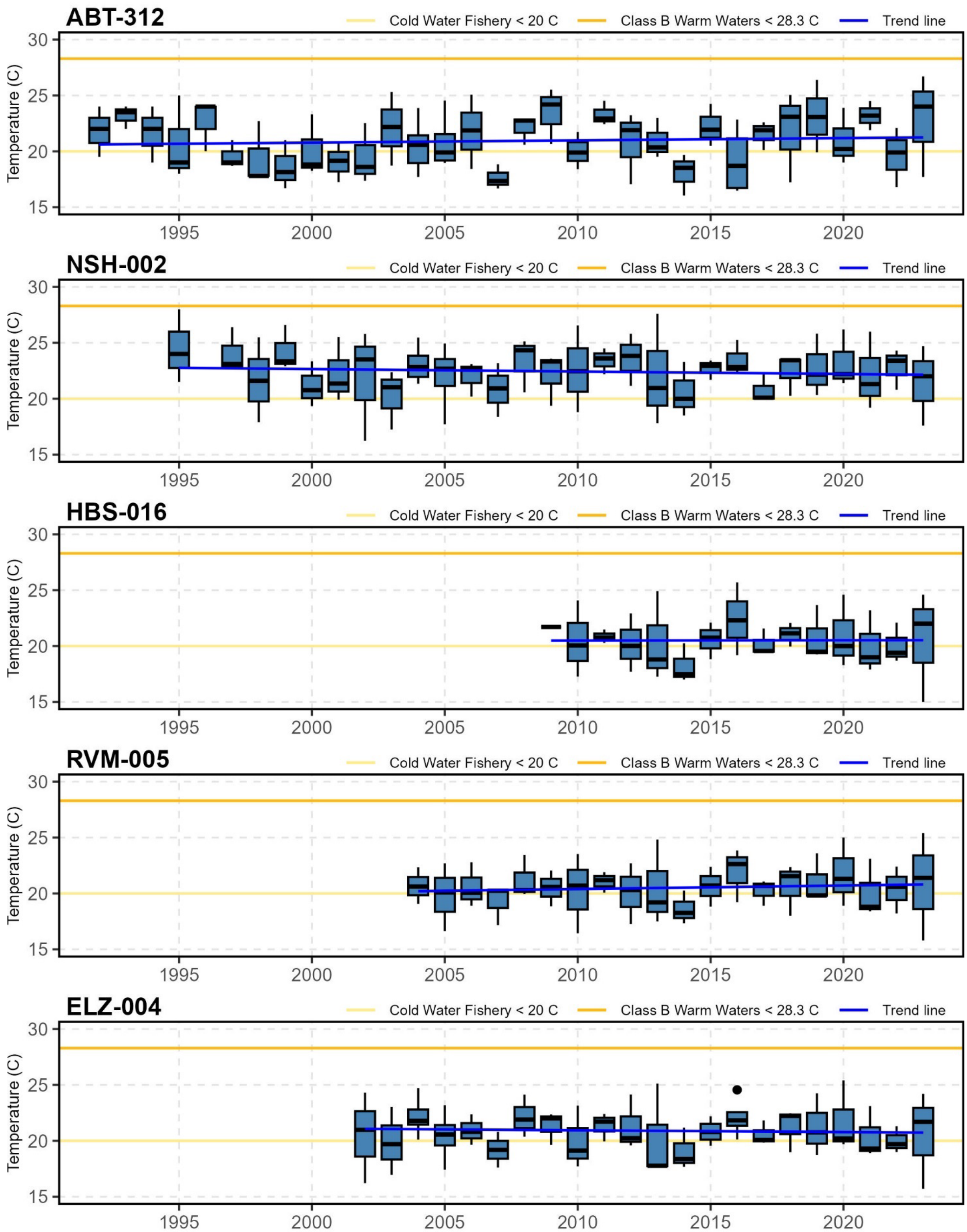

Figure 13: Water temperature by year for selected tributaries (June/July/August)

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 streams supporting good mixed fisheries have a range between 150 and 500 µS/cm (Ellis, 1944).

OARS' mainstem sites have been above that range in recent years, but the heavy rains and flows after June 2023 diluted conductivity significantly (Figure 14 and Figure 15). Monthly analysis usually shows conductivity increasing later in the summer as flows decrease and salts become more concentrated, but in 2023 conductivity decreased with higher flows. 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. However, OARS has conducted surveys of other tributaries (River Meadow Brook, Fort Pond Brook, and Nashoba Brook) 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. River Meadow Brook (RVM-005) and Northborough Hop Brook (HOP-011) consistently have the highest readings of non-WWTP sites. Both are immediately downstream of major highways.

Year-on-year analysis of conductivity shows a clear upward trend for all river sections and tributaries (Figure 16 and Figure 17). The years 2021 and 2023 were deviations from this trend due to significantly higher precipitation and flow in those two years. This is a trend that is being noticed throughout New England, and it is believed to be a direct result of road-salt application and its accumulation in sediments and groundwater (Daley, 2009; Zuidema, 2018; Evans, 2018). See the section below on chloride for additional discussion about salt pollution.

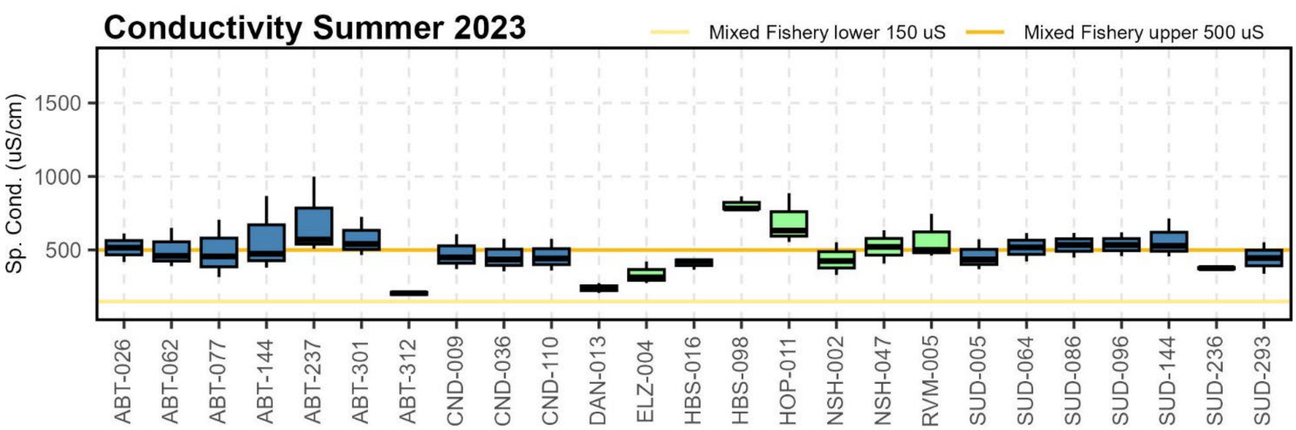

Figure 14: Specific conductance by site, summer (Jun-Aug 2023)

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.

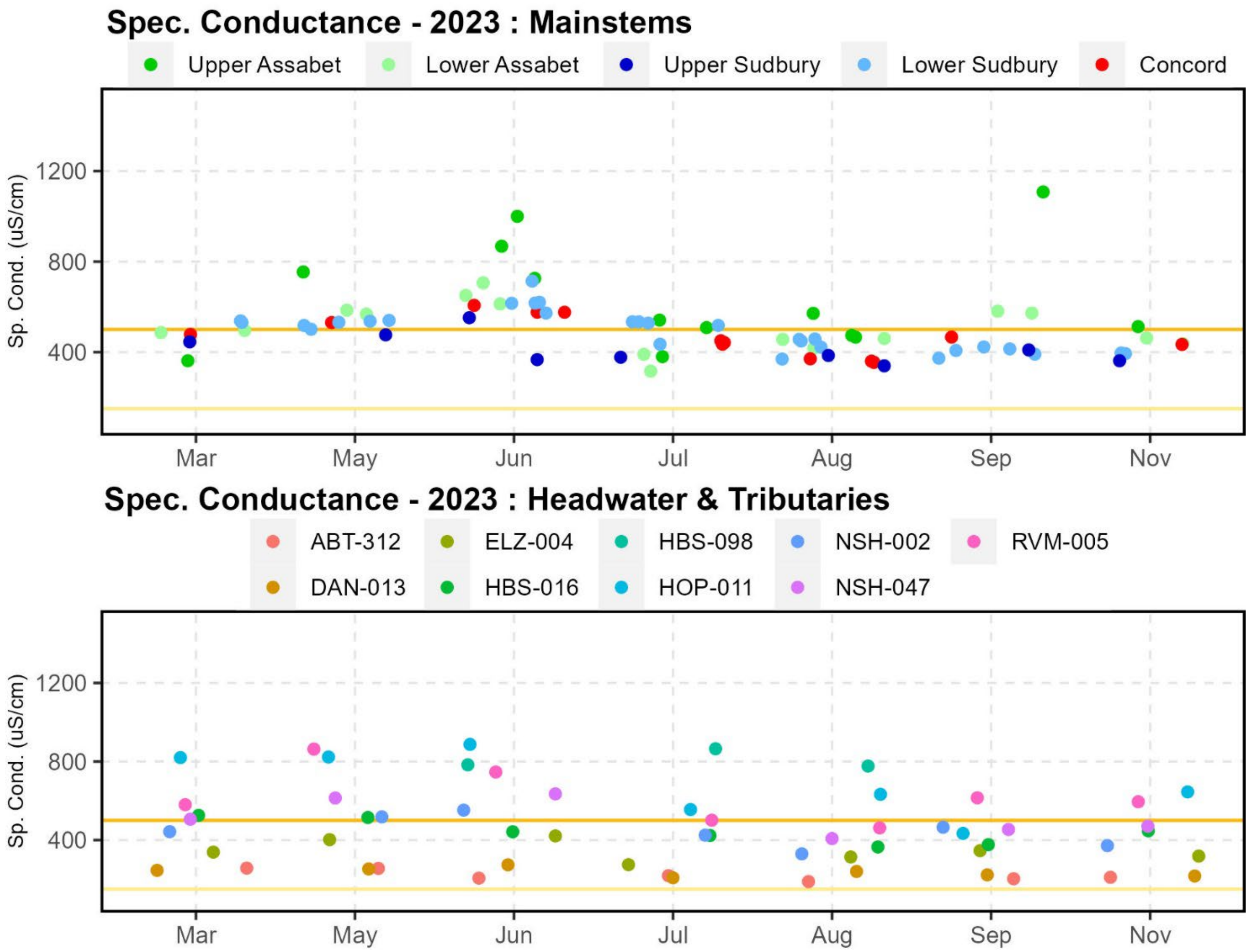

Figure 15: Specific conductance by month and site (2023)

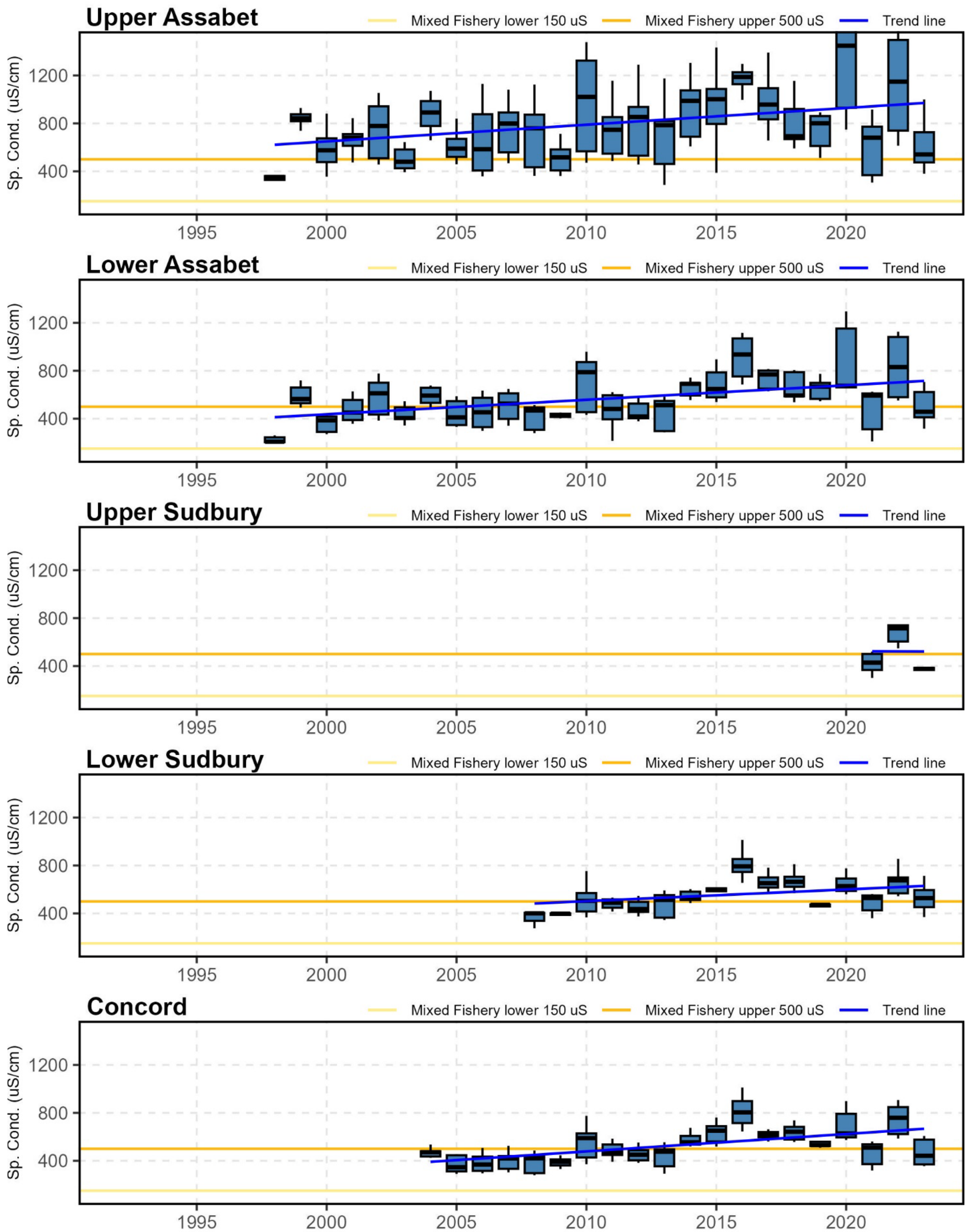

Figure 16: Specific conductance by year and section (June/July/August)

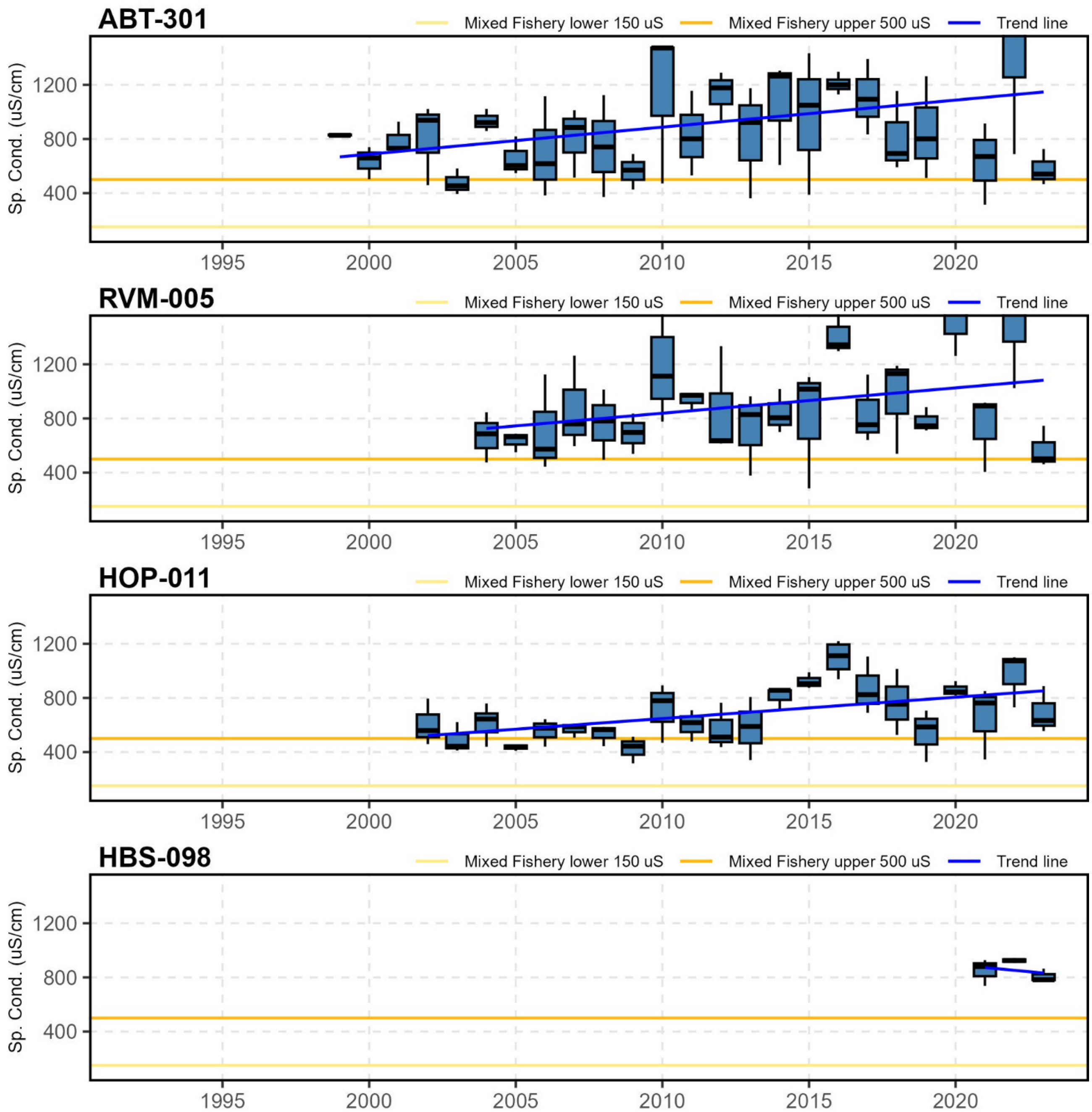

Figure 17: Specific conductance by year for selected sites (June/July/August)

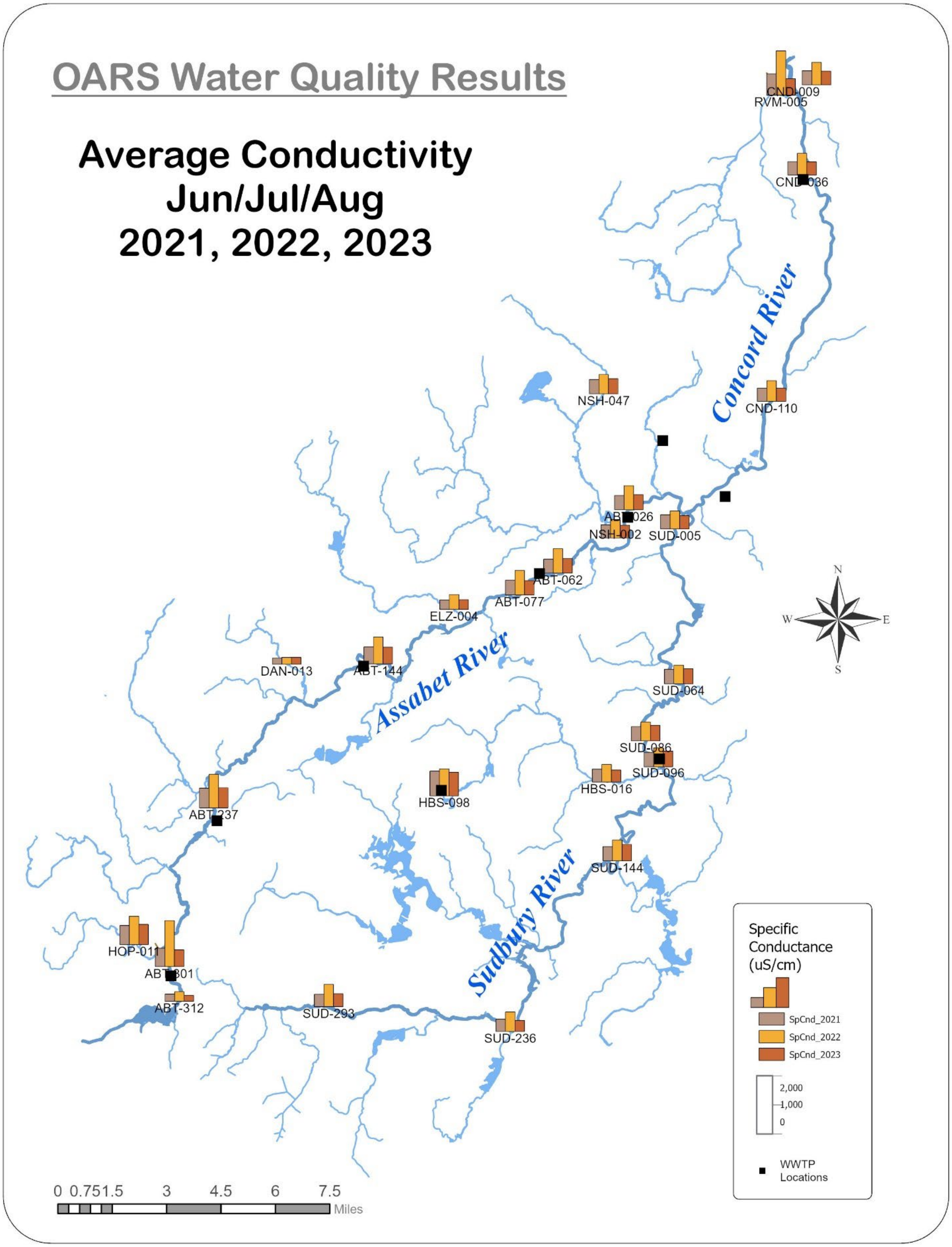

Figure 18: Map of average summer conductivity by site (2021-2023)

Dissolved Oxygen

Dissolved oxygen (DO) concentrations during the growing season are generally lowest between 5 am and 8 am after plant and microbial respiration has 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 19 and Figure 20). The Lower Sudbury is surrounded by large wetland areas and wetlands naturally have low DO levels due to still water and high respiration. In 2023, low DO levels were extreme in the lower Sudbury and also at site CND-110 in the Concord. The Sudbury sites SUD-005 and SUD-064 were recorded at or below 1 mg/L for July, August, and September. The Hop Brook site (HBS-016) also displayed the same dynamics, with DO below 2 mg/L for all three months. As discussed in the pH section below, low DO levels can coincide with low pH in eutrophic conditions. This was especially evident in 2023 for SUD-005, SUD-064, HBS-016, and the Sudbury headwaters (SUD-293). They all had very low DO and pH levels and large flooded wetlands upstream.

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 21). This is especially evident after the year 1999 when all four wastewater plants had implemented treatment to reduce summer phosphorus discharge concentrations below 1 mg/L. The trend continued in 2023 despite the flooding. In the Lower Sudbury River, we have been watching a concerning downward trend in DO levels, and this trend continued in 2023. The Hop Brook site (HBS-016) continues to show a distinct improvement in DO since 2015, which is the same year upgrades were completed at the Marlborough Easterly WWTP (Figure 22). The Nashoba Brook site (NSH-002) has shown a decline in DO over the last five years (Figure 22). This site is downstream of Warner's Pond in Concord, which is now in a critical state with aquatic biomass. The town is evaluating what to do to reduce the biomass.

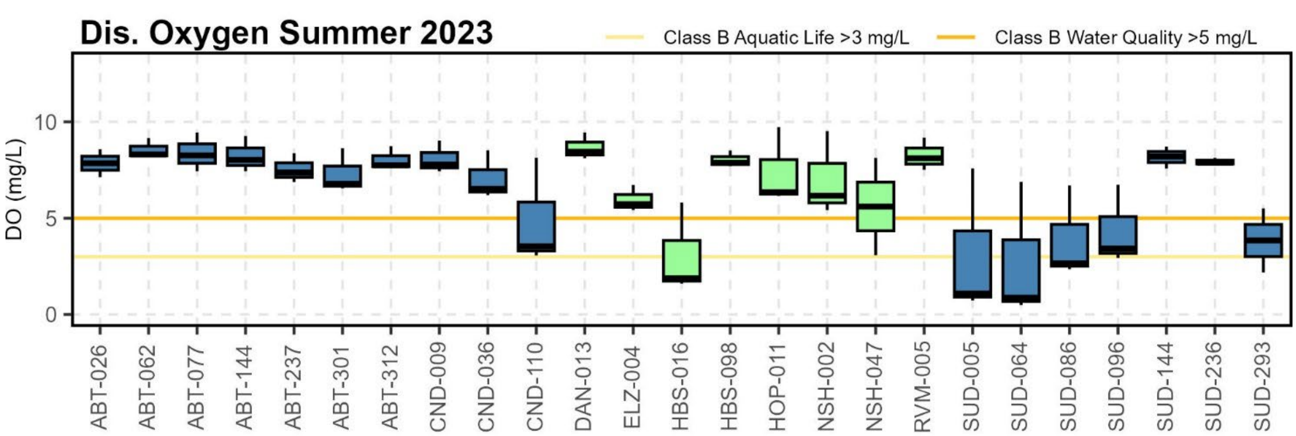

Figure 19: Dissolved Oxygen concentration by site, summer (Jun-Aug 2023)

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.

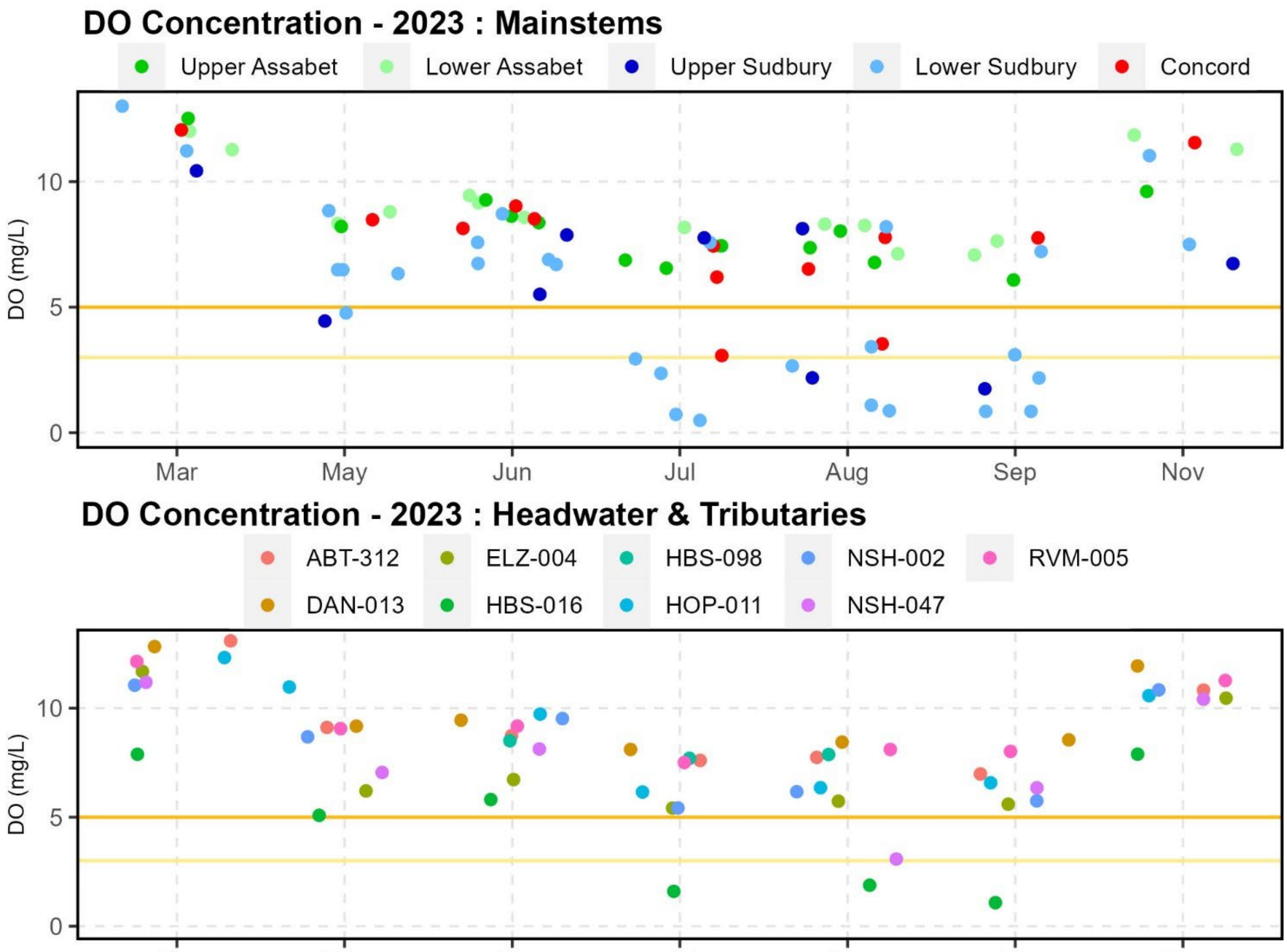

Figure 20: Dissolved Oxygen by month and site (2023)

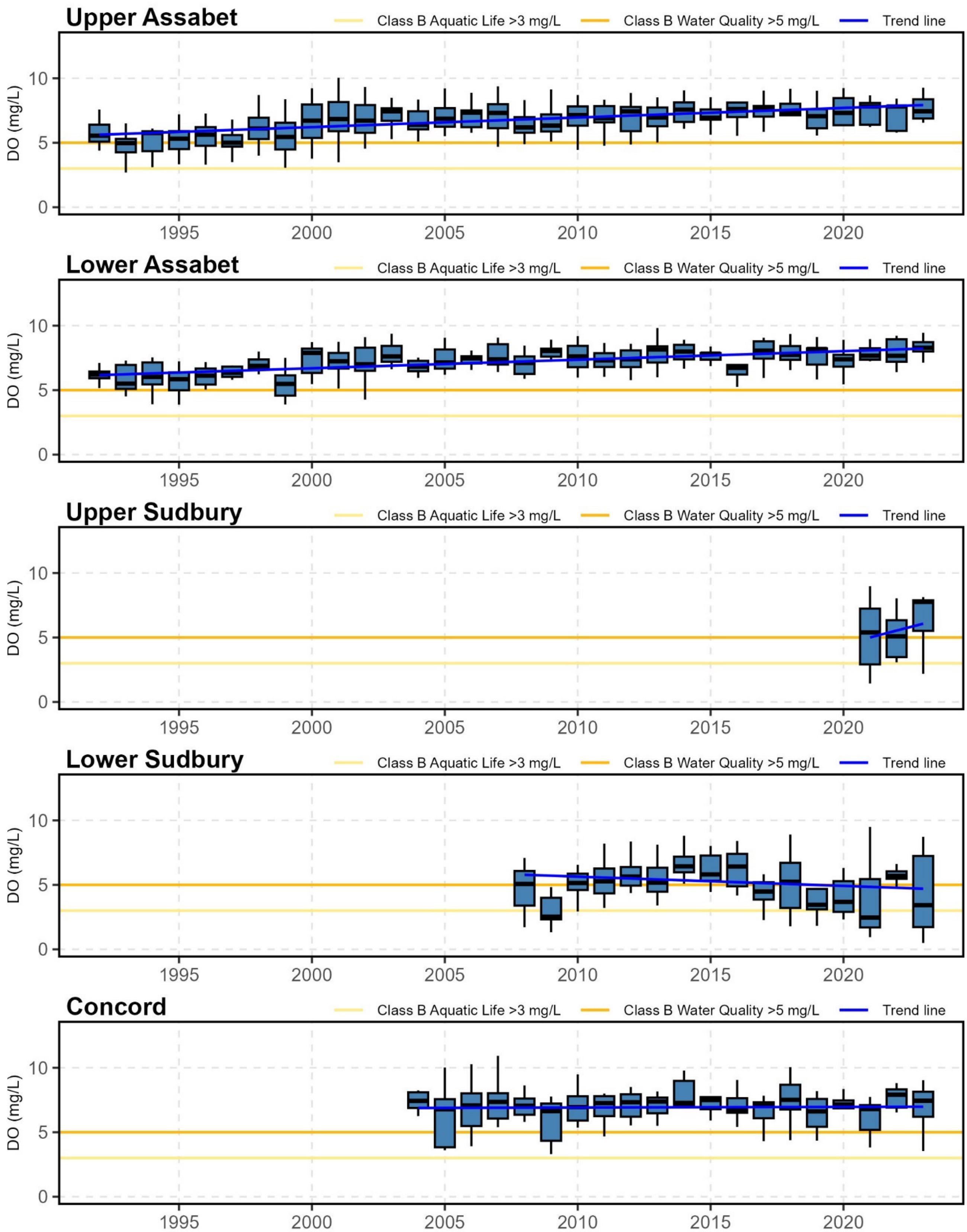

Figure 21: Dissolved Oxygen by year and section (June/July/August)

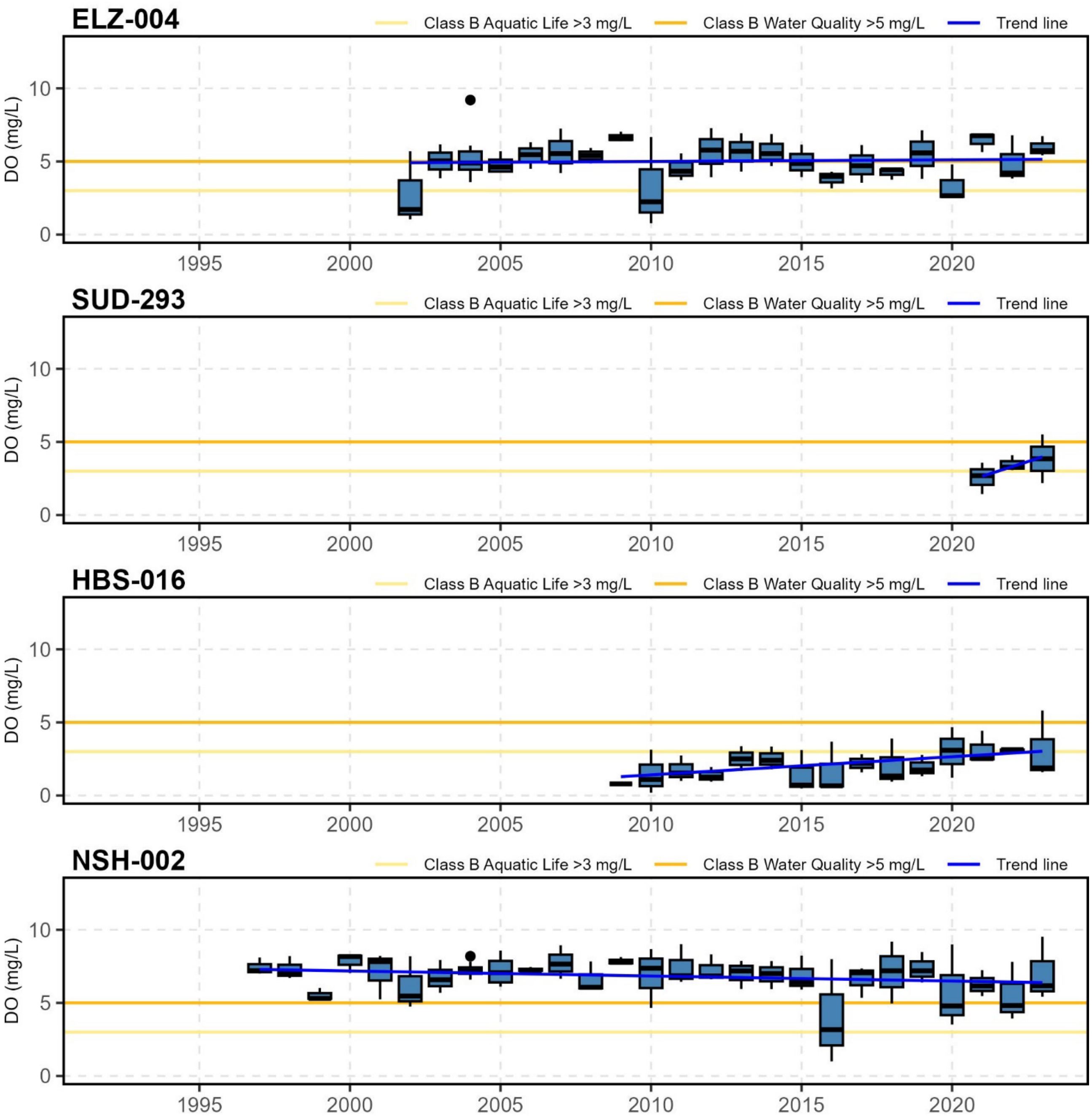

Figure 22: Dissolved Oxygen by year for selected sites (June/July/August)

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 pH is 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 significantly reduced by heavy rains and decomposition activity on floodplains. Many samples in July, August, and September were below the Class B lower standard of pH 6.5 (Figure 24). The by-site comparison highlights very low pH levels at the lower Sudbury sites (SUD-005, SUD-064) and at the Sudbury headwaters site (SUD-098) (Figure 23). Both these locations also had very low dissolved oxygen levels related to the inundation of upstream wetlands. For the second year in a row, site ABT-077 tended to have higher pH than upstream sites. The time-series view of ABT-077 in Figure 26 shows a clear increasing trend for pH, which could be a positive result of the reduced biomass in the Ben Smith impoundment (see the Biomass section later).

Year-on-year analysis of summer pH shows a visible upward trend in pH for the Assabet River (Figure 25). This may be 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 higher pH. This hypothesis is also supported by the corresponding improvement in dissolved oxygen shown above (Figure 21). For four years in a row, the Elizabeth Brook site (ELZ-004) has had depressed (more acidic) pH levels (Figure 26). This warrants some further study.

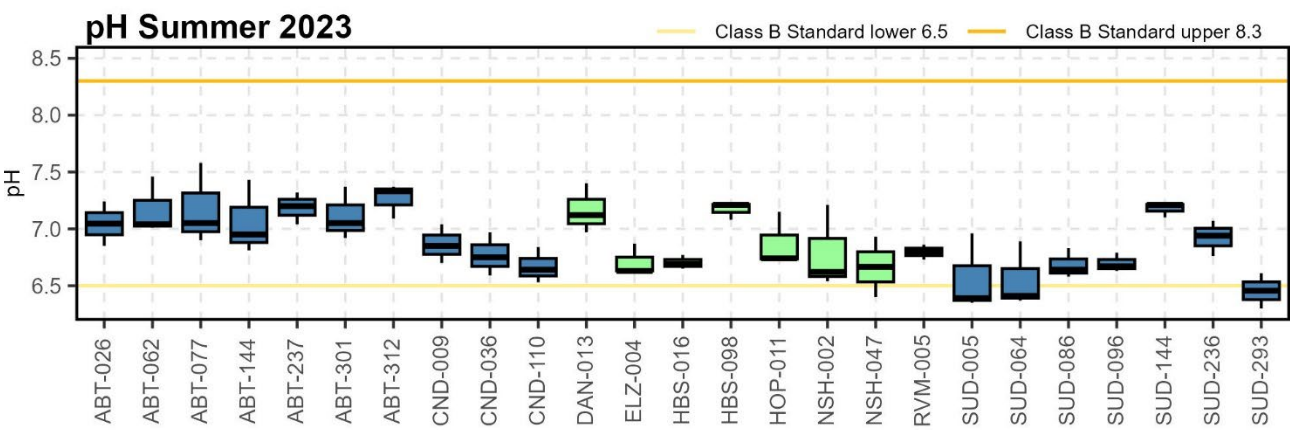

Figure 23: pH by site, summer (Jun-Aug 2023)

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.

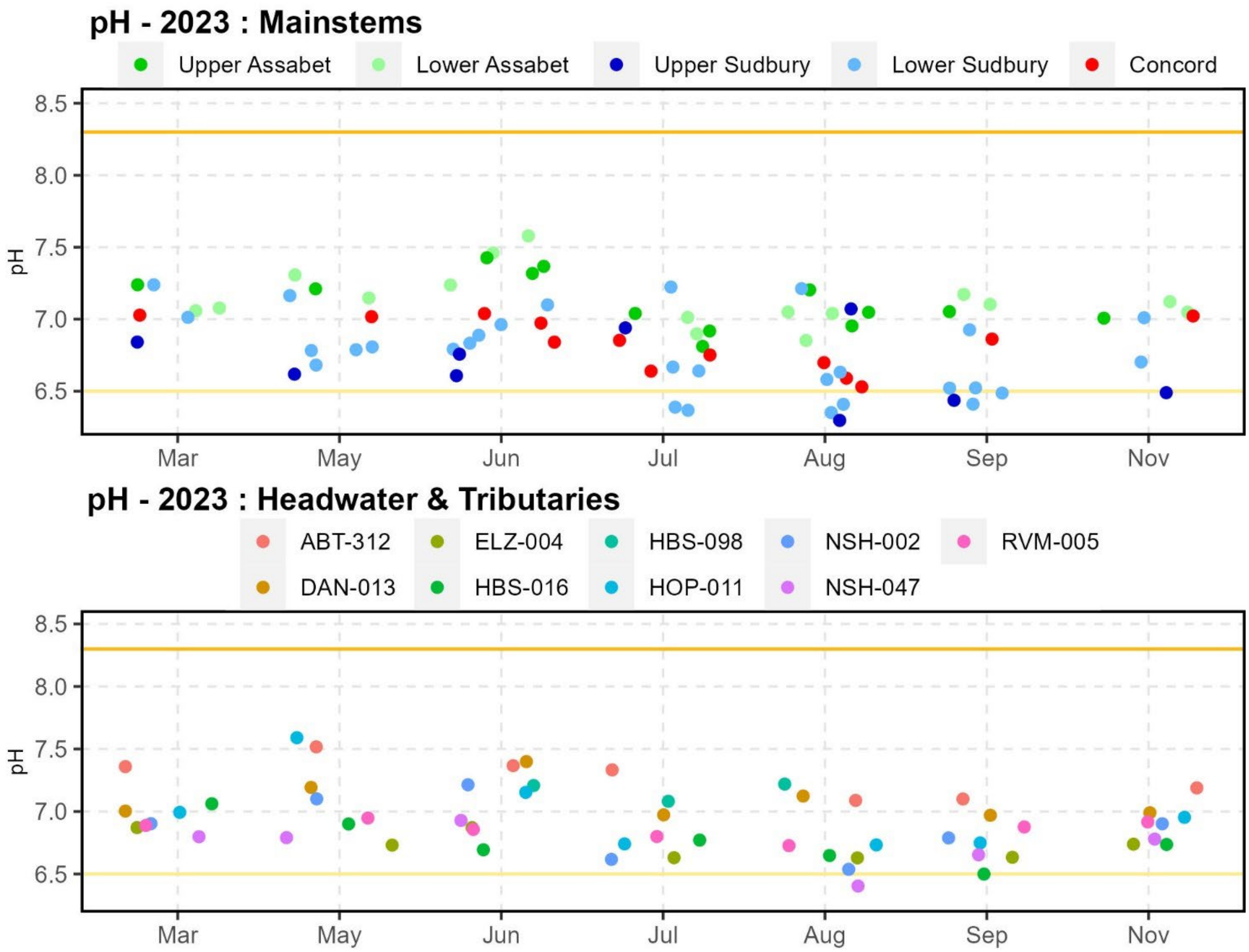

Figure 24: pH by month and site (2023)

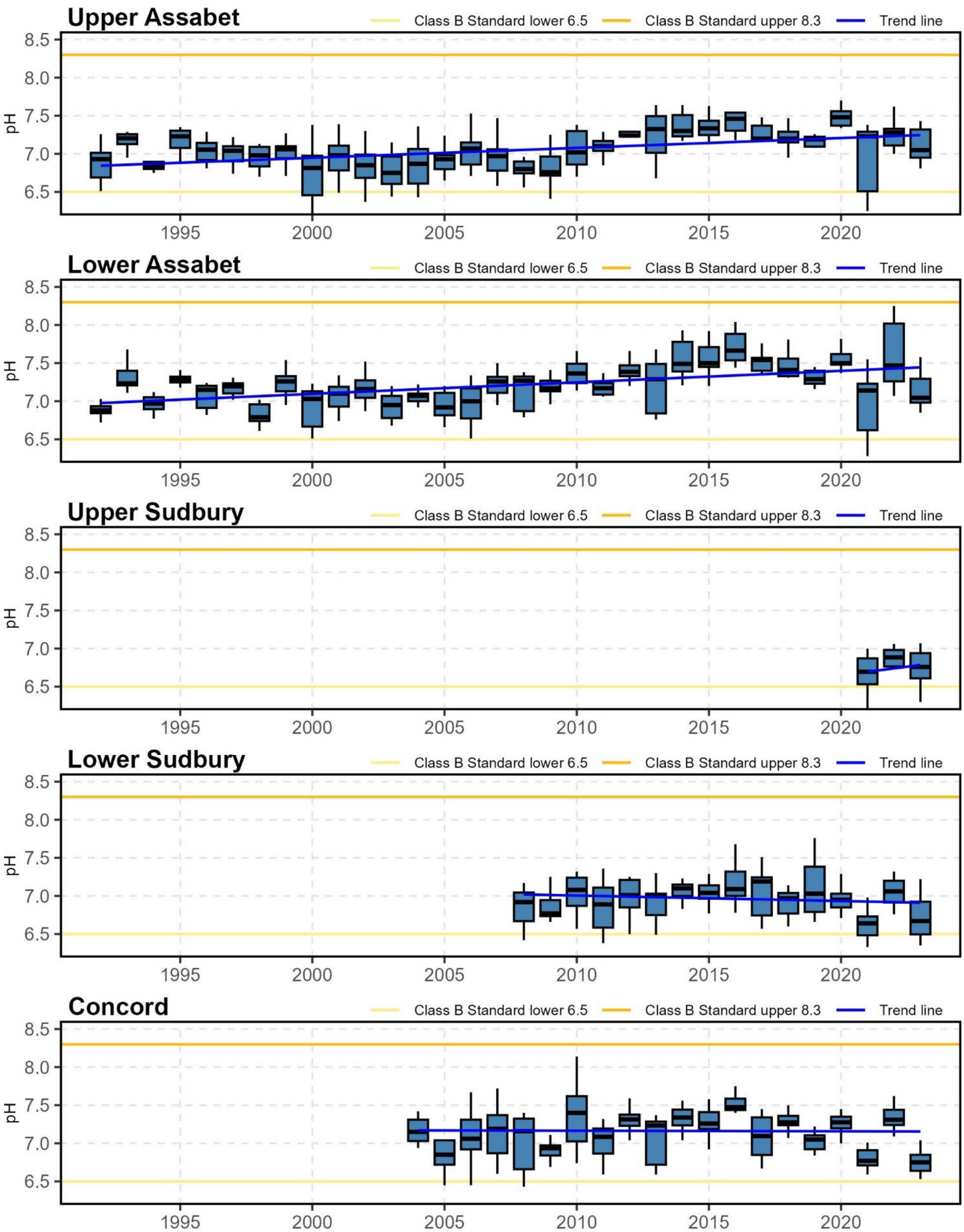

Figure 25: pH by year and section (June/July/August)

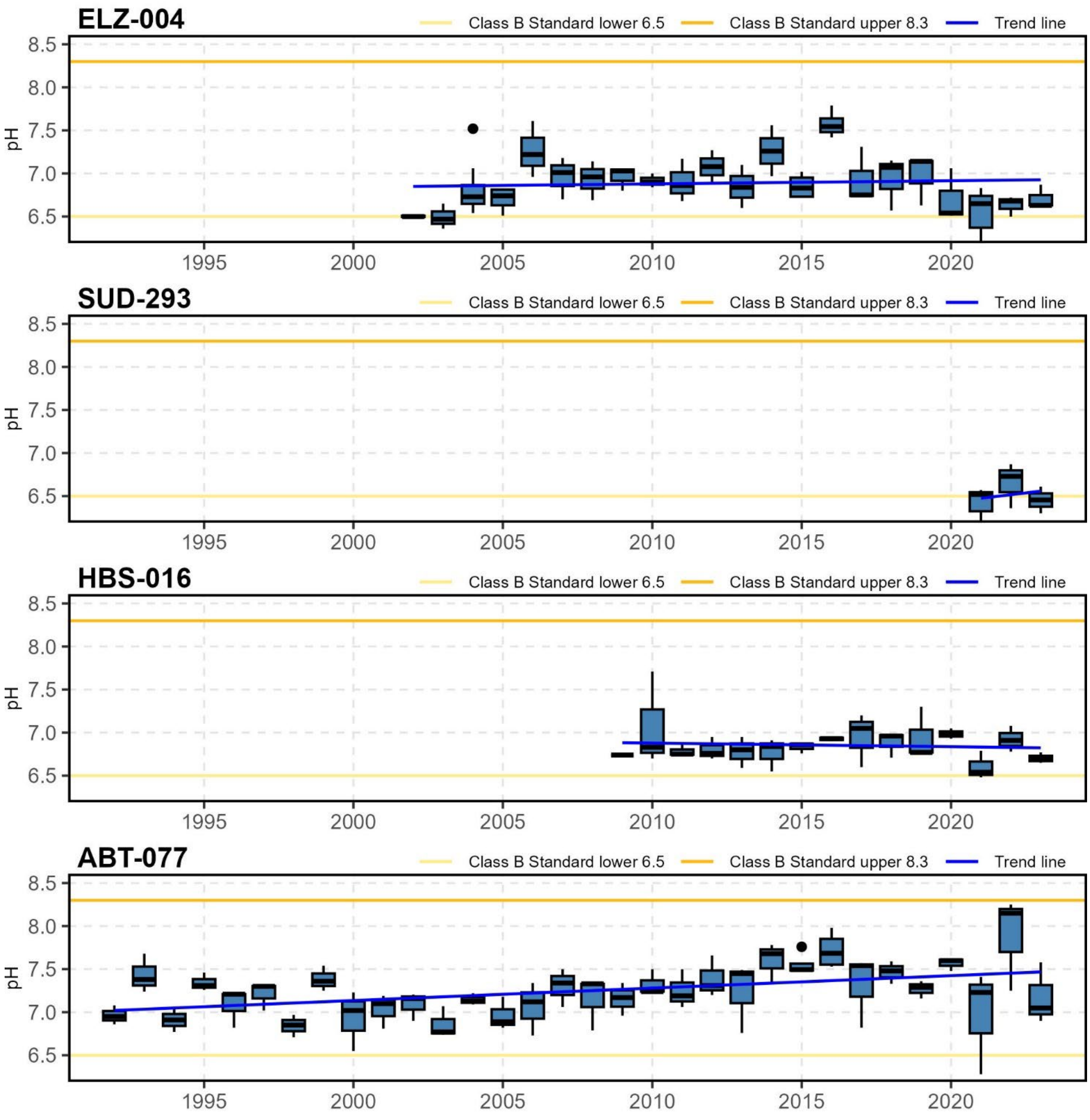

Figure 26: pH by year for selected sites (June/July/August)

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 for each of the wastewater treatment plants (WWTPs) to meet the TMDL. Significant reductions in instream phosphorus concentrations have been achieved since 2004 as a result of these permit limits (Figure 29).

In 2023 (Figure 27 and Figure 28), Total Phosphorus (TP) concentrations were elevated starting in July due to the heavy precipitation and high flow, often exceeding the EPA "Gold Book" recommendation of 0.05 mg/L. Almost all mainstem sites exceeded recommendation in July, when samples were collected in high flow conditions and during a major rainstorm. Especially noteworthy were the ABT-301 site, downstream of the Westborough WWTP, and the Lower Sudbury sites. All sites downstream of major wetland floodplains exhibited very high TP levels in July/Aug/Sep reflecting phosphorus that was washed off the land by high waters. The Hop Brook in Sudbury (HBS-016) was an extreme example of this, but we have also been watching this site as an indicator of legacy phosphorus being flushed from upstream impoundments. Very high TP levels were also measured at the farthest upstream Upper Sudbury site (SUD-293) in Sep/Nov. We do not know what caused this, but there was major bridge construction upstream of this site for the whole year.

Year-on-year analysis of TP shows the improvements delivered by the Assabet WWTP upgrades in 2000 and 2012 (Figure 29). Major progress in reducing phosphorus concentrations has been achieved as a result of the NPDES permits and plant upgrades. There was a concerning increase in TP concentrations in all river sections in 2019, 2020, and 2021, but concentrations came back down to target levels in 2022 and, though slightly higher, retained that level in 2023. The year 2020 was extremely dry, resulting in less dilution, and 2021 was extremely wet, resulting in more nonpoint source runoff. While we have primarily been focusing on phosphorus and algae growth in the Assabet, it should be noted that both the Sudbury and Concord rivers have had median phosphorus levels at or above the 0.05 mg/L threshold continuously since 2019.

Looking at load instead of concentration shows a much different picture (Figure 30). 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. Using the graph of annual summer loads, a clear connection can be drawn with the years of highest flow (Figure 6). The years 2003, 2006, 2009, 2013, 2021, and 2023 are all examples of high flow years with high TP loads. The magnitude of the high-flow loads is telling because it demonstrates how a single high-flow event 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. High flows also carry phosphorus out of the system, so the net effect is not clear. This load analysis helps clarify the situation in 2020. Even though concentrations in 2020 were high, loads were very low, indicating that the 2020 concentrations were most likely a factor of lack of water and dilution. The high flows in 2023 and 2021 produced similar high loads in both years. The slightly higher loads in 2021 were probably a result of the longer period between high flow years and more accumulated phosphorus in the system.

WWTP discharge concentrations and loads are also included for reference (Figure 33, Figure 34, Figure 35, Figure 36). Total WWTP phosphorus load rose in 2023 to its highest level since 2016. This was mostly driven by the Hudson WWTP, which exceeded its NPDES permit discharge limits eight of twelve months in 2023. Hudson also exceeded its limits four months in 2022. OARS is working with the Hudson plant and MassDEP to address this situation. The Marlborough Easterly WWTP also discharged its largest loads since 2015. This is noteworthy because OARS has been working on a special study with the Hop Brook Protection

Association to evaluate high phosphorus levels in Hop Brook. Hop Brook site (HBS-016) still consistently has the highest TP concentrations in our watershed and Hop Brook does exhibit eutrophic conditions.

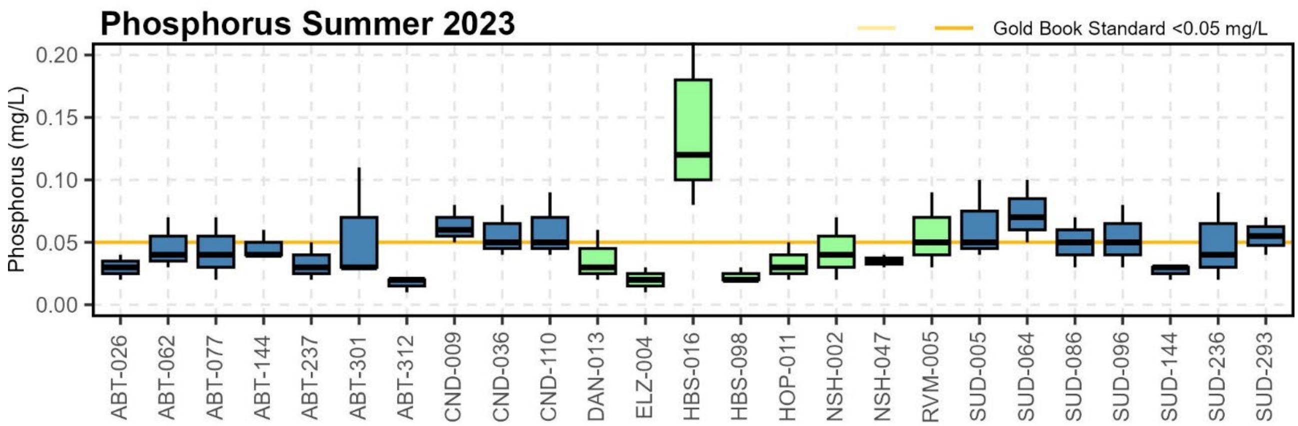

Figure 27: TP concentration by site, summer (Jun-Aug 2023)

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.

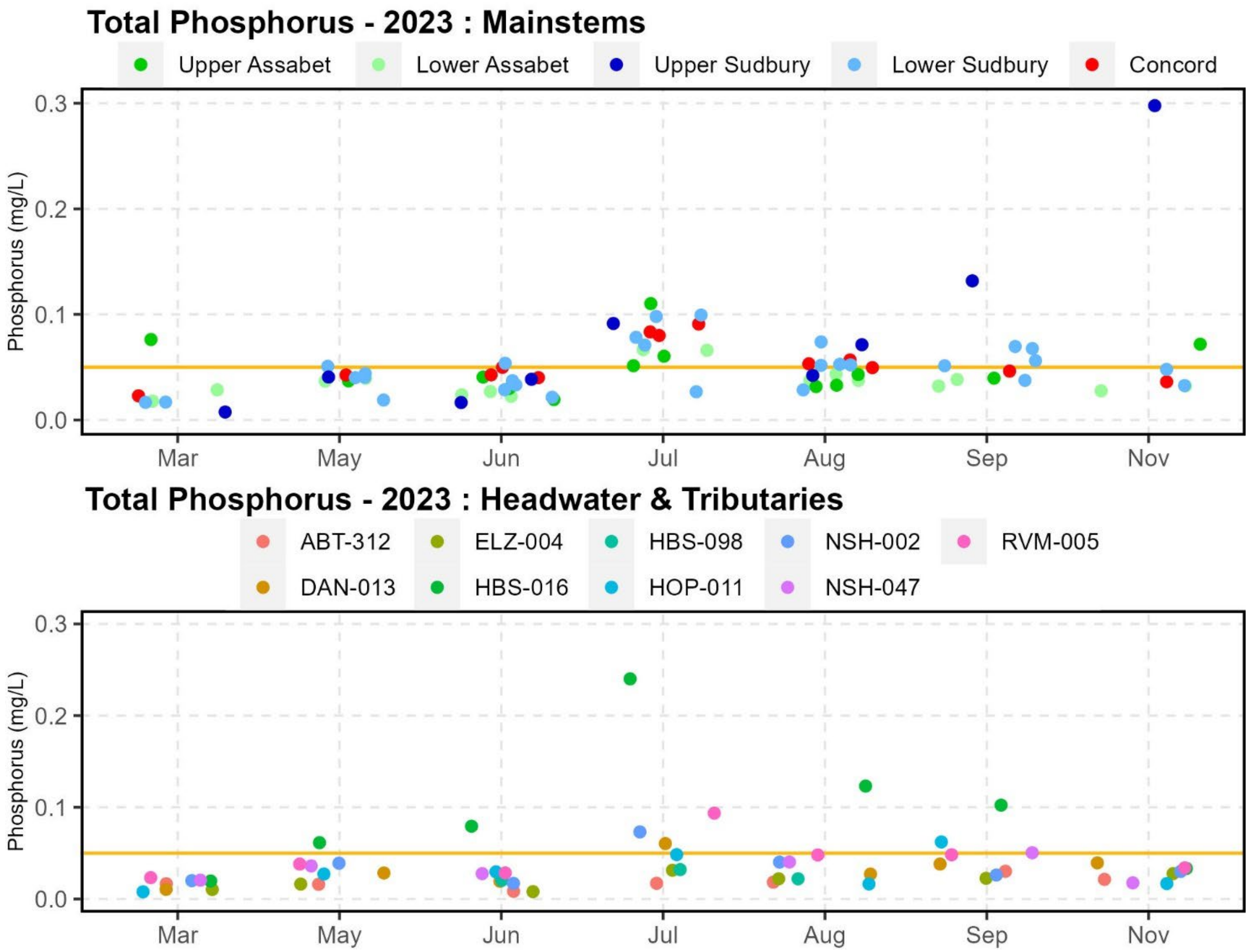

Figure 28: TP concentration by month and site (2023)

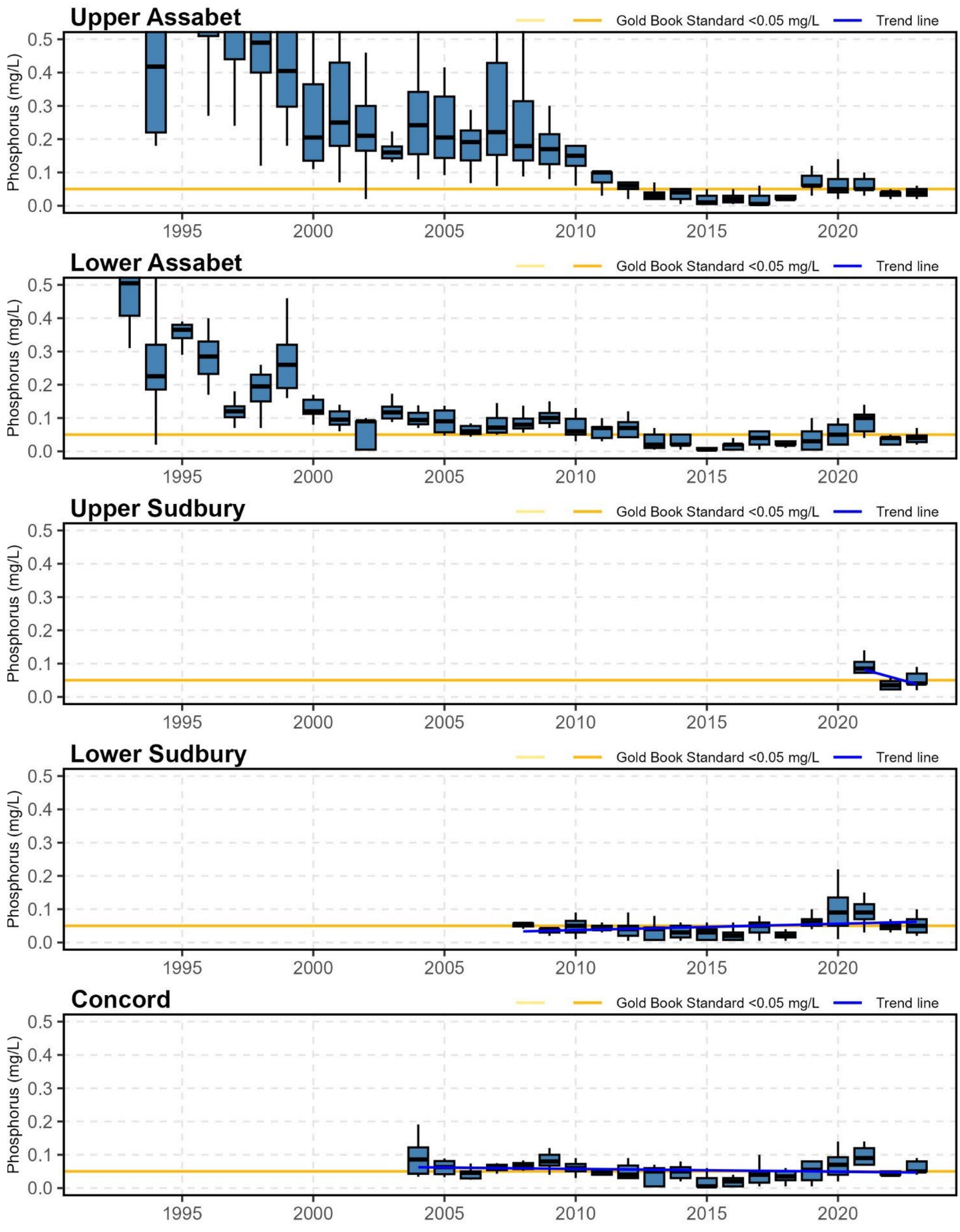

Figure 29: TP concentration by year and section (June/July/August)

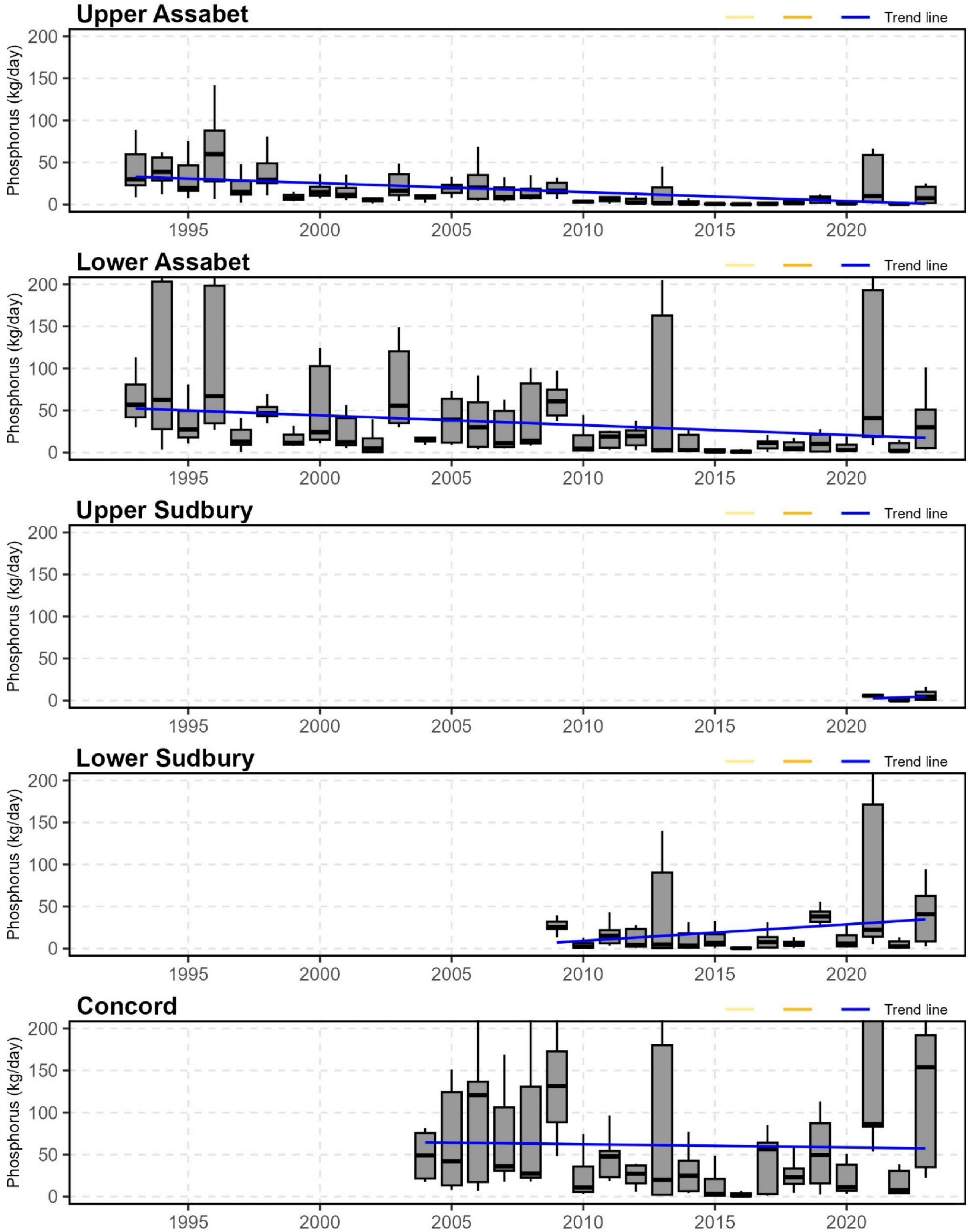

Figure 30: TP estimated load by year and section (June/July/August)

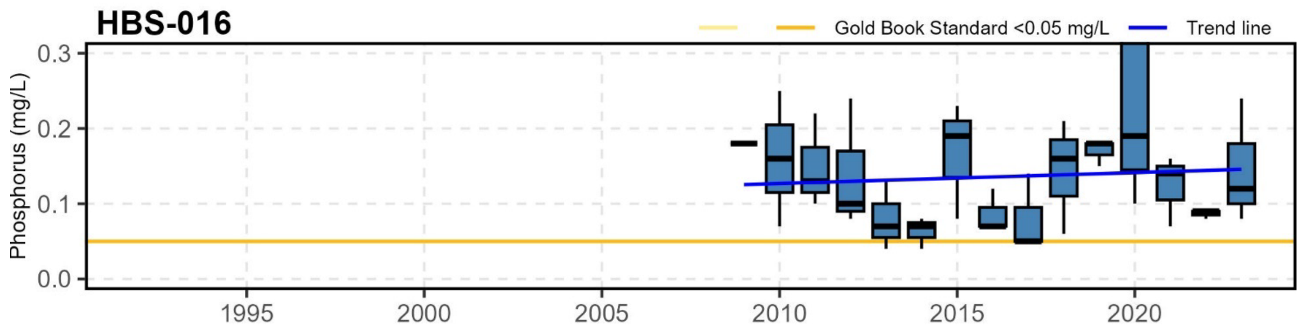

Figure 31: TP concentration by year selected sites (June/July/August)

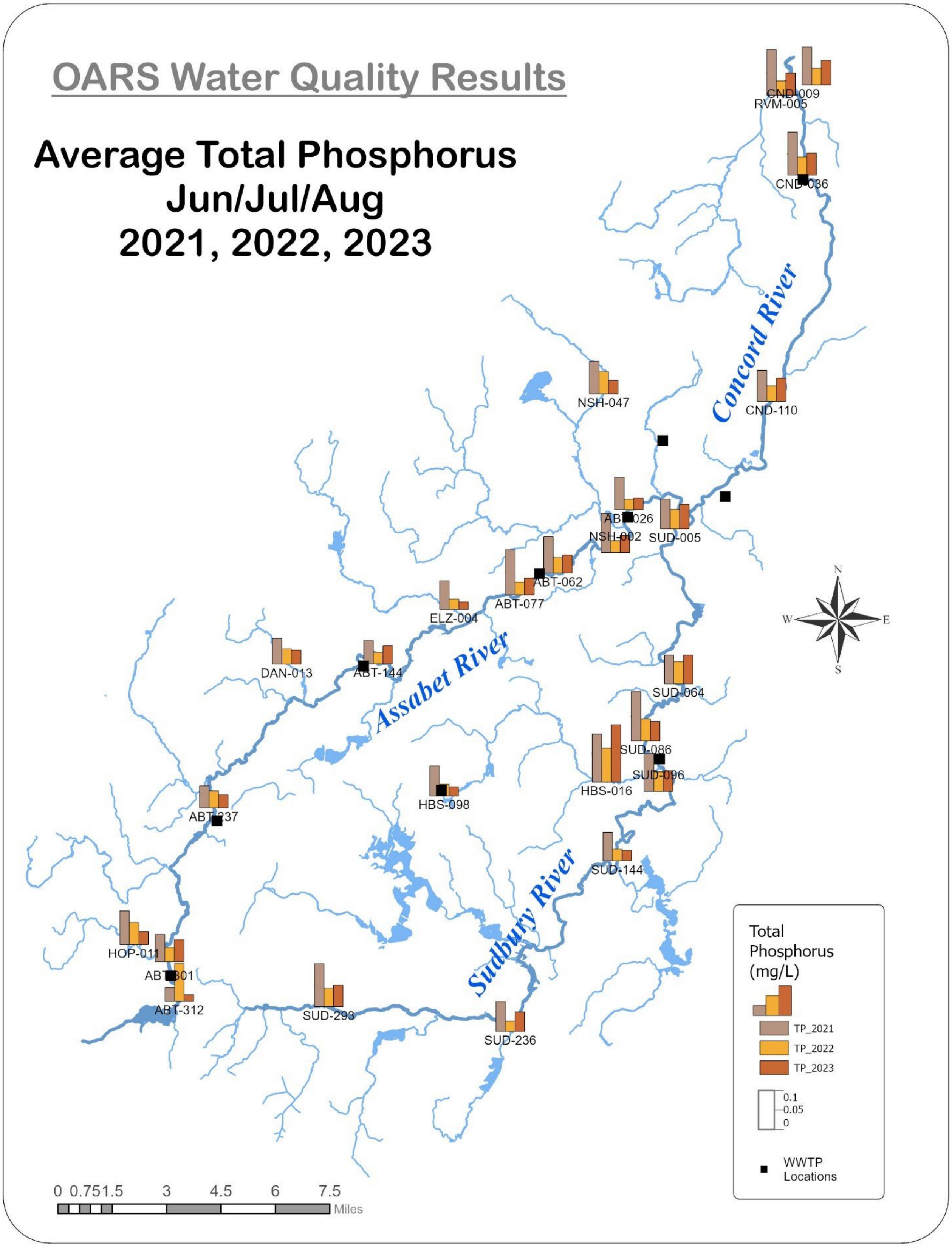

Figure 32: Map of average summer Total Phosphorus by site (2021-2023)

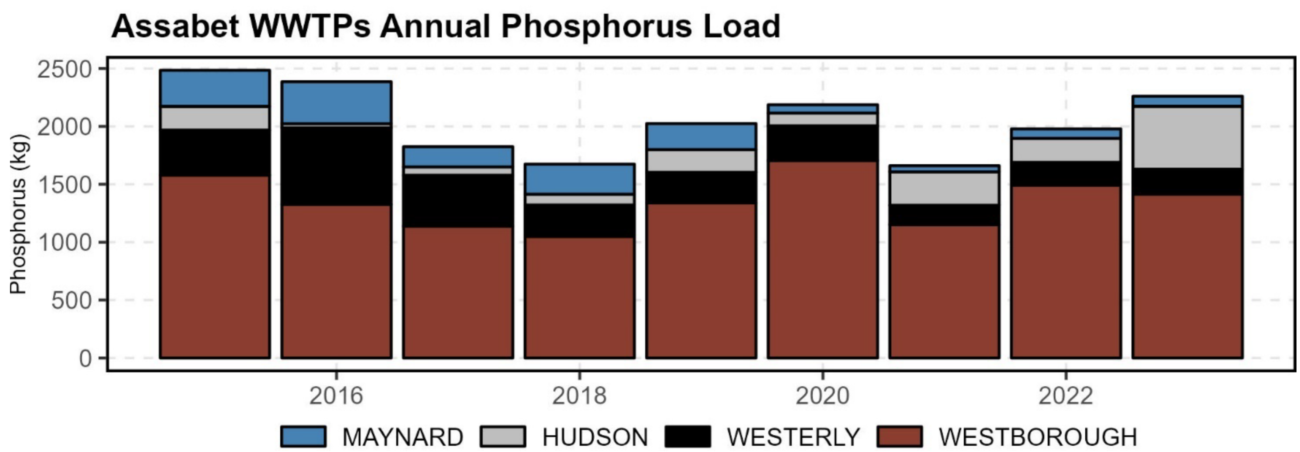

Figure 33: Major Assabet WWTPs TP discharge (2015-2023)

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

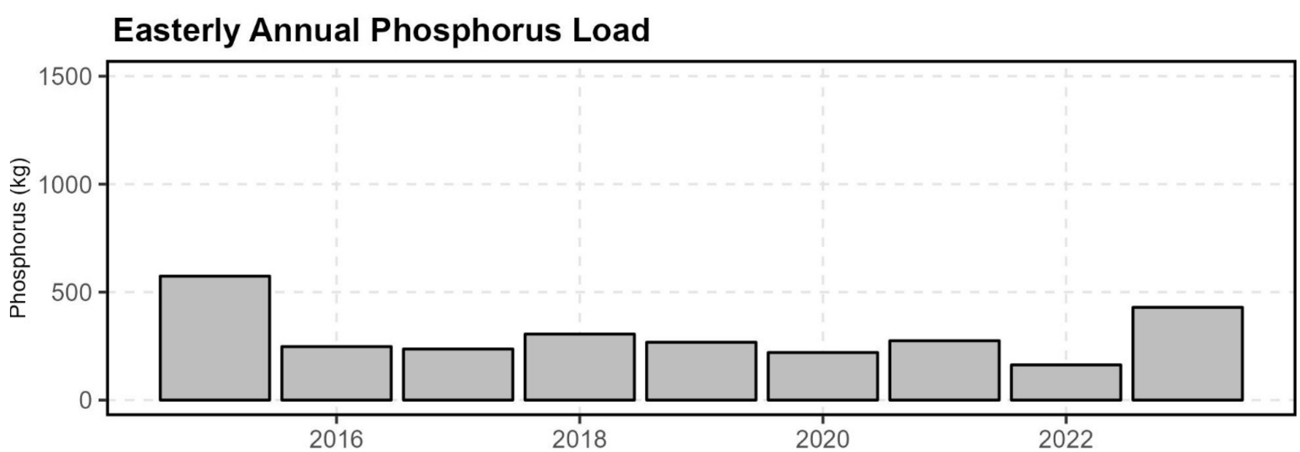

Figure 34: Major Sudbury WWTP TP discharge (2015-2023)

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

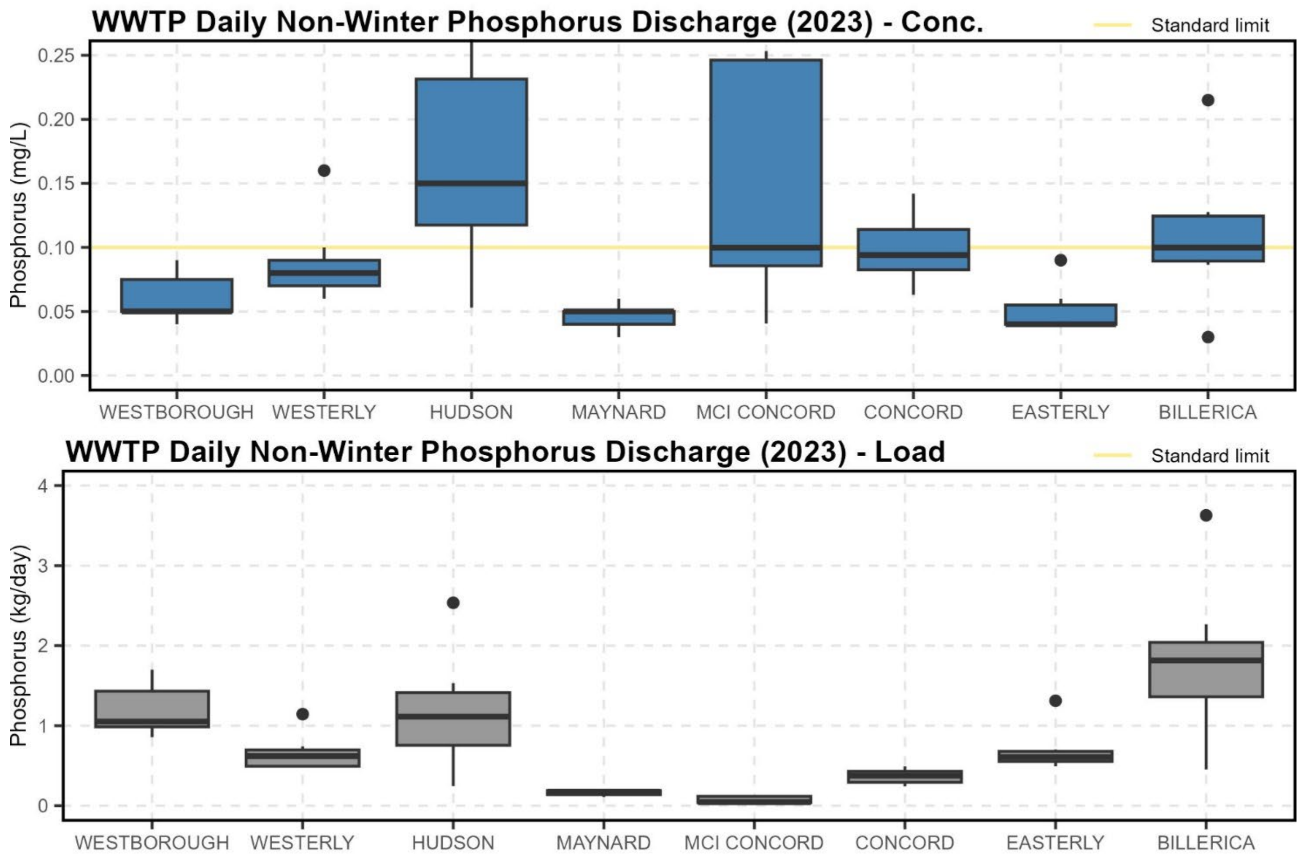

Figure 35: WWTP Daily TP Discharge - summer (2023, Apr-Oct)

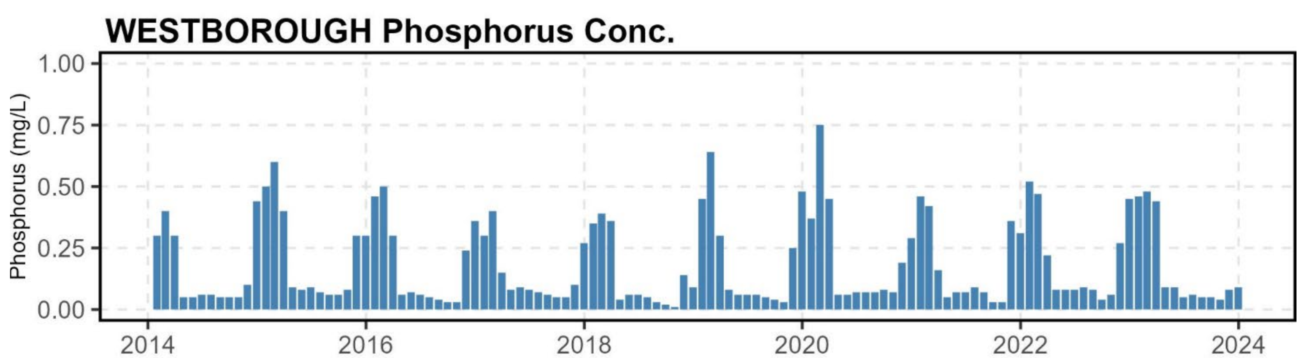

Figure 36: Westborough WWTP TP discharge by month (concentration)

Orthophosphate

Orthophosphate represents the portion of Total Phosphorus that is bioavailable and in dissolved form in water. It is 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 bioavailable phosphates represented from 27% to 71% of TP during the summer in 2023 (Figure 37). Hop Brook in Sudbury (HBS-016), which always has the highest TP levels, had 45% orthophosphate. This site is located in a large wetland and downstream of several impoundments with large quantities of legacy phosphorus in the sediments. Note the 71% orthophosphate at HBS-098, downstream of the Easterly WWTP. Monthly analysis of orthophosphate shows a high proportion in the Upper Assabet in March and a moderate proportion in November (Figure 38). This is a change from previous years, when both March and November had high proportions, because a stricter winter permit limit was implemented during 2023 for the Westborough WWTP. The very low proportions in the Upper Sudbury in September and November seem to confirm that the high TP values there were a result of disturbing non-bioavailable phosphorus in the sediment at the upstream bridge construction site.

In the year-on-year analysis, the Assabet plots show clearly how the proportion of TP represented by orthophosphate decreased significantly after the WWTP upgrades in 2011 (Figure 39).

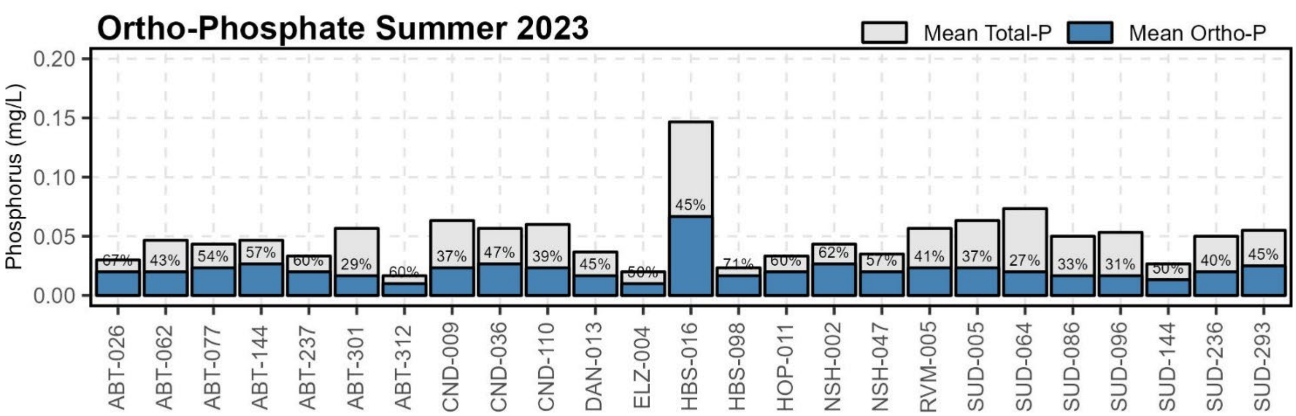

Figure 37: Ortho-P concentration by site, summer (Jun-Aug 2023)

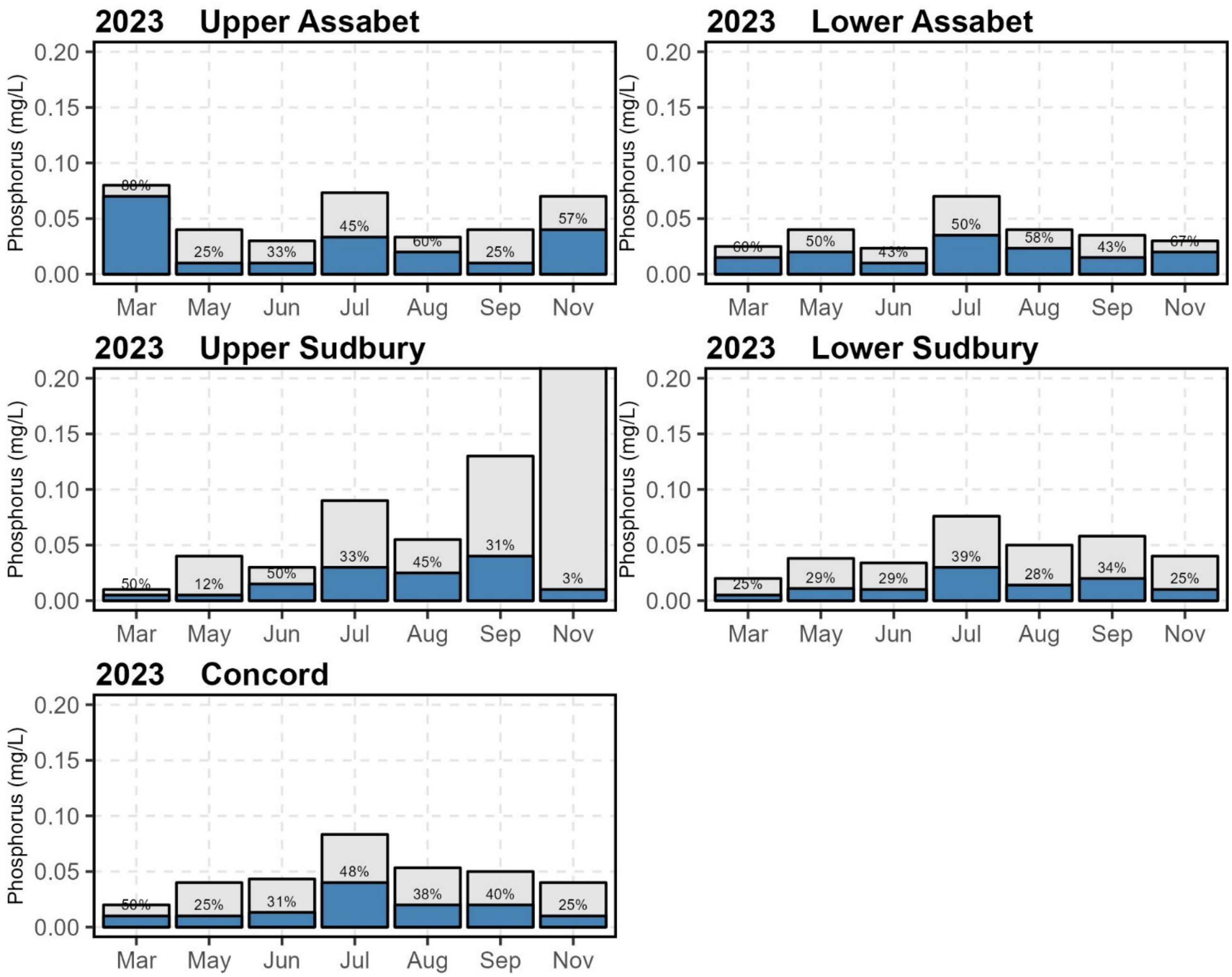

Figure 38: Ortho-P concentration by month and section (2023)

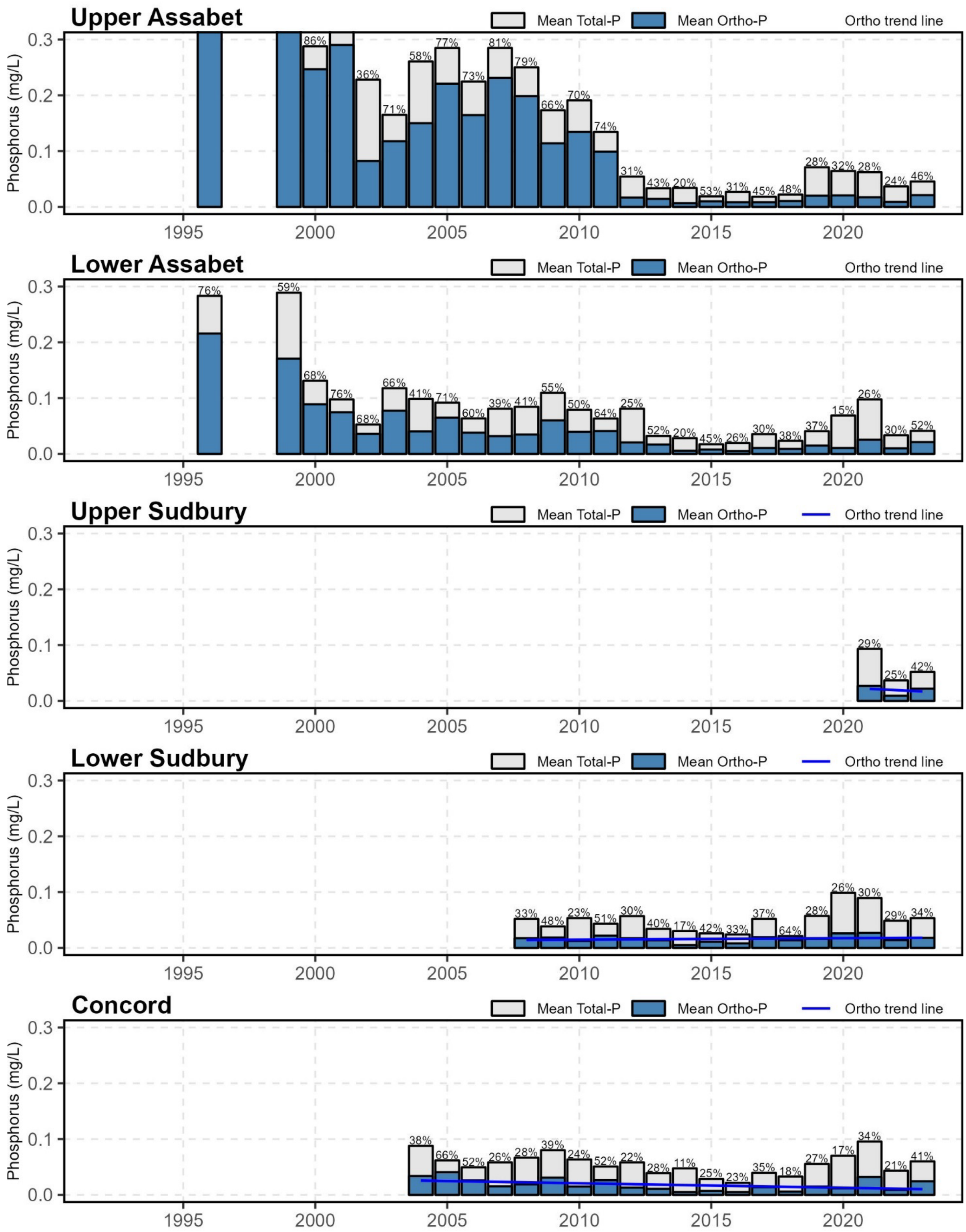

Figure 39: Ortho-P concentration by year and section (June/July/August)

<u>Nitrate</u>
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 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 2023 results with the highest concentrations in the Upper Assabet below the Westborough (ABT-301), Westerly (ABT-237), and Hudson (ABT-144) WWTPs (Figure 40 and Figure 41). This results in most Assabet sites having concentrations orders 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 (HBS-098) has also shown high nitrate levels, but that site was not analyzed for nitrate in 2023. *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.* Monthly analysis of nitrate shows the effect of dilution on concentrations, with concentration decreasing as flows increased after June.

Year-on-year analysis of NO_3 shows what seems to be an increasing trend in concentration and load in the Assabet (Figure 42 and Figure 43). Note that 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 are significant (Figure 43).

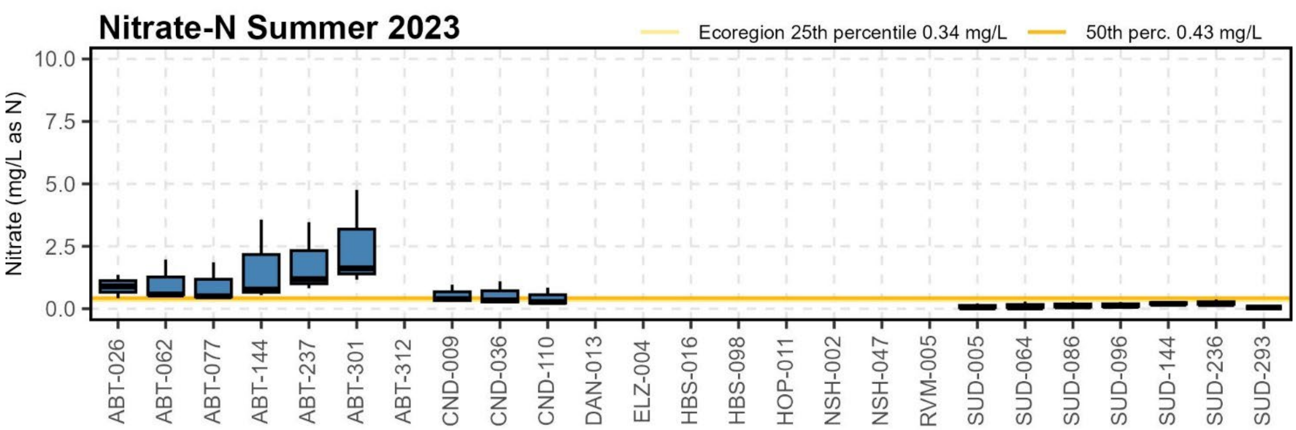

Figure 40: Nitrate concentration by site, summer (Jun-Aug 2023)

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.

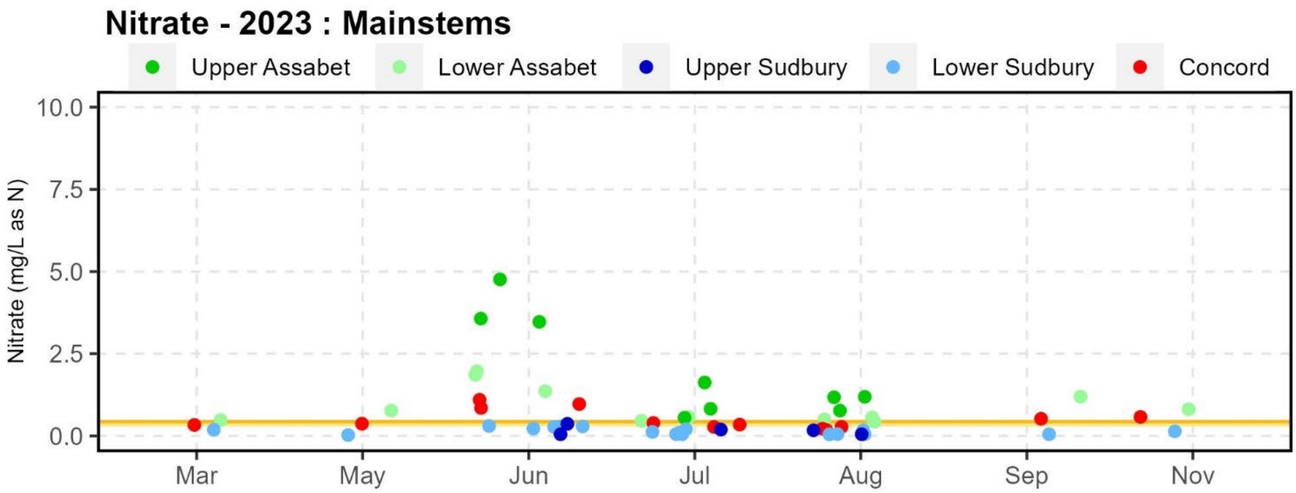

Figure 41: Nitrate concentration by month and site (2023)

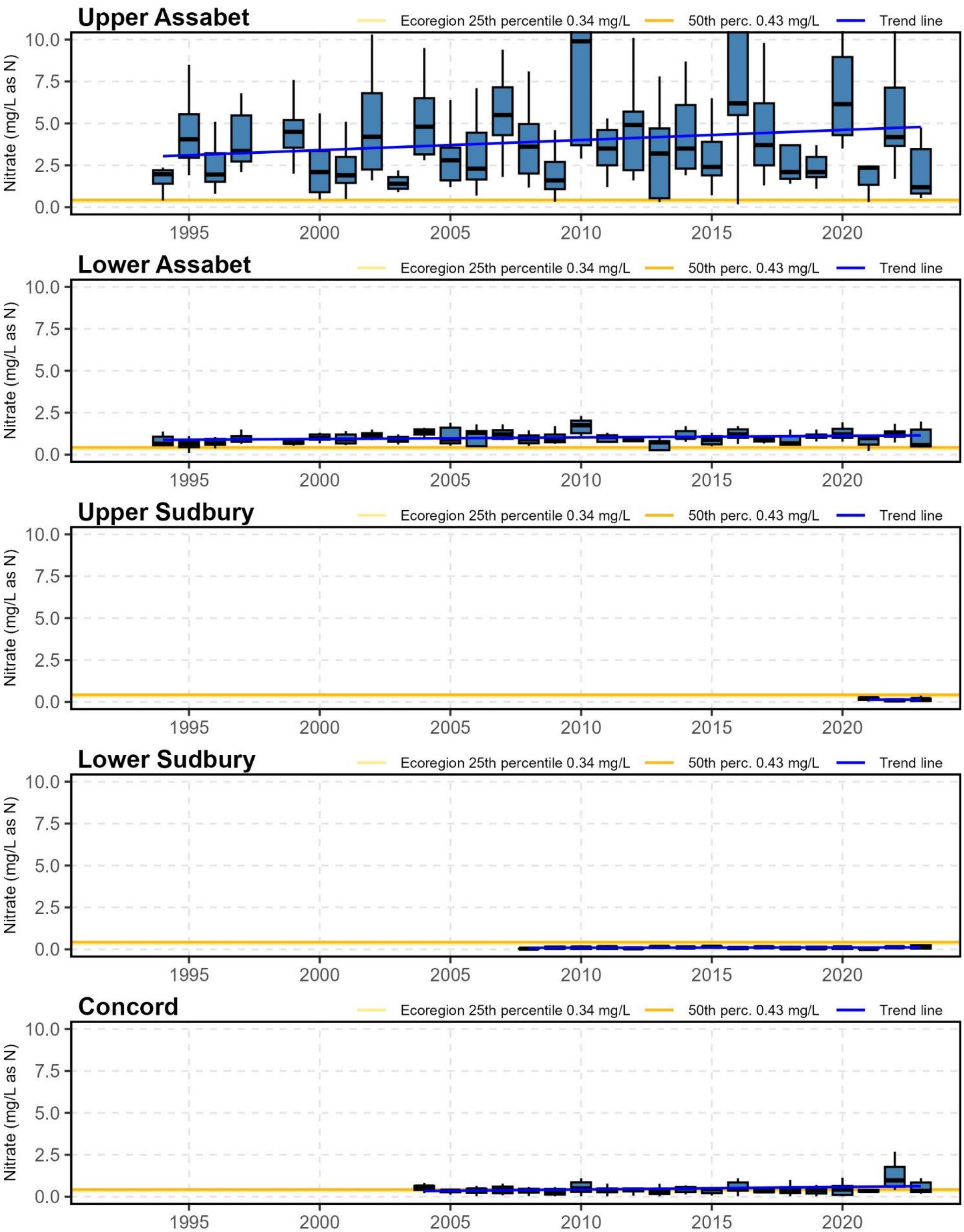

Figure 42: Nitrate concentration by year and section (June/July/August)

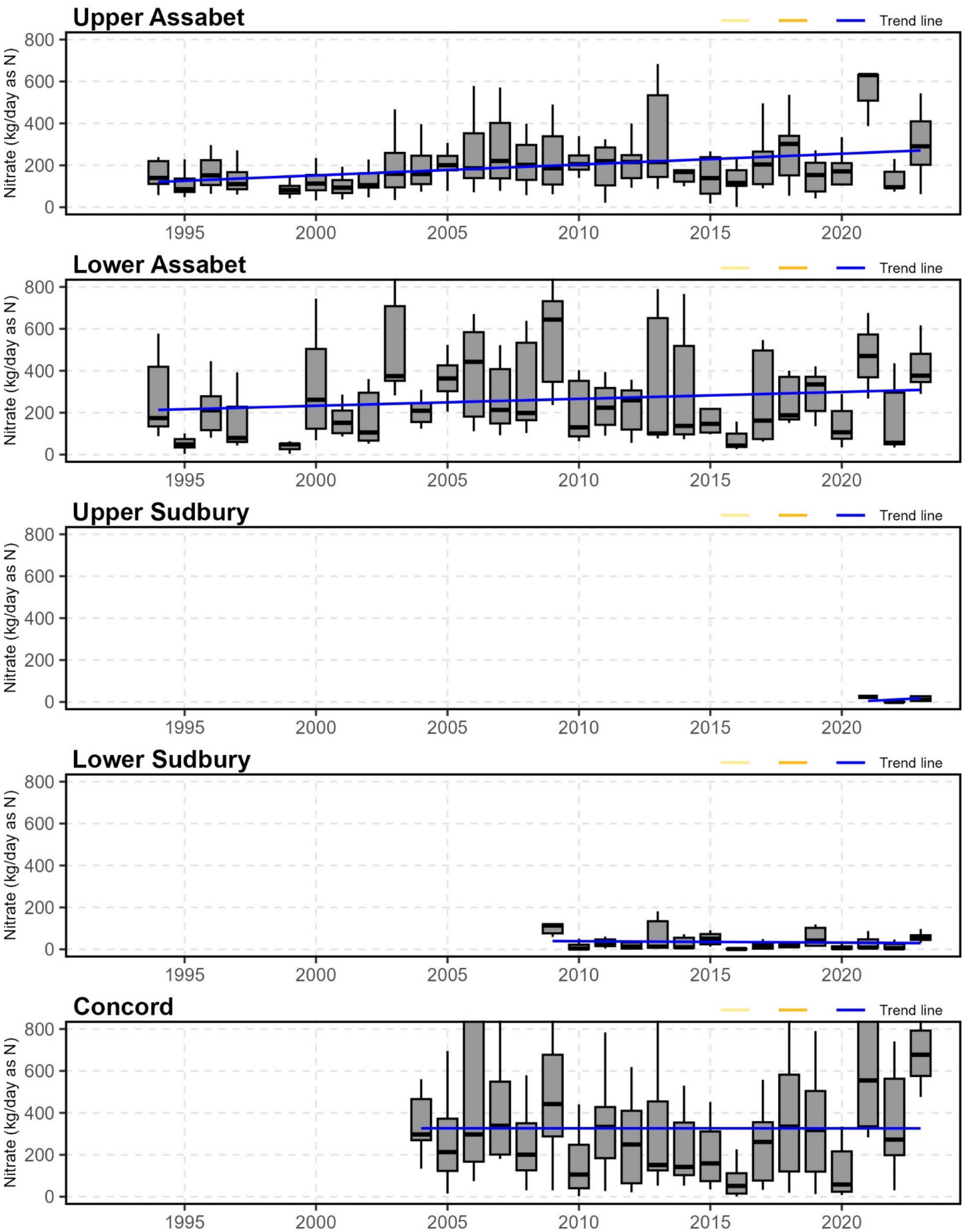

Figure 43: Nitrate estimated load by year and section (June/July/August)

Ammonia

Ammonia (NH_3) is a form of nitrogen that can be toxic to aquatic life at high concentrations. Sources of ammonia include industry (used 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 2023, the maximum summer ammonia concentration we measured was 0.46 mg/L in Hop Brook (HBS-016), with 91% of samples below 0.1 mg/L, well below concentrations toxic to fish (Figure 44 and Figure 45). Brooks with organic matter decomposition tend to have the highest ammonia levels, but two sites below WWTPs do show up in 2023 with slightly elevated levels (HBS-098 and ABT-301).

Year-on-year analysis shows that ammonia levels have been low since 2000, when the first ammonia discharge limits were applied to the WWTPs, and most ammonia measurements have been below the detection limit of 0.1 mg/L since 2012, when the WWTP upgrades were completed (Figure 46). There was an uptick in ammonia levels in 2017, which was the year following the most severe drought in recent history. It is possible that the drought resulted in high levels of decaying organic wastes for the following year. Only a few sites have had frequent results above the detection limit. These include HBS-016 (Hop Brook) and RVM-005 (River Meadow Brook) (Figure 47).

Daily discharge from the WWTPs is also included for reference (Figure 48). Note that Maynard WWTP consistently discharges concentrations above the EPA chronic threshold but within permitted limits. 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.

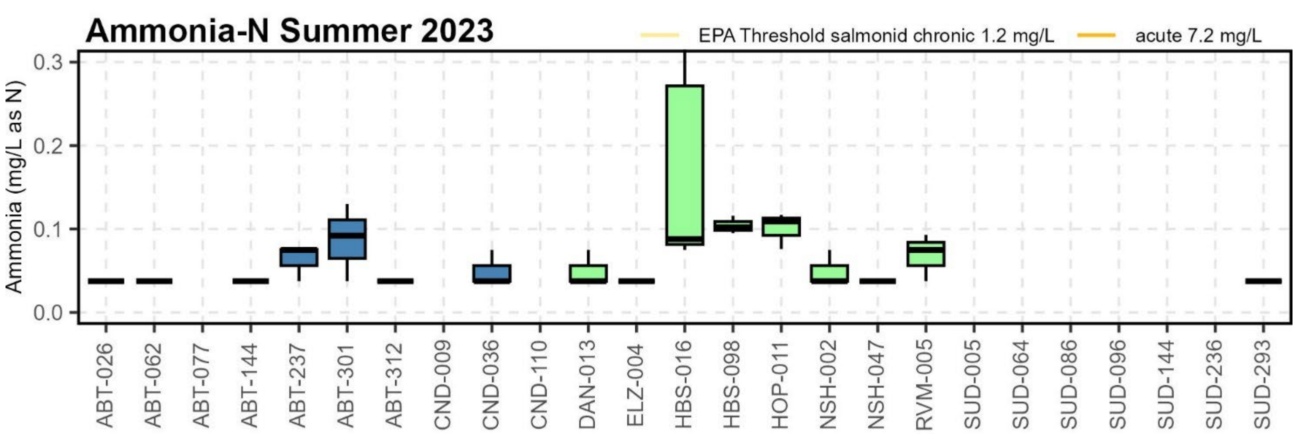

Figure 44: Ammonia concentration by site, summer (Jun-Aug 2023)

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.

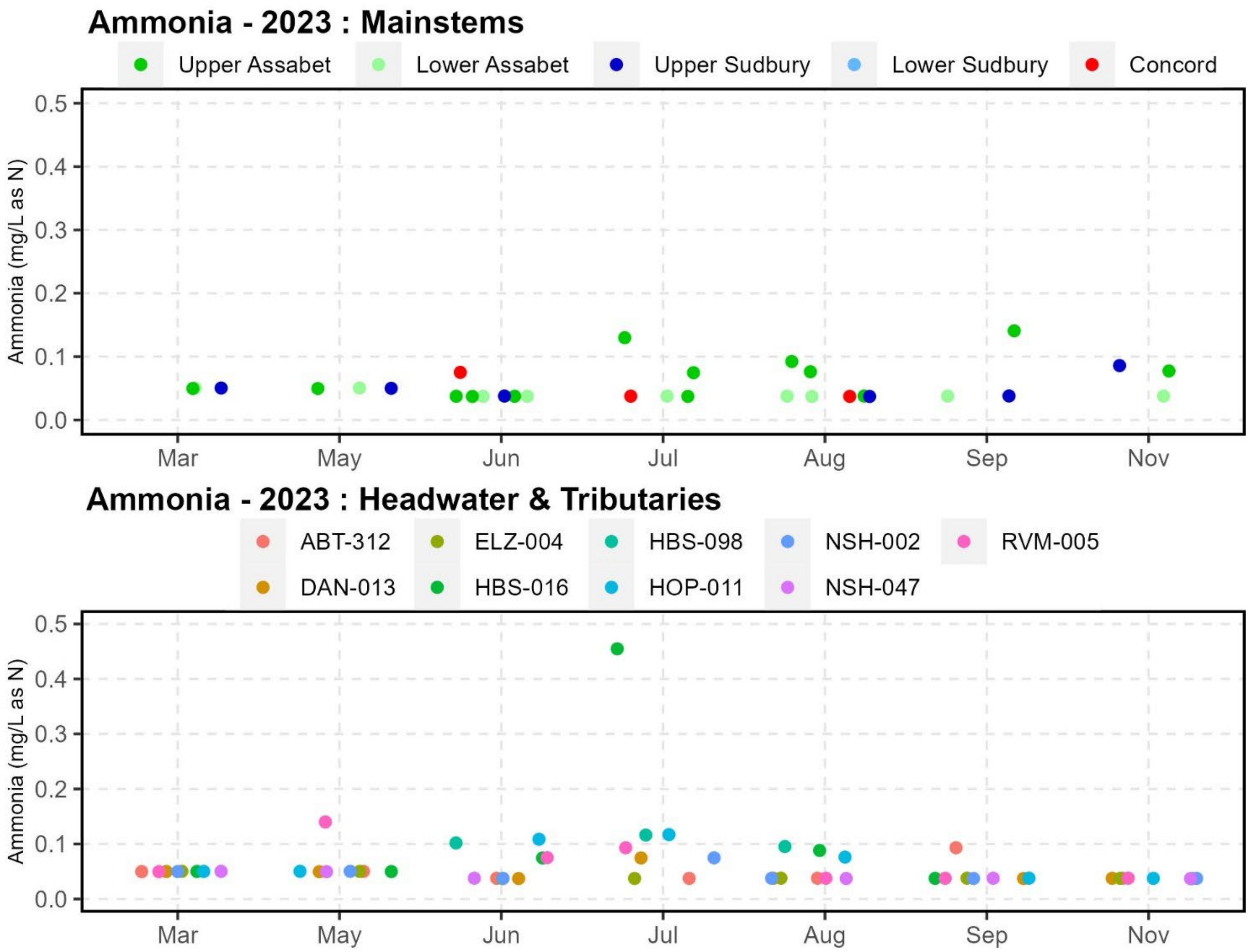

Figure 45: Ammonia concentration by month and site (2023)

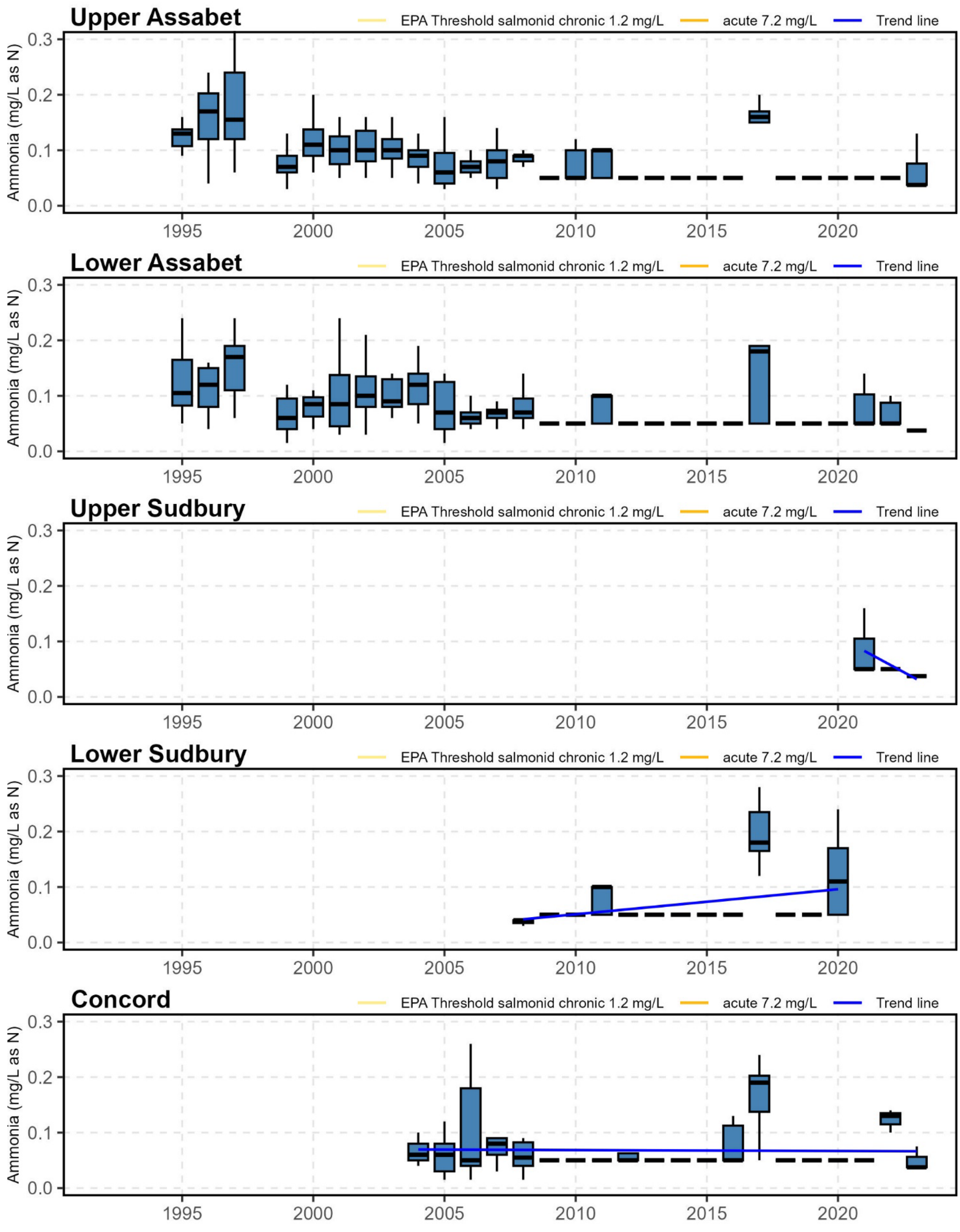

Figure 46: Ammonia concentration by year and section (June/July/August)

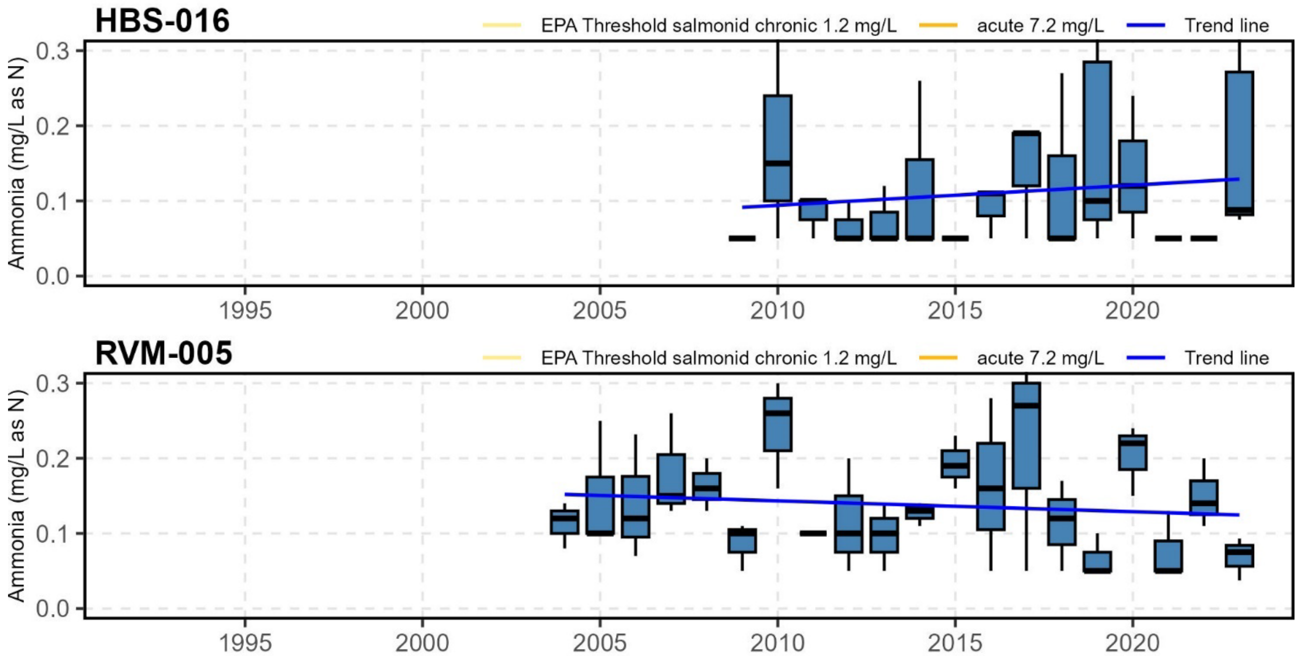

Figure 47: Ammonia concentration by year for selected sites (June/July/August)

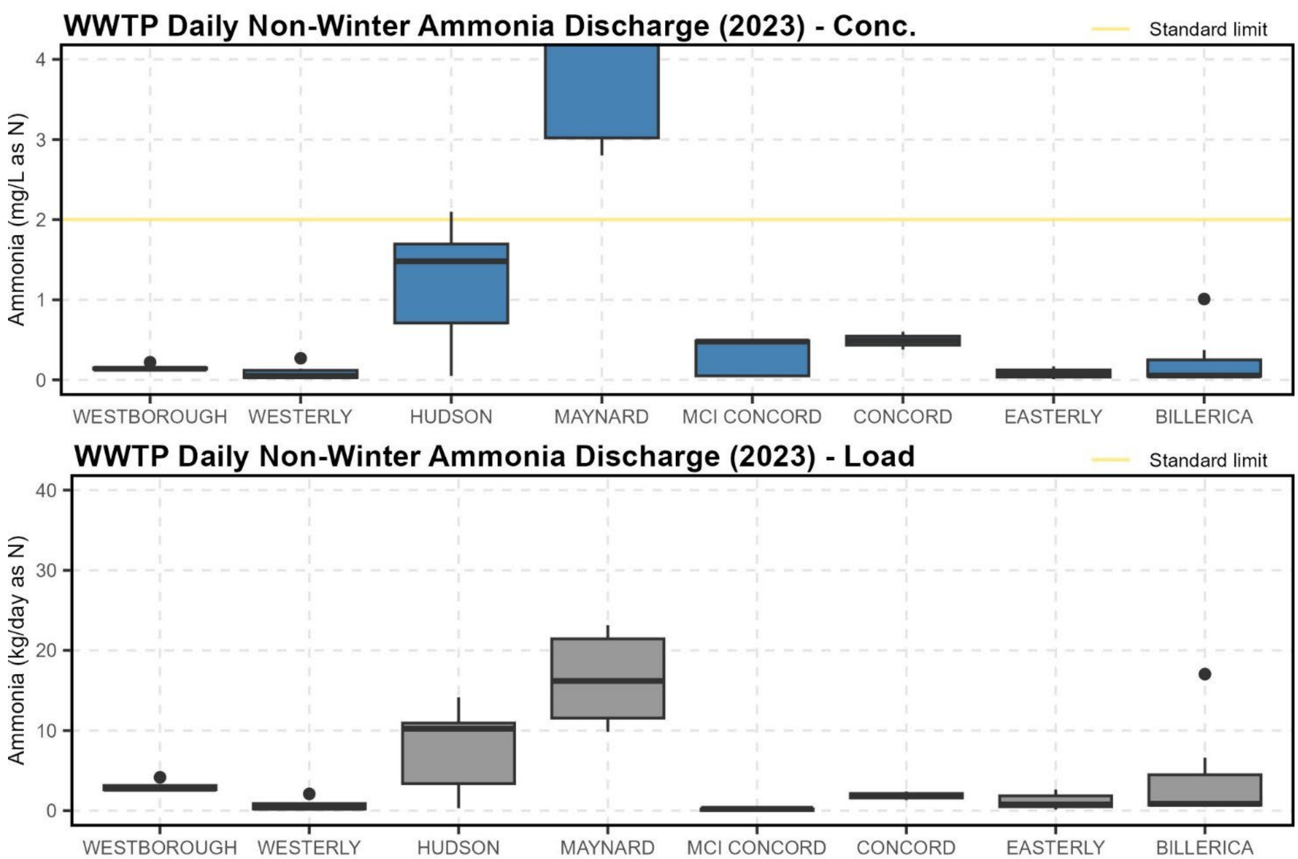

Figure 48: WWTP Daily Ammonia (NH_3 and NH_4^+) Discharge - summer (2023, Apr-Oct)

<u>Total Suspended Solids</u>
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 2023, as a result of the high dilution, TSS levels were generally subdued, but not in all cases (Figure 49 and Figure 50). The Lower Sudbury and Concord river sites often have much higher TSS than the rest of the sites, but this was not the case in 2023 after June. High TSS concentrations were recorded during the heavy rain storm in July at ABT-301 and SUD-236, but otherwise TSS was moderate. It is surprising that the upper Sudbury at Fruit Street (SUD-293) did not register high TSS levels from the bridge construction upstream, especially considering the high TP concentrations in September and November.

Year-on-year analysis of TSS concentration shows improving trends in all river sections, perhaps due to improved non-point source pollution controls (Figure 51). It also shows 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 52). While concentrations were moderated in 2023 by dilution, total load was significantly increased by runoff and flow.

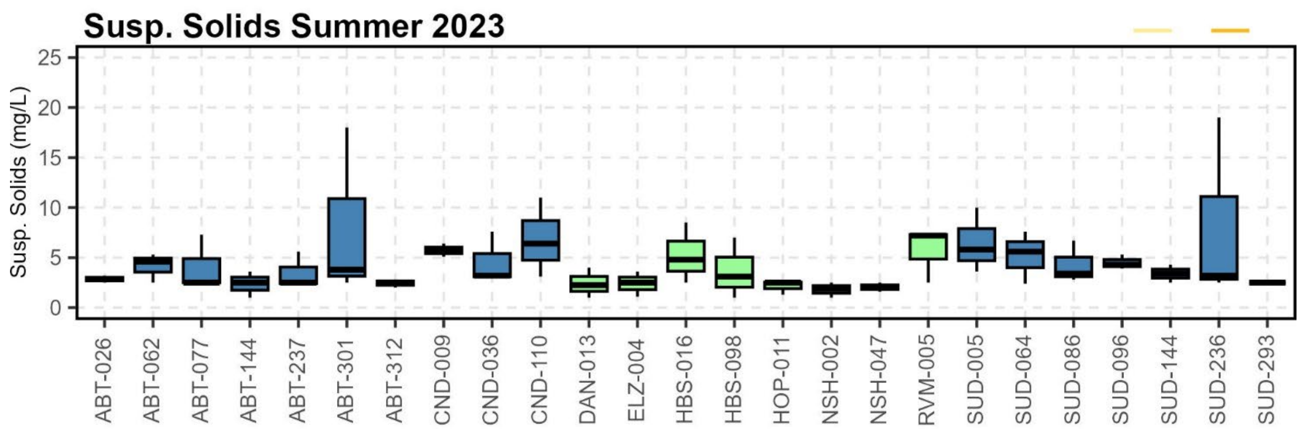

Figure 49: TSS concentration by site, summer (Jun-Aug 2023)

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.

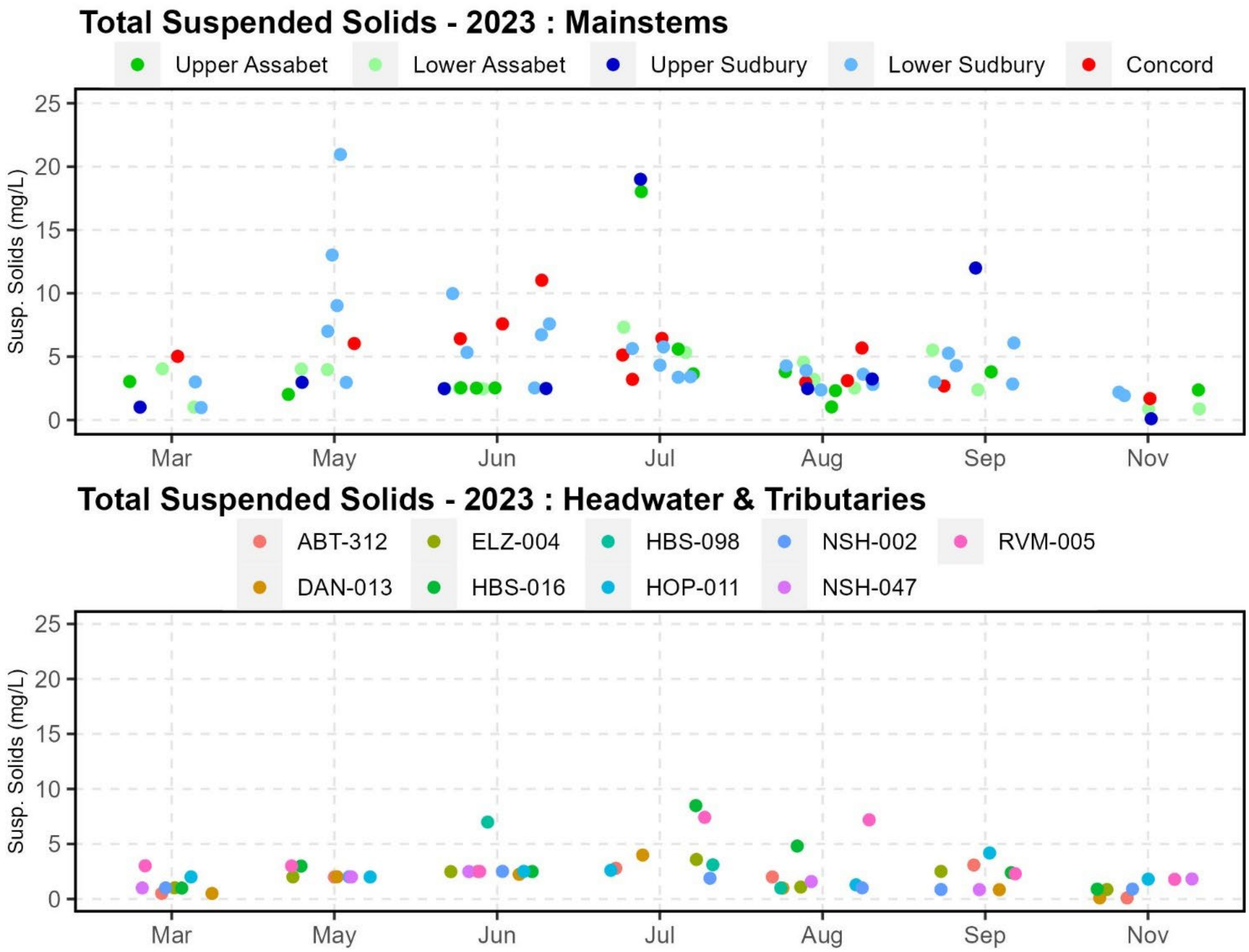

Figure 50: TSS concentration by month and site (2023)

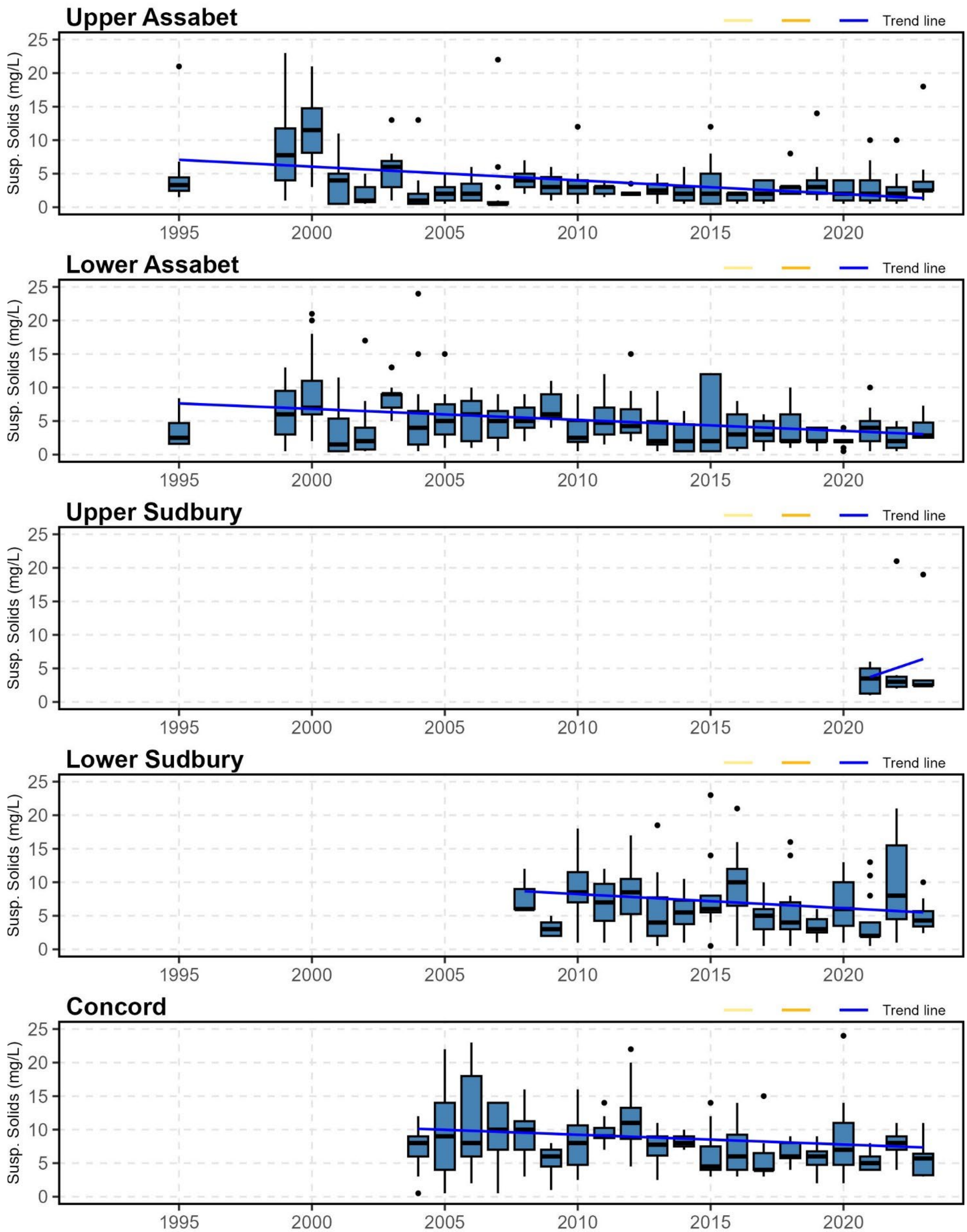

Figure 51: TSS concentration by year and section (June/July/August)

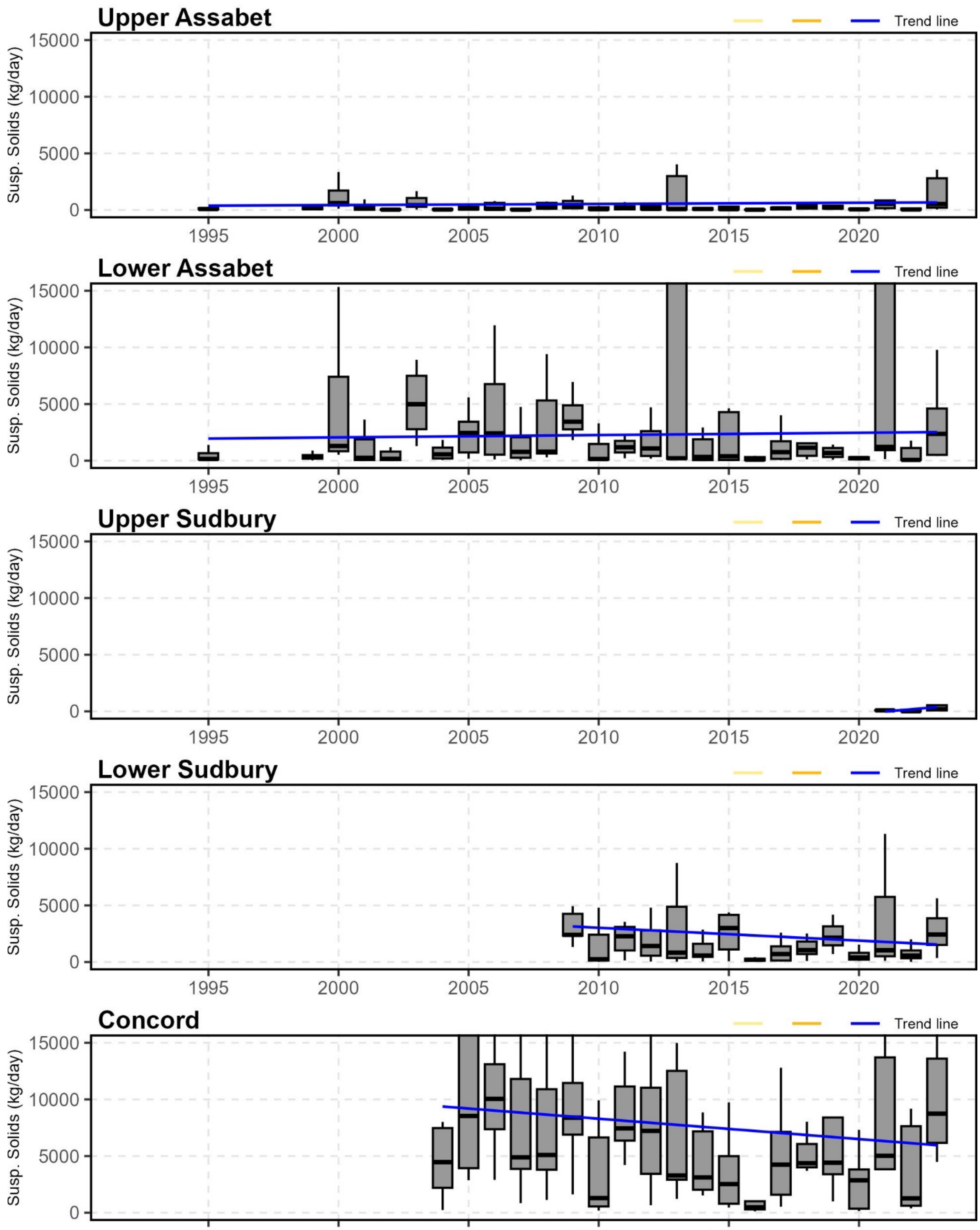

Figure 52: TSS estimated load by year and section (June/July/August)

<u>Chlorophyll *a*</u>

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 (25th percentile 2 µg/L, and 50th 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 2023, chlorophyll *a* concentrations were lower than normal due to high precipitation and flows (Figure 53 and Figure 54). Concentrations ranged from <2 to 10 µg/L. Chlorophyll *a* concentrations in the Sudbury tend to increase downstream. This was very slightly evident in the 2023 data. By month, chlorophyll *a* concentrations tend to increase from June to August, though this is not a rule and depends on temperature and flow. There was a slight increase in August 2023.

Year-on-year analysis of chlorophyll *a* shows what seems to be an improving trend since 2010 (Figure 55). The year 2023 continued this trend, but primarily due to heavy rainfall.

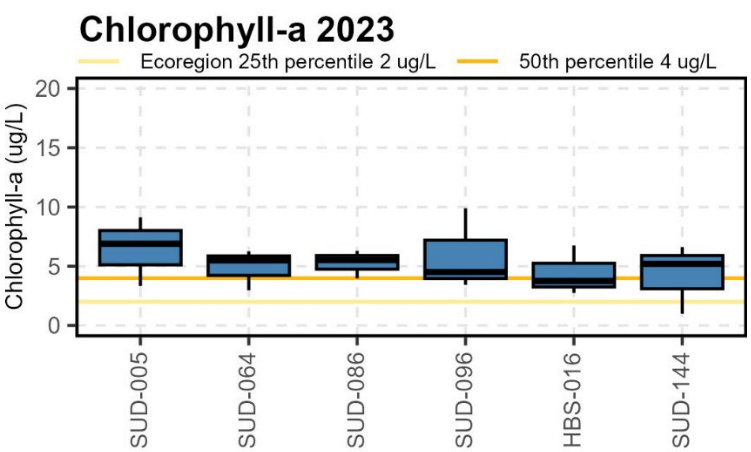

Figure 53: Chlorophyll *a* concentration by site, summer (Jun-Aug 2023)

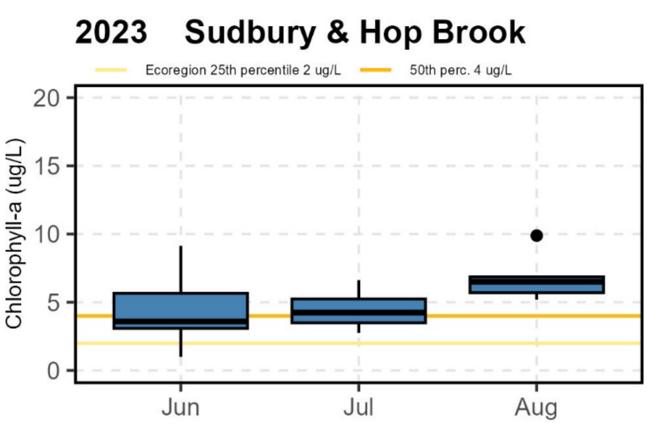

Figure 54: Chlorophyll *a* concentration by month (2023)

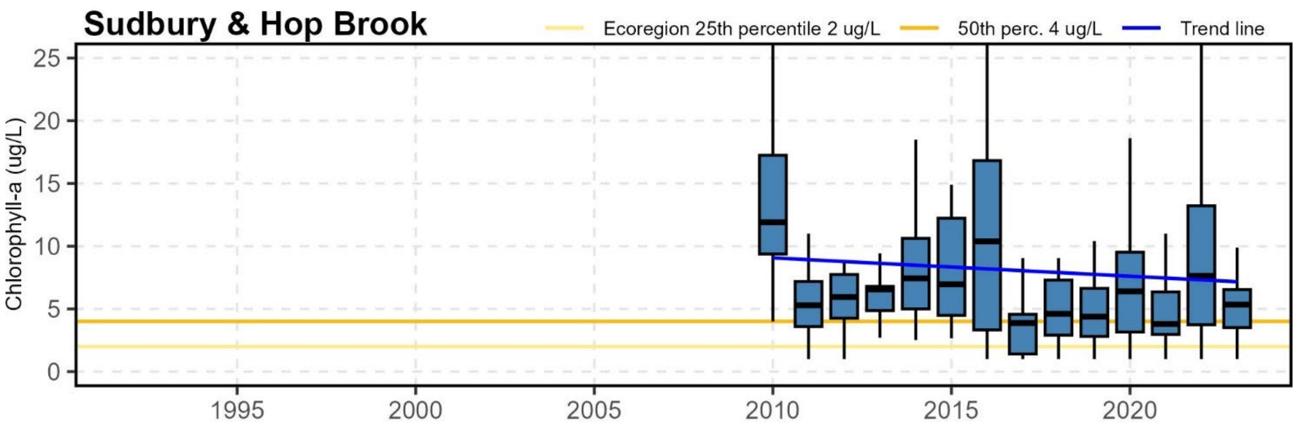

Figure 55: Chlorophyll *a* concentration by year (June/July/August)

Chloride

Chloride is a component of salt and 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). 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 56 shows all of OARS' chloride measurements since 2018 compared with conductivity measurements taken at the same time. Our linear regression on this 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 make conclusions with confidence about chloride based on easily collectable conductivity measurements, so we do not have to sample for chloride separately. Therefore, we tend to focus on conductivity and have not been analyzing samples for chloride since establishing our basin-specific correlation. The year-on-year summer conductivity graphs above show a clear upward trend in conductivity/chloride for all our rivers (Figure 16). 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 limit.

In September 2023, we did start to do analysis for chloride at the site downstream of the Westborough WWTP because we have noticed very high conductivity there and MassDEP requires direct chloride results in order to classify waters downstream of WWTPs as impaired. The results were as follows: September 290 mg/L, and November 100 mg/L. We will continue to do chloride analysis each month at this site in 2024.

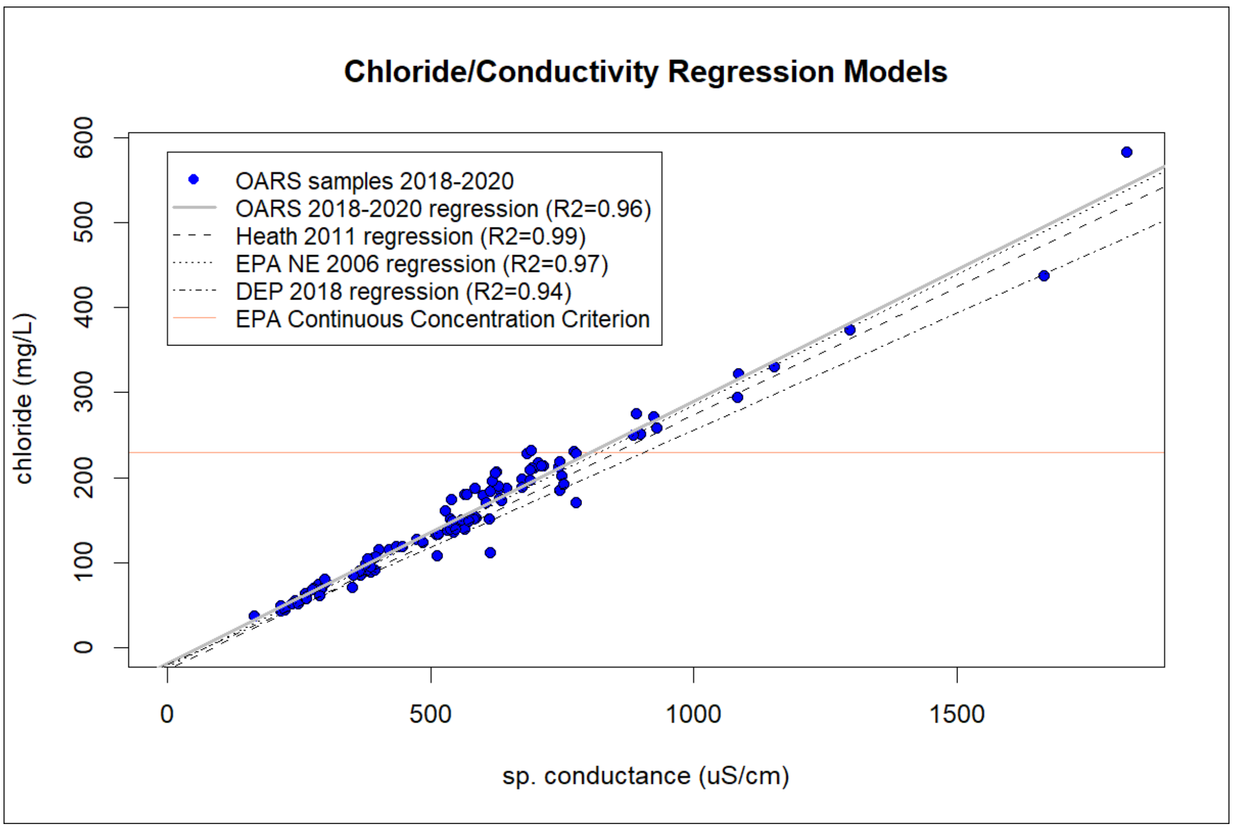

Figure 56: Chloride vs. Conductivity (2018-2020)

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 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[3]. 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 2023 five-year average are compared with the 2018 five-year average in Table 12 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 2019 and 2023 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 57). As mentioned earlier, the index is highly influenced by precipitation and flooding, which affect concentrations and dissolved oxygen. The Upper Assabet's index shows large fluctuations which are primarily driven by fluctuations in nitrate concentration also influenced by precipitation and flow. We only started computing the index for the Upper Sudbury in 2021.

Table 12: Water Quality Index calculations (2023 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

2019-2023	Nitrogen	Phosphorus	Suspended Solids	Dissolved Oxygen	Temperature	WATER QUALITY INDEX (harmonic mean)
Upper Assabet	23	59	79	80	93	46
Lower Assabet	47	64	78	85	89	67
ASSABET (area weighted)	35	61	79	82	91	56
Upper Sudbury	92	57	72	49	94	60
Lower Sudbury	95	59	68	58	90	63
SUDBURY (area weighted)	94	58	70	54	92	61
Upper Concord	72	59	60	63	83	62
Lower Concord	62	56	62	83	84	64
CONCORD (area weighted)	71	59	60	65	83	63
WATERSHED (area weighted)	64	60	72	68	90	59

[3] **https://ecoreportcard.org**

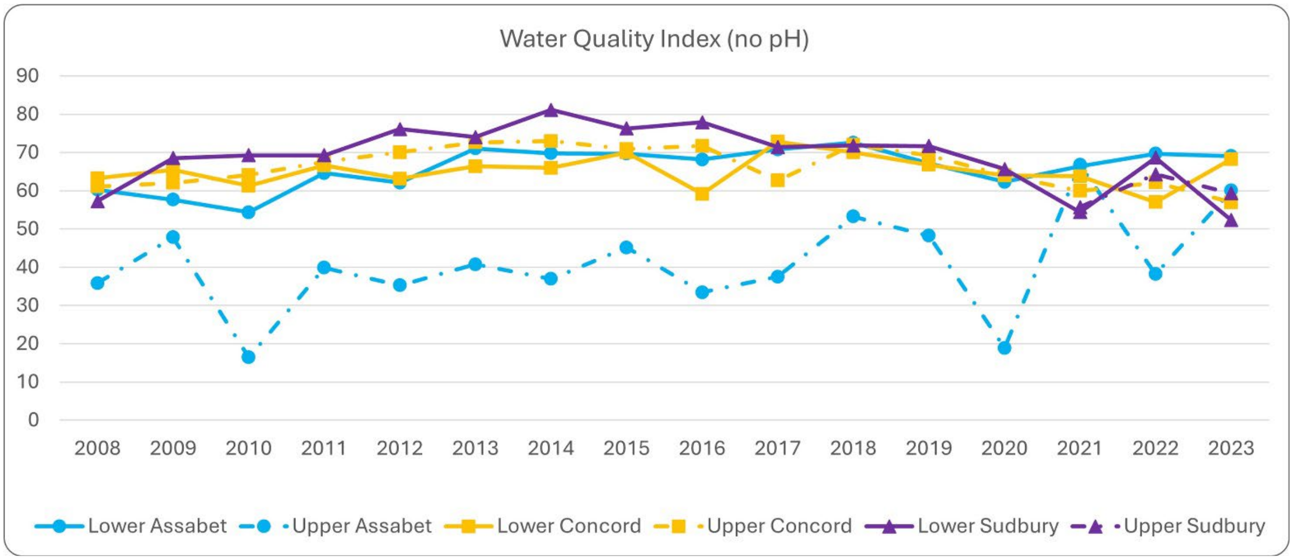

Figure 57: Water Quality Index year-on-year results (2008–2023)

Bacteria Results

OARS has been monitoring for *Escherichia coli* (*E. coli*) bacteria at six locations in the Assabet, Sudbury, and Concord rivers starting in 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 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. CFU stands for colony-forming unit and is a standard reporting measure for bacteria. It is functionally interchangeable with MPN (Most Probable Number). Bacteria data are normally analyzed on a logarithmic scale because bacteria counts in surface waters tend to change exponentially, driven by exponential changes in pollution inputs. For this same reason, averages of bacteria results are calculated using a geometric mean instead of an arithmetic mean.

Our 2023 Bacteria monitoring highlighted the same sites of concern as previous years. The Ashland, Lowell, and Maynard sites all had frequent exceedances of the Beach Action Value and seasonal geometric means above 126 CFU/100 ml (Figure 58). These three sites also all show consistent high bacteria levels in dry weather, which indicates a high probability of sanitary sewer contamination (Figure 59). Please see our 2023 Bacteria Monitoring Results report for more details (OARS, 2023b).

<u>Maynard Bacteria Special Study</u>

In 2023, OARS conducted a special study of bacteria levels at the Route 27 bridge in Maynard. As part of the study, OARS conducted bacterial source tracking, environmental DNA analysis, and detergent indication surveys. The study identified a short section of the Assabet downstream of the Route 117 bridge as a probable source of sewage contamination and it highlighted three storm sewer drains that have detectable detergent pollution. Please see our white paper “OARS Assabet in Maynard Bacteria Study—2023” for a detailed summary of the study (OARS, 2024b). Funding for the study was provided by the Greater Lowell Community Foundation.

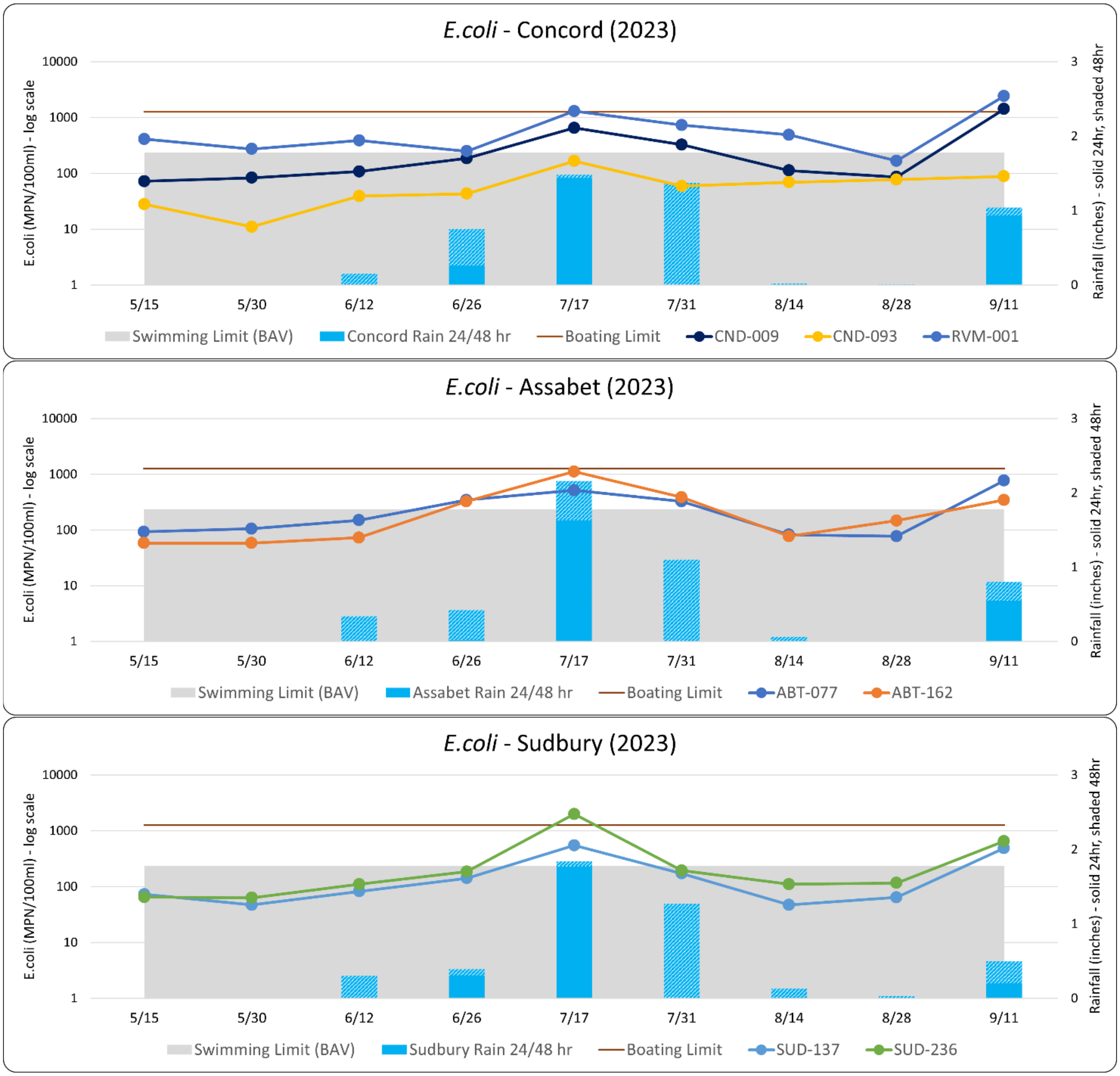

Figure 58: Graphical view of bacteria vs. rainfall (2023)

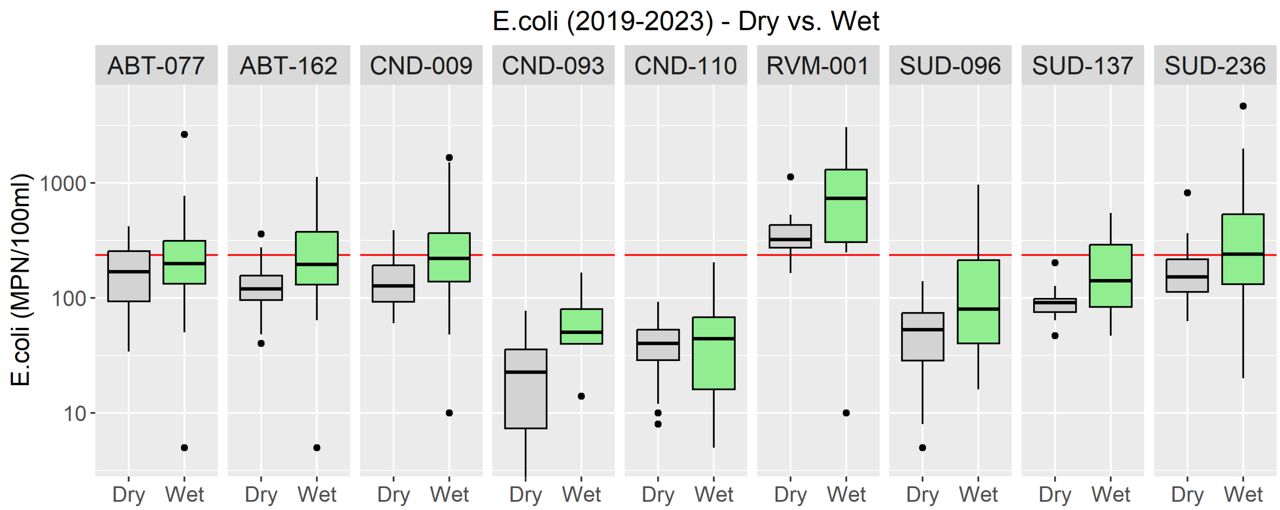

Figure 59: Boxplot analysis of bacteria for wet vs. dry days (2019–2023)

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 of total floating biomass for the Hudson, Gleasondale, and Ben Smith impoundments from 2005 to 2023 is shown in Figure 60. Trend lines for each impoundment are drawn in the graph, showing a significant upward trend in biomass for Hudson, a downward trend for Ben Smith, and no visible trend for Gleasondale. The summer of 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. High flow reduces the amount of time water resides in the impoundment and thus the amount of time algae can grow, and high flows wash more algae downstream. The Hudson impoundment, which has been choked with filamentous green algae (FGA) in recent years, had the lowest biomass levels recorded since this survey began and FGA was minimal. The Gleasondale and Ben Smith impoundments also had unusually low amounts of floating biomass. A similar analysis of duckweed (Figure 61) does not show any noticeable trends for Hudson and Gleasondale, but the lack of duckweed in the last three years in Ben Smith is noticeable and the Ben Smith trend line has a strong downward slope.

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 13). All three impoundments show some inverse correlation with rainfall, especially Ben Smith. There is a tendency toward a positive correlation with temperature, but only Hudson has a strong positive correlation. Hudson is the shallowest of the three impoundments.

Please see our white paper "OARS Biomass Summary 2023" for a detailed summary of biomass results (OARS, 2023c).

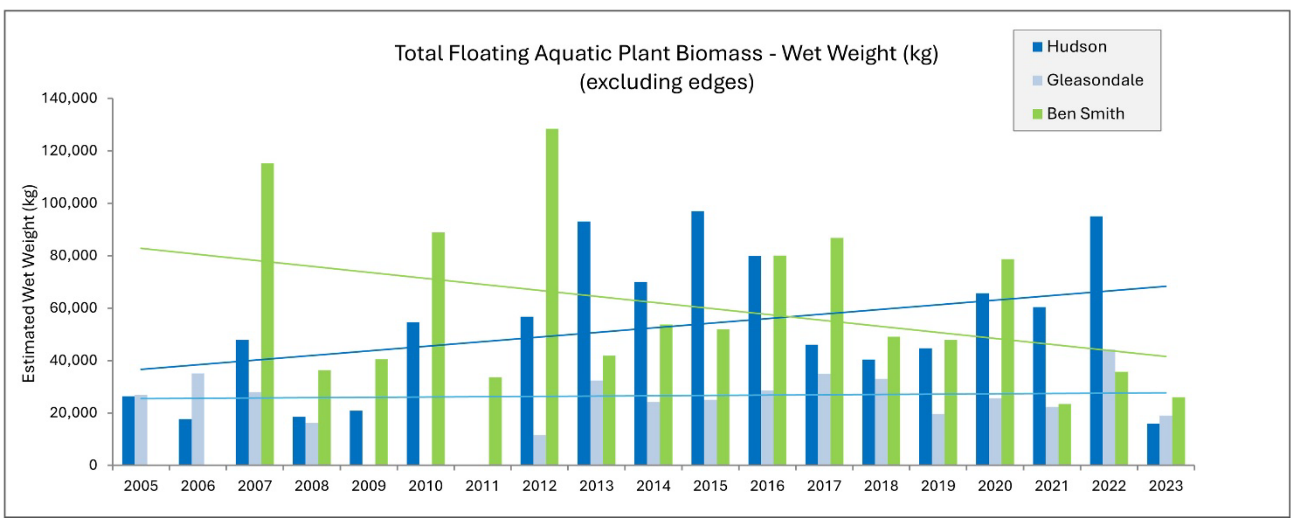

Figure 60: Total floating aquatic plant biomass (2005–2023)

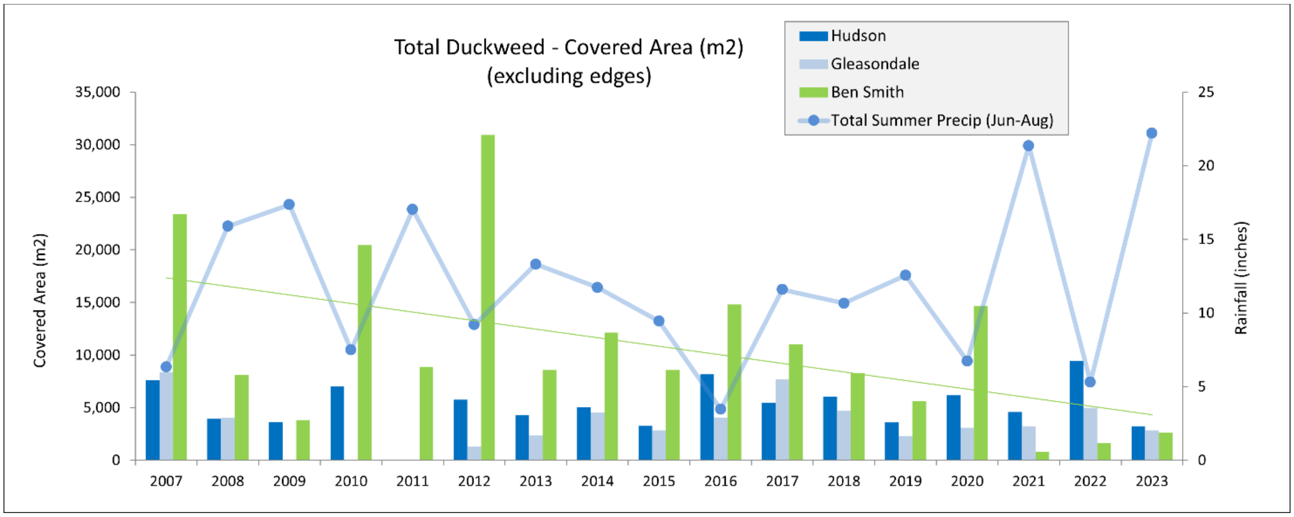

Figure 61: Total duckweed coverage (2007–2023)

Table 13: Pearson Correlation Coefficients—Total Biomass vs Temperature and Rainfall

Pearson Corr.	Hudson	Gleasondale	Ben Smith
Temperature	0.26	0.16	0.03
Precipitation	-0.54	-0.30	-0.65

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Appendix I Mainstem Statistics

2023 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 19, 2023	Concord	1	6.2	97		12.1	478	7.0	5.0	0.020	0.010	0.33			
	Lower Assabet	2	7.0	96		11.6	491	7.1	2.5	0.025	0.015	0.48	0.05		
	Upper Assabet	1	5.8	100		12.5	362	7.2	3.0	0.080	0.070		0.05		
	Lower Sudbury	2	5.6	97		12.1	535	7.1	2.0	0.020	0.005	0.19			
	Upper Sudbury	1	4.9	82		10.4	445	6.8	1.0	0.010	0.005		0.05		
May 14, 2023	Concord	1	19.3	92		8.5	531	7.0	6.0	0.040	0.010	0.37			
	Lower Assabet	2	19.1	93		8.6	577	7.2	4.0	0.040	0.020	0.77	0.05		
	Upper Assabet	1	16.3	84		8.2	754	7.2	2.0	0.040	0.010		0.05		
	Lower Sudbury	5	19.4	72		6.6	526	6.8	10.6	0.038	0.011	0.03			
	Upper Sudbury	1	17.7	47		4.5	476	6.6	3.0	0.040	0.005		0.05		
June 11, 2023	Concord	3	18.3	91		8.6	586	7.0	8.3	0.043	0.013	0.97	0.08		
	Lower Assabet	3	17.8	96		9.1	657	7.4	2.5	0.023	0.010	1.73	0.04		
	Upper Assabet	3	16.5	90		8.8	865	7.4	2.5	0.030	0.010	3.93	0.04		
	Lower Sudbury	5	17.5	77		7.3	628	6.9	6.4	0.034	0.010	0.27			4.6
	Upper Sudbury	2	15.9	68		6.7	460	6.7	2.5	0.030	0.015	0.21	0.04		
July 16, 2023	Concord	3	25.7	68		5.6	442	6.7	4.9	0.083	0.040	0.33	0.04		
	Lower Assabet	2	25.1	95		7.8	353	7.0	6.3	0.070	0.035	0.52	0.04		
	Upper Assabet	3	23.9	83		7.0	476	6.9	9.1	0.073	0.033	1.00	0.08		
	Lower Sudbury	5	25.7	35		2.8	510	6.7	4.5	0.076	0.030	0.10			4.8
	Upper Sudbury	1	24.4	93		7.8	377	6.9	19.0	0.090	0.030	0.19			

2023 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 13, 2023	Concord	3	23.2	70	5.9	362	6.6	3.9	0.053	0.020	0.22	0.04		
	Lower Assabet	3	22.9	92	7.9	445	7.0	3.4	0.040	0.023	0.50	0.04		
	Upper Assabet	3	22.4	85	7.4	504	7.1	2.4	0.033	0.020	1.04	0.07		
	Lower Sudbury	5	23.6	38	3.2	431	6.6	3.4	0.050	0.014	0.07			6.8
	Upper Sudbury	2	21.8	59	5.2	362	6.7	2.9	0.055	0.025	0.11	0.04		
September 10, 2023	Concord	1	24.5	93	7.8	466	6.9	2.7	0.050	0.020	0.52			
	Lower Assabet	2	23.9	87	7.4	577	7.1	4.0	0.035	0.015	1.19	0.04		
	Upper Assabet	1	22.3	70	6.1	1108	7.1	3.8	0.040	0.010		0.14	290	
	Lower Sudbury	5	23.9	35	2.8	402	6.6	4.3	0.058	0.020	0.05			
	Upper Sudbury	1	22.7	20	1.8	410	6.4	12.0	0.130	0.040		0.04		
November 5, 2023	Concord	1	9.0	100	11.6	434	7.0	1.7	0.040	0.010	0.58			
	Lower Assabet	2	8.3	99	11.6	450	7.1	0.9	0.030	0.020	0.81	0.04		
	Upper Assabet	1	11.3	88	9.6	513	7.0	2.4	0.070	0.040		0.08	100	
	Lower Sudbury	2	9.7	82	9.3	395	6.9	2.1	0.040	0.010	0.14			
	Upper Sudbury	1	8.1	57	6.7	362	6.5	0.1	0.300	0.010		0.09		

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, 2024).

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	Censored and Missed Records	% Completeness	Hit/ Miss	Notes
Air Temp	178	4	3	96%		3/19/23 ABT-301, ABT-312, HOP-011, SUD-293 measured with a car thermometer instead of the field thermometer. Qualified.
Ammonia	89	1	3	96%		7/16/23 RVM-005 field blank showed signs of possible contamination.
Chl a	18	1		94%		8/14/23 HBS-016 field duplicate did not meet RPD DQO.
Chloride	2	0		100%		
DO	162	0	3	98%		
DO saturation	162	0	3	98%		
E.coli	99	1		99%		7/17/23 ABT-089 lab appears to have mistakenly swapped site sample with QC field blank. Qualified.
Flow	71	5	1	92%		HOP-011 flow qualified for all dates where flow was within curve. Rating curve may need calibration.
gauge	75	0	1	99%		
Nitrate	85	0		100%		

Parameter	Number of Data Records	Number of Qualified Records	Censored and Missed Records	% Completeness	Hit/ Miss	Notes
Ortho P	162	1	3	98%		7/16/23 RVM-005 NH3 and Ortho field blanks showed possible insignificant contamination. Due to heavy rain and muddy site, qualifying full site as precaution.
pH	162	0	3	98%		
Sp Conductance	162	0	3	98%		
TP	162	2	3	97%		7/16/23 RVM-005 NH3 and Ortho field blanks showed possible insignificant contamination. Due to heavy rain and muddy site, qualifying full site as precaution. 11/5/23 SUD-293 analytical result unusually high but all data records are sound. Qualified as precaution.
TSS	138	4	3	95%		7/16/23 RVM-005 NH3 and Ortho field blanks showed possible insignificant contamination. Due to heavy rain and muddy site, qualifying full site as precaution. 5/14/23 SUD-005, 6/11/23 CND-110, 7/16/23 SUD-096 qualified each because field duplicate missed DQO.
Water Temp	259	0	5	98%		5/15/23 SUD-137, SUD-236 both readings read low by sampler. Censored.

Notes:

Water Quality sites ABT-026, NSH-047, and SUD-293 were missed in July due to a violent storm. This resulted in 3 missed records for Air Temp, Ammonia, DO, Ortho, pH, Sp. Conductance, TP, TSS, and Water Temp and 1 missed record for gauge and Flow.

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	13595	20779	5782	1764	1655	623
	2006	26376	13221	0	2122	1764	714
	2007	0	21643	8635	13296	623	0
	2008	1954	41621	623	0	0	0
	2009	10676	24900	8621	0	0	0
	2010	7475	22760	0	4038	714	9210
	2011	nr	nr	nr	nr	nr	nr
	2012	3807	11207	18918	4340	1764	4161
	2013	6091	1780	11557	5776	5128	13866
	2014	2582	13686	13625	1764	3204	9336
	2015	0	7871	9299	3918	13691	9418
	2016	3005	11618	10256	4878	1708	12732
	2017	0	22060	16926	1764	0	3447
	2018	623	20526	17802	5247	0	0
	2019	0	22215	16034	1764	3469	714
	2020	0	14895	12379	8781	3982	4161
	2021	0	11583	19884	5210	7521	0
	2022	0	4888	15078	5289	7794	11149
	2023	13460	27805	2218	714	0	0
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
Gleasondale Impoundment	2005	17488	0	2056	0	539	6062
	2006	11364	3967	1594	0	3667	5554
	2007	0	15481	3918	2907	3839	0

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
	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

* 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.

* Conversion Factors (based on mean OARS field measurements and trend line): Class 0 = 0 g/m^2; Class 1 = 427 g/m^2; Class 2 = 1,186 g/m^2; Class 3 = 2,000 g/m^2; Class 4 = 2,855 g/m^2; Class 5 = 3,782 g/m^2. Area * class conversion factor /1,000 = total wet weight in kilograms.

Appendix V Coldwater Fishery Resources

Massachusetts Division of Fisheries and Wildlife List of Coldwater Fishery 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 Nourse Brook	8248530
UNT to Nashoba Brook	8246876
UNT to North Brook	8247435
UNT to Second Division Brook	8247076
Wrack Meadow Brook	8247440