OARS

FOR THE ASSABET SUDBURY & CONCORD RIVERS

Water Quality Monitoring Program Final Report: 2022 Field Season

April 2023

Acknowledgments

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Cover pictures clockwise from top left: great blue heron on the Assabet River (Ben Wetherill); collecting bacteria samples in Lowell (Kim Kastens); muskrat on the Concord River (Ben Wetherill); measuring water flow in Westborough (Ben Wetherill).

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Executive Summary

This report presents the water quality, streamflow, bacteria, and aquatic plant biomass data OARS collected on the Assabet, Sudbury, and Concord Rivers and tributary streams in 2022. It also summarizes and evaluates trends in the data that have become evident for the period of record between 1992 and 2022. Following are the high-level findings for each parameter. The details for each are laid out in the body of the report.

The year 2022 was noteworthy as a very dry year, with precipitation, flows, and groundwater all well below average – the second lowest in the past 20 years. This factor had a major effect on almost all of the parameters monitored and is in contrast with the previous year which was extremely wet.

Water Temperature is an important characteristic for aquatic life and is particularly important to watch considering concerns of global warming. In 2022, water temperatures did not reach the concerning levels that we saw in 2020, the most recent drought year, though tributaries were still generally above the Cold Water standard. Our data have not yet reflected a long-term warming trend because we recorded several warm years in the early 1990s at the beginning of our time-series, but there is a possible upward trend visible in the Assabet headwaters and River Meadow Brook.

Conductivity levels are very high in the Upper Assabet and some tributaries, especially downstream of wastewater treatment plant discharges and roadway runoff. 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 of our waterways.

pH readings in 2022 were generally elevated (less acidic) due to the drought and lack of rainwater. Trend analysis continues to show 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 at two sites: ABT-077 had unusually high pH levels in July and August downstream of the Ben Smith impoundment, and ELZ-004 has had unusually low pH levels for the last three years.

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, but DO levels in 2022 were much higher than previous years, possibly related to high chlorophyll levels that were documented at the same times. The Hop Brook in Sudbury has consistently had very low DO levels, but its trend continues to show 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.

Total Phosphorus (TP) is the primary indicator that we watch as improvements are made to the wastewater treatment plants on the Assabet. Trend analysis shows the dramatic reduction in TP through 2012, when the final upgrades were implemented. Since 2012, TP levels have been relatively stable. The treatment plants are generally meeting their NPDES discharge permit limits, but our rivers are hovering at or above the targeted 0.05 mg/l and we still have consistently high TP concentrations in Hop Brook downstream of the Marlborough Easterly WWTP. The year 2022 was unusually dry, which should have resulted in higher concentrations but did not. Calculated loads suggest that the unusually wet conditions of the previous year may have washed a lot of the phosphorus out of the system. Analysis of TP load highlights the major role of wet weather events on the amount of phosphorus passing through the river system. And as a final note, as TP discharges from wastewater treatment plants are coming under control, a new pattern is emerging in our data regarding the effect of wetlands on phosphorus concentration. In 2022 the highest TP concentrations were recorded at sites downstream of major wetlands.

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 percentages of orthophosphate. 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 primarily a concern for tidal estuaries downstream of our rivers, but it may be something we need to watch more closely.

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: Maynard WWTP, Marlborough Easterly WWTP, Hop Brook in Sudbury, River Meadow Brook, and Nashoba Brook.

Total Suspended Solids have consistently been highest in the Lower Sudbury and Concord Rivers, possibly driven by motorized boating that is common in these sections. In 2022 there were some higher TSS concentrations related to low waters during drought, but our long-term data show an improving trend in all of our rivers. Load analysis of all years highlights the role of heavy flows in carrying suspended solids downstream.

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, but 2022 results were much higher than previous years. This spike was probably a result of the drought conditions and reduced flow.

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 fluctuates differently for each river, with 2018 representing a favorable point across most river sections. For the Assabet and Concord, recent changes in the index have been primarily driven by nitrate concentrations. For the Sudbury, changes in recent years have been driven by phosphorus and suspended solids. The Upper

Assabet index 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 four years since have generally followed a similar pattern. The Maynard, Ashland, and Lowell sites consistently have concerning levels of bacteria, hovering near or above the MA DEP swimming threshold. All three have consistent 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. 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.

Biomass has been surveyed at three impoundments in the Assabet since 2005 to track progress toward the goal of reducing nuisance biomass. The data have not shown a reduction in biomass over this time period, but they do show a fairly strong negative correlation between biomass and rainfall, especially for duckweed. Trend analysis shows the Hudson impoundment increasing in biomass over time, and 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 high nitrate concentrations in the Upper Assabet.

Water quality reports for 1999–2021 (OAR, 2000; OAR, 2001; OAR, 2002; OAR, 2003; OAR, 2004; OAR, 2005; OAR, 2006b; OAR, 2007; OAR, 2009; OARS, 2011; OARS, 2013; OARS, 2015; OARS, 2016; OARS, 2017; OARS, 2018; OARS, 2020; OARS, 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 Assabet, Sudbury, 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 by a group of concerned citizens, OAR added the Sudbury and Concord Rivers to its mission in 2011, becoming OARS. Currently the organization has approximately 750 individual and family memberships, a twelve-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 36 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, although management has kept them largely under control. 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 2018/2020 assessment (2018/2020 Integrated List of Waters), Massachusetts Department of Environmental Protection lists all sections of the Assabet and Concord Rivers, from the Assabet River Reservoir (A1 Impoundment) in Westborough to the confluence with the Merrimack River in Lowell, on the Impaired Waters List as Category 5 ("Waters Requiring a TMDL") for a variety of impairments (MA DEP, 2021b). The Sudbury River upstream of the Fruit Street bridge in Hopkinton/Westborough is listed as Category 2 ("Attaining some uses; other uses not assessed"). All other sections of the Sudbury River from Fruit Street downstream to the confluence with the Assabet in Concord (including the Framingham Reservoirs) are listed as Category 5 for mercury in fish tissue. Many sections in all three rivers are also listed for *E. coli*. Nine of the tributaries in the basin are listed as Category 5 Waters: Beaver Brook (*E. coli,* DO), Coles Brook (*E. coli,* Chloride), Eames Brook (aq. macroinvertebrates, taste/odor, excess algal growth, trash), Elizabeth Brook (*E. coli*), Hop Brook in Sudbury (total phosphorus, dissolved oxygen, noxious aquatic plants, eutrophication), Nashoba Brook (*E. coli*, temperature, dewatering), North Brook (temperature, invasive species), River Meadow Brook (*E. coli*, temperature, trash), Cochituate Brook (*E. coli*, trash, macroinvertebrates).

Nutrient limits were first set for the Assabet River wastewater treatment plants (WWTPs) in 1993, seven years after OAR was established. The EPA and MA DEP 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 (MA DEP, 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. MA DEP 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 slower moving and 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 WWTPs' phosphorus discharge reductions would almost meet the MA DEP 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, MA DEP 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 Assabet, Sudbury, 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 2022 was OARS' 31st consecutive year collecting data at mainstem Assabet River sites, its 21st year collecting data at tributary sites, its 19th year collecting data at mainstem Concord River sites, its 13th year collecting Sudbury River data, its 18th year assessing aquatic plant biomass in the large impoundments of the Assabet River, its 5th year collecting chloride data, and its 4th year collecting 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, 2022b), 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 2022

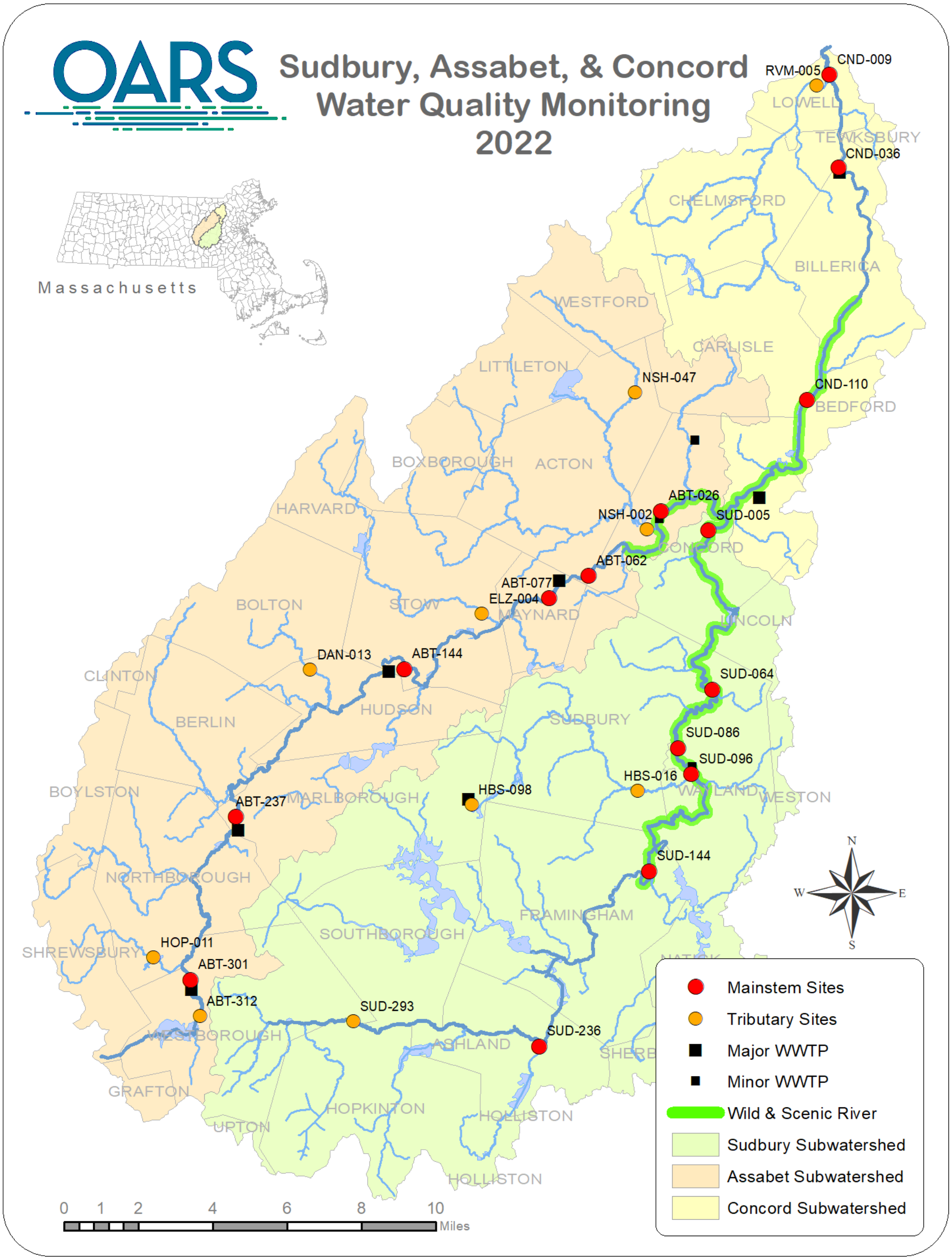


Table 1: Water Quality Monitoring Sites 2022

OARS Site #	Waterbody	Site Description	Municipality	SARIS #	Lat/Lon	Sampling Dates			Gage reading /streamflow*
						June/Jul/ Aug	May/ Sept	Nov/ March	
CND-009	Concord River	Rogers Street	Lowell	46500	42° 38' 09"/ -71° 18' 05"	√	√	√	(USGS Gage)
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 Gage	Maynard	46775	42° 25' 55"/ -71° 26' 59"	√	√	√	(USGS Gage)
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 Gage)
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 gage)
RVM-005	River Meadow	Thorndike Street	Lowell	46525	42° 37' 55"/ -71° 18' 32"	√	√	√	√

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

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

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

Figure 2: Bacteria Sampling Sites 2022

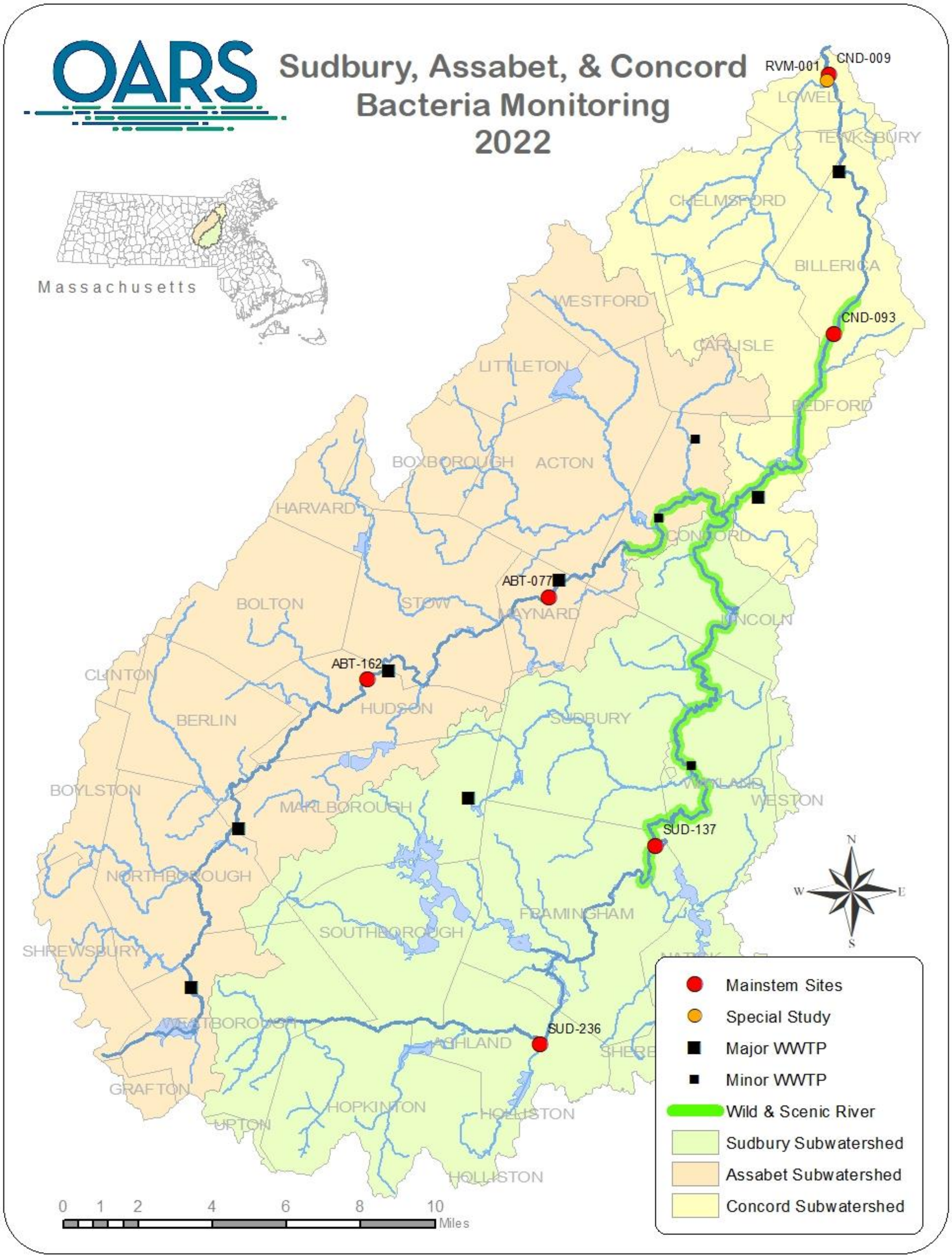


Table 2: Bacteria Sampling Sites 2022

OARS Site #	Waterbody	Description	Municipality	Lat/Lon
ABT-077	Lower Assabet River	USGS Maynard Gage	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-096	Lower Sudbury River	Route 20	Wayland	42° 21' 49"/ -71° 22' 31"
SUD-137	Upper Sudbury River	Little Farms Rd	Framingham	42° 20' 06"/ -71° 23' 40"

Water Quality Monitoring

Water Quality Sampling Methods

Trained volunteers and OARS staff monitored water quality at sites throughout the watershed (Figure 1 and Table 1). Each site is assigned a three-letter prefix for the waterbody name plus a three-number designation indicating river miles 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 are sampled in June, July, and August. In March, May, September, and November, only selected sites are sampled. From May to September (the growing season) monitoring is 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 is conducted before 12:00pm. Streamflow was calculated from stage readings of OARS' gages using stage/discharge rating curves developed per the United States Geological Survey (USGS) standards (Rantz, 1982, Smoot, 1968) or recorded from the USGS real-time gage web pages.

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 mid-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 3 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 3: Water Quality Sampling and Analysis Methods

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	1 – 100 mg/L	bottle	Nashoba Analytical
Total Phosphorus	EPA 200.7	0.01 – 1 mg/L	bottle	Nashoba Analytical
Orthophosphate	SM4500-P-E	0.01 – 1 mg/L	bottle	Nashoba Analytical
Nitrate-N	EPA 300.0	0.05 – 10 mg/L	bottle	Nashoba Analytical
Ammonia-N	SM4500-NH3-D	0.1 – 10 mg/L	bottle	Nashoba Analytical
Chloride	EPA 300.0	1 – 1000 mg/L	bottle	Nashoba 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 2). OARS selected the sites based on the MA DEP 303d list of river segments impaired by bacteria (MA DEP, 2021) 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 4 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 4: 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 (MA DEP, 2021) (Table 5). 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 34 tributary streams in the basin as Coldwater Fishery Resources (CFRs) (MA DFW, 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 6).

Table 5: MA DEP Class B Water Quality Standards and Guidance (MA DEP, 2013)

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 6: 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

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

Table 7: Sites for trend analyses

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
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
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
	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
	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
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
	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
	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
	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
	CND-036																														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
	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
	SUD-064																		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
	SUD-096																					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
Upper Sudbury	SUD-236																														X	X
	SUD-293																														X	X
Hop Sudbury	HBS-016																		X	X	X	X	X	X	X	X	X	X	X	X	X	X
	HBS-098																														X	X
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
	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
	ELZ-004											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															
	RVM-005													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													
	SPN-003											X	X	X	X	X	X															
	NSH-047																	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

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

<u>River Reaches and Tributaries</u>

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. For some analyses, the headwater and tributary sites are combined. Table 9 lists tributary and mainstem basin characteristics calculated using USGS's StreamStats program.

Table 8: MA DEP 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
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

Table 9: StreamStats Drainage Basin Statistics

	Statistics at Mouth of River or Tributary[a]				
Mainstem Rivers Headwaters Tributary Streams	Latitude/Longitude at Mouth	Drainage Area (sq.mi.)	Stratified Drift Area (sq.mi.)	% area stratified drift	Slope [b] (%)
Assabet River, Concord	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, Northboro	42.2887/-71.6449	7.87	2.09	26.6	3.57
Cold Harbor Brook, Northboro	42.3238/-71.6413	6.86	1.97	28.7	5.01
North Brook, Berlin	42.3576/-71.6188	16.89	4.12	24.4	4.38
Danforth Brook, Hudson	42.3897/-71.5666	7.17	2.06	28.7	3.58
Fort Meadow Brook, Hudson	42.3975/-71.5169	6.25	1.76	28.2	3.77
Elizabeth Brook, Stow	42.4217/-71.4776	19.09	6.93	36.3	3.73
Nashoba Brook, Concord	42.4592/-71.3942	48.05	19.05	39.7	2.29
Sudbury River, Concord	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, Lowell	42.6351/-71.3015	400.0	197.97	49.5	2.63
River Meadow Brook, Lowell	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 2022 differed dramatically in precipitation from the previous year (Figure 3 and Figure 4). The summer of 2021 was characterized by substantially higher precipitation than normal, and the summer of 2022 had the second lowest precipitation since 1999. According to the U.S. Drought Monitor (https://droughtmonitor.unl.edu), the SuAsCo watershed experienced extreme drought for the month of August, 2022 and severe drought from July to mid-October, 2022 (Figure 5). The summer of 2021 was wet all season. According to the Massachusetts Water Resources Commission, at the end of September, 2022, the 9-month Standardized Precipitation Index for Northeast MA was only 13%, as opposed to 96% in 2021 (MA DCR, 2022).

Figure 3: Annual summer precipitation (1999-2022)

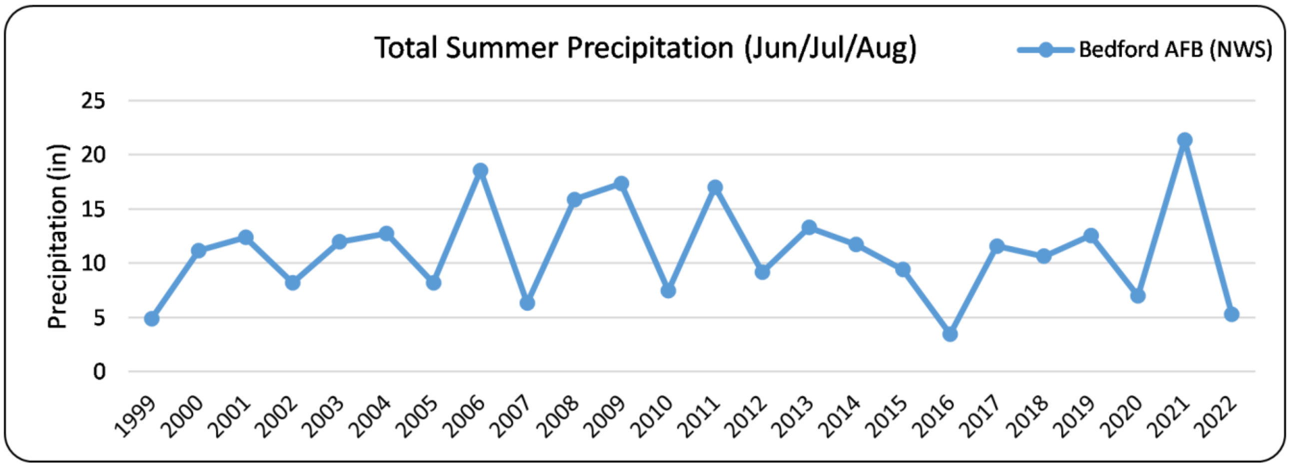
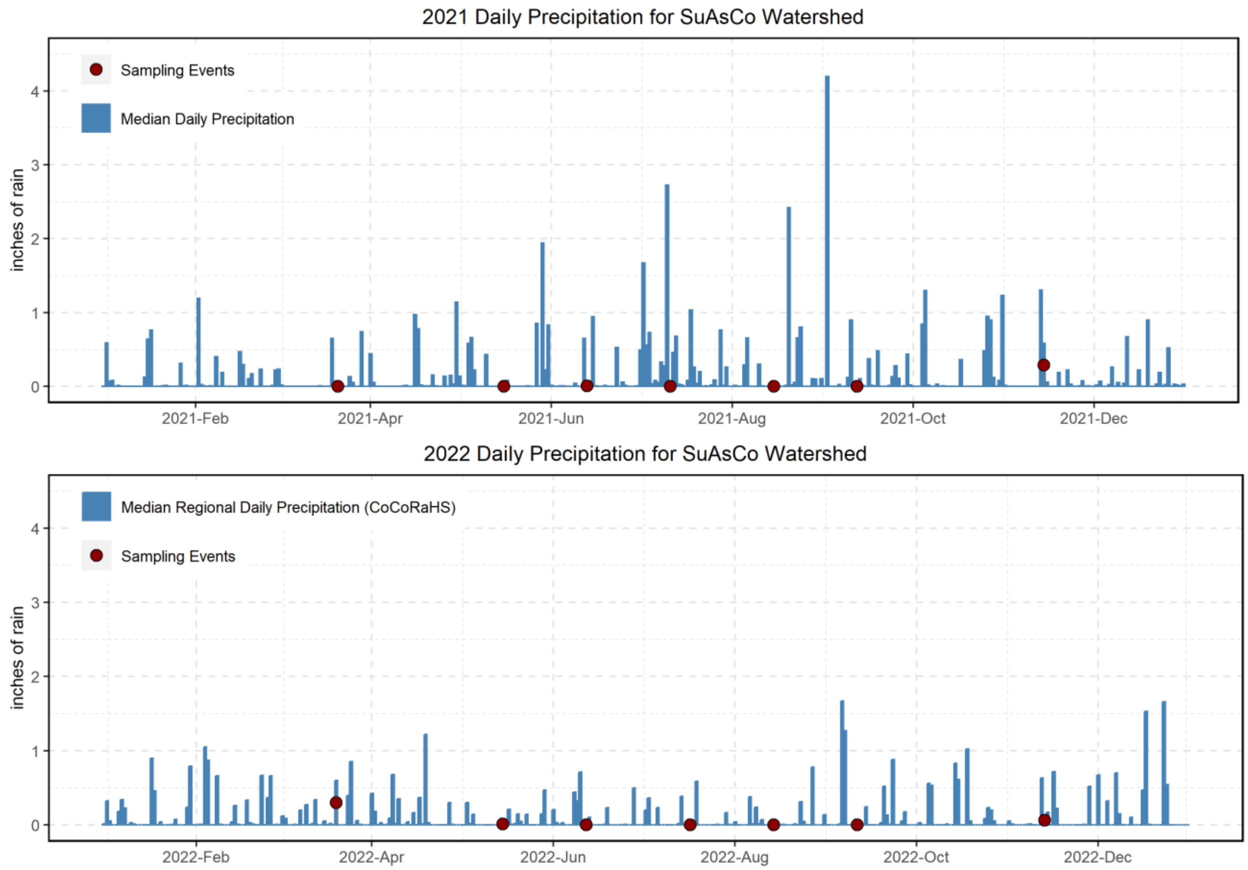
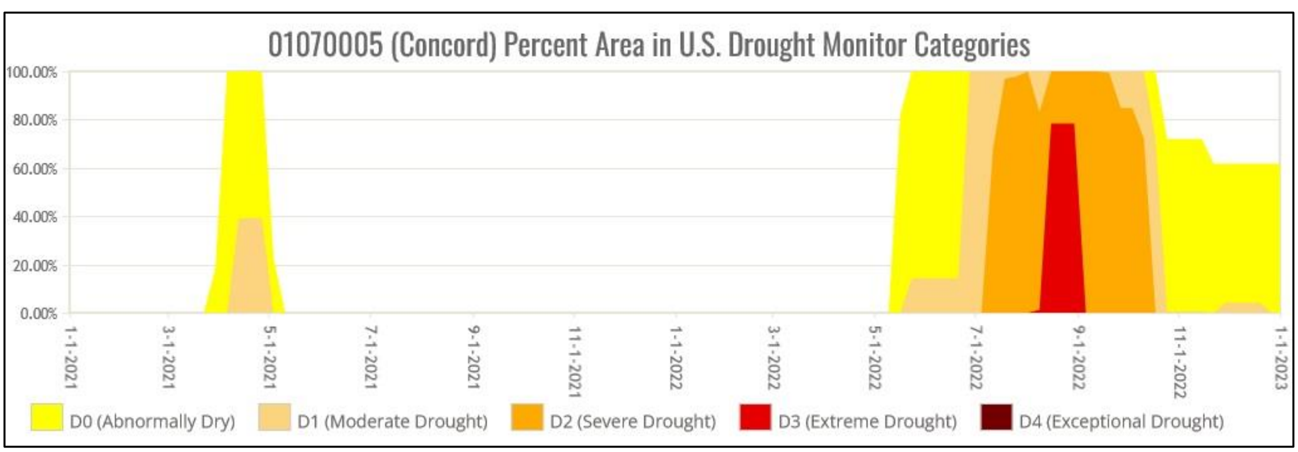


Figure 4: Daily rainfall with sampling dates 2021-2022



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

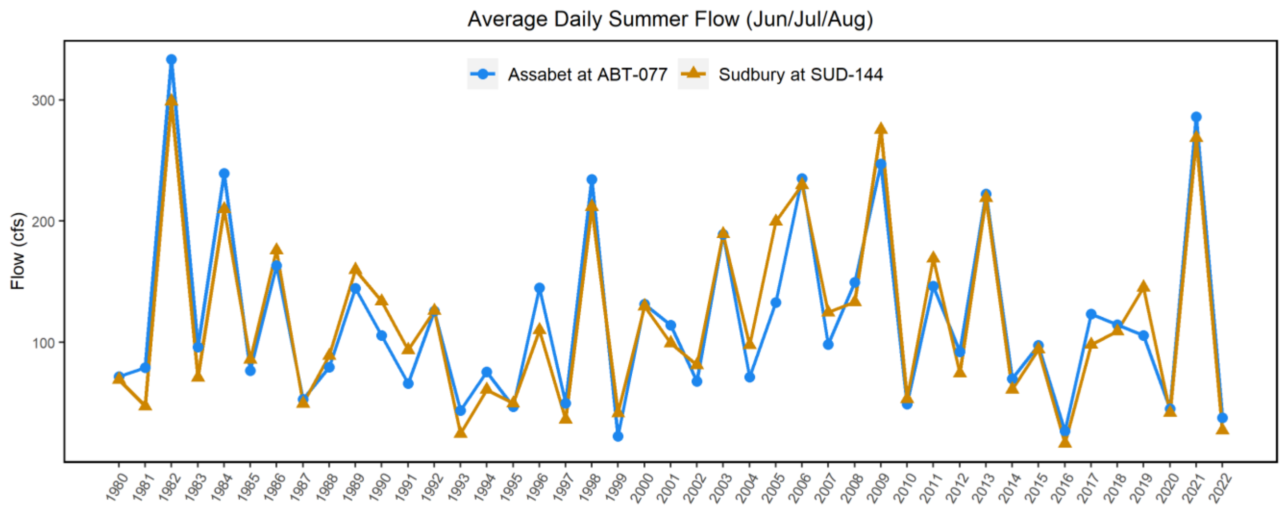
Figure 5: U.S. Drought Monitor status for SuAsCo watershed (HUC 8) 2021-2022



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

As a direct result of the low precipitation, streamflow in 2022 was also extremely low. Figure 6 shows year-on-year average summer streamflow for the Assabet and Sudbury since 1980. The summer of 2022 had the second or third lowest streamflow over this period, while 2021 had the second highest streamflow for the period. Figure 7 shows mean daily streamflow for 2021 and 2022 at the Assabet, Sudbury, and Concord River gages compared with the historic mean streamflow for the period of record. The Concord River is mainly a reflection of the combined flows of the Assabet and Sudbury. In 2022, streamflow for all rivers was well below average from the beginning of May through the end of November.

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



Flow data sourced from USGS gages in Maynard and Saxonville.

Figure 7: Mean Daily Streamflow, by River, 2021-2022

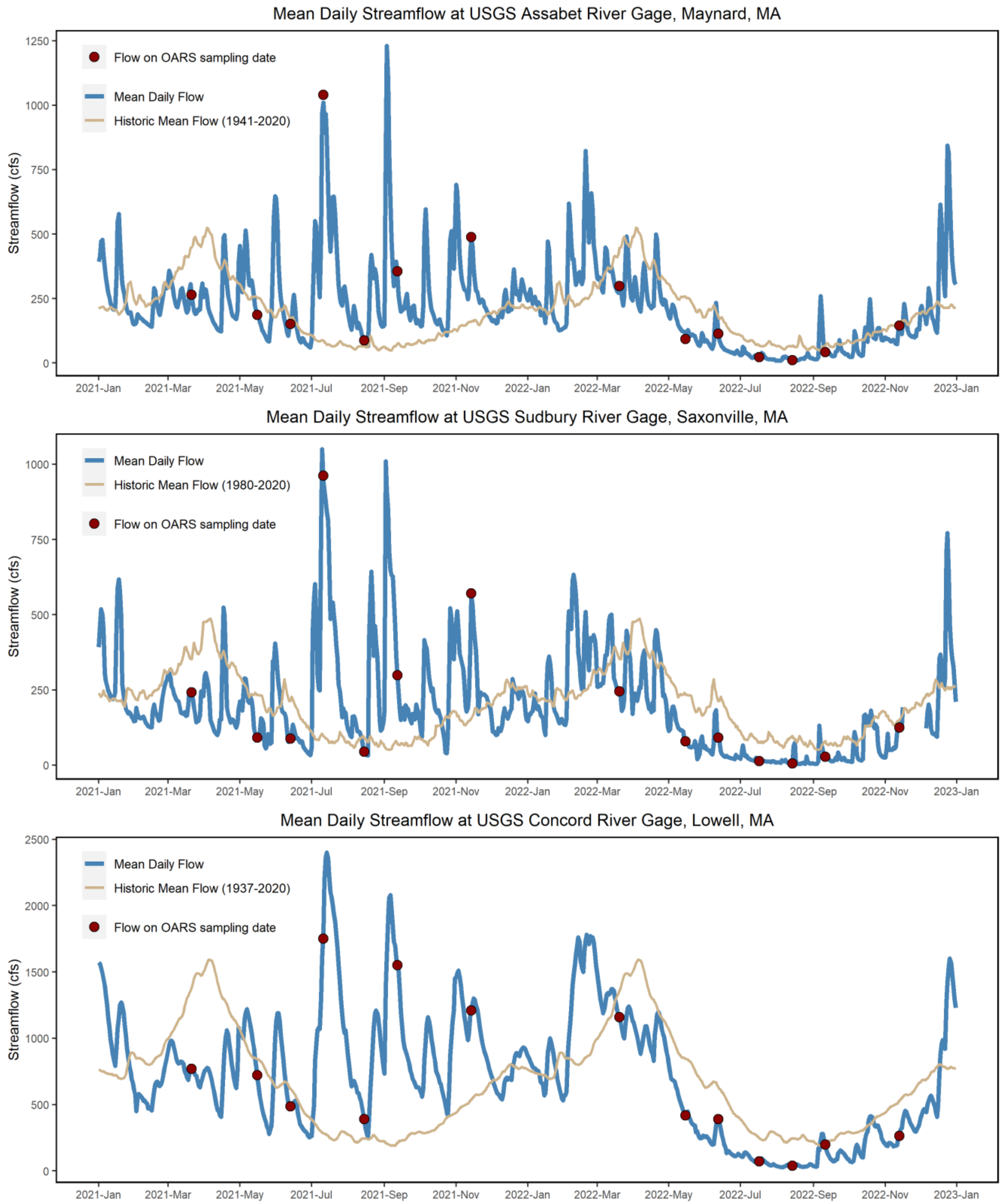
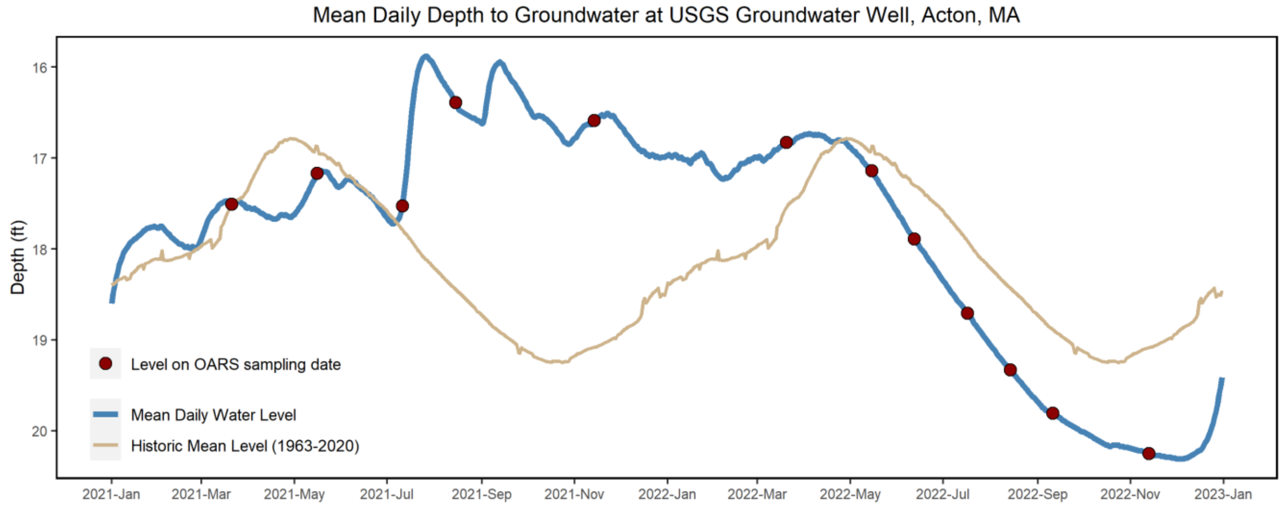


Figure 8 shows groundwater levels in 2021 and 2022 compared with historic mean levels from the USGS monitoring well in Acton (USGS 422812071244401 MA-ACW 158 ACTON, MA).

Groundwater levels tracked the major precipitation trends with well-above-average levels in the second half of 2021 and well-below-average levels in 2022. Changes in groundwater levels reflect the combination of precipitation and evapotranspiration rates and, in turn, affect baseflow to the streams.

Figure 8: Groundwater Levels (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 gage as rising, falling, or flat hydrograph (Table 10). 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 gage in Saxonville/Framingham is sometimes affected by reservoir dam manipulations upstream.

Table 10: Hydrograph and Precipitation Summary for Water Quality Sampling 2022

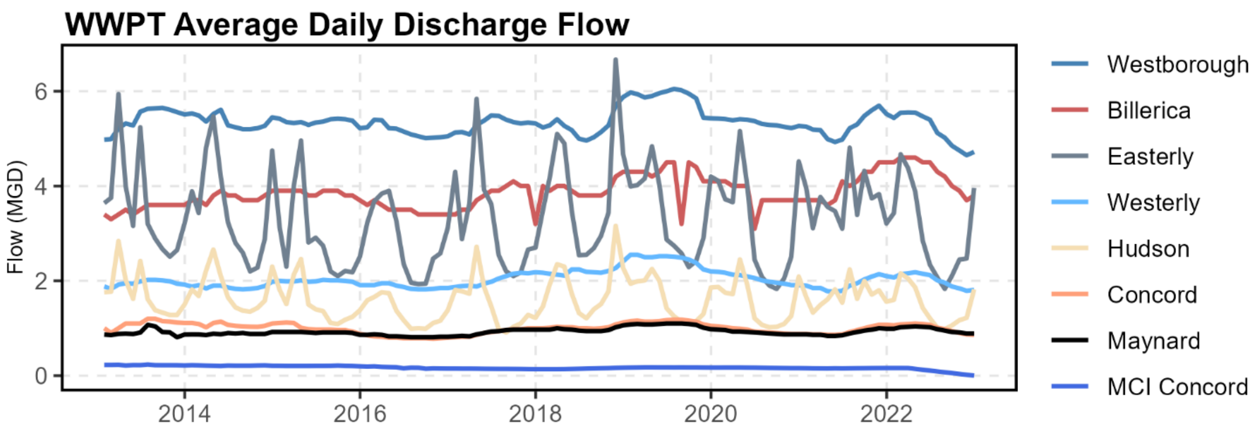
	Hydrograph at USGS gage			Precipitation (inches)
Sampling Date	Assabet River at Maynard	Sudbury at Framingham	Concord at Lowell	Previous 48 hours
Mar 20, 2022	Falling	Falling	Falling	0.30
May 15, 2022	Falling	Falling	Falling	0.01
Jun 12, 2022	Falling	Falling	Rising	0 *(0.71 prev. 72 hrs)
Jul 17, 2022	Flat	Flat	Flat	0
Aug 14, 2022	Flat	Flat	Flat	0
Sep 11, 2022	Falling	Falling	Falling	0
Nov 13, 2022	Rising	Rising	Rising	0.70

Wastewater Treatment Plant Discharge

There are eight wastewater treatment plants discharging significant volumes of water into the three rivers (Figure 9). 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 gage 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 12.9 cfs to the river from May through September in 2022 (EPA, 2023). This compares with the average flow for this period at the Assabet River gage of 60 cfs and the minimum flow of 9 cfs. Since the WWTP flows are fairly stable, there are times when they may represent a majority of the total flow. In August of 2022, treatment plant flow may have constituted almost 100% of the river flow.

Figure 9: WWTP Discharge Flow (daily - 2013-2022)



* Note that we believe there is an issue with the EPA Discharge Monitoring Report that provides this discharge flow data. It appears that Westborough, Billerica, 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

Reach and tributary 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 2022, by-month detail for 2022, 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. 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).

<u>Water Temperature</u>

Water temperatures at all sites met the Class B warm water fisheries standard (28.3°C) on all the regular testing dates in 2022 (Figure 10). The Lower Assabet, Lower Sudbury, and Concord Rivers often come close to this threshold, but stayed below 27°C in 2022 (Figure 11). Many of the tributary streams support or have supported cold water fisheries, therefore, tributary and headwater temperature readings are compared with the cold water standard of 20.0°C, which is the recommended single-reading maximum for brook trout (23.9°C for brown trout). *The tributary sites are easy to see in the by-site chart because they are all grouped together and colored green, from DAN-013 to RVM-005.* Hop Brook in Northborough (HOP-011) and Nashoba Brook in Concord (NSH-002) both exceeded 20.0°C in 2022. They are both directly downstream of large impoundments. It is interesting to note that the most downstream Assabet site (ABT-026) had much lower temperatures than the upstream sites. This is an unusual dynamic that was also evident in 2020, another low-precipitation year, and may be an indication of the benefits of the upstream Wild & Scenic River stretch.

Year-on-year comparisons of temperature data show very little statistical change in water temperatures for the period of record (Figure 12). Trend lines are level for most sections except the Concord, but the Concord upward slope seems to be a function of the fact that measurements only started in 2005. In the tributaries, there is a slight upward trend in temperature in River Meadow Brook (RVM-005), and the Assabet headwater site (ABT-312) would have an upward trend if 2022 temperatures had not been unusually cool (Figure 13). It is worth noting that ABT-312 often has low water temperatures during low flow years (2007, 2016, 2022), implying influence of a cold-water spring.

Figure 10: Water temperature by site, summer (2022)

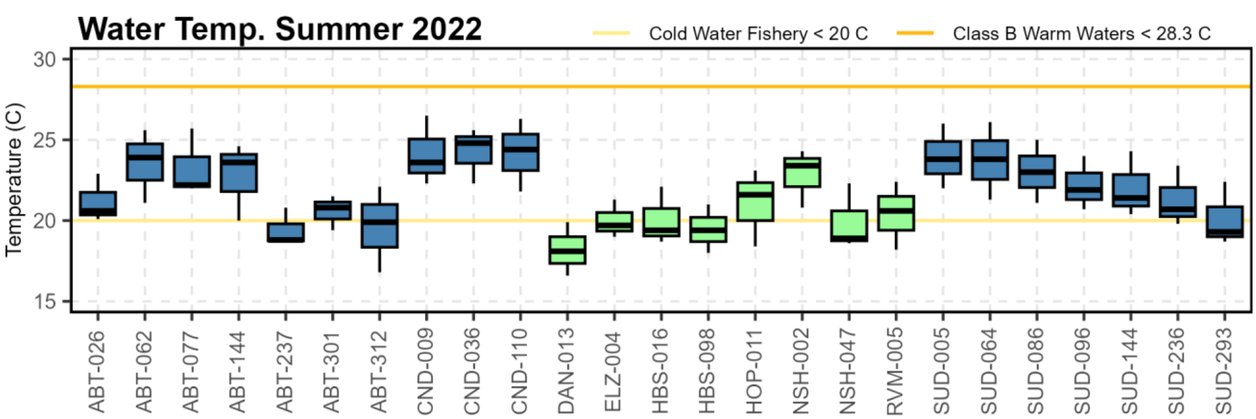
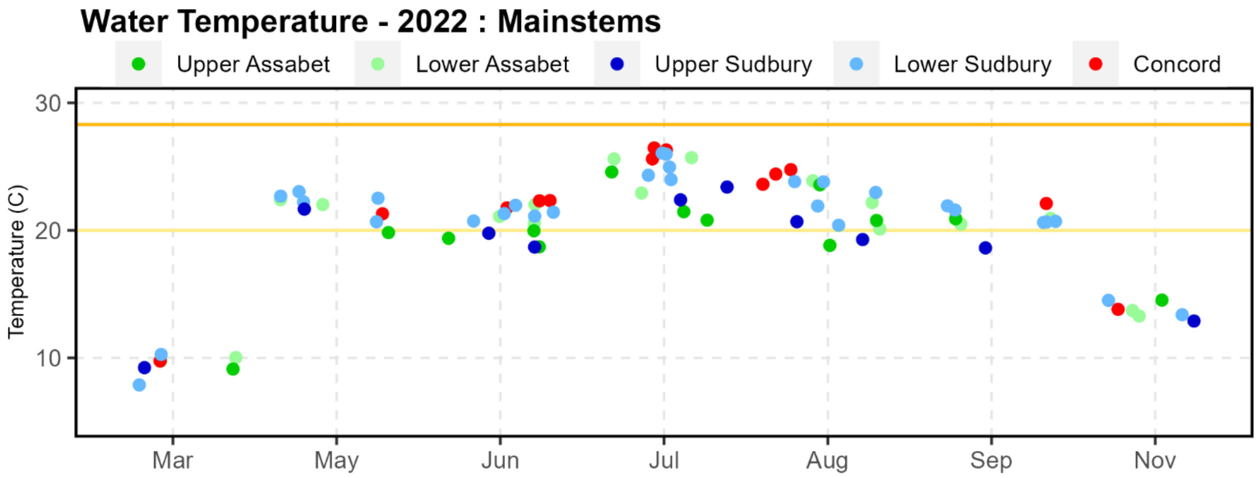


Figure 11: Water temperature by month and section (2022)



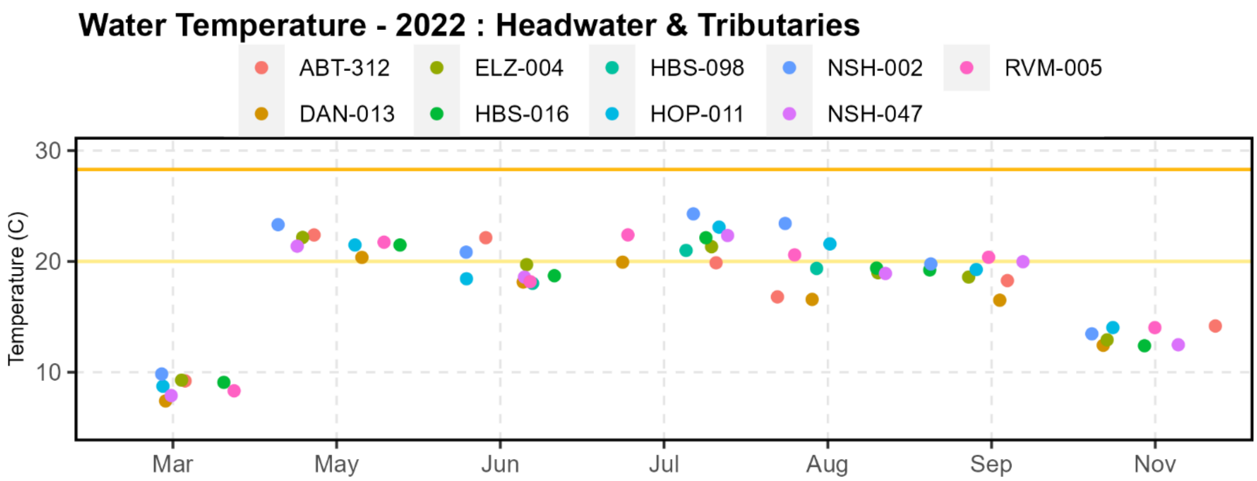


Figure 12: Water temperature by year and section (June/July/August)

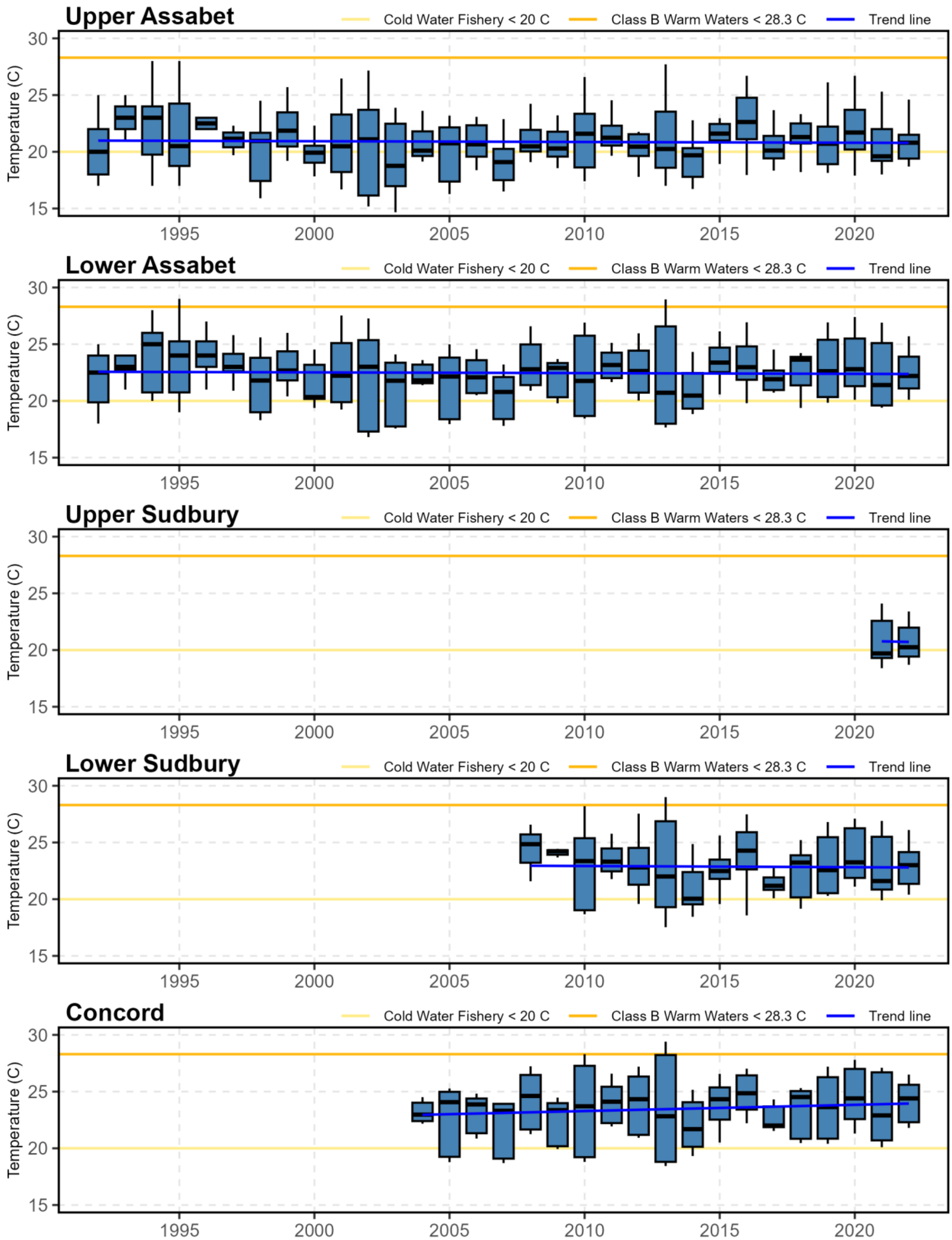
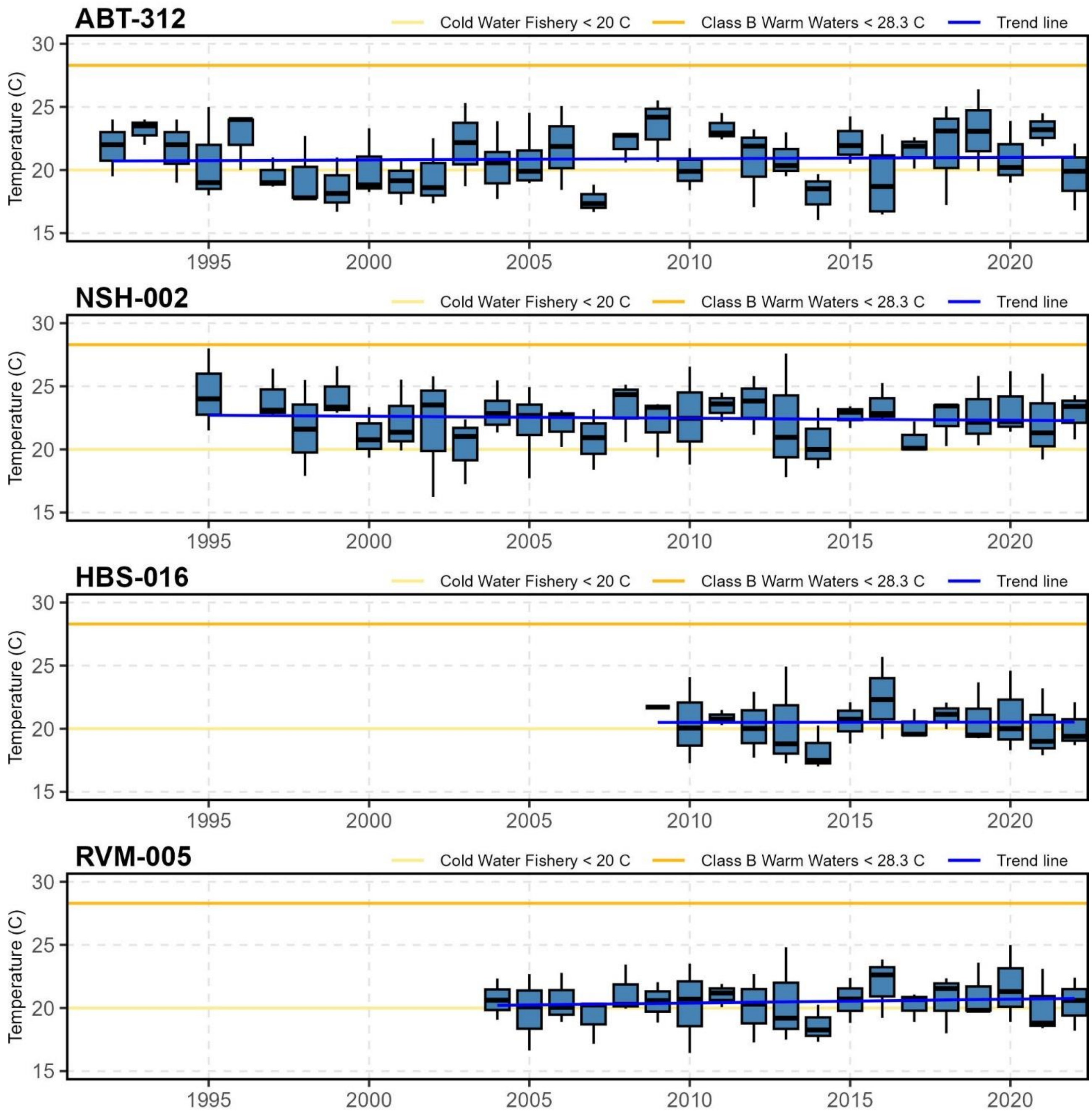


Figure 13: Water temperature by year for selected tributaries (June/July/August)



<u>Conductivity</u>
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). Most of OARS' mainstem sites are above that range (Figure 14). The Assabet sites tend to have the highest conductivity levels, driven by WWTP discharge, with ABT-301 (below Westborough WWTP) averaging close to 2000 µS/cm, much higher than most streams in New England (Campo, 2003). 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 two other tributaries (River Meadow Brook and Fort Pond 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.

Monthly analysis shows conductivity generally increasing later in the year (Figure 15). Even though conductivity is heavily impacted by winter road salt, in-stream salt concentrations are affected all year by discharge of salt-contaminated groundwater and are inversely correlated with flow due to the effect of dilution. Flow is usually much higher in spring than in late summer.

Year-on-year analysis of conductivity shows a clear upward trend for all river sections (Figure 16 and Figure 17). 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 on chloride below.

Figure 14: Specific conductance by site, summer (2022)

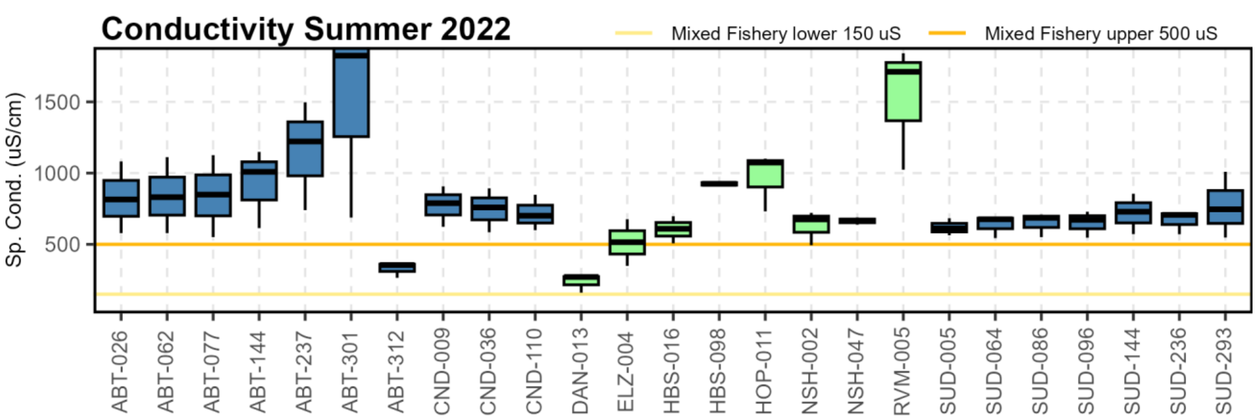
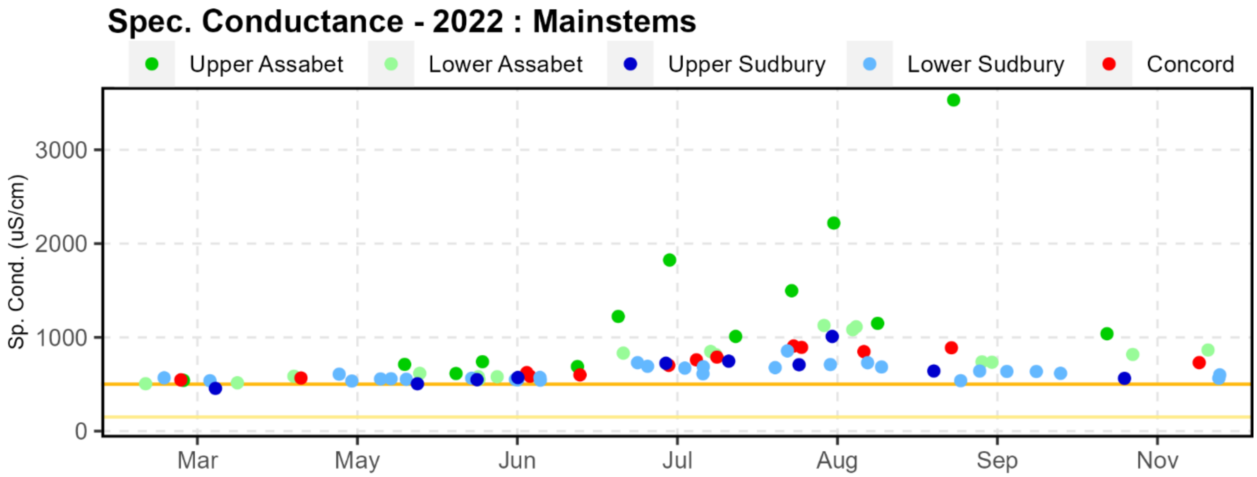


Figure 15: Specific conductance by month and section (2022)



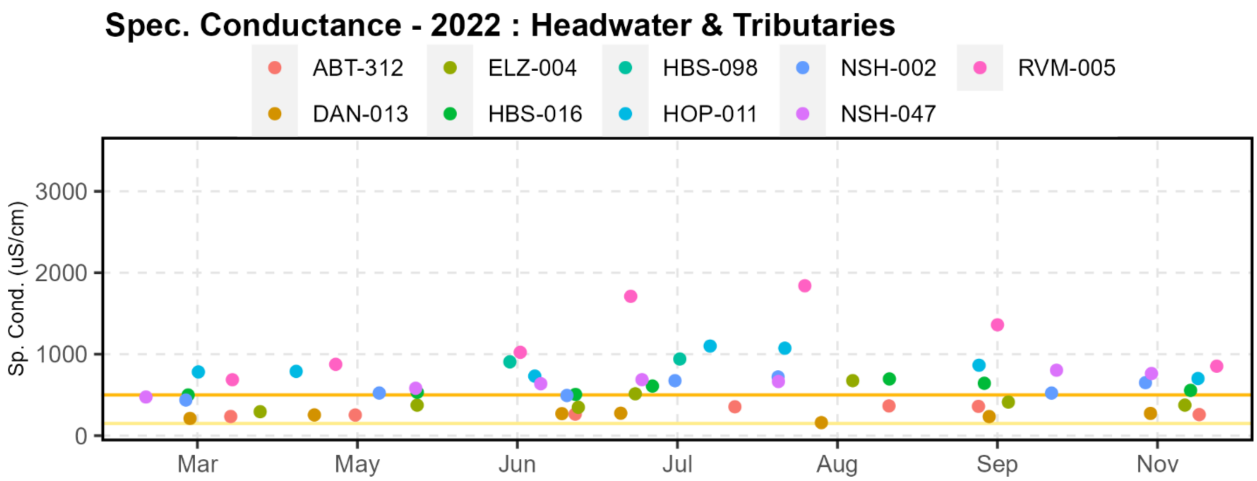


Figure 16: Specific conductance by year and section (June/July/August)

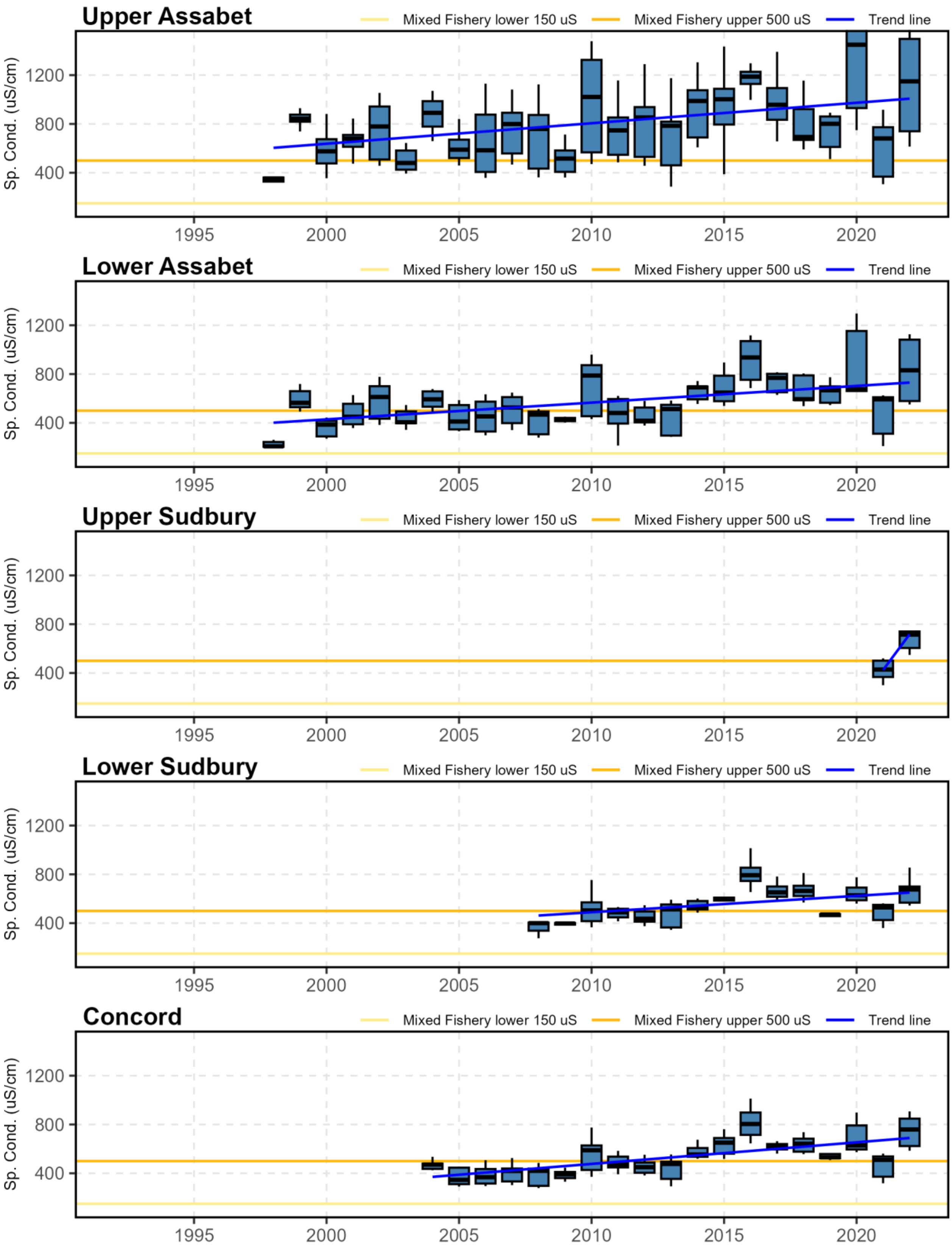


Figure 17: Specific conductance by year for selected sites (June/July/August)

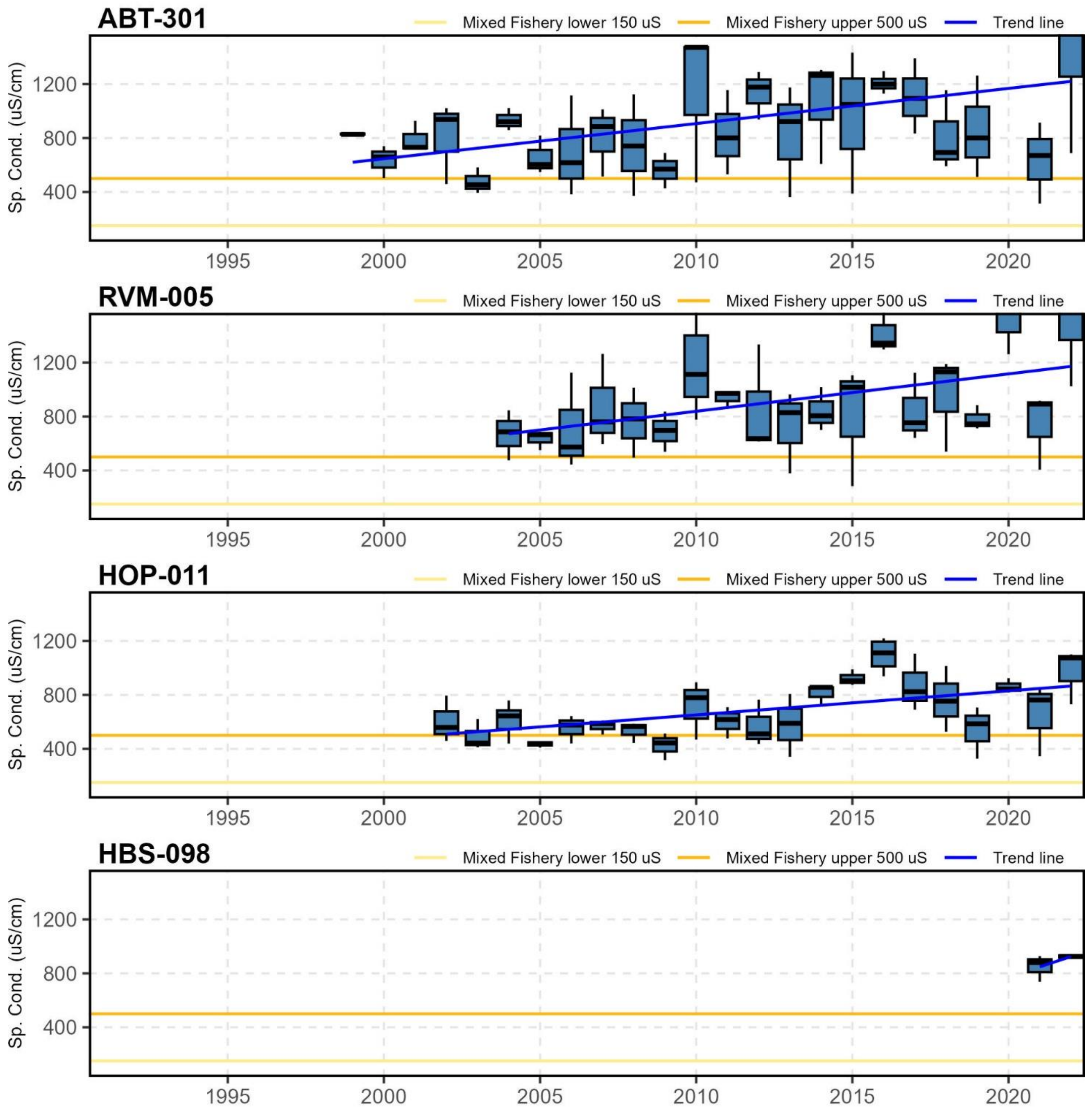
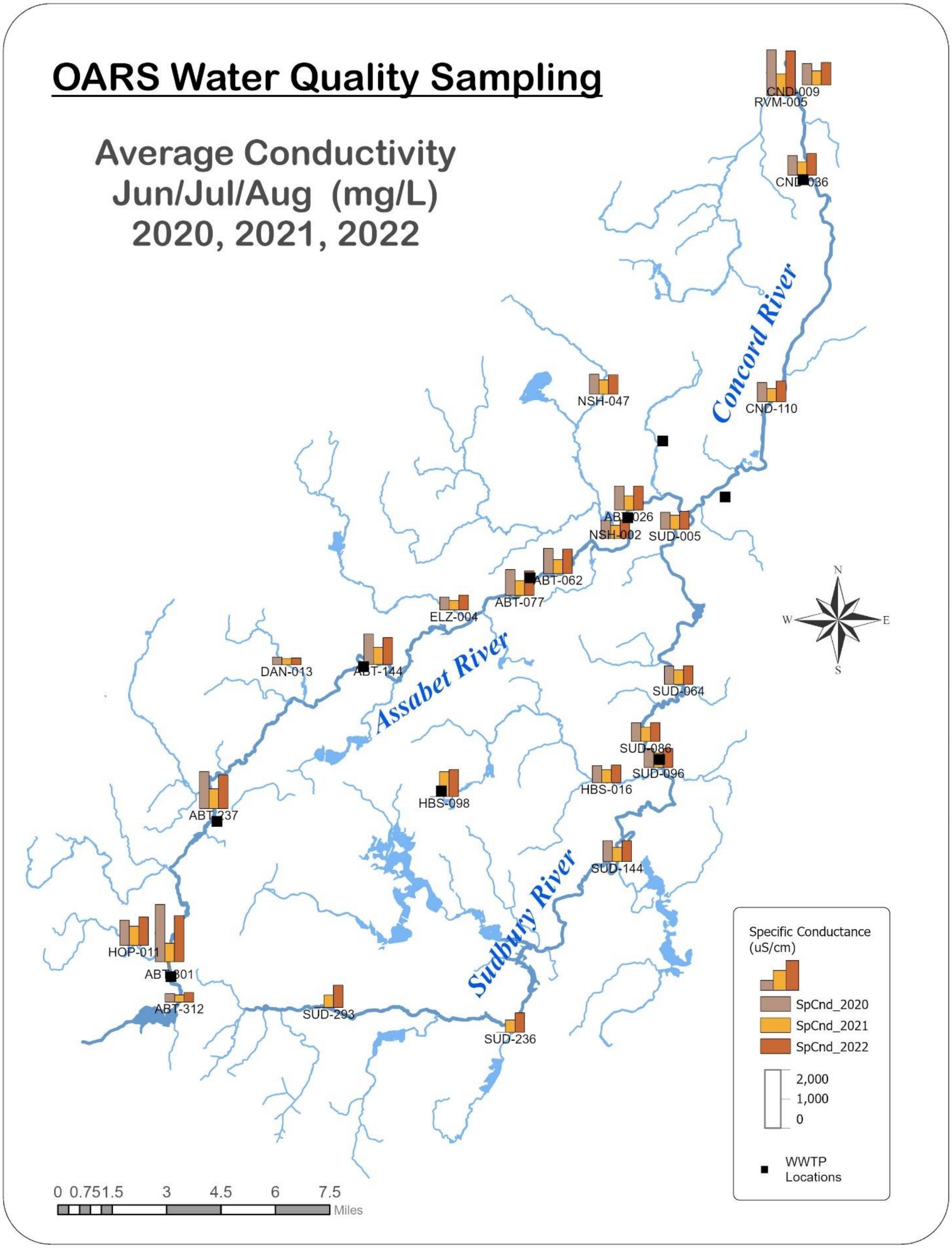


Figure 18: Map of average summer conductivity by site (2020-2022)



<u>Acidity (pH)</u>

There are a number of factors that can affect pH. Rainwater 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. In 2022, pH was generally on the high side, compared to previous years, due to low precipitation. The site ABT-062 (downstream of the Maynard WWTP) usually has the highest pH levels in the rivers, driven by WWTP effluent (Figure 19). However, in 2022, the site ABT-077 (upstream) had even higher pH. It is not clear why this was, but ABT-077 is just downstream of the Ben Smith impoundment, and we noticed unusually low levels of surface vegetation in Ben Smith in 2022 (see the Biomass section later). Reduced vegetation could mean reduced plant decomposition and thus reduced carbon dioxide in the water, resulting in higher pH. See Figure 22 for a time-series view of pH at ABT-077.

Year-on-year analysis of summer pH shows a visible upward trend in pH for the Assabet River (Figure 21). 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 below (Figure 25).

Site ELZ-004 (Elizabeth Brook) had notably low pH in 2022. It also had low DO in 2022 (Figure 23), which could be an indicator of high respiration levels or eutrophication. A time-series review of ELZ-004 shows that the low pH has been consistent for the last three years (Figure 22).

Figure 19: pH by site, summer (2022)

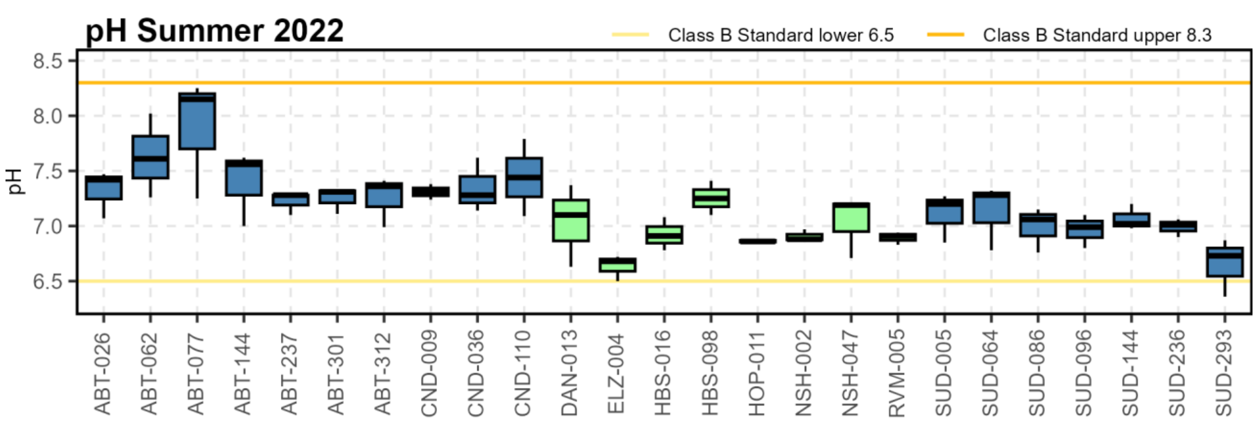


Figure 20: pH by month and section (2022)

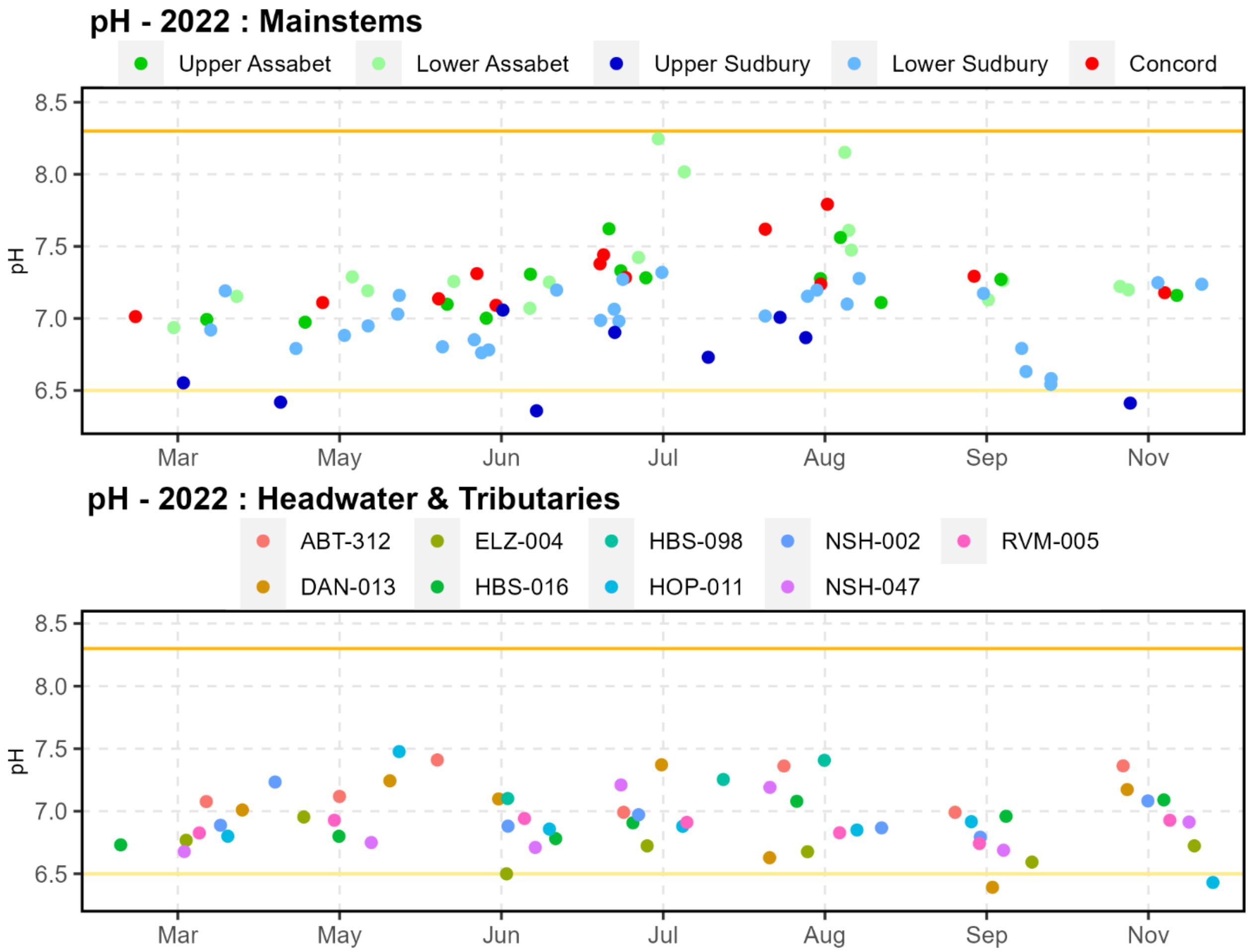


Figure 21: pH by year and section (June/July/August)

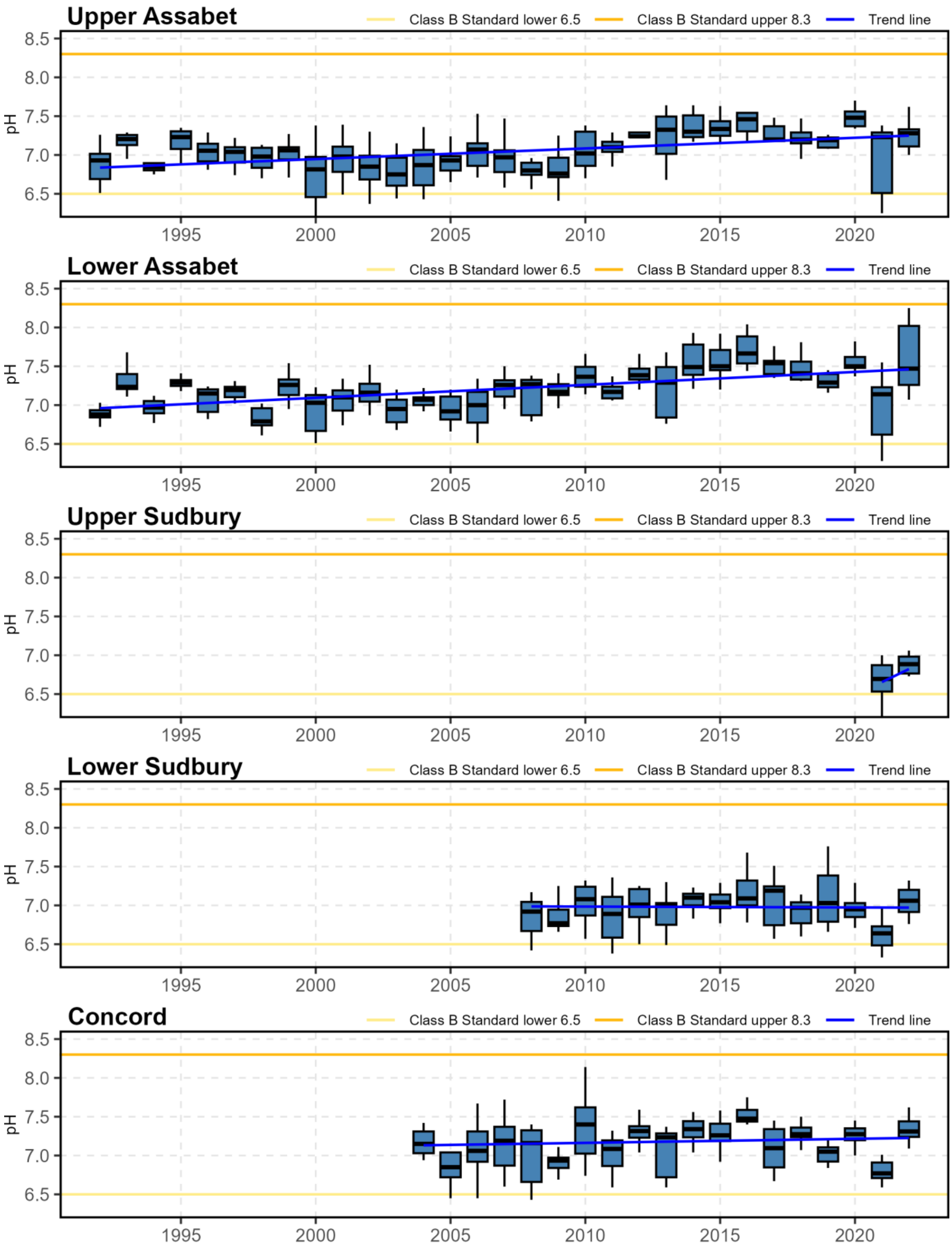
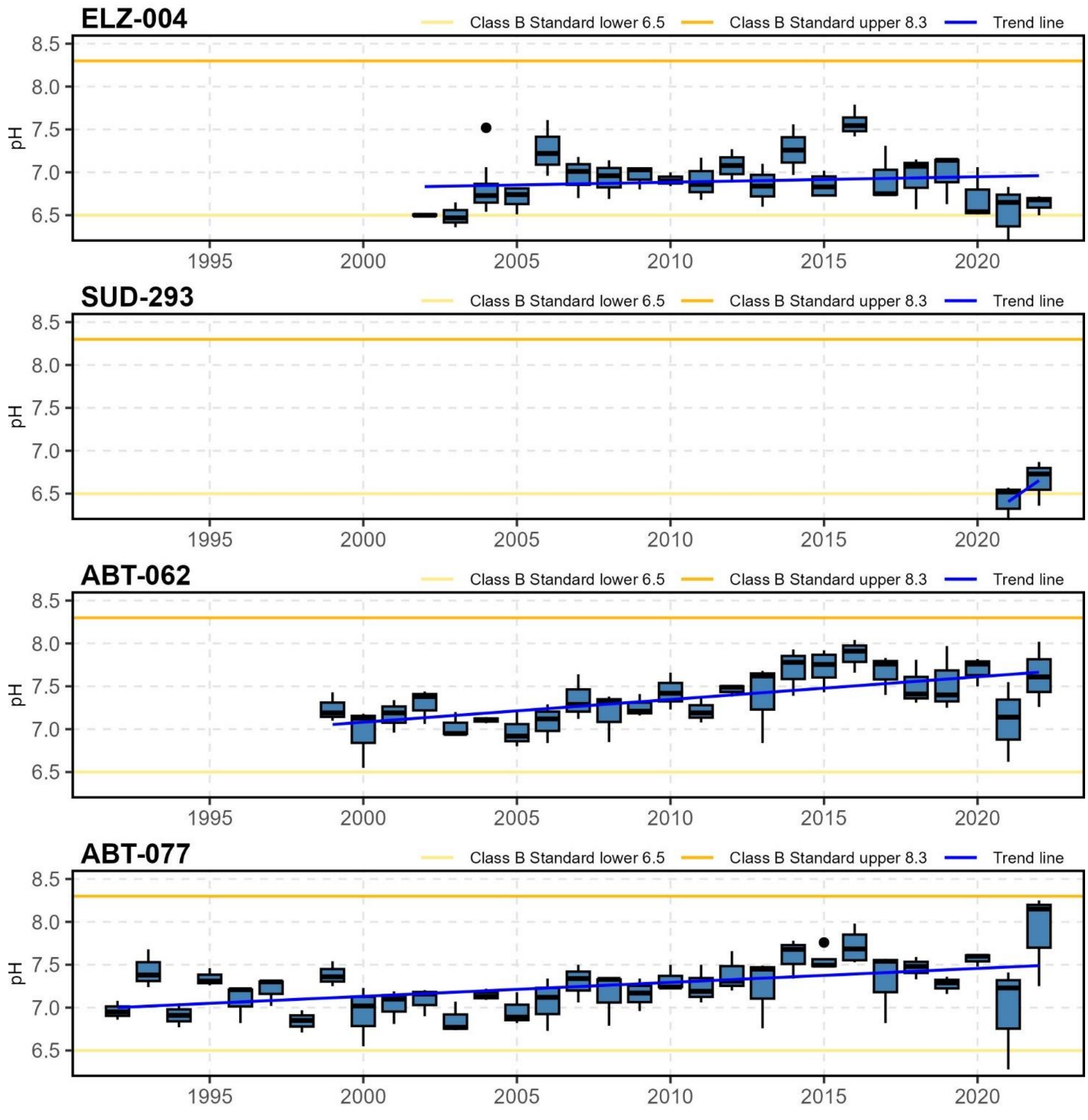


Figure 22: pH by year for selected sites (June/July/August)



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 Water Quality standard (>5.0 mg/L) (Figure 23). The Lower Sudbury is surrounded by large wetland areas and wetlands naturally have low DO levels due to still water and high respiration.

Year-on-year analysis of dissolved oxygen shows several interesting trends. DO levels in the Assabet River have improved significantly over the period of record (Figure 25). This is especially evident after the year 1999 when all four wastewater plants had implemented treatment to reduce summer phosphorus discharge concentrations below 1 mg/L. In the Lower Sudbury River, we have been watching a concerning downward trend in DO levels, but in 2022 DO levels increased significantly. This was most likely related to the extremely low precipitation and flow in 2022. Our monitoring showed that chlorophyll-*a* concentrations were higher than normal in 2022, which could explain higher DO levels (see the Chlorophyll-*a* section below).

In the pH discussion above, it was noted that low DO levels can correspond with low pH in eutrophic conditions. This is especially evident for Elizabeth Brook (ELZ-004) and the Sudbury headwaters (SUD-293). Both consistently have very low DO levels and both have large wetlands upstream (Figure 26).

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 26). The Nashoba Brook site (NSH-002) is showing a decline in DO, especially in the last four years (Figure 26). 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 23: Dissolved Oxygen concentration by site, summer (2022)

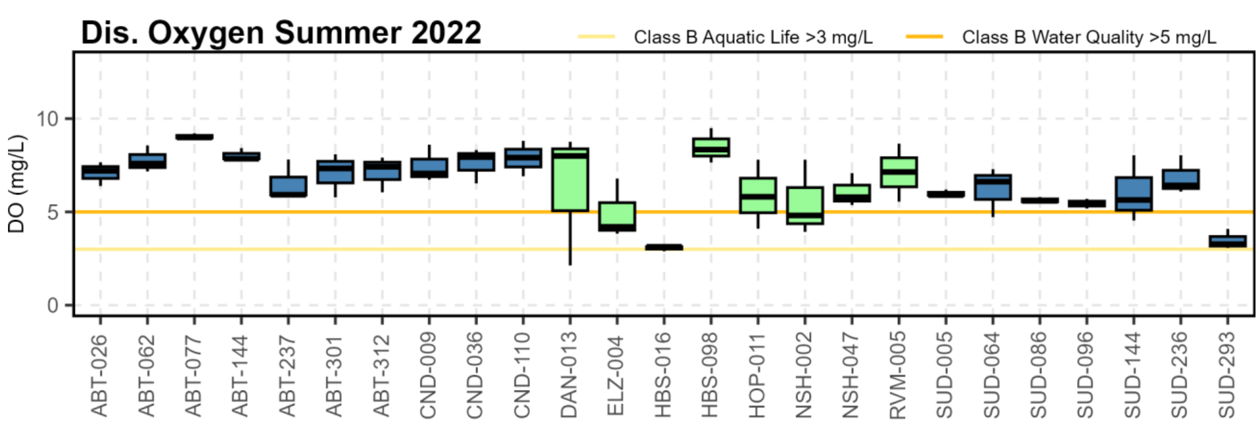
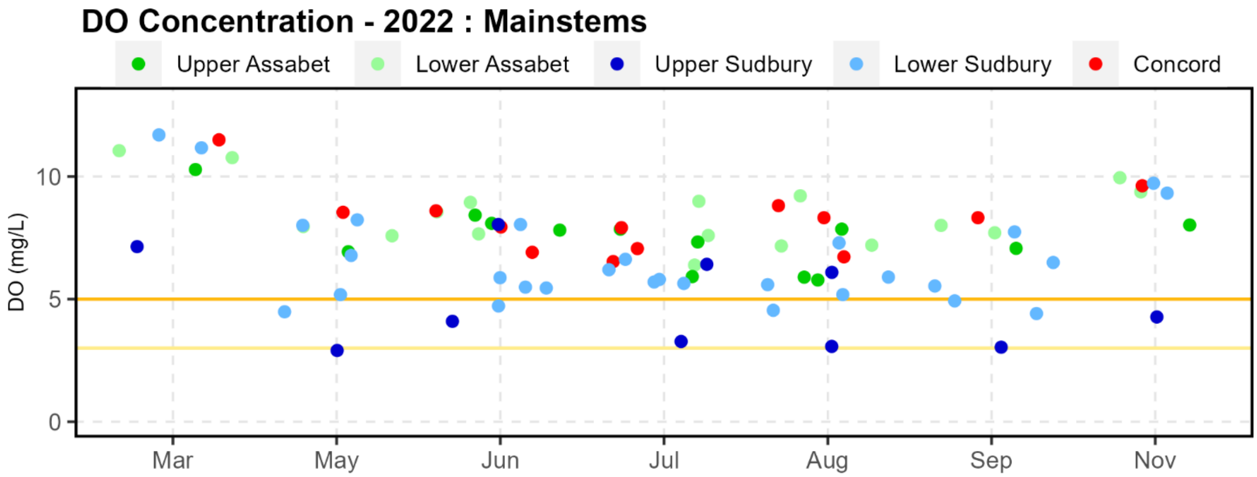


Figure 24: Dissolved Oxygen by month and section (2022)



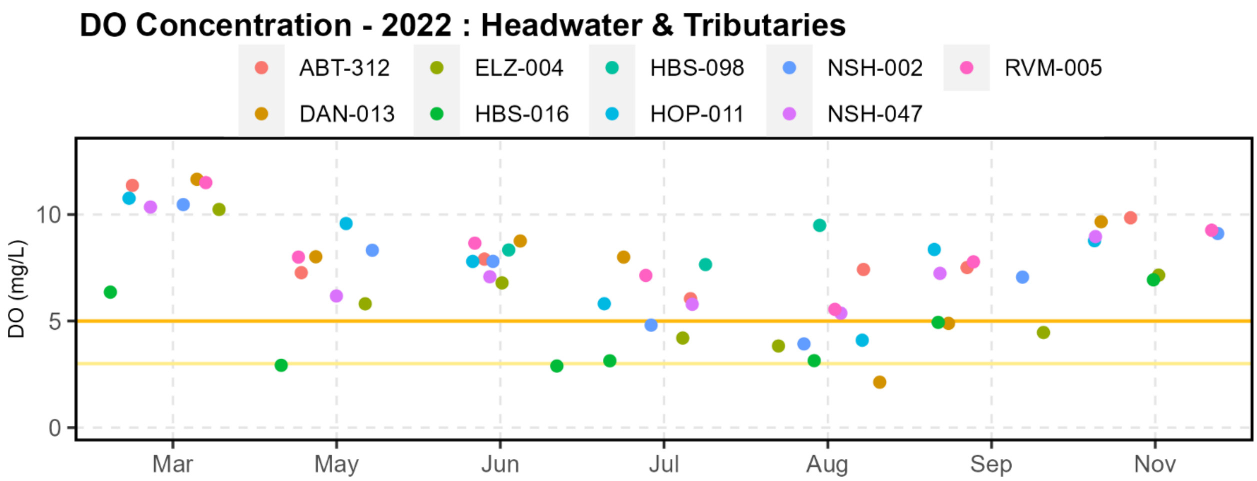


Figure 25: Dissolved Oxygen by year and section (June/July/August)

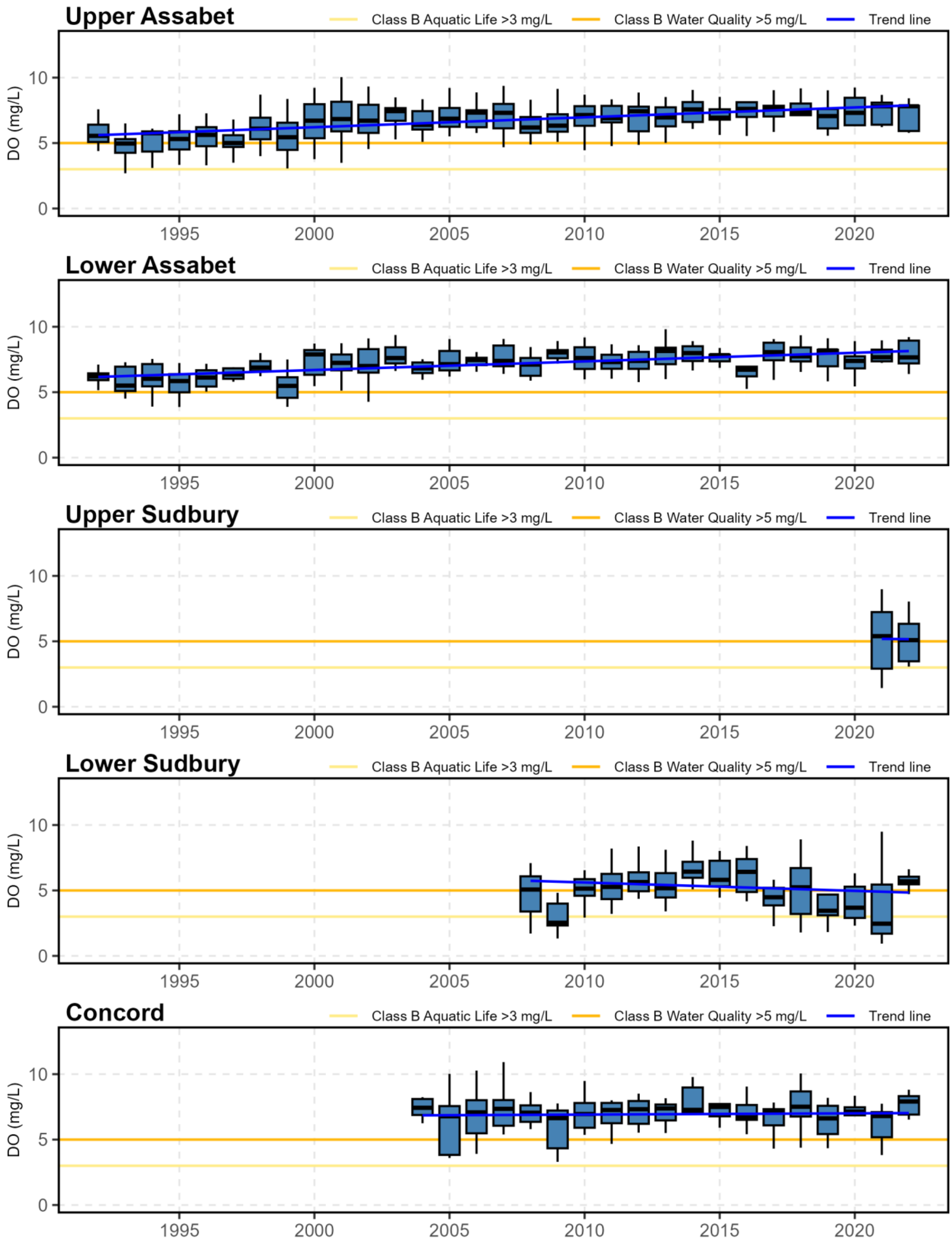
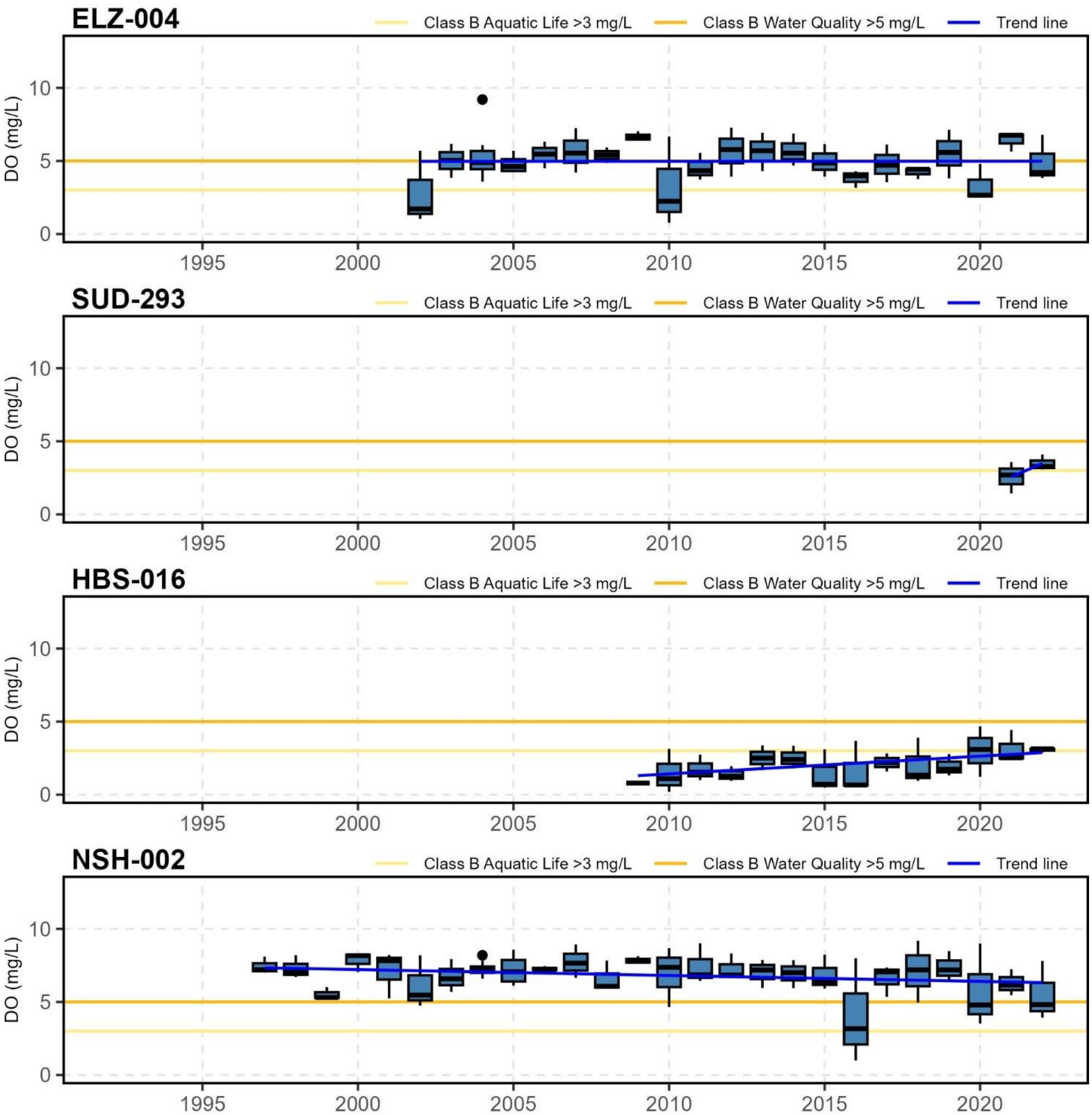


Figure 26: Dissolved Oxygen by year for selected sites (June/July/August)



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 (MA DEP, 2004). In 2022, Total Phosphorus (TP) concentrations for the Assabet River were consistently below the EPA "Gold Book" recommendation of 0.05 mg/L (Figure 27). However, the Assabet headwater (ABT-312) and tributaries Hop Brook Northborough, Hop Brook Sudbury, and Nashoba Brook (HOP-011, HBS-016, NSH-047) exhibited noticeably higher TP concentrations than the mainstem. The Lower Sudbury sites also showed slightly higher TP concentrations. It is worth noting that all the sites with higher TP levels are directly downstream of impounded wetlands, where phosphorus is cycled annually between sediments and plant matter. Note that the ABT-312 levels were driven by one very high sample in July (Figure 32).

A monthly analysis of TP concentrations by section shows little seasonal change in 2022 (Figure 28). This is a major difference from previous years which showed higher concentrations in the summer months and is surprising because we expected higher concentrations as the result of low streamflow and decreased dilution during the severe drought in late summer.

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. We had been watching a concerning increase in TP concentrations in all river sections in 2019, 2020, and 2021. In 2022, concentrations are back down to target levels. The cause of the increase is unknown, but 2020 and 2021 were notable for abnormal precipitation. The year 2020 was extremely dry, resulting in less dilution, and 2021 was extremely wet, resulting in more nonpoint source runoff.

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, and 2021 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, possibly nullifying savings due to low concentrations. High flows also carry phosphorus out of the system, so the net effect is not clear, but this could explain the low TP levels in 2022, following the extreme high flows in 2021.

WWTP discharge concentrations and loads are also included for reference (Figure 34, Figure 35, Figure 36, Figure 37). It is noteworthy that the total amount of phosphorus (load) discharged by the WWTPs to the Assabet in 2020 was about 30% greater than in 2018, providing another possible explanation for high 2020 river concentrations. In 2022, Westborough discharge loads again approached 2020 levels. Both were very dry summers. We need to ask the WWTP why phosphorus loads were higher in dry years. Also note the dramatic reduction in TP discharge at the Marlborough Easterly WWTP as a result of the 2015 plant improvements (Figure 35). This reduction was significant, but the downstream Hop Brook site (HBS-016) still consistently has the highest TP concentrations in our watershed and Hop Brook is known for its eutrophic conditions. We believe this is due to release of legacy phosphorus from the sediments in the numerous impoundments in Hop Brook. To this end, OARS has been working on a special study of Hop Brook with the Hop Brook Protection Association since 2020.

Figure 27: TP concentration by site, summer (2022)

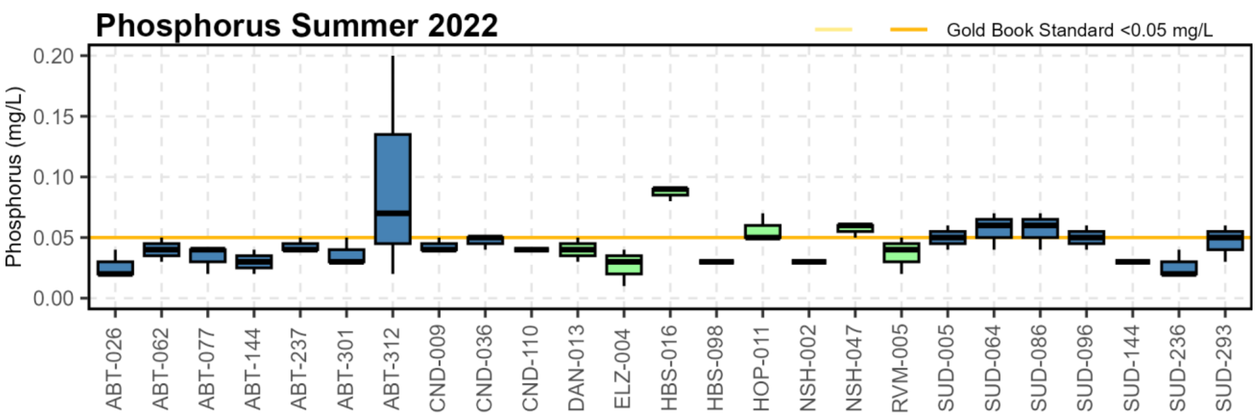


Figure 28: TP concentration by month and section (2022)

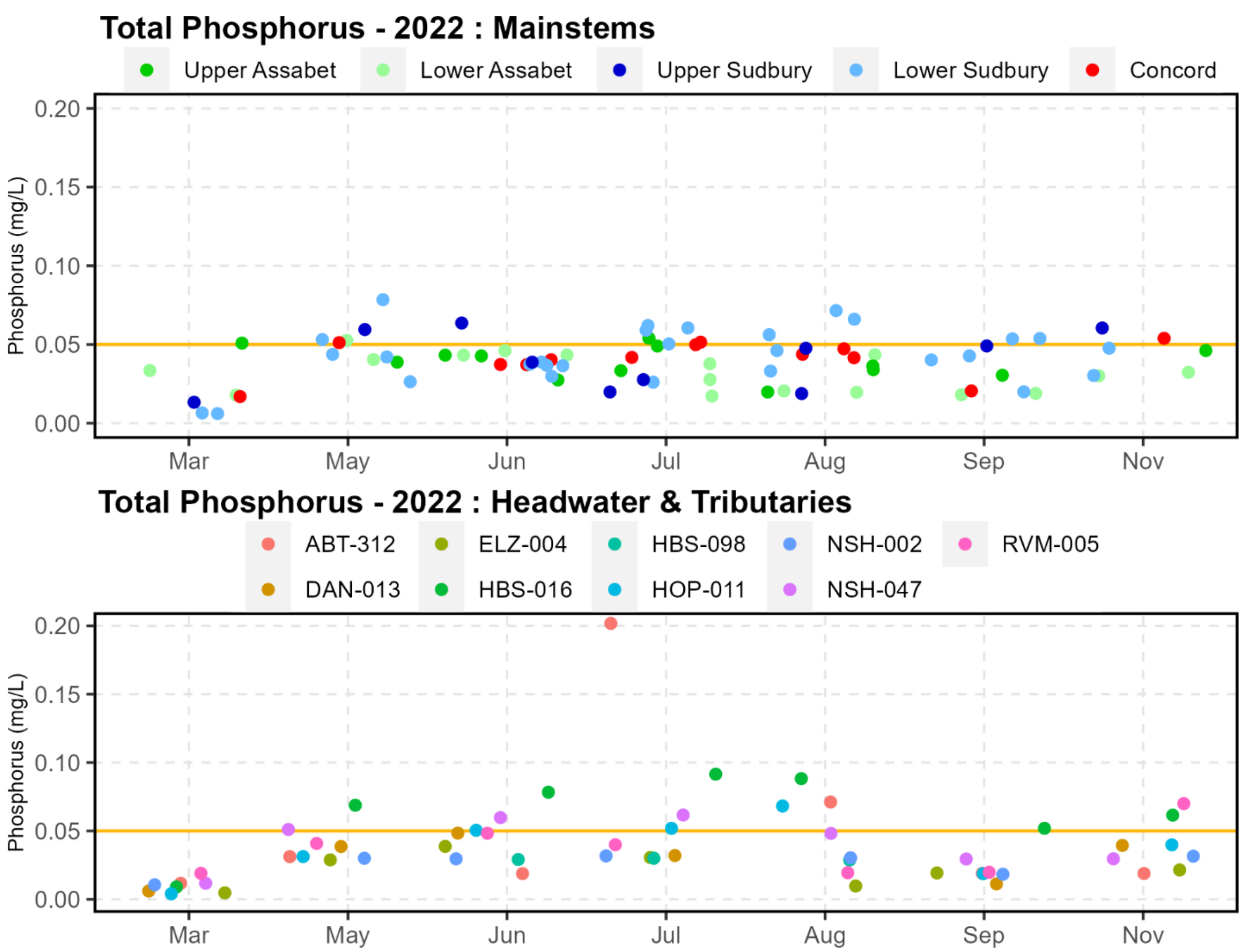


Figure 29: TP concentration by year and section (June/July/August)

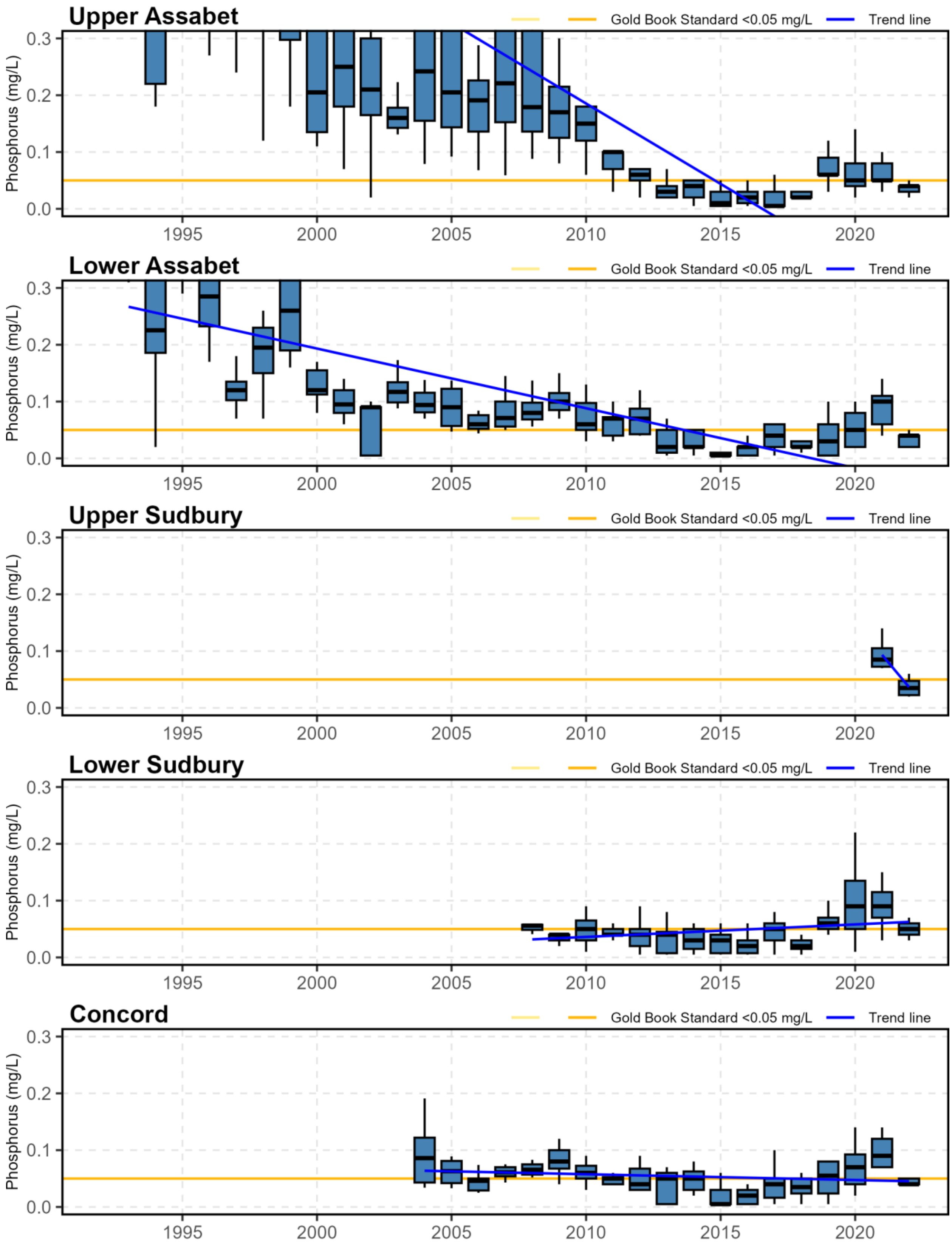


Figure 30: TP estimated load by year and section (June/July/August)

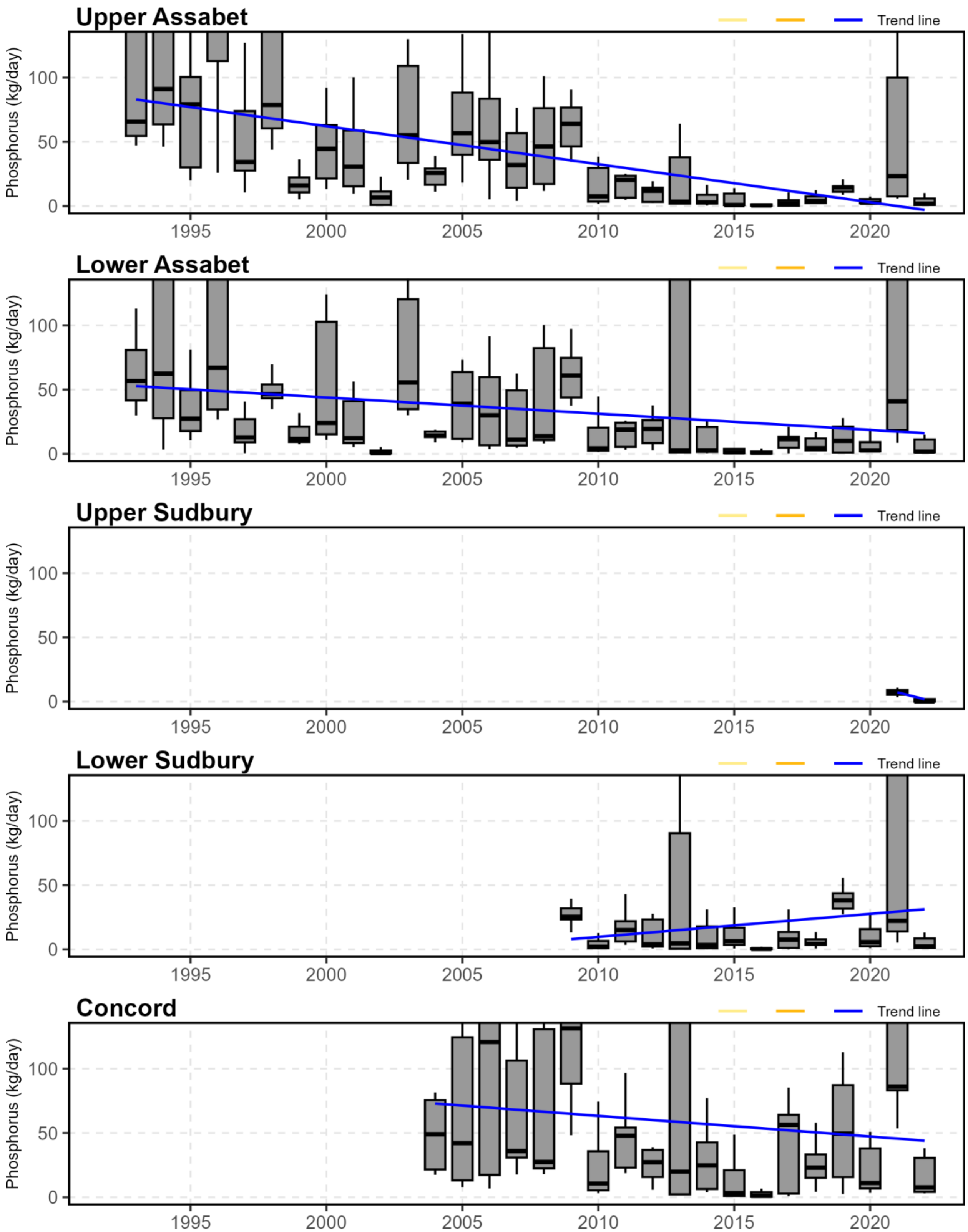


Figure 31: TP concentration by year selected sites (June/July/August)

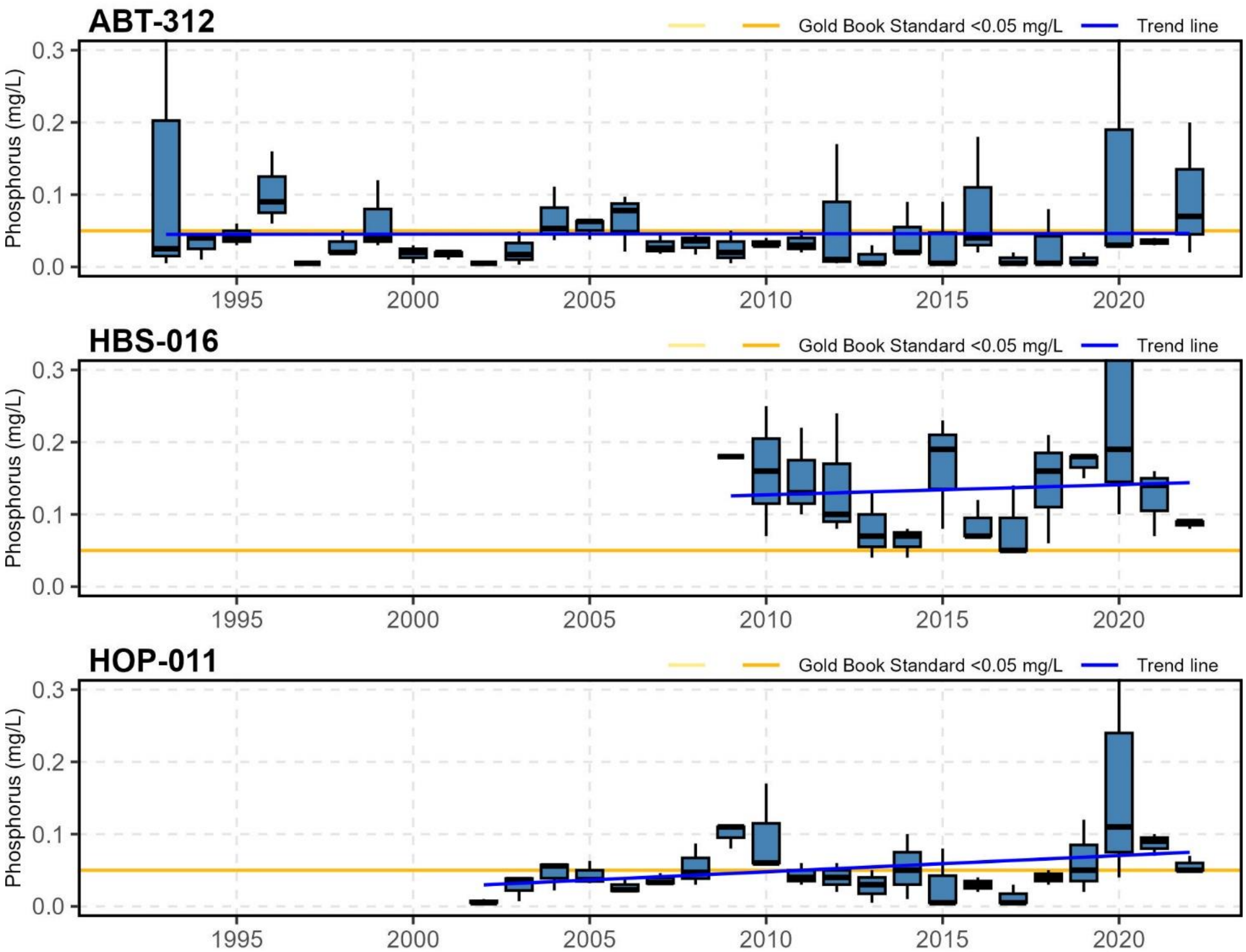


Figure 32: ABT-312 sample detail TP and TSS

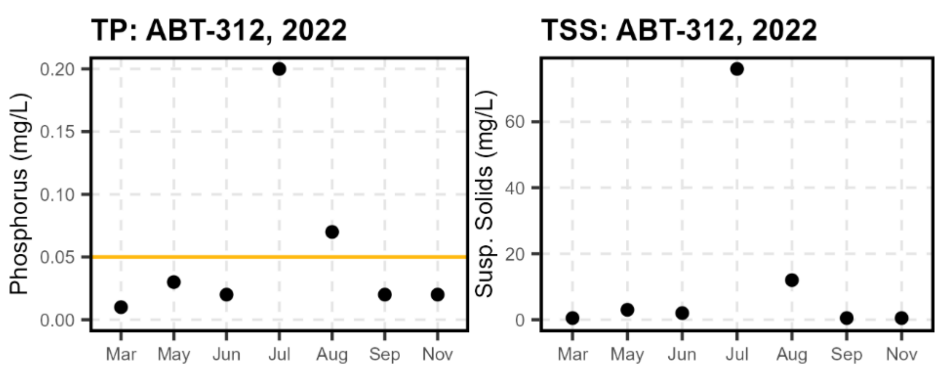


Figure 33: Map of average summer Total Phosphorus by site (2020-2022)

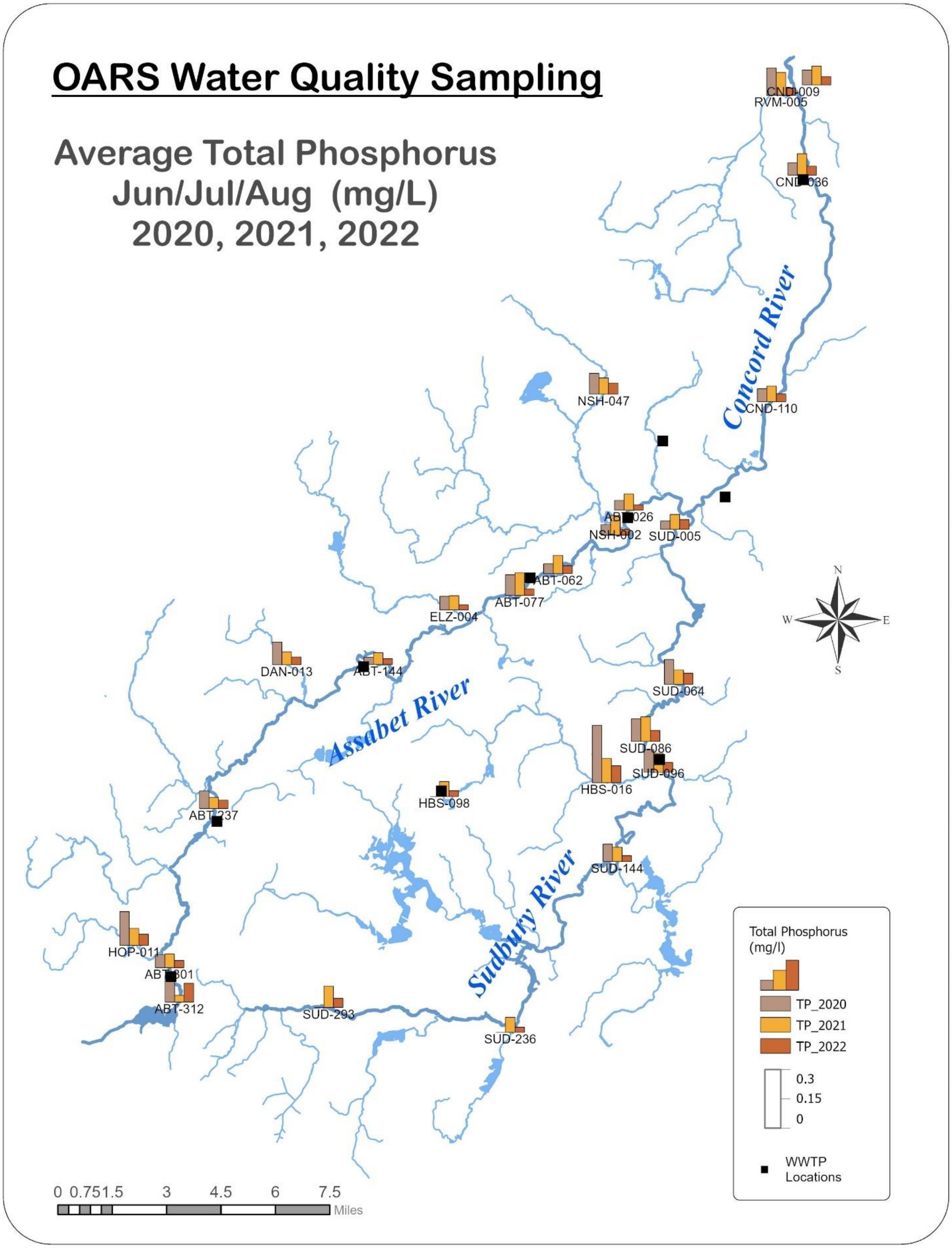
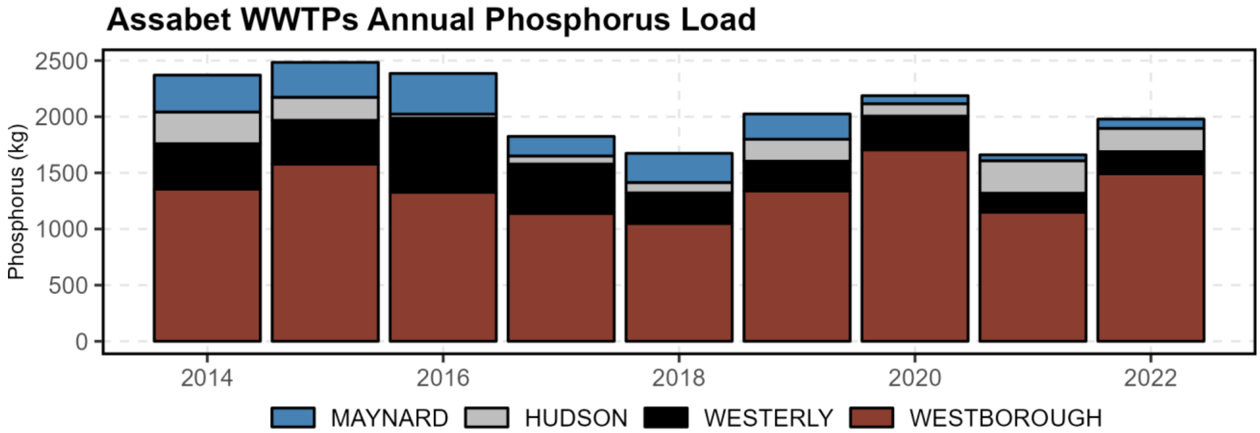
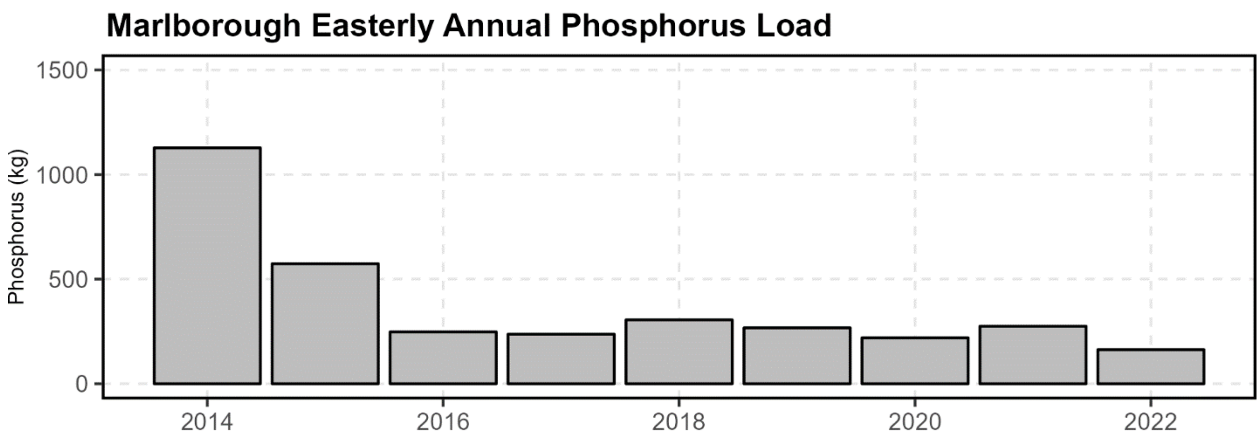


Figure 34: Major Assabet WWTPs TP discharge (2014-2022)



* Annual discharge is calculated as effective annual discharge for the summer period – sum of November through October.

Figure 35: Major Sudbury WWTP TP discharge (2014-2022)



* Annual discharge is calculated as effective annual discharge for the summer period – sum of November through October.

Figure 36: WWTP Daily TP Discharge - summer (2022, Apr-Oct)

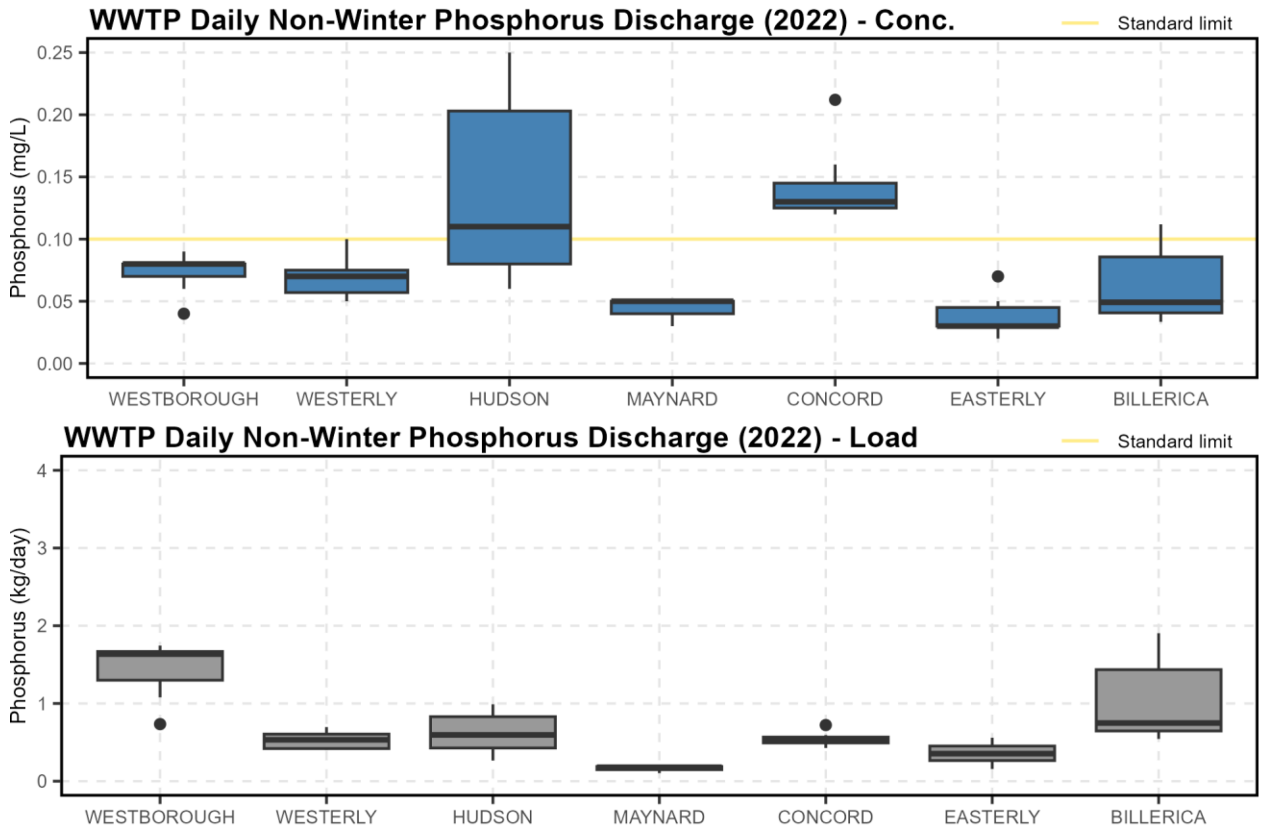
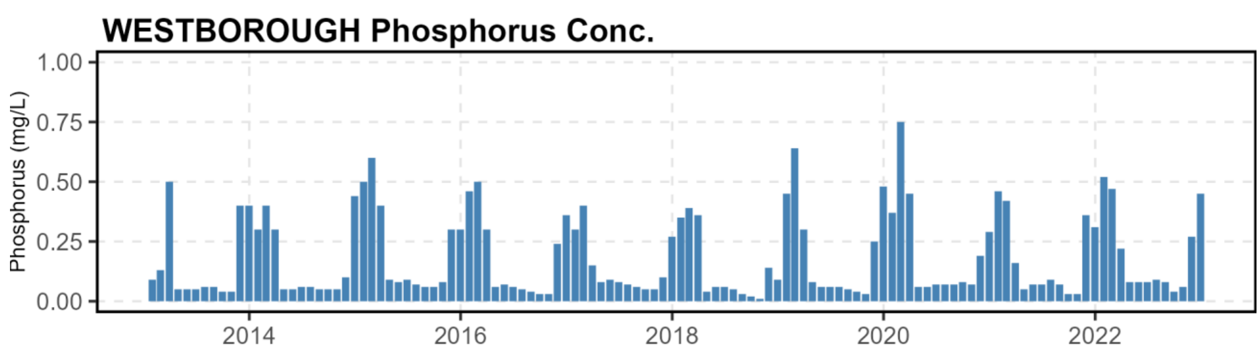


Figure 37: Westborough WWTP TP discharge by month (concentration)



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 13% to 58% of TP during the summer in 2022 (Figure 38). Hop Brook in Sudbury (HBS-016) had the highest proportion of orthophosphate at 58%. This site is located in a large wetland and downstream of several impoundments with large quantities of legacy phosphorus in the sediments.

Monthly analysis of orthophosphate data shows high proportions in the Upper Assabet in March and November (Figure 39). This occurs every year and is most likely a result of higher winter phosphorus discharge permit limits at the Westborough WWTP. The high proportions in the Upper Sudbury in September and November probably represent decaying plant matter from the upstream Cedar Swamp area. It is also worth noting that the June sampling event showed higher than normal percentages of orthophosphate in all sections because it was taken two days after a large precipitation and flow event.

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 40).

Figure 38: Ortho-P concentration by site, summer (2022)

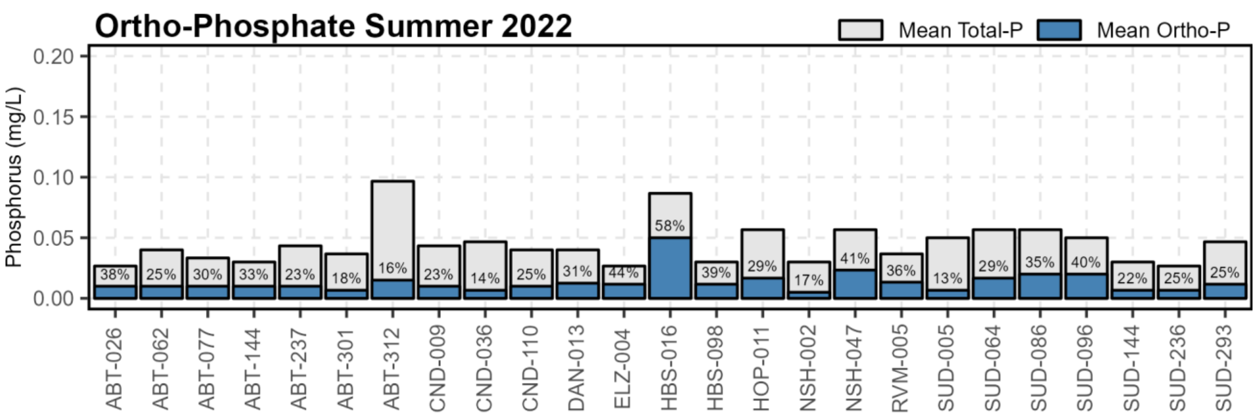


Figure 39: Ortho-P concentration by month and section (2022)

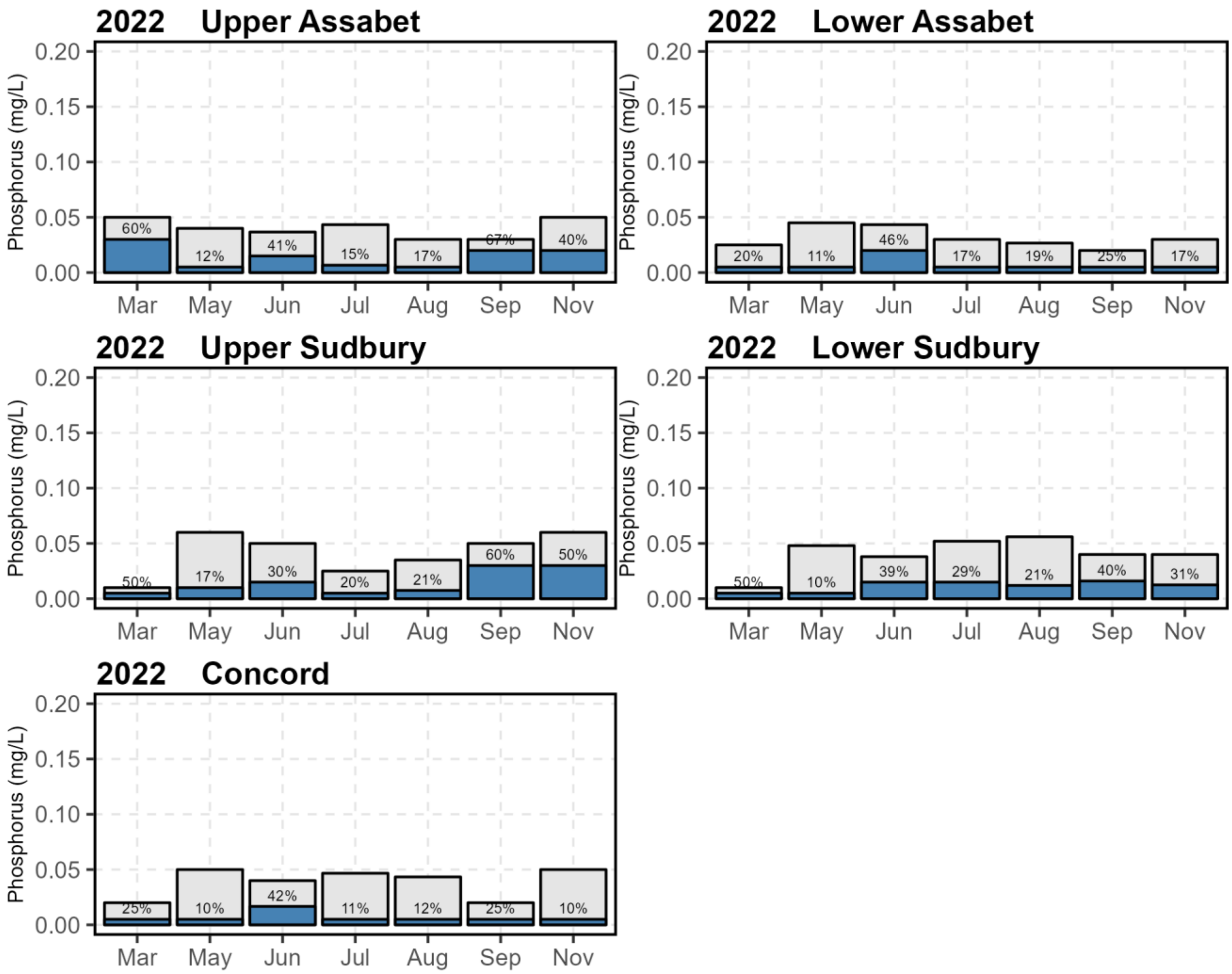
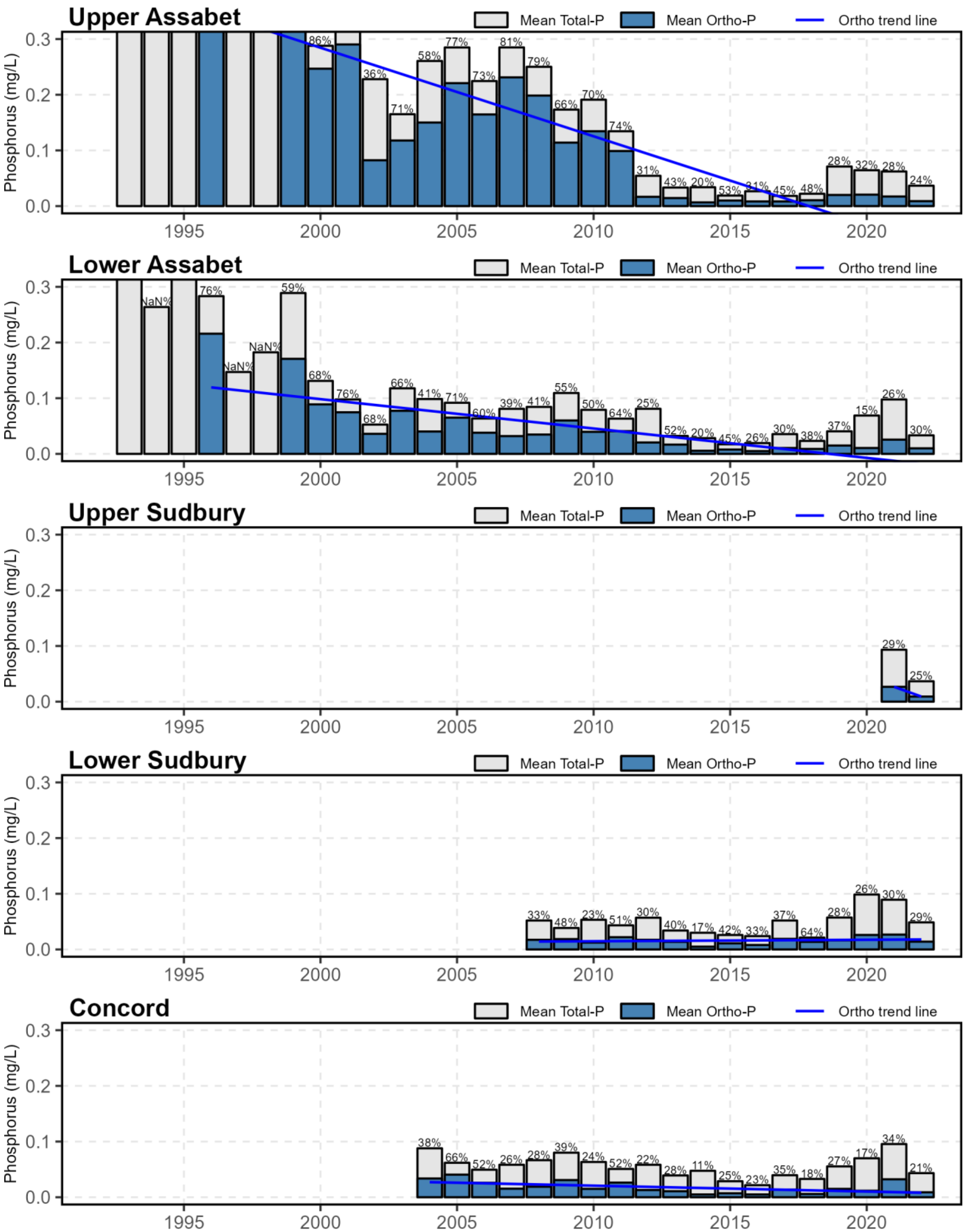


Figure 40: Ortho-P concentration by year and section (June/July/August)



<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. The by-site graphs show very high nitrate-N concentrations below the Westborough (ABT-301), Westerly (ABT-237), and Hudson (ABT-144) WWTPs (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-N levels, but that site was not analyzed in 2022. *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 NO_3 shows the effect of dilution on concentrations, with concentration increasing as flows decrease in late summer (Figure 42).

Year-on-year analysis of NO_3 shows what seems to be an increasing trend in concentration in the Assabet (Figure 43). For load, the increasing trend is even clearer (Figure 44). Note that load from the Upper Assabet WWTPs is also visible flowing downstream in the Lower Assabet and Concord. Loads remain at similar levels downstream, even though flow volumes are much larger.

Figure 41: Nitrate concentration by site, summer (2022)

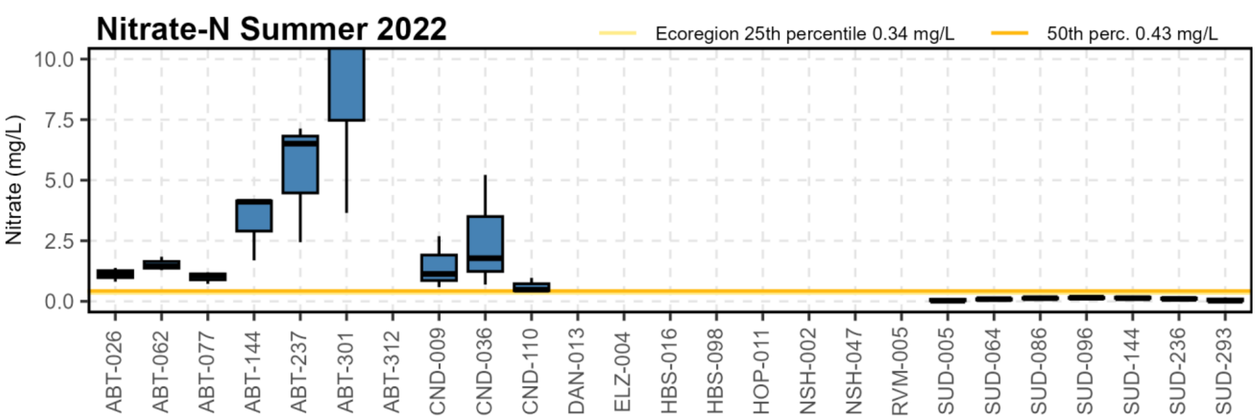


Figure 42: Nitrate concentration by month and section (2022)

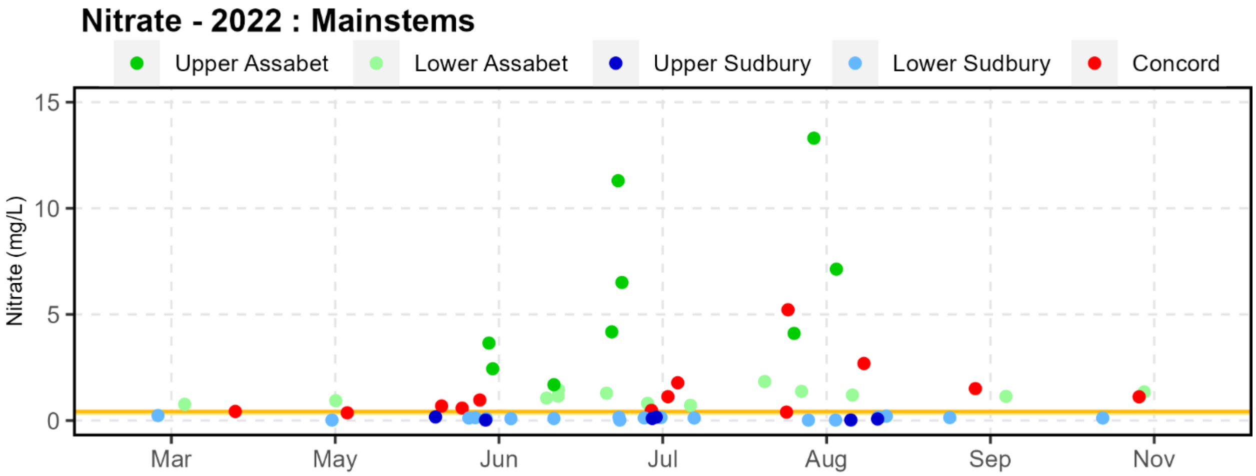


Figure 43: Nitrate concentration by year and section (June/July/August)

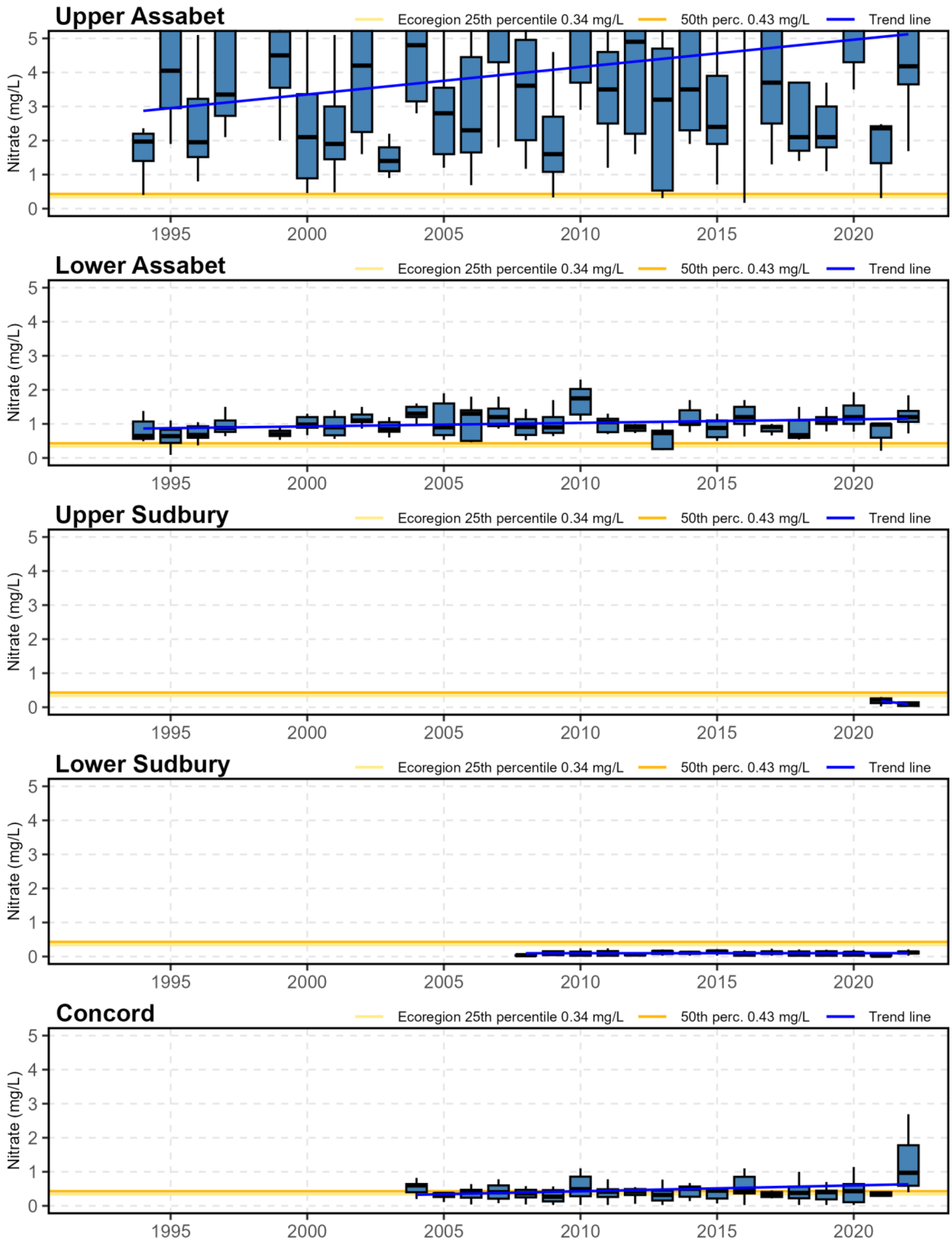
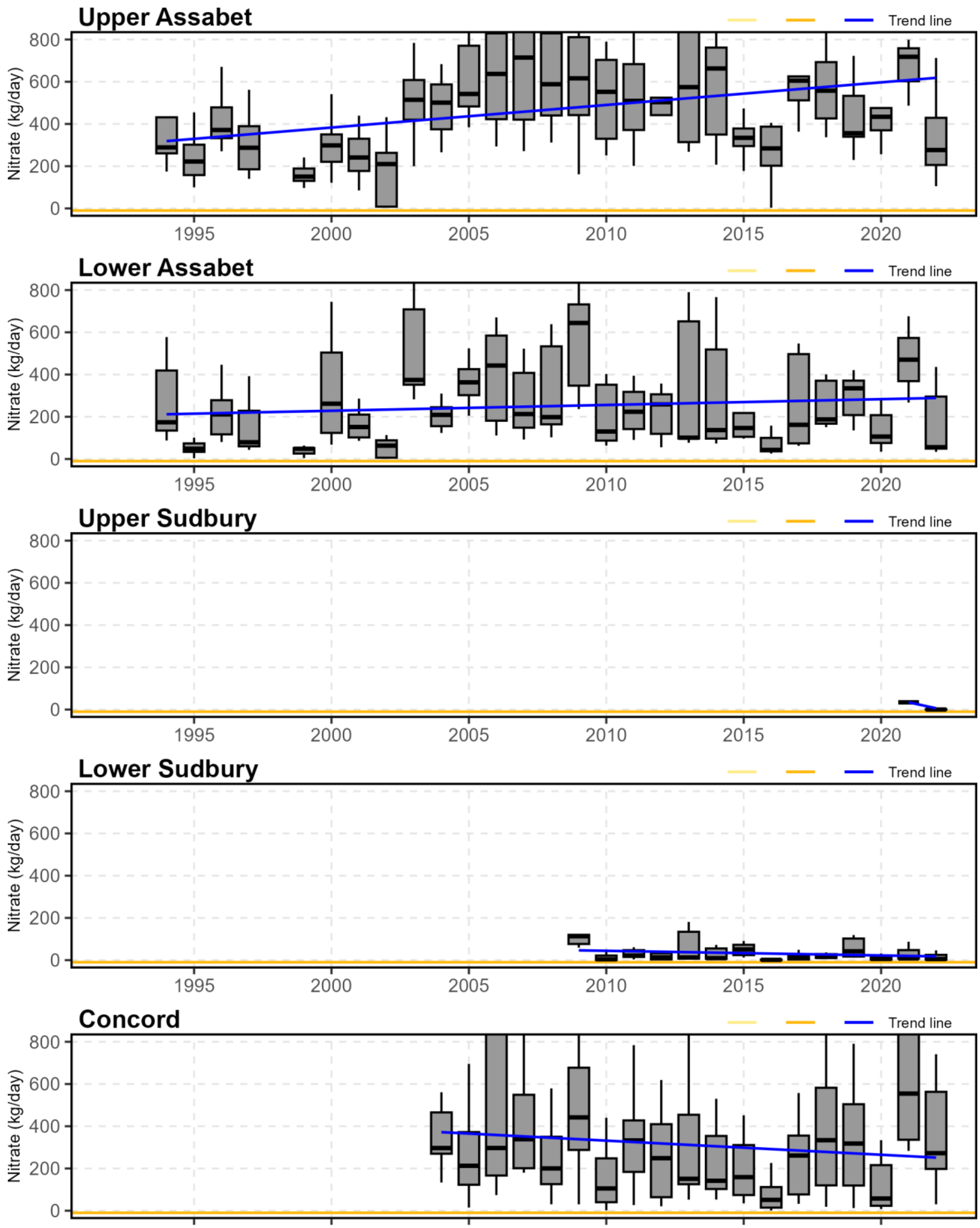


Figure 44: Nitrate estimated load by year and section (June/July/August)



<u>Ammonia</u>

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). The maximum summer level we measured in 2022 was 0.21 mg/L in Elizabeth Brook (ELZ-004), with 71% of samples below 0.1 mg/L (Figure 45). Brooks with organic matter decomposition tend to have the highest ammonia levels, but two sites below WWTPs do show up in 2022 with slightly elevated levels (CND-036 and HBS-098).

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 47). 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 ABT-062 (downstream of Maynard WWTP), HBS-016 (Hop Brook), HBS-098 (downstream of Easterly WWTP), NSH-047 (Nashoba Brook), RVM-005 (River Meadow Brook). It is interesting that HBS-016 has had no detectable ammonia for the past two years since the heavy rains. Also of note, RVM-005 has the most frequently occurring high ammonia events (Figure 48).

Daily discharge from the WWTPs is also included for reference (Figure 49). Note that Maynard WWTP consistently discharges above the EPA chronic threshold, which explains the relatively higher ammonia levels at ABT-062. 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 45: Ammonia concentration by site, summer (2022)

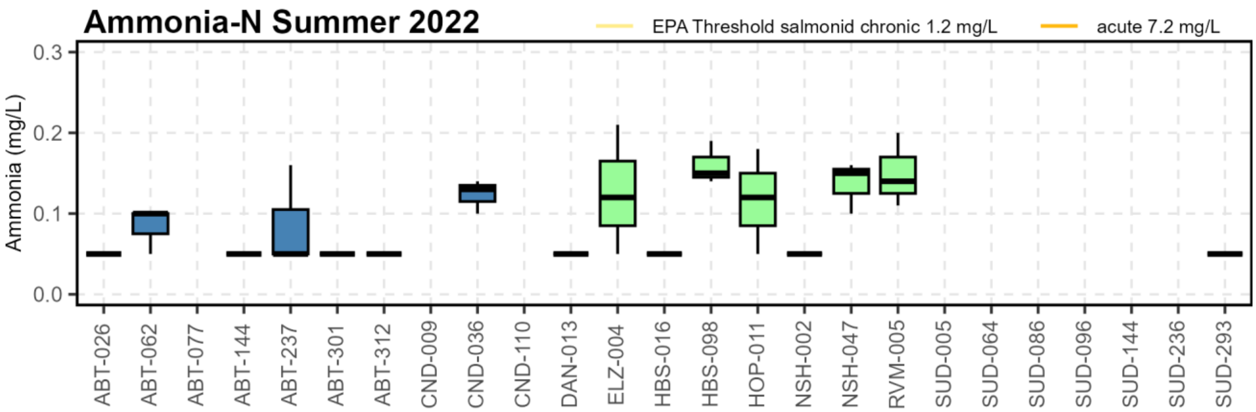
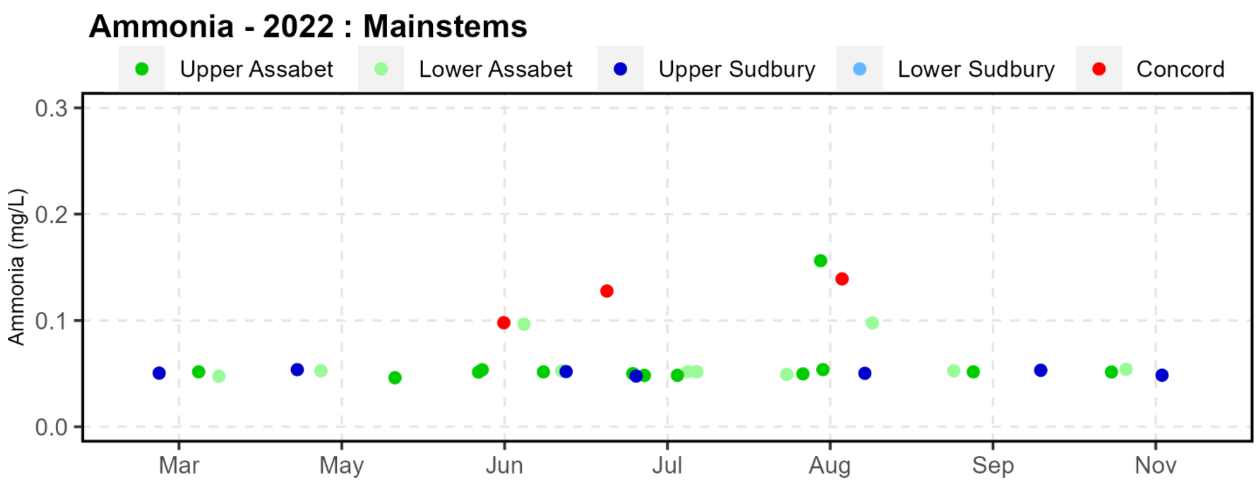


Figure 46: Ammonia concentration by month and section (2022)



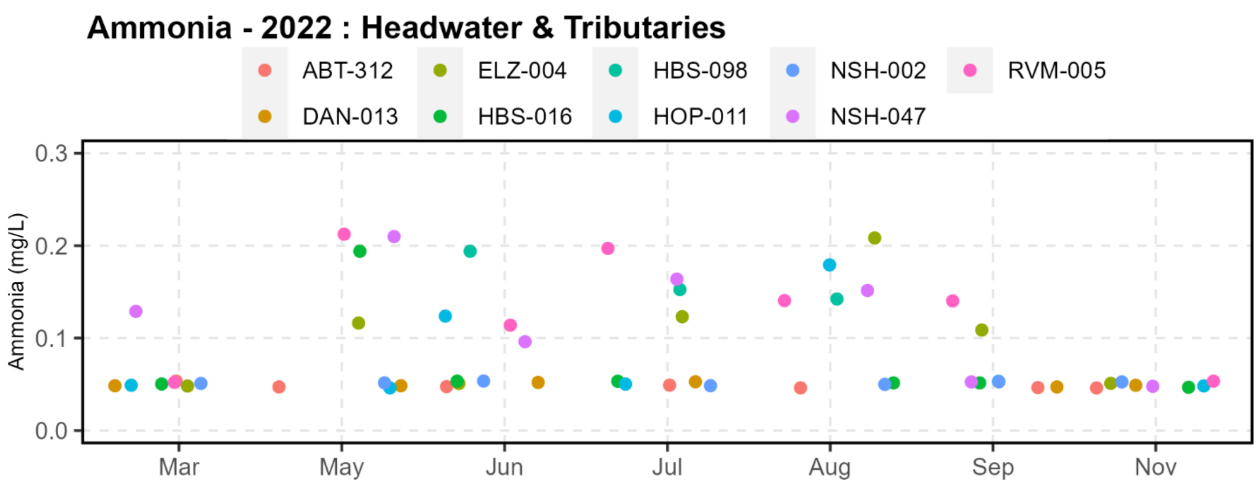


Figure 47: Ammonia concentration by year and section (June/July/August)

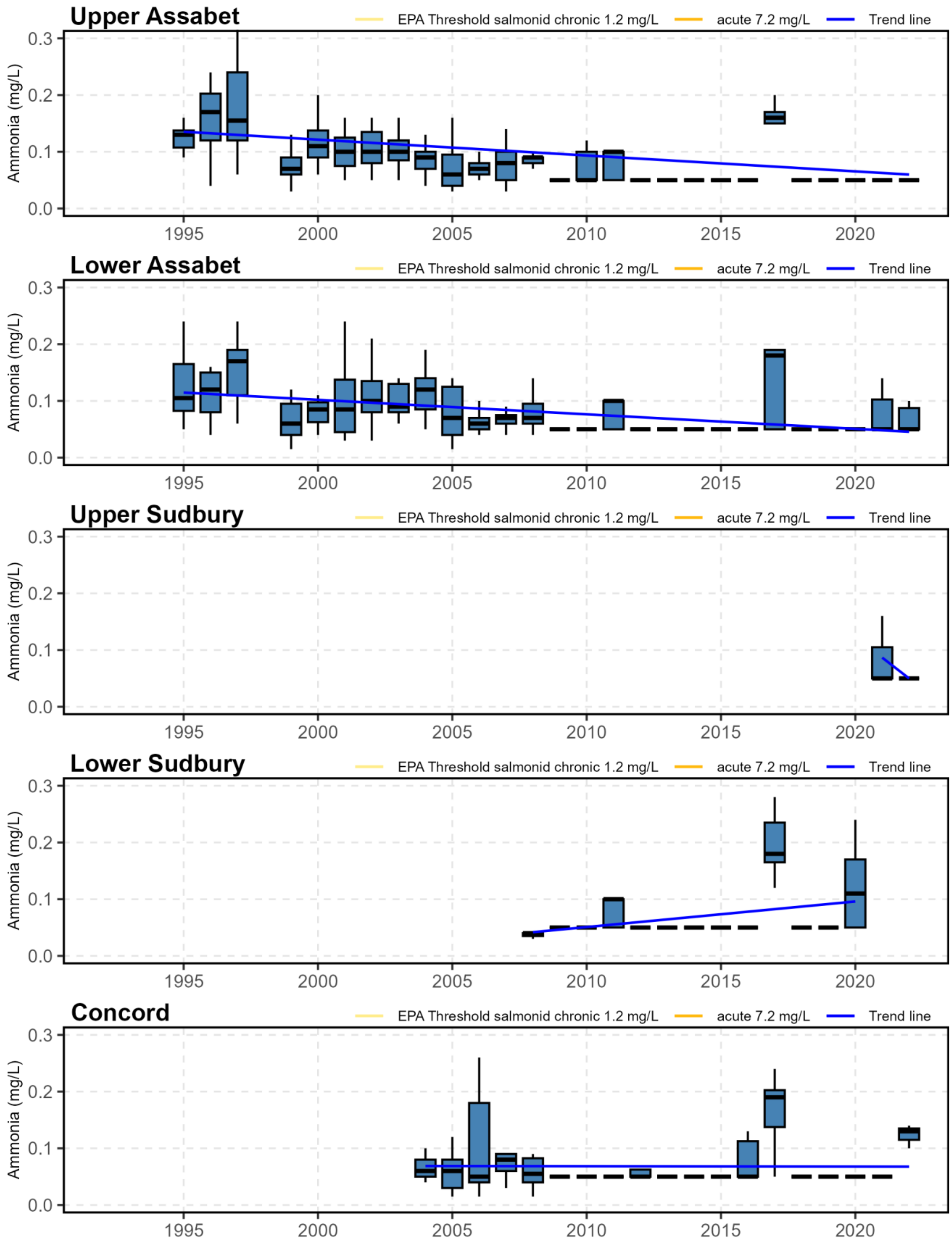


Figure 48: Ammonia concentration by year for River Meadow Brook (June/July/August)

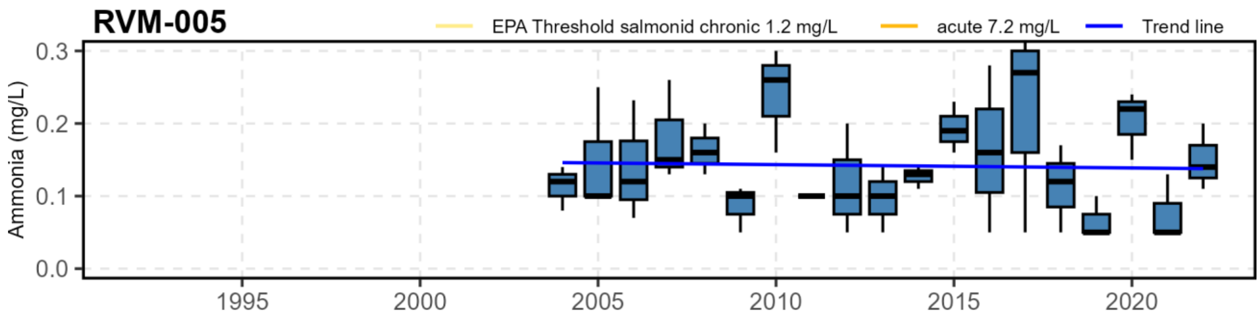
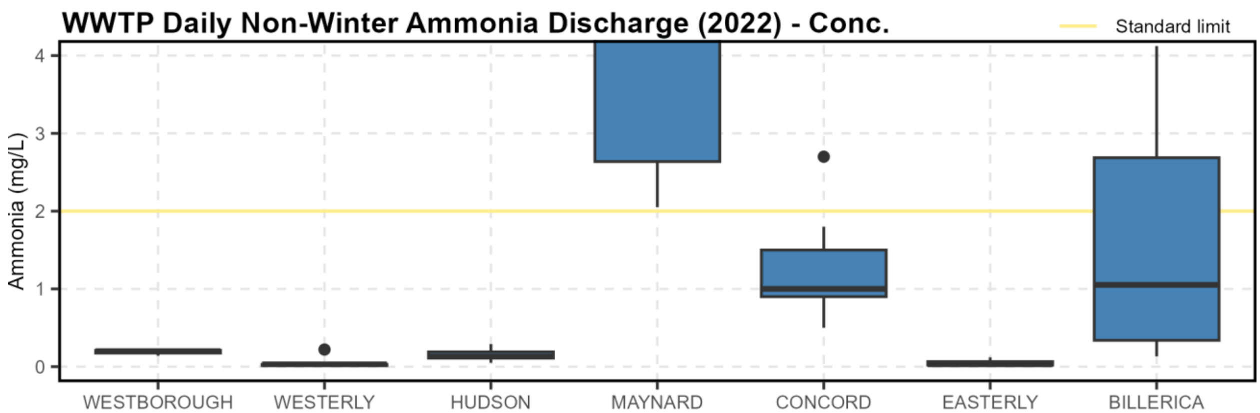
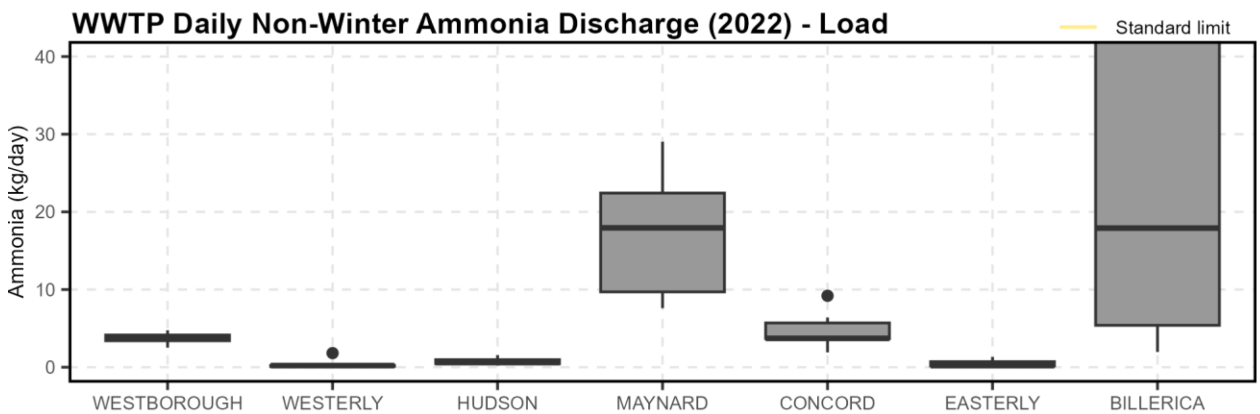


Figure 49: WWTP Daily Ammonia (NH_3 and NH_4^+) Discharge - summer (2022, Apr-Oct)





Total Suspended Solids

Total Suspended Solids (TSS) measures all non-dissolved particulates in the water. High concentrations of TSS can indicate erosion, runoff, live or decaying algae, disturbed sediment, or discharge of sediment-laden water. By-site results show several sites that experienced very high TSS measurements in the 2022 (Figure 50). ABT-312 is downstream of an impoundment undergoing weed removal activities. It often displays high TSS and in 2022 it showed extremely high TSS and particulate phosphorus in one sample in July (Figure 32). The Sudbury and Concord River sites often have higher TSS. The high result at CND-110 was from the June sampling, which was collected during a high flow event. The high levels at the Lower Sudbury sites were from July and August when river levels were extremely low. They could have been a result of boating activity or the high chlorophyll-a that was measured at the same time. The high levels in the upper Sudbury at Fruit Street (SUD-293) were most likely a result of bridge construction directly upstream.

Year-on-year analysis of TSS shows improving trends in most river sections (Figure 52). It also shows that the Lower Sudbury and Concord tend to have higher-than-average TSS levels. The Lower Sudbury 2022 data were an exception to the improving trend, but load analysis shows that the high concentrations were most likely a factor of the extremely low flows, since total TSS load was actually quite low (Figure 53). Year-on-year analysis of TSS load also shows the effect of high flows on the suspended solids load that was carried downstream in 2013 and 2021.

Figure 50: TSS concentration by site, summer (2022)

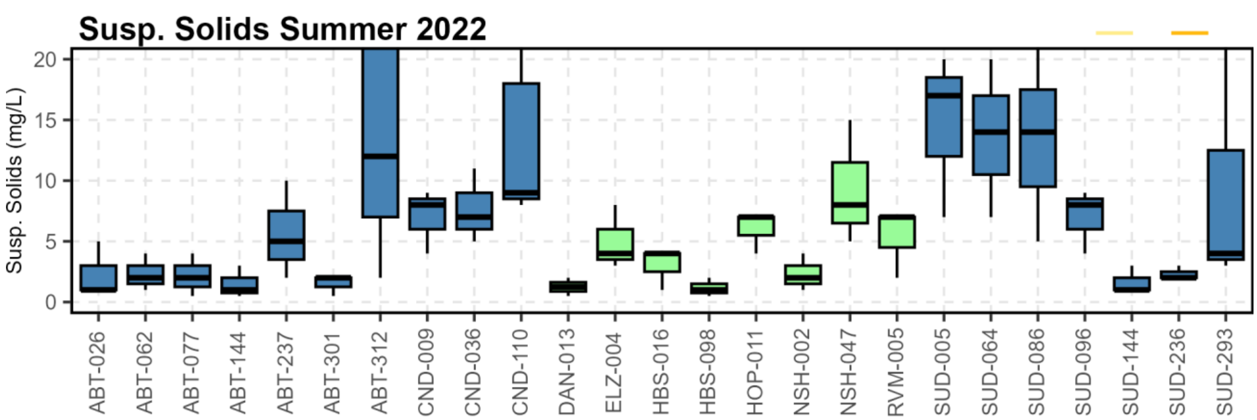


Figure 51: TSS concentration by month and section (2022)

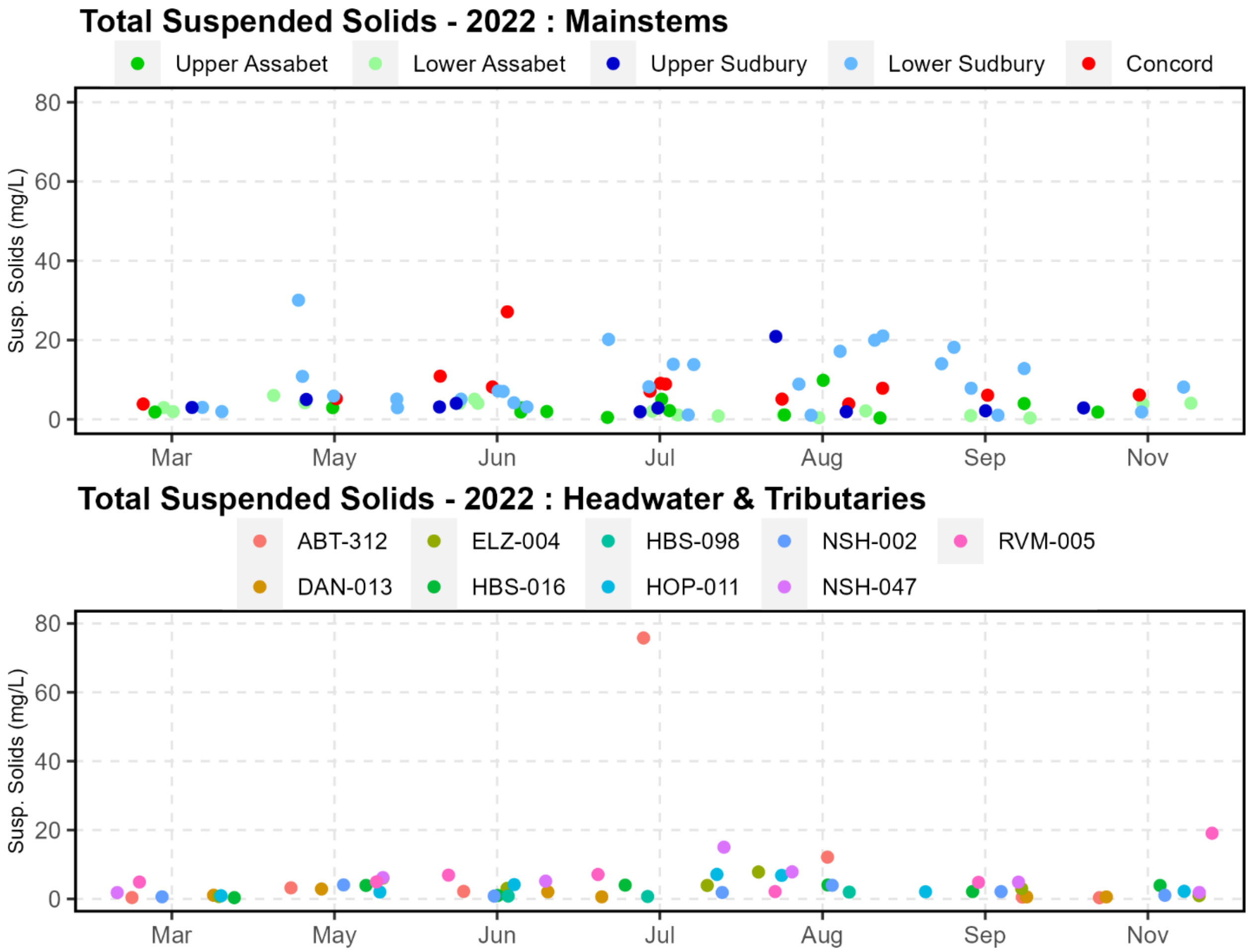


Figure 52: TSS concentration by year and section (June/July/August)

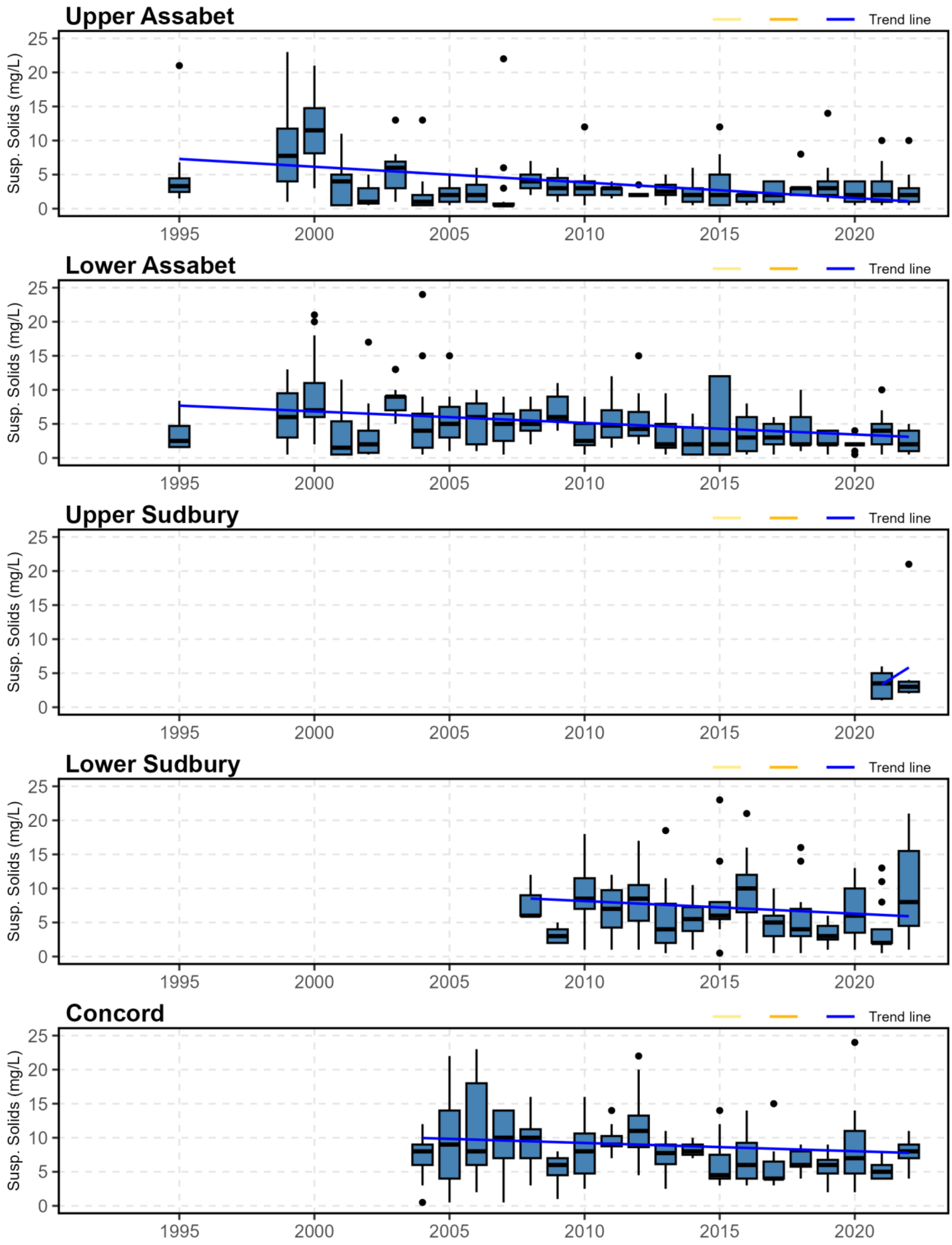
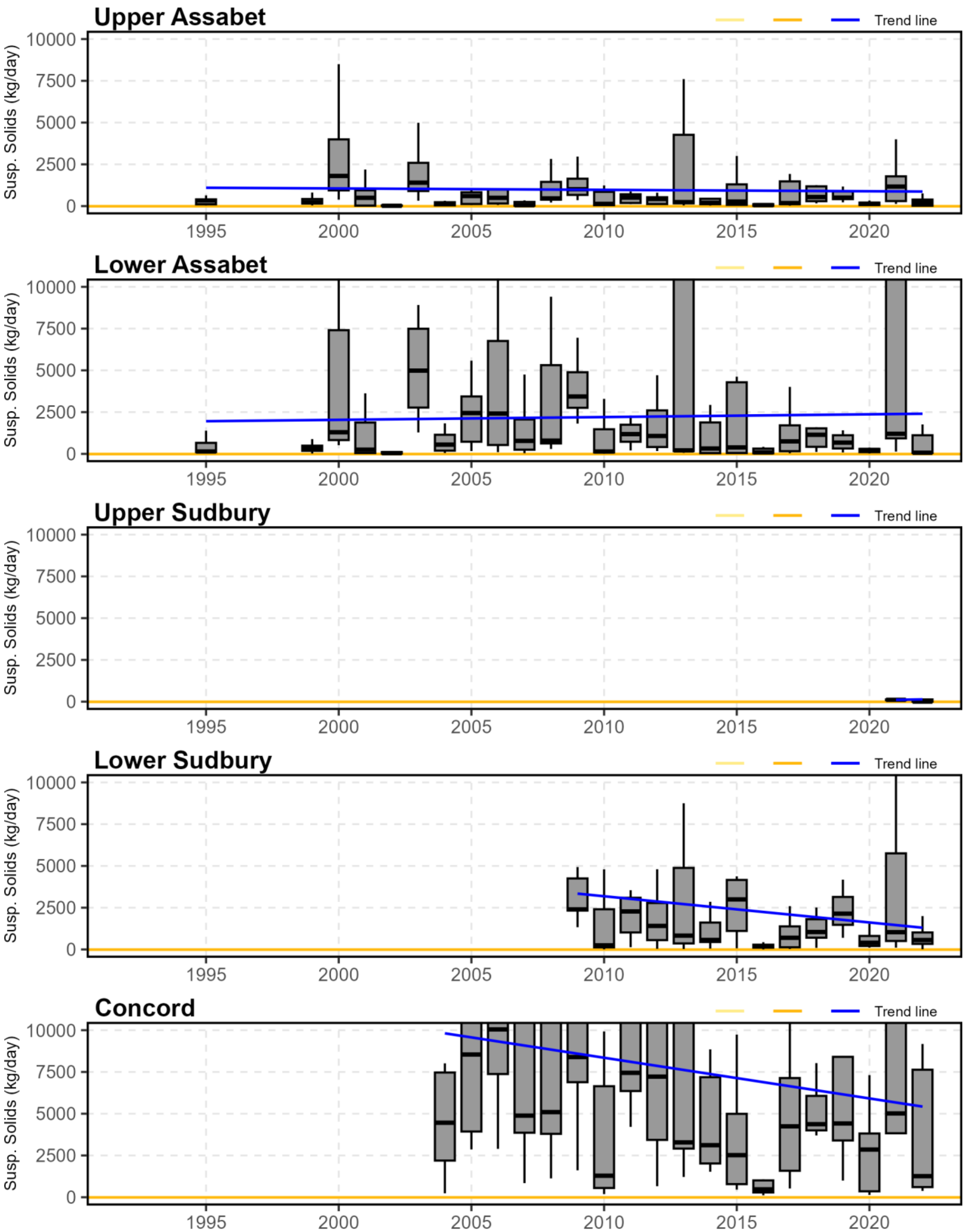


Figure 53: TSS estimated load by year and section (June/July/August)



<u>Chlorophyll *a*</u>

Chlorophyll *a* is the principle 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*.

By-site analysis shows concentrations ranging from <2 to 50 µg/L, with all of the sites below Hop Brook averaging above 4 µg/L (Figure 54). Chlorophyll *a* concentrations in the Sudbury tend to increase downstream. By month, chlorophyll *a* concentrations tend to increase from June to August (Figure 55), though this is not a rule and depends on temperature and flow.

Year-on-year analysis of chlorophyll *a* shows what seems to be an improving trend since 2010, though results in 2022 were much higher than previous years, most likely due to the drought conditions (Figure 56).

Figure 54: Chlorophyll *a* concentration by site, summer (2022)

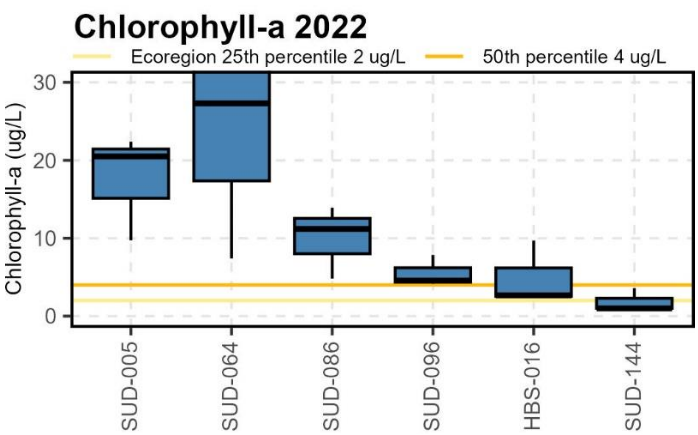


Figure 55: Chlorophyll *a* concentration by month (2022)

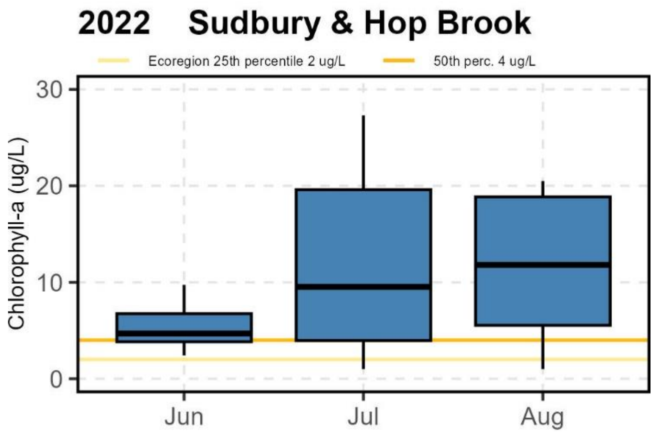
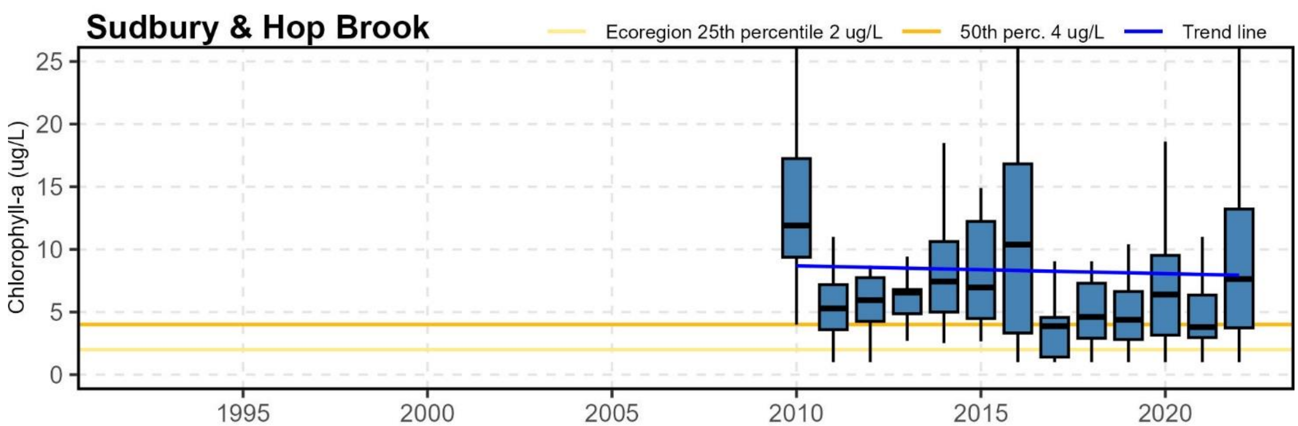


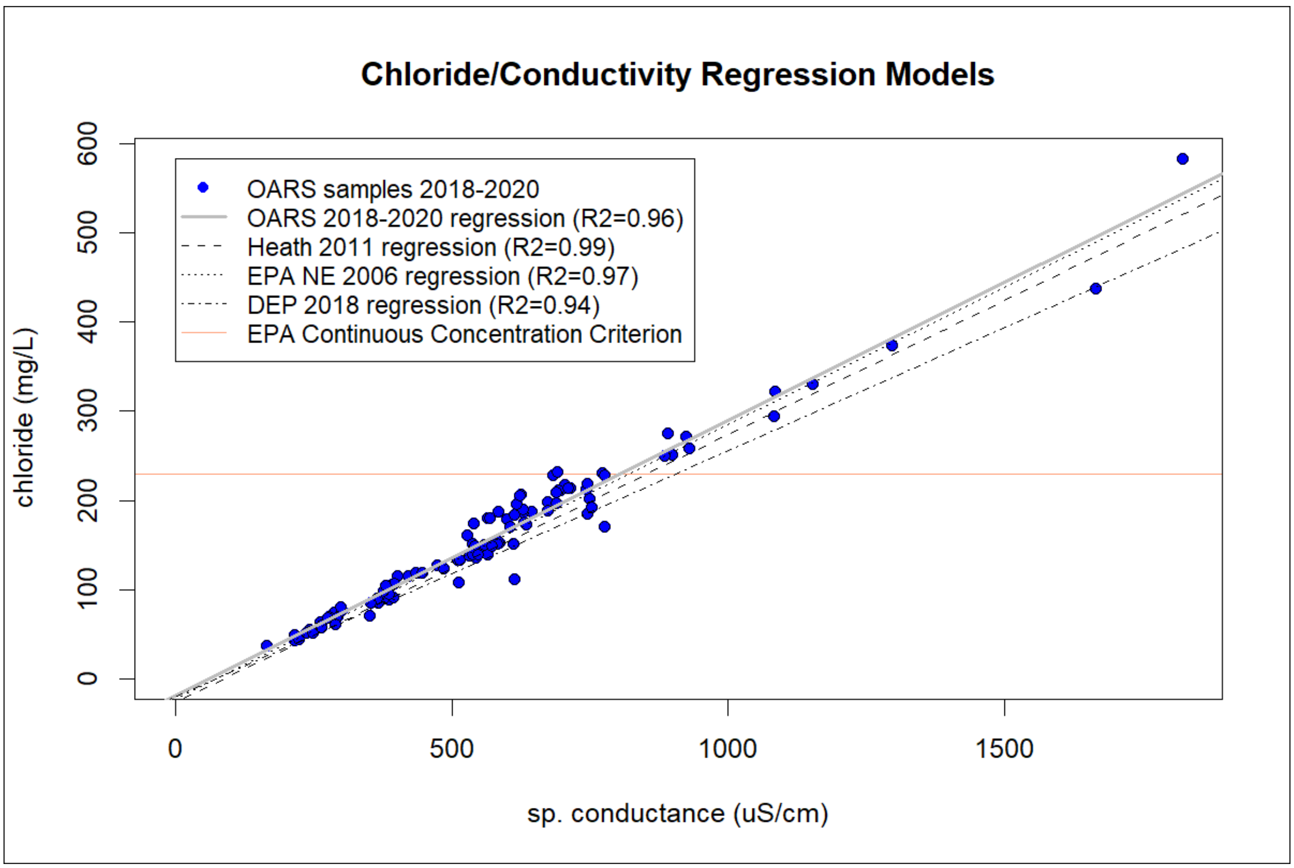
Figure 56: Chlorophyll *a* concentration by year (June/July/August)



<u>Chloride</u>

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. The plot in Figure 57 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 R2 value of 0.96 and it lines up very closely with similar regressions conducted by other agencies in our region (Heath, 2011; MA DEP, 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 did not analyze water samples for chloride in 2022, but we are carefully monitoring conductivity. The year-on-year summer conductivity graphs above show a clear upward trend in conductivity/chloride for all of 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.

Figure 57: 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 Health Report Card (see https://ecoreportcard.org). For the Report Card, the index is calculated for samples taken between May 1st and September 30th at 15 mainstem sampling sites. Calculations for 2022 are compared with 2018 in Figure 58 because 2018 was a relatively favorable year for the index.

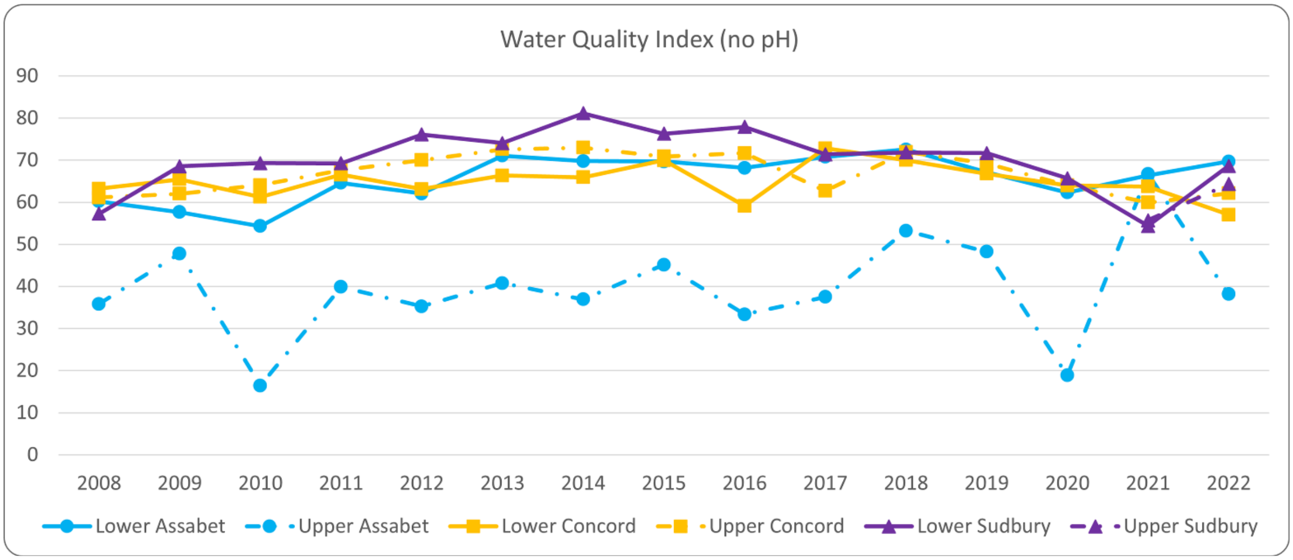
Year-on-year tracking of the Water Quality Index shows a general downward (worsening) trend since 2018 for the Concord, Lower Sudbury, and Lower Assabet (Figure 59). In the Concord and Lower Assabet, the change is primarily driven by nitrate concentrations. In the Lower Sudbury, it is primarily driven by phosphorus and suspended solids. The index is highly influenced by climatic trends such as precipitation, which affects concentrations. The Upper Assabet's index shows large fluctuations, which are primarily driven by fluctuations in nitrate concentration influenced by precipitation and flow. We have just recently started computing the index for the Upper Sudbury, which has a low DO index component due to very low DO levels at Fruit St.

Figure 58: Water Quality Index calculations (2022 vs. 2018)

2022	Nitrates	TP	TSS	DO	Temp	WATER QUALITY INDEX
Upper Assabet	12	66	80	77	95	38
Lower Assabet	43	70	84	84	89	70
ASSABET (area weighted)	27	68	82	81	92	54
Upper Sudbury	97	65	71	46	95	64
Lower Sudbury	96	61	57	70	90	69
SUDBURY (area weighted)	97	62	64	59	92	67
Upper Concord	60	63	46	84	79	62
Lower Concord	41	63	60	84	82	57
CONCORD (area weighted)	58	63	48	84	79	62
WATERSHED (area weighted)	60	65	69	72	90	60

2018	Nitrates	TP	TSS	DO	Temp	WATER QUALITY INDEX
Upper Assabet	26	81	77	85	94	53
Lower Assabet	53	76	74	87	91	73
ASSABET (area weighted)	40	79	76	86	93	63
Upper Sudbury	NA	NA	NA	NA	NA	NA
Lower Sudbury	96	84	69	58	93	72
SUDBURY (area weighted)	96	84	69	58	93	72
Upper Concord	89	69	62	68	87	72
Lower Concord	61	72	60	87	86	70
CONCORD (area weighted)	86	70	62	70	87	72
WATERSHED (area weighted)	70	79	71	72	92	68

Figure 59: Water Quality Index year-on-year results (2008-2022)



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 (MA DEP, 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 the bacteria multiply exponentially. For this same reason, averages of bacteria data are calculated using a geometric mean instead of an arithmetic mean.

Our 2022 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 the swimming threshold of 126 CFU/100 ml (Figure 60). These three sites also all show consistent high bacteria levels in dry weather, which indicates a high probability of sanitary sewer contamination (Figure 61). Please see our 2022 Bacteria Monitoring Results report for more details (OARS, 2022c).

Lowell Bacteria Special Study

Between 2020 and 2022, OARS conducted a special study of bacteria levels at the Rogers Street Bridge in Lowell. The study identified River Meadow Brook as the primary source of bacterial pollution in that section of the Concord River. The study confirmed that there is persistent bacterial pollution in several sections of River Meadow Brook and possibly also at low levels all along the developed sections of the brook. As part of the study, OARS conducted bacterial source tracking, environmental DNA analysis, and detergent indication surveys. Please see our white paper “OARS River Meadow Brook Bacteria Monitoring Results – 2022” for a detailed summary of the study (OARS, 2023). Funding for the study was provided by the Greater Lowell Community Foundation.

Figure 60: Graphical view of bacteria vs. rainfall (2021)

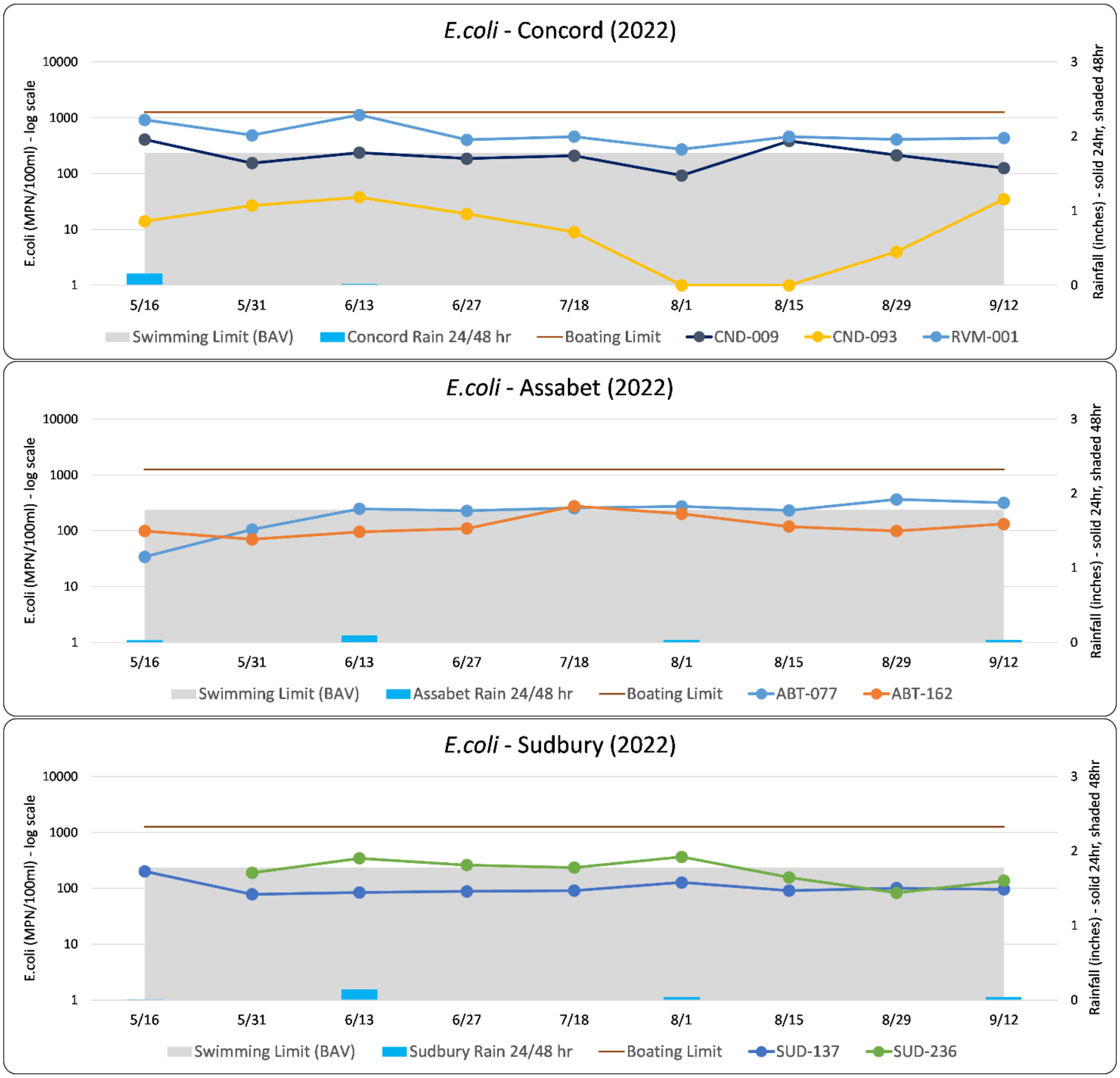
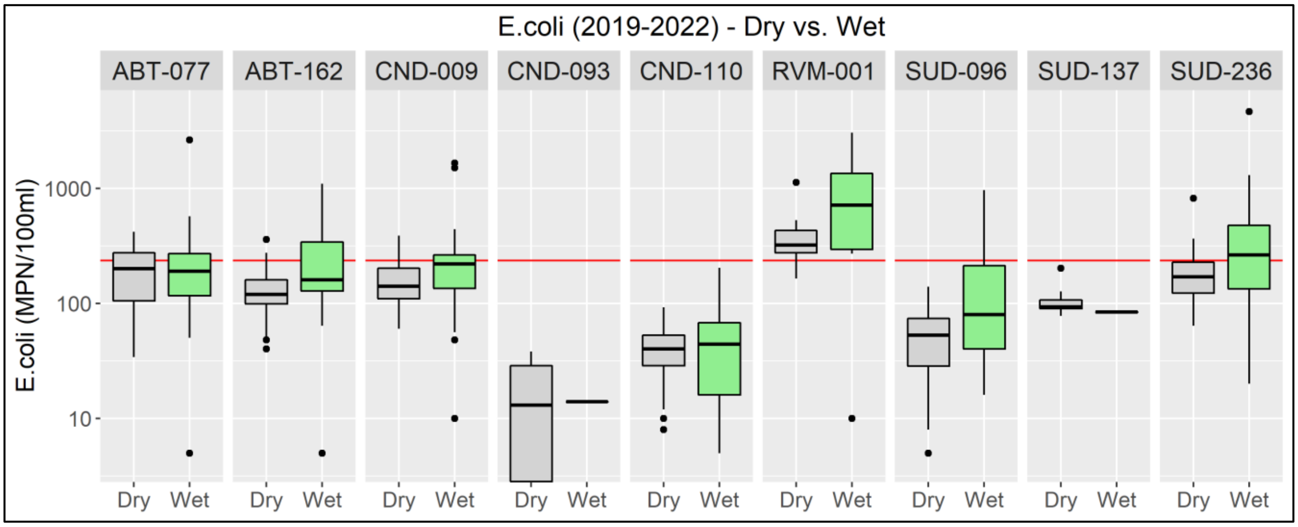


Figure 61: Boxplot analysis of bacteria for wet vs. dry days (2019-2022)



Aquatic Plant Biomass Sampling

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. 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: "A substantial reduction in total biomass of at least 50% from July 1999 values is considered a minimum target for achieving designated uses." (MA DEP, 2004)

Biomass Survey Methods

These surveys have focused on three large impoundments as the most eutrophic areas of the river. Impoundment locations include:

(1) Hudson impoundment, Hudson, about 0.5 miles upstream from the dam at Route 85
(2) Gleasondale impoundment, Stow, about 0.6 miles upstream from the dam near Route 62
(3) Ben Smith impoundment, Maynard, about 0.7 miles upstream from the dam near Route 62/117.

The impoundments are divided into observation grids, based on the grid system originally developed by USGS for MassDEP duckweed monitoring in 2007 (Zimmerman et al., 2011). Using this method, visual observations are conducted by OARS staff from a kayak or canoe at the peak of the growing season each summer. Observations are recorded in the field using hand-held GIS/GPS devices. At each grid cell the following observations are recorded:

- visual assessments of…
  - total percent coverage of floating plants
  - percent coverage of duckweed (*Lemna minor*) ignoring the other floating plants
  - percent volume of the grid's water column filled with submerged plants
- dominant and other species in each category (floating, submerged)
- presence of invasive species

To compare conditions between years and between impoundments, total wet weight of the floating plant biomass is calculated for each impoundment. Field estimates of total floating plant cover are converted to consistent classes (0 = 0% coverage, 1 = 1–25% coverage, 2 = 25–50% coverage, 3 = 50–75% coverage, 4 = 75–99% coverage, 5 = 100% coverage). The total grid surface area (from GIS) for each class is summed for each impoundment, and total floating biomass wet weight is calculated using conversion factors developed by OARS: 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. *Caveat: These conversion factors were developed on a local mixture of floating and rooted aquatic plants, so biomass is relative (i.e. comparable within this analysis but not with analyses done in other water bodies).*

This survey is subjective, depending on estimates by the surveyor. The OARS aquatic scientist conducting the survey changed between 2018 and 2019. Note that starting in 2020, the survey was conducted on the central areas of the impoundments only. Edges were excluded to increase efficiency and in the belief that the real objective of the survey should be biomass in the central portion of the impoundments, not biomass that has collected or grown along the shore. Also, the edge sectors, as drawn, included large portions of exposed land, so percent coverage was somewhat misleading. All years have been adjusted accordingly.

Biomass Results

The calculated wet weight of total floating biomass for the Hudson, Gleasondale, and Ben Smith impoundments from 2005 to 2022 is shown in Figure 62. Trend lines for each impoundment are drawn in the graph, showing a continuing significant upward trend in biomass for Hudson and minimal to zero trend for Gleasondale and Ben Smith. The year 2022 was characterized by severe drought and very warm temperatures. It was one of the three driest years since these surveys began, and average temperature was higher than any year since the surveys began. The three impoundments reacted quite differently to the extreme conditions. The Hudson impoundment was more than 60% covered on average with filamentous green algae (FGA). The Gleasondale impoundment also had much more floating biomass than previous years, more than it has ever had in these surveys, but it was not dominated by a single species. The Ben Smith impoundment had much less floating biomass than previous years. We have not found a good explanation for why Ben Smith's biomass was so low.

A similar analysis of duckweed does not show any noticeable trends, though the lack of duckweed this year in Ben Smith is noticeable. Low levels in Ben Smith in 2021 were attributed to the high rainfall, but there is no clear explanation for 2022 (Figure 63).

Because aquatic plant growth is strongly affected by precipitation and temperature, correlation coefficients have been calculated between biomass and temperature and biomass and rainfall (Table 11). All three impoundments show some inverse correlation with rainfall, especially Ben Smith. There is usually 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 2022" for a detailed summary of biomass results (OARS, 2022d).

Figure 62: Total floating aquatic plant biomass (2005-2022)

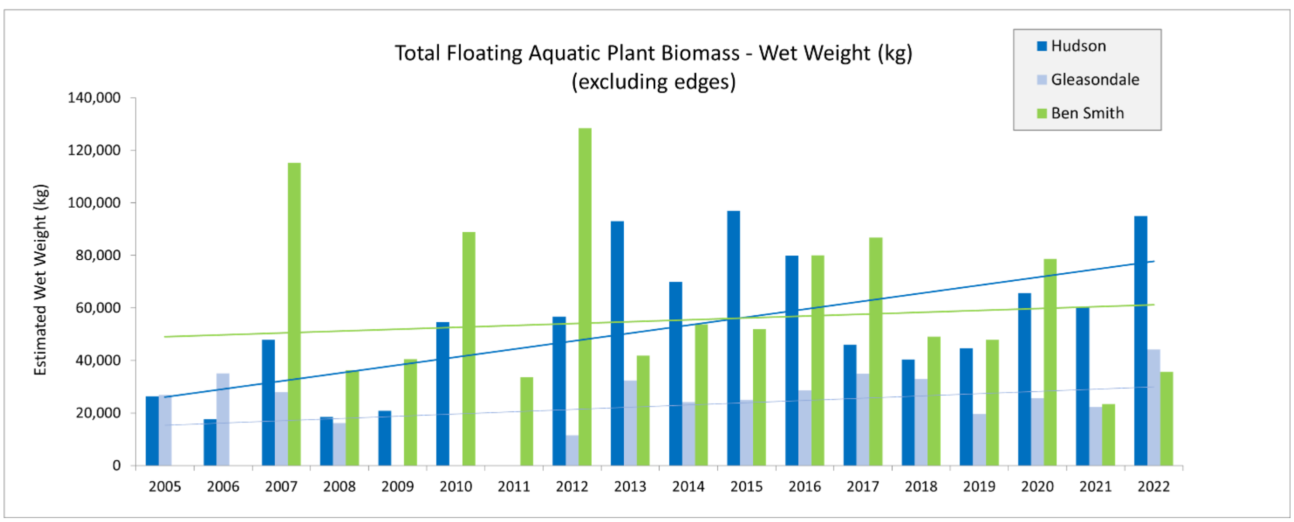


Figure 63: Total duckweed coverage (2007-2022)

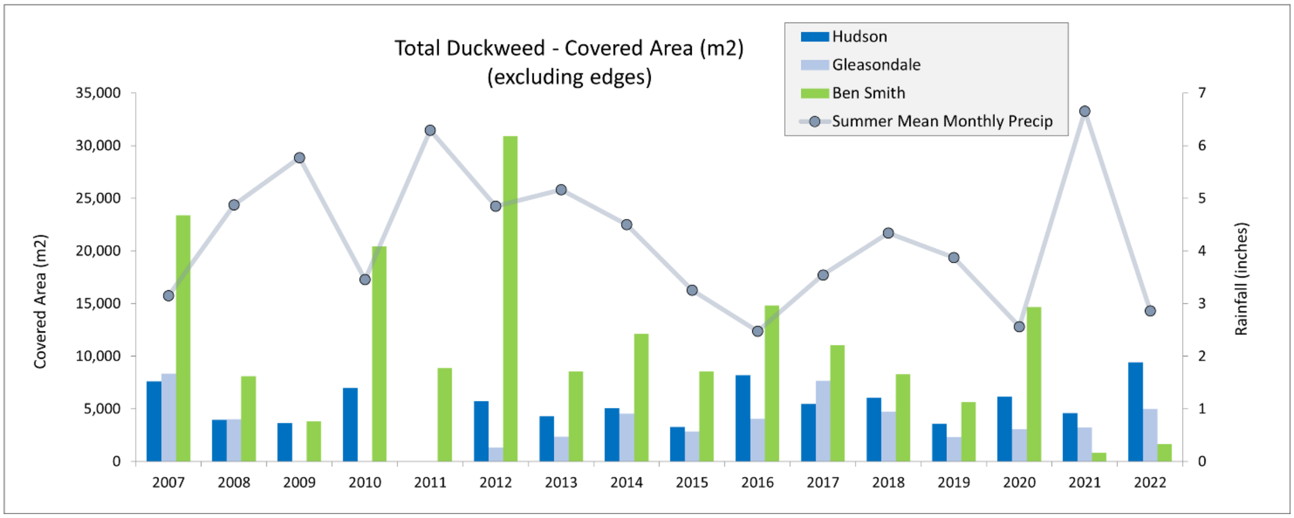


Table 11: Pearson Correlation Coefficients – Total Biomass vs Temperature and Rainfall

Pearson Corr.	Hudson	Gleasondale	Ben Smith
Temperature	0.49	0.03	0.14
Precipitation	-0.35	-0.30	-0.48

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Appendix I Mainstem Reach and Tributary Statistics

2022 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 20, 2022	Concord	1	9.8	101	11.5	546	7.0	4.0	0.020	0.005	0.43			
	Lower Assabet	2	9.9	97	10.9	510	7.0	2.5	0.025	0.005	0.77	0.05		
	Upper Assabet	1	9.1	89	10.3	541	7.0	2.0	0.050	0.030		0.05		
	Lower Sudbury	2	9.1	99	11.4	553	7.1	2.5	0.010	0.005	0.24			
	Upper Sudbury	1	9.2	63	7.1	455	6.6	3.0	0.010	0.005		0.05		
May 15, 2022	Concord	1	21.3	97	8.5	566	7.1	5.0	0.050	0.005	0.37			
	Lower Assabet	2	22.2	90	7.8	601	7.2	5.0	0.045	0.005	0.94	0.05		
	Upper Assabet	1	19.8	76	6.9	711	7.0	3.0	0.040	0.005		0.05		
	Lower Sudbury	5	22.2	75	6.5	561	7.0	11.0	0.048	0.005	0.03			
	Upper Sudbury	1	21.7	33	2.9	504	6.4	5.0	0.060	0.010		0.05		
June 12, 2022	Concord	3	22.1	90	7.8	602	7.2	15.3	0.040	0.017	0.75	0.10		
	Lower Assabet	3	21.2	95	8.4	570	7.2	4.3	0.043	0.020	1.22	0.08		
	Upper Assabet	3	19.4	88	8.1	681	7.1	2.3	0.037	0.015	2.59	0.05		
	Lower Sudbury	5	21.3	65	5.9	556	6.9	5.2	0.038	0.015	0.11			6.0
	Upper Sudbury	2	19.3	66	6.1	560	6.7	3.5	0.050	0.015	0.10	0.05		
July 17, 2022	Concord	3	26.1	89	7.2	750	7.4	8.3	0.047	0.005	1.13	0.13		
	Lower Assabet	3	24.7	93	7.7	832	7.9	1.3	0.030	0.005	0.94	0.05		
	Upper Assabet	3	22.3	82	7.0	1352	7.4	2.5	0.043	0.007	7.33	0.05		
	Lower Sudbury	5	25.1	73	6.0	678	7.1	11.4	0.052	0.015	0.12			14.0
	Upper Sudbury	2	22.9	57	4.8	735	6.8	2.5	0.025	0.005	0.13	0.05		

2022 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 14, 2022	Concord	3	24.3	96	8.0	883	7.6	5.7	0.043	0.005	2.77	0.14		
	Lower Assabet	3	22.1	90	7.9	1107	7.7	1.2	0.027	0.005	1.47	0.08		
	Upper Assabet	3	21.1	74	6.5	1621	7.3	3.8	0.030	0.005	8.18	0.09		
	Lower Sudbury	5	22.6	66	5.7	730	7.2	13.6	0.056	0.012	0.11			18.0
	Upper Sudbury	2	20.0	51	4.6	858	6.9	11.5	0.035	0.008	0.05	0.05		
September 11, 2022	Concord	1	22.1	96	8.3	888	7.3	6.0	0.020	0.005	1.51			
	Lower Assabet	2	20.7	88	7.9	736	7.2	0.8	0.020	0.005	1.14	0.05		
	Upper Assabet	1	20.9	80	7.1	3531	7.3	4.0	0.030	0.020		0.05		
	Lower Sudbury	5	21.1	66	5.8	613	6.7	10.8	0.040	0.016	0.14			
	Upper Sudbury	1	18.6	33	3.0	641	6.0	2.0	0.050	0.030		0.05		
November 13, 2022	Concord	1	13.8	93	9.6	730	7.2	6.0	0.050	0.005	1.12			
	Lower Assabet	2	13.5	93	9.7	841	7.2	4.0	0.030	0.005	1.35	0.05		
	Upper Assabet	1	14.5	79	8.0	1038	7.2	2.0	0.050	0.020		0.05		
	Lower Sudbury	2	14.0	93	9.5	582	7.2	5.0	0.040	0.013	0.12			
	Upper Sudbury	1	12.9	40	4.3	562	6.4	3.0	0.060	0.030		0.05		

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' Quality Control Report on request.

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	0.1	-	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	-
Gage	ft	-	-	all	<= 0.01	-	-	-	-
Nitrate	mg/l	0.05	-	all	< 30%	< 20%	BDL	BDL	<= 15%
Ortho P	mg/l	0.01	-	< 0.05	<= 0.01	<= 0.01	BDL	BDL	<= 0.01
Ortho P	mg/l	0.01	-	>= 0.05	< 20%	< 20%	BDL	BDL	<= 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	<= 0.01
TP	mg/l	0.01	-	>= 0.05	< 30%	< 20%	BDL	BDL	<= 15%
TSS	mg/l	1	-	<= 3	<= 1	<= 1	BDL	BDL	-
TSS	mg/l	1	-	> 3	< 30%	< 20%	BDL	BDL	-
Water Temp	deg C	-	-	all	<= 1.0	<= 1.0	-	-	<= 1.0

Data Qualifiers

Data qualifiers	Description
NA	not sampled
P	provisional data (QA/QC not yet performed)
Q	data met most but not all QA/QC requirements
NR	data censored and not reported

Summary of qualified and censored data:

Parameter	Number of Data Records	Number of Qualified Records	% Completeness	Hit/ Miss	Number of Censored Records	Notes
Air Temp	159	3	98%			Qualified ABT-077 3/20/22 (unusually high), SUD-236 7/17/22 (unusually high), SUD-064 6/12/22 (sampler noticed air pocket in thermometer)
Ammonia	91	1	99%			Qualified RVM-005 6/12/22 (field duplicate miss and noted particulate matter in sample)
Chl a	18	2	89%	MISS		Qualified the two samples with field duplicate misses, but the DQO may not be realistic for chlorophyll a. It is easily affected by particulate matter.
DO	141	1	99%			Qualified HBS-098 8/14/22 because conductivity probe was out of water, but other probe readings seemed to be okay.
DO saturation	141	1	99%			See DO
E.coli	62	0	100%			
Gage	67	2	97%			Qualified NSH-002 3/20/22 (sampler had trouble reading gage), HOP-011 5/15/22 (sampler wrote 44 but believes they meant 4.40)
Nitrate	60	0	100%			
Ortho P	140	1	99%			Qualified NSH-047 6/12/22 (high value and noticed particulate matter in sample)
pH	141	1	99%			Qualified HBS-098 8/14/22 because conductivity probe was out of water, but other probe readings seemed to be okay.
Sp Conductance	140	0	100%		1	Censored HBS-098 8/14/22 – meter out of water.
TP	140	6	96%			Qualified all Middle Assabet sites 7/17/22 (ABT-077, ABT-144, ABT-237, DAN-013, ELZ-004, HBS-098) because TP and TSS field duplicates missed DQO, but all values were low.
TSS	140	6	96%			Qualified all Middle Assabet sites 7/17/22 (ABT-077, ABT-144, ABT-237, DAN-013, ELZ-004, HBS-098) because TP and TSS field duplicates missed DQO, but all values were low.
Water Temp	203	2	99%			Qualified RVM-001 7/18/22 (hard to read sampler's writing). Qualified HBS-098 8/14/22 because conductivity probe was out of water, but other probe readings seemed to be okay.
Flow	56	7	88%			Qualified all flow calculations for NSH-002 because the stage-discharge curve is out of calibration by 30-50%.

Appendix III Water Quality Data

(contact OARS for full data set)

Appendix IV Aquatic Plant Biomass Survey Data 2005 - 2022

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
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
Gleasondale Impoundment	2005	17488	0	2056	0	539	6062
	2006	11364	3967	1594	0	3667	5554
	2007	0	15481	3918	2907	3839	0
	2008	1775	20295	2307	614	851	304
	2009	nr	nr	nr	nr	nr	nr

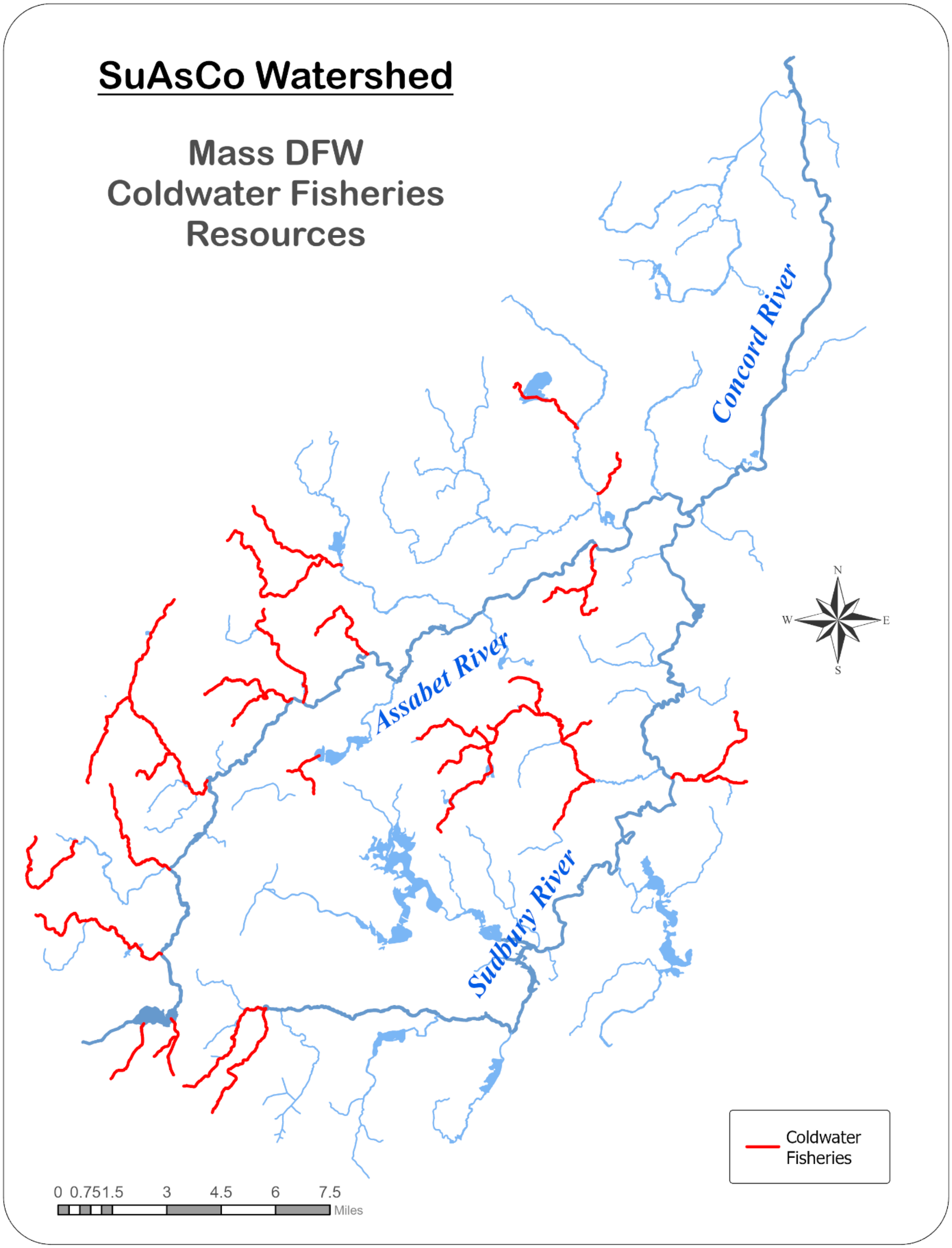
Section	Year	Class 0 Area (m^2) No floating biomass	Class 1 Area (m^2) 1-25% cover	Class 2 Area (m^2) 26-50% cover	Class 3 Area (m^2) 51-75% cover	Class 4 Area (m^2) 76-99% cover	Class 5 Area (m^2) 100% cover
	2010	nr	nr	nr	nr	nr	nr
	2011	nr	nr	nr	nr	nr	nr
	2012	18909	3346	1611	0	509	1770
	2013	8913	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

* 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 (MA DFW, 2017). 34 Streams. *Note that MA DEP identifies 27 tributary streams as CFRs in its Sustainable Water Management Initiative viewer (MA DEP, 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
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 (1) (Nourse Brook)	8247627
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
NT to Nashoba Brook	8246876
UNT to North Brook	8247435
UNT to Pine Brook	8247965
UNT to Second Division Brook	8247076
UNT (Nourse Brook)	8248530
Wrack Meadow Brook	8247440