SACO RIVER CORRIDOR COMMISSION 2020 WATER QUALITY ANALYSIS

DECEMBER 2021

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2020 WATER QUALITY ANALYSIS

Prepared by FB Environmental Associates for the Saco River Corridor Commission

Support provided by the Maine Outdoor Heritage Foundation

FINAL REPORT

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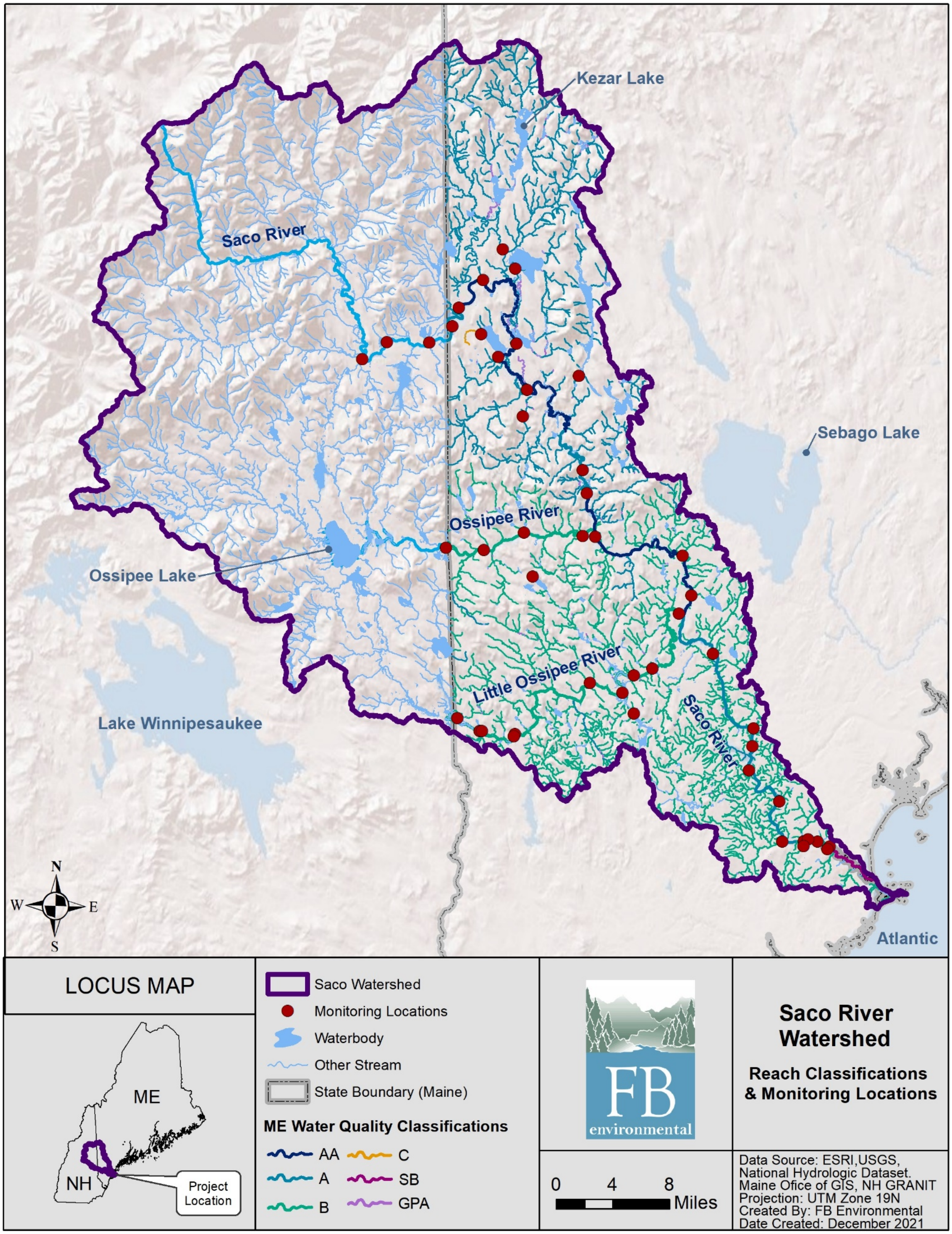
Kezar Lake
Saco River
Sebago Lake
Ossipee River
Ossipee Lake
Little Ossipee River
Saco River
Lake Winnipesaukee
Atlantic
N
W
E
S
LOCUS MAP
ME
NH
Project Location
Saco Watershed
Monitoring Locations
Waterbody
Other Stream
State Boundary (Maine)
ME Water Quality Classifications
AA
A
B
C
SB
GPA
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0
4
8
Miles
Saco River Watershed
Reach Classifications & Monitoring Locations
Data Source: ESRI,USGS, National Hydrologic Dataset, Maine Office of GIS, NH GRANIT
Projection: UTM Zone 19N
Created By: FB Environmental
Date Created: December 2021

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INTRODUCTION

The Saco River flows from its headwaters in the White Mountains of New Hampshire to the Gulf of Maine where it empties into the Saco River estuary at Saco and Biddeford, Maine. Along the 136-mile journey from source to sea, the Saco flows past forested landscapes, agricultural areas, village centers, and urban areas, draining a watershed of over 1,700 square miles – an area larger than Rhode Island. The Saco's waters support diverse aquatic ecosystems and provide innumerable opportunities for fishing, boating, wildlife viewing, and other recreational and educational activities to local communities and visitors. The Saco's high-quality waters are also drawn on by Saco, Biddeford, and other communities as their public source of drinking water.


View from one of the SRCC monitoring sites along the Saco River during the winter. (Photo: SRCC)

The Saco River's water quality, or the ability of the Saco's waters to support healthy aquatic ecosystems and human uses such as drinking and recreation, is protected at the federal level by the Clean Water Act, and by state law in New Hampshire and Maine. State agencies, principally the New Hampshire Department of Environmental Services (NHDES) and the Maine Department of Environmental Protection (MEDEP), are responsible for writing and enforcing regulations that carry out the law, and collectively make up a framework for designated uses of the river and managing activities on the landscape that could have the potential to contaminate the Saco. In practice, a great deal of authority and responsibility falls to the local level, and effective conservation and protection depend heavily on leadership from local and regional communities and organizations.

The Saco River Corridor Commission (SRCC) is a quasi-state agency that regulates land use in the land corridor on either side of the Saco, Ossipee, and Little Ossipee Rivers and functions much like a regional planning board with land use permitting authority. The Commission writes and enforces regulations specific to the needs of the Saco River Corridor and designates districts (Resource Protection, Limited Residential, and General Development) according to appropriate land uses for that specific area. Each of the riverfront municipalities is represented by two commissioners. The purpose of the SRCC is summarized in the agency's mission statement, as follows:

> *"The Saco River Corridor Commission is committed to protecting public health and safety and the quality of life for the state of Maine. The commission regulates land and water uses, protects and conserves the region's unique and exceptional natural resources, and prevents the detrimental impacts of incompatible development."*

In addition to its regulatory role, the SRCC is also the lead organization carrying out a water quality monitoring program over several decades. The SRCC originally established the monitoring program in July 2001, and the program was significantly restructured in 2009 with changes to the site selection and frequency with which chemical parameters were analyzed by a laboratory.

Water quality monitoring is the essential tool for understanding the functions and values provided by a water body, and how they might change in response to natural and human disturbances and impacts. Monitoring of water quality data through sampling and collection of field measurements provides a snapshot of water quality parameters that indicate the Saco River's ability to support designated uses at any given time. In addition, baseline water quality data collection over decades allows scientists to detect small changes and greatly aids in determining the cause of these changes.

The SRCC monitoring effort is in direct collaboration with the Green Mountain Conservation Group (GMCG) through a shared Quality Assurance Project Plan (QAPP) that spans one watershed, two states, and twenty-six towns. With over fifteen years of monitoring data at many sites, the SRCC has sufficient data to assess long-term trends in water quality across the Saco River watershed and make educated watershed management decisions based on the assessments outlined in this report. The intended use of these analyses will be to establish a baseline from which to assess future changes in water quality as a result of human disturbance or climate change.

Water Quality Monitoring Program History

The SRCC collaborates with the Green Mountain Conservation Group, headquartered in Effingham, New Hampshire, to administer the Regional Interstate Volunteers for the Ecosystems and Rivers of Saco (RIVERS) Water Quality Monitoring (WQM) program. The goal of the RIVERS WQM program is to capture water quality data as a reference for assessing future water quality and to help preserve the high-quality surface and groundwater resources of the Saco River basin.

Volunteers help ensure the success of long-term monitoring in the Saco River Watershed (Photo: SRCC).

Over the past twenty years, SRCC volunteers have collected field parameter measurements such as pH, conductivity, and dissolved oxygen, from a selection of over 50 stations. Volunteers have also collected grab samples that have been analyzed for a variety of water quality parameters. The SRCC makes these data available to municipalities and the MEDEP for use in water quality management. The SRCC monitoring program collects surface water quality data from May to September with field meters and grab samples at sites along the Saco River, the Ossipee River, the Little Ossipee River, and several smaller tributaries and ponds. In 2019, the SRCC monitored 34 sample sites within the Saco River Corridor. The SRCC is currently in the process of expanding the program by increasing sample sites and frequency. The farthest upstream site is in Conway, New Hampshire at Davis Park just downstream of the Saco/Swift River confluence, and the farthest downstream site is in Biddeford, Maine in the tidally influenced segment of the Saco before it empties into the Gulf of Maine.

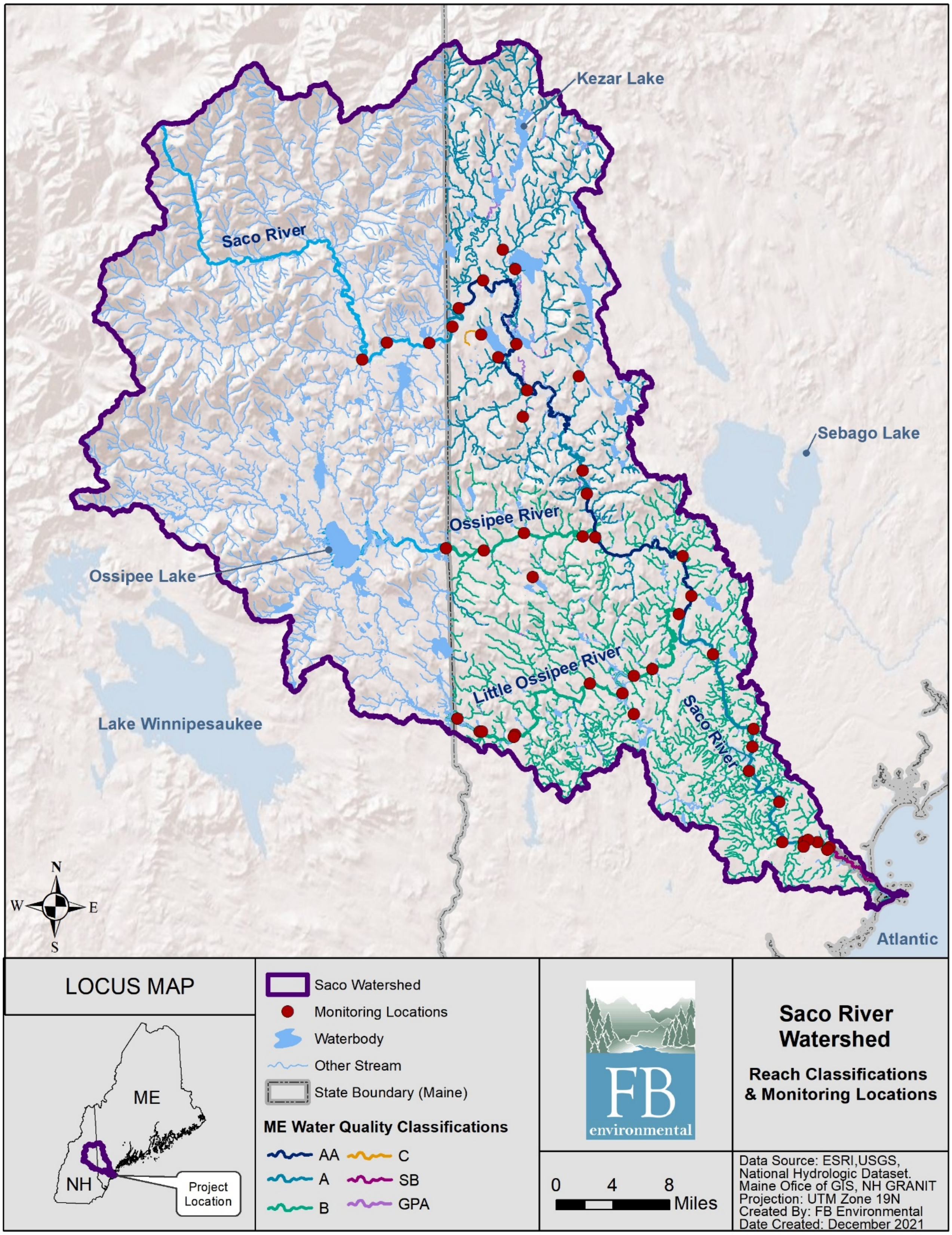


Figure 1. Map of Maine water quality classifications and SRCC monitoring locations within the Saco River watershed.

Defining Water Quality Standards and Thresholds

How are regulators, public officials, and clean water professionals to know what constitutes "good" or "bad" water quality? The approach used for the last 50 years at all levels of government in the United States is to implement standards by which to judge whether a given water body possesses good/desirable or bad/undesirable water quality. Standards begin with the definition of "designated uses" – the ways water is used by humans and wildlife, such as for drinking water and fish habitat. If water supports a beneficial use, water quality is said to be "good" or "unimpaired." If water does not support a designated use, water quality is said to be "poor" or "impaired." Good water quality implies that contaminants (whether derived from human activity or naturally) are absent or at trace levels in the water, and the needed physical or chemical constituents (e.g., dissolved oxygen) are present. To determine whether a designated use is supported, water quality "criteria"– numerical values of important water quality parameters such as dissolved oxygen, temperature, nitrogen concentration – are set according to the best scientific information on how that use might be impaired if a given water quality parameter was exceeded or fallen below.

Tributary to the Saco River. (Photo: SRCC)

All Maine surface waters must meet minimum standards according to the federal Clean Water Act's fishable-swimmable requirement, or otherwise be considered impaired and subject to legally mandated cleanup actions. In Maine, some waters are held to higher standards determined by their "classification" – a system of defining the water quality goals of the State for each waterbody. Maine sets water quality standards for different biological, physical, and chemical attributes based on classification, which all waters must meet to support their designated beneficial uses. The freshwater classes are AA (highest), A, B, and C. Nearly the entirety of the Saco River drainage in Maine – the Saco and its tributaries – is Class B or higher, with several stretches designated Class AA. Notably, a stream that empties into an estuary may be classified with a freshwater classification (i.e., AA through C) for its freshwater portion and a classification for its estuarine or marine waters, of which there are three in Maine: SA, SB, and SC.

Water quality standards serve as a yardstick for identifying water quality exceedances and for determining the effectiveness of state regulatory pollution control and prevention programs designed to protect beneficial uses. To determine if a waterbody is meeting its designated beneficial uses, water quality standards for various water quality parameters (such as total phosphorus, dissolved oxygen, pH, and turbidity) are applied to water quality data. If a waterbody meets or is better than the water quality standard, the designated use is supported. If a waterbody does not meet the water quality standard, it is considered impaired for the designated use. It is helpful to point out that the standards are based on upper limits for all water quality parameters except dissolved oxygen, which has lower limits. In other words, decreasing values in dissolved oxygen indicates a deteriorating trend compared with all other parameters where increasing values indicate water quality deterioration.

For some water quality parameters, no standard or criteria has been set by the State (e.g. total phosphorus or TP). For these parameters, FBE has assembled clean water "thresholds" that should be considered comparative guidelines for good quality water. Table 1 lists and describes key water quality parameters collected and analyzed by the SRCC, along with their applicable water quality standard or threshold.

Table 1. Descriptions of key water quality parameters and their importance, and relevant state standards, thresholds, or indicators (continues on next page).

Parameter	Definition	Importance as a Water Quality Parameter	ME Water Quality Standard	NH Water Quality Standards / Natural Background Levels from Literature
pH	Measure of acidity in terms of hydrogen ion concentration in water (ranges from 0 to 14 with 7 being neutral)	Affects chemical and biological processes; organisms function under optimal range	Must occur between 6.5 and 8.5	Background levels as low as 6.0 due to acid rain and low buffering capacity of underlying geology
Water Temperature	Measure of the degree of heat in a waterbody	Regulates metabolic rates of organisms and growth of aquatic plants; influences amount of dissolved gases	No quantitative standard	Coldwater fish species thrive under maximum weekly and instantaneous temperatures of 19° and 24° C, respectively
Turbidity	Measure of the amount of suspended material in water, such as clay, silt, algae, sediment, and decaying plant material	Indicator of soil erosion, particularly during rain events; high turbidity clogs fish gills and covers stream bottom habitats	No quantitative standard	NH Class A= 0 NTU, NH Class B<10 NTU | Natural background level = 1.0 NTU
Specific Conductivity	Measure of the electrical current in water normalized to a water temperature of 25° C; surrogate measure for chemical ions in water	Indicator of pollution from road salting, septic systems, and stormwater runoff	No quantitative standard	Background level less than 100 µS/cm, above which is likely a result of human disturbance
Dissolved Oxygen (DO)	Measure of the concentration or percent saturation of dissolved oxygen in water	Facilitates critical chemical reactions within the channel and benthic sediments that support life processes and functions	ME Class A: Shall not fall below 7 mg/l or 75% saturation	Low dissolved oxygen can occur naturally in slow-moving waters or waterbodies located downstream of wetlands

Parameter	Definition	Importance as a Water Quality Parameter	ME Water Quality Standard	NH Water Quality Standards / Natural Background Levels from Literature
Total Phosphorus (TP)	Measure of all dissolved phosphorus (i.e. organic and inorganic) as well as phosphorus contained in or adhered to suspended particles, such as sediment and plankton	Indicator of eutrophication likely due to human disturbance	No quantitative standard	Eutrophication threshold > 40 µg/L
Phosphate (PO_4^{3-})	Measure of the inorganic component of total phosphorus	Indicator of eutrophication likely as a result of human disturbance; serves as an essential nutrient for growth; most biologically available form	No quantitative standard	Eutrophication threshold > 40 µg/L
Total Kjeldahl Nitrogen (TKN)	Measure of a component of inorganic nitrogen in water; product of ammonium nitrification under oxidizing conditions	Indicator of eutrophication likely as a result of human disturbance; serves as an essential nutrient for growth	No quantitative standard	Eutrophication threshold > 0.45 mg/l
E. coli	Measure of bacteria common to the intestines of humans and many mammal and bird species.	Indicator of contamination from fecal waste (human, dog, wildlife).	ME Class A & AA: 90-day geo mean< 64 CFU/100mL	NH Class A: 60-day geo mean<47 CFU/100mL | Background level less than 20 MPN/100mL
Enterococcus	Measure of bacteria, similar to *E. coli*, but more representative in marine or brackish waters.	Indicator of contamination from fecal waste (human, dog, wildlife).	ME Class SA & SB waters: 90-day geo mean< 8 CFU/100mL	NH tidal waters: 60-day geo mean<35 CFU/100mL

WATER QUALITY ANALYSIS METHODS

The development of this water quality analysis was composed of four key components:

1. Watershed description using GIS mapping
2. Compilation of precipitation and streamflow (aka discharge) data from online sources
3. Database management such as outlier identification, verification (using field data sheets or original lab reports), and removal if necessary
4. Data analysis in the form of summary statistics, data visualization, and trend analysis

In the subsections below, each of these components is described in detail.

Watershed Description

The Saco River originates in the White Mountains of New Hampshire at Saco Lake in Crawford Notch, and converges with the Ossipee River in Cornish, Maine before emptying into the Atlantic Ocean via Saco Bay in Maine. The Saco River watershed has an area of 1,700 square miles that includes 63 municipalities in New Hampshire and Maine. Elevations in the basin range from 6,288 feet at the summit of Mount Washington in Sargent's Purchase, New Hampshire to sea level at the mouth of the Saco River in Saco and Biddeford, Maine (SMRPC, 1983). The Saco River has seen a dramatic increase in recreation and shoreline development in recent years, and much of the land bordering its surface waters is privately-owned.

There are three major tributaries of the Saco River: the Swift, Ossipee, and Little Ossipee Rivers. The Swift River drains approximately 114 square miles and flows east for 21 miles from Mount Kancamagus in Livermore, New Hampshire to its confluence with the Saco River in Conway, New Hampshire. The Ossipee River originates at the outlet of Ossipee Lake in Effingham Falls, New Hampshire and enters the Saco River in Cornish, Maine 18 miles to the east, draining approximately 455 square miles of land. Beginning at the outlet of Balch Pond in Wakefield and Acton, New Hampshire, the Little Ossipee River flows east until it meets the Saco River in Limington, Maine.

The Saco River watershed contains many significant aquifers in both Maine and New Hampshire, including New Hampshire's largest stratified drift aquifers (the Ossipee and Upper Saco Valley aquifers). This type of aquifer recharges more rapidly than any other aquifer due to its porous and gravel soils deposited by water from melting glaciers, but it also allows pollution and contamination to be carried more rapidly into groundwater supply. In many areas of the Ossipee Aquifer, water can travel more than 2,000 ft^2 per day, depending on the permeability of soils above the aquifer. Because of this, conservation of recharge lands and their surface waters are vital to protecting drinking water supplies. Fortunately, roughly 20% (5,557 acres) of the 27,000 acres of high yield aquifer are already currently protected beneath conservation land in the Ossipee Lake watershed, ensuring high-quality source water for the Ossipee River. Similarly, the headwaters of the Saco and Swift Rivers lie in the White Mountain National Forest, where the US Forest Service manages forestlands in part for source water protection.

For the purposes of this report, the portions of the Saco River and its tributaries covered by the SRCC monitoring program were divided into five large-scale reaches or regions. This division allows for easier visualization of the geography of the river and the SRCC monitoring stations.

Upper Saco River Region

The Upper Saco region consists of the 23 monitoring sites in the Saco River watershed from Conway, New Hampshire to Standish, Maine. The Upper Saco region has 16 river sites and seven lake/pond sites (LWP 1,2,3,4, & 5, MPB22, and BMP1). The portion of the Saco River classified as the Upper Saco region in Maine has water quality classifications of AA and A, the two highest quality classifications. From the New Hampshire-Maine boarder to approximately 1,000 feet below Swan's Falls Dam in Fryeburg, Maine the Saco River is Class A. The Saco River is then classified as Class AA until the impoundment of Hiram Dam in Hiram, Maine where it becomes Class A until 1,000 feet below the dam (Figure 2).

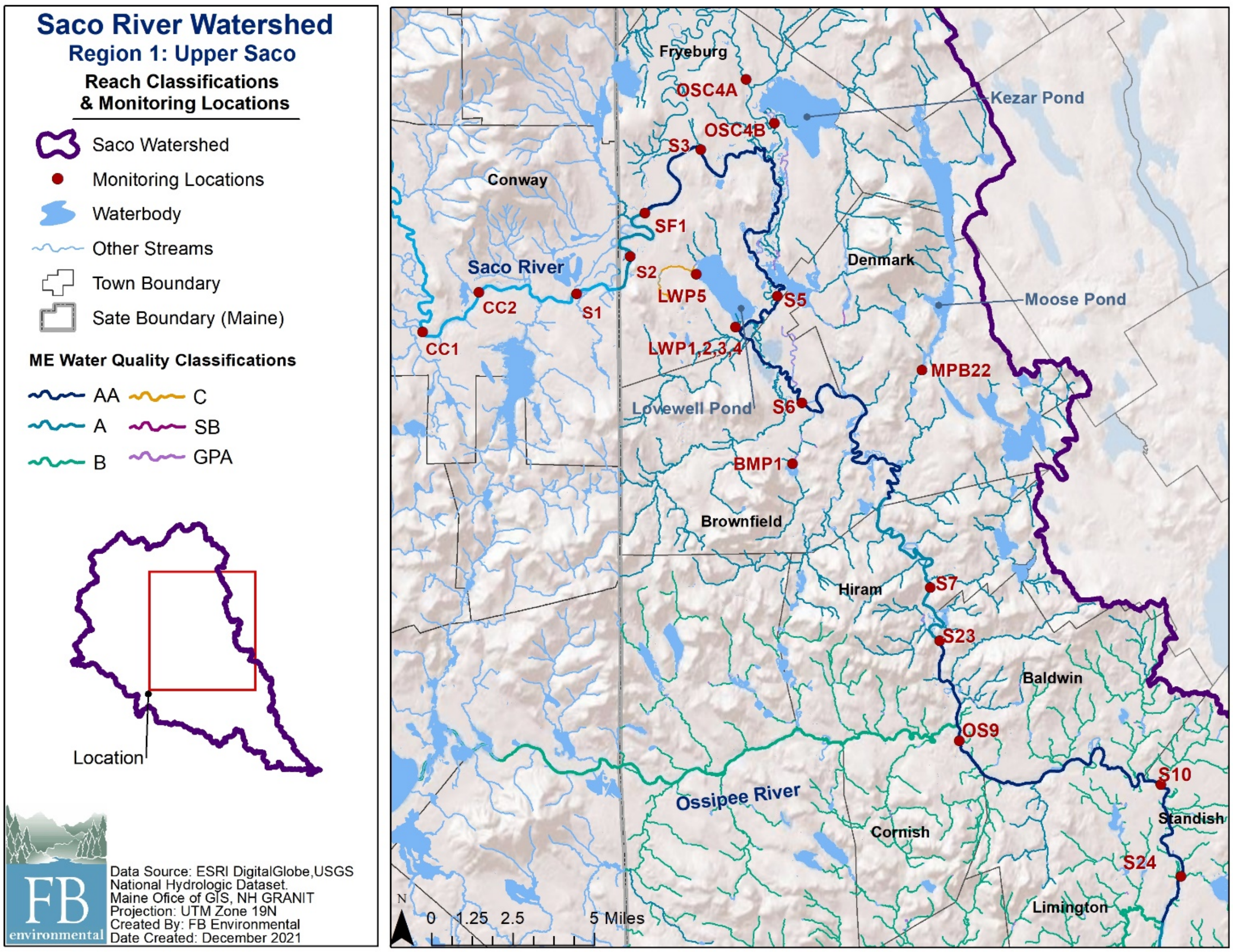


Figure 2. Map of Maine water quality classifications and SRCC monitoring locations along the Saco River in the Upper Saco River region.

Ossipee River Region

The Ossipee River region of the Saco River watershed includes four river monitoring sites. The portion of the Ossipee River and its tributaries that are located in Maine have a water quality classification of B.

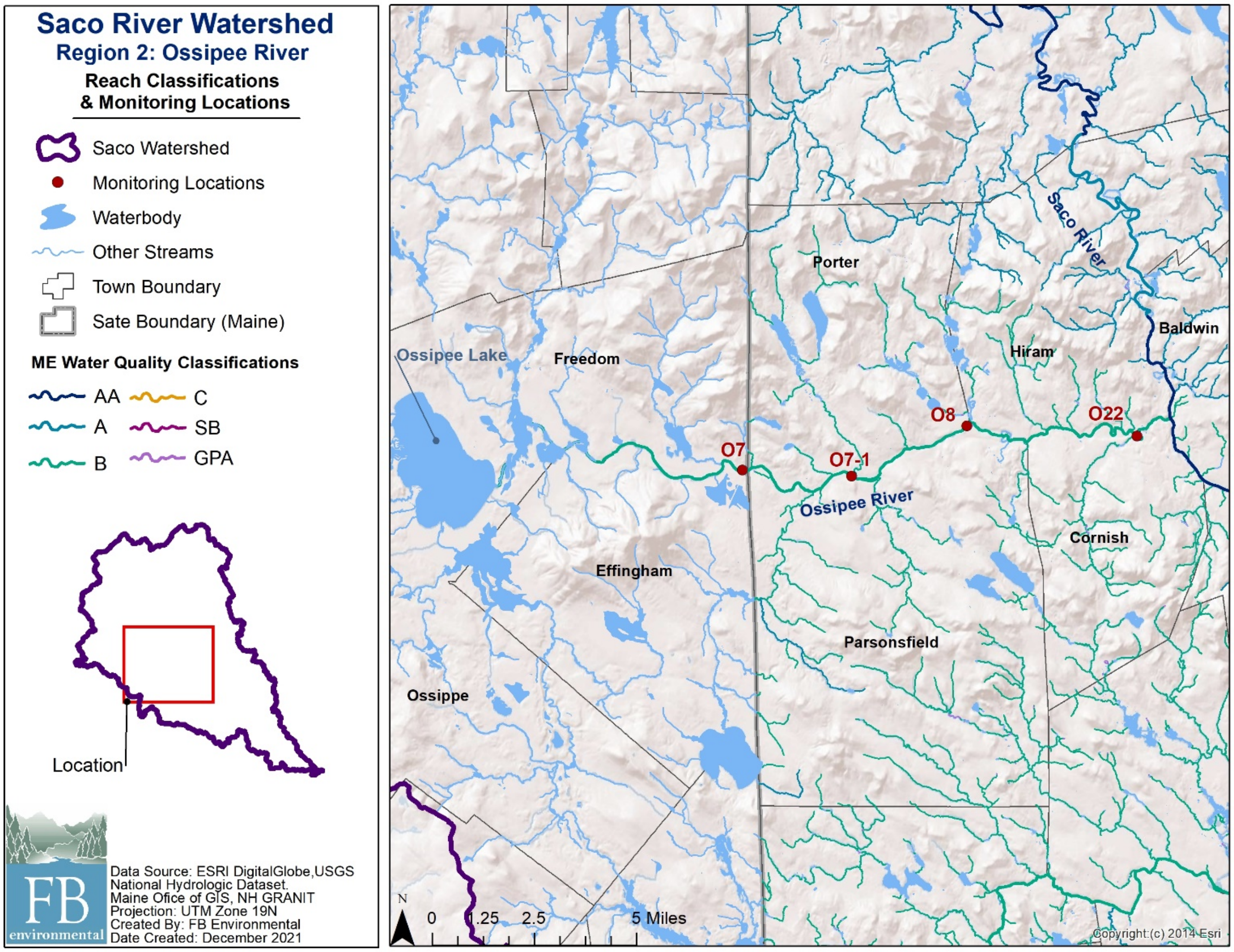


Figure 3. Map of Maine water quality classifications and SRCC monitoring locations along the Ossipee River.

Little Ossipee River Region

The Little Ossipee River region of the Saco River watershed includes 13 monitoring sites, six river sites and 7 lake sites (LO11, LO11-1, SP13-1, LO14, LO14-1, LO25, and LP1). The Little Ossipee River and its tributaries have a Maine water quality classification of B.

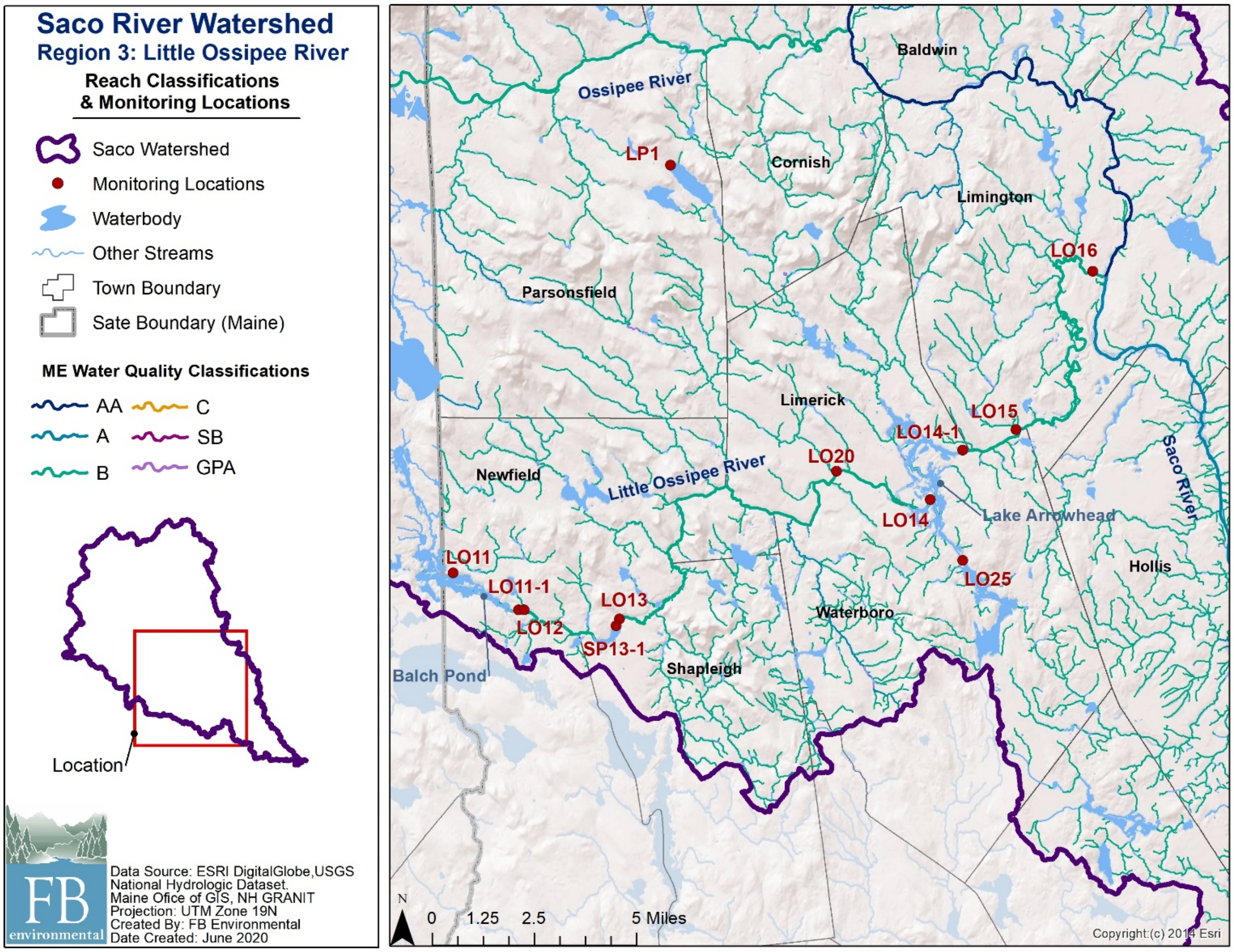


Figure 4. Map of Maine water quality classifications and SRCC monitoring locations within the Little Ossipee River region.

Lower Saco River Region: Freshwater and Tidal

The Lower Saco freshwater portion has seven river monitoring sites and one lake site (S19-A-U). The stretch of the Saco River classified as Region 4, has water quality classifications of A and B. The Saco River is classified as class A from the confluence of the Little Ossipee River down to the I-95 bridge in Biddeford, ME. From the I-95 bridge to tidewater the Saco River is class B.

The Lower Saco tidal portion (Region 5) has two river monitoring sites (S21 and S22) and has a Maine water quality classification of SB.

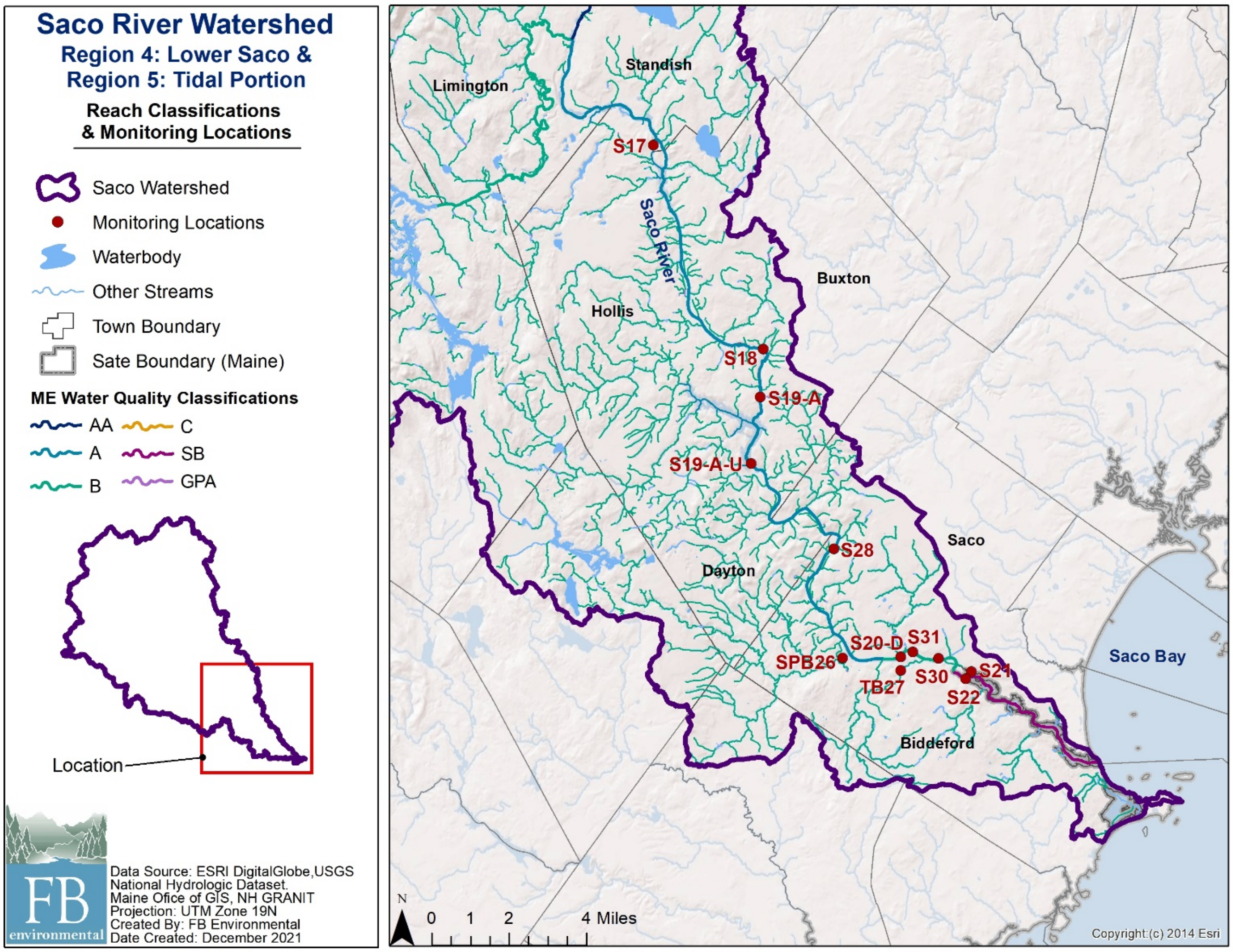


Figure 5. Map of Maine water quality classifications and SRCC monitoring locations along the Saco River within the Lower Saco and Tidal reaches.

Precipitation and Streamflow Data

Rainfall can play a large role in surface water quality by affecting its physical and chemical composition as runoff from the landscape can influence temperature, pH, and nutrient and sediment loading. During dry periods, pollutants accumulate in uplands and are ultimately flushed to receiving waters during storm events. Precipitation data were compiled into annual totals from four stations in the Saco River watershed (Table 2).

Table 2. Summary of total annual precipitation (inches) data from four stations in the Saco River watershed. (Note: precipitation records at the Parsonsfield, ME station began in 2010.)

Year	Parsonsfield, ME	Hollis, ME	Fryeburg, ME	North Conway, NH
	----- Inches -----			
2001	-	37	31	32
2002	-	50	45	40
2003	-	47	51	55
2004	-	42	43	44
2005	-	75	59	66
2006	-	66	57	61
2007	-	55	43	49
2008	-	72	58	65
2009	-	59	56	61
2010	43	59	50	52
2011	45	60	56	56
2012	46	53	48	55
2013	35	45	40	47
2014	52	52	48	49
2015	42	43	44	45
2016	40	45	41	41
2017	47	50	48	51
2018	48	51	41	49
2019	49	53	47	57

Data from the Parsonsfield, Maine (Lat: 43.76687, Long: -70.86572) rain gauge was obtained from the National Centers for Environmental Information (NCEI) for a 10-year period from January 2010 to May 2020. Precipitation data from the Hollis and Fryeburg, Maine and North Conway, New Hampshire rain gages was obtained from NCEI from January 2001 to May 2020. Annual precipitation totals for the selected rain gages are shown in Table 2. On average, the Hollis gage received the greatest annual precipitation while the Parsonsfield gage received the least amount of precipitation annually.

Month-to-month variation in precipitation was considerable in some years, as in October 2005 when record rainfall amounts and flows were documented in many areas of the northeast (Figure 6). These heavy rains and flooding contributed to turbulent waters along many rivers in New Hampshire and caused uprooted trees and scoured shorelines as floodwaters overflowed riverbanks. In May of 2006, New Hampshire received record amounts of rainfall once again, also known as the "Mother's Day Storm," which resulted "in excessive soil erosion and increased nutrient loading to surface waters throughout the State" (NHDES, 2006; Olson, 2007).

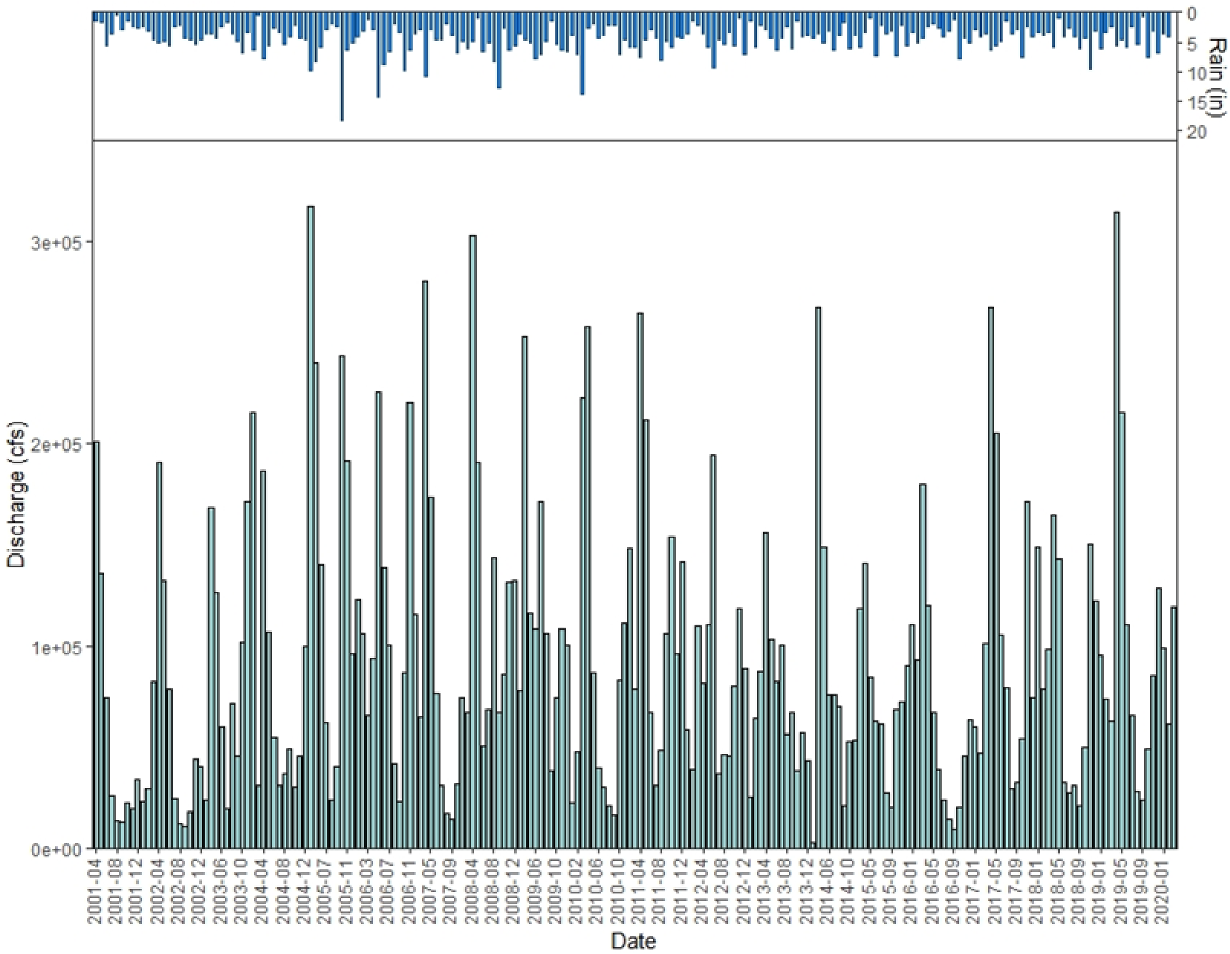


Figure 6. Summary of monthly mean discharge (cfs, bottom panel) and precipitation (inches, top panel) for the period 2001-2020, measured at USGS 01066000 (Saco River at Cornish, Maine).

There are four stream gages located along the Saco River that allow for the measurement of the flow (aka discharge, or the volume of water conveyed in streamflow per unit time, commonly measured in cubic feet per second) within the river channel helping to document severe flooding events. These gages are in the Towns of Bartlett and Conway, New Hampshire and Cornish and Biddeford, Maine. The Biddeford gage is tidal, so only gage height data is available, and discharge is not calculated. The Conway and Cornish gages have data for the extent of the SRCC's monitoring period being evaluated in this report (2001-2019). The Bartlett gage begins in September of 2009 and extends to the end of the monitoring data being evaluated in this report. There are historical stream gages on the Ossipee River located at the Effingham Falls Dam (1942-1990) and in Cornish, Maine (1916-1996). There is a historical gage located near South Limington, Maine (1940-1982) on the Little Ossipee River. However, this period of gage data does not overlap with SRCC water quality data.

Two of the most recent major flooding events to hit the Saco River watershed were Hurricane Irene and an October 2017 (10/30-31/2017) flooding event. The flooding in October of 2017 was a result of a storm on October 24th-27th causing saturated conditions followed by Tropical Storm Phillipe (29th-30th). The peak discharge (48,700 cfs) observed at the USGS gage in Conway during the 2017 storm occurred on October 30th. The peak discharge estimated at the Conway gage during Hurricane Irene occurred on August 28, 2011 and was 58,200 cfs.

Because most measured water quality parameters are presented as concentrations (i.e., mass per volume), discharge is an important consideration when comparing changes in concentration over time. For example, if total phosphorus (TP) shows a decreasing trend over time while flow is increasing, TP is likely being diluted by higher flows. Turbidity can display a positive relationship with discharge, indicating that wet weather mobilizes sediment from the land surface or from the riverbed (Figure 7). Thus, when evaluating water quality, it is important to examine flows and in some cases quantify the impacts that flow may have on water quality.

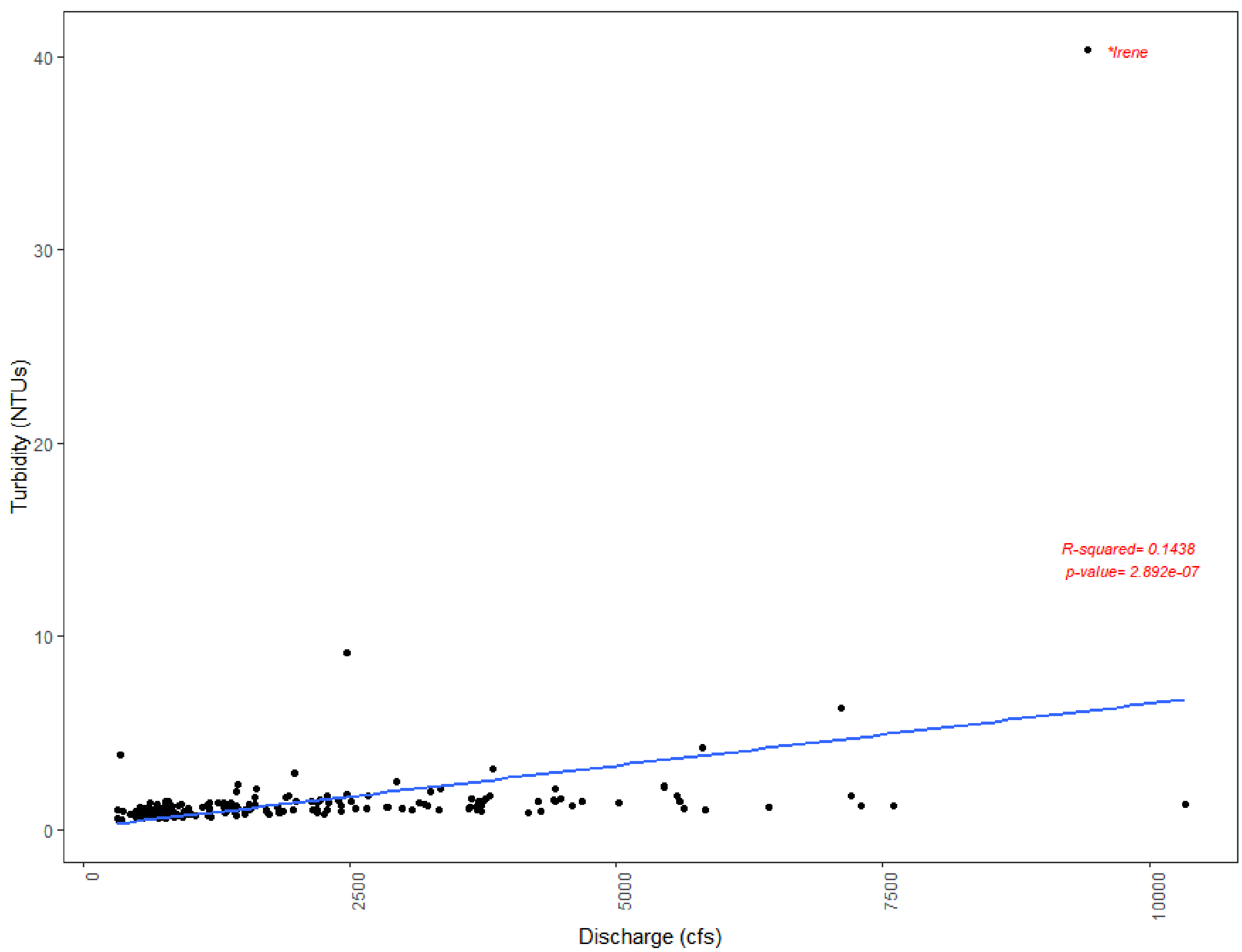
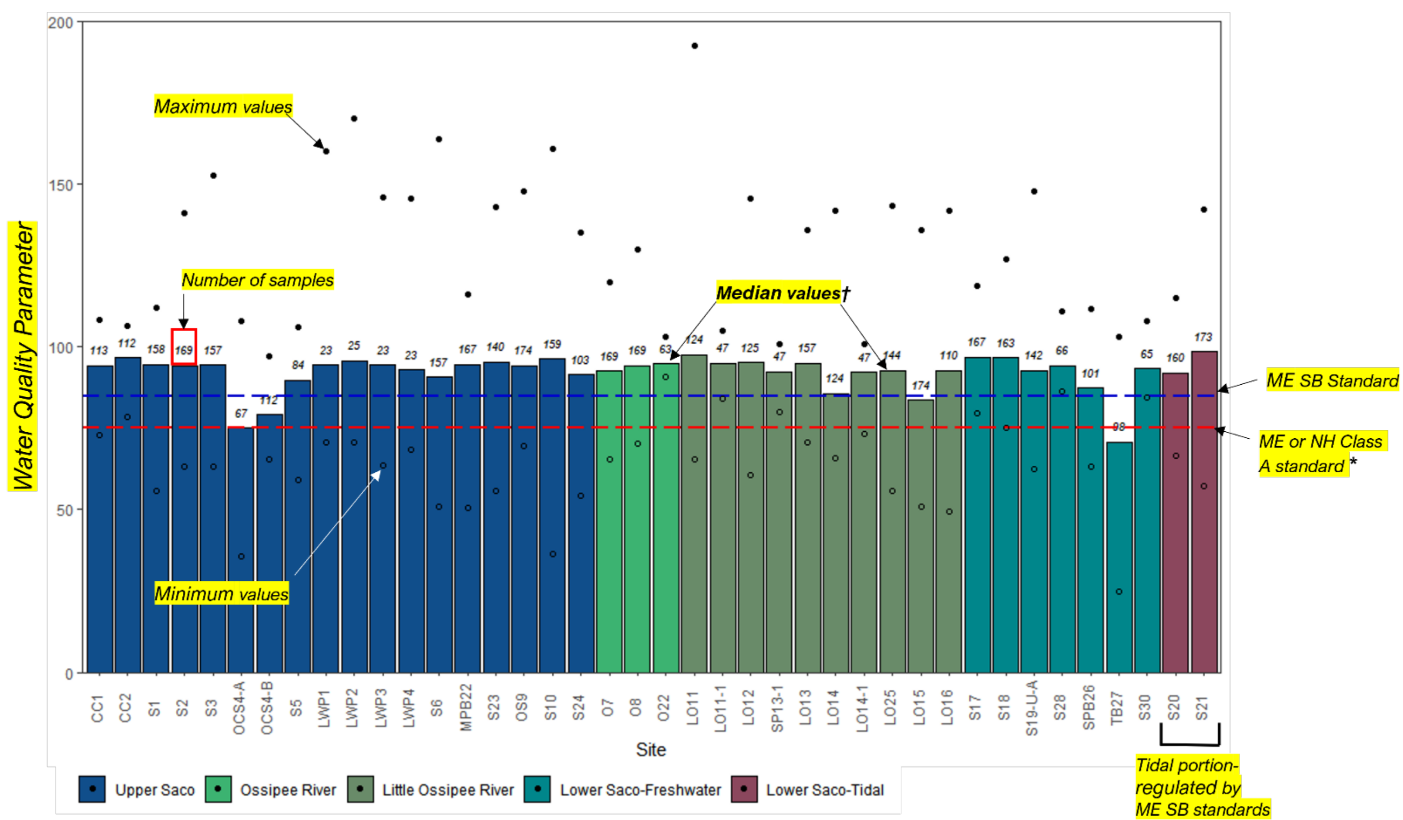


Figure 7. Relationship between turbidity (NTU) and discharge (cubic feet per second) at site OS9, on the Saco River in Cornish, ME. The low p-value ($p > 1x10^{-7}$) indicates the positive relationship

is highly statistically significant. Note the historical outlier (top right) represented by a sample during Hurricane Irene.

Water Quality Summary and Data Analysis

Water quality data from of the 37 RIVERS sites and 15 lake sites were used in the water quality analysis. All water quality data was organized by site and outliers were assessed visually. Data visualization through histograms, boxplots, and scatterplots of the data was used to identify potential outliers. Potential outliers were then screened and corrected by checking field and lab forms. For the purposes of this report, the data for each site are summarized in bar graphs of median, maximum, and minimum values. For aid with interpretation, relevant State water quality standards or non-regulatory guidelines and thresholds, where applicable, were displayed on summary figures. Where Maine standards were available, they were preferentially used over New Hampshire standards in this analysis, as the Maine-based SRCC monitoring program primarily produces these data as a resource to Maine state and local governments (Figure 8).



†The bars in the *E. coli* graph represent geometric mean values.

*The dashed red line represents ME Class A standards, if applicable. If not, NH Class A standard is used. If neither exist, then natural background/minimal disturbance levels are used.

Figure 8. Example figure to guide interpretation of water quality summary figures for parameters.

Trend analyses were also conducted by FBE using the R open-source statistical software platform. First, simple non-parametric Mann-Kendall trend tests (Mann-Kendall trend tests; USGS, 2002; USEPA, 2009) were run for water quality parameters at each site. The Mann-Kendall trend test is a non-parametric statistical test that determines if the central value (median) of a dataset has changed over time. A non-parametric test is appropriate here because it does not make assumptions about the normality or variability of the dataset; variation seen year-to-year or within seasons will not influence the results of non-parametric analysis the way that it can confound parametric tests.

Seasonal water quality for the summer (defined as the second week of May through the third week of September) median annual tributary data was used in the trend analysis. It was screened for the following criteria: for inclusion in the analysis, the dataset for a site must a) have five or more years of data collected in continuous years, and b) have a minimum of three samples per year of data collected.

WATER QUALITY ANALYSIS: RESULTS

pH

pH is a measure of the acidity of water in terms of hydrogen ion concentration. pH below 7.0 is acidic and above 7.0 is alkaline. pH affects many chemical and biological processes in water, and various organisms flourish under different pH ranges, the most preferred being between 6.5 and 8.0. The ability of aquatic organisms to complete a life cycle greatly diminishes as pH falls below 5.0 or exceeds 9.0. Levels below 5.5 can severely limit growth and reproduction in fish, as is the case with brook trout in New England streams. Low pH can also allow toxic elements and compounds such as heavy metals to become mobile and available for uptake by aquatic plants and animals, which in turn can cause deformities in fish and produce conditions that are toxic to aquatic life. These low pH levels can be due to naturally occurring conditions, such as the influence of tannic and humic acids from decaying plants in wetlands. Low pH can also be influenced by industrial pollution in the form of atmospheric deposition of nitric and sulfuric acids in acid rain. The discharge of wastewater from treatment plants can also affect natural pH.

Only one site, OCS4-B (the Old Course Saco River in Fryeburg, Maine at Hemlock Bridge) has a median pH value that falls below the Maine Class A standard of 6.5 (this site's median is just below the standard at 6.4). Minimum values at all sites fall below the 6.5 pH standard, indicating that low pH is at least occasionally experienced everywhere in the Saco River, its tributaries, and the lakes and ponds in the watershed.

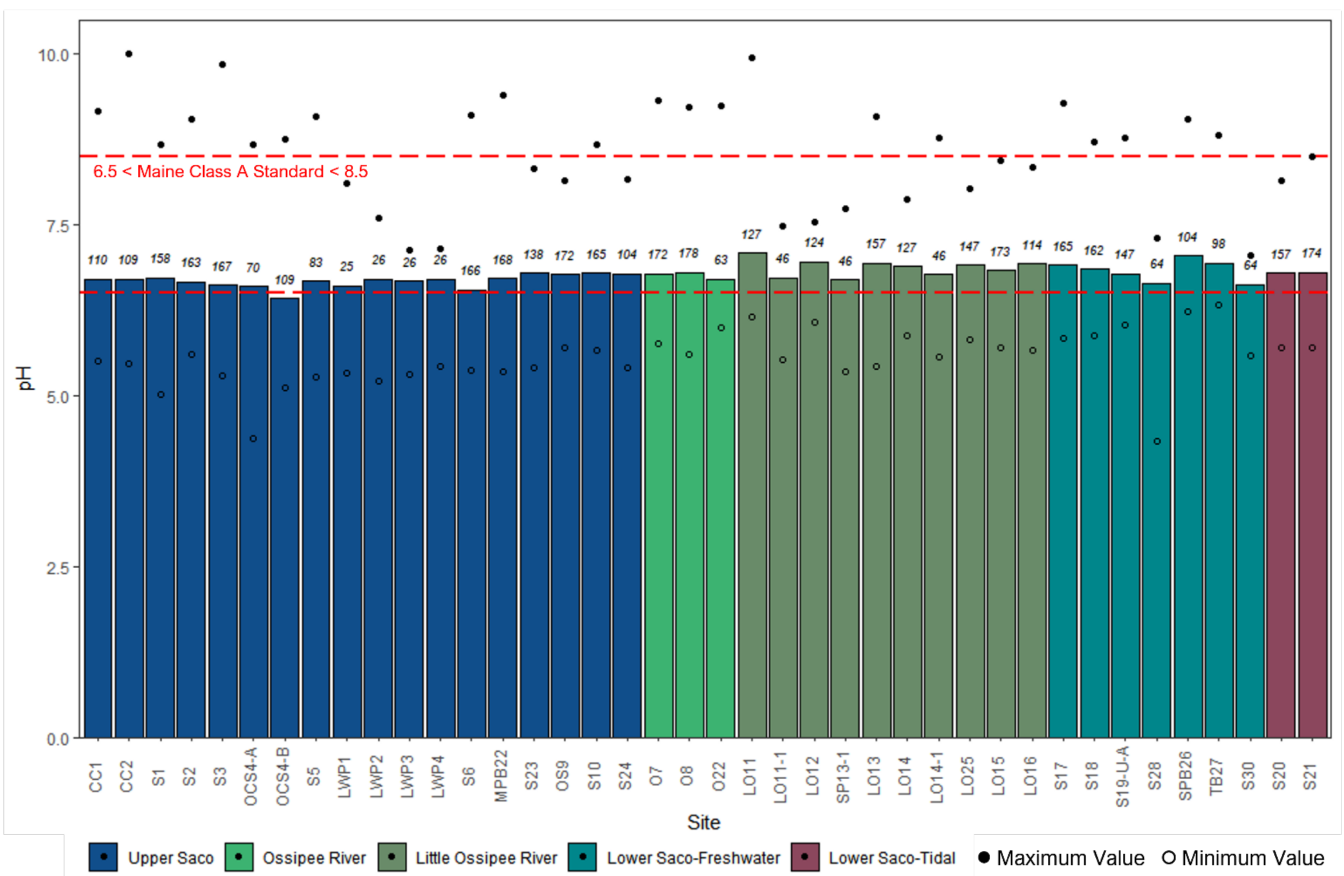


Figure 9. Summary of pH values for all monitoring sites. Height of bar represents median of all samples (number of samples is noted above each bar). Color groupings are by river reach. Black circles are maximum values; empty circles are minimum values. The red dashed lines indicate the Maine Class A Standard.

According to the Mann-Kendall trend test, 13 monitoring sites exhibited significant decreasing trends, indicating greater acidity over time (a worsening water quality trend). Table 3 lists the 13 sites and their significance (i.e., p-values). A site with a p-value less than 0.05 has a significant trend and the smaller the p-value, the more significant it is.

Table 3. List of the SRCC monitoring sites with significant degrading water quality trends (increasing acidity) in pH over the study period. The sites are listed in order of smallest to largest significant p-value.

Site	Location	Median (pH)	P-value
OS9	Cornish Station	6.78	0.001
S20	The Saco River at South Street in Biddeford	6.80	0.002
S1	The Saco River at Saco Pines Landing	6.73	0.003
S10	The Saco River off Route 11	6.80	0.003
S21	The Saco River at the public boat launch, Front Street, Saco	6.81	0.004
MPB22	Moose Pond Brook below Moose Pond	6.72	0.005
LO15	The Little Ossipee River at Doles Ridge Road	6.84	0.008
LO13	The Little Ossipee River below Shapleigh Pond	6.94	0.019
S19-U-A	Skeleton Head Pond Dam	6.79	0.019
LWP1	Lovewell Pond at Wards Beach	6.61	0.027
SP13-1	The Shapleigh Pond Boat Launch	6.71	0.027
S18	The Saco River above Bar Mills Dam	6.85	0.034
S2	Weston's Beach	6.67	0.042

Alkalinity

Alkalinity is a measure of acid-buffering compounds in a water sample that describes the water's ability to resist changes in pH due to the adding of acids. Carbonates such as calcium carbonate ($CaCO_3$) are usually the dominant component of alkalinity in natural waters. A lake or river with naturally high alkalinity will experience less of a decrease in pH with the addition of acid precipitation than will a lake or river with low alkalinity. Total alkalinity is described as a concentration (e.g., milligrams per liter, mg/l) and is commonly measured by titrating acid into a sample to measure the amount needed to lower pH to 4.2, at which point the alkalinity is used up. A waterbody with alkalinity below 20 mg/l is sensitive to acidification, and below 5 mg/l a lake or river would be considered highly susceptible to acidification and resulting harm to aquatic life. Due to the region's geology, most of Maine and New Hampshire (including the Saco River watershed) has naturally low alkalinity and thus is more susceptible to the effects of acidic precipitation (aka acid rain) than a region with abundant carbonate geology.

Alkalinity data are available for a smaller subset of the SRCC monitoring sites (14 sites) than for other parameters such as pH. Several sites only have one alkalinity sample in the data record (O7, O22, LO14), while others have a robust record with dozens of samples (e.g., S2, TB27). The median alkalinity data show that much of the Saco River network has low alkalinity, with only TB27 (Thatcher Brook in Biddeford) exhibiting alkalinity above the threshold for sensitivity of 20 mg/l.

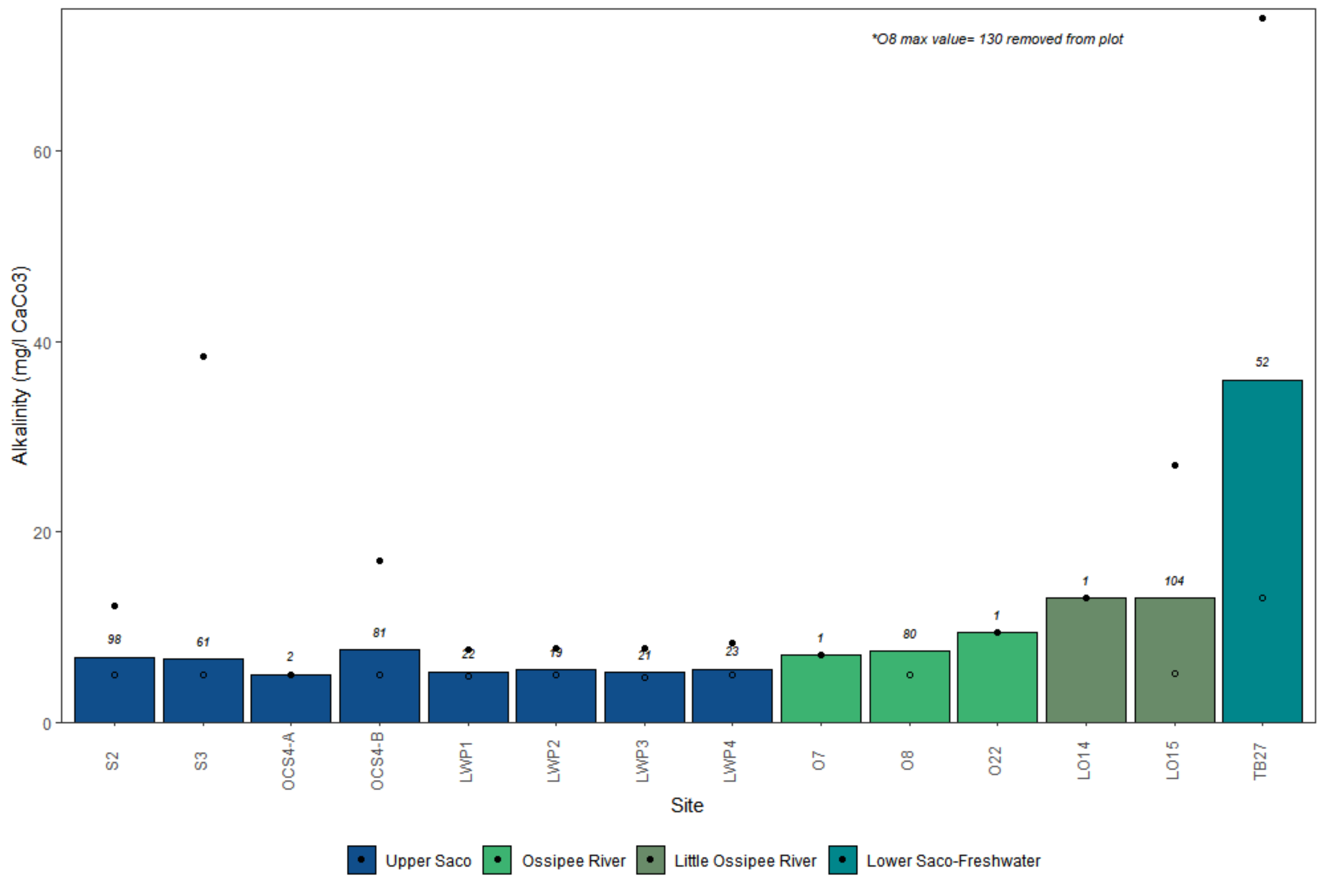


Figure 10. Summary of alkalinity data at all monitoring sites. Height of bar represents median value for site (number of samples above bar). Filled circles are maximum values; empty circles are minimum values.

The Mann-Kendall trend analysis determined that none of the monitoring sites had significant trends in alkalinity.

Temperature

Water temperature is influenced by many variables, including air temperature, sunlight, shading, water source, and the width, depth, and circulation of the waterbody. Human activities that can affect water temperature include stormwater runoff from impervious surfaces, industrial discharge of water used as coolant (thermal pollution), removal of shade-providing trees in the riparian zone, erection of dams or other impoundments, and erosion of soil (e.g. turbid water absorbs more heat from the sun). The metabolic rates of organisms and the growth of aquatic plants increase with increasing water temperature, which in turn increases the need for oxygen as organisms require oxygen for metabolic processes and bacteria use up oxygen to decompose dead plant material. Since gases dissolve more easily in cooler water, water temperature also plays a large role in the amount of dissolved oxygen found in waterbodies. Coldwater organisms, such as trout and mayfly nymphs, thrive in cooler, more oxygen-rich waters (13 ºC and below), while other organisms, such as bass and most plant life, prefer warmer waters (20 ºC and above). Generally, coldwater fish species thrive under maximum instantaneous temperatures of 24°C, and weekly temperatures of 19° C/66.2°F.

Only eight sites across the monitoring network had median temperature values below this 19°C value: five sites on the upper Saco River in Conway, New Hampshire and Fryeburg, Maine (CC1, CC2, S1, S2, and S3), S24 below Watchic Lake in Standish, SPB28 (Swan Pond Brook in Biddeford), and TB27 (Thatcher Brook in Biddeford).

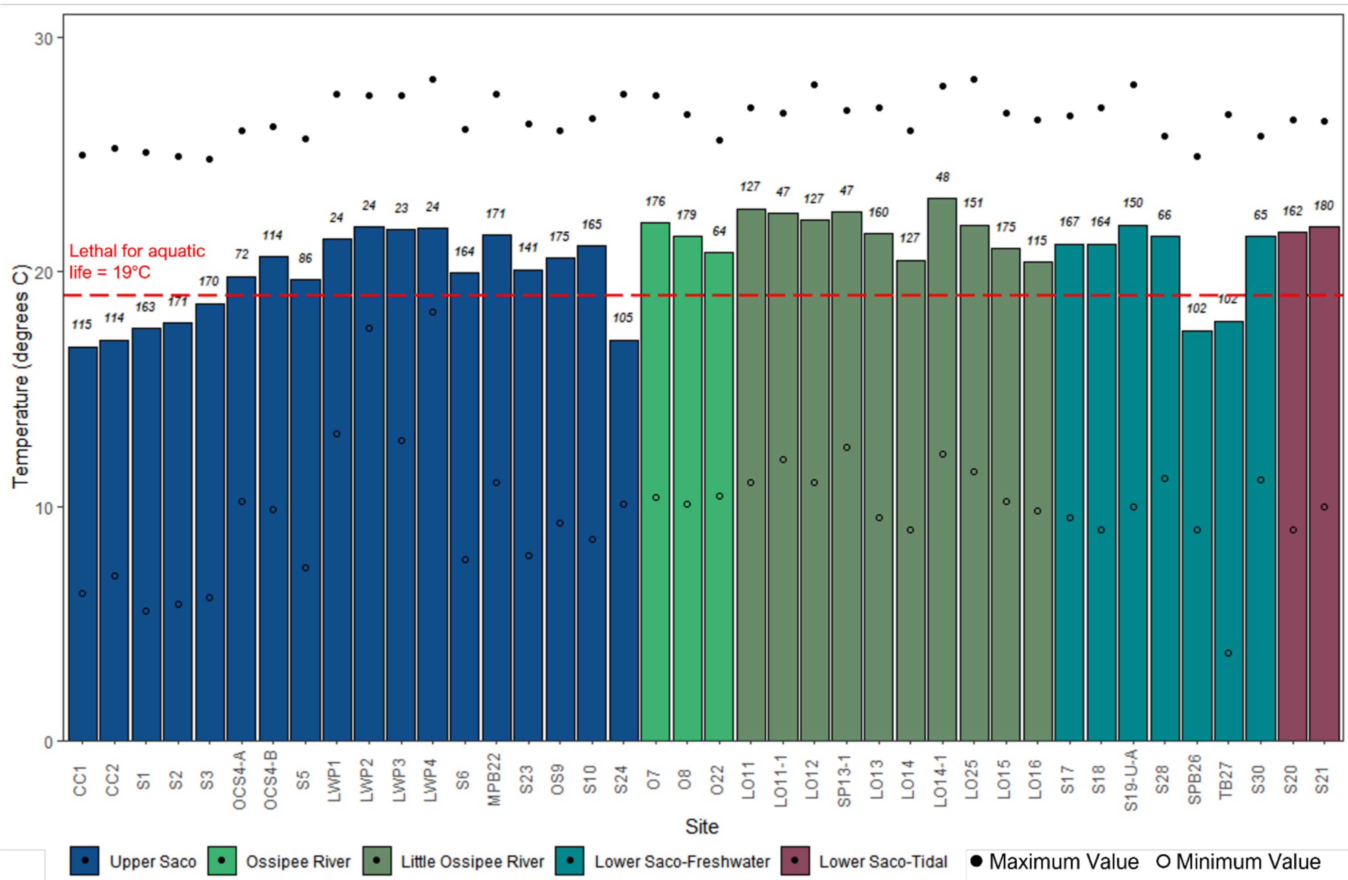
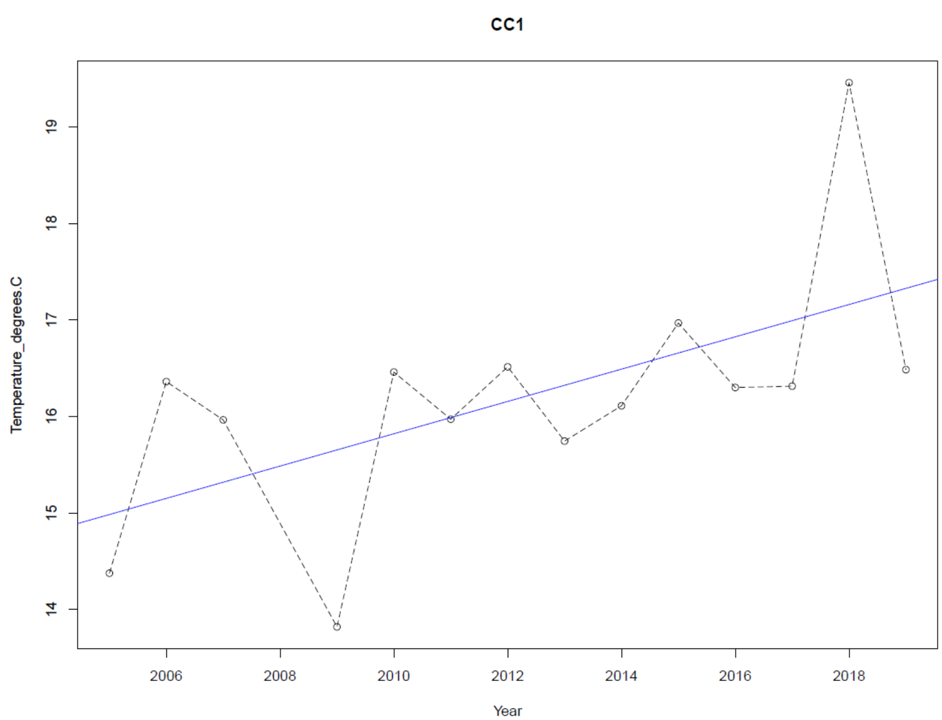


Figure 11. Summary of temperature values for all sites. Height of bar represents median value for site (number of samples above bar). Filled circles are maximum values; empty circles are minimum values.

Six sites had significant increasing trends (degrading water quality) in temperature as determined by the Mann-Kendall trend analysis (Table 4).

Table 4. List of the SRCC monitoring sites with significant degrading water quality trends (increasing) in temperature over the study period. The sites are listed in order of smallest to largest significant p-value. Median temperature values denoted in red are greater than the "lethal for aquatic life" threshold (19°C).

Site	Location	Median (° C)	P-value
LO25	Little Ossipee Pond	**22**	0.001
CC2	The Saco River at Redstone, Conway	17.1	0.003
LO16	The Little Ossipee at Hardscrabble Road	**20.4**	0.024
CC1	The Saco River at Davis Park in Conway	16.8	0.029
TB27	Thatcher Brook, Biddeford	17.9	0.029
S6	The Maine State Landing on the Saco River downstream of the Brownfield Bog	**19.95**	0.049



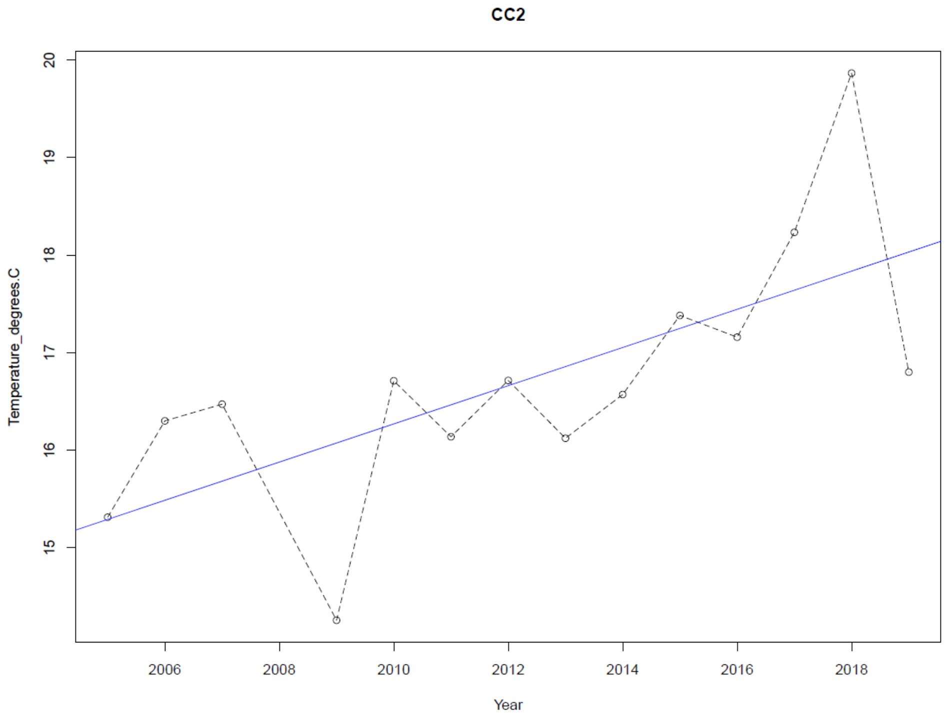


Figure 12. Increasing trends in annual mean temperature (°C) at CC1 (Saco River at Davis Park in Conway, New Hampshire) and CC2 (Saco River at Redstone, Conway, New Hampshire).

Turbidity

Turbidity is a measurement of the amount of suspended material in water, such as clay, silt, algae, sediment, and decaying plant material. Turbidity is measured in nephelometric turbidity units (NTU), which measure light refraction through a vial of water. The more suspended material in water, the more light is refracted and the higher the turbidity reading. In general, the murkier the water, the higher the turbidity.

Sources of increased turbidity include soil erosion, waste discharge, stormwater runoff, and excessive algal growth. Rain events often contribute to surface water turbidity by flushing sediment, organic matter, and other materials from the surrounding landscape. These suspended materials can clog fish gills, which reduces disease resistance in fish, lowers growth rates, and affects egg and larval development. As particles settle, they can blanket the stream bottom, especially in slower moving waters, and smother fish eggs and benthic macroinvertebrates. High turbidity can increase water temperature as suspended particles absorb more heat. This reduces the concentration of dissolved oxygen because warm water holds less oxygen than cold water. High turbidity can also reduce the amount of light that penetrates water, which reduces photosynthesis and the production of life-supporting dissolved oxygen.

There is no water quality standard established in Maine for turbidity, so an approximate background turbidity level of 1 NTU is used for comparative purposes. Many natural processes may account for elevation in turbidity above 1 NTU, but this indicator value serves as a convenient screening guideline for high turbidity vs. low turbidity, clear waters. Nineteen of the monitoring sites exceed the turbidity background level of 1 NTU, spanning all regions of the Saco River network. Notably, all monitoring sites in the Lower Saco freshwater and tidally influenced reaches have median turbidity values over 1 NTU. SPB23 (Swan Pond Brook) and TB27 (Thatcher Brook), both in Biddeford, exhibit very high turbidity values frequently, with median values above 6 NTU.

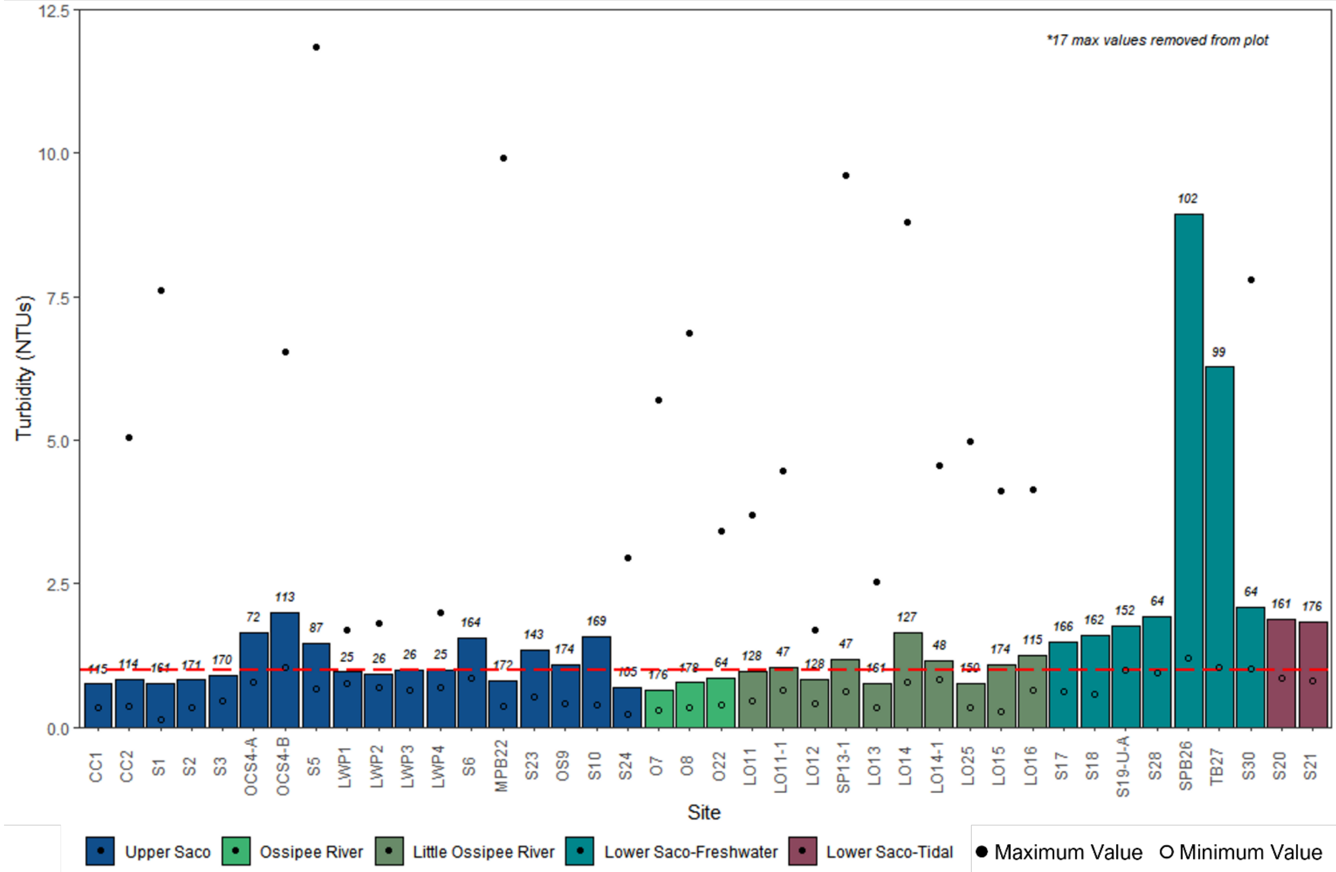


Figure 13. Summary of turbidity values for each monitoring site, grouped by river reach. Height of bar represents median turbidity value in nephelometric turbidity units (NTU). The approximate natural background level of freshwater is 1 NTU (represented by the dashed line).

According to the Mann-Kendall trend test, six sites showed significant increasing (degrading water quality) trends in turbidity over time.

Table 5. List of the SRCC monitoring sites with significant degrading water quality trends (increasing) in turbidity over the study period. The sites are listed in order of smallest to largest significant p-value. Median temperature values denoted in red are greater than the 1 NTU reference threshold.

Site	Location	Median (NTU)	P-value
O8	The Ossipee River downstream of Kezar Falls Village	0.78	0.0002
LO15	The Little Ossipee River off of Doles Ridge Road in Limington	**1.08**	0.0041
S23	The Saco River below Hiram Falls Dam	**1.34**	0.0060
OS9	The Saco River below the Ossipee River confluence in Cornish (aka Cornish Station)	**1.095**	0.0143
LO11	Balch Lake in Wakefield, New Hampshire	0.98	0.0375
LO13	The Little Ossipee River below Shapleigh Pond	0.77	0.0408

Of these sites with significant increasing turbidity, LO15, S23, and OS9 were also among the sites with median turbidity above 1 NTU. Site 23 is sampled below a dam in the Saco River downstream of a gravel mining operation in West Baldwin, Maine. The mining operation could be a potential source of increased turbidity observed.

Dissolved Oxygen

Dissolved oxygen (DO) is commonly expressed as a concentration in terms of milligrams per liter (mg/l) or as a percent saturation. Percent saturation is the amount of oxygen dissolved in water divided by the maximum amount of oxygen that water can hold at a given temperature; this depends on temperature and atmospheric pressure as gases dissolve more easily in cooler water under higher pressure. Water flow, depth, and the amount of organic matter can also influence DO in water.

DO facilitates critical chemical reactions within water and benthic sediments that support life processes and functions. Depletion of available oxygen (known as hypoxia or anoxia) inhibits physiological functioning of aquatic life and its persistence can reduce the diversity and abundance of biota. DO fluctuates naturally on a diurnal basis depending on a suite of interactions and resource availability (e.g. light, nutrients, organic matter, temperature, etc.). DO is often highest during the day when sunlight drives photosynthesis (produces oxygen), while DO is often lowest at night when autotrophic respiration and decomposition of organic matter dominates (consumes oxygen). In some instances, water can become saturated with more than 100% DO when turbulent water enhances gas exchange with the atmosphere and/or when photosynthesis by aquatic plants (i.e. production of oxygen) exceeds respiration (i.e. consumption of oxygen). The SRCC monitoring program mitigates this effect by sampling before 9:00 am when DO values should be at their lowest point in the diurnal cycle, before photosynthesis has ramped up during the brightest part of the day.

Two sites had mean DO concentration values that fell below Maine class A standards of 7 mg/l (Figure 14):

1. OCS4-A, the Old Course Saco River off Route 5 in Fryeburg. The nearby site OCS4-B, also on the Old Course Saco River, at Hemlock Bridge, had a median value barely meeting state standards.
2. TB27, Thatcher Brook in Biddeford.

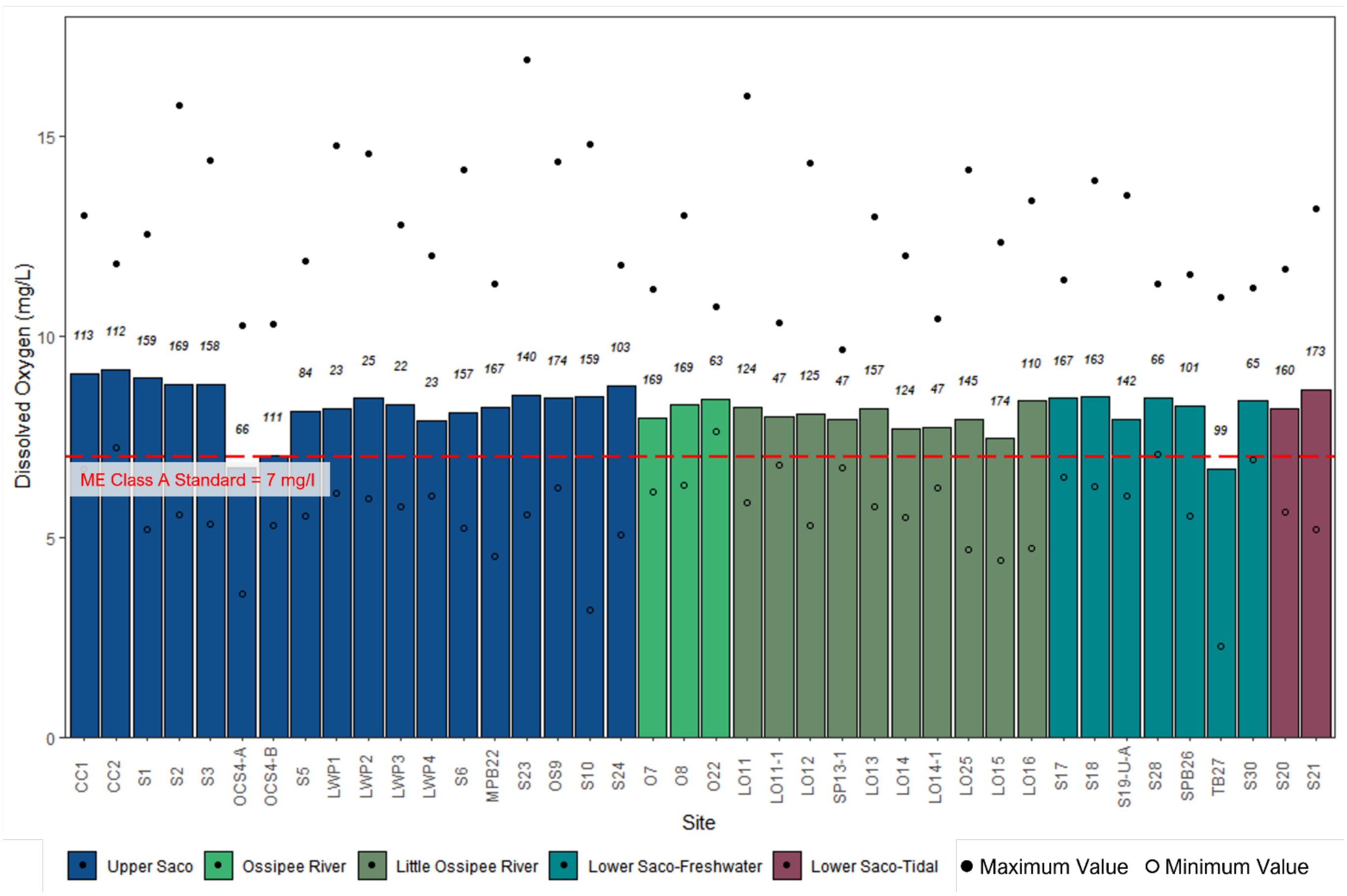


Figure 14. Summary of dissolved oxygen concentrations for each monitoring site, grouped by river reach. Height of bar represents median dissolved oxygen concentration. The Maine Class A water quality standard for DO concentration is 7 mg/l (represented by dashed line).

Turning to DO percent saturation, the same two sites that had low DO concentration values also had median values for DO percent saturation that fell below Maine Class A standards. DO percent saturation also carries a Maine Class SB standard applicable to estuarine and marine waters like TB27, and TB27's median value fell below that standard of 75% saturation (Figure 15).

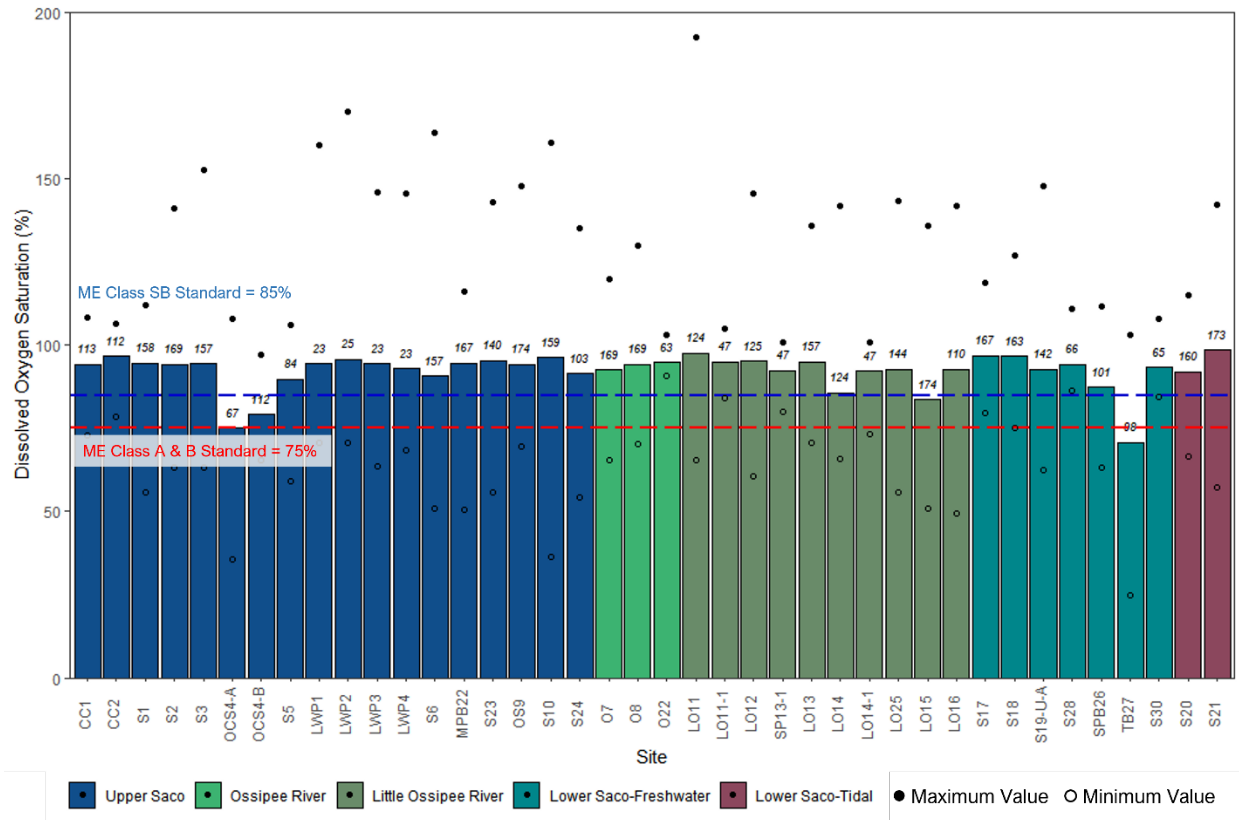


Figure 15. Median dissolved oxygen saturation for each monitoring site, grouped by river reach. The Maine Class A water quality standard for DO saturation is 75% and the Class SB standard (applicable to estuarine or marine waters) is 85% (represented by dashed lines).

The trend analysis was conducted on both DO concentration and DO saturation, and the trend significance results were not identical between concentration and saturation.

Three sites had a **significant increasing trend in DO saturation** over the monitoring period:

1. MPB22 Moose Pond Brook below Moose Pond in Denmark
2. S18, the Saco River above Bar Mills Dam in Buxton
3. S20, the Saco River at South Street in Biddeford

Of these three sites, S18 and MPB22 had **significant increasing trends in DO concentration**.

Four sites had a **significant decreasing trend in DO concentration**:

1. LO11-1, beside Balch Pond Dam in Newfield
2. LO15, the Little Ossipee River at Doles Ridge Road in Limington
3. LO16, the Little Ossipee at Hardscrabble Road, also in Limington
4. TB27, Thatcher Brook in Biddeford

TB27 also had a **significant decreasing trend in DO saturation**. This site was also identified above as a site with low median DO saturation, not meeting Maine Class B standards.

Table 6. List of the SRCC monitoring sites with significant degrading water quality trends (decreasing) in dissolved oxygen (DO) concentration over the study period. The sites are listed in order of smallest to largest significant p-value. Median DO values denoted in red are less than the Maine Class A standard (7 mg/l). Site TB27 has decreasing trends in both DO concentration and percent saturation.

Site	Location	Median (mg/l)	P-value
TB27	Thatcher Brook in Biddeford	6.71 (*70.8 %*)	0.013 (*0.008*)
LO16	The Little Ossipee at Hardscrabble Road, also in Limington	**8.39**	0.016
LO15	The Little Ossipee River at Doles Ridge Road in Limington	**7.46**	0.017
LO11-1	Beside Balch Pond Dam in Newfield	**8.01**	0.027

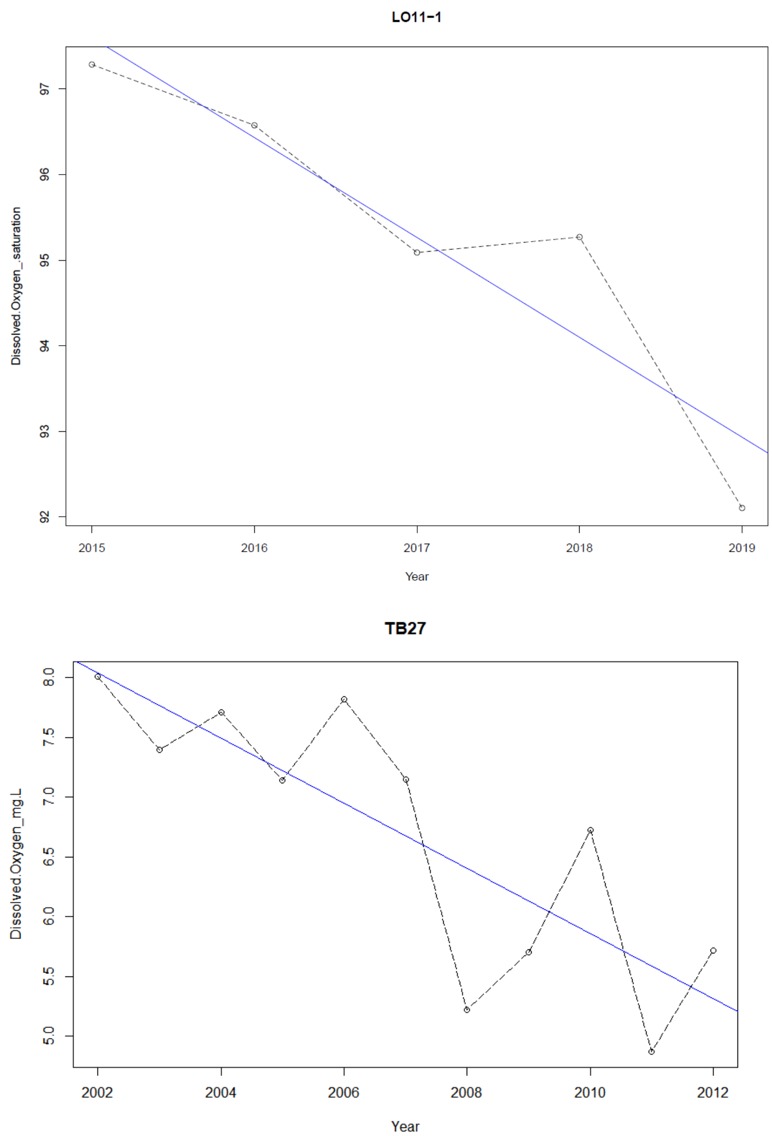


Figure 16. (Top) Decreasing trend in dissolved oxygen saturation (%) at Site LO11-1 over the time period 2015-2019. (Bottom) Decreasing trend in dissolved oxygen concentration (mg/l) at Site TB27. Note that data collection at Site TB27 ended in 2012.

Phosphorus

Phosphorus, genreally the most important growth-limiting nutrient in freshwaters, is typically very low in natural systems. Even small increases in contributions from nearby land use can have a large impact, potentially triggering problematic algal blooms and plant growth that can lead to eutrophication. Eutrophication (nutrient enrichment that increases productivity) can cause anoxia, or deficiency of oxygen, for aquatic organisms and can lead to other water quality problems. Higher concentrations of phosphorus are primarily associated with human activities within a watershed and are therefore important to monitor and control. Sources of phosphorous include: human waste, animal waste, industrial waste, soil erosion, fertilizers, disturbance of land and vegetation (e.g. draining or filling wetlands), agricultural runoff, and stormwater runoff. Synthetic phosphates are also often used in laundry detergents as a water softener. Phosphorus tends to "stick" to sediment, and in instances of shoreline disturbance or heavy rain events causing erosion, phosphorus attached to soil particles can be washed into waterways. Total Phosphourous (TP) will also accumulate in slow moving stream reaches and in impoundments (i.e. upstream of a dam, and in lakes and wetlands) where particulate phosphorus settles out of the water column.

Neither Maine nor New Hampshire has numerical water quality criteria for TP or orthophosphate, but TP has narrative language that allows for requiring controls on point and nonpoint source inputs in eutrophic waters. The Maine DEP Draft Nutrient Criteria proposes a TP value of 40 ppb (0.04 mg/l) in freshwater (Maine DEP, 2021). In lakes and ponds, 10 ppb is a common indicator of trophic status, above which it becomes difficult to maintain a lake's oligotrophic (low productivity, clear water) status.

Sites that would be considered phosphorus-enriched were distributed throughout the Saco River network. Eight sites had median values that exceeded the 0.04 mg/l TP eutrophication threshold: S5, MPB22, O8, O22, LO12, LO13, LO15, and S30. SPB26's median value fell just below the 0.04 mg/l threshold.

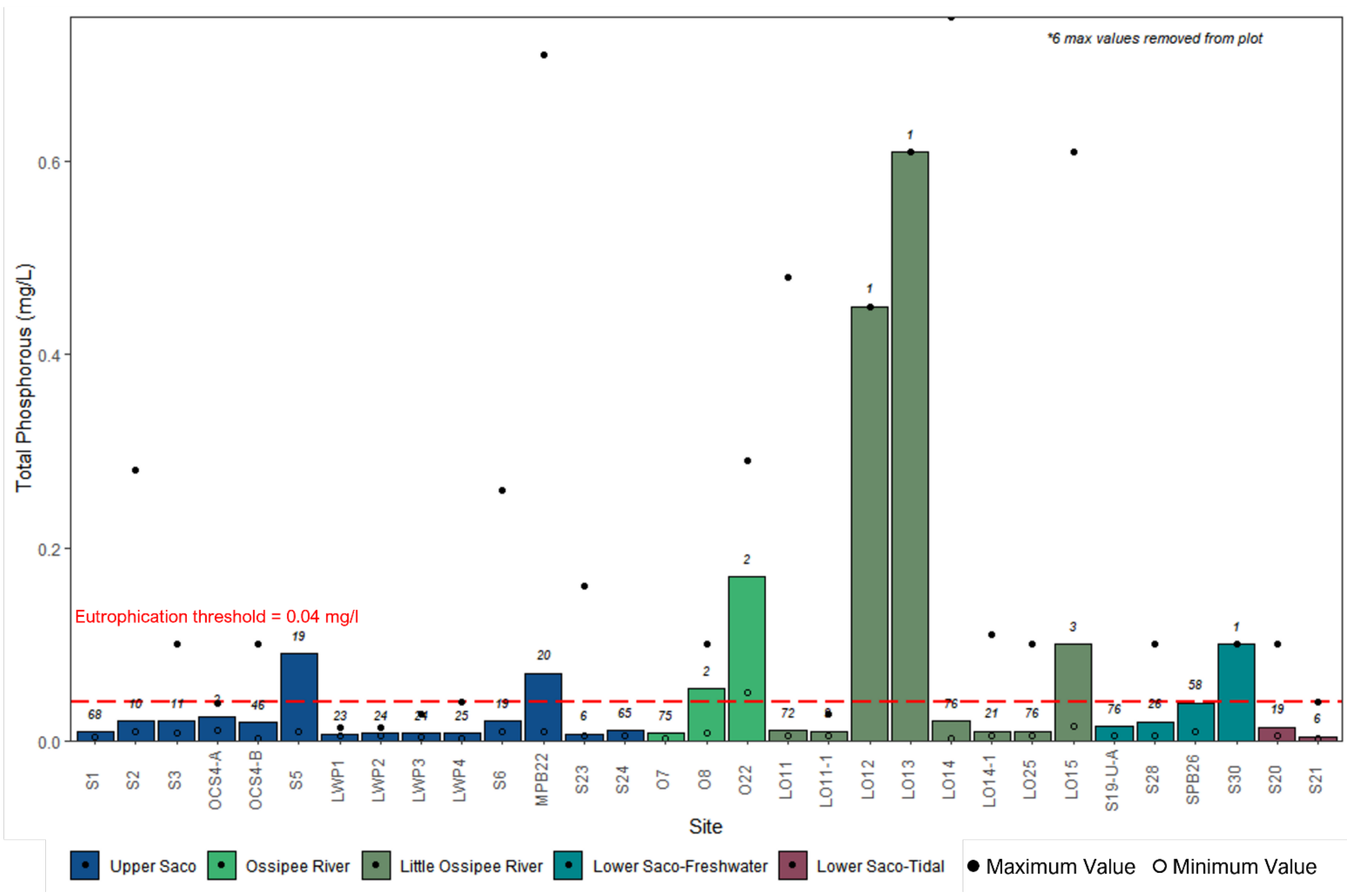


Figure 17. Median Total Phosphorus (TP) concentrations for each monitoring site, grouped by river reach. The general eutrophication threshold for freshwaters is 0.04 mg/l of TP (represented by dashed line).

According to the Mann-Kendall trend test, only one site showed a significant long-term trend in TP. Site S28 (Across Route 5 Bridge from the Homestead Campground, Saco) significantly (p-value= 0.035) decreased in TP levels from 2013 to 2019 (Figure 18).

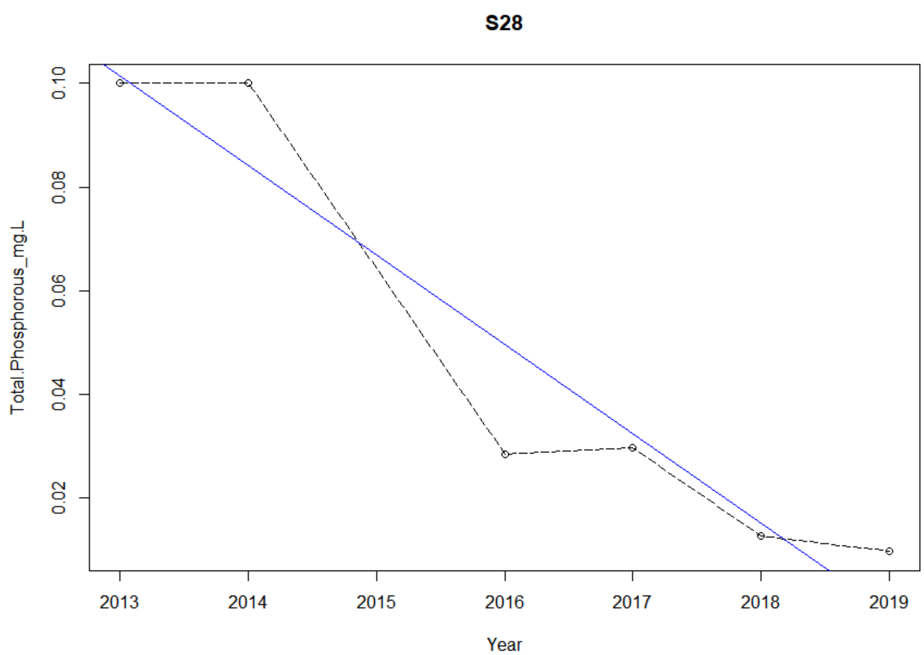


Figure 18. Decreasing trend in total phosphorus concentration (mg/l) at Site S28 over the time period 2013-2019.

Nitrogen

Nitrogen composes 78% of the earth's atmosphere in the form N_2, which is not biologically available until microorganisms transform it in a process known as nitrogen fixation. Since the late 19th century, societies have had the ability to fix nitrogen in the industrial Haber-Bosch process. In nature, nitrogen is found in all plant and animal tissues, is an essential component of proteins, and is one of the main limiting nutrients to primary productivity in lakes and rivers. Excess nitrogen loading in streams can act as a fertilizer to algae and other aquatic plants, resulting in unwanted algal blooms and excessive plant growth; this eventually leads to anoxia that can degrade aquatic life function. Dissolved inorganic nitrogen (DIN) enters waterbodies from stormwater runoff, septic systems, animal waste, agricultural runoff, excess fertilizer from lawns, and discharge from car exhausts, while dissolved organic nitrogen (DON) is typically generated by natural processes that occur in wetlands and forest soils. Ammonium is easier for plants and microorganisms to absorb or assimilate because it is more energy efficient to use than nitrate. However, ammonium is typically low in undisturbed streams as a result of direct uptake or nitrification to nitrate. High levels of ammonium usually indicate some type of pollution.

Total Kjeldahl Nitrogen (TKN) is a form of nitrogen that sums organic nitrogen and nitrogen bound in ammonium and ammonia, named for a scientist who pioneered the laboratory technique in the late 19th century for measuring proteins and biochemical processes. TKN concentration also serves as a useful measure of the bioavailable nitrogen in water samples, especially when combined with nitrate concentration, which is another biologically available form that is not included in TKN.

Maine and New Hampshire have no criteria for nitrogen in any form, including TKN. For this report, a threshold of 0.45 ppm (mg/l) was used for comparison purposes which is within the mid to upper range of published data at which indicators of eutrophication or impairment to benthic organisms may be observed (Howes et. al., 2003, Howes et. al., 2013).

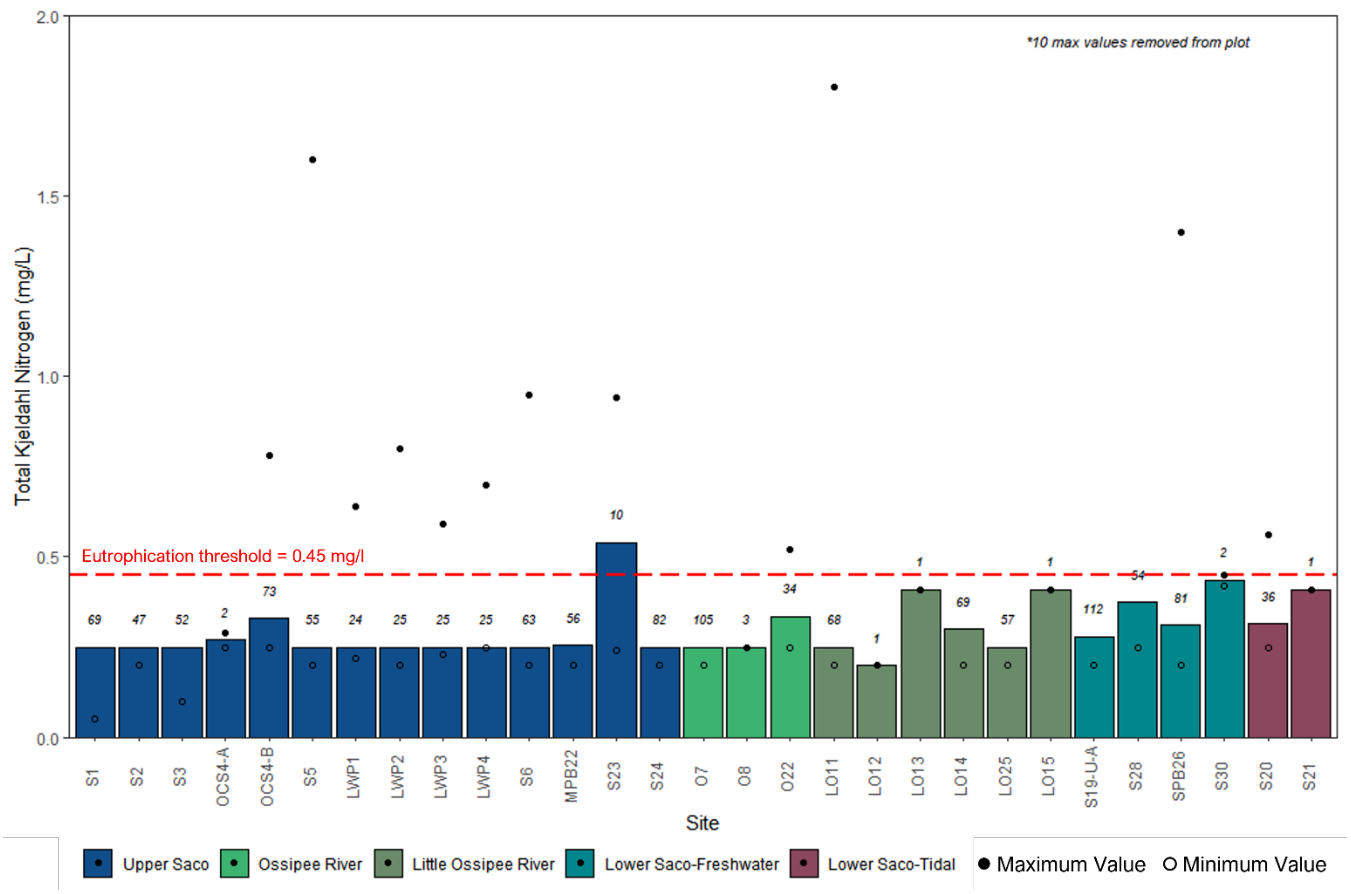


Figure 19. Summary of Total Kjeldahl Nitrogen (TKN) concentrations for each monitoring site, grouped by river reach. Height of bar represents median TKN value. Number of samples is shown above each bar. The general eutrophication threshold for freshwaters is 0.45 mg/l of TKN (represented by dashed line).

Only one site (S23) had a median value that exceeded the 0.45 mg/l eutrophication threshold for nitrogen, but five sites had median values that were just below the threshold (LO13, LO15, S28, S30, and S21). The median value at many sites corresponds to half the detection limit of the laboratory analytical method, which explains why many of the bars are the same height (especially in the Upper Saco region). The trend analysis determined that there were no significant long-term trends in TKN.

E. coli and *Enterococcus*

A measure of bacteria common to the intestines of warm-blooded animals (including humans), *E. coli* is a fecal indicator bacterium that is used to determine the presence of fecal waste – and potential pathogens – in water. *E. coli* abundance is measured in the laboratory by incubating a sample and then counting "colony forming units" – the masses of bacteria that are visible to the naked eye – per 100 milliliters of sample, commonly abbreviated as CFU/100 ml. The Maine Class A standard for *E. coli* is not based on a single sample but rather on two measures of exceedance over any given 90-day period:

1. A geometric mean of 64 CFU/100 ml over a 90-day interval, or
2. Values of 236 CFU/100 ml or more in more than 10% of the samples in any 90-day interval.

Similar to *E. coli*, Enterococcus is a measure of bacteria but is more representative of bacteria levels in marine and brackish waters than *E. coli.* Maine Class SB standards for marine and estuarine waters have an *enterococcus* bacteria standard measured two ways:

1. A geometric mean of 8 CFU per 100 milliliters in any 90-day interval, or
2. 54 CFU per 100 milliliters in more than 10% of the samples in any 90-day interval.

The geometric mean values for Class A and Class SB standards are shown on the graph below for comparison purposes to the median *E. coli* values, but note that this is not meant to be a direct comparison. Median values over the entire period of record do not approximate 90-day geometric means, but the 90-day geometric mean value still gives the viewer a reference point. Additionally, while the Maine Class SB standard for *enterococcus* is shown in the graph below, *enterococcus* was not measured at any of the SRCC sites. The tidal sites (i.e., S20 and S21) were measured for *E. coli*. Starting in 2020, the SRCC switched to measuring *enterococcus* at the tidal sites to match Maine state standards.

Four of the freshwater SRCC monitoring sites had median *E. coli* values that exceeded Maine Class A standards for the 90-day geometric mean: S18, SPB26, TB27, and S30. Sites OCS4-A and OCS4-B also had frequent high *E. coli* levels throughout their monitoring periods. The two estuarine sites (S20 and S21) had median *E. coli* values that exceeded Maine Class SB *enterococcus* standards for the 90-day geometric mean.

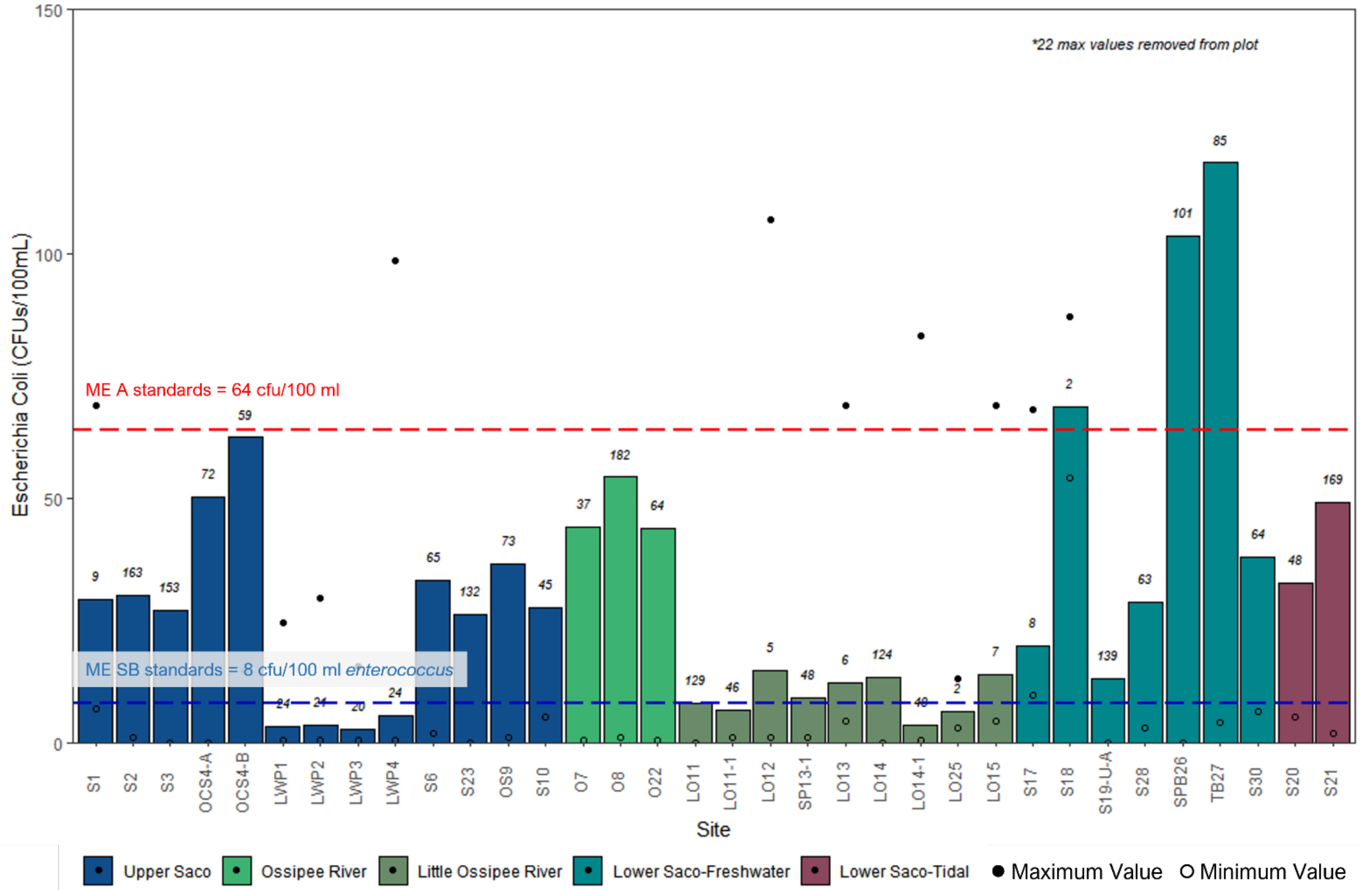


Figure 20. Median *E. coli* concentration for each monitoring site, grouped by river reach. The Maine Class A water quality standard for *E. coli* is 64 CFU/100 ml (represented by the red dashed line). The Maine Class SB water quality standard for *enterococcus* is 8 CFU/100 ml (represented by the blue dashed line).

Table 7. Summary of *E. coli* Geometric Means for all Lower Saco River freshwater and estuarine sites.

Site	Region	*E. coli* (CFU/100mL)
S17	Lower Saco-Freshwater	20
S18	Lower Saco-Freshwater	69
S19-U-A	Lower Saco-Freshwater	13
S28	Lower Saco-Freshwater	29
SPB26	Lower Saco-Freshwater	104
TB27	Lower Saco-Freshwater	119
S20	Lower Saco-Tidal	33
S30	Lower Saco-Freshwater	38
S21	Lower Saco-Tidal	49

According to the Mann-Kendall trend analysis, three sites had significant trends in *E. coli* abundance.

1. LO11, Balch Lake near the marina on Whitehouse Road, Wakefield, New Hampshire
2. S19-U-A, Skeleton Head Pond, Skeleton Dam, off of Simpson Road, Buxton
3. SPB26, Swan Pond Brook, Biddeford

Site LO11 on Balch Lake, above the headwaters of the Little Ossipee River, had a significant (p-value= 0.049) decreasing (improving water quality) trend in *E. coli*. *E. coli* levels were relatively high (40 – 80 CFU/100 ml) from 2001-2003 and then dropped (<30 CFU/100 ml) from 2004-2014. (Figure 21). Site S19-U-A also had a significant (p-value= 0.0103) decreasing (improving) trend in *E. coli* from 2002-2017. Site SPB26 had a significant (p-value= 0.0195) increasing (degrading water quality) trend in *E. coli* (Figure 22).

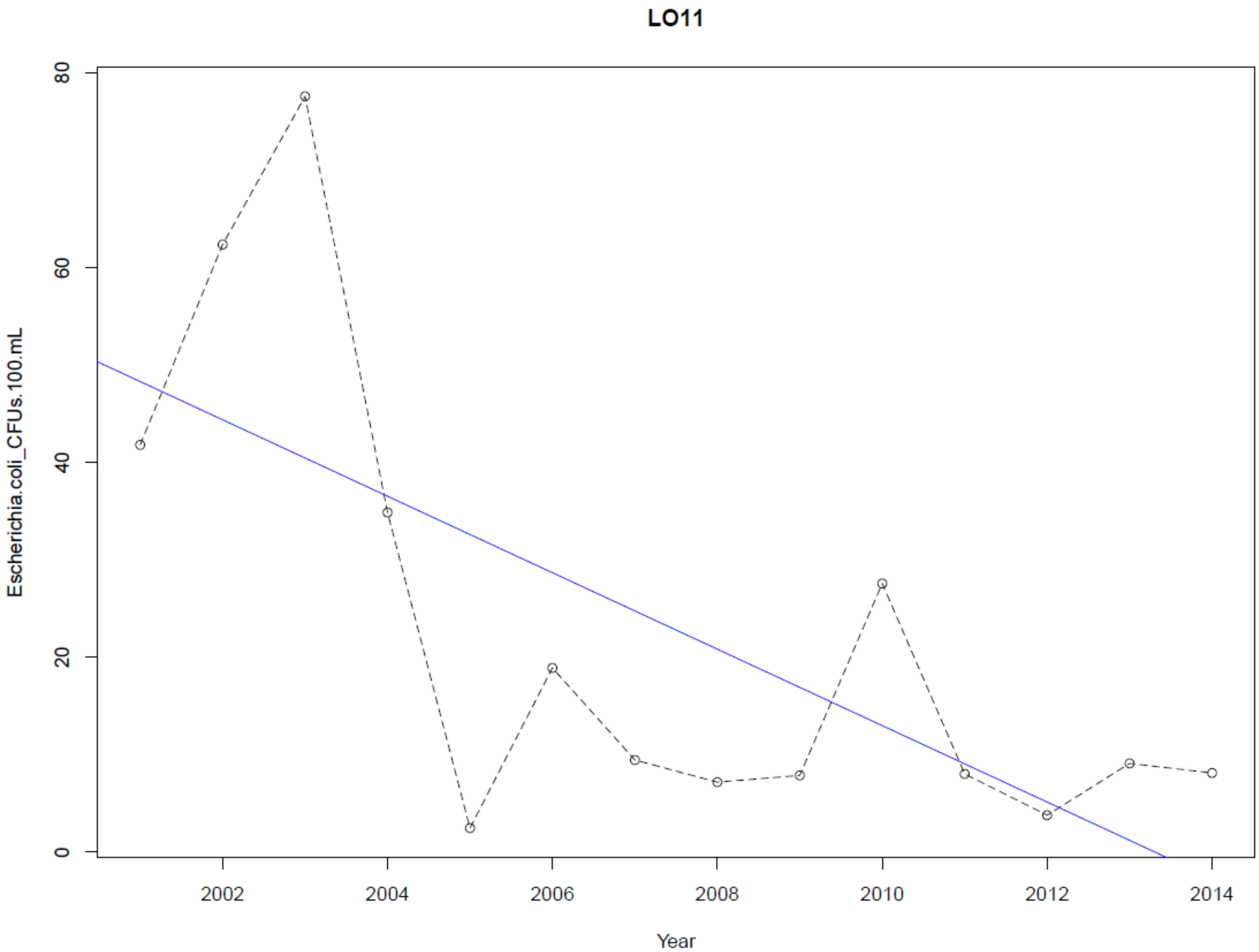


Figure 21. Decreasing trend in *E. coli* (colony forming units/100 milliliters) over time at site LO11, Balch Lake in Newfield, Maine.

After Thatcher Brook, Swan Pond Brook has the highest median *E. coli* numbers of any site in the monitoring network. This was also the only site to have a significant increasing (degrading) trend in *E. coli* (Figure 22).

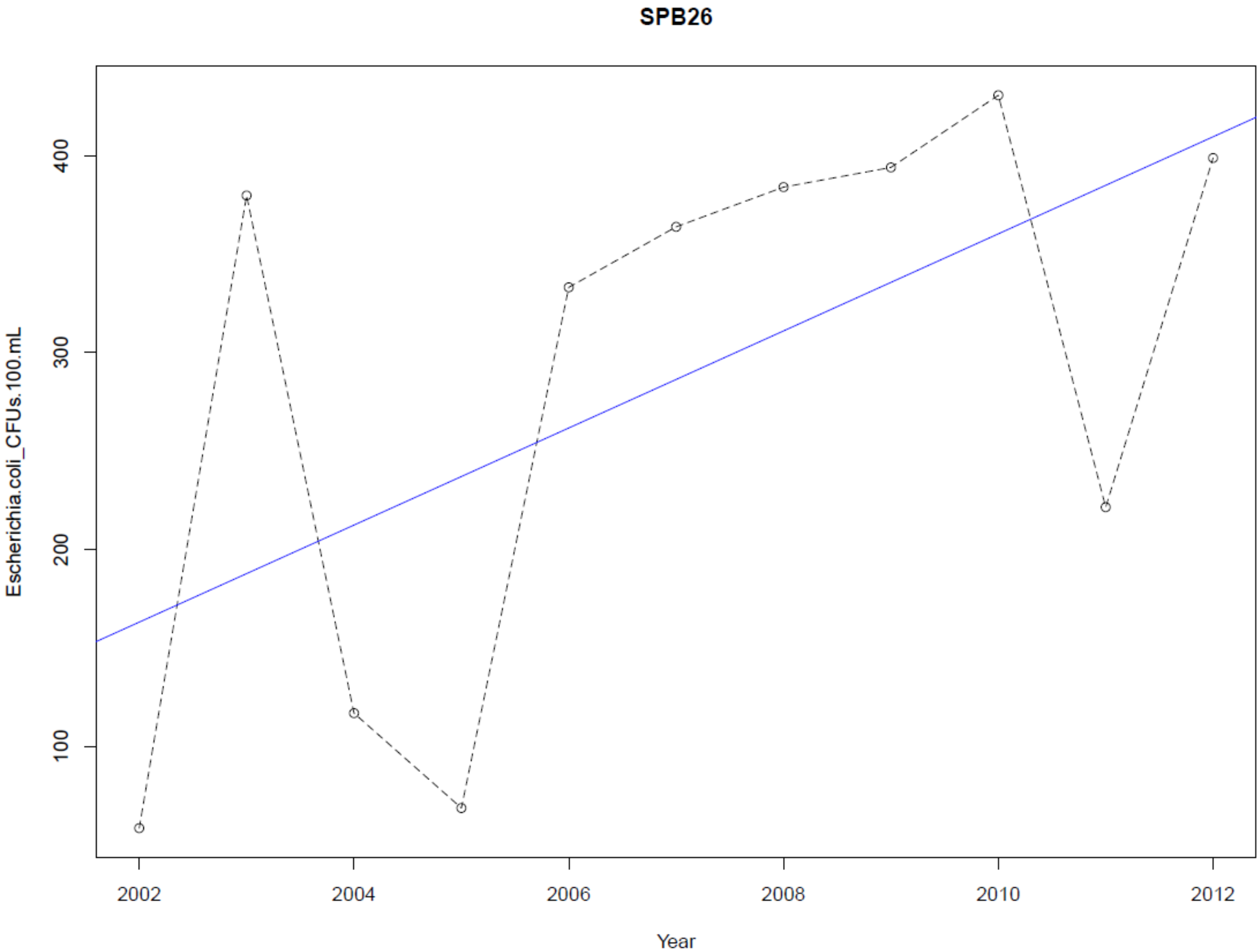


Figure 22. Increasing trend in *E. coli* (colony forming units/100 milliliters) over time at site SPB26 (Swan Pond Brook) over the time period 2002-2012.

Table 8. Summary of water quality indicator exceedances and trend analysis results for all sites, all water quality parameters. ✓ = median value exceeded state standards; ! = median value exceeded other applicable threshold for background water quality; * = significant degrading water quality trend over time; * = significant improving water quality trend over time.

Reach	Site ID	Site Description	Town	Physical Parameters			Chemical Parameters							Trend analysis results			
				pH	Temp	Turbidity	DO (mg/l)	DO (% sat)	TP	PO_4^{3-}	TKN	*E. coli*	Alkalinity	✓	!	*	*
Upper Saco	CC1	Davis Park	Conway, NH		*		✓	✓						2	0	1	0
Upper Saco	CC2	Redstone	Conway, NH		*		✓	✓						2	0	1	0
Upper Saco	S1	Saco Pines Landing	Conway, NH	*			✓	✓						2	0	1	0
Upper Saco	S2	Weston's Beach	Fryeburg	*			✓	✓						2	0	1	0
Upper Saco	S3	Canal Bridge Beach	Fryeburg				✓	✓						2	0	0	0
Upper Saco	OSC4-A	Old Course of the Saco	Fryeburg		!	!		✓						1	2	0	0
Upper Saco	OSC4-B	Old Course- Downstream of Hemlock Bridge	Fryeburg	✓	!	!	✓	✓						3	2	0	0
Upper Saco	S5	Walkers Fall Rd	Fryeburg		!	!	✓	✓	!					2	3	0	0
Upper Saco	LWP1	Lovewell Pond- Wards Beach	Fryeburg	*	!		✓	✓						2	1	1	0
Upper Saco	LWP2	Jordan's Camp	Fryeburg		!		✓	✓		!				2	2	0	0
Upper Saco	LWP3	Deep Spot	Fryeburg		!		✓	✓						2	1	0	0
Upper Saco	LWP4	Saco Outlet	Fryeburg		!		✓	✓						2	1	0	0
Upper Saco	S6	State Landing downstream of Brownfield Bog	Brownfield		*!	!	✓	✓						2	2	1	0

Reach	Site ID	Site Description	Town	Physical Parameters			Chemical Parameters							Trend analysis results			
				pH	Temp	Turbidity	DO (mg/l)	DO (% sat)	TP	PO_4^{3-}	TKN	*E. coli*	Alkalinity	✓	!	*	*
	MPB22	Below Moose Pond	Denmark	*	!		*✓	*✓	!					2	2	1	2
	S23	Below Hiram Falls Dam	Hiram			*!	✓	✓						2	1	1	0
	OS9	Cornish Station	Cornish	*	!	*!	✓	✓						2	2	2	0
	S10	Off Route 11	Standish	*	!	!	✓	✓						2	2	1	0
	S24	Below Watchic Lake					✓	✓						2	0	0	0
Ossipee River	O7	NH-ME Boarder	Effingham, NH		!		✓	✓						2	1	0	0
	O8	Downstream of Kezar Falls Village	Parsonsfield		!	*	✓	✓	!					2	2	1	0
	O22	Bridge Street Bridge	Hiram		!		✓	✓	!	!				2	3	0	0
Little Ossipee River	LO11	Balch Lake, Whitehouse Rd	Wakefield, NH		!	*	✓	✓				*		2	1	1	1
	LO11-1	Beside Balch Pond Dam	Newfield		!	!	*✓	✓		!				2	3	1	0
	LO12	Downstream of Balch Pond Dam			!		✓	✓	!					2	2	0	0
	SP13-1	Shapleigh Pond Boat Launch	Shapleigh	*	!	!	✓	✓						2	2	1	0
	LO13	Below Shapleigh Pond		*	!	*	✓	✓	!					2	2	2	0
	LO14	Lake Arrowhead, Silver Lane	Limerick		!	!	✓	✓						2	2	0	0
	LO14-1	Above Lake Arrowhead Dam			!	!	✓	✓						2	2	0	0
	LO25	Little Ossipee Pond	Waterboro		*!		✓	✓						2	1	1	0

Reach	Site ID	Site Description	Town	Physical Parameters			Chemical Parameters							Trend analysis results			
				pH	Temp	Turbidity	DO (mg/l)	DO (% sat)	TP	PO_4^{3-}	TKN	*E. coli*	Alkalinity	✓	!	*	*
	LO15	Doles Ridge Rd	Limington	*	!	!	*✓	✓	!					2	3	2	0
	LO16	Hardscrabble Rd	Limington		*!	!	*✓	✓						2	2	2	0
Lower Saco-Freshwater	S17	Bonny Eagle Island	Buxton		!	!	✓	✓						2	2	0	0
Lower Saco-Freshwater	S18	Above Bar Mills Dam	Buxton	*	!	!	*✓	*✓				✓		3	2	1	2
Lower Saco-Freshwater	S19-A-U	Skeleton Head Pond Dam	Buxton	*	!	!	✓	✓				*		2	2	1	1
Lower Saco-Freshwater	S28	Across Bridge from Homestead Campground	Saco		!	!	✓	✓	*					2	2	0	1
Lower Saco-Freshwater	SPB26	Swan Pond Brook	Biddeford			!	✓	✓				*✓		3	1	1	0
Lower Saco-Tidal	TB27	Thatcher Brook	Biddeford			!	*	*				✓		1	1	2	0
Lower Saco-Tidal	S20	South Street	Biddeford	*	!	!	✓	*✓				✓		3	2	1	1
Lower Saco-Tidal	S30	Irving Street Boat Launch	Saco		!	!	✓	✓	!		!			2	4	0	0
Lower Saco-Tidal	S21	Public Boat Launch, Front Street	Saco	*	!	!	✓	✓				✓		3	2	1	0

✓ *Exceeded State standards*

! *No State standards for parameter, but exceeded natural background levels likely as a result of human activities*

* *Degrading water quality trend (Mann-Kendall tests)*

* *Improving water quality trend (Mann-Kendall tests)*

WATER QUALITY ANALYSIS: DISCUSSION

Further discussion of the broader meaning of these results is essential for interpreting and incorporating this information into goals and actions. Below, factors that generally influence each water quality parameter are described and evaluated for their potential influence on the SRCC monitoring data. No discussion of these factors is complete without considering nearby human activities and land uses. A complete review of land use in the greater Saco River watershed or in the reaches is beyond the scope of this report, but general consideration of nearby or watershed land use can be essential to understanding both desirable and degraded water quality, as well as improving or worsening water quality parameters and indicators. Regional differences are also essential to consider, as generally speaking, land use varies by region and natural conditions like bedrock and surficial geology, soils, and vegetation also tend to vary by region.

pH, Alkalinity, and Acid Deposition

Acidic pH was only observed at one site across the entire Saco River network, despite the prevalence of decreasing pH trends in monitoring sites. Thirteen sites exhibited decreasing pH trends for at least a five-year span (the minimum interval required for the Mann-Kendall test) during the study period of 2001-2020, but none of the thirteen had a median pH value below 6.5. Decreasing pH trends are therefore neither strong enough nor consistent enough to be driving acidification to levels harmful for aquatic life. Numerous studies have documented the process of recovery from excessive acidic deposition (aka “acid rain”), which began to decline in the 1980s and accelerated with the Clean Air Act amendments in the 1990s. These new statutes led to tighter regulation in the production of sulfates in industrial areas, which in turn led to decreases in acid deposition, especially in the northeastern US. The regulations have been less successful in controlling the deposition of nitrates, which in addition to providing acidity results in enrichment of nitrogen. Lakes and rivers have recovered to some extent, but regional pH and alkalinity are still relatively low.

Factors Influencing Turbidity

Turbidity can be naturally high in waters with an abundance of colored compounds like tannic and humic acids, or in naturally high productivity waters with abundant algal growth. Human-induced increases in turbidity can be linked with erosion and sedimentation from eroding streambanks or lake/pond shorelines, stormwater runoff, or flow modifications that scour riverbanks. Productivity can also be driven to excessive levels by human-induced enrichment with nutrients (see Factors Influencing Nitrogen and Phosphorus below).

Factors Influencing Water Temperature

All but eight sites in the monitoring network exhibited median water temperatures greater than 19° C. Above this threshold, the warm water induces stress on coldwater fish species and reduces the saturation concentration of water. In other words, warmer water holds less oxygen, making “temperature pollution” a critical threat to aquatic ecosystems. Relatively shallow and stagnant waters are more susceptible to high temperatures unsafe to aquatic life, while deep lakes and rivers draining forested landscapes are less susceptible and contain sufficient cold water refuges for aquatic life.

Several factors can influence temperature in rivers and lakes and cause warming trends. Modification of riparian vegetation can lead to the loss of shade trees along shorelines, which allows for more sunlight to be absorbed in rivers and lakes and warm the receiving waters. Impervious surfaces that absorb the sun's rays on their dark asphalt or concrete surfaces can heat rainwater as it runs off, blunting the cooling effect of rain in the warm summer months. Wastewater treatment plants and large industrial water users can release water into rivers that has been warmed by sitting in settling or treatment tanks or been used to cool industrial processes (this form of temperature pollution is highly regulated by point source pollution discharge elimination regulations, which cover both wastewater plants and industrial dischargers). Dams and impoundments can artificially heat water by creating slow-moving open waters with no shade, and by spilling warmed water over the top of the dam (many dams are required to release colder bottom waters to address exactly this problem). Lastly, climate change and the warming air temperatures that result from human-induced heating of the global atmosphere are leading to warming of surface waters as well.

Factors Influencing Dissolved Oxygen

Dissolved oxygen median values and trends were largely indicative of good dissolved oxygen content in the river/stream and lake/pond sites. Only two sites had median values of DO concentration or saturation that fell below Maine Class A or Class SB (for estuarine/marine waters) standards. Three sites had significant increasing trends during the time period studied, MPB22, S20, and S18. Only four sites had significant decreasing trends in either DO concentration or DO percent saturation.

Thatcher Brook in Biddeford (TB27) is one of the sites that had a significant downward trend in DO saturation and a median value that is below state standards for DO. Thatcher Brook drains a watershed of approximately eight square miles in Arundel and Biddeford that is highly developed with urban and suburban areas. The Maine Department of Environmental Protection listed Thatcher Brook on the 303(d) list of impaired water bodies in Maine under the Clean Water Act, for failing to meet its statutory water quality designation under Class B, both for aquatic life support and for the presence of fecal indicator bacteria (City of Biddeford 2015). Aquatic macroinvertebrate organisms such as insect larvae are periodically monitored by biologists to determine whether a waterbody supports a normal abundance and diversity of these important organisms. A lack of sufficient dissolved oxygen is a key stressor that can limit the macroinvertebrate community in a waterbody to only the most tolerant organisms. It is likely that low dissolved oxygen played a role in impacting aquatic life in Thatcher Brook. It is important to note that the trend observed in Thatcher Brook is based on samples taken from 2002 to 2012. The SRCC stopped monitoring at Thatcher Brook in 2013 when the Maine DEP determined that Thatcher Brook was an impaired water body.

Low dissolved oxygen can have many root causes, some natural and some human-induced. Deep, stagnant water can often have dissolved oxygen depleted through natural processes; the breakdown of organic matter consumes oxygen. Excessive nutrients can lead to runaway algal growth, aka "blooms," that contribute excessive organic matter to the water; when these algae die and cease photosynthesis (which adds dissolved oxygen to water), their biomass sinks and decomposes, depleting oxygen in the water and potentially stressing or killing aquatic life.

Factors Influencing Nutrients: Phosphorus and Nitrogen

In addition to the significant trends in degrading water quality at the site on Dole Ridge Rd in Limington, Maine (LO15), this site also had a median TP value that exceeds the eutrophication threshold. This area is largely a rural, forested area with undulating topography and some small-scale agriculture (i.e. orchard). However, there are numerous sand pits in the surrounding area around Lake Arrowhead, the largest of which is very close to LO15 on Cape Rd. It appears that the water quality along the Little Ossipee River decreases downstream of Lake Arrowhead.

Many factors could be responsible for enrichment with TKN and other forms of nitrogen, including both human-caused and natural sources. As an example of a natural nitrogen source, certain wetlands naturally produce high organic nitrogen levels as productive vegetation decomposes and breaks down into constituent parts such as organic nitrogen, which is among the compounds measured by the TKN analysis along with ammonium/ammonia. The abundance of intact wetlands in the relatively remote and pristine Moose Pond Brook site (MPB22) at the outlet of Moose Pond may explain why TKN values are so high at that site. Wetlands are less associated with high phosphorus concentrations, which is also observed at MPB22, but phosphorus can also be released by the breakdown and decomposition of organic matter. TP is a bulk measure of all types of phosphorus in water: particulate, dissolved, organic, and inorganic. Inorganic phosphorus is mostly composed of orthophosphate, which is more likely to stay dissolved and bioavailable in low-oxygen waters.

Many human-caused disturbances to waterbodies may result in high values of TKN or other forms of nitrogen such as nitrate. Acid deposition from industrial air pollution has been shown to affect the entire northeastern U.S. and has enriched nitrate levels in pristine, remote ponds and urbanized river valleys alike, in the form of nitric acid. Nitric acid can be carried in dust and aerosol particles (dry deposition) or dissolved in rain or snow (wet deposition), but when it reaches surface waters it supplies both acid hydrogen ions (H^+) and nitrate. Stormwater runoff from impervious surfaces carries both wet and dry deposition from the land surface directly to receiving waters, instead of allowing the nitrate contained in the runoff to infiltrate into groundwater and be biologically processed by land-based organisms in the soil and vegetation. Nitrate data are not available for the SRCC monitoring network from 2001 to 2020 but nitrate analysis has been conducted beginning in 2021 for a selection of ten sites (i.e., OSC4-B, LWP5, O8, O22, LO11-1, LO14-1, SP22 (new site), LO16, S28, S20). The SRCC is currently in the process of expanding the program and increasing sampling frequency and sites.

Agricultural fertilizer is a common source of human-induced nitrogen (and phosphorus) enrichment in lakes and rivers. Ammonium/ammonia and nitrates are the most frequently applied inorganic nitrogen compounds in fertilizers. Similarly, septic systems introduce organic nitrogen, ammonium/ammonia, and nitrates into soils. When functioning properly, septic systems process TKN to nitrate and allow nitrate to be processed in turn by plants and microorganisms in the soil, but when malfunctioning or when occupying poor sites such as waterlogged or flooded soils, septic systems can potentially release all forms of nitrogen directly where it can be carried by stormwater runoff or groundwater flow.

Factors Influencing *E. coli*

E. coli median values were generally indicative of good water quality in the monitoring network, falling below the Class A geomean standard (used for comparison purposes only) at all but three sites. For those three sites, different factors are likely to be influencing *E. coli* abundance owing to the very different nearby land uses at the Old Course Saco River, a waterbody surrounded by agriculture and timber, and Swan Pond Brook and Thatcher Brook in urbanized coastal watersheds.

All warm-blooded animals contribute *E. coli* to the land or water where they deposit their solid waste. Natural waters can be thought of as having a "budget" of fecal indicator bacteria like *E. coli* that they can process and break down; when human-induced increases in fecal waste exceed this budget, the waterbody can no longer process all the waste and the *E. coli* numbers increase.

CONCLUSIONS AND RECOMMENDATIONS

As the results of this water quality analysis show, the SRCC has designed an effective monitoring program to address the goal (identified in the 2020 QAPP) to develop a long-term dataset that can be used to summarize water quality at many sites along the Saco River and its tributary streams, lakes and ponds. The data set was also successfully used to identify and statistically evaluate trends in key water quality parameters. FBE took a forward-looking approach to making recommendations that can further improve the interpretive power of the growing SRCC dataset.

In designing our recommendations for the SRCC monitoring program, we focused on key data gaps identified by the report FBE produced in 2020 in collaboration with the Saco Headwaters Alliance, Watching Our Waters: A Report on Water Resource Monitoring in the Saco Headwaters Watershed. This 2020 report focused on data gaps and monitoring needs in the Saco headwaters above the Saco-Ossipee confluence – an area of substantial overlap with the SRCC service area. Below, we examine the consistency of the SRCC monitoring program with key actions and recommendations identified in that report, particularly Actions 3 and 4 that are most relevant to the SRCC's goals.

Watching Our Waters Action #3. Expand surface water quality monitoring efforts to cover more of the Saco's major tributaries and headwater streams, and to cover winter conditions.

Water quality sampling on the Saco River should continue to be a core function of the monitoring program, with the SRCC monitoring stations and USGS streamgaging stations as the obvious candidates to be considered core sites. Monitoring the tributaries and headwater streams is also extremely important because data at a far downstream site may not capture the signal of a threat in a distant upland subwatershed. Thus, a range of drainage sizes and land uses should be prioritized, as should certain valuable resources. The Swift River and Ellis River watersheds in particular should receive monitoring attention. Water quality sensors that record, at a minimum, temperature and conductivity, should be installed where practical at monitoring stations, so that a continuous record of dense observations during all flow conditions (e.g. flood, baseflow, low flow/drought) can be maintained. The choice of sensors should reflect the state of the technology in 2020 and beyond, and the data should be hosted online and publicly available. **We recommend that SRCC continue to pursue opportunities to partner and coordinate with other monitoring institutions to align and leverage water quality monitoring program aims and goals. SRCC long-term sites are excellent**

candidates for expanded monitoring such as real-time temperature/conductivity sensors, especially when aligned with USGS or state agency streamgaging stations. A corollary to this is ensuring that SRCC sites are aligned with existing streamgaging stations, as stream discharge records greatly expand the interpretive power of water quality grab sampling. Water quality trends can be compared to discharge levels to observe characteristic patterns. In addition, concentration values from grab samples can be used in combination with discharge values to calculate loads (mass per time), a key variable for downstream water quality. Site OS9 is one such example of an SRCC site that is in close proximity to a USGS streamgaging station.

Watching Our Waters Action #4: Ensure the continuity of a core set of water quality parameters to be tested and add selective parameters based on specific research or regulatory questions.

At its core, a water quality monitoring program for the Saco Headwaters watershed must be able to detect changing conditions in chronic threats and must also adapt to developing threats. Routine grab sampling will always have a crucial role to play in both of these functions, and the parameters to be analyzed should all serve multiple purposes and/or assess multiple threats. For example, nitrogen parameters measure the presence of contamination from wastewater, stormwater, and agricultural runoff, and allow evaluation of the risk of nutrient enrichment and eutrophication. Major anion analysis yields chloride data that is essential for assessing road salt contamination, but also sulfate which is a key component in acid rain.

The recommended list of core water quality parameters for laboratory analysis is as follows: Major anions (chloride, sulfate, nitrate) and cations (sodium, potassium, magnesium, calcium); Ammonia/ammonium; Total dissolved nitrogen; Dissolved organic carbon; Soluble reactive phosphorus; Total phosphorus; Total nitrogen. **SRCC parameters differ slightly from this list. Most notably, the SRCC does not collect anions/cations or dissolved organic carbon. The SRCC added nitrate to their sampling in 2021, and chloride is slated to be added to the parameter list in 2022. FBE recommends that additional parameters be added from this list, with dissolved organic carbon/total nitrogen a top priority and the full suite of anions/cations a lower priority.**

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