Monitoring Water Quality in Niantic River Tributary Streams from 2012 through 2022

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Niantic River Watershed Committee, Monitoring Subcommittee

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Photographs:

Cover page: Latimer Brook at its dam in the Flanders section of East Lyme, a sampling location during all 10 years of this study. The USGS Latimer Brook streamflow gage, which is located downstream of the dam on the far side of I-95, recorded a discharge of 101 cfs at the time the photograph was taken. At lower discharge volumes (ca. 35-45 cfs during our studies, but less now due to a large sedimentation event occurring in the impoundment from Tropical Storm Ida in September 2021 that decreased depth), all water flows through a notch found in the center of the dam. Under very high flows or specifically during spring, water is also released through the dam's fishway (located beyond the bottom of the photograph and not shown here), primarily operating to allow for the passage of alewives to upstream spawning areas in the brook.

This page: Looking downstream in Latimer Brook from a point about 100 feet south of the Chapman Drive bridge in East Lyme. Although its immediate riparian corridor is largely wooded, the brook passes through increasing density of housing and commercial development from its upstream sources in Montville and Salem to its discharge into the Niantic River in East Lyme-Waterford.

[Both photographs were taken on January 28, 2023]

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LIST OF ACRONYMS AND ABBREVIATIONS

&	and
~	approximately
^{o}C	degrees Celsius, a measure of temperature
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
+	mathematical symbol used to indicate addition
-	mathematical symbol used to indicate subtraction
x	mathematical symbol used to indicate multiplication
/	mathematical symbol used to indicate division
=	mathematical symbol used to indicate equality
±	mathematical symbol meaning “plus or minus”
*	mathematical symbol used to indicate achieving a probability level of 0.05
**	mathematical symbol used to indicate achieving a probability level of 0.01
µS/cm	microSiemens per centimeter, a measure of specific conductance
%	percent
ANOVA	a statistical test, Analysis of Variance
BLD	below limit of detection
BMP	Best Management Practices
cfs	cubic feet per second
CI	95% confidence interval, a statistic that represents the range that theoretically contains the true values at a 95% level of certainty
cm	centimeters
CMB	Cranberry Meadow Brook
CMB-L	Lower Cranberry Meadow Brook sampling station
CMB-U	Upper Cranberry Meadow Brook sampling station
CT	Connecticut
CT DEP	Connecticut Department of Environmental Protection (name of CT DEEP prior to 2011)
CT DEEP	Connecticut Department of Energy and Environmental Protection (name of CT DEP after 2011)
DIN	dissolved inorganic nitrogen = ammonia + nitrate + nitrite
DO	dissolved oxygen
DPO	Darrow Pond discharge outlet sampling station
E	unknown error
E. coli	*Escherichia coli* bacterium species
ECCD	Eastern Connecticut Conservation District
e.g.	for example (*exempli gratia*)
et al.	and others (*et alii*)
etc.	and the rest (*et cetera*)

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

exp	exponential; the term "exp(x)" is the same as writing ex or e^x or "e to the x" or "e to the power of x"
F crit	output from ANOVA, critical value of the F statistic, a specific value comparing an F-value to determine statistical significance
F value	F statistic output from ANOVA, the ratio of between group variation and within group variation
Fig.	figure
GLM	a statistical test, General Linear Model
HOBO® Pro V2	a water temperature data logger manufactured by the Onset Computer Corporation
I-95	Interstate Highway 95
i.e.	that is (*id est*)
in	inch or inches
kg	kilograms
lbs	pounds
LB	Latimer Brook
LB_DS	downstream of the confluence of Latimer Brook and Cranberry Meadow Brook
LB_US	upstream of the confluence of Latimer Brook and Cranberry Meadow Brook
ln	mathematic term meaning the natural logarithm transformation
MEL	Dominion Energy's Millstone Environmental Laboratory
mg/L	milligrams per liter, a unit for nutrients and dissolved oxygen, equivalent to ppm
mi	mile or miles
mi^2	square miles
microS/cm	microSiemens per centimeter, a measure of specific conductance
mL	milliliters, a measure of volume
n	number of samples
N	used when referring to an acid: normal, a unit measure of the concentration of acid
N	used when referring to a substance, the scientific notation for nitrogen
nitrate	nitrate as nitrogen (N)
nitrate-N	nitrate as nitrogen (N)
nitrite-N	nitrite as nitrogen (N)
NRWC	Niantic River Watershed Committee
NRWC MSC	Niantic River Watershed Committee Monitoring Subcommittee
NRWPP	Niantic River Watershed Protection Plan
NS	non-significant
NWS	National Weather Service
OMB	Oil Mill Brook or Oil Mill Brook sampling station
p	p-value, statistical term defined as the probability under the assumption of no effect or no difference (null hypothesis); obtaining a result equal to or more extreme than what was actually observed
pH	a measure of acidity (low = acidic; high = alkaline; pH of 7 = neutral; scaled from 0 to 14)

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

ppm	parts per million, a unit for nutrients and oxygen, equivalent to mg/L
P-R	precipitation-related sampling
r	Pearson correlation coefficient, a statistic that indicates the strength and direction of a relationship and used to identify patterns
R^2	coefficient of determination, a statistic that indicates the strength of a model
RBV	Stream Riffle Bioassessment by Volunteers program, a citizen monitoring program managed by CT DEEP
SAS	Statistical Analysis System, a comprehensive software system for data management, analysis, and reporting
SB	Stony Brook
SB-L	lower Stony Brook sampling station
SB-U	upper Stony Brook sampling station
SD	standard deviation, a statistical measure of the amount of variation or dispersion of a set of values
su	standard unit, used to denote the unitless nature of pH
t-test	statistical test, used to compare the means of two groups
T-B	tributary-based sampling
temp	temperature
U.S.	United States of America
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WELSCO	Waterford-East Lyme Shellfish Commission
WQ	water quality
YSI	Yellow Springs Instrument Company, a manufacturer of WQ sampling equipment now owned by Xylem Analytics

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Monitoring Water Quality in Niantic River Tributary Streams from 2012 through 2022

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Niantic River Watershed Committee, Monitoring Subcommittee

EXECUTIVE SUMMARY

The Niantic River, a tidal estuary in southeastern CT, has a watershed area of 31.3 mi^2 located within four towns, including Salem, Montville, East Lyme, and Waterford. The largest Niantic River tributary is Latimer Brook, which has its sources in Salem and Montville, flows through much of East Lyme and forms this town's boundary with Waterford when entering the Niantic River. The largest tributary of Latimer Brook is Cranberry Meadow Brook, which is in East Lyme. The second and third largest Niantic River tributaries are Oil Mill Brook and Stony Brook, both located in Waterford.

For nearly two decades the Niantic River Estuary has been designated by the CT Department of Energy and Environmental Protection as impaired due to excessive amounts of nutrients and bacteria entering the river. The Niantic River Watershed Committee was concerned about environmental impairments to the Niantic River affecting water quality, which also might affect eelgrass beds, promote algal blooms, and contribute to hypoxia in deeper waters of the river. Having a lack of water quality data, we initiated a monthly sampling program in Niantic River tributaries in April 2012. Six stations established in Latimer Brook ranged from the farthest upstream located just below the Beckwith Reservoir dam in Montville to the most downstream station at the Latimer Brook dam in Flanders, just upstream of the Niantic River. There was also one station found in lower Cranberry Meadow Brook. Additional stations were established at the outlet of Darrow Pond in May 2012, in upper Cranberry Meadow Brook in October 2012, and another one in lower Latimer Brook in February 2014. After a preliminary analyses of data collected through 2014, the two most upstream stations in Latimer Brook and the Darrow Pond outlet station were dropped in April 2014 with sampling then starting at single sites in both Oil Mill and Stony Brooks. This sampling continued through March 2017.

The tributary-based sampling showed that water temperatures and dissolved oxygen showed expected seasonal variations and were not significantly different among stations. pH levels decreased from upper to lower stations in Latimer Brook and were relatively low in upper Cranberry Meadow Brook and Stony Brook. Specific conductance was highest in Stony Brook with much overlap in the values found at all other stations. Nitrate concentrations were highest during summer and winter months. Nitrate increased when proceeding downstream in Latimer Brook with the two stations in Flanders having significantly greater concentrations than the other stations, where values were similar, except for upper Cranberry Meadow Brook, which had significantly lower nitrate concentrations than the other stations.

In Summer 2017, water quality sampling shifted to a quarterly schedule with samples taken only at the Latimer Brook dam over a period of days just before and after precipitation events. The precipitation-related sampling continued through Spring 2022. During this sampling, the greatest Latimer Brook streamflows mostly occurred in Winter with the lowest found during Summer. Most rainfall events increased streamflow only for a few days with flows eventually returning to approximately the same levels present before precipitation started. Most water quality parameters were highly correlated among themselves and with streamflow values. When about 8 years of daily Latimer Brook streamflow records available from the United States Geological Survey were examined, a mean daily flow of 29.46

cfs was calculated. About one-half of the daily mean discharge values were less than 20 cfs with few daily mean discharge values greater than 110 cfs.

Specific conductance values decreased with increasing streamflow in Latimer Brook. This relationship implies that when changes occur in streamflow, they produce a proportional and linear change in specific conductance values with rapid decreases occurring under increasing stream discharge volumes. This also indicates that the ionic composition producing the conductivity becomes diluted when stream water volumes become larger. This process continues proportionately until flow volumes become large enough that specific conductance values finally level off, perhaps due to increasing presence of sediments in high flows and, therefore, additional ionic loading. Specific conductance values and nitrate concentrations appear to vary similarly. Like specific conductance, nitrate concentrations exhibited a power curve relationship with streamflow values, with nitrate concentrations decreasing at higher stream flows. Nitrate concentrations showed a significant negative linear relationship with streamflow when a natural logarithmic transformation was applied.

Overall, the 10 years of sampling in four Niantic River tributary streams demonstrated that water quality parameter values were consistent in supporting desirable aquatic life forms. This notion is supported by data available from other sampling programs conducted by CT DEEP and other professional scientists, and through citizen science sampling programs. Water temperatures appear to have remained relatively stable in recent years, although warmer summers and any increasing trend over time may affect the suitability of these streams for trout, particularly in Latimer Brook. Dissolved oxygen concentrations are mostly high and show relatively high temperature-dependent percent saturation levels. In the few instances when low dissolved oxygen concentrations were observed during dry summers at the upper Cranberry Meadow Brook station, fish were observed, indicating no adverse effects. Although water in tributary streams was consistently acidic, pH values were not within ranges that would have affected aquatic organisms. Variability found in pH during precipitation-related sampling may reflect acidic rain and other terrestrial inputs resulting from rainfall.

Given the nutrient-related impairments noted for the Niantic River, the measurement of nitrate concentrations in the tributary streams were of great importance in this study. In a comprehensive study of nitrogen in Niantic River tributary streams, Mullaney (2013) reported nitrate concentrations increased when proceeding downstream in Latimer Brook from its upper reaches to its dam in Flanders, as was found in this study. This may be related to increased housing and commercial property development occurring in this area of the Latimer Brook watershed, where most properties discharge sanitary wastes into septic systems and there are many stormwater discharges. Lower Cranberry Meadow Brook has a higher concentration of nitrate than does the upper reaches of Latimer Brook. Similarly, this brook flows through increased housing as well as agricultural areas. However, this input of nitrate is offset by a smaller water volume added from Cranberry Meadow Brook after the two streams join. On average, we determined that Cranberry Meadow Brook contributes about 38% of the combined flows of these two streams and upper Latimer Brook about 62%. Nitrate concentrations in Oil Mill and Stony Brooks were found to be lower than in Latimer Brook and combined with their lower streamflow volumes, represent smaller inputs of nitrogen into the Niantic River, which was also a finding of Mullaney (2013). Our estimates of nitrate concentration at the Latimer Brook Dam were remarkably like Mullaney's estimates. Although our estimates of the flux of nitrogen from Latimer Brook into the Niantic River were about 50% higher than Mullaney's estimate, our streamflow calculations were also much higher than his and may represent more typical discharges of water from the brook into the river.

INTRODUCTION

The Niantic River (NR) is a lagoon-type tidal estuary formed from a drowned river valley located in southeastern Connecticut and discharging its waters into Long Island Sound (CT DEP 2006). The NR is bounded by Waterford to the east and East Lyme to the west (Fig. 1). Its watershed encompasses about 31.3 mi^2 found within four towns: Salem, Montville, East Lyme, and Waterford.

The largest freshwater tributary of the NR is Latimer Brook (LB), having a drainage basin of about 17.6 mi^2 (Mullaney 2013). LB has its headwaters within New London Water & Water Pollution Control Authority property and privately held forested lands in Salem and Montville having restricted public access. Fairy Lake and Barnes and Bogue Brook Reservoirs feed Beckwith Reservoir, the most downstream of these water bodies. The discharge from Beckwith Reservoir marks the start of free-flowing LB. The outflow from Horse Pond (13 acres; Jacobs and O'Donnell 2002) in Salem joins LB in this area. LB then flows downstream from Montville into East Lyme, which is a landscape with increasing housing and commercial development, roads, and agricultural drainage. Important tributaries of LB include Cranberry Meadow Brook (CMB), which has a drainage area of about 2.47 mi^2 (Mullaney 2013), and the discharge from the outlet of the 47-acre Darrow Pond (ECERT 2013), both of which are in East Lyme. LB continues into the more developed Flanders area and flows over a small dam having a fishway used primarily by anadromous alewife, but also sea-run brown trout. Catadromous American eel are also found in LB and other NR tributaries along with other freshwater fishes (CT DEEP Undated a). LB enters the NR through Banning Cove in the Golden Spur locality of East Lyme and Waterford.

Two other important NR tributaries are in Waterford, including Oil Mill Brook (OMB), the second largest (watershed area of 5.7 mi^2; Mullaney 2013), which is fed from the outlet of Lake Konomoc. Lake Konomoc is a City of New London Public Utilities water supply reservoir with a largely protected watershed, although it does have CT Route 85 passing along its western shoreline. Stony Brook (SB), which is the third largest tributary (2.86 mi^2; Milone & MacBroom 2009), has headwaters in wetlands just southeast of Route I-395 in Waterford. Its upper watershed is largely undeveloped with most homes and commercial development found in the southern portion of its watershed. Both OMB and SB directly enter the NR in Waterford, into Banning Cove and Keeney Cove, respectively.

Under the auspices of the Connecticut Department of Environmental Protection (CT DEP; now the Department of Energy and Environmental Protection: CT DEEP) Office of Long Island Sound and in cooperation with the four watershed towns, an environmental consulting firm, Kleinschmidt Associates, Inc., drafted the NR Watershed Protection Plan (NRWPP) in 2006 (CT DEP 2006). The NRWPP was updated in 2020 (Fuss & O'Neill 2020). The NRWPP raised concerns over nonpoint source pollution within the watershed as the NR does not currently meet Connecticut Water Quality standards. Fuss & O'Neill (2020) noted that the NR Estuary was assessed as impaired by CT DEEP for nearly two decades. In CT DEEP (2018), it was listed as being impaired for aquatic habitat, direct consumption of shellfish and recreation. These deficiencies are due to elevated levels of fecal indicator bacteria and some degradation of aquatic life, such as a significant loss of bay scallops and changes to the fish community.

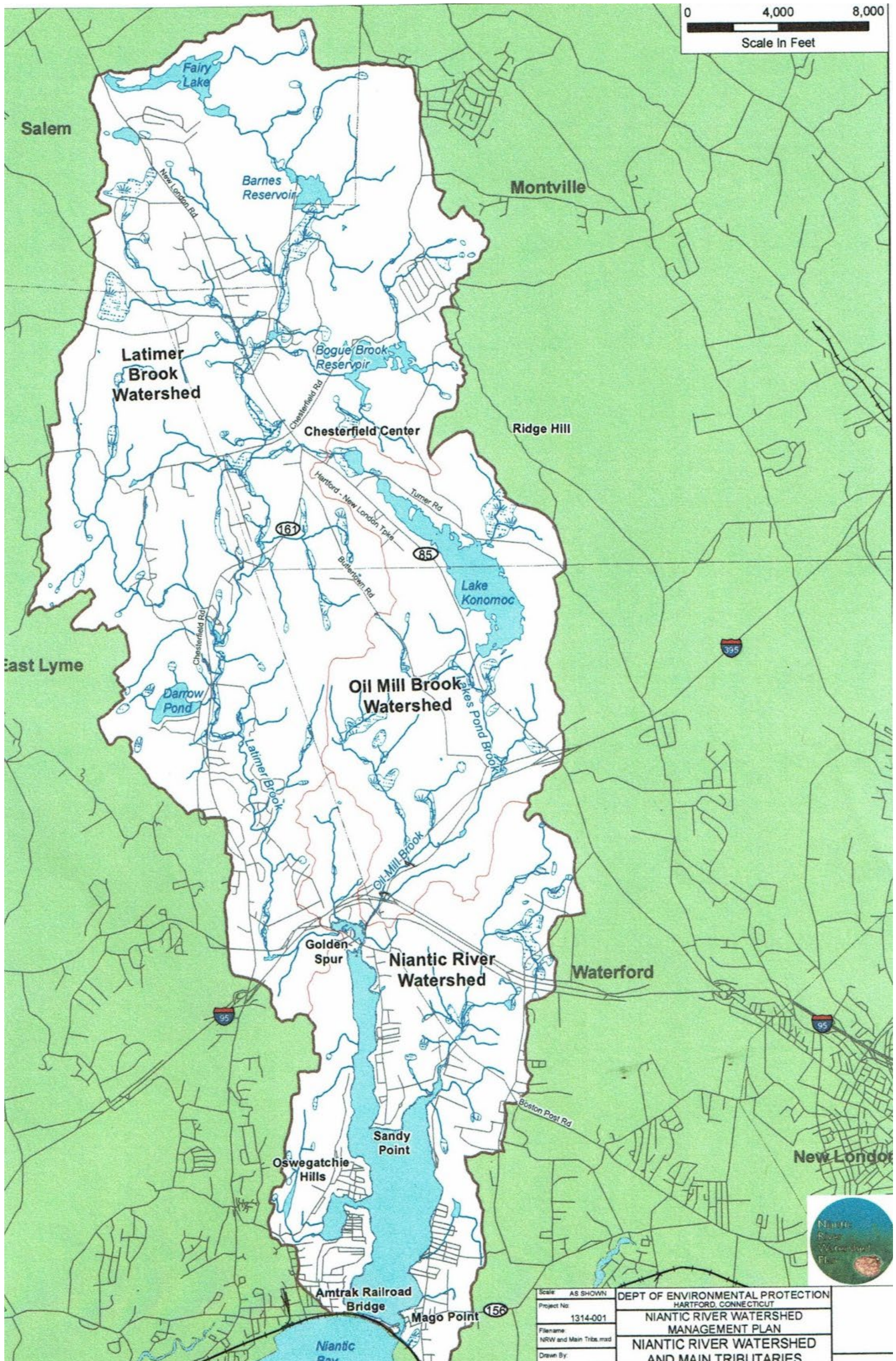

FIGURE 1. Map of the NR Watershed showing major streams, water bodies, and other geographic features (figure first presented in CT DEP 2006).

The most likely reason for these harmful changes was an excessive amount of nutrients entering the river, particularly the various types of nitrogen. The NR's major tributaries were also listed in CT DEEP (2018), with two tributaries having three segments listed as impaired, including the lower 0.23 miles of SB south of its crossing at U.S. Route 1, which was impaired for recreation by *Escherichia coli* bacteria; the lower 4.23 miles of LB south of its confluence with CMB, which was impaired for recreation by *E. coli* and aquatic life from flow regime modifications; and the 3.43-mile segment of LB between Beckwith Reservoir and its confluence with CMB, impaired for aquatic life by flow regime modifications.

As one of the recommendations of the NRWPP, the Niantic River Watershed Committee (NRWC) was formed in 2009. The NRWC is made up of members appointed from the four watershed towns. We have an *ex officio* member from CT DEEP and a Watershed Coordinator, who is associated with the Eastern Connecticut Conservation District (ECCD). Our mission is to restore good water quality and preserve the environment within the watershed by promoting inter-municipal cooperation, developing sound land use practices, mitigating pollution, and supporting all approved usages.

METHODS AND MATERIALS

Water Quality Sampling Frequency and Stations

Due to concerns about excess nutrient input into the NR estuary potentially affecting eelgrass beds and promoting noxious algal blooms and a lack of water quality (WQ) information as noted in the NRWPP, the NRWC initiated a sampling program in the freshwater tributaries of the NR. A high priority goal was to examine the concentration of nitrate-nitrogen (henceforth termed "nitrate" within most of this report) entering the NR from its freshwater tributaries. Therefore, we initiated WQ monitoring in the NR tributaries to characterize the health of these streams and find locations where the greatest amounts of nitrate are being introduced. With knowledge of WQ deficiencies and identification of where nitrate concentrations are highest, remedies could be proposed to remediate adverse conditions.

For our first step, as the chair of the NRWC Monitoring Subcommittee (NRWC MSC), I drafted a sampling plan and field data sheet, both of which were reviewed and approved by the Watershed Coordinator and the NRWC MSC. We followed our sampling plan protocols to maintain consistency and quality of the data collected. In the first phase, sampling occurred monthly over a 5-year period from April 2012 through March 2017.

We initially selected WQ sampling stations in LB and lower CMB (Figs. 2 and 3; Table 1). In the southern LB watershed these included: Station 1 at the LB dam in Flanders, an area including a highly developed commercial district; Station 2, located in a dense residential area; and Stations 3 and 4, both located farther upstream in East Lyme, also in residential areas, although less densely developed than downstream. Upper watershed stream stations included Station 5 in the Chesterfield section of Montville, which runs through mostly agricultural, forested, and low density residential and commercial development; and Station 6, which receives water discharged from Beckwith Reservoir, the upstream-most location of LB accessible to the public in Montville. We also established a station (CMB-L) in the lowermost reach of CMB, a cool-water tributary to LB in East Lyme. The watershed of CMB includes much of the agricultural sector of East Lyme, less dense rural housing, and extensive forested areas, including the Nehantic State Forest. In May 2012, we initiated sampling at the outlet of Darrow Pond (DPO), a small pond with a largely undeveloped watershed. After a short run, the pond's outflow runs downhill, enters a culvert under Chesterfield Road (CT 161) in East Lyme, and drains into LB.

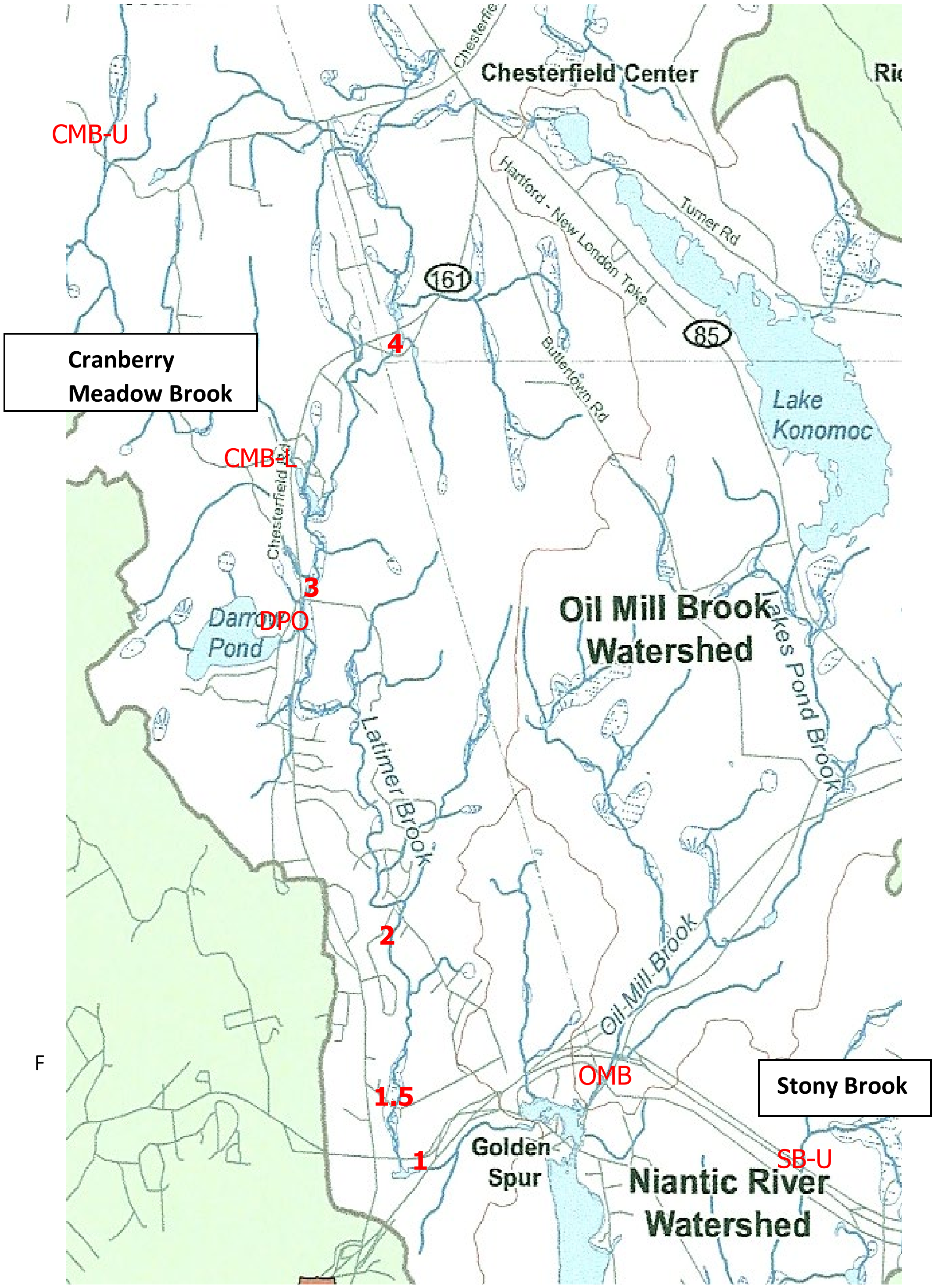

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FIGURE 2. Stations shown by red numbers and letters that were used for WQ sampling within the southern portion of the NR Watershed from April 2012 through March 2017. SB-L (not shown) is located just upstream of the U.S. Route 1 bridge over Stony Brook in Waterford. Station 1 was retained in the precipitation-related sampling program from Summer 2017 through Spring 2022. (Figure modified from one presented in CT DEP 2006).

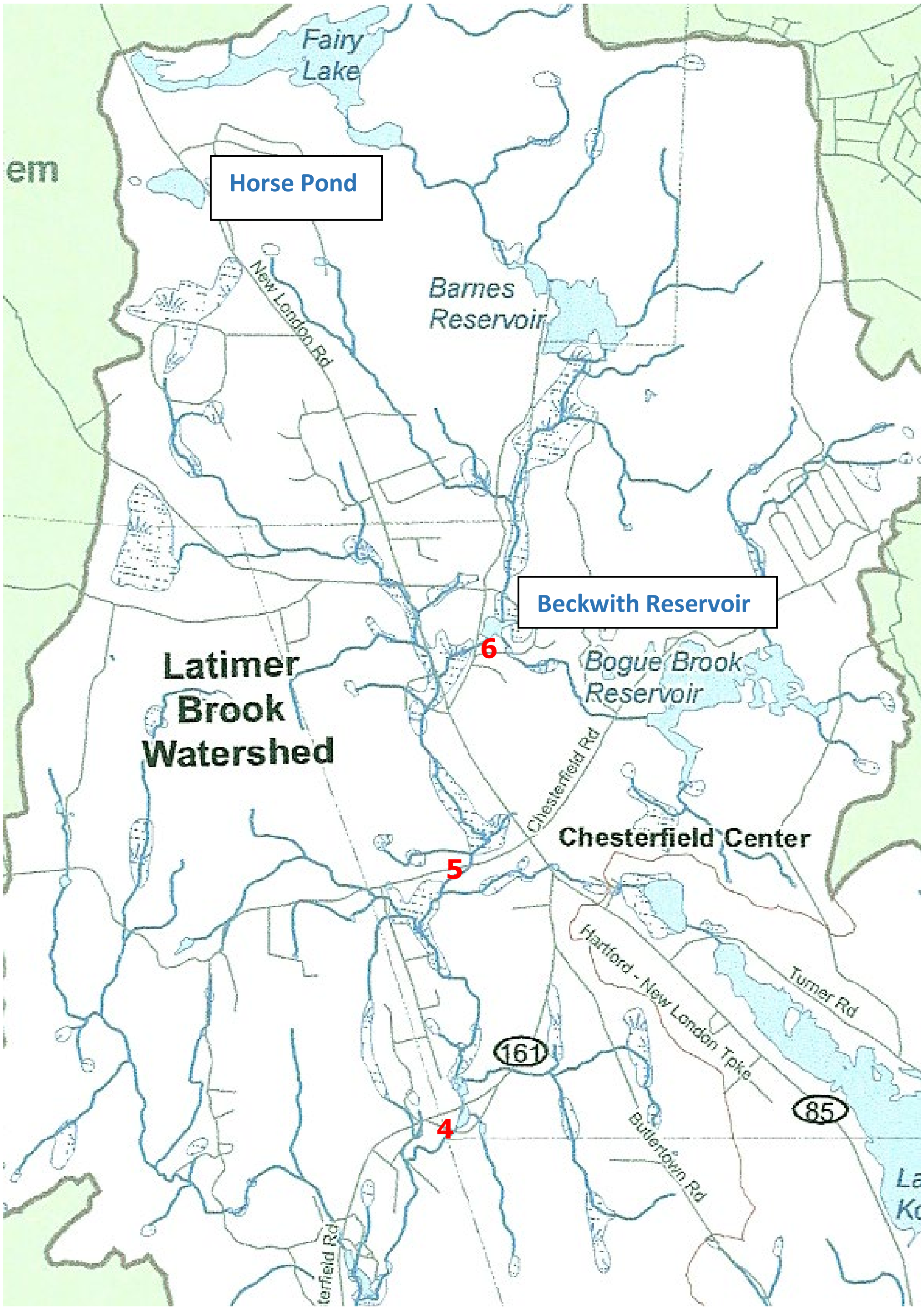

FIGURE 3. Stations shown by red numbers that were used for WQ sampling within the northern portion of the NR Watershed from April 2012 through March 2017. (Figure modified from one presented in CT DEP 2006).

TABLE 1. Location of sampling stations used to sample WQ in the Niantic River Watershed by the NRWC during 2012-22.		
Station	Location	Remarks
1	Immediately upstream of the Latimer Brook dam and fishway, on U.S. Route 1, East Lyme	The lowermost station in LB immediately upstream of a low-head dam with a small impoundment (see cover page for photograph). Influenced by relatively dense upstream commercial development, schools, and housing.
1.5	Immediately upstream of the Egret Road culvert, East Lyme	LB passes through considerable housing upstream to station 4, including the immediate area of this station.
2	About 25 yards upstream of the Colony Road culvert, East Lyme	LB passes through considerable housing upstream to station 4, although riparian corridor is largely wooded in many areas.
DPO	Immediately at the Darrow Pond discharge outlet on Mostowy Road, East Lyme	Largest natural pond within the lower LB watershed and unknown source of nutrients. Samples taken at concrete outlet discharge structure.
3	About 5 yards upstream of the Rocco Drive culvert, East Lyme	LB impounded slightly downstream of this location. Housing development, campground, and CMB input just upstream.
4	About 15 yards downstream of the Chapman Drive bridge, East Lyme	Downstream of two small impoundments near Silver Falls Road and some housing. Upstream LB areas otherwise less developed than downstream (see inside cover page for a nearby photograph).
5	Immediately upstream of the Grassy Hill Road Bridge, Montville	Relatively undeveloped upstream, although stream and tributaries are close to CT Route 85 and some commercial development. Downstream of this site LB flows through some agricultural areas.
6	About 50 yards downstream of the Beckwith Reservoir dam on Beckwith Road, Montville	Sample taken relatively close to Beckwith Reservoir in a constructed channelized streambed. No development upstream, which has three reservoir impoundments in the LB headwaters within protected lands.
CMB-L	About 10 yards upstream of the Walnut Hill Road Bridge over CMB, East Lyme	Presumed high-quality tributary of LB. CMB sampled on private property on the northeastern side of Walnut Hill Road culvert. Flow from upstream passes through light residential and agricultural development and considerable forested areas.
CMB-U	About 5 yards downstream of culvert at #82-84 Grassy Hill Road (west of its intersection with Walnut Hill Road), East Lyme	CMB accessed on private property in a small pool just downstream of the Grassy Hill Road culvert. Location is very close to wetlands and the headwaters source of CMB.
SB-L	About 10 yards upstream (north side) of the U.S. Route 1 bridge, Waterford	Sample taken on the E side of SB just upstream of the U.S. Route 1 bridge. Immediate area upstream is undeveloped.
SB-U	immediately upstream of the culvert (north side) at Parkway North, Waterford	SB passes through extensive forested area with the only nearby development the Sonalysts facility located to the east.
OMB	Immediately upstream of the culvert (north side) on Gurley Road, Waterford	Some housing in the area on upper Oil Mill Road and close by, but immediate area upstream is undeveloped. I-95 is nearby upstream with OMB flowing parallel to Oil Mill Road.

We employed a proactive management strategy with respect to WQ sampling by evaluating results as they were obtained. As such, following discussions with the NRWC MSC, the sampling plan was revised several times to gather additional information or address deficiencies in data collection. The exact positions of some stations were modified during the first few months of sampling but remained in their general vicinities. One of the unexpected findings early on was a relatively high nitrate concentration found at the CMB-L station. We thought that nitrate in lower CMB might have been introduced by homes and farms, including some having animals, through which CMB flows. As a result, in October 2012 we added a second, upstream station (CMB-U; Fig. 2), which was upstream of agricultural and more dense residential areas and close to the headwaters of CMB. We also found that nitrate tended to increase downstream as LB passed through the Flanders section of East Lyme, being highest at station 1 at the dam, so in February 2013 we added another station (1.5) in the lower LB area between the existing stations 1 and 2. Over the 5 years of sampling I occasionally had to chop through ice to sample some of our stations during winter when the streams or Darrow Pond froze over.

In April 2014, we also expanded our sampling to include OMB and SB, the second and third largest NR tributaries (Fig. 2). In doing so, we discontinued sampling in upper LB at stations 5 and 6 and DPO, the rationale for which is discussed later in this report. The initial sampling station in SB (SB-U) was in the upper watershed north of I-95 and Parkway North, but in August 2014 we moved this station farther downstream to SB-L, which is immediately upstream of the U.S. Route 1 bridge over SB. This was our final change to the stream stations sampled, the monitoring of which continued through March 2017, a 5-year period. Although there were some differences apparent in WQ parameters at the two SB stations, I combined their data in analyses (designated herein as station SB) as there were only four monthly samples taken at SB-U before the station was moved downstream to SB-L.

We established one additional water sampling site, although not in a brook or pond, but one that was in the surface discharge of a curtain drain. This drainpipe discharged a small volume of water onto the lawn of the property adjacent to our CMB-L station, about 10 yards away from the brook. We could not ascertain the source of this water except that it was most likely from groundwater flowing down the moderately steep elevation of Walnut Hill Road in East Lyme. On many occasions during our monthly sampling this discharge was dry. However, sometimes we observed a flow of water that soaked into the lawn a few feet from the discharge, but at other times this water reached CMB. These observations prompted us to sample this discharge to determine if it was a source of nitrate. We sampled the curtain drain discharge from January through May in 2016 and December 2016-March 2017.

No WQ sampling occurred during April-June 2017. Beginning in July 2017, we instituted a major change to our sampling by changing the sampling frequency from monthly to quarterly, where January-March was defined as Winter, April-June as Spring, July-September as Summer, and October-December as Fall. Sampling took place in association with major (ideally >1 in) precipitation events. Our focus was to determine how WQ parameters and nitrate concentration changed over time from precipitation and increased water flow in LB. The sampling location also changed from stations found throughout the NR watershed to only one, which was at the LB Dam in Flanders (i.e., station 1), the one closest to the NR. In scheduling this sampling, media forecasts had to be relied on, which often overestimated rainfall that eventually occurred in our area. Also, during very dry or drought periods quarterly samples were taken whenever possible, which sometimes depended upon my availability. Most of the time, this precipitation-related sampling consisted of a pre-rainfall sample followed by an immediate post-rainfall sample with other samples subsequently taken once during following days. Occasionally, additional rainfall during precipitation-related monitoring resulted in additional days of sampling, up to 7. This sampling continued through Spring of 2022, a 5-year period.

WQ Data Collection

In our monitoring, I recorded WQ data, including water temperature (^oC), dissolved oxygen (DO; mg/L), conductivity or specific conductance (µS/cm), and pH (standard units; su). A YSI Professional Plus meter was used to instantaneously measure these WQ parameters near the shore of the streams just below the water surface. We received this instrument via a loan from the U.S. Environmental Protection Agency (USEPA). In conjunction with laboratory staff, I periodically calibrated our YSI meters at Dominion Energy's Millstone Environmental Laboratory (MEL), a CT DEEP certified facility. From January through July 2016, I used a YSI 85 WQ meter borrowed from the MEL to measure DO as our YSI Professional Plus meter had a faulty DO probe. Due to issues with the YSI instrument or methodological errors, there were occasional faulty or unavailable readings for some WQ parameters, mostly DO and pH, but at times included all parameters, even water temperature. At these times, water temperature was recorded (nearest 0.5^oC) using an alcohol thermometer. The NRWC replaced the USEPA YSI meter by purchasing a new YSI Professional Plus instrument in January 2020, which alleviated most of the WQ equipment issues. In addition to WQ data recorded at each station, I also made observations of weather, relevant stream conditions (e.g., icing; water color), and any larger wildlife present.

I recorded conductivity for all samples taken from April 2012 through Fall 2019, but all these values were subsequently converted to specific conductance using a standard formula (USGS 2019):

Specific conductance = Conductivity / (1 + 0.02 x (Water Temperature - 25))

This conversion was made because water temperature affects conductivity readings, whereas specific conductance is conductivity that has been standardized to a water temperature of 25^oC. This made comparisons among samples taken at various times of the year more appropriate. As of Winter 2020, I recorded only specific conductance values when sampling.

I also determined the concentration (mg/L) of the nutrient nitrate-nitrogen on all dates sampled. At each station a water sample was taken and stored in a 125 mL polyethylene bottle. The concentration of nitrate was determined in these water samples shortly after the field collections were completed using a LaMotte SMART3 Colorimeter instrument and the cadmium reduction method (LaMotte Undated). Zero values for nitrate were recorded as "BLD" (Below Limit of Detection) in our database, but these samples were considered numerically 0 in data analyses I completed for this report. On rare occasions, I could not determine nitrate concentrations for some stations due to a lack of reagents.

One change to our nitrate sampling protocol was made during the precipitation-related sampling, which took place over many days. I immediately acidified the water sample by injecting approximately 0.25 mL of 1.0 N sulfuric acid into the 125 mL polyethylene water sample bottle and then froze the sample bottle. Before processing to determine nitrate concentration, water samples were thawed and allowed to warm up to room temperature. The LaMotte SMART3 Colorimeter cadmium reduction methodology was again used to determine nitrate concentrations. Other WQ data were recorded using the YSI Professional Plus meter at the time when each sample was taken.

Bias in Measuring Nitrate Concentration

Bias in determining nitrate concentrations was addressed in two ways. First, as suggested by the LaMotte SMART3 Colorimeter Operator's Manual and Test Procedures, I used nitrate reagents with a sample of deionized water, processing this blank the same way as that of a stream water sample. I completed this process during all sampling events, whether tributary-based or precipitation-related.

Beginning in Winter 2019, I used dice to randomly select a water sample that was processed to measure a second, duplicate estimate of nitrate concentration. I then compared the values of each to find the percent difference in the nitrate concentrations. This duplicate processing was not done for every quarterly sampling event, mostly because of a shortage of available sample reagents.

Information on Precipitation Events and LB Streamflow Discharge Volumes

Public data on both precipitation (rainfall expressed as in) and LB stream discharge volume (cfs) available from the U.S. Geological Service (USGS) were important for our analyses when we initiated these studies (USGS Undated). Having discharge data from gaged streamflow in LB (or any of the other NR tributaries) coupled with nitrate concentration data allowed us to see how nitrate concentration varied with streamflow and to calculate total nitrogen loading to the NR. Also, knowledge of precipitation events and total rainfall amounts might be useful in assessing how WQ parameters varied due to increased discharge volume.

The USGS rain gage was located near Flanders Village in East Lyme, which is close to where LB enters the NR. This rain gage was taken out of service after February of 2015. Thereafter, for a few months (but not all) I obtained precipitation data online from various sources, including a private rain gage in East Lyme and one maintained by the East Lyme Harbor Master in Niantic. Some of these records were only monthly summaries of daily rainfall. These rainfall data were sometimes viewed as inaccurate as I received anecdotal reports that the Niantic rain gage may have had extraneous materials deposited into it and with neglected cleaning, errors occurred in accurately recording rainfall totals.

For the entirety of the precipitation-related sampling, for which accurate rainfall records were necessary, the Waterford-East Lyme Shellfish Commission (WELSCO) rain gage located near the southern end of the NR in Niantic provided daily precipitation (termed “water equivalent”) and other weather data. This gage went into service in late March of 2017. These data were obtained through our subscription to the Davis WeatherLink Network (see www.weatherlink.com/user/welsco).

The USGS streamflow gage for LB was located downstream of the Flanders dam on the far (southeast) side of I-95, under which LB passes through a culvert. Unfortunately, the operation of this gage was discontinuous during our sampling. The USGS terminated data collection for budgetary reasons in December of 2012, and the gage remained out of service through June 2014. Having left much of the necessary hardware in place, the USGS re-initiated the flow volume gage in July 2014, and it remained operating until once again it was discontinued in October 2015. Also, during this latter period, no flow records were available from January through March of 2015 because of extensive icing in the stream that winter, which resulted in inaccurate flow volume data. The USGS gage once again resumed operation in late January 2020 and provided LB discharge data through our last precipitation-related sampling in Spring 2022 (USGS Undated). Note that in October 2022 the USGS stated on the website for this station that the Latimer Brook discharge flow gage will be taken out of service on March 31, 2023.

To account for varying LB streamflow volume when lacking USGS gage data during the precipitation-related sampling, I measured water depth at standard locations at the northeast corner of the LB dam. This assumed that water depth (cm) could be used as a surrogate for LB flow volume. No measurements were made during the initial precipitation-related sampling in Summer 2017, but from Fall 2017 through Summer 2019 a meter stick was placed with its end on the streambed along the angled concrete dam face in the NE corner with the distance (cm) measured from the stream bottom to the top of the dam. Maximum angled distance at this location is 47.5 cm, above which water would spill over the top of the dam rather than only flowing through the dam's center notch opening. Note that the LB dam is not level as when the stream water level is higher than the dam, more water spills over the top of the south side of the dam's center notch than on the north side. I eventually realized that this process (i.e., the angled measurements) only gave me a relative rather than a true vertical measure of water depth at the dam. Therefore, beginning in Fall 2019, I used a meter stick to measure absolute vertical water depth (cm) at a fixed location on the north face of the dam's concrete structure.

Based on previous measurements, after Tropical Storm Ida passed through our area on September 1-2, 2021, the resulting flooding in LB deposited approximately 10 cm of gravel and sediments into the impoundment just upstream of the LB dam. With such a large physical change occurring to the LB impoundment, I ceased taking water depth measurements for this and subsequent sampling events.

With the USGS LB flow gage re-established in January 2020, I compared 29 actual flow measurements with the vertical depth measurements taken from Winter through Fall of 2020. On various dates from October 2020-September 2021, these comparison data points were subsequently supplemented by 31 additional water depth measurements, many made during higher flow periods. This helped to overcome a lack of high flow data points found during the routine quarterly precipitation-related sampling events. These comparative data allowed the computation of a mathematical relationship (i.e., a power curve) between USGS gaged flow and vertical water depth measurements, which I obtained by plotting these data in the DeltaGraph 4.0 graphics and statistical package (DPI 1993). Having found a mathematical relationship, I then back-calculated estimated LB flow volumes using my earlier water depth measurements that were taken when the USGS flow gage was not in service.

An issue remained that the Fall 2017 through Summer 2019 angled measurements needed to be converted to true vertical water depth measurements so that flow volume could also be estimated for these samples. In taking water depth measurements at the dam, I realized that the angled corner formed a right triangle with respect to vertical water depth measurements (Fig. 4). I then made measurements from the bottom of the impoundment to the ledge on the north dam face. The right triangle had measured sides of 68 cm (vertical leg), 29.2 cm (horizontal leg), and 74 cm (the hypotenuse). Using trigonometry, I determined that the angles formed by this right triangle were 90

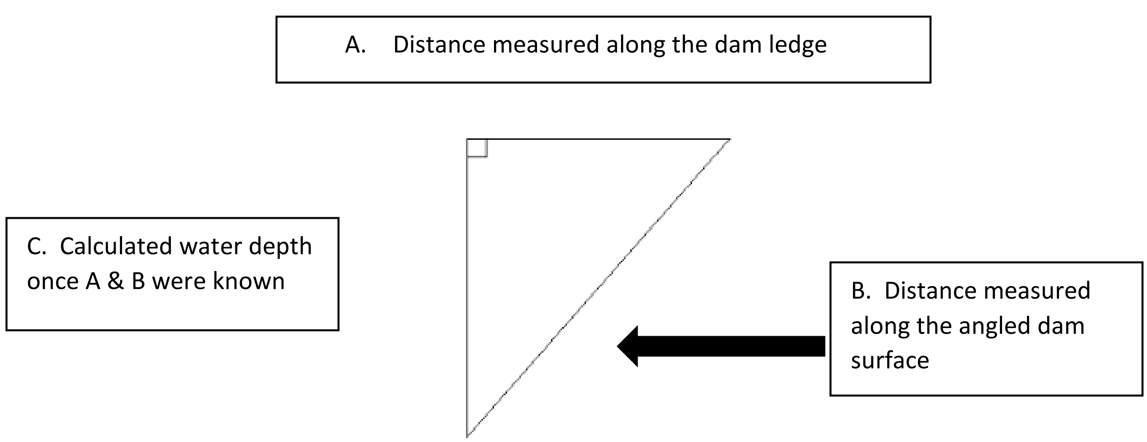

FIGURE 4. Graphic representation of how water depth was calculated at the LB Dam in Flanders when measurements were made along the angled dam surface. The acute angles of the triangle were determined once lengths A, B, and C were known.

(a given), 23.23, and 66.77 degrees. Next, having the original angled water depth measurements (these constituted the hypotenuse), the opposite vertical side (i.e., water depth) equaled the hypotenuse (angled depth) times the sine of 66.77^{o}, which has a value of 0.918. Another water depth correction was necessary because the vertical water depth was 1 cm less at the angled corner than where I took the water depth measurements a bit farther upstream during Fall 2019 and subsequent samplings. So, the final corrected water depth was equal to the calculated water depth plus 1 cm. I then multiplied the corrected angled water depth values by 0.918 to compute the true vertical measurements.

Relative Contributions of Water from Upper LB and CMB to Their Combined Flow in Lower LB
In our WQ studies, we noted that the water temperature in CMB was normally several degrees cooler than LB. Having nitrate concentration data from both CMB and LB, we thought it might be useful to know the relative water volumes contributed by both streams at their confluence. We hypothesized that being conservative, the differing water temperatures could serve as a surrogate for streamflow volumes, thereby enabling a calculation of the relative contribution of each stream after they join.

To undertake this special targeted study, we used HOBO® Pro V2 data loggers to record continuous readings of hourly water temperature (^{o}C) from 2014 to 2016. This long-term water temperature recorder has an accuracy of about ±0.11°C. Each logger was placed into a small PVC pipe, anchored using a sash weight or metal plate and tie-wrapped to roots found in undercut banks to keep them in place and out of direct sunlight. We chose three locations just south of the Aces High RV Park on Chesterfield Road (CT 161) in East Lyme, near where CMB enters LB (Fig. 2). One location was in CMB about 10 yards upstream of its confluence with LB and two were in LB, one about 20 yards upstream of the confluence (LB-US) and one about 50 yards downstream of the confluence (LB-DS). Water temperature data were downloaded several times over the course of this study. We found that the initial deployment in early 2014 did not provide useful data as one of the loggers failed. We had acceptable water temperature data from August 15, 2014 through May 5, 2015 and July 22, 2015 through April 27, 2016.

The underlying model for this water temperature study was:

$$LB\_DS_{temp} = LB\_US_{temp} + CMB_{temp} \pm E, \text{ where } E \text{ is unknown error}$$

The magnitude of the regression coefficients (i.e., LB_US_{temp} and CMB_{temp}) provided estimates of the relative contribution of each stream to LB_DS_{temp} which is the combined flow of the two streams.

Data Storage and Analyses
All our WQ data were retained in Microsoft® Excel® spreadsheets, which also provided statistical software I used to perform some data summaries and analyses. Statistical tests, including Analysis of Variance (ANOVA) and *t*-tests, were used to determine significant ($p \leq 0.05$ * or $p \leq 0.01$ **) or non-significant (NS) differences for WQ parameters among or between stations or time periods. Some data were analyzed using the Statistical Analysis System (SAS) General Linear Model (GLM) procedure, which is essentially an ANOVA having unequal observations. After this test was completed, I used the Kramer-Tukey multiple range test available in SAS to examine for any significant differences found for a variable. In some instances, I also determined correlations (r) of WQ data among various stations, including, through SAS, the nonparametric Spearman's rank-order correlation. In addition to Excel, I used the DeltaGraph 4.0 graphics and statistical package (DPI 1993) for plotting various data and performing some analyses, particularly in fitting curves with various WQ data.

RESULTS AND DISCUSSION

Missing Data

The two sampling programs, 5 years of monthly tributary-based sampling (April 2012-March 2017) followed by 5 years of quarterly precipitation-related sampling at LB station 1 (Summer 2017-Spring 2022), had different objectives, so results are presented separately in following report sections. During this 10-year period only one month of sampling was missed, that of February 2015, which was due to frequent snowstorms resulting in a heavy snowpack and mostly below freezing air temperatures creating heavy icing in the streams. A methodological error was made when processing the October 2012 nitrate samples, so all values for that sampling were listed as "Not Determined." Missing data, mostly from YSI malfunctions, are summarized in Table 2. Most missing values are for DO and pH.

TABLE 2. Summary of missing data collected during the NRWC WQ study from April 2012 through Spring 2022.

Date	WQ parameter	Known or suspected reason for missing data
April 2012	Nitrate at stations CMB-L and 6	Lack of available reagents for analysis at these stations
June 2012	DO, pH, specific conductivity	YSI not functioning properly
October 2012	Nitrate	Believe to be an analytical error (all stations had 0 value)
January 2013	DO	Believe a bad YSI DO membrane
June 2013	DO	Retrospectively found YSI DO probe had been loose
August 2013	pH	Unknown – YSI readings not stable, so not recorded
August 2014	DO	No reason was recorded in field notes
December 2014	DO	Very high values given by YSI, believed to be unreliable
February 2015	All	No sampling this month due to harsh winter conditions
March-July 2015	pH	Very high values given by YSI, believed to be unreliable
April 2015	DO	Retrospectively found YSI DO probe had been capped
December 2015	DO	YSI DO probe not functioning properly
January 2016	DO at station 4	YSI DO probe not functioning properly
Spring-Fall 2018	DO	YSI DO probe not functioning properly
Winter 2019	DO, pH, specific conductivity	YSI not functioning properly
Spring-Fall 2019	DO	YSI DO probe not functioning properly
Spring 2019	All parameters on the third day of sampling	YSI not functioning properly

Relative Contributions of Water from Upper LB and CMB to Their Combined Flow in Lower LB

We were interested in determining the relative contributions of upper LB and CMB to their combined flow in lower LB. This could be accomplished by examining their respective water temperatures, which are highly conservative measures. Prior to the deployment of HOBO® Pro V2 data loggers in LB and CMB, we had 626 air temperature data observations recorded either before their placement into the streams or after their retrieval. At these times, the loggers were all held together in a common environment, so these air temperature records could be statistically compared to see if there were any significant differences found among the recorders. This would help us determine if there was any possible bias due to instrument error. The air temperature readings were highly ($r = 0.95$-0.99) correlated. A one-way ANOVA test showed no significant differences in temperature among the recorders, indicating there was no bias among the loggers used in this study (Table 3).

TABLE 3. One-way ANOVA comparing air temperatures recorded by the HOBO® Pro V2 data loggers used in the LB-CMB water temperature study before and after their deployments in the streams.						
SUMMARY:						
	Groups	n	Sum	Average	Variance	
	LB_US	626	11533.008	18.423	16.436	
	LB_DS	626	11531.907	18.422	17.211	
	CMB	626	11557.477	18.462	16.052	
ANOVA:						
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability value	F crit
Between groups	2	0.668	0.334	0.020 NS	0.980	3.001
Within groups	1875	31061.661	16.566			
Total	1877	31062.328				

For water temperature analyses, I combined the data from the two successful deployments extending from August 15, 2014 through May 5, 2015 and July 22, 2015 through April 27, 2016. Data collected during the first deployment from January 6 through March 15, 2015 were deleted because in a *post hoc* analysis I concluded that ice cover at the LB_DS site during this period apparently skewed temperature data recorded at this location. The combined data record had 11,611 hourly observations of water temperature at each of the three sites. The model fit was highly significant ($R^2 = 0.997$) and coefficients and had relatively small 95% confidence intervals (CI), with only a 1-2% difference from the estimated parameter values (Table 4). This model showed that about two-thirds of the water in lower LB was coming from upstream LB and the remainder from CMB. However, the intercept (i.e., the error term) of this model was relatively large, having a 95% CI about ±3% of the estimate. I viewed this as somewhat problematic. Therefore, I chose to formulate a second model in which the data were forced to go through the origin (i.e., the intercept value was set to 0). Thus, simply:

LB_DS = LB_US + CMB.

The fit to the second model was also highly significant ($R^2 = 0.999$) and the coefficients had relatively small 95% CI's (Table 5). The parameter value for CMB differed little from the first model, whereas it appears that most of the error term was attributed to LB_US. Thus, based on the regression coefficients, on average, about 62% of the water in LB downstream of the confluence with CMB is likely coming from upper LB and 38% from CMB.

TABLE 4. Parameter estimates for a water temperature model $LB\_DS_{temp} = LB\_US_{temp} + CMB_{temp} \pm E$, where *E* is the unknown error term, to predict the relative contribution of water from CMB and upstream LB (LB_US) to their combined flow in downstream LB (LB_DS).			
	Estimate	Lower 95% CI	Upper 95% CI
Intercept (error term *E*)	-2.306	-2.380	-2.232
LB_US	0.665	0.659	0.671
CMB	0.378	0.372	0.384

TABLE 5. Parameter estimates for a re-formulated water temperature model $LB\_DS_{temp} = LB\_US_{temp} + CMB_{temp}$ (without an intercept error term) to predict the relative contribution of water from CMB and upstream LB (LB_US) to their combined flow in downstream LB.			
	Estimate	Lower 95% CI	Upper 95% CI
LB_US	0.622	0.615	0.629
CMB	0.378	0.371	0.386

I further examined model residuals to examine how different any of the observed hourly readings were from those predicted by the model. If a model is highly biased, then the pattern of residuals might help indicate where and when this occurs. I found that there was some summertime warming at LB_DS (i.e., the water temperature there is warmer than one would expect from the two upstream inputs). This might have been from differential exposure of this site to the summer sun than at the other two locations, which had more shade from trees. Also, LB_US is in a riffle, whereas LB_DS is in a more pool-like environment, which may enhance warming at the latter location. I also found that in September 2014, CMB water temperatures were warmer than LB_US, which was rarely the case as CMB is almost always cooler than LB. I attributed this to drought conditions during the summer of 2014, when the lower flow volume of CMB was more affected by warm air temperatures than was LB. This led to the higher water temperatures that were temporarily found in CMB. However, I believe neither of these two deviations from the norm biased results of the final regression model as each occurred only briefly.

Tributary-based WQ Sampling

Modification in WQ Stations Sampled during 2014

As noted above, ongoing evaluations of our data led to programmatic changes. Because monthly samples by station were unequal due to added stations and some missing samples, 2013-14 nitrate concentration data were analyzed using the SAS GLM procedure, which is an ANOVA for data with unequal observations. Not unexpectedly, station differences were found to be highly significant (Table 6). A multiple range test (Tukey's Studentized Range Test) was then used to determine significant differences among the stations (Table 7). This analysis showed that stations 1 and 1.5 had similar nitrate concentrations that were significantly greater than those found at the other stations. Nitrate concentrations at stations 2 through 5 and CMB-L were statistically similar and means of stations 3 to 5 overlapped with that of station 6. Nitrate values were lowest and statistically similar at stations 6, CMB-U, and DPO. As a result of this analysis, the NRWC MSC decided to drop the upper LB stations 5 and 6 and DPO from routine monitoring in April 2014. We also could have dropped station 4, as the nitrate values there were not significantly different from station 3, but station 4 was retained for additional information on water temperature. CMB-U was also retained as it is a headwater site. As a result of this decrease in sampling effort, we were able to reduce our effort in LB and initiate sampling in the other two major NR tributaries, OMB and SB, resulting in a sampling regime that continued through March 2017. I discuss results from the three dropped stations separately below.

Results at Stations 5, 6, and DPO during 2012-14

Station 6 is located immediately downstream of Beckwith Reservoir, the smallest and most downstream of the New London Water & Water Pollution Control Authority reservoirs (see Fig. 3). This site marks where LB moves onto public lands, but until the brook exits the culvert under Beckwith Road it flows through a constructed, channelized streambed. During dry spells or after ice forms, no water spills over

TABLE 6. Results of SAS GLM analysis of nitrate concentration at NRWC WQ monitoring stations during 2013-14.					
Dependent variable: monthly nitrate concentration at each WQ station					
Source	Degrees of freedom	Sum of Squares	Mean square	F value	Probability > F
Station	9	2.232	0.248	30.35	<0.0001
Error	202	1.651	0.008		
Corrected total	211	3.883			
n = 212	R^2 = 0.575		Overall nitrate mean = 0.16 mg/L		

the Beckwith Reservoir dam and any flow at this station is likely from seepage and groundwater. Water temperature and DO values at these two stations were highly correlated (Table 8). Nitrate concentration (r = 0.557) and specific conductance (r = 0.795) were least correlated, with most values found at 6 smaller than at 5. These stations were sampled sequentially from April 2012 through March 2014, after which both were dropped.

Particularly during summer, station 6 had warmer water temperatures than 5, likely a result of low flow volume at the former station (Fig. 5). DO was the most similar WQ parameter recorded at these two stations and values were sufficient for aquatic life. Most pH values were lower at 5 than 6. The reasons for this difference are not known but may be due to higher alkalinity in the source Beckwith Reservoir or exposure to more acidic sources, whether geological or biological, in downstream areas. Over the period of sampling, a decline occurred in the pH values. Specific conductance readings were more variable at 6 than 5. Although similar in many months, several peaks (December 2012 and October-November 2013) were observed in specific conductance at 6 in comparison to 5. My field notes

TABLE 7. Results of Tukey-Kramer Multiple Range Test comparing significant differences in nitrate concentration among WQ stations.

Groupings[a]	Mean nitrate concentration	Number of observations	Station
A	0.381	14	1.5
A	0.317	23	1
B	0.213	22	CMB-L
B	0.203	23	2
C B	0.152	23	5
C B	0.141	23	3
C B	0.123	23	4
C D	0.084	22	6
D	0.025	17	CMB-U
D	0.025	22	DPO

[a] Means sharing the same letter are not significantly different from one another.

TABLE 8. Correlations between WQ parameters at stations 5 and 6 from April 2012 through March 2014.				
Water temperature (^{o}C)	DO (mg/L)	pH (su)	Specific conductance (μS/cm)	Nitrate (mg/L)
0.991	0.931	0.928	0.795	0.557

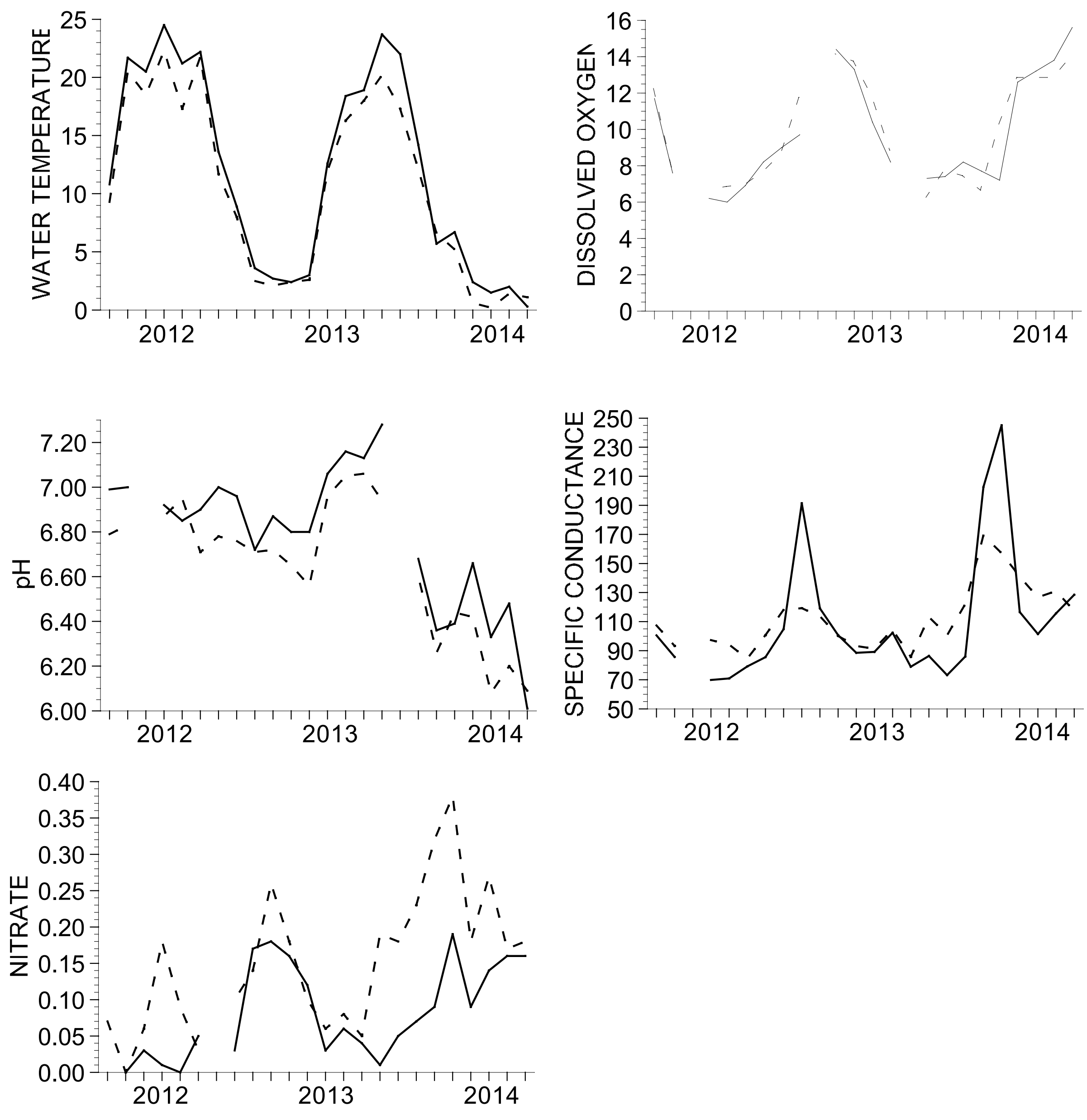

FIGURE 5. Comparison of water temperatures (^{o}C), DO concentration (mg/L), pH (su), specific conductance (μS/cm), and nitrate concentration (mg/L) from 24 samples taken at LB Station 5 (dashed line) and Station 6 (solid line) from April 13, 2012 through March 14, 2014.

indicated extremely low water flow during these months with mostly static conditions found at 6, which apparently resulted in the relatively high specific conductance values found. An exception was during summer months of 2013, when the values were about the same at both stations. Nitrate concentrations were higher at 5 than 6, likely indicating nitrogen inputs from more developed areas around and upstream of 5 than from the undeveloped upstream reservoir lands upstream of 6.

Using *t*-tests, I found no significant differences between stations 5 and 6 for all WQ parameters except nitrate, where 5 > 6 ($p < 0.01$**). This is at odds with the SAS GLM results given above (Table 7), which showed that the mean values of these stations were similar. However, the means for these two stations were the most dissimilar of all the upper LB stations, so this result may be an outlier, particularly as an *a posteriori* statistical test may not be sensitive to relatively minor differences in individual means or for small subsets of data (Sokal and Rohlf 1969). In this case, there are only 22 paired observations. On most dates sampled, station 5 clearly had a higher nitrate concentration (Fig. 5).

DPO differs from the tributary stream stations as it is located at the outlet of the relatively small Darrow Pond. Conditions in the pond, likely both physical and biological, affected WQ parameters at this site. As I observed at the Beckwith Reservoir dam at station 6, there was often little outflow at DPO when the pond had low water levels. I compared results from DPO to the nearby retained station 3 in LB (see Fig. 2). Water temperature, DO, and pH at these two sites were highly correlated (Table 9). As found for stations 5 and 6, the most variable WQ parameters were specific conductance and nitrate, which also had the lowest correlation coefficients ($r = 0.548$ and 0.458, respectively).

Typical for a pond, water temperatures were nearly always warmer at DPO than at the LB stream station 3, particularly during summer, with more similar temperatures found in winter (Fig. 6). DO was relatively similar at both locations. The values of pH were also relatively similar, but specific conductance was always much higher at station 3. This was likely due to considerably more minerals and salts being found in LB than in Darrow Pond. Nitrate was also mostly higher in LB than the pond. I attribute this to two factors: the relatively undeveloped, small sub-watershed of Darrow Pond in relation to the much larger area feeding LB and secondly by the uptake of nitrate by aquatic plants in Darrow Pond, especially during spring and summer. Among the aquatic plants I observed in Darrow Pond were considerable growths of variable-leaf water milfoil, watershield, yellow water lily, and white water lily. I also occasionally saw masses of filamentous green algae in the pond.

I completed *t*-tests on the WQ data, which indicated both specific conductance and nitrate were significantly ($p < 0.01$) higher at 3 than DPO. This was unsurprising when one compares data from both these stations, where nearly all values of both these WQ parameters were higher at station 3 when compared to DPO (Fig. 6).

TABLE 9. Correlations between WQ parameters at stations 3 and DPO from April 2012 through March 2014.

Water temperature (^oC)	DO (mg/L)	pH (su)	Specific conductance (^oC)	Nitrate (mg/L)
0.991	0.937	0.873	0.548	0.458

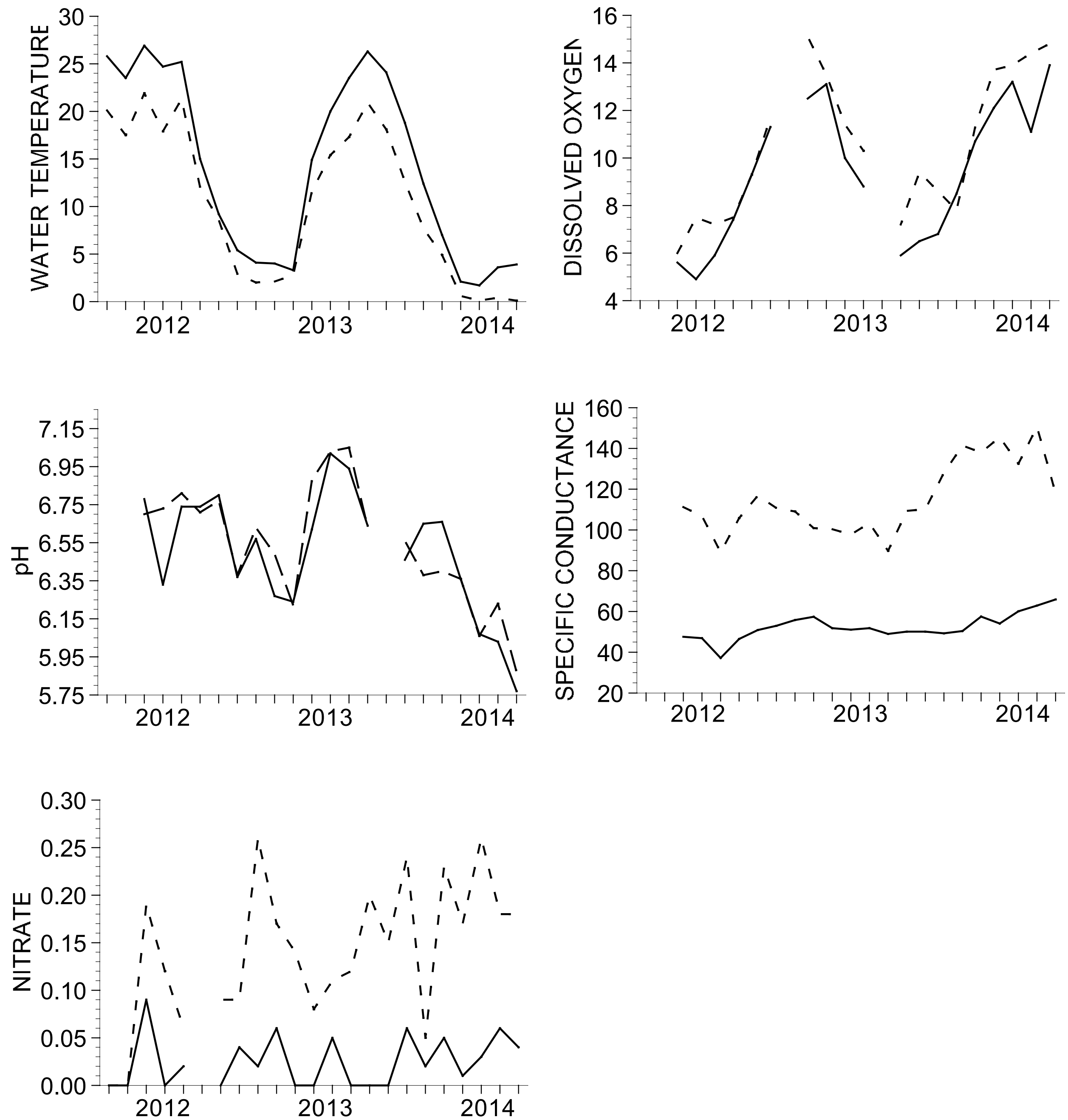

FIGURE 6. Comparison of water temperatures (^{o}C), DO concentration (mg/L), pH (su), specific conductance (µS/cm), and nitrate concentrations(mg/L) from 22 samples taken at LB Station 3 (dashed line) and DPO (solid line) from May 30, 2012 through March 14, 2014.

WQ Monitoring at Nine Stations in NR Tributaries during 2012-2017

Number of Observations and Comparative Statistics

I sampled nine stations for routine WQ parameters during all or most of the 5-year period, five in LB, two in CMB, and one each in SB and OMB (see Figs 2 and 3). Stations CMB-U, 1.5, SB (both U and L), and OMB were not sampled over this entire duration. Note also that SB-U was only sampled four times before the SB station was moved farther south to SB-L. For the purposes of this report, data for the two SB stations were combined, even though there may have been some differences in WQ parameters

TABLE 10. Summary of statistics for the WQ parameters recorded at nine stations during sampling in NR tributaries from April 2012 through March 2017.

Statistic	Water temperature (^oC)	DO (mg/L)	pH (su)	Specific conductance (µS/cm)	Nitrate (mg/L)
Number of observations	467	412	410	461	451
Minimum	0.0	0.5	5.18	57.3	0.00
Maximum	23.2	20.8	7.62	450.1	1.22
Mean	10.5	10.1	6.55	140.3	0.22
Standard error	0.3	0.2	0.02	2.3	0.01
Standard deviation	7.2	3.2	0.45	50.1	0.19
First Quartile	2.9	7.5	6.23	109.5	0.10
Median	10.1	9.7	6.61	132.1	0.19
Third Quartile	16.9	12.6	6.87	155.8	0.29

between these two sites. Total observations of WQ parameters include 467 records of water temperature, 412 of DO, 410 of ph, 461 of specific conductance, and 451 of nitrate. Statistics for the WQ parameters combined over all stations are given in Table 10.

The nonparametric Spearman rank-order correlation was used to examine relationships among the WQ parameters as this analysis is not dependent upon specific data distributions or assumptions (Sokal and Rohlf 1969). The highest correlation (r = -0.882) was between water temperature and DO (Table 11). The negative sign indicated that highest DO values occurred at lowest water temperatures, which was expected due to the physicochemical characteristics of DO solubility in water. Despite most comparisons showing some level of statistical significance (e.g., temperature-pH; DO-pH; DO-specific conductance; nitrate-specific conductance), most other correlation coefficients are weakly positive or negative, indicating that many changes in these parameters from month to month may be occurring somewhat independently of one another. Each WQ parameter recorded during the tributary-based sampling is discussed in the following sections of this report.

TABLE 11. Spearman correlation coefficients among WQ parameters recorded at nine stations during sampling in NR tributaries from April 2012 through March 2017. Comparative sample sizes are given in Table 10.

Parameter	Water temperature (^oC)	DO (mg/L)	pH (su)	Specific conductance (µS/cm)
DO	-0.882 <0.0001 **			
pH	0.354 <0.0001 **	-0.308 <0.0001 **		
Specific conductance	-0.029 0.541 NS	-0.156 0.0015 **	0.027 0.581 NS	
Nitrate	0.049 0.300 NS	-0.123 0.014 *	0.099 0.0498 *	0.361 <0.0001 **

Seasonal Differences in WQ Parameters

Water temperature. Seasonal differences in the WQ parameters were not unexpected given local climatic influences and the physicochemical relationships that exist between some of them (e.g., water temperature and DO). Water temperatures (all stations combined within a season) were lowest and varied least in Winter, increased in Spring, rose to a maximum in Summer, and then decreased again in Fall, which had the greatest seasonal variation (Fig. 7). Given these differences, I expected to find the highly significant differences that occurred for water temperature among seasons (Table 12).

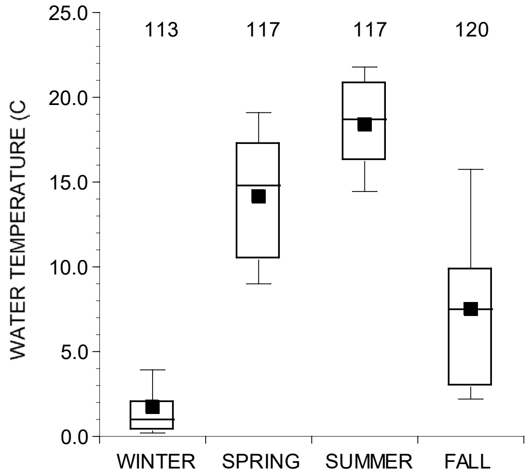

FIGURE 7. Box plot of water temperature values (^{o}C) by season during WQ sampling at nine stations in NR tributaries from April 2012 through March 2017. The boxes present information as follows: the top, bottom, and line through the middle of each box correspond to the 75th percentile, 25th percentile, and 50th percentile (median), respectively. The top and bottom whiskers correspond to the 90th and 10th percentiles, respectively. The filled-in rectangle represents the mean value. The number of observations available for each season are shown above the corresponding box.

TABLE 12. Results of SAS GLM analysis comparing water temperatures (^{o}C) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in water temperature values.

Season	n	Mean	Standard deviation		
Winter	113	1.7	2.1		
Spring	117	14.1	3.8		
Summer	117	18.4	2.9		
Fall	120	7.5	4.6		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	18556.121	6185.374	507.4 **	<0.0001
Error	463	5644.067	12.190		
Corrected total	466	24200.189			

Tukey-Kramer test results:

Summer > Spring > Fall > Winter

DO. Conversely to water temperature, DO concentrations were highest in Winter and lowest in Summer, with intermediate values found during Spring and Fall (Fig. 8). Mean and median values were very close in magnitude. Again, I expected to find significant seasonal differences in DO concentrations, with Summer having significantly lower values and Winter the highest (Table 13). Fall and Spring DO values were not significantly different from one another. Even in summer months, however, DO values in NR tributary streams were at levels sufficient for aquatic life.

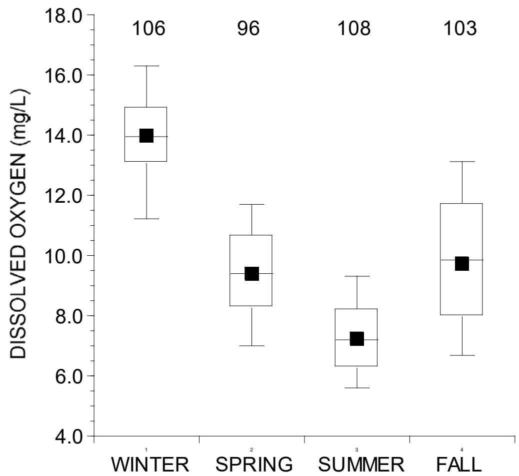

FIGURE 8. Box plot of DO concentrations (mg/L) by season during WQ sampling at nine stations in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 13. Results of SAS GLM analysis comparing DO concentrations (mg/L) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in DO values.

Season	n	Mean	Standard deviation		
Winter	1060	14.0	1.9		
Spring	96	9.4	1.8		
Summer	108	7.0	1.7		
Fall	103	9.8	2.6		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	2681.177	8933.726	222.7 **	<0.0001
Error	409	1641.701	4.014		
Corrected total	412	4322.878			

Tukey-Kramer test results:

Winter > [Fall = Spring] > Summer

pH. pH is defined as the temperature-independent measure of the negative logarithm of hydrogen ion concentration in a solution. pH is largely related to the carbon dioxide cycle in water (Hutchinson 1957; Ruttner 1963). pH values range between 0 and 14; a value of 7 is neutral, 0 highly acidic, and 14 highly alkaline. There are many reasons why pH varies in water bodies, including physicochemical factors, underlying geology affecting buffering, environmental and human factors (e.g., acid rain), and effects due to biological organisms. Most pH values found in NR tributary streams were acidic, although not to the detriment of aquatic life (Fig. 9). In Summer and Fall, the mean values were less than the medians, indicating that I recorded a few low, outlying values. pH values in Spring and Summer were similar and significantly greater than those found in Fall and Winter, which were also similar (Table 14).

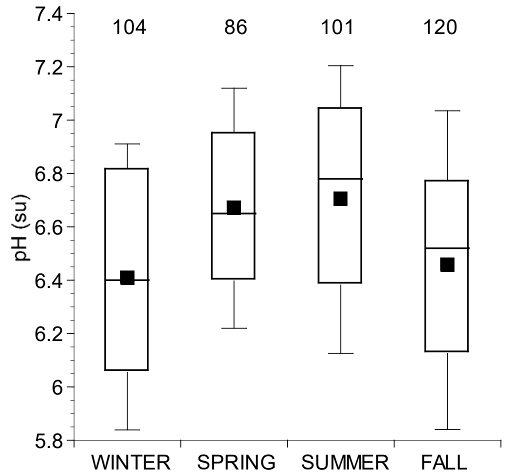

FIGURE 9. Box plot of pH values (su) by season during WQ sampling at nine stations in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 14. Results of SAS GLM analysis comparing pH values (su) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in pH values.

Season	n	Mean	Standard deviation		
Winter	104	6.41	0.43		
Spring	86	6.68	0.36		
Summer	101	6.70	0.44		
Fall	120	6.46	0.46		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	6.883	2.295	12.38 **	<0.0001
Error	407	75.417	0.185		
Corrected total	410	82.300			

Tukey-Kramer test results:

[Summer = Spring] > [Fall = Winter]

Specific conductance. Conductivity is a measure of electrical conductance in a solution; higher values indicate this happens more readily. Conductivity depends upon the number of ions (e.g., sodium, calcium, magnesium, sulfate, chloride) present in water, which is related to local geology, and factors such as inputs of sediments from precipitation and runoff of road salts. As previously noted, specific conductance is a conductivity value standardized to a temperature of 25^{o}C. In NR tributary streams, specific conductance showed some seasonal differences with highest and most variable values found during Fall (Fig. 10). Mean values exceeded median values in all seasons. Fall had a particularly high 90th percentile, indicating that I recorded some relatively large values at some of the stations. Seasonal values of specific conductance were somewhat similar with only Fall significantly greater than Spring (Table 15). Summer and Winter had means similar to one another and their adjacent seasons.

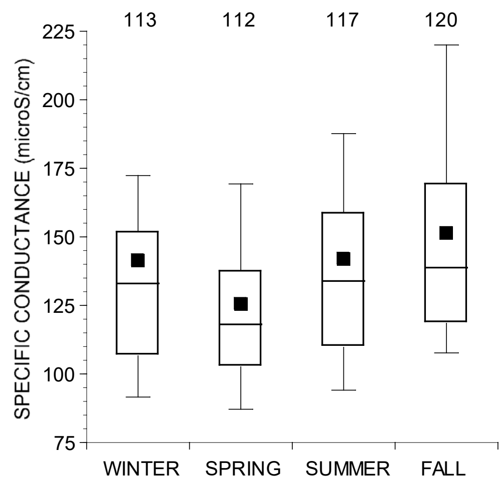

FIGURE 10. Box plot of specific conductance values (μS/cm) by season during WQ sampling at nine stations in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 15. Results of SAS GLM analysis comparing specific conductance values (μS/cm) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in specific conductance values.

Season	n	Mean	Standard deviation		
Winter	113	141.4	57.3		
Spring	112	125.4	41.6		
Summer	117	142.0	47.2		
Fall	120	151.3	50.3		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	39958.393	13319.464	5.45 **	<0.0001
Error	458	1119055.331	2443.352		
Corrected total	461	1159013.725			

Tukey-Kramer test results:

[Fall = Summer = Winter] and [Summer = Winter = Spring]

Nitrate. Nitrate concentrations were significantly higher in Summer than during Spring and Fall but were not different from those found during Winter (Fig. 11; Table 16). Winter nitrate concentrations were also not significantly different from those occurring in Fall and Spring. In all seasons, the mean value was higher than the median, indicating that some relatively high nitrate concentrations were found at some stations compared to the others. Nitrate concentrations were least variable in Winter relative to the other seasons. A possible reason for this might be related to seasonal fertilizer use in the NR watershed. It does not appear that biological uptake in the streams has resulted in large reductions in overall nitrate concentrations observed, unlike what was seen at the pond DPO site (see Fig. 6).

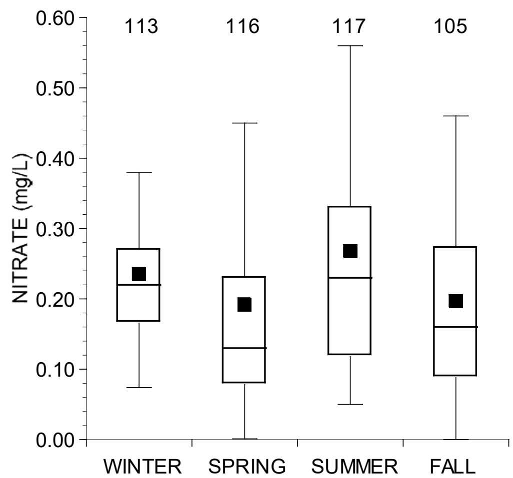

FIGURE 11. Box plot of nitrate concentrations (mg/L) by season during WQ sampling at nine stations in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 16. Results of SAS GLM analysis comparing nitrate concentrations (mg/L) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in nitrate values.

Season	n	Mean	Standard deviation		
Winter	113	0.24	0.15		
Spring	116	0.19	0.19		
Summer	117	0.27	0.21		
Fall	105	0.20	0.17		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	0.432	0.144	4.30 **	0.0053
Error	447	14.984	0.033		
Corrected total	450	15.417			

Tukey-Kramer test results:

[Summer = Winter] and [Winter = Fall = Spring]

Spatial Differences in WQ Parameters

Water temperature. Water temperatures showed a typical seasonal pattern at all stations with expected highest annual temperatures occurring in summer months and lows during winter months (Fig. 12). Overall, recorded water temperatures ranged between 0 and 23.2°C (see Table 10). Some higher water temperatures may have occurred on many other summer days during the 5-year period as I randomly performed monthly WQ sampling during this portion of our study, which was related to my availability and prevailing weather. The overall mean water temperature was 10.5°C, which is close to the average annual air temperature of 10.1°C calculated for New London, CT (Weatherbase 2022). Note that in contrast to the LB and CMB stations, which we visited during most months of the 5 years of study, OMB and SB were only sampled over a 3-year period. Also, station 1.5 is not shown in Figure 12, but water temperature values there (10 fewer months sampled at 1.5 than at our other LB stations) were like those recorded at stations 1 and 2, which bracketed this site. This exception of not plotting 1.5 data with that from the other stations also applies to the other WQ parameters discussed below.

Box plots of our data show some differences in water temperature range among the stations (Fig. 13). Lowest mean and median water temperatures and least variability occurred at the upstream stations of LB and in the smaller streams (CMB, OMB, and SB). The warmest water temperature of 23.2°C was recorded at station 2, which also had the highest mean, and was slightly warmer than the mean at station 4. The headwater station of CMB-U had the coolest water temperatures, even though at times when summer rainfall was low, this site often was an isolated pool with little in- or outflow to moderate water temperatures.

The SAS GLM procedure was used to examine differences in station water temperature (Table 17). Despite having a difference of 2.4°C between the highest (11.5°C; station 2) and lowest (9.1°C; SB-U) mean water temperatures, no significant differences were found among water temperatures by station. This indicated common environmental factors were likely affecting water temperatures at all sites.

TABLE 17. Results of SAS GLM analysis comparing water temperatures (°C) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017.

Station	n	Mean	Standard deviation		
1	59	11.0	7.4		
1.5	49	10.4	7.2		
2	59	11.5	7.7		
3	59	10.7	7.4		
4	59	11.2	7.7		
CBM-L	59	9.7	6.8		
CMB-U	53	9.1	7.0		
OMB	35	10.6	6.8		
SB	35	9.9	6.4		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	8	267.865	33.484	0.64 NS	0.7435
Error	458	23932.324	52.254		
Corrected total	466	24200.189			

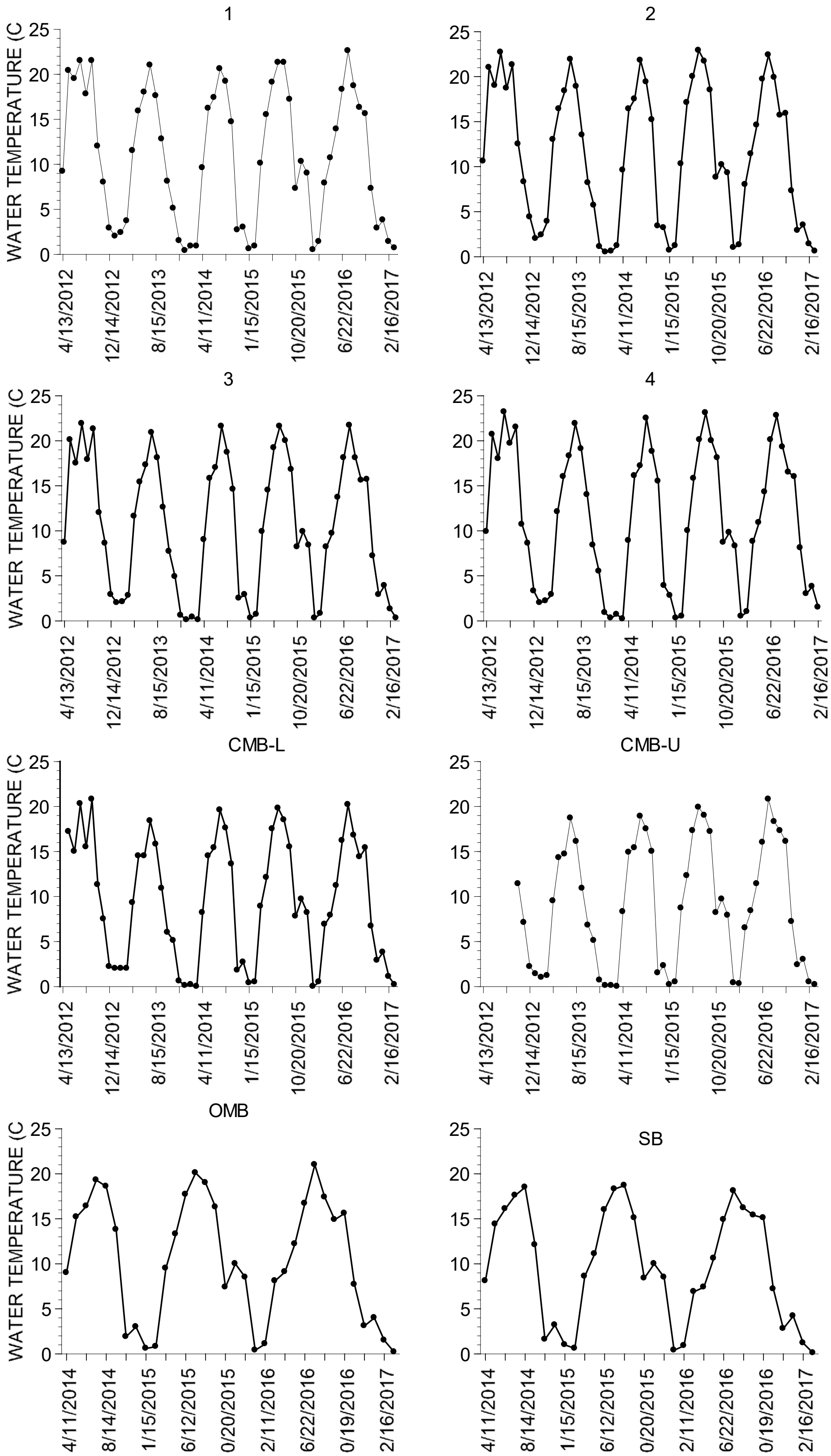

FIGURE 12. Water temperatures (^oC) at stations in LB (except for station 1.5) and CMB recorded from April 2012 through March 2017 and at the OMB and SB stations from April 2014 through March 2017.

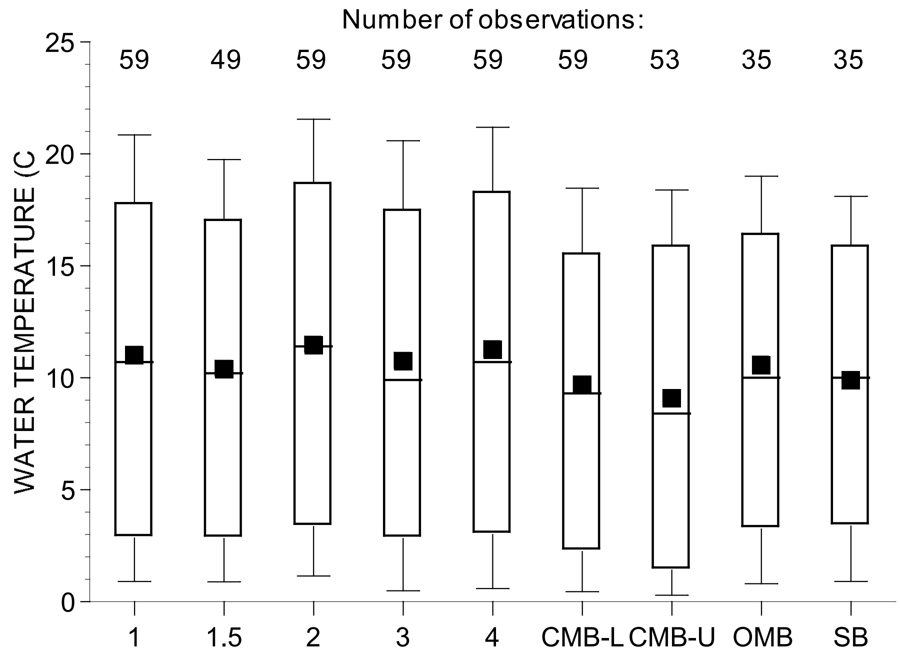

FIGURE 13. Box plot of water temperature values (^{O}C) recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available at each station is shown above the corresponding box.

Dissolved Oxygen (DO). Unlike water temperature records, there were some missing values for DO, which resulted from several reasons, mostly issues related to the YSI instrument used (see Table 2). In general, most DO values in the streams I sampled exceeded 5 mg/L (Figs. 14 and 15). Overall, DO values ranged from 0.5 mg/L to 20.8 mg/L, had an overall mean of 10.2 mg/L, and a slightly lower median value of 9.7 mg/L (see Table 10). As for water temperature, no significant differences were found for DO concentrations among the stations sampled (Table 18), illustrating the close association of these two WQ parameters. Unless there is high biological or chemical demand, DO values are mostly a result of the ability of water to hold oxygen as a function of its temperature. Although not recorded during this study, as indicated by the YSI instrument, I typically observed high percent saturation levels that corresponded to prevailing water temperatures.

The range of DO values was similar at all stations except CMB-U (Fig. 14). As noted previously, DO values were inversely correlated with water temperature, so highest values are found in Winter and lowest in Summer, illustrating an annual periodicity (Fig. 15). Unlike water temperature, where station means and medians were close in value, the means for DO at each station were higher than the median value. Five instances were found during July-October of 2014-16 when CMB-U had low (0.5-1.7 mg/L) DO values. My field notes mentioned there was little or no water flow entering the small pool that served as the sampling point for this station, which is located near the headwaters of CMB. Besides low DO values, anomalously high specific conductance values were also recorded at these times, indicating unusual WQ conditions present at that station when there was little or no streamflow. Despite occasional low DO concentrations in the pool at CMB-U, in both July and August of 2016 (DO = 0.5 and 0.6 mg/L, respectively) I observed a few small minnows there. I never saw any dead or distressed organisms at CMB-U or elsewhere regardless of any WQ conditions deviating from usual norms.

TABLE 18. Results of SAS GLM analysis comparing DO (mg/L) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017.

Station	n	Mean	Standard deviation		
1	53	9.6	3.5		
1.5	44	10.2	2.8		
2	52	9.8	3.0		
3	52	10.1	3.0		
4	51	10.3	3.0		
CBM-L	52	11.2	2.7		
CMB-U	47	9.2	4.5		
OMB	31	10.6	2.8		
SB	31	9.9	3.3		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	8	128.474	16.059	1.55 NS	0.1392
Error	404	4194.404	10.382		
Corrected total	412	4322.878			

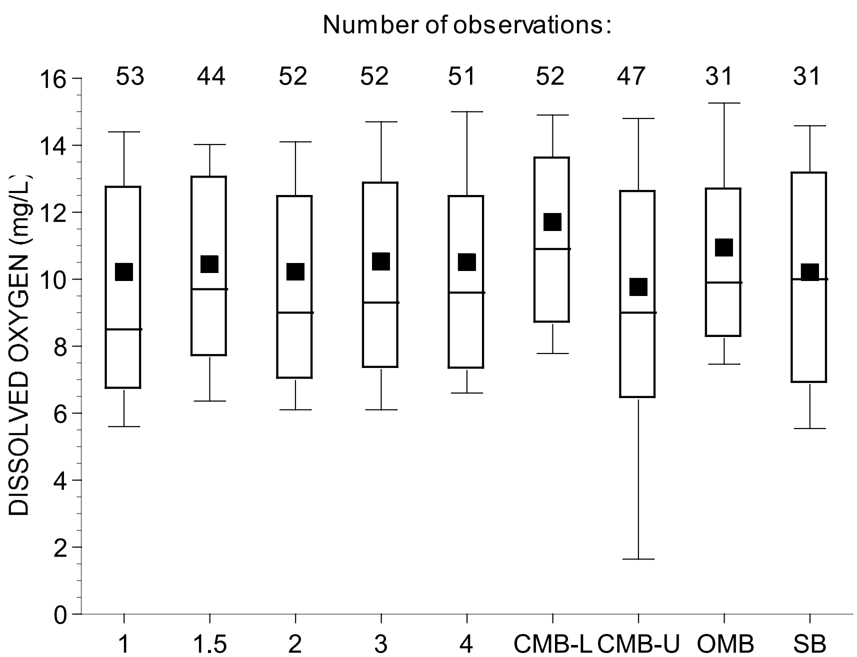

FIGURE 14. Box plot of DO values (mg/L) recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available at each station is given above the corresponding box.

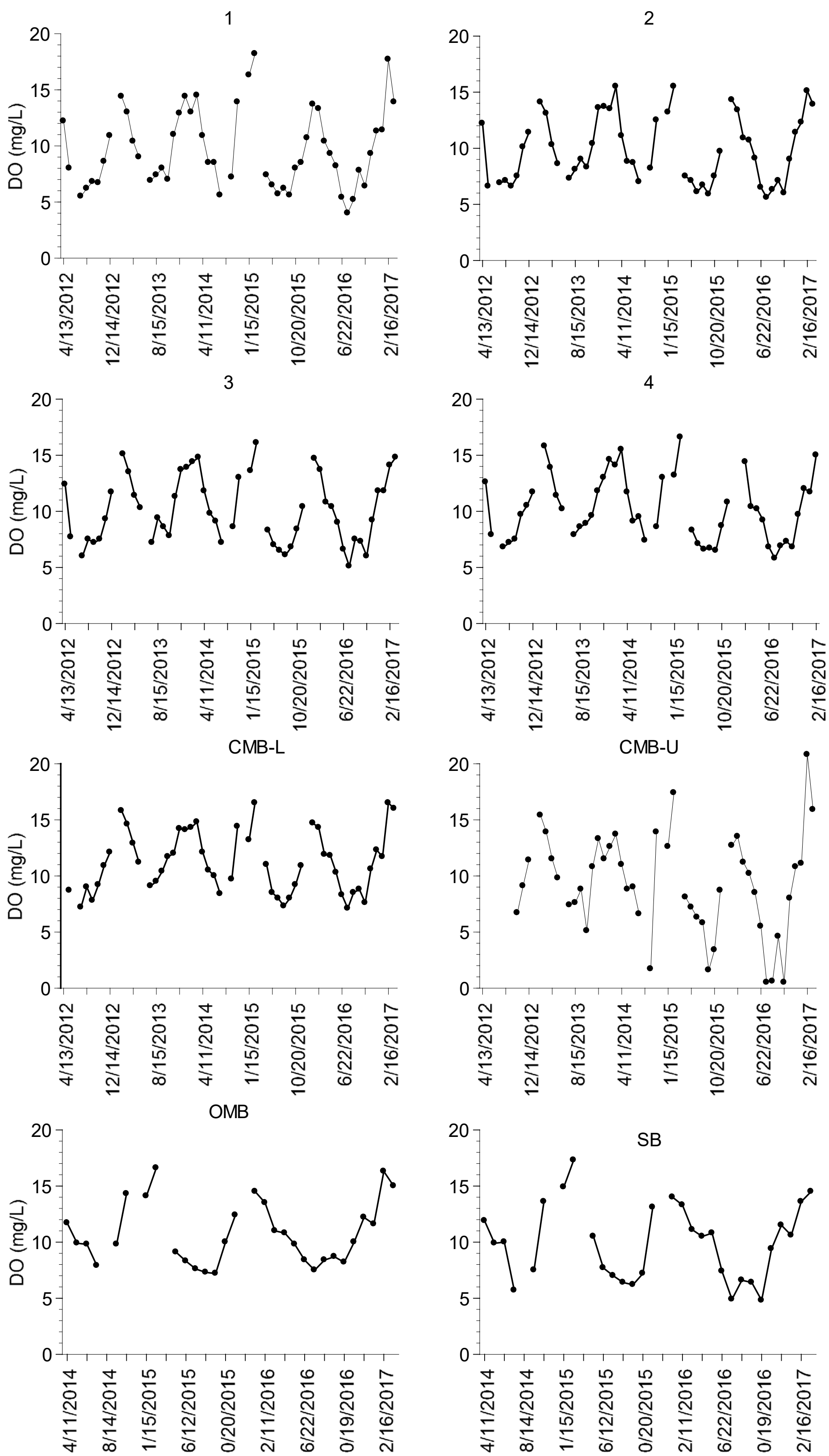

FIGURE 15. Dissolved oxygen (DO; mg/L) at stations in LB (except for station 1.5) and CMB recorded from April 2012 through March 2017 and at the OMB and SB stations from April 2014 through March 2017.

pH. Overall, pH values ranged between 5.18 and 7.62 su (see Table 10). The median pH value of 6.61 su was slightly higher than the mean of 6.55 su and all stations had mean values in the acidic (<7.00 su) range (Table 19). I observed some periodicity in pH values with those recorded during the second half of this study generally higher than those during the first half (Fig. 16). The GLM analysis showed significant differences among stations (Table 19). A Tukey-Kramer multiple range test indicated considerable overlap in station means, but overall, the downstream LB stations, CMB-U, and SB had lower pH values than upstream LB stations, CMB-L, and OMB (Table 20). This is clearly seen in Figure 17, where there are progressively decreasing pH values in LB from station 4 moving downstream to station 1. I have no hypothesis for why pH decreases downstream in LB (opposite of CMB), only to note that there is increasing groundwater and stormwater discharges entering LB when proceeding downstream within this watershed.

TABLE 19. Results of SAS GLM analysis comparing pH (su) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017.

Station	n	Mean	Standard deviation		
1	53	6.27	0.52		
1.5	43	6.46	0.37		
2	52	6.55	0.35		
3	52	6.66	0.35		
4	52	6.85	0.35		
CBM-L	52	6.85	0.37		
CMB-U	47	6.28	0.43		
OMB	30	6.70	0.38		
SB	30	6.23	0.30		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	8	21.551	2.693	17.83 **	<0.0001
Error	410	60.749	0.151		
Corrected total	418	82.300			

TABLE 20. Results of Tukey-Kramer Multiple Range Test comparing significant differences in pH values among WQ stations.

Groupings[a]	Mean	Station
A	6.85	CBM-L
A	6.85	4
A B	6.70	OMB
A B	6.66	3
B	6.55	2
C B	6.46	1.5
C	6.28	CBM-U
C	6.27	1
C	6.23	SB

[a] Means sharing the same letter are not significantly different from one another.

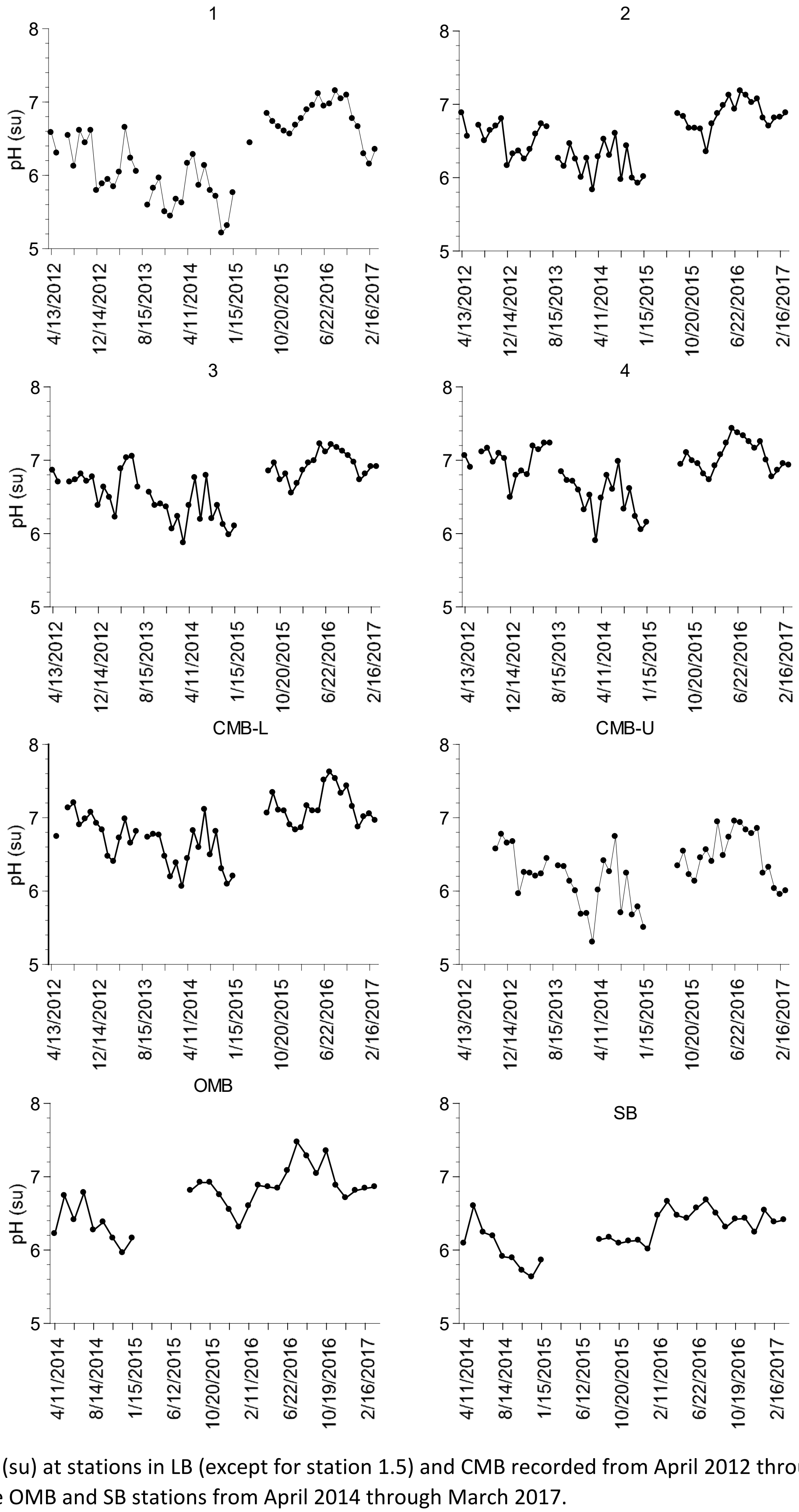

FIGURE 16. pH (su) at stations in LB (except for station 1.5) and CMB recorded from April 2012 through March 2017 and at the OMB and SB stations from April 2014 through March 2017.

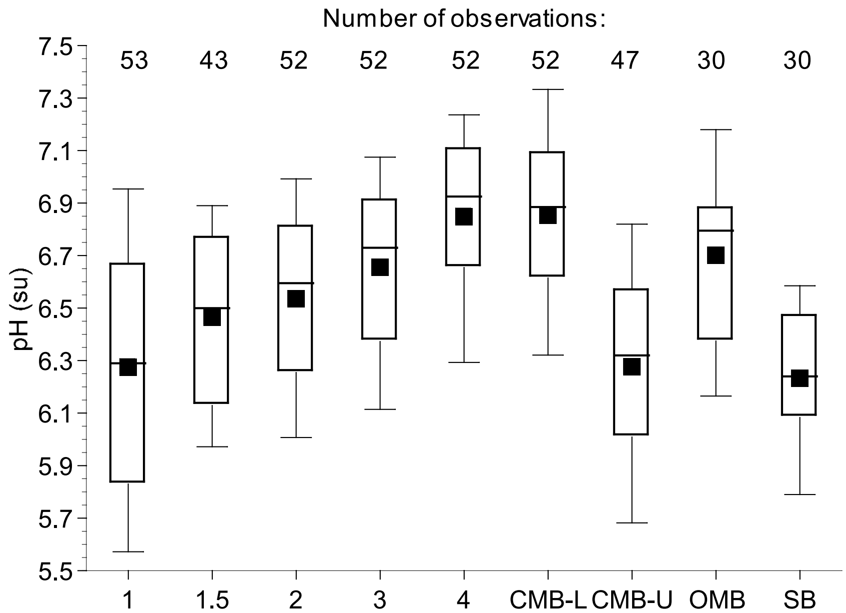

FIGURE 17. Box plot of pH values (su) recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available at each station is given above the corresponding box.

Specific Conductance. Specific conductance values having a relatively large range of 57.3 to 450.1 µS/cm were recorded during this study (see Table 10). The overall mean value was 140.3 µS/cm, which is somewhat larger than the median value of 133.2 µS/cm. Specific conductance was generally higher at SB, OMB, and CMB-U than at the LB stations or CMB-L (Fig. 18). Station variability was greatest at LB stations 2 and 4 and SB, three of the five stations having mean values larger than the median values.

The most extreme specific conductance values occurred at CBM-U, which was related to very low or static conditions. These instances likely affected water chemistry, as was previously discussed about DO. This also happened at LB station 6, which was also discussed previously (see Fig. 5). The higher values found at SB and OMB are likely related to underlying geology in their watersheds. Except during abnormally low flow conditions at CBM-U, the two CMB stations had the lowest specific conductance values, which may again be related to local geology and other watershed-specific conditions, including potential inputs from stormwater runoff.

Highly significant differences occurred in specific conductance values among stations (Table 21). The Tukey-Kramer test indicated that SB had significantly higher specific conductance values than all the other stations (Table 22). There was considerable overlap in values among the other stations. LB station 2 and the CMB stations formed a cluster having the lowest specific conductance values.

At LB stations 1-4 and SB, there appears to be increasing trends in specific conductance values from 2012 through 2017 (Fig. 19). These increases were less apparent in OMB and CMB. To examine this, a linear regression analysis was performed on the time-series of data from each station. Results indicated highly significant ($p \leq 0.002$**) increases occurred at all the LB stations and SB. The regression for CMB-U was significant ($p = 0.034$*), but there was also considerable variation seen at this site. Regressions for CMB-L and OMB were not significant and specific conductance at these sites varied without any trend. I have no explanation why specific conductance increased over the course of this 5-year study.

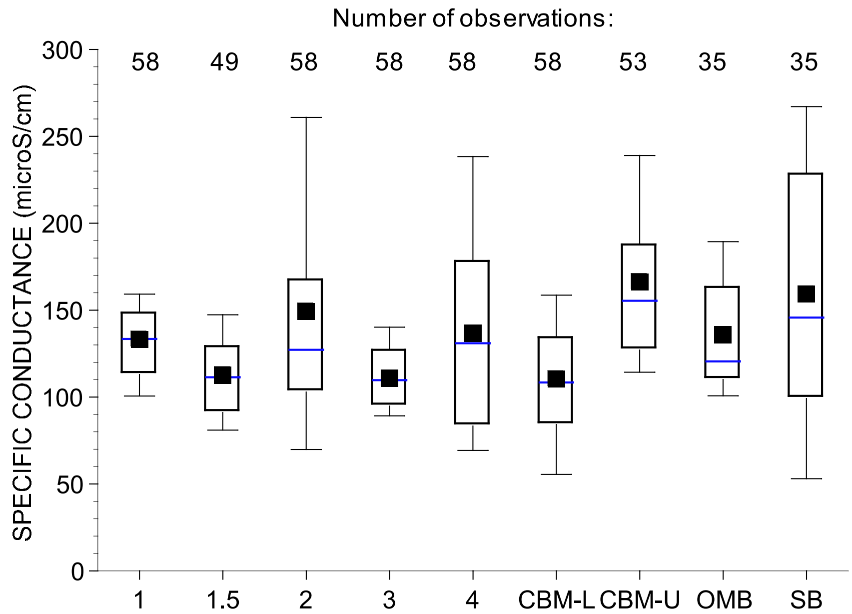

FIGURE 18. Box plot of specific conductance values (µS/cm) recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available at each station is given above the corresponding box.

In four of the six public water supply wells in East Lyme, a similar statistically significant increasing trend was found for sodium, an ion that was measured annually from 2005 to 2022 (ELCCNR 2022). These wells are in the Pattagansett River and Bride Brook watersheds, so perhaps similar increases in ions (e.g., particularly chloride: Mullaney et al. 2009; Cassanelli 2011) that increase specific conductance have been occurring over a wider local area, including in streams found within the NR watershed.

TABLE 21. Results of SAS GLM analysis comparing specific conductance (µS/cm) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017.

Station	n	Mean	Standard deviation		
1	58	150.5	33.3		
1.5	49	140.1	23.7		
2	58	127.5	21.2		
3	58	129.6	22.2		
4	58	130.6	23.4		
CBM-L	58	117.2	19.0		
CMB-U	53	108.5	62.7		
OMB	35	145.3	40.5		
SB	35	259.1	53.0		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	8	607184.993	75898.124	62.31 **	<0.0001
Error	453	551828.732	1218.165		
Corrected total	461	1159013.725			

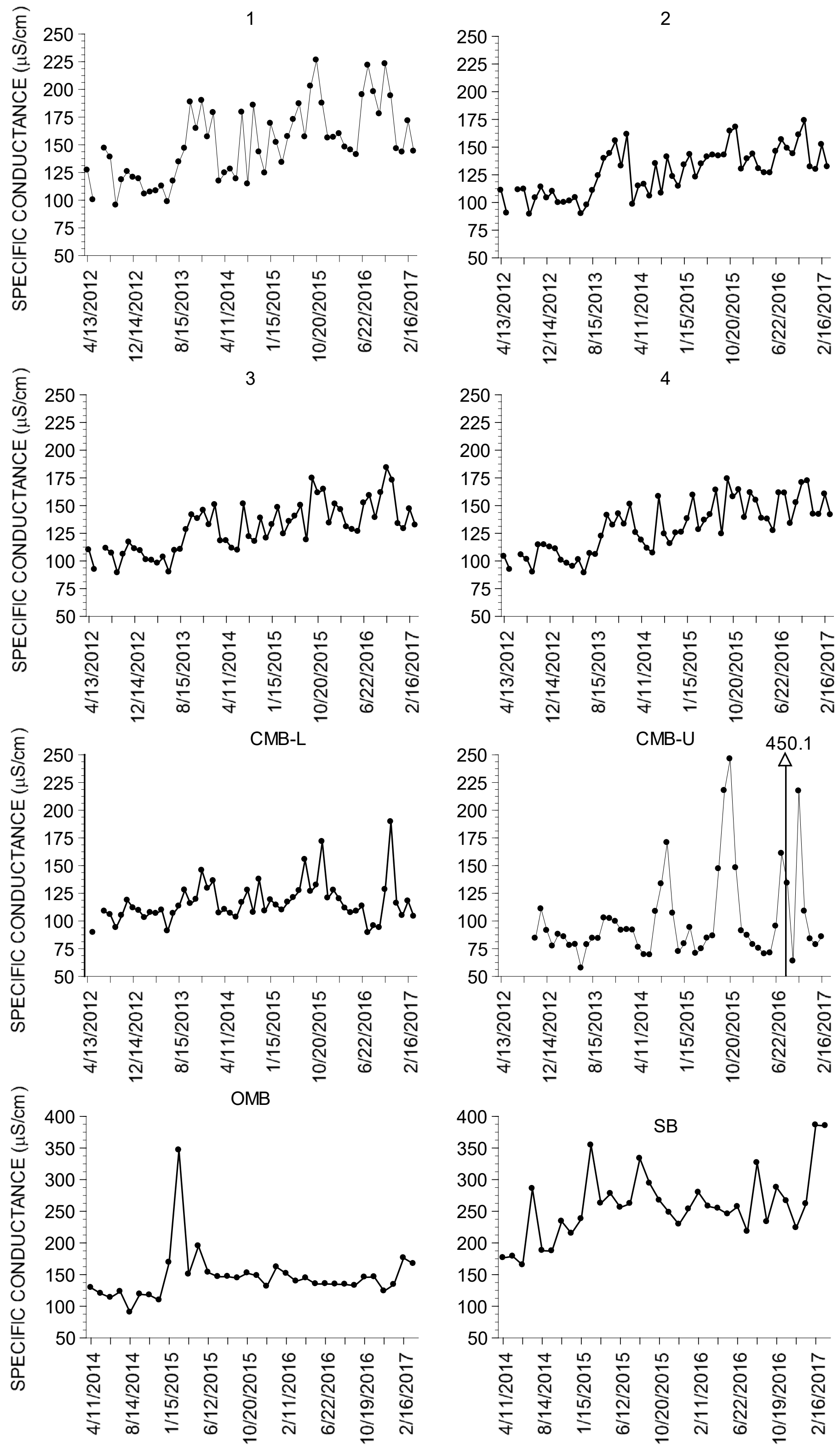

FIGURE 19. Specific conductance (µS/cm) at stations in LB (except for station 1.5) and CMB recorded from April 2012 through March 2017 and at the OMB and SB stations from April 2014 through March 2017. Note differences in the Y-axis scales by station and one extreme value at CMB-U shown by an arrow.

TABLE 22. Results of Tukey-Kramer Multiple Range Test comparing significant differences in specific conductance values among WQ stations.		
Groupings[a]	Mean	Station
A	259.1	SB
B	150.5	1
C B	145.3	OMB
C B	140.1	1.5
C B D	130.8	4
C D	129.6	3
C E D	127.5	2
E D	117.2	CMB-L
E	108.5	CBM-U

[a] Means sharing the same letter are not significantly different from one another.

Nitrate. Nitrate concentrations ranged from 0 to 1.22 mg/L (see Table 10). The overall mean value of 0.22 mg/L exceeded the median nitrate concentration of 0.19 mg/L. Stations showed considerable variation in the range of values recorded over the 5-year period (Fig. 20). The range of values was highest at stations 1, 1.5, and SB and lowest at CMB-U. Nitrate concentrations increased when going downstream in LB from stations 4 to 1.5 and 1 and from CMB-U to CMB-L. CMB-L contributed relatively more nitrate to LB than its upstream stations, although its flow volume is less than LB. OMB and SB had values like those observed at CMB-L and LB stations 3 and 4, which are about midway downstream in the LB watershed. As noted previously, nitrate concentrations were highest during Summer and Winter (see Fig. 11; Table 16). This was less apparent in the plots of data by station, which showed an

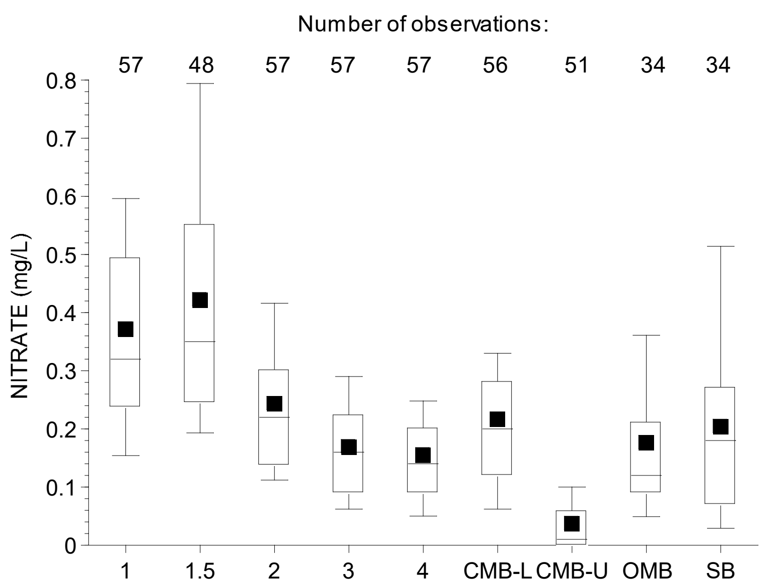

FIGURE 20. Box plot of nitrate values (mg/L) recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available at each station is given above the corresponding box.

inconsistent pattern from month to month (Fig. 21). Nitrate can vary among stations and over time if most of it comes from human sources (septic, agriculture, fertilizer use) and accumulates downstream within a watershed. Relatively low nitrate concentrations are found in headwater areas, such as CMB-U, likely from its small surrounding area, mostly wooded surroundings, and very low developmental density. Increases are seen in more downstream areas, such as in Flanders (stations 1 and 1.5) after LB has flowed through areas of increasing housing and commercial development, where many homes not in Flanders Village are non-sewered and there is also an increasing frequency of stormwater drains.

The GLM analysis indicated highly significant differences among stations (Table 23). A Tukey-Kramer test showed that, as expected, stations 1 and 1.5 in LB had similar and significantly higher nitrate concentrations than the other stations (Table 24). CMB-U had nitrate values significantly lower than all other stations sampled. The remaining stations were mostly not significantly different from each other.

TABLE 23. Results of SAS GLM analysis comparing nitrate (mg/L) recorded at WQ stations in LB, CMB, OMB, and SB from April 2012 through March 2017.

Station	n	Mean	Standard deviation		
1	57	0.37	0.19		
1.5	48	0.42	0.24		
2	57	0.25	0.14		
3	57	0.17	0.11		
4	57	0.15	0.12		
CBM-L	56	0.22	0.13		
CMB-U	51	0.04	0.05		
OMB	34	0.18	0.15		
SB	34	0.20	0.17		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	8	5.459	0.682	30.29 **	<0.0001
Error	442	9.957	0.023		
Corrected total	450	15.417			

TABLE 24. Results of Tukey-Kramer Multiple Range Test comparing significant differences in nitrate concentration among WQ stations.

Groupings[a]	Mean	Station
A	0.42	1.5
A	0.37	1
B	0.24	2
B C	0.22	CMB-L
B C	0.20	SB
B C	0.18	OMB
B C	0.17	3
C	0.15	4
D	0.04	CMB-U

[a] Means sharing the same letter are not significantly different from one another.

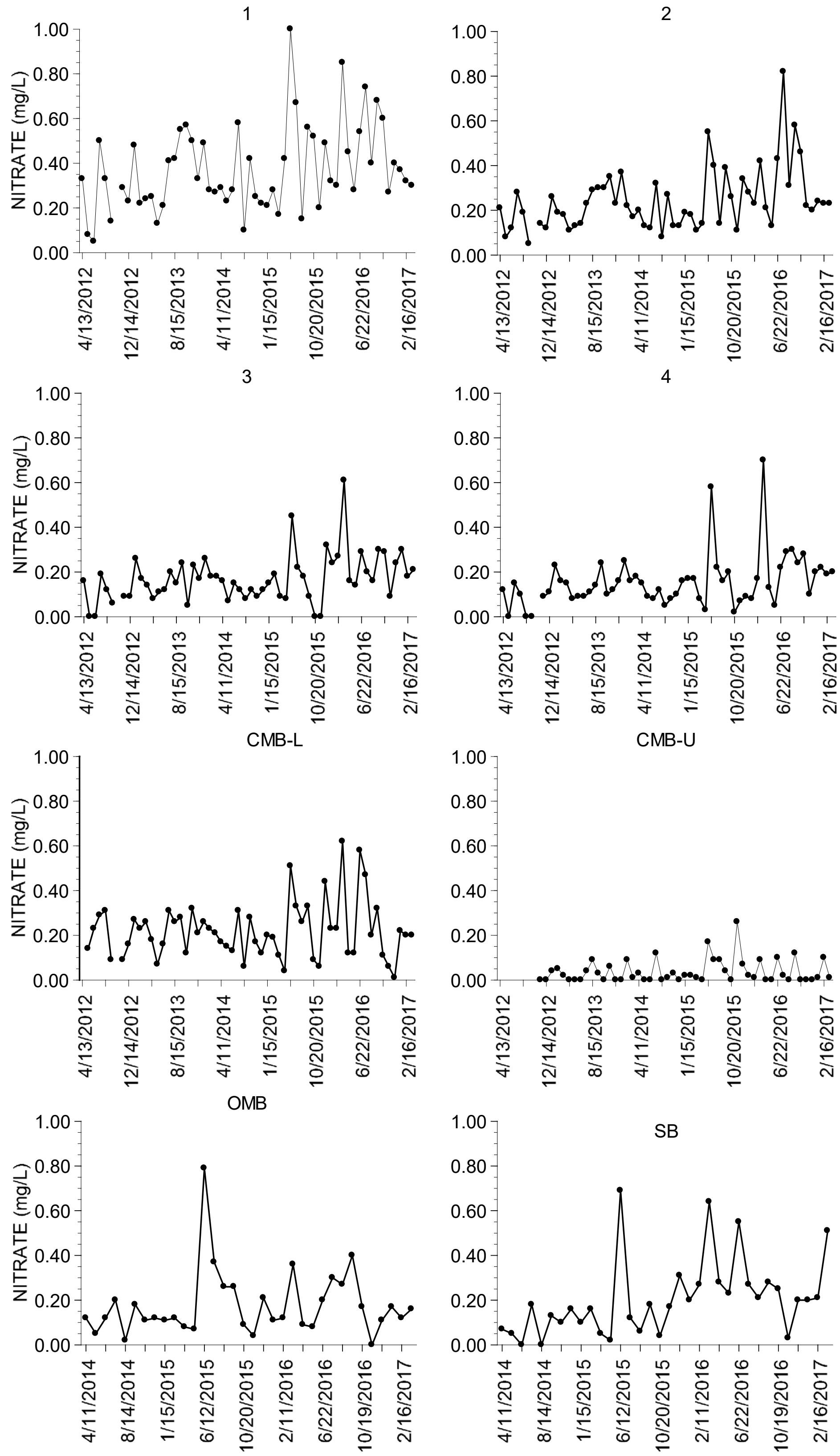

FIGURE 21. Nitrate (mg/L) at stations in LB (except for station 1.5) and CMB recorded from April 2012 through March 2017 and at the OMB and SB stations from April 2014 through March 2017.

As nitrate is an important WQ parameter due to its capability to affect the biota and ecology of the NR, I examined its presence in greater detail than the other WQ parameters. Monthly nitrate concentrations were compared among the three most downstream stations in LB: 2, 1.5, and 1 from February 2013 (the start of sampling at station 1.5) through March 2017 (Fig. 22). In nearly all months, nitrate values were lower at 2 than further downstream, which reflects the significant station differences found (Table 24). However, station 1.5 usually had somewhat higher nitrate concentration than 1, but not always. Station 1.5 was sampled at a road culvert in a housing development and 1 is at the LB dam in Flanders (see Table 1 and Fig. 2). As noted previously, in its lower reaches, LB has passed through an area of increasing housing density from station 4 downstream. In the immediate vicinity of station 1, Flanders Village also has several public schools and considerable commercial development, although many of these properties are now sewered. However, this does not take into consideration homeowner fertilizer use and other potential sources of accumulating nitrate. One possible reason station 1 has a somewhat (but not significantly) different concentration of nitrate than 1.5 is that it is at the downstream end of a small impoundment supporting both aquatic macrophytes and algal growths. These plants and algae are less dense in the more stream-like environments at stations 1.5 and 2. As I saw at DPO, aquatic macrophytes may be utilizing any available nitrate, thereby locally reducing concentration.

I also examined whether nitrate concentration has any relationship to the other WQ parameters recorded during this study (see Table 11). Water temperature was not significantly correlated with nitrate concentration and showed considerable scatter (Fig. 23). Although both DO and pH were weakly correlated with nitrate values, I again did not observe any apparent relationship when examining their plotted values (Figs. 24 and 25). However, nitrate and specific conductance had a stronger relationship (Spearman's rank-order correlation coefficient = 0.361 **; Table 11). The positive sign indicated that as specific conductance increased, so did nitrate. Again, a plot of the data shows considerable scatter with higher values of both parameters likely influencing this relationship (Fig. 26). A fit of the data to a linear

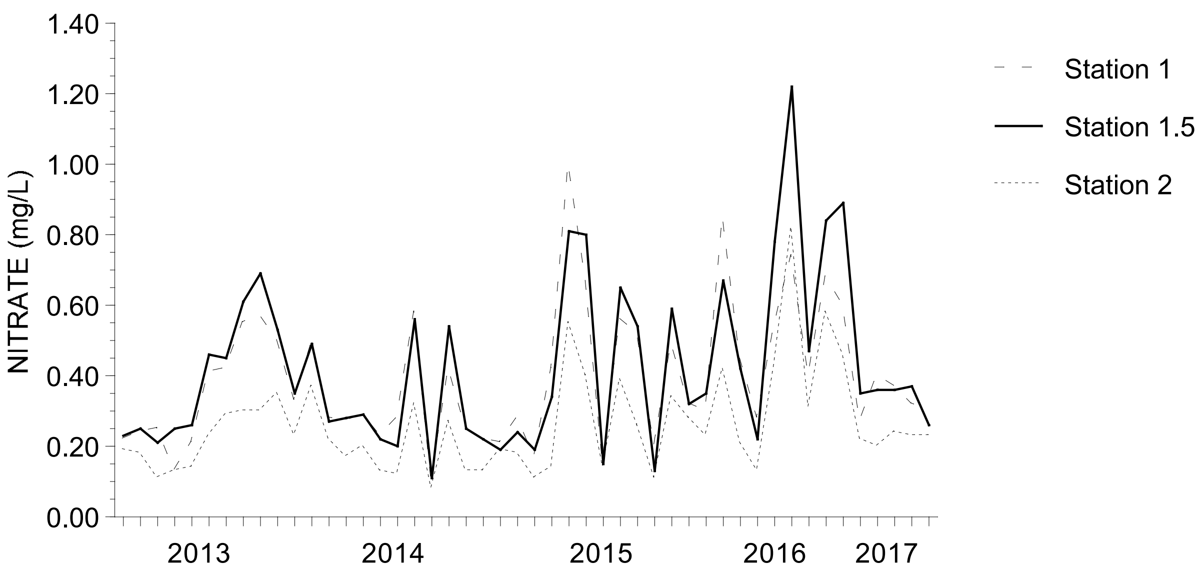

FIGURE 22. Comparison of nitrate values (mg/L) at stations 1, 1.5, and 2 recorded from February 2013 through March 2017.

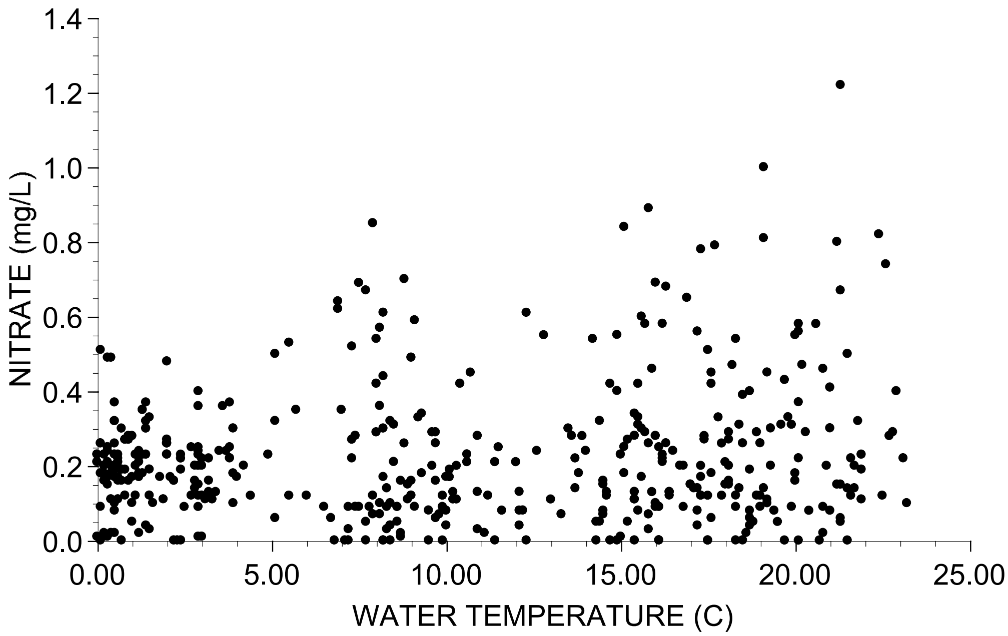

FIGURE 23. Scatter plot of nitrate (mg/L) and water temperature (^{o}C) values recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017.

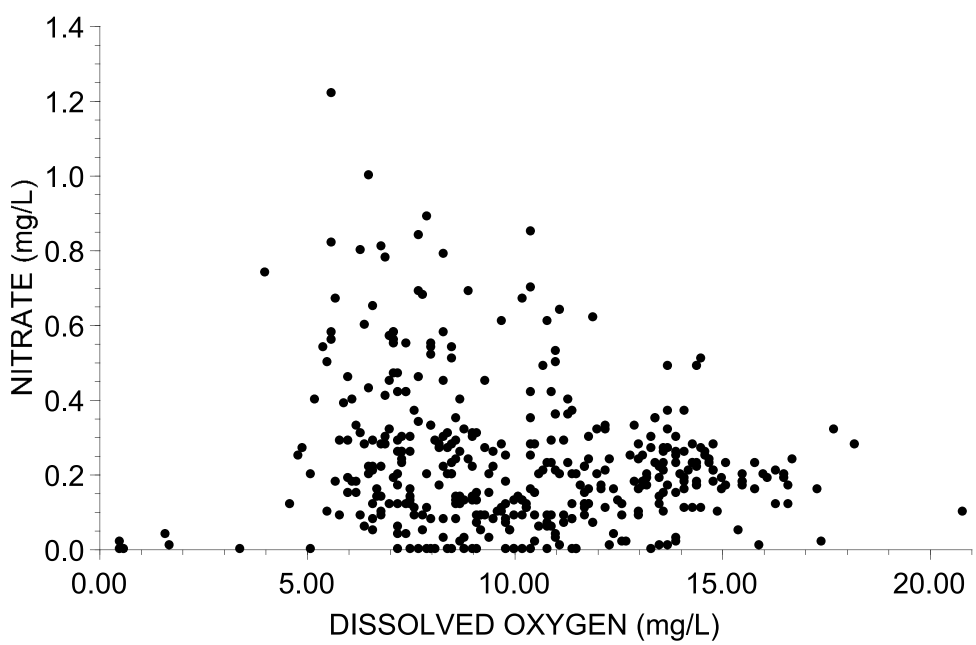

FIGURE 24. Scatter plot of nitrate (mg/L) and dissolved oxygen (mg/L) values recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017.

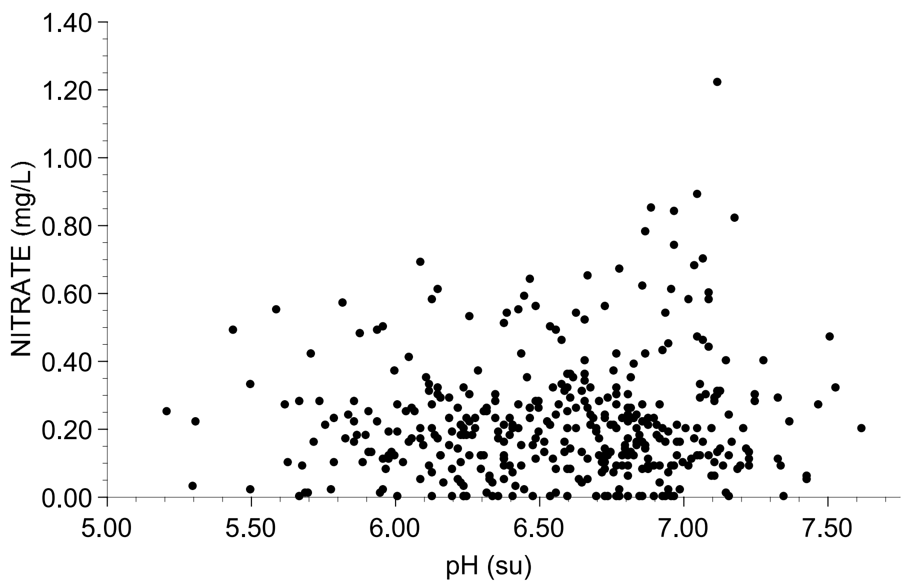

FIGURE 25. Scatter plot of nitrate (mg/L) and pH (su) values recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017.

relationship had a poor fit ($r^2 = 0.05$). I found several instances of anomalously high specific conductance values resulting from very low or no flow conditions at several stations during this study and SB had significantly higher specific conductance values than all the other stations (see Table 22). Therefore, all SB values and several outliers from OMB and CMB-U were deleted in a revised analysis and plot (Fig. 27). Although much of the data scatter remains, the relationship appears more positive, and the linear regression has an increased r^2 of 0.25. I can only speculate on reasons why nitrate and specific conductance may be related. They may reflect precipitation-related inputs of both minerals and nutrients, which then simultaneously increase the values of both specific conductance and nitrate.

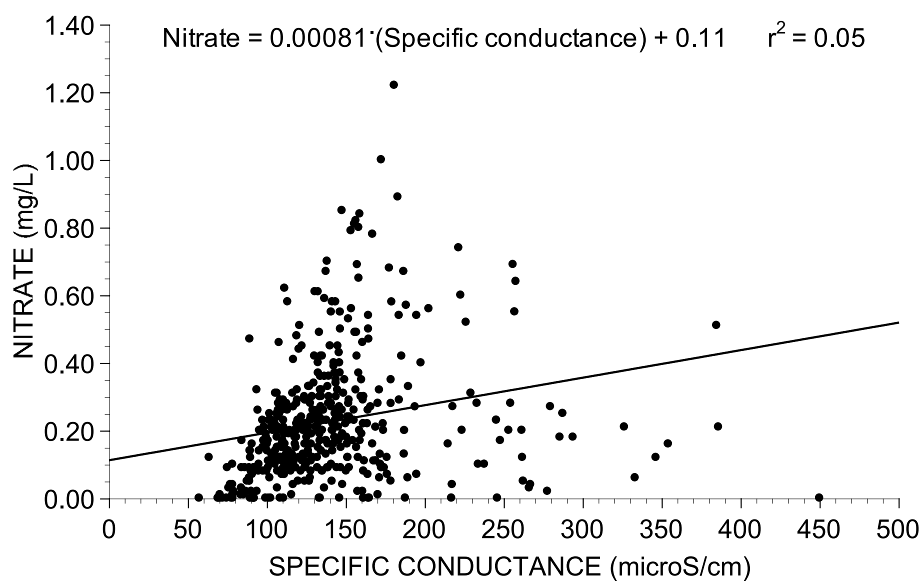

FIGURE 26. Scatter plot of nitrate (mg/L) and specific conductance (µS/cm) values recorded at nine stations during WQ sampling in NR tributaries from April 2012 through March 2017. A linear regression was fit to the data with the formula and correlation coefficient shown.

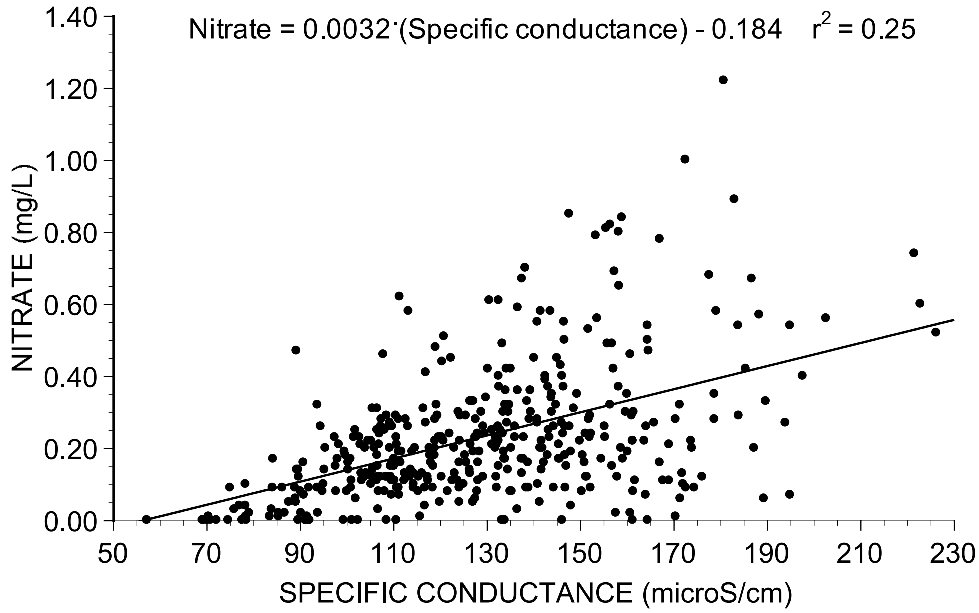

FIGURE 27. Scatter plot of nitrate (mg/L) and specific conductance (µS/cm) values recorded at eight stations (SB and three other outlier observations omitted) during NRWC WQ sampling in NR tributaries from April 2012 through March 2017. A linear regression was fit to the data with the formula and correlation coefficient shown.

Contributions of Nitrate from Upper LB and CMB to Lower LB

As previously shown, on average, upper LB supplies about 62% and CMB 38% of the water volume of lower LB (see Table 5). These fractions were applied to the nitrate concentrations determined at both station 4 (representing upper LB) and CBM-L from May 2012 through March 2017 to calculate nitrate concentrations for this station combination that could be compared with nitrate concentrations that were found by sampling at station 3, the first LB station downstream of the confluence of the two streams. Unlike comparisons previously made among all stations sampled in the tributary-based sampling (see Tables 23 and 24), a one-way ANOVA using data from just the three stations showed that nitrate concentration at CMB-L was significantly larger than the mean values of stations 3 and 4 (Table 25). A *t*-test showed that the latter two stations were not significantly different ($p = 0.535$) from one another, demonstrating that, in relative terms, CMB has the potential to provide more nitrate to lower LB than does upper LB (see also Fig. 20). However, this is offset by the smaller streamflow volume of CMB in comparison to LB. Correlations among nitrate concentrations for the three stations and the calculated combined stations 4 & CMB-L values showed the highest *r* was between station 4 and the combined station data (Table 26). This is not surprising as nitrate concentration values at station 4 contributed to nearly two-thirds of the combined station value. Yet, the station 3 values also showed a reasonably high correlation (0.846) with the values calculated for combined stations 4 & CMB-L.

A comparison of the calculated and actual values showed that they were relatively similar, although there were some deviations, both negative and positive (Fig. 28). A second comparison of these values showed a linear relationship ($r^2 = 0.72$) between the combined stations 4 & CMB-L nitrate concentrations and those specifically measured at station 3 (Fig. 29). With this additional analysis, I conclude that my results from the water temperature study to determine fractions of water from CMB and upper LB contributing to the flow volume in lower LB were reasonably accurate.

TABLE 25. One-way ANOVA comparing nitrate concentrations (mg/L) at stations 3, 4, and CMB-L from May 2012 through March 2017.						
SUMMARY:						
	Groups	Count	Sum	Average	Variance	
	Station 4	56	8.70	0.15	0.014	
	CMB-L	56	12.32	0.22	0.016	
	Station 3	56	9.45	0.17	0.012	
ANOVA:						
Source of variation	Degrees of freedom	Sum of squares	Mean square	F Value	Probability value	F crit
Between groups	2	0.120	0.065	4.614 *	0.011	3.051
Within groups	165	2.331	0.014			
Total	167	2.461				

TABLE 26. Correlations between nitrate concentrations at stations 3, 4, and CMB-L and a calculated value for stations 4 and CMB-L combined from May 2012 2012 through March 2017.			
	CMB-L	Station 4	Station 3
Station 4	0.635		
Station 3	0.690	0.820	
Calculated combined CMB-L and Station 4 data	0.857	0.942	0.846

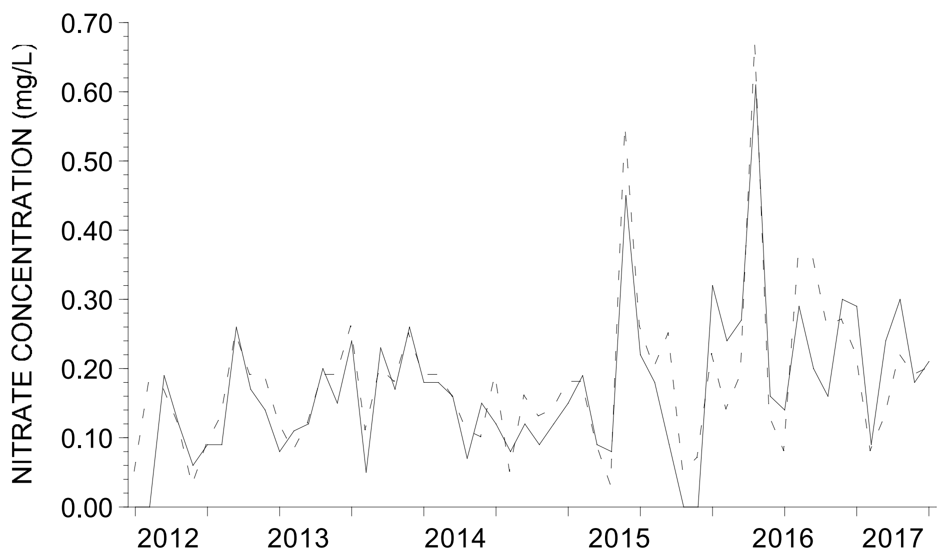

FIGURE 28. Nitrate concentration (mg/L) calculated from values at stations 4 and CMB-L combined (dashed line) compared to the actual concentration found at station 3 (solid line) from May 2012 through March 2017.

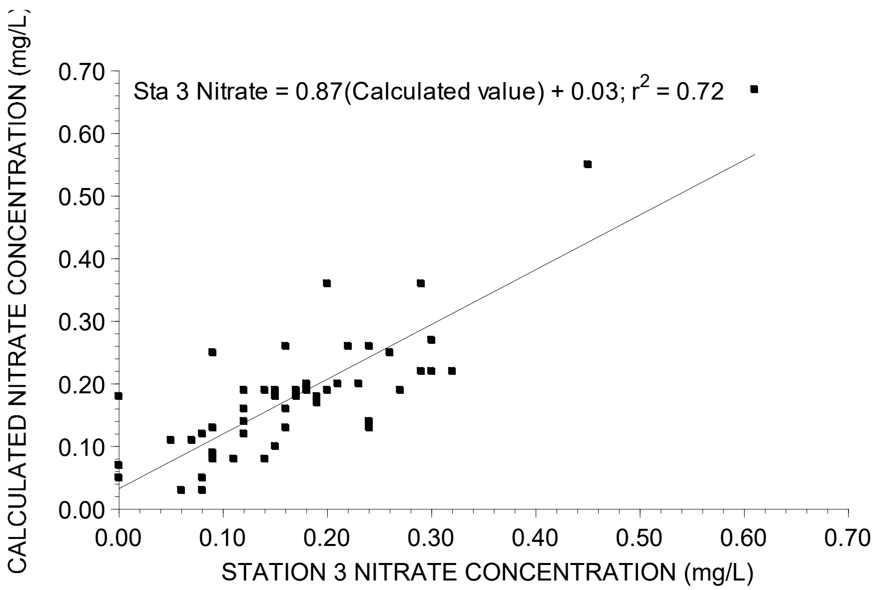

FIGURE 29. Actual nitrate concentrations (mg/L) found at station 3 from May 2012 through March 2017 plotted against calculated values for stations 4 and CMB-L data combined.

WQ Samples Taken in a Curtain Drain Discharge near CMB-L during 2016-17

Although most certainly occurring before then, during our sampling in March 2013 I first noted a discharge of water from a curtain drainpipe that opened onto the lawn of the house where CMB-L is located. This discharge point is about 10 yards from CMB. In subsequent observations I found heaviest flows occurred in winter and early spring months, sometimes reaching the brook, but more often this flow of water sank into the lawn after traveling only a few yards. The more persistent water flows often contained considerable growths of a filamentous green alga, indicating nutrients were present in this water source. During summer and fall months, this flow and the algae contained within it dried up. I am uncertain of the specific source of this discharge, only that it probably was from groundwater flowing down a relatively steep portion of Walnut Hill Road. With all homes in this area having septic systems for sanitary wastes, I was also unsure if this flow contributed any nutrients to CMB. Therefore, sampling this source of water for nitrate began in January 2016 and continued through May 2016, after which the flow ceased. Sampling resumed in December 2016 and monthly samples were taken through March 2017, the last month of the tributary-based sampling. Nearby CMB-L almost always had a greater concentration of nitrate than the curtain drain discharge and over time the two concentrations mostly mirrored one another (Fig. 30). An exception was in December 2016, when the nitrate concentration in CMB-L was very low (0.01 mg/L) but was 0.31 mg/L in the curtain drain. A second water sample was taken in April 2016 when the curtain drain flow was great enough to reach CMB. The nitrate concentration of 0.09 mg/L in the second curtain drain sample taken by the stream edge was about one-half that of the 0.17 mg/L found at the pipe opening and less than the concentration of 0.12 mg/L found in the brook. The curtain drain discharge is likely not a significant source of nutrients input into CMB, particularly when algae are apparently utilizing much of their mass before any of this flow reaches the brook.

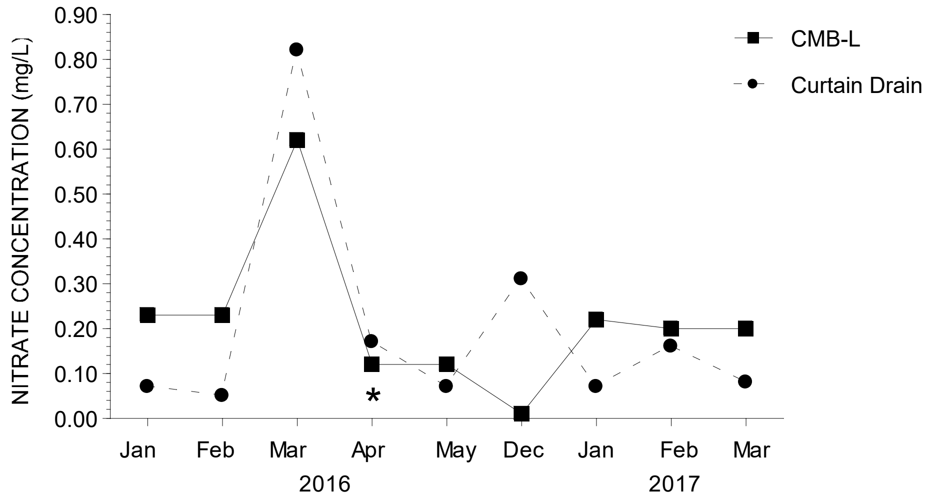

FIGURE 30. Concentration of nitrate (mg/L) in water samples taken at the CMB-L WQ station and from the discharge of a nearby curtain drain during January-May 2016 and December 2016-March 2017. The '*' indicates the nitrate concentration in a second water sample taken in April 2016 where the curtain drain flow entered CMB.

Precipitation-related WQ Sampling

Rainfall Occurring during the 2017-2022 Precipitation-related Sampling

Although the WELSCO weather station location in Niantic is relatively close (~3.5 miles) to the LB dam in Flanders, I observed that the timing and intensity of rain sometimes differed between these two locations, so precipitation entering LB may differ slightly from what falls and is recorded in Niantic. However, I consider these differences to be relatively trivial and not likely to have affected any of the data analyses or conclusions presented in this report.

Although precipitation-related sampling did not begin until Summer of 2017, daily precipitation records recorded for every 15-min period were accessed and summarized by month from April 2017 through June 2022, when they were available through the Davis WeatherLink website for the WELSCO weather station in Niantic. The Davis WeatherLink website maintains records of precipitation termed as "water equivalent", although these records are referred to as rain in this report. During this 5-year period, 2018 (total annual precipitation of 48.93 in) and 2019 (47.75 in) were relatively wet compared to 2020 (35.04 in) and 2021 (35.58 in) (Table 27). Only partial year records were either available or examined for 2017 and 2022, so I also compared months in common among these years. Total precipitation from May through December during 2017-21 showed that the 2017 total of 28.98 in was greater than the totals for those months in 2020 (26.38 in) and 2021 (27.73 in), but considerably less than in 2018 (37.67 in) and 2019 (38.25 in). The January-June totals for 2018-22 indicated that 2022 (14.23 in) had the least precipitation for this period when compared to the other 4 years (range of 15.70-22.31 in).

During the 5-year period, the wettest months were October (monthly mean of 4.69 in) and April (4.05 in) and January (2.67 in) and June (2.78 in) the driest (Table 27). Overall, the grand monthly mean was 3.35 in (SD = 0.55). Largest rainstorms occurring during each year ranged from 1.30 in (2022) to 4.00 in (2021) (Table 28). Largest annual storms tended to occur in late summer and fall. The highest rainfall event of 4.00 in, occurring on September 1-2, 2021, was associated with the passage of Tropical Storm Ida. Note, however, that according to the September 2, 2021 edition of *The [New London] Day*, the National Weather Service (NWS) reported that East Lyme received 7.36 in of rain from this storm.

TABLE 27. Total monthly precipitation (in) as recorded by the WELSCO rain gage in Niantic from April 2017 through June 2022.

Month	2017	2018	2019	2020	2021	2022	Mean
January	-	2.95	4.21	2.00	2.26	1.93	2.67
February	-	5.20	2.83	3.10	2.02	2.75	3.18
March	-	3.11	2.46	3.92	3.57	2.52	3.12
April	6.03	3.74	4.90	4.36	2.73	2.56	4.05
May	4.78	2.39	3.59	2.30	4.14	2.19	3.23
June	3.68	2.42	4.32	2.97	0.98	2.28	2.78
July	1.73	2.59	4.77	1.70	4.25	-	3.01
August	1.88	3.72	5.69	2.30	3.23	-	3.36
September	1.68	7.80	0.59	1.01	5.52	-	3.32
October	5.55	4.12	6.48	3.16	4.14	-	4.69
November	1.94	7.14	2.35	4.17	1.57	-	3.43
December	1.71	3.75	5.56	4.41	1.17	-	3.32
Total	28.98[a]	48.93	47.75	35.04	35.58	14.23[a]	
						Monthly mean	3.35
						SD	0.55

[a] Partial year totals.

TABLE 28. Largest rainstorms (cumulative amount if occurring over a multi-day period) of each year from April 2017 through June 2022 as recorded by the WELSCO rain gage in Niantic.

Year	Total rainfall (in)	Dates of rainstorm
2017	2.60	October 24-26
2018	3.61	September 25-28
2019	2.61	July 22-23
2020	1.52	December 5-6
2021	4.00	September 1-2 (Tropical Storm Ida)
2022	1.30	April 19

The daily records allowed for an examination of the frequency and amount of precipitation occurring during various rain or snowstorms. Monthly summaries provided by Davis WeatherLink gave rainfall totals for each day and summed up the daily precipitation records of a month in two ways: the number of events with rainfall greater than 0.01 in and those equal to or greater than 0.10 in. I noted numerous records of daily precipitation exactly equaling 0.01 in that were ignored in these totals. Perhaps many of these instances were attributed to condensation rather than rain, so they were not counted, although I am unsure of this. The greatest frequency of precipitation events >0.01 in occurred during February-May, October, and December (Table 29). Driest months included June through September. The fraction of precipitation events that were ≥0.10 in of all the daily precipitation events >0.01 in were calculated. These calculations indicated that percentages of larger precipitation events were mostly uniform across

TABLE 29. Total monthly events with a daily total precipitation of >0.01 in, ≥0.10 in, and the fraction of the larger (≥0.10 in) precipitation events of all events >0.01 in within each month from April 2017 through June 2022.

Precipitation events > 0.01 in:							
	2017	2018	2019	2020	2021	2022	Mean
January	-	6	8	12	5	8	7.8
February	-	15	9	11	13	11	11.8
March	-	9	9	10	10	12	10.0
April	12	12	19	11	9	12	12.5
May	11	11	16	13	11	9	11.8
June	10	9	10	7	7	9	8.7
July	6	8	6	12	13	-	9.0
August	10	10	7	9	8	-	8.8
September	7	12	6	5	9	-	7.8
October	11	11	15	10	8	-	11.0
November	10	14	9	8	7	-	9.6
December	9	10	11	9	12	-	10.2
Total	86	127	125	117	112	61	
Precipitation events ≥ 0.10 in:							
	2017	2018	2019	2020	2021	2022	Mean
January	-	5	5	5	3	6	4.80
February	-	13	7	8	5	8	8.20
March	-	4	5	7	5	7	5.60
April	6	6	10	9	5	4	6.67
May	8	7	9	7	9	7	7.83
June	7	6	9	4	3	5	5.67
July	5	5	5	5	8	-	5.60
August	7	5	4	5	6	-	5.40
September	4	8	2	4	5	-	4.60
October	8	6	10	8	7	-	7.80
November	4	9	5	7	4	-	5.80
December	3	5	8	7	6	-	5.80
Total	52	79	79	76	66	37	
Percentage of Precipitation Events ≥ 0.10 in:							
	2017	2018	2019	2020	2021	2022	Mean
January	-	83.3	62.5	41.7	60.0	75.0	61.5
February	-	86.7	77.8	72.7	38.5	72.7	69.5
March	-	44.4	55.6	70.0	50.0	58.3	56.0
April	50.0	50.0	52.6	81.8	55.6	33.3	53.3
May	72.7	63.6	56.3	53.8	81.8	77.8	66.2
June	70.0	66.7	90.0	57.1	42.9	55.6	65.4
July	83.3	62.5	83.3	41.7	61.5	-	62.2
August	70.0	50.0	57.1	55.6	75.0	-	61.4
September	57.1	66.7	33.3	80.0	55.6	-	59.0
October	72.7	54.5	66.7	80.0	87.5	-	70.9
November	40.0	64.3	55.6	87.5	57.1	-	60.4
December	33.3	50.0	72.7	77.8	50.0	-	56.9

most months, with lowest values found for September (59%), December (57%), March (56%), and April (53%) and highest in February (69%) and October (71%).

The criterion for taking precipitation-related water samples at the LB dam was an expected rainfall of 1 in or more. WELSCO precipitation records were further examined, and the frequencies and total rainfall amounts for precipitation events of 0.70 in or more were calculated, an arbitrary amount I considered to be a substantial precipitation event. As rainfall data were totaled over each calendar date, storms beginning in the evening frequently carried over to the following day. Also, in some cases, rain fell over several consecutive days. Therefore, both the number of days and precipitation amounts were summed over each rainfall event. Rain totaling ≥0.10 in fell over periods of from 1 to 8 consecutive days, with 1 to 3-day rainfall events the most common. The percentage of days in each year having recorded rainfall of ≥0.01 in were relatively similar, ranging from 37.5 to 43.7% (Table 30). The wetter years of 2018 and 2019 had the highest frequency of rain events of 0.70 in or more and about three-quarters or more of total annual rain came during these heavier rainstorms. A similar fraction of total rain in 2021 (72.5%) and somewhat smaller fraction in 2020 (62.4%) was made up by heavier rainstorms, but the frequency of these storms in both these years was only about two-thirds of those occurring in 2018 and 2019. Thus, it appears that the frequency of larger rainstorms is what results in wetter or drier years. Of note, the precipitation data indicated that the first half of 2022 was particularly dry.

As the precipitation-related sampling only took place once each quarter, the number of rainstorms totaling ≥0.70 in were summarized for each quarter sampled (Table 31). Largest rainstorms occurred most frequently in Winter and Fall with fewest in Summer. Once again, 2018 and 2019 had heavier rainstorms than the other years with 2017 and 2022 having relatively fewer heavier rainstorms later and earlier in the year, respectively.

TABLE 30. Annual precipitation (ppt.), total rainfall (in), number of days with a daily total precipitation of ≥0.01 in, precipitation events ≥0.70 in, percentage of days having these precipitation events, and the fraction of the larger (≥0.70 in) precipitation events of all precipitation events ≥0.01 in from April 2017 through June 2022 as recorded by the WELSCO rain gage in Niantic.

Year	Days in year examined	Days when ppt. ≥0.01 in	Total annual ppt. (in)	% days when ppt. ≥0.01 in	Days with ppt. events ≥0.70 in	Total ppt. (in) when ppt. events ≥0.70 in[a]	% days when ppt. events ≥0.70 in	% annual ppt. when ppt. events ≥0.70 in
2017	275[b]	103	28.98	37.5	23	17.9	8.4	62.0
2018	364[c]	159	48.20	43.7	61	35.3	16.8	73.2
2019	366[c]	157	48.48	42.9	61	38.6	16.7	79.5
2020	366	138	35.04	37.7	42	24.9	11.5	62.4
2021	365	148	35.58	40.8	40	25.8	11.0	72.5
2022	181[b]	77	14.23	42.5	16	6.8	8.8	47.6

[a] Events included periods of 1 to 8 days of precipitation in succession with a cumulative total of ≥0.70 in.
[b] Partial years of data, including April 1-December 31, 2017 and January 1-June 30, 2022.
[c] A precipitation event starting on December 31, 2018 was carried over to 2019, so annual totals for those years differ from those presented in Table 27.

TABLE 31. The number of precipitation events ≥0.70 in by quarter from Summer 2017 through Spring 2022[a], the period of precipitation-related sampling at the LB dam.

	2017	2018	2019	2020	2021	2022	Total	Percent
Winter	-	7	8	7	5	4	31	28.7
Spring	-	5	9	5	3	3	25	23.1
Summer	2	7	5	3	5	-	22	20.4
Fall	4	9	7	7	3	-	30	27.8
Annual total	6	28	29	22	16	7	108	

[a] If a precipitation event overlapped a year or quarter, it was counted where the daily total of the event was highest.

LB Discharge Flow Volumes as Computed from Water Depth Measurements during 2017-19

During precipitation-related sampling, streamflow discharge records (cfs) were available once the USGS gage, located just downstream of the LB dam, was reinstated in January 2020, and operated through the end of this sampling in Spring 2022 (USGS Undated). To have a complete record of LB discharge volumes into the NR, I needed to estimate values that were unavailable when the USGS gage was not operating from Fall 2017 through Fall 2019. I accomplished this by comparing the water depths (cm) I measured at the northeast corner of the LB dam (29 measurements taken during sampling events and 31 supplemental observations) with corresponding USGS records of streamflow discharge volumes. These values include water depths calculated from angled measurements of depth at the dam (see Fig. 4 and associated text). I computed the following relationship by comparing water depths at the LB dam with corresponding LB discharge flows:

$$\text{Flow (cfs)} = \exp(-12.468) \times \text{water depth}^{4.266} \quad (R^2 = 0.967;\ n = 60)$$

This relationship has a good fit to the data and the resulting power curve and data points are shown in Figure 31. However, it is apparent that this relationship underestimates discharge volumes during high flows as most of the higher streamflow data points are found above the calculated power curve line. Thus, I partitioned the data to compute the relationships at water depths of both less than and greater than 44 cm (Fig. 32). The resulting relationships are:

$$\text{Flow (cfs)} = \exp(-13.755) \times \text{water depth}^{4.631} \quad (R^2 = 0.976;\ n = 17) \text{ for water depths} > 44 \text{ cm}$$

and

$$\text{Flow (cfs)} = \exp(-10.708) \times \text{water depth}^{3.746} \quad (R^2 = 0.950;\ n = 43) \text{ for water depths} < 44 \text{ cm}$$

I concluded that partitioning the data in this way gave me more useful results. The above two formulae were used to estimate flow volume (cfs) for sampling periods when there were water depth measurements but no flow values available from the UGGS gage. In the eight quarterly samplings where flow values were computed, three were calculated using the upper formula (water depths >44 cm) and five using the lower formula (water depths <44 cm).

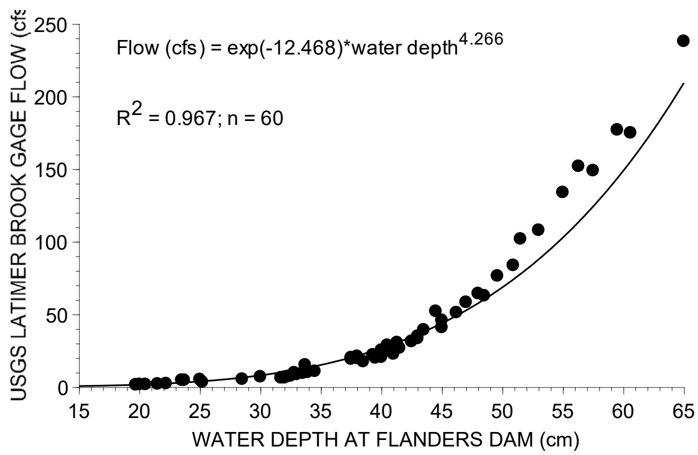

FIGURE 31. Relationship between the discharge volumes (cfs) of LB as recorded by the USGS gage and water depths measured at the northeast corner of the LB dam. A power curve was fit to the flow-water depth data points.

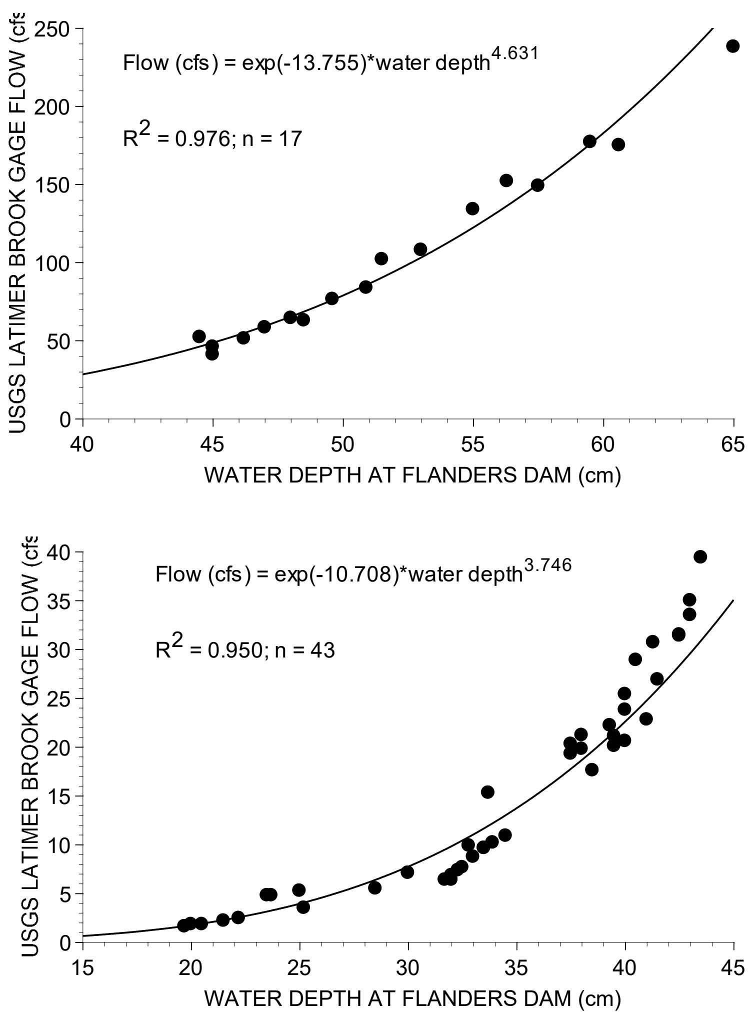

FIGURE 32. Relationship between the discharge volumes (cfs) of LB as recorded by the USGS gage and water depths measured at the northeast corner of the LB dam. The data were divided into two groups: water depths >44 cm and water depths <44 cm. A power curve was fitted to each set of flow-water depth data points.

LB Discharge Flow Volumes during the 2017-2022 Precipitation-related Sampling

As discussed above, LB discharge flows were estimated from Fall 2017 through Fall 2019. Discharge flow estimates are not available for Summer 2017 as LB water depths were not measured, and for Winter 2018, when heavy icing prevented accurate measurements of water depths from being taken. I estimated LB discharge flow values or obtained them directly from USGS data records for each quarterly sampling event, which varied depending upon the number of WQ samples taken in each quarter. The number of discharge flow observations and WQ samples taken were usually related to the frequency and timing of rain falling during each quarterly sampling. I took more samples during extended rain events and these point samples varied between 5 and 12 observations per quarter.

Comparative statistics for LB discharge volumes during sampling events when I calculated them (Fall 2017-Fall 2019) and those that were retrieved directly from the USGS gage (Winter 2020-Summer 2022) are given in Table 32. Note that the USGS gage records flow data every 15 minutes throughout the day, so I downloaded data for the time closest to when I sampled. LB discharge flow values in our database were nearly equal between those I calculated (n = 62) and directly measured by the USGS gage (68). Both sets of flow values were highly skewed. The calculated values had a mean flow value of 34.55 cfs (SD = 77.49), but a median of only 12.28 cfs. The USGS data records resulted in a mean flow of 54.97 cfs (SD= 150.68), having a median of 19.55 cfs. Combining the two datasets resulted in a mean of 45.24 cfs (SD = 147.74) with a median value of 14.88 cfs for the set of precipitation-related samples. The minimum flow recorded during the precipitation-related sampling was 1.62 cfs on August 27, 2020 and the maximum was 1570 cfs, which occurred during Tropical Storm Ida on September 2, 2021.

TABLE 32. Statistics for stream discharge (cfs) from observations taken during the times of precipitation-related WQ sampling at LB station 1. LB flow was either calculated from water depth measurements from Fall 2017 through Fall 2019 or recorded directly from data provided by the USGS gage from Winter 2020 through Spring 2022.

Statistic	Calculated discharge (cfs)	USGS discharge records (cfs)
n	62	68
Mean	34.55	54.97
SD	77.49	150.68
Minimum	2.44	1.62
First Quartile	5.85	8.86
Median	12.28	19.55
Third Quartile	28.65	42.33
Maximum	544	1570
	Combined discharge records (cfs) from above	
n	130	
Mean	45.24	
SD	147.74	
Minimum	1.62	
First Quartile	7.13	
Median	14.88	
Third Quartile	38.22	
Maximum	1570	

LB streamflow values calculated or recorded during precipitation-related sampling events are shown in Figure 33. Besides the Tropical Storm Ida maximum flow of 1570 cfs, a streamflow of 545 cfs occurred on October 17, 2019, which was the month having the second highest precipitation of the 5-year sampling period (see Table 27). Although the WELSCO-recorded rainfall of 1.47 in for this sampling event was not exceptional, another rain gage in East Lyme reported 2.85 in of rain. Due to the relative severity of rainstorms in relation to my sampling, there was no clear distinction by season, with Summer having the highest mean flow (80.94 cfs) because of the tropical Storm Ida data point, but also the lowest median value of 7.13 cfs (Table 33). With the median likely being the best comparative statistic for these data, Winter (41.53 cfs) clearly had the highest flow values during these 5 years of sampling.

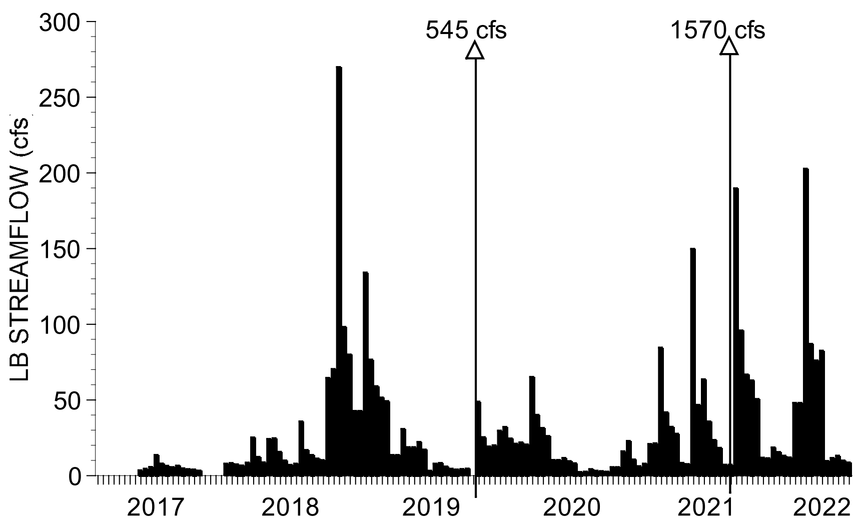

FIGURE 33. Calculated or actual LB streamflow (cfs) from Fall 2017 through Spring 2022 during precipitation-related sampling completed once per quarter. The largest recorded flow values of 545 cfs in Fall (October 17) 2019 and 1570 cfs in Summer (September 2) 2021 were not plotted to maintain a lower Y-axis maximum but are shown by the arrows when they occurred.

TABLE 33. Statistics by season for stream discharge (cfs) from observations taken during the times of precipitation-related WQ sampling at LB station 1. LB flow was either calculated from water depth measurements from Fall 2017 through Fall 2019 or recorded directly from data provided by the USGS gage from Winter 2020 through Spring 2022.

Statistic	Summer	Fall	Winter	Spring
n	27	36	30	37
Mean	80.94	39.77	51.31	19.57
SD	300.37	98.96	38.97	24.88
Minimum	1.62	2.55	19.30	5.36
First Quartile	3.41	4.82	25.78	8.00
Median	7.13	10.29	41.53	11.66
Third Quartile	25.59	19.43	62.87	21.51
Maximum	1570.00	544.91	202.00	149.00

Daily Discharge Flow Volumes of LB as Recorded by the USGS Gage

Graphs of LB streamflow data by quarter were downloaded from the USGS website for Winter 2020 (starting on January 24) through Spring 2022 (ending on June 30), which are presented in Appendix Figures 1 through 10. These figures show daily mean flows and how they compare to a 7-year median daily flow for corresponding dates. At the time of this writing, streamflow data recorded after August 3, 2021 were considered as provisional by the USGS.

The daily mean discharge volumes for the same 2020-22 period noted above were requested and received from the USGS (T. Sargent, USGS, East Hartford, CT, pers. comm.). During this time, there were 14 daily observations missing that occurred between January 11 and February 16, 2022, resulting in 990 daily mean discharge values. Based on USGS notes in the data I received, I believe these missing observations were related to ice conditions in LB, which apparently affected proper streamflow discharge measurements by the gage.

The USGS January 2020-June 2022 daily mean streamflow records in LB were compared with the combined set of discharge values calculated or retrieved from the USGS gage records during specific instances when I performed once daily precipitation-related sampling (Table 34). Our expectation for precipitation-related sampling was that rainfall would result in increased discharge flow in LB. This was apparent when comparing mean discharge values, where the 2.5-year USGS mean daily flow was 27.32 cfs (SD = 40.33), whereas the mean discharge value during precipitation-related sampling events was 45.24 cfs (SD = 147.74). The large difference in the standard deviations associated with these mean values illustrated more rapid and substantial changes occurring in LB discharge volume during sampling, a smaller sample size, and the chance of observing larger discrete streamflow values. The median for the precipitation-related sampling was less than one-third the mean value, showing the positive skewness of these data resulting from rainfall. During this sampling, I usually saw a rapid increase in LB flow volume from precipitation runoff that was followed in subsequent days by a corresponding rapid decrease to more baseline values over the days sampled. The similarity in medians and first and third quartile values between these two data records, however, indicated that most observations made during the precipitation-related sampling were more typical of routine LB streamflow conditions immediately preceding and following the rain event.

TABLE 34. Statistics of LB streamflow discharge (cfs) calculated for USGS gage daily mean records from January 24, 2020 through June 30, 2022 and streamflow discharge observations made during each time a precipitation-related sample was taken.

	USGS daily mean discharge records (cfs)	Combined point records of discharge (cfs) from sampling (repeated from Table 32)
n	990	130
Mean	27.32	45.24
SD	40.33	147.74
Minimum	0.4	1.62
First Quartile	6.37	7.13
Median	17.10	14.88
Third Quartile	35.78	38.22
Maximum	872	1570

The USGS daily mean discharge volumes illustrate the periodicity of streamflow over this nearly 2.5-year period (Fig. 34). These flows, however, may not be indicative of long-term conditions in LB as indicated in the previous discussion about rainfall. I noted that 2020 and 2021 were relatively dry in comparison to 2018 and 2019 and Winter-Spring of 2022 was particularly dry. Nonetheless, LB daily discharges volumes in Summer and early Fall were mostly less than those occurring during Winter and Spring, which was expected. Most annual maximum daily flows for this period peaked at about 200-300 cfs. A notable exception was a brief time on and just after September 2, 2021, when Tropical Storm Ida passed through our area, resulting in a one-time very high mean daily flow of 872 cfs. Overall, this pattern of discharge flow volumes certainly reflects local precipitation and perhaps, more rarely, increases in air temperature resulting in rapid melting should there be existing large piles of snow.

Frequency of LB discharge volumes (combined into 10-cfs increments) sequentially declined from the lowest to highest daily flow increments (Fig. 35). About one-half of the daily mean discharge values were less than 20 cfs. Daily mean discharge values greater than 110 cfs rarely occurred.

Determining the long-term mean daily discharge of LB, including data beyond the periods of sampling we completed, would be useful in calculating, for example, the flux (i.e., loading) of nitrate from LB into the NR. Recent available LB discharge data from the USGS gage included September 17, 2008 through September 30, 2012, July 1, 2014 through September 30, 2015, and January 24, 2020 through January 23, 2023 (note that the gage will continue to operate through March 21, 2023, but I chose to download

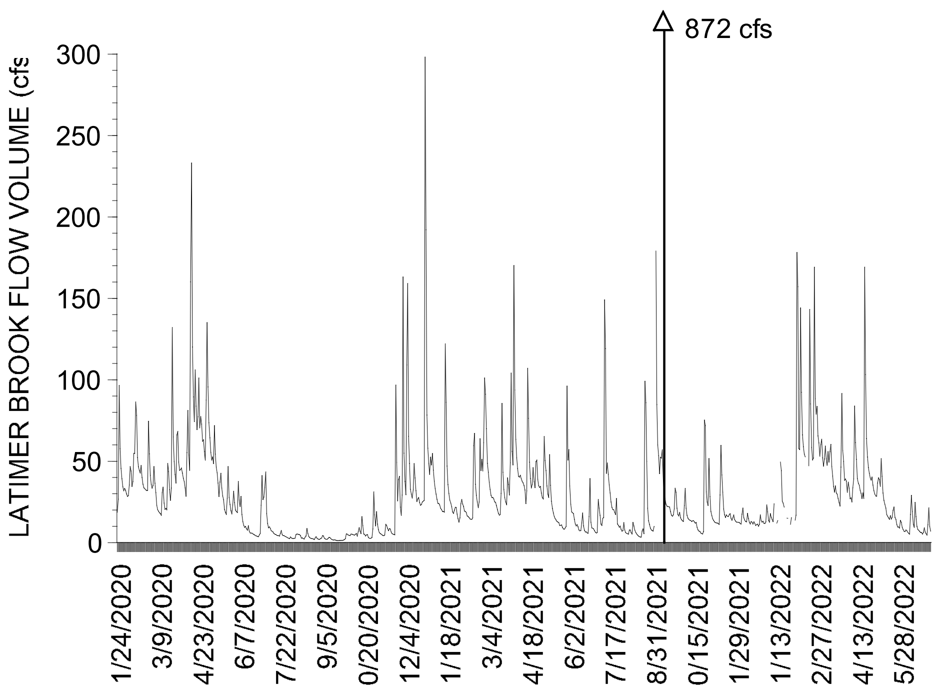

FIGURE 34. Mean daily LB streamflow volume (cfs) from January 24, 2020 through June 30, 2022 as determined by the USGS LB gage. The largest mean flow value of 872 cfs was not plotted here to maintain a lower Y-axis maximum but is shown by the arrow when it occurred on September 2, 2021.

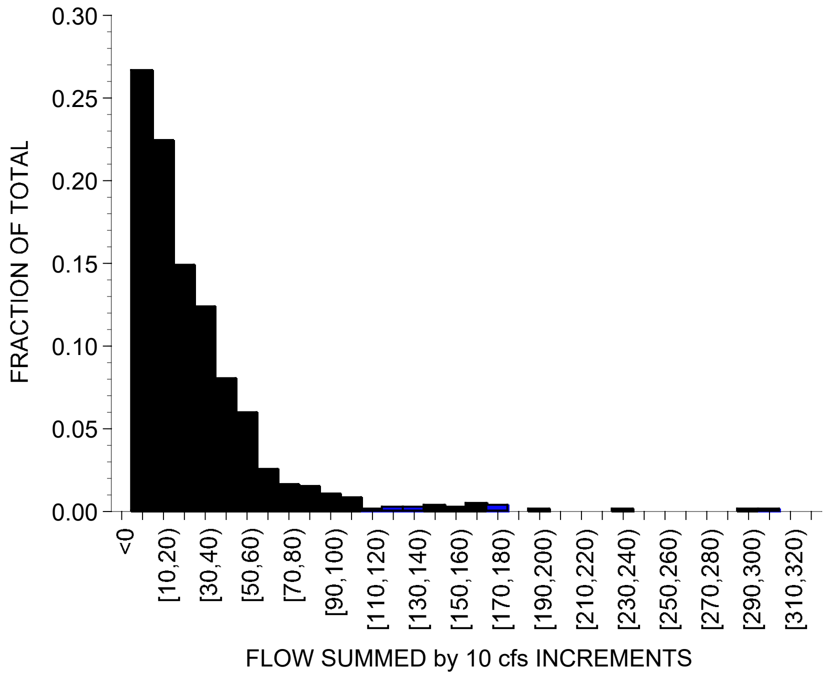

FIGURE 35. Frequency of daily LB streamflow volume (cfs) from January 24, 2020 through June 30, 2022 as determined by the USGS LB gage by 10 cfs increments.

only these data to make a complete 3-year period). Mean daily discharge values (cfs) varied among these three periods, ranging from 16.98 in 2014-15 to 34.75 cfs in 2008-12 (Table 35). These differences likely reflected the number of observations in each period, the specific months included, and rainfall variation. The lowest median value of 9.68 cfs also occurred in 2014-15, but the highest median of 17.80 was found in 2020-23 rather than 2008-12 (14.60 cfs). Combining all these records resulted in a mean daily discharge flow from LB of 29.46 cfs having a 95% confidence interval of ±1.73. Unexpectedly, the median value of 18.20 cfs for all data combined was greater than those computed within each of the three discrete time periods.

TABLE 35. Statistics for mean daily mean stream discharge (cfs) from observations recorded by the USGS gage in LB at various periods from September 17, 2008 through January 23, 2023.

	September 17, 2008 - September 30, 2012	July 1, 2014 - September 30, 2015	January 24, 2020 - January 23, 2023	All 2008-23 data combined
n	1475	457	1081	3013
Mean	34.75	16.98	27.52	29.46
SD	58.14	23.27	39.66	48.36
95% CI	±2.97	±2.14	±2.37	±1.73
Minimum	1.22	1.24	0.40	0.40
First Quartile	10.70	3.09	6.52	7.45
Median	14.60	9.68	17.80	18.20
Third Quartile	38.60	19.50	35.70	35.70
Maximum	1350	171	872	1350

Precipitation-related WQ Monitoring at the Flanders LB Dam during 2017-2022

Number of Observations and Comparative Statistics

I recorded less than one-third of the observations of the five WQ parameters during my 5 years of precipitation-related sampling (Table 36) than I did during my 5 years of tributary-based sampling (see Table 10). In addition, I made precipitation-related WQ sampling observations seasonally rather than monthly, but I did sample over 4-7 consecutive days at one location, the LB dam (station 1), whereas the tributary-based sampling took place in four different NR tributary streams on one day. I had fewer available DO observations than the other parameters due to issues with the YSI WQ instrument. Similarly, I could not take pH or specific conductance readings during two quarterly samplings nor any WQ readings except for a nitrate water sample in two instances.

In comparing findings only for station 1 (see Tables 17-19, 21, and 23), the mean water temperature was lower in 2012-17 (11.0°C) than during the 2017-22 sampling period (13.8°C). The mean DO concentration of 8.9 mg/L in the precipitation-related sampling was lower than previous (9.6 mg/L) as were the means for pH (5.99 su; 6.27 su), specific conductance (134.7 µS/cm; 150.5 µS/cm), and nitrate (0.30 mg/L; 0.37 mg/L). I discuss these results in the report sections that follow.

As I did with the tributary-based sampling results (see Table 11), I used the nonparametric Spearman's rank-order correlation to examine relationships among the five WQ parameters as well as with the calculated or USGS gaged LB streamflow (cfs) that I recorded with each sample (Table 37). All but two correlations were highly significant ($p < 0.01$ **). The non-significant relationship was between pH and water temperature. pH-nitrate was significant ($p < 0.05$ *), although at 0.183 the correlation coefficient was relatively small in magnitude. Not unexpectedly, one of the highest correlations (-0.791) was found between water temperature and DO, reflecting in part the capacity of water at lower temperatures to hold a greater amount of DO in addition to any biological controls, such as higher respiration rates in summer. The highest correlation coefficient of -0.902 was found between specific conductance and LB streamflow, illustrating that when discharge increases, specific conductance decreases, most likely due to dilution of the ions found in the brook water. Increased streamflow also resulted in lower values of all other WQ parameters except for DO, which increased. This is logical as rainfall increasing streamflow usually cools LB, thereby increasing DO; may reduce pH from acid rainfall; and dilutes the prevailing nitrate concentration. Specific conductance and nitrate had a relatively high positive correlation of 0.724, indicating possible similar effects under all LB streamflow conditions.

TABLE 36. Summary of statistics for the WQ parameters recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022.

Statistic	Water temperature (°C)	DO (mg/L)	pH (su)	Specific conductance (µS/cm)	Nitrate (mg/L)
Number of observations	139	91	132	132	141
Minimum	0.1	2.9	4.78	33.2	0.04
Maximum	23.8	13.8	7.24	221.3	0.99
Mean	13.8	8.9	5.99	134.7	0.30
Standard deviation	6.3	2.6	0.67	38.6	0.18
First Quartile	8.5	6.9	5.33	105.6	0.15
Median	15.6	8.2	5.92	128.8	0.26
Third Quartile	18.8	11.7	6.58	167.2	0.39

TABLE 37. Spearman correlation coefficients among WQ parameters recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022. Comparative sample sizes for these parameters are given on Table 36.

Parameter	Water temperature (°C)	DO (mg/L)	pH (su)	Specific conductance (µS/cm)	Nitrate (mg/L)
DO	-0.791 <0.0001 **				
pH	0.140 0.109 NS	-0.430 <0.0001 **			
Specific conductance	0.397 <0.0001 **	-0.615 <0.0001 **	0.233 0.007 **		
Nitrate	0.402 <0.0001 **	-0.448 <0.0001 **	0.183 0.036 *	0.724 <0.0001 **	
LB Stream Discharge (cfs)	-0.507 <0.0001 **	0.707 <0.0001 **	-0.334 0.0002 **	-0.902 <0.0001 **	-0.626 <0.0001 **

Seasonal Differences in WQ Parameters

Water temperature. As I found previously when analyzing the tributary-based sampling WQ data, I was not surprised to find highly significant seasonal differences in water temperatures during precipitation-related sampling (Fig. 36; Table 38). As before, water temperatures in Summer were highest, followed by Spring, Fall, and Winter, the means for all of which differed significantly. Seasonal median water temperatures were like their respective mean values. The sample sizes among seasons were also similar with water temperature showing greatest variability in Fall, followed by Winter. Spring had some negative skewness in the data, whereas Summer had a more positive distribution, although the ranges between first and third quartile values for these two seasons were relatively small.

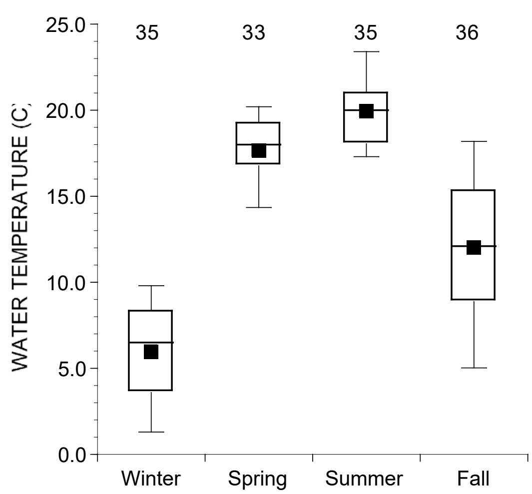

FIGURE 36. Box plot of water temperatures (°C) by season during precipitation-related WQ sampling at station 1 from Summer 2072 through Spring 2022. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 38. Results of SAS GLM analysis comparing water temperatures (^{o}C) recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in water temperatures.					
Season	n	Mean	Standard deviation		
Winter	35	6.0	4.6		
Spring	33	17.6	2.3		
Summer	35	19.9	2.2		
Fall	36	12.0	4.6		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	4070.310	1356.770	131.4 **	<0.0001
Error	135	1394.021	10.326		
Corrected total	138	5464.331			
Tukey-Kramer test results: Summer > Spring > Fall > Winter					

DO. My 5 years of precipitation-related sampling at LB also showed similarities to the findings of the tributary-related sampling. Highest DO concentrations were found in Winter and lowest values in Summer, reflecting the water temperatures during these seasons (Fig. 37). Fewer DO observations were made in comparison to temperature due to WQ instrument issues, particularly in Spring. Fall DO concentrations had relatively high variability. I recorded no DO values in Fall 2018 or 2019 and my field notes indicated a suspected issue with DO values on several days sampled in Fall 2017, when particularly low values were found. But these low values may also have reflected an effect related to precipitation as 4 of the 11 days sampled that quarter had precipitation (0.14-0.29 in; aggregate total of 0.77 in). Regardless, all DO values recorded during this sampling were more than adequate for aquatic life.

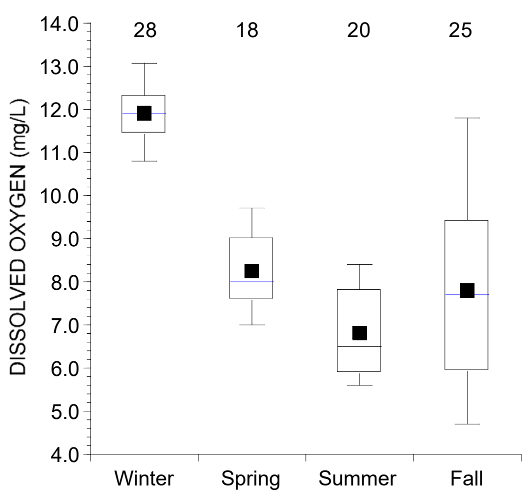

FIGURE 37. Box plot of DO concentrations (mg/L) by season during precipitation-related WQ sampling at station 1 from Summer 2072 through Spring 2022. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 39. Results of SAS GLM analysis comparing DO concentrations (mg/L) recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in DO concentrations.

Season	n	Mean	Standard deviation		
Winter	28	11.9	0.8		
Spring	18	8.2	1.0		
Summer	20	6.8	1.1		
Fall	25	7.8	2.8		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	379.690	126.563	45.01 **	<0.0001
Error	87	244.610	2.811		
Corrected total	90	624.301			

Tukey-Kramer test results[a]:

A Winter
B Spring
B C Fall
C Summer

[a] Means sharing the same letter are not significantly different from one another.

The SAS GLM analysis indicated significant differences in DO concentrations among seasons (Table 39). The Tukey-Kramer test showed that Winter had significantly greater DO concentrations than other seasons, which is to be expected given greater DO solubility in colder water. Winter was followed by Spring and Fall. Likely due to the variable Fall DO concentrations I measured, Fall was not significantly different from Summer, which had the lowest DO values. This was an expected result.

pH. Although pH values had differing mean and median values within and among seasons (Fig. 38), I found no significant seasonal differences (Table 40). This was likely a result of the variability seen in pH values during the precipitation-related sampling, which had a relatively wide range during all seasons. The pH values found during this 5-year period at LB were much lower than found throughout the earlier tributary-wide sampling (see Table 10 and Fig. 9). This result reflects the previous finding that station 1 had the lowest mean pH value of all the LB stations sampled during 2012-17 (see Tables 19 and 20). In addition, although not significantly different, the seasonal pattern in 2017-22 (Fig. 38) showed highest mean and median values in Winter and Fall, whereas in the tributary-wide sampling Spring and Summer pH values were significantly greater than found in Fall and Winter (see Fig. 9 and Tables 19 and 20). pH had mostly lower correlations with the other WQ parameters (see Table 37) and perhaps this finding reflected greater variability resulting from precipitation effects, possibly due to rain being more acidic (e.g., from precipitated sulfates) and associated effects from increased streamflow, rather than a tendency for pH values to move in a more positive or negative direction along with the other WQ parameters. My field notes indicated that under higher flows after rainfall, the water in LB was often tannic-colored, perhaps from input of acidic organic compounds that might also be affecting pH.

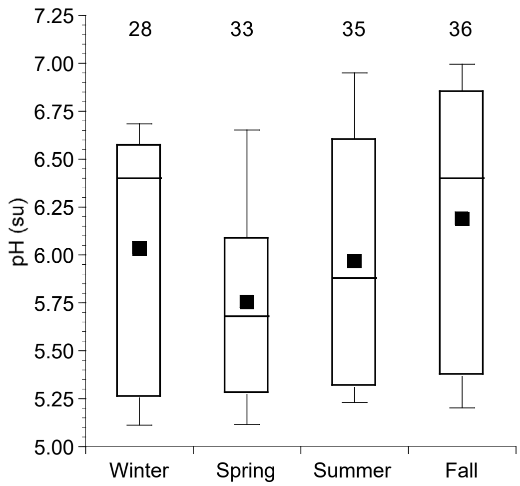

FIGURE 38. Box plot of pH values (su) by season during precipitation-related WQ sampling at station 1 from Summer 2072 through Spring 2022. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 40. Results of SAS GLM analysis comparing pH values (su) recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022 by season.

Season	n	Mean	Standard deviation		
Winter	28	6.03	0.67		
Spring	33	5.75	0.53		
Summer	35	5.97	0.69		
Fall	36	6.18	0.72		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	3.329	1.109	2.55 NS	0.0587
Error	128	55.725	0.435		
Corrected total	131	59.054			

Specific conductance. Specific conductance values during the precipitation-related sampling showed high variability in Fall, negative skewness in Summer, and positive skewness in Spring (Fig. 39). The range of values recorded increased each season from Winter through Fall. Mean and median values differed in all seasons. Unlike pH, which showed a somewhat similar amount of variability within and among seasons, for specific conductance I found significant differences among seasons (Table 41). However, a Tukey-Kramer test showed only small differences among seasons with considerable overlap among the means. Fall, Summer, and Spring were not significantly different from one another nor were Spring and Winter. Only Winter values were significantly less than those found in Fall and Summer.

As specific conductance paired with LB discharge flow had the largest Spearman rank-order correlation coefficient of -0.902 (see Table 37), I plotted all their paired data to see the form of this relationship (Fig. 40). Specific conductance values decreased relatively rapidly as streamflow increased from 1.62 to about 50 cfs, but then leveled off. Values for the two largest (545 and 1570 cfs) streamflow values

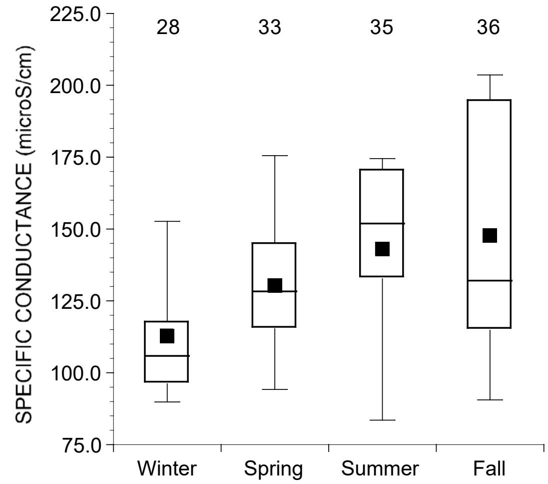

FIGURE 39. Box plot of specific conductance values (µS/cm) by season during precipitation-related WQ sampling at station 1 from Summer 2072 through Spring 2022. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

encountered during this study were not plotted to maintain a more compact X-axis, but these two data points were not out of line in this relationship. As this plot suggested a curvilinear (i.e., power function) relationship, a simplifying transformation was appropriate (Sokal and Rohlf 1969). Therefore, I applied a natural logarithmic transformation to specific conductance and streamflow data (Fig. 41). On this scale, the plot showed a linear trend, where specific conductance decreased as LB discharge flow increased with a relatively good fit ($r^2 = 0.79$) to the data. This relationship implies that when changes occur in

TABLE 41. Results of SAS GLM analysis comparing specific conductance values (µS/cm) recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in specific conductance values.

Season	n	Mean	Standard deviation		
Winter	28	112.8	27.5		
Spring	33	130.2	29.9		
Summer	35	143.0	39.3		
Fall	36	147.6	45.0		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	22498.737	7499.579	5.57 **	0.0013
Error	128	172243.482	1345.655		
Corrected total	131	194742.219			

Tukey-Kramer test results[a]:

A Fall
A Summer
A B Spring
B Winter

[a] Means sharing the same letter are not significantly different from one another.

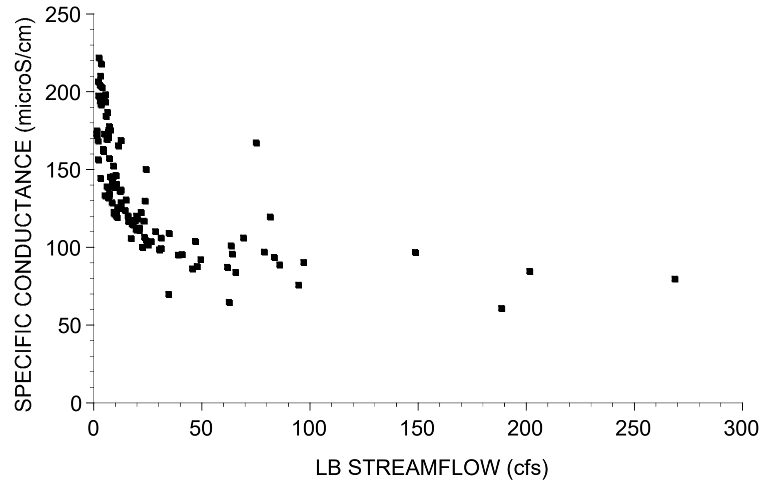

FIGURE 40. Relationship between specific conductance (µS/cm) and LB streamflow (cfs). All pairs of streamflow and specific conductance values from Fall 2017 through Spring 2022 were used in determining this relationship except specific conductance at the two largest streamflow values of 545 and 1570 cfs were omitted in this plot.

LB streamflow, they produce a proportional and linear change in specific conductance values. The rapid decrease occurring in specific conductance values when LB discharge volumes increase from low to moderately high levels likely indicates a dilution in the ionic composition producing the conductivity. This process continues proportionately until flow increases to a point where specific conductance values finally level off, perhaps due to increasing sediment content and, therefore, additional ionic loading.

Brown et al. (2011) found increases occurring in specific conductance in both SB and Jordan Brook (also located in Waterford) during winter and early spring from runoff of road salts applied to roads. During spring and summer, specific conductance decreased during discharge events as stormwater diluted concentrations of ions, particularly chloride. However, they did find some peaks in specific conductance well after winter storm events and road salt usage that they attributed to salts remaining stored in snow piles or flushed from soils or shallow groundwater, which then entered the streams.

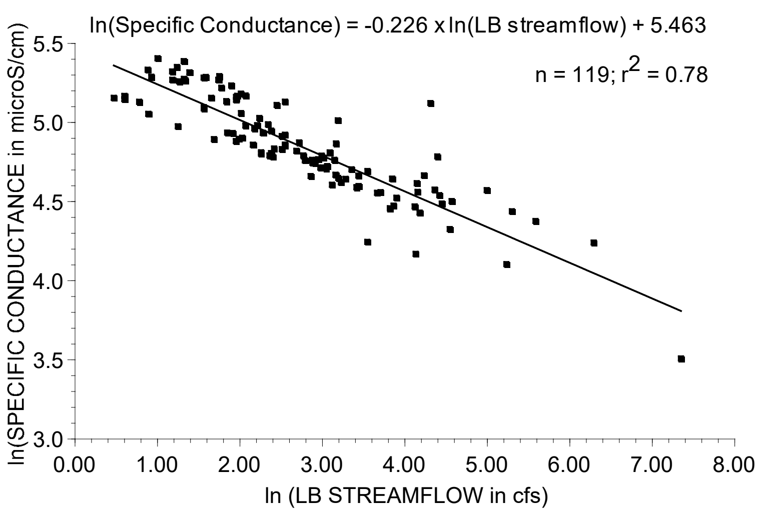

FIGURE 41. Logarithmic relationship between specific conductance (µS/cm) and LB streamflow (cfs). All pairs of streamflow and specific conductance values from Fall 2017 through Spring 2022 were used in determining this relationship.

Nitrate. I observed the highest nitrate concentrations during the precipitation-related sampling in Spring, which also had the greatest range of concentrations with Winter having the least (Fig. 42). The reasons for seasonal differences are unknown, but homeowner fertilizer use is likely greatest in Spring and may contribute to higher nitrate concentrations. In all seasons, median values were less than the mean, which is likely related to a larger number of samples taken before or after discrete peaks in nitrate concentrations that were related to precipitation and streamflow. Spring values were significantly greater than those found during other seasons, which were not different from one another (Table 42). This is a different pattern than I saw in the tributary-based sampling, where Summer and Winter had highest and similar nitrate concentrations (see Table 16).

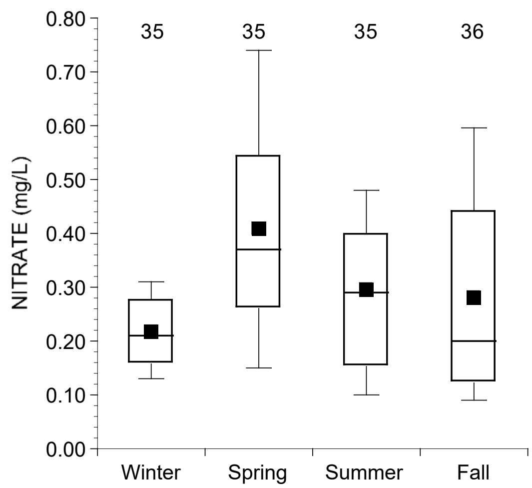

FIGURE 42. Box plot of nitrate concentrations (mg/L) by season during precipitation-related WQ sampling at station 1 from Summer 2072 through Spring 2022. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations available for each season are shown above the corresponding box.

TABLE 42. Results of SAS GLM analysis comparing nitrate concentrations (mg/L) recorded at LB station 1 during precipitation-related sampling from Summer 2017 through Spring 2022 by season and a Tukey-Kramer Multiple Range Test comparing significant differences in nitrate concentrations.

Season	n	Mean	Standard deviation		
Winter	35	0.22	0.07		
Spring	35	0.41	0.22		
Summer	35	0.30	0.15		
Fall	36	0.28	0.20		
ANOVA:					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability > F
Model	3	0.665	0.222	7.8 **	<0.0001
Error	137	3.894	0.028		
Corrected total	140	4.5559			

Tukey-Kramer test results:
Spring > [Summer = Fall = Winter]

Nitrate Concentrations as Related to Precipitation and LB Discharge Flow Volumes

Nitrate concentration at the LB dam is affected by streamflow, which itself is affected by precipitation. Higher nitrate concentrations appear to be associated with lower stream discharges and vice versa (Fig. 43). As previously presented, nitrate concentrations were significantly negatively correlated with LB streamflow (r = -0.626 **; see Table 37).

To understand how nitrate concentrations at the LB dam were related to precipitation, I combined observations into various hourly periods before and after discrete rain events occurred. There are many sources of variability in these data, including variable initial nitrate concentrations and variable incidences and intensity of rainfall. As some quarterly sampling events had more than one precipitation event, I had to place nitrate values into appropriate time intervals after a second or third rainfall event commenced. For this analysis, I ignored minor rainfall events (≤0.07 in) that had occurred. Results showed that nitrate concentrations were highest prior to the start of rainfall and up to +3 h afterwards (Fig. 44). The initial response of nitrate to precipitation was somewhat variable in the +1 to 3 h period after rain commenced as the mean concentration showed the largest deviation from the median value. The following two periods (+5 to 15 h and +20 to 32 h) had similar means, which illustrated some stabilization occurred in nitrate concentrations. The smallest mean and median nitrate concentrations were found within 38 to 49 h after precipitation. One to two days later (+54 to 73 h), nitrate concentrations had mostly returned to the levels found at the start of sampling, but this was followed by a dip at +78 to 108 h. About 5-6 days after the start of precipitation (+115 to 143 h), nitrate concentrations again increased.

I compared discrete nitrate concentration values and the rainfall events occurring during each quarterly sampling event to see if there were any distinct patterns (Fig. 45). I note that there were two instances of relatively extreme rainfall where I had two different precipitation estimates available. These are both shown in Figure 45 as notes. One was in Fall 2019, when the WELSCO rain gage reported 1.46 in of rain, but a rain gage at Laurel Hill in Niantic recorded 2.85 in and the other was the previously mentioned Tropical Storm Ida in Summer 2021, when the WELSCO gage showed 4.0 in of rain, whereas the NWS reported that 7.36 in of rain fell in East Lyme. Nonetheless, the USGS streamflow gauge reflected both heavy rain events by recording the extremely high LB discharge volumes associated with them.

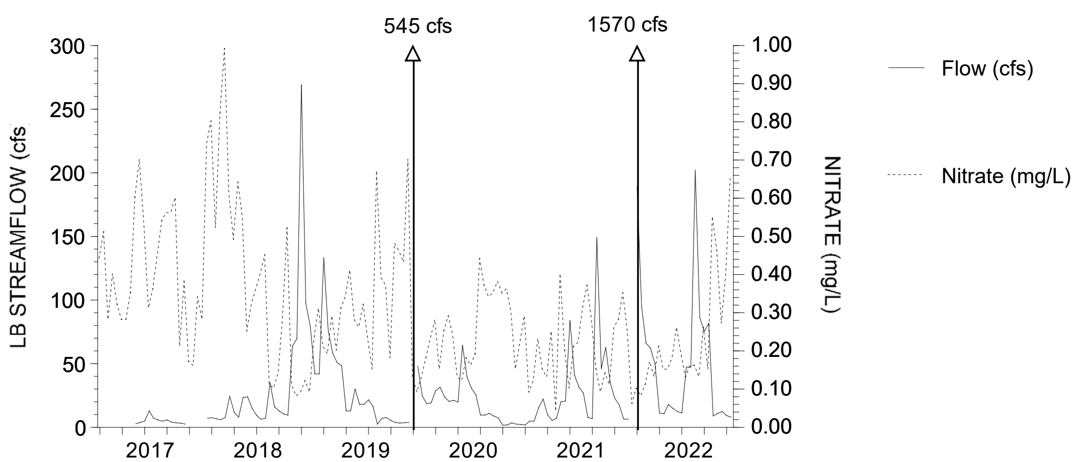

FIGURE 43. Values of nitrate (mg/L) and LB streamflow volume (cfs) calculated or recorded from Summer 2017 through Spring 2022 at the LB dam (note that no flow values are available for Summer 2017 or Winter 2018). The two largest flow values are shown by arrows to maintain a smaller Y-axis maximum.

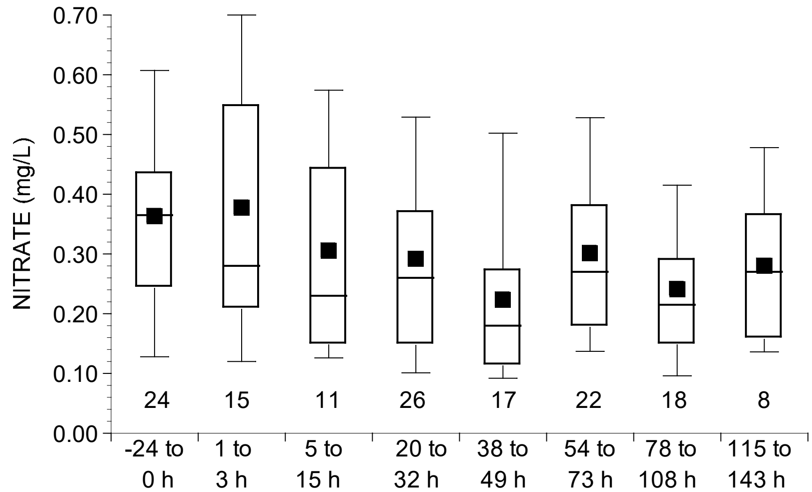

FIGURE 44. Box plot of nitrate values (mg/L) recorded at the LB dam from Summer 2017 through Spring 2022 partitioned by time periods that were defined as the number of hours before (-24 through 0 h) and after (+1 through +143 h) the time of initial and subsequent precipitation events that occurred during each seasonal sampling. See Figure 7 for an explanation of the plotted boxes and lines. The number of observations for each time period is given below the corresponding box.

I found it difficult to assess the effects of precipitation on nitrate concentration in LB with certainty. For example, in Summer 2017, following several rain events, the first of which was 0.71 in, nitrate first increased and then decreased (Fig. 45). A higher initial nitrate concentration in Fall 2017 decreased by about one-half following a modest rainfall of 0.16 in, but then steadily increased after a series of three more similar rain events before nitrate concentration declined again. I believe some of the variability may be related to the timing of my sampling in relation to the time and magnitude of each rainfall event, with multiple precipitation events confounding my understanding.

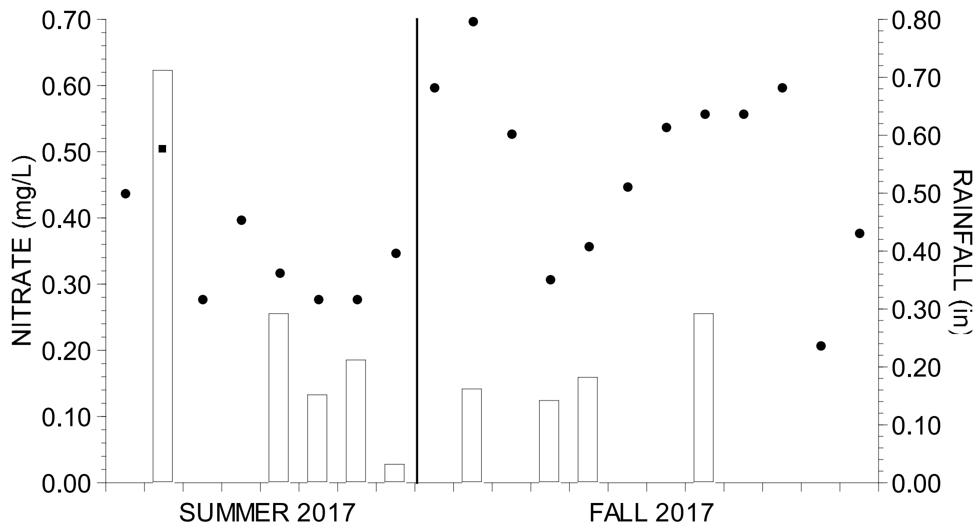

FIGURE 45. The concentration of nitrate (mg/L; indicated by dots) and rainfall (in; indicated by vertical bars) occurring during quarterly sampling from Summer 2017 through Spring 2022 (quarterly sampling periods are separated by vertical lines). Note that the scales of both Y-axis (nitrate concentration and rainfall) vary among the seven plots presented in this figure.

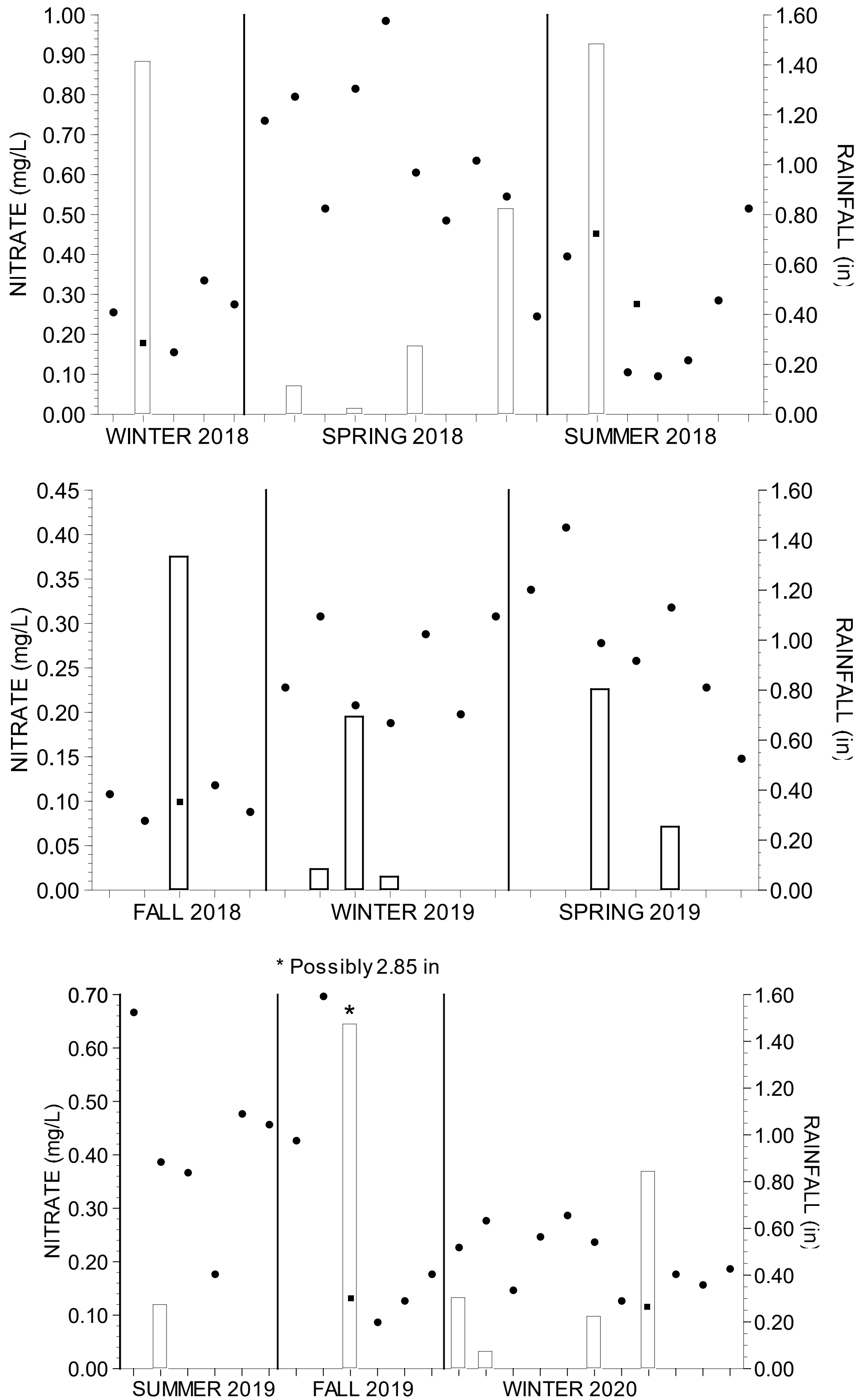

FIGURE 45. (continued). See above for additional information.

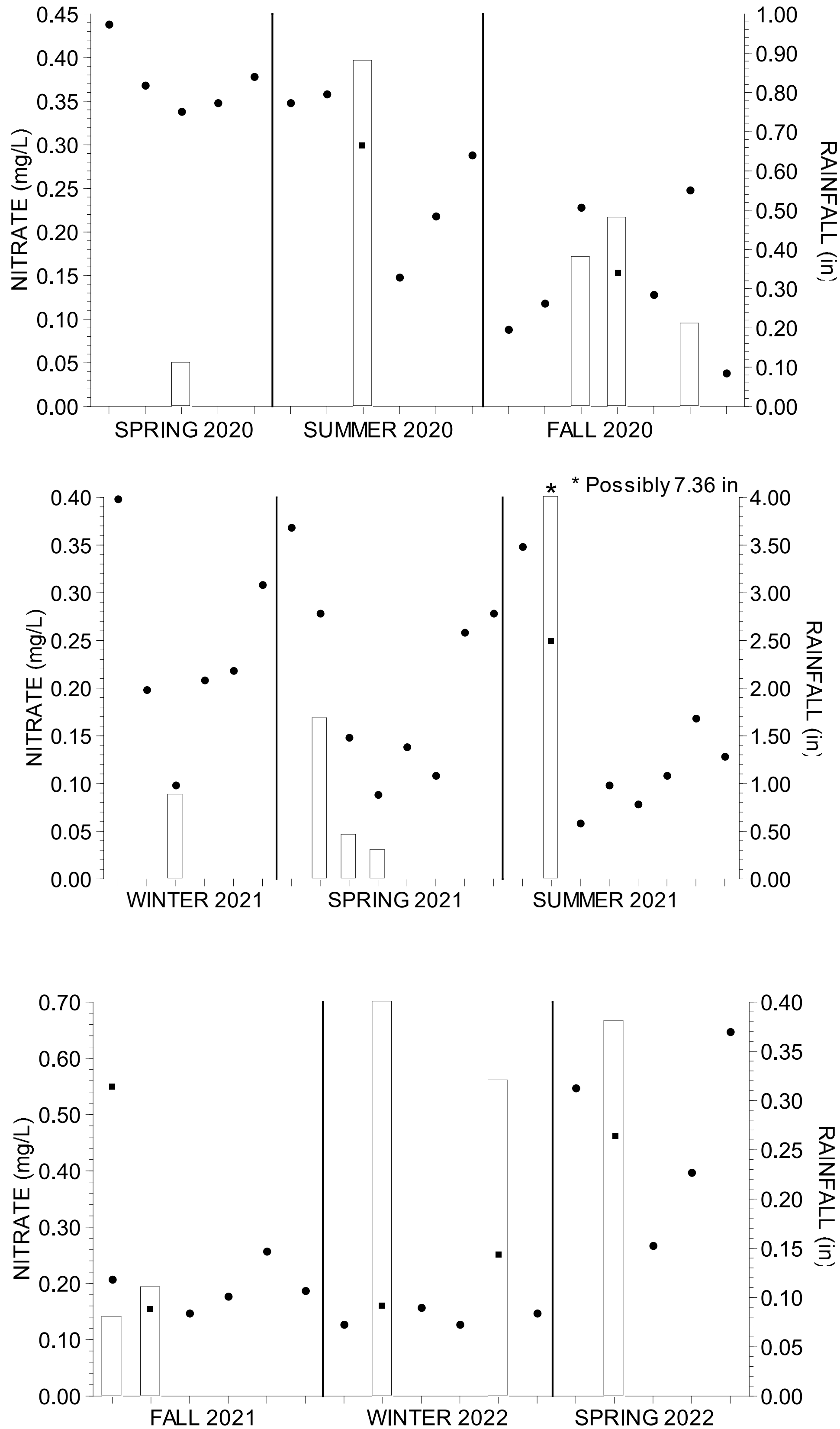

FIGURE 45. (continued). See above for additional information.

Relatively large rain events (e.g., Summers of 2018, 2020, and 2021; Fall 2019) appeared to reduce nitrate concentrations in subsequent samples, even though the base flows in LB at the start of the sampling differed substantially among these quarters, as did the rate streamflow decreased following precipitation events. Even relatively modest rain (e.g., Spring 2020, Winter 2021, and Fall 2021) appeared to decrease nitrate concentration, if only briefly. Yet in Winter 2022, the first of two more substantial rainfalls only increased nitrate concentration slightly, which was then followed by a decrease. Subsequently, a second rainfall increased nitrate concentration again, but this was quickly followed by a decline to levels found during the first 4 days of sampling. In many quarters, nitrate concentrations either decreased or increased linearly in association with precipitation events.

A perhaps better way of illustrating the effects of precipitation on nitrate concentrations in LB is to use streamflow volume, which not only reflects periodic precipitation, but for which I had records available that corresponded with nearly all nitrate samples taken, with the exceptions of Summer 2017 and Winter 2018. As I found with the WQ parameter specific conductance (see Fig. 40), a plot of nitrate concentration versus LB streamflow showed a curvilinear or power function relationship; three large (269-1570 cfs) streamflow values were omitted in this calculation (Fig. 46). Although there was a wide range of nitrate concentration values (0.04-1.00 mg/L) when LB streamflow was less than about 30 cfs, I found no concentrations exceeding about 0.35 mg/L when discharge volumes exceeded this level. Also, at discharge flows >60 cfs, all nitrate values exceeded the curve fit.

As I did with specific conductance, I next applied a natural logarithmic transformation to both nitrate concentration and streamflow data. On a logarithmic scale, the plot of these data was linear, where nitrate decreased as LB discharge volume increased (Fig. 47). The fit of the data was not as strong (r^2 = 0.37) as was found for specific conductance (for it, r^2 = 0.78) as there was more scatter of the data points in the nitrate relationship. Nonetheless, the logarithmic relationship showed that when changes occurred in LB streamflow, they produced a relatively proportional and log-linear change in nitrate values. The parameter estimates with 95% CI for the log nitrate-log streamflow model are given in Table 43.

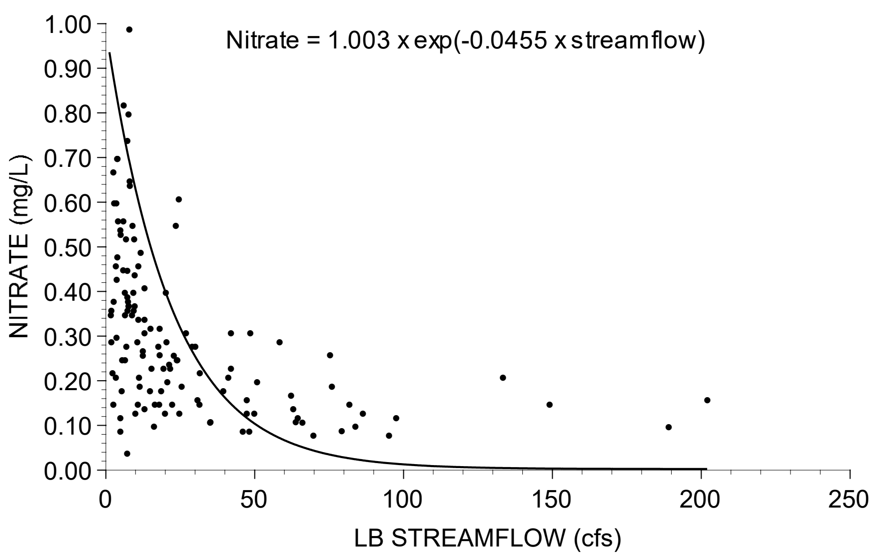

FIGURE 46. Exponential relationship between nitrate (mg/L) and LB streamflow (cfs). Streamflow and nitrate values from Fall 2017 through Spring 2022 (except Winter 2018) were used in determining this relationship except that the three largest streamflow values of 269, 545, and 1570 cfs were omitted in this plot and curve fit.

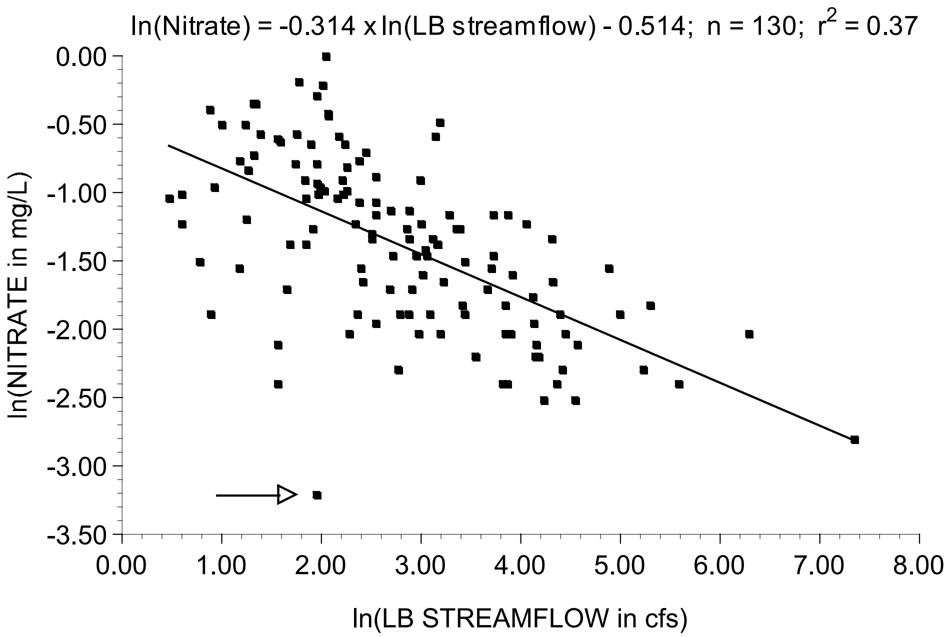

FIGURE 47. Logarithmic relationship between nitrate concentration (mg/L) and LB streamflow (cfs). All streamflow and nitrate values from Fall 2017 through Spring 2022 except Winter 2018 (missing streamflow) were used in determining this relationship.

I noted that in Figure 47 there was one anomalous data point, which is indicated by an arrow in this figure. This was a nitrate concentration value of 0.04 mg/L, which was recorded for the last sample taken in the Fall 2020 sampling (see also Fig. 45 for this specific data point and preceding values). As this aberrant nitrate concentration could have been the result of sampling or processing error, I performed another analysis of the logarithmic relationship without this data point. By eliminating this one outlier I achieved a slightly better fit to the data ($r^2 = 0.42$) and smaller 95% CIs around the parameter estimates of the nitrate-streamflow model (Table 44; Fig. 48).

TABLE 43. Parameter estimates for a LB nitrate-streamflow model: ln(LB_nitrate) = ln(LB_streamflow) ± *E*, where *E* is the unknown error term. All 130 observations from Fall 2017 through Spring 2022 except Winter 2018 (missing streamflow) were used in determining this relationship. (See Figure 47).

	Estimate	Lower 95% CI	Upper 95% CI
Intercept (error term *E*)	-0.514	-0.734	-0.296
ln(LB_streamflow)	-0.314	-0.385	-0.242

TABLE 44. Parameter estimates for a LB nitrate-streamflow model: ln(LB_nitrate) = ln(LB_streamflow) ± *E*, where *E* is the unknown error term. 129 observations from Fall 2017 through Spring 2022 except Winter 2018 (missing streamflow) and an anomalously low nitrate value of 0.04 mg/L in Fall 2020 were used in determining this relationship. (See Figure 48).

	Estimate	Lower 95% CI	Upper 95% CI
Intercept (error term *E*)	-0.473	-0.678	-0.268
ln(LB_streamflow)	-0.323	-0.390	-0.256

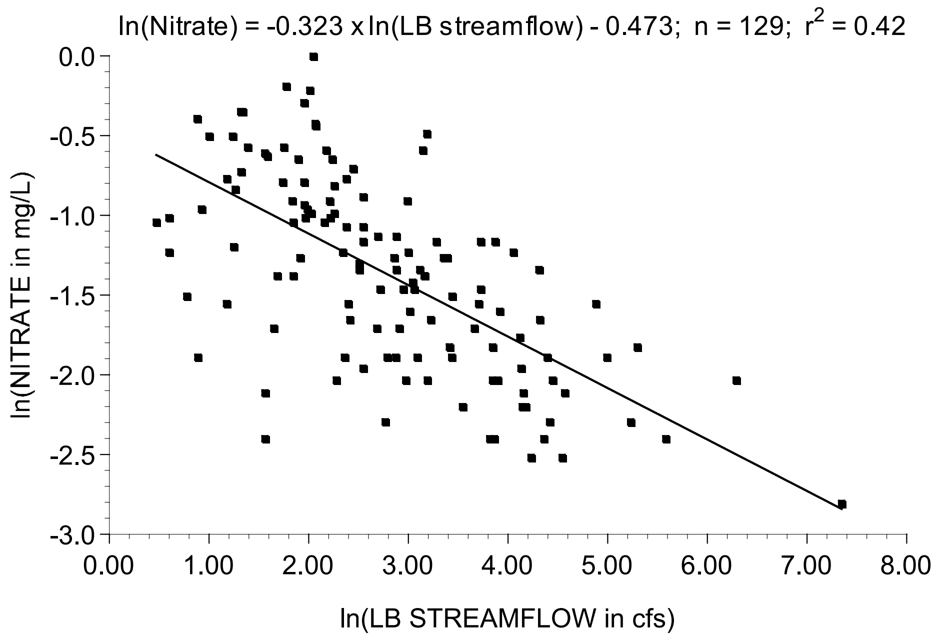

FIGURE 48. Logarithmic relationship between nitrate concentration (mg/L) and LB streamflow (cfs). All streamflow and nitrate values from Fall 2017 through Spring 2022 except Winter 2018 (missing streamflow) and an anomalously low nitrate value of 0.04 mg/L in Fall 2020 were used in determining this relationship.

There are many confounding factors associated with how nitrate concentrations vary in relation to variable precipitation and streamflow. Sources of nitrate in streams include mixtures of soil nitrate and ammonium fertilizers, wastewater discharges (e.g., septic systems), animal wastes, and atmospheric deposition (Trench et al. 2012; Mullaney 2013, 2015; Barclay and Mullaney 2021). I assume that atmospheric deposition and nonpoint sources of nitrate in stormwater discharges would increase concentrations relatively quickly after rainfall, but groundwater movements and soil sources may lag, as the movements of nitrate in soil depend upon prevailing moisture levels. At some point, large precipitation events increasing streamflow volumes proportionately more than nitrate input would result in decreased nitrate concentrations through dilution. With multiple sources of nitrate and dilution effects, it is no wonder that I found considerable variability in nitrate concentrations in LB and the other NR tributary streams, particularly while sampling during periods when periodic rainfall events and rapidly changing streamflow regimes interacted with all the potential sources of nitrate.

Bias in Measuring Nitrate Concentration

Bias in determining nitrate concentrations in both the tributary-based and precipitation-related sampling was addressed by processing a blank (i.e., deionized water sample) using the nitrate reagents and by comparing nitrate concentrations of a randomly selected field-collected water sample and its duplicate.

Although ostensibly not having any nitrate, only about one-third (n = 24) of the 78 blank water samples showed a determination of no nitrate (i.e., recorded as BLD) (Table 45). Positive values for nitrate ranged from 0.01 to 0.22 mg/L. For all of these samples, the median nitrate concentration was 0.02 mg/L and the mean was 0.025 mg/L (SD =0.038). However, there were 4 consecutive months (June-September) in 2016 for which the notes I made during sample processing indicated an issue with the reagents being used at the time. Normally, the presence of nitrate imparts a pink color to the water being tested (LaMotte Undated), except at very low nitrate concentrations when the pink color is much less discernible to the human eye, although not to the LaMotte Colorimeter. In these 4 months, I observed a black precipitate in the blank water samples. This substance likely interfered with the optical method the LaMotte Colorimeter uses to determine nitrate concentration, resulting in the high values found. These four values, which I believe to be spurious, were 0.22, 0.09, 0.22, and 0.07 mg/L, and represented the highest values found in all the blank tests for bias. I observed that all the stream water samples, except for CMB-U in August, had nitrate present with a normal pink color developing upon processing. Once the reagents used during these months were expended, I observed no further instances of this anomaly. Deleting these values resulted in a similar median value for the blanks of 0.02 mg/L, but a lower mean value of 0.018 mg/L having a much smaller SD of 0.018 (Table 45).

Only 10 duplicate samples were processed, all during the precipitation-related sampling (Table 46). Differences between nitrate concentration values for the original and duplicate samples processed ranged from -18% to +18%. The median value was +2%. Using the absolute values of the percent differences, the median difference in nitrate concentration was 8%.

In summary, although each reagent blank sample provided a measure of sample processing error, when its value was larger than 0, it was not applied as a correction to the nitrate concentrations determined for stations sampled on that date. The small mean and median value of 0.02 mg/L for the sample blanks and the less than 10% difference found between original and duplicate water samples indicated reasonably low error in determining nitrate concentrations during our WQ studies.

TABLE 45. Statistics associated with the values found for blank (deionized water) samples processed with the reagents used to determine the concentration of nitrate (mg/L).

Observations	Minimum	Maximum	Median	Mean	Standard deviation
78	0.00	0.22	0.020	0.025	0.038
74[a]	0.00	0.06	0.020	0.018	0.018

[a] Four observations that I thought spurious were deleted.

TABLE 46. Comparison of nitrate concentration (mg/L) in original and duplicate water samples.

Sampling quarter	Original sample	Duplicate sample	Percent difference
Winter 2019	0.21	0.23	+9
Spring 2019	0.26	0.25	-4
Summer 2019	0.18	0.22	+18
Summer 2020	0.15	0.17	+12
Fall 2020	0.13	0.13	0
Winter 2021	0.31	0.27	-15
Spring 2021	0.26	0.28	+7
Fall 2021	0.21	0.22	+5
Winter 2022	0.13	0.11	-18
Spring 2022	0.55	0.53	-4
Median % difference			+2

The Flux of Nitrogen from LB into the NR

An important goal of the NRWC WQ study was to evaluate the flux (i.e., discharge) of nitrogen into the NR from its major tributary streams. Comparison of our values with those reported by Mullaney (2013), who performed a 5-year study on nutrient (nitrogen and phosphorus species) concentrations, as well as *E. coli* bacterium densities found in NR tributaries, would be meaningful. Mullaney's study was more scientifically rigorous and had different objectives than the NRWC sampling and should be referred to for his more comprehensive findings on nutrients found within NR watershed streams.

I first compiled nitrate concentration statistics from both the tributary- and precipitation-related sampling programs at LB station 1 (LB dam), OMB, and SB. Our values were compared to those reported in Mullaney (2013) for the same stream locations (Table 47). There were remarkable similarities between the mean nitrate concentration of 0.37 mg/L at the LB dam from the NRWC tributary-based study with the value of 0.35 mg/L reported by Mullaney (2013). Lower mean (0.30 mg/L) and median (0.26 mg/L) values were determined in the precipitation-related samples, which was unsurprising given the previously discussed variability associated with this sampling from effects of precipitation and increased LB discharge volumes. Mean nitrate values at OMB were also very similar in both studies (0.16 and 0.18 mg/L, respectively). Statistics were computed using nitrate concentration data from both NRWC sampling programs for a period within about 1 month before or after June 1 of a year for later comparison with Mullaney's nitrogen discharge calculations, which were based on single days of sampling in June 2005.

The largest difference found between the two studies was for SB, where our tributary-based study showed a mean nitrate concentration of 0.20 mg/L, but Mullaney (2013) reported a smaller mean concentration of 0.11 mg/L. For SB, Mullaney also had a larger sample size (n = 51 versus our 34) and smaller third quartile (0.14 versus 0.27 mg/L) and maximum (0.31 versus 0.69 mg/L) nitrate concentration values than I found. Mullaney did not sample in CMB during his long-term study.

TABLE 47. Comparison of nitrate-nitrogen concentrations[a] (mg/L) determined in this study and those reported by Mullaney (2013: Table 7) for samples taken from August 2008 through February 2012.

Study	Location	Sample size	Minimum	Mean	25th percentile	Median	75th percentile	Maximum
Mullaney	1	51	0.05	0.35	0.21	0.33	0.51	0.71
NRWC (TB)[b]	1	57	0.05	0.37	0.24	0.32	0.49	1.00
NRWC (PB)[b]	1	141	0.04	0.30	0.15	0.26	0.39	0.99
NRWC (M-J)[c]	1	14	0.08	0.40	0.24	0.36	0.52	1.00
Mullaney	OMB	51	<0.02	0.16	0.09	0.17	0.22	0.32
NRWC (TB)	OMB	34	0.00	0.18	0.10	0.12	0.21	0.79
Mullaney	SB	51	<0.02	0.11	0.05	0.10	0.14	0.31
NRWC (TB)	SB	34	0.00	0.20	0.09	0.18	0.27	0.69

[a] Mullaney (2013) measured and termed this constituent as nitrite + nitrate-nitrogen.
[b] TB = data used from the 5-year (2012-17) tributary-based sampling and PB = data used from the 5-year (2017-22) precipitation-related sampling. See Table 48 for other relevant notes concerning the both the NRWC and Mullaney (2013) studies.
[c] Data used were from about 1 month prior and 1 month after June 1 from both TB and PB sampling programs for later comparisons to nitrogen loading results presented in Mullaney (2013).

Mullaney (2013) also determined the concentrations of more nitrogen constituents than did the NRWC study. His samples included total ammonia plus organic nitrogen, and, although this constituent was previously termed as nitrate, he measured nitrite in combination with nitrate-nitrogen. Only the latter was determined in our studies. Vaudrey et al. (2019) reviewed USGS data from Latimer Brook collected between August 20, 2008 and September 11, 2012, which indicated that within the dissolved inorganic fraction of nitrogen (DIN), nitrate-N accounted for 94% of DIN, nitrite-N accounted for <1% of DIN, and ammonia accounted for 6% of DIN. Thus, measurements of nitrate alone were considered a fair representation of the inorganic fraction in these tributaries. The organic fraction is less available for biological uptake than the inorganic fraction and, in some cases, is largely unavailable. In calculations of the flux of nitrogen into the NR, which is discussed below, I assumed that nitrite was an inconsequential nitrogen constituent in NR tributary streams as it is usually found in very low concentrations in non-polluted, well-oxygenated surface waters (Hutchinson 1957; Minero et al. 2007; CT DPH 2009).

Mullaney provided values of total ammonia plus organic nitrogen concentrations in his comprehensive WQ stream sampling, which took place from August 2008 through February 2012 (Mullaney 2013: Table 7). As did Mullaney (2013), I subsequently added his total ammonia plus organic nitrogen estimates to my mean nitrate-nitrogen values to obtain total nitrogen concentrations (mg/L) for each of the NRWC stations that I used to compare with his results (Table 48; Fig. 49).

To determine the daily flux of nitrogen from LB into the NR, which included all its constituents, the proper units of measure transformations were made so total nitrogen concentration values in mg/L could be combined with known LB stream discharge volumes in cfs to obtain estimates of nitrogen flux in both kg and lbs per day. Mullaney (2013) calculated nitrogen loading based on single days of observation in June 2005 at three locations in LB and one each in CMB, OMB, and SB (Table 48). Based on his descriptions, Mullaney's stations were at the same stream locations as ours or nearly so.

Besides nitrogen constituents, Mullaney (2013) also measured instantaneous stream discharge (cfs) at all his locations, which enabled him to calculate nitrogen flux at each of his stations. Having no upstream flow records and limited nitrate concentration data, I only computed nitrogen flux at LB station 1, which is located just upstream of the NR. For my calculations I used a grand mean LB streamflow value of 29.5 cfs, which was computed using all available USGS LB streamflow data records (n = 3,013) from September 2008 through January 2023 (see Table 35). The mean LB flow during the precipitation-based sampling was 45.24 cfs, but this mean value was skewed by a few very large discharge values as the median flow during this sampling program was only 14.88 cfs. I chose to use my calculated grand mean flow of 29.5 cfs with these data as it is approximately midway between the mean and median values. I also calculated a mean LB discharge flow of 25.0 cfs for the combined months of May and June over those same years, which was somewhat less than the NRWC grand mean flow, but greater than Mullaney's value of 16 cfs that he observed at LB station 1 on June 2, 2005 (Table 48).

Using data from both our NRWC sampling programs for May and June of 2012-22, the mean nitrate-nitrogen concentration at LB station 1 was 0.40 mg/L. This mean was somewhat larger than the tributary-based and precipitation-related sampling means of 0.37 and 0.30 mg/L, respectively. All the NRWC means were lower than Mullaney's nitrate-nitrogen value of 0.49 mg/L at this site, the value for which he obtained on June 2, 2005 and subsequently used in his nitrogen loading calculations. This nitrate value at station 1 was larger than the mean of 0.35 mg/L that he found in his more comprehensive 2008-12 WQ sampling, which was more comparable to NRWC estimates (see Table 47).

TABLE 48. Comparison of nitrogen constituent concentrations and loadings in the NR Watershed as reported in Mullaney (2013) and determined or calculated in this study.

Study	Station[a]	Sampling date(s)[b]	Stream discharge (cfs)[c]	Total ammonia + organic nitrogen (mg/L)[d]	Nitrite + nitrate-N (mg/L)[e]	Total nitrogen (mg/L)[f]	Total N instantaneous load (kg/day) / (lbs/day)
Mullaney	6	6/2/05	1.9	0.27	0.04[g]	0.31	1.4 / 3.1
NRWC	6	4/12-3/14	-	-	0.08 (n=22)	-	-
Mullaney	3	6/2/05	12	0.24	0.20	0.44	12.9 / 28.5
NRWC	3	4/12-3/17	-	-	0.17 (n=57)	-	-
Mullaney	CMB-L	6/2/05	2.3	0.24	0.23	0.47	2.6 / 5.8
NRWC	CMB-L	4/12-3/17	-	-	0.22 (n=56)	-	-
Mullaney	1	6/2/05	16	0.23	0.49	0.72	28.2 / 62.1
NRWC (TB)	1	4/12-3/17	29.5	0.27	0.37 (n=57)	0.64	46.1 / 101.4
NRWC (PB)	1	7/17-5/22	29.5	0.27	0.30 (n=141)	0.57	41.1 / 90.4
NRWC (May-June)[h]	1	2012-17	25.0	0.27	0.40 (n=14)	0.67	41.0 / 90.2
Mullaney	OMB	6/3/05	5.4	0.21	0.17	0.38	5.0 / 11.1
NRWC	OMB	4/14-3/17	-	0.22	0.18 (n=34)	0.40	-
Mullaney	SB	6/1/05	3.2	0.31	0.09	0.40	3.1 / 6.9
NRWC	SB	4/14-3/17	-	0.27	0.20 (n=34)	0.47	-

[a] Based on his Figure 1, stations used in the Mullaney (2013) study appear to be the same or very close to the ones used in the NRWC study, the designations for which are given herein (see Figs. 2 and 3 and Table 1).

[b] Data from all 10 years (2012-22) of the NRWC study were used for station 1, including the precipitation-related sampling (PB) and from the 5-year (2012-17) tributary-based sampling (TB), which provided data for the other stations. Mullaney (2013: Table 3) values were instantaneous and based on a single day of sampling.

[c] Mullaney (2013) determined stream discharge volumes at all his stations, whereas the NRWC study value is a mean determined using all available records (9/17/08-9/30/12, 7/1/14-9/30/15, and 1/24/20-1/23/23; see Table 35) from the USGS gage located just downstream of station 1 in LB, the only station for which nitrogen loading was determined in this study. Note that at the time of this report preparation LB discharge data after August 3, 2021 were considered as provisional by the USGS.

[d] These nitrogen constituents were not determined during the NRWC study, but were entered for stations 1, OMB, and SB by using the mean values given for these stations in Mullaney (2013: Table 7).

[e] Values given for the NRWC study are only for nitrate-nitrogen. Mullaney's values include nitrite and are from single instantaneous samples taken during June 1-2, 2005. The number of samples used to compute the mean values for this study are given parenthetically.

[f] These values are the sums of the previous two columns.

[g] The value given at this station for these constituents was noted by Mullaney (2013: Table 3) to be an estimate.

[h] Nitrate concentrations from both TB and PB sampling within about 1 month of June 1-3 and mean streamflow values during May and June from USGS records for 2009-12, 2015, and 2020-22 were used in this calculation.

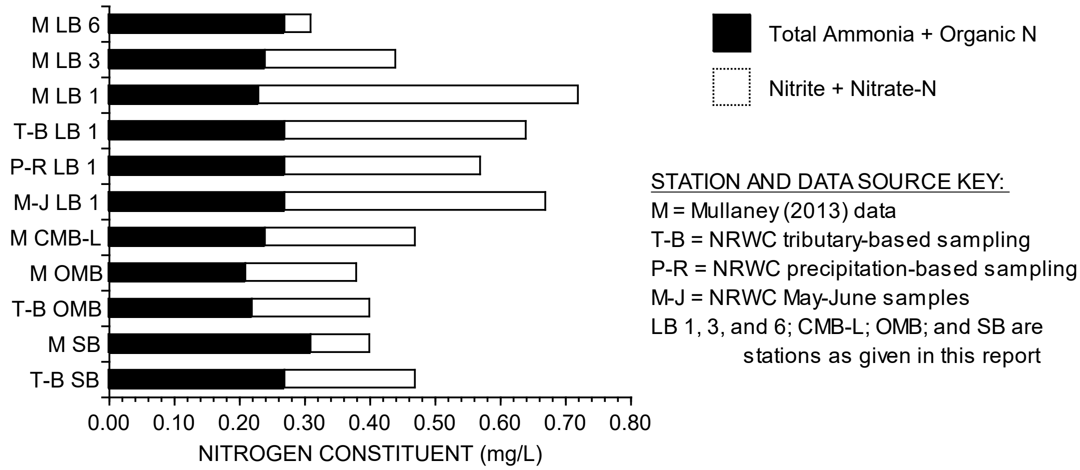

FIGURE 49. Sum of the nitrogen constituents of total ammonia + organic N and nitrite + nitrate-N in determining total nitrogen loading by station.

Mullaney's nitrate-nitrogen concentrations for OMB (0.17 and 0.16 mg/L) and SB (0.09, 0.11 mg/L) were similar in magnitude between his two studies. Although nitrogen flux estimates could not be computed for NRWC stations other than LB station 1, the mean nitrate-nitrogen concentrations at LB stations 6 (0.08 mg/L) and 3 (0.17), CMB-L (0.22), and OMB (0.18) were very similar to Mullaney's values, except for SB, where the NRWC mean of 0.20 mg/L was more than twice his value of 0.09 mg/L (Table 48).

Mullaney (2013) showed that total nitrogen loading to the NR increased when moving downstream from upper LB (1.4 kg or 3.2 lbs per day at station 6), to middle LB (12.9 kg or 28.5 lbs per day at station 3), and lower LB (28.2 kg or 62.1 lbs per day at station 1; Table 48; Fig. 50). This finding is consistent with the additional watershed area contributing to the nitrate at stations when moving downstream and implies minimal biological or chemical uptake of nitrogen in the streams. NRWC nitrogen flux estimates at station 1 were larger, ranging from 41.0 kg (90.2 lbs) to 46.1 kg (101.4 lbs) per day. Even though our total nitrogen concentrations of 0.57-0.67 mg/L were less than Mullaney's figure of 0.72 mg/L, our LB mean discharge flow values of 25-29.5 cfs were much larger than his value of 16 cfs. As his study objectives were different than ours, Mullaney sampled during a stable, low flow period having no predicted precipitation. My calculations included mean streamflow values and total nitrogen values over longer time periods, so perhaps may be more indicative of the overall flux of nitrogen into the NR. Mullaney did note that his estimated loads might have been lower than expected because he sampled when base flows were about one-half of long-term average conditions. He concluded that nitrate was the predominant constituent of nitrogen in LB that was discharged into the NR.

For CMB, a comparison of the stream discharge values given in Mullaney (2013) indicated that the 2.3 cfs he recorded at CMB-L was much less than the flow of 12 cfs he found at station 3 in LB (Table 48). Like my findings, Mullaney found a higher nitrate-nitrogen value (0.23 mg/L) at CMB-L than he did at LB station 3 (0.20 mg/L). These differences were just 0.02 mg/L less than the differences as I found when comparing these stations using tributary-based sampling data (0.22 versus 0.17 mg/L; see Table 25). This again indicates that CMB contains more nitrogen than upper reaches of LB. However, this higher concentration is ameliorated by the lower streamflow volume imparted from CMB into LB.

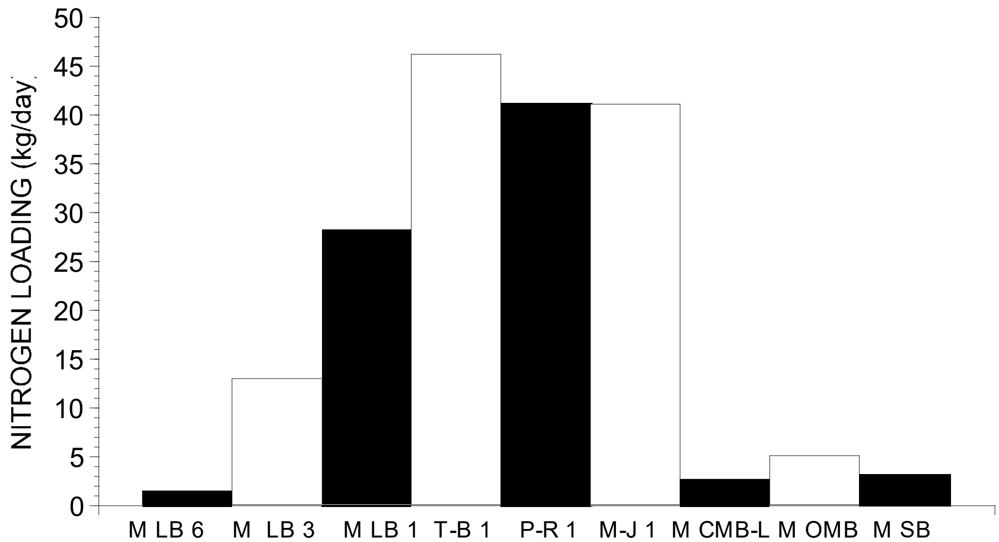

FIGURE 50. Calculated nitrogen loadings to the NR by station. Station designations and data sources are as given in Figure 49.

Mullaney (2013) reported that total ammonia and organic nitrogen predominated in the total nitrogen discharges from OMB and SB into the NR (Fig. 49). His calculations showed relatively low nitrogen loading from these two streams, with 5.0 kg (11.1 lbs) per day for OMB and 3.1 kg (6.9 lbs) per day from SB (Table 48). In comparison, the larger LB contributes 78-80% of the nitrogen input to the NR, much more than these two smaller streams combined.

Considerably more information on the sources of nitrogen and its loading into various surface and ground waters are given in Grady and Mullaney (1998) for surficial aquifers in CT and eastern NY, Trench et al. (2012) for major river basins in the northeastern U.S., Mullaney (2013) for NR watershed streams, and Mullaney (2015) for groundwater discharging into the NR. Several of these publications give more specific information on nitrogen loading and sources, demonstrating that, for example, less developed landscapes (e.g., forested) result in smaller nitrogen inputs than agricultural or urban areas.

I am refraining from offering potential remedies to reduce nitrogen inputs to the NR or addressing other potential WQ impairments in the NR tributaries. The updated NRWPP (Fuss & O'Neill 2020) offers a wealth of information on managing potential pollution in the NR Watershed, provides management recommendations, Best Management Practices (BMP), and presents measures and strategies to reduce pollutant loads. This publication also includes potential sources of technical assistance and funding that would be helpful to the four municipalities within the NR Watershed and the many organizations striving to protect our environment. As such, I recommend that the reader visit these sources for additional information and pathways useful for improving WQ in the NR watershed.

Do Our Study Streams Meet Temperature Criteria Established for Connecticut Trout Streams?

Although certainly not a focus of the NRWC WQ studies, our data allowed me to assess the value of NR tributary streams as habitat for trout species, which require cool to cold water. Collections made at various times from 1993 to 2016 by CT DEEP fisheries biologists (CT DEEP Undated a) and Cole (2016) confirmed that populations of brook trout exist (or have existed) in all our study streams. All streams but SB also had brown trout collected, identified as both stocked and wild specimens (i.e., naturally spawned). In addition, CT DEEP also collected a few stocked and wild rainbow trout in LB. However, CT DEEP Fisheries collection records suggest that trout abundance has been declining since the 1990s, which could indicate deteriorating habitat conditions for trout, especially in LB.

In a state-wide study, Beauchene et al. (2014) classified Connecticut streams using CT DEEP Fisheries stream survey fish collections and water temperature data during June-August as follows: cold-water streams had a mean water temperature of less than 18.2°C during this period, cool-water streams were between 18.29 and 21.7°C, and warm-water streams had temperatures greater than 21.7°C. These temperature range criteria triggered changes in stream fish communities. Two fishes, brook trout and slimy sculpin, were characteristic of cold-water streams in Connecticut. Note, however, that the slimy sculpin has a limited distribution in Connecticut and is mostly confined to the northwestern region of the state (Kanno and Vokoun 2008), so is not present in our study streams as an indicator species. Beauchene et al. (2014) noted that warm-water streams were typically characterized by various sunfishes and bullheads. CT DEEP fisheries surveys found specimens of these fishes were commonly collected in LB, perhaps indicating that this stream might have less suitability as trout habitat.

I examined summer (June 1-August 31) water temperatures from the tributary-based sampling in 2012-17 to see if our sampled streams met water temperature classification criteria for trout as proposed by Beauchene et al. (2014). The number of water temperature records was not large, ranging from 9 in OMB and SB to 46 in the lower section of LB (Table 49). Median values were nearly the same as the means. Based on June-August water temperature means, all sections of LB (means = 19.9-20.7°C) and OMB (18.5°C) classify as cool-water streams and CMB (17.6°C) and SB (17.2°C) as cold-water streams. However, maximum water temperatures in all LB segments (22.9-24.5°C) during the June-August period fell well within the warm-water stream classification. If trout, particularly the brook trout, which requires cooler water temperatures than brown trout (Smith 1985), are to persist in LB, then they likely need to find cool water temperature refugia during warm periods. During these 5 years of WQ studies, I did not observe any increasing trend in peak summer water temperature, so the thermal regime in LB appears to have been stable in recent years (see Fig. 12).

TABLE 49. Statistics for water temperature (°C) in sections of LB[a], CBM[a], OMB, and SB during June-August[b] of 2012-17 as recorded during the tributary-based WQ sampling.

Statistic	Lower LB	Middle LB	Upper LB	CMB	OMB	SB
Number of observations	46	34	16	29	9	9
Minimum	17.3	17.0	17.3	14.5	16.4	14.9
Maximum	22.9	23.2	24.5	20.8	21.0	18.7
Mean	19.9	19.9	20.7	17.6	18.5	17.2
Standard error	0.2	0.3	0.5	0.4	0.5	0.5
Standard deviation	1.7	1.8	2.2	1.9	1.6	1.4
First Quartile	18.5	18.2	18.8	16.0	17.4	16.1
Median	19.8	20.0	20.9	17.5	18.6	17.6
Third Quartile	21.3	21.6	22.1	19.0	19.3	18.3

[a] Lower LB = stations 1, 1.5, and 2; Middle LB = stations 3 and 4; Upper LB = stations 5 and 6: CMB = CMB-L and CMB-U.

[b] Temperature data from May 30 and September 5, 2012, just outside the June-August period, were included to increase sample size for the calculations.

Considerable additional water temperature records were also available for SB from a long-term monitoring study, which collected data continuously (recorded at 1-hour intervals) from December 11, 2020 through January 6, 2022 (Danila and Gonzalez 2022). This study found June-August long-term mean water temperatures of 18.7-19.2^{o}C at three locations in SB, including the SB-U site and two located farther upstream in SB, and at one site in OMB, which was about 0.37 mi upstream of the NRWC OMB sampling site. Danila and Gonzalez (2022) concluded that both SB and OMB could support the year-round thermal regimes required for trout species. I also believe that CMB has similar attributes with respect to water temperature and habitat suitability for trout, particularly brook trout, which I observed within this stream while sampling.

In summary, should persistent water temperature increases occur in the future, the long-term suitability of LB as trout habitat may be in question. The other three streams may be more resilient, although future developments within their watersheds could impact annual temperature regimes, particularly from the loss of forest cover and increased stormwater runoff from impervious surfaces. As I discussed previously, all our study streams currently have ranges of DO and pH values that are suitable for aquatic life forms. All the NR tributary streams examined in our WQ study are important state resources and aquatic habitats. This is important because when CT DEEP fisheries survey data for towns located along Connecticut's coastline are examined, it shows that nearly all streams currently supporting brook trout are only found east of the Connecticut River within New London County.

Do Our Study Streams Meet Water Quality Criteria as Indicated by Macroinvertebrate Sampling?

The Stream Riffle Bioassessment by Volunteers program (RBV) is a statewide volunteer water quality monitoring program coordinated by the CT DEEP Volunteer Water Monitoring Coordinator. A full description of this program and recent (2019-21) annual reports of this program are available online; earlier reports are available upon request to the Coordinator (CT DEEP Undated b). In this citizen science program, collections of stream-dwelling macroinvertebrates are made using specified procedures and equipment, with net sampling usually occurring during October or November. Just after field collections are made, program volunteers identify collected macroinvertebrates to various taxonomic levels, ranging from genus to phylum. Subsequently, field sheets with collection data and ethanol preserved voucher samples of organisms are sent to CT DEEP, where their professional biologists or qualified consultants confirm or correct these identifications.

There are 28 taxa used for the RBV program to help evaluate WQ. All these taxa have known pollution sensitivities, are relatively common, and have state-wide distributions. These taxa are divided into four categories: "Most Wanted", "Moderately Wanted", "Least Wanted", and "Others". Note that this sampling is presence-absence based and not otherwise quantitative. The "Most Wanted" taxa include 12 types of various stoneflies, mayflies, and caddisflies. All "Most Wanted" taxa require streams having good WQ for their habitat and they are the most sensitive to pollution. If four or more of these insects are collected at a site, then the stream segment sampled is considered as fully supportive of CT WQ standards for aquatic life. Fewer taxa, however, may not necessarily indicate poor WQ, as a site just may not be a good one for this type of sampling (e.g., lack of stones in a riffle, both of which are desirable habitat features for these species). "Moderately Wanted" types (eight categories of various aquatic insects) are considered moderately sensitive to pollution. "Least Wanted" (seven types, including five invertebrate types that are not insects), are least sensitive to pollution and "Others" include various miscellaneous macroinvertebrate taxa collected, all of which provide less qualitative information with respect to good or poor WQ.

In conjunction with the East Lyme Commission for the Conservation of Natural Resources and other volunteers, I conducted RBV sampling for many years at locations in LB and CMB (Table 50). Other groups, such as the East Lyme Boy Scouts, also sampled sites in LB for a year or two. In addition, a former NRWC Coordinator along with other volunteers completed RBV sampling in OMB and SB in 2013-14. Results of the RBV sampling indicate that there has been some year to year variation in sampling results in both LB and CMB. Overall, LB appears to have enough "Most" and "Moderately Wanted" types to indicate good WQ, even at the downstream site behind the commercially developed Flanders IGA Plaza, located between NRWC WQ sampling stations 1 and 1.5.

Although our studies and observations showed that CMB has apparently good WQ and a viable brook trout population, RBV results at the CMB-L site in 2012 and 2013 were not indicative of good WQ. Following these 2 years, RBV sampling was moved to an upstream site in 2016 and 2017 and the results indicated good WQ. However, there were difficulties in accessing this site, which was a considerable distance from a road, and the streambed there was mostly bedrock and deep pools, which limited areas for proper RBV sampling. As a result, in 2019 the CMB site was moved to another location much closer to the CMB-U WQ sampling site. Results at this location during 2019-21 were again disappointing, even though when sampling we collected both a brook trout and a rare mussel in our RBV net samples, species that we believe indicated good WQ. Again, results at this site were likely more influenced by local habitat, having more bedrock and sand substrates than the desired reaches of rocky riffles.

TABLE 50. Results of Rapid Bioassessment for Volunteers (RBV) macroinvertebrate sampling In NR tributary streams from 2012 through 2021. Digits separated by dashes represent the total number of taxa collected in the four RBV-defined categories in order as follows: "Most Wanted", "Moderately Wanted", "Least Wanted", and "Others".

Stream	Location[a]	2012	2013	2014	2015[b]	2016[b]	2017	2019[c]	2020	2021[c]
LB	1 : 1.5		2-6-1-2	4-5-3-2	6-5-3-4	5-6-6-2	3-7-3-3	5-6-5-5	3-7-2-7	3-6-4-2
LB	2	5-5-1-1	2-6-1-3	3-6-2-2	5-8-2-1	6-7-2-2	4-9-4-3	1-8-3-3	3-5-1-1	3-7-2-3
LB	~3			3-4-2-1	2-5-2-2					
LB	5 : 6	3-5-1-1								
CMB	CMB-L	1-3-1-1	2-5-0-4							
CMB	U : L					6-8-1-5	4-7-1-5			
CMB	~CMB-U							0-8-0-6	2-4-2-3	2-7-2-3
OMB	~OMB		2-3-0-1					4-5-0-1		
SB	SB-L		2-6-2-1	1-3-1-1						
SB	SB-U		2-1-1-3							

[a] RBV locations very close to or at NRWC WQ stations are indicated by the latter's station designation (e.g., 2), locations somewhat near NRWC WQ stations are designated with a ~ (e.g., ~3), and stations located between two NRWC WQ stations have these station numbers separated by a colon (e.g., 1 : 1.5).

[b] I had no CT DEEP RBV reports for these years but did have a data spreadsheet provided to me by the CT DEEP Volunteer Monitoring Coordinator. I determined the number in each taxonomic category by station by summing up the given identifications, aided by referring to other RBV annual reports (CT DEEP Undated b) and Pennak (1953). Any errors in classification type or total numbers in each category are mine alone.

[c] No RBV sampling was conducted in 2018 or 2022, the former due to high flows and the latter because of low flows in the streams.

The less than adequate habitat likely limited the distribution of the most desired aquatic insect types. Our team performing RBV sampling in the headwaters area of CMB may look for a better location when performing any future work.

OMB and SB were only sampled in 2013 and 2014. As with the earlier CMB results, the RBV sampling in these two streams did not indicate good WQ. Yet, both streams were found by CT DEEP to have resident brook trout with OMB also having brown trout, some of which successfully spawned in the stream. Fortunately, there was additional macroinvertebrate sampling performed in these two streams by Cole (2016) in 2014 and 2015. Using a more rigorous CT DEEP macroinvertebrate sampling protocol, Cole (2016) sampled at three locations each in OMB and SB. The OMB sites were all upstream of the NRWC OMB WQ site. One of his SB sites was close to the NRWC SB-U site, and one was slightly downstream of our SB-L site; his other site was approximately in-between these two locations. Cole's results showed that his farthest OMB upstream site (near the Waterford Speed Bowl site) had relatively poor WQ in comparison to the other locations, indicating moderate changes to the biotic community by loss of sensitive species and increasing abundance of more pollution-tolerant macroinvertebrates. However, over his 2 years of sampling the other two OMB stations mostly showed natural or minimal changes to the fauna, which were indicative of good WQ. He found all three SB stations to have demonstrated changes in the biotic community with the disappearance of sensitive species, although these sites still had a diverse community. With his macroinvertebrate sampling augmented by observations of resident brook (both streams) and brown trout (OMB), Cole (2016) concluded that these two streams remained relatively intact and continued to support native fish and macroinvertebrate communities.

Wildlife Observations

I often made notes about wildlife observed at the sampling stations during both sampling programs (Table 51). I limited these observations to either vertebrate animals associated with water courses or otherwise larger, more charismatic fauna or their signs. For example, I did not make notes about the many songbirds that might be seen along the study streams or the many types of insects. Also, certainly many smaller animals are cryptic and therefore remain unobserved by me and my companions. I could not identify some specimens to species, particularly small minnows. A few species dominated the observations, including alewives and unidentified minnow species among fishes, green frogs for amphibians, mallard ducks and great blue herons among birds, and whitetail deer for the mammals. Of note, I observed no aquatic reptiles, such as turtles or water snakes, except for one shed snakeskin.

In addition to wildlife, I often made notes about the presence of various aquatic plants, algal blooms, and what I believed to be iron bacteria observed in several locations. However, as these forms are not mobile and were often common and long-lasting, I did not include them in the observations summarized in Table 51. Nevertheless, their occurrences were noted in the sampling observations recorded and found in the NRWC WQ monitoring data file.

TABLE 51. Observations of wildlife at stations used to sample WQ in the NR watershed from April 2012 through May 2022.

Date	Station	Observation (one specimen unless a number or estimate given)
April 13, 2012	CMB-L	2 mallard ducks and possible brook trout
May 30, 2012	DPO	Dead beaver at DPO outlet culvert

TABLE 51 (continued).		
October 23, 2012	DPO	5 mallard ducks and 3 unknown migratory ducks on Darrow Pond
March 22, 2013	1.5	Great blue heron just downstream of station
	6	6 mallard ducks on Beckwith Pond
April 26, 2013	1	Many alewives downstream of LB Dam. Many Canada geese in pond.
	3	Drake mallard duck
	6	Whitetail deer
May 10, 2013	3	Green frog
	6	14 Canada geese, mallard duck, and osprey on or near Beckwith Pond
	DPO	Largemouth bass
June 21, 2013	1	Hen mallard duck with many young
	DPO	Great blue heron
July 30, 2013	2, 3, CMB-U	Green frog
	CMB-U	Few small minnows (possibly blacknose dace)
August 15, 2013	2, CMB-U	Green frog
	3, CMB-U	Few small unknown minnows
	3	Shed skin of unknown snake species
September 24, 2013	CMB-U	Green frog
October 25, 2013	3	2 mallard ducks
November 22, 2013	1.5	Large animal feces, possibly from a coyote
December 20, 2013	2	2 mallard ducks
January 27, 2014	DPO	Large flock of seagulls on Darrow Pond ice
February 21, 2014	1	3 hooded mergansers
April 11, 2014	1	Many alewives below LB dam and Canada goose in the pond
May 15, 2014	1	Few alewives below LB dam and great blue heron in the pond
	3	Drake mallard duck
June 13, 2014	1	2 great blue herons
	1.5	Calling green frogs heard
July 11, 2014	1.5	Calling green frog heard
	CMB-U	Few small minnows (possibly blacknose dace)
September 27, 2014	3, CMB-U	Few green frogs
	CMB-L	4 unknown minnows
January 15, 2015	OMB	2 pairs of mallard ducks just upstream
March 13, 2015	SB-L, CMB-L	Pair of mallard ducks
April 27, 2015	1	Many alewives below LB dam and double-crested cormorant in the pond
	CMB-L	Hen mallard duck
May 14, 2015	1	Many alewives below LB dam
	2	Mallard duck
	4	~8 small minnows
June 12, 2015	CMB-U	Unknown frog species
July 15, 2015	1	Great blue heron
	CMB-U	School (number unknown) of small minnows
September 15, 2015	SB-L	Pickerel frog
December 17, 2015	1.5	Flock of turkeys heard vocalizing
February 11, 2016	CMB-L	Homeowner reported recent sighting of a mink at this station
March 24, 2016	1.5	2 mallard ducks. Dead blue jay seen in the stream.
	4	Dead yellow perch seen in the stream
April 21, 2016	1	Many alewives below the LB dam, in the fishway, and a few in the pond.

TABLE 51 (continued).		
April 16, 2016	4	Great blue heron
May 20, 2016	1	2 Canada geese
	2	Whitetail deer tracks alongside the stream
June 22, 2016	1	Green frog heard calling
	3	Great blue heron
	CMB-U	Small minnow
July 19, 2016	1	Small sunfish (possibly bluegill)
	CMB-U	Green frog and about 5 small minnows
August 24, 2016	1.5	Black-crowned night heron
	CMB-U	Few small minnows
March 16, 2017	2	Turkey tracks observed in snow
	4	Buck whitetail deer
July 6, 2017	1	3 mallard ducks
August 27, 2020	1	Bluegill

POINT SUMMARY

1. The Niantic River (NR), a tidal estuary in southeastern CT, has a watershed area of 31.3 mi^2 located within four towns, including Salem, Montville, East Lyme, and Waterford.
2. The largest NR tributary is Latimer Brook (LB), which has its sources in Salem and Montville, flows through much of East Lyme and forms this town's boundary with Waterford when entering the NR. The largest tributary of LB is Cranberry Meadow Brook (CMB), which is in East Lyme.
3. The second and third largest NR tributaries are Oil Mill Brook (OMB) and Stony Brook (SB), both located in Waterford.
4. For nearly two decades the NR Estuary has been assessed by CT DEEP as impaired for designated uses of marine aquatic life, recreation and shellfish harvesting due to excessive amounts of nutrients and fecal indicator bacteria entering the river.
5. Concerned about environmental impairments to the NR affecting water quality (WQ), which also might affect eelgrass beds and promote algal blooms, and with a lack of WQ data, the Niantic River Watershed Committee (NRWC) initiated a WQ sampling program in the NR tributaries in 2012.
6. A sampling plan was prepared by the NRWC Monitoring Subcommittee (NRWC MSC) as well as the acquisition of necessary equipment. Monthly tributary-based (T-B) WQ sampling began during April 2012 at six stations in LB (1-6; numbered sequentially from downstream at the LB dam to upstream just below Beckwith Reservoir) and one in lower CMB (CMB-L).
7. WQ parameters, including water temperature, dissolved oxygen (DO), pH, and conductivity or specific conductance were measured and recorded at each station, where a water sample was also taken for determining the concentration of nitrate-nitrogen, which is termed "nitrate" throughout much of this report.
8. The NRWC MSC revised the sampling plan several times in 2012-13 to add additional stations, including the outlet of Darrow Pond (DPO); one station designated as 1.5, found between LB stations 1 and 2; and one site located in the headwaters area of CMB (CMB-U).
9. In April 2014, a data analysis resulted in the NRWC MSC dropping sampling at DPO and upper LB stations 5 and 6, which then allowed WQ sampling at single sites in both OMB and SB.

10. The NRWC completed an independent study in 2014-16 to determine the relative contributions of water volumes from upper LB and CMB to their combined flow in LB downstream of their confluence. Water temperatures in these two streams were different enough such that it could be used as a surrogate for water flow and long-term loggers were placed in CMB just above where the stream enters LB and at locations in LB sufficiently above and below the confluence. An analysis of the long-term water temperature data resulted in an estimate that, on average, about 62% of the water in lower LB came from upper LB and 38% from CMB.
11. Five years of T-B WQ sampling concluded following the sampling in March 2017.
12. For the T-B sampling data, water temperature and DO were significantly negatively correlated, as warmer water has less physical capacity to hold DO than colder water.
13. Many other WQ parameters were also significantly negatively or positively correlated with one another, but the correlation coefficients were relatively small, so many of the changes in parameter values were likely occurring independently.
14. Water temperatures were significantly different among all seasons, being lowest and least variable in Winter (January-March), followed by those of Fall (October-December), Spring (April-June), and Summer (July-September).
15. In contrast to water temperature, DO concentrations were significantly highest during Winter and lowest in Summer; Fall and Spring values were intermediate and not significantly different from one another. All quarterly time periods had DO values fully supportive of aquatic life.
16. pH values in the streams were mostly acidic but none were detrimental to aquatic life. pH values in Spring and Summer were similar and significantly higher than those found in Fall and Winter, which were also like one another.
17. In all seasons, mean specific conductance values were higher than median values, illustrating that some exceptionally large values had been recorded. Specific conductance was highest and most variable in Fall, which had significantly greater values than Spring. Summer and Winter means were not significantly different from each other or their adjacent seasons.
18. Nitrate concentrations were significantly higher in Summer than those in Spring and Fall but were not different from those found in Winter. Mean values were higher than medians, indicating that some relatively high nitrate concentrations were found.
19. Among the stations, lowest water temperatures and least variability occurred at the upstream LB sites and in the smaller streams (CMB, OMB, and SB), but there were no significant differences found among all the stations.
20. DO levels at all stations were generally high, suitable for aquatic life, and not significantly different from one another. An exception was CMB-U, where this small pool was occasionally isolated during low flow periods and had a few DO values as low as 0.5-1.7 mg/L. Nonetheless, small minnows were observed at this site despite the low DO and no dead or distressed organisms were ever seen.
21. pH levels varied significantly among stations, although there was considerable overlap among station means. The downstream LB stations (1 and 1.5), CMB-U, and SB had lower pH values than upper LB stations (2-4), OMB, and CMB-L.
22. There was a fairly large range of specific conductance values, with most of the extremely high values found at CMB-U, which were related to low flow or static conditions there, likely affecting water chemistry. Despite these few occurrences, mean specific conductance at the two CMB stations were among the lowest with the mean at SB the highest. These findings may be related to

underlying geology in their watersheds affecting their ionic distributions. Specific conductance at LB stations and SB significantly increased over the 5-year T-B study.

23. Considerable variation occurred in nitrate concentrations among stations and years. Nitrate increased when going downstream in LB. Significantly highest values were found for stations 1 and 1.5 with the lowest mean at CMB-U. Values for OMB and SB were approximately the same as at upper LB stations 3 and 4, with the mean for CMB-L nearly the same as LB station 2. Differences throughout LB and CMB were likely related to increasing housing developments and stormwater discharges when proceeding downstream.
24. There were no strong correlations found between nitrate and water temperature, DO, or pH. Although the data showed considerable scatter, a statistically significant positive relationship existed between nitrate and specific conductance. This relationship was stronger after deleting data from SB and several data outliers. The result may reflect precipitation-related inputs of both minerals and nutrients, which simultaneously increased both specific conductance and nitrate.
25. An analysis of nitrate concentrations at LB stations 3 and 4 and CMB-L confirmed the long-term water temperature study findings that upper LB supplies about 62% and CMB 38% of the water volume in lower LB.
26. In July 2017, 5 years of quarterly seasonal precipitation-related (P-R) WQ sampling was initiated. Sampling only took place at the LB dam in Flanders (also used as T-B station 1) and ended following the Spring 2022 sampling.
27. The P-R sampling was conducted when significant (ideally, ≥1 in) rainfall was expected, although in many quarters, particularly during relatively dry periods, this was not possible. One daily sample was taken over a period of 4-7 days, with most starting 1 day before the initial precipitation event.
28. Besides measuring WQ parameters and taking water samples for nitrate analysis, records of precipitation were mostly obtained from the Waterford-East Lyme Shellfish Commission (WELSCO) rain gage in Niantic, and available streamflow discharge volumes from the U.S. Geological Survey (USGS) gage located in LB in an area downstream of the dam.
29. Rainfall records indicated that 2018 and 2019 were relatively wet years in comparison to 2020 and 2021. Partial year records obtained for 2017 and 2022 indicated that the former was a wet year and the latter dry.
30. The largest rainstorms recorded in each year ranged from 1.30 in (2022) to 4.00 in (2021). The latter rainfall was during the passage of Tropical Storm Ida, for which the National Weather Service reported that East Lyme received 7.36 in of rain. Thus, there is a disparity among these two reports of rainfall from this storm.
31. The wettest months were February-May, October, and December and driest June through September. However, the fractions of larger precipitation events ($\geq$ 0.10 in) to all rain events were relatively even across all months, ranging from 53% in April to 71% in October.
32. The frequency of heavier (≥0.70 in) rainstorms in dry years was only about two-thirds of that occurring in wetter years, indicating a greater frequency of heavier rainstorms contributed to wetter years.
33. The USGS LB streamflow gage was not in operation during all the P-R WQ sampling events, including from Fall 2017 through Fall 2019. Most missing streamflow values were calculated using a mathematical relationship found between the water depth measurements made at the LB dam and USGS streamflow records when the gage was in operation.

34. Both the USGS-recorded and calculated LB discharge flow measurements were highly skewed due to several large discharge records related to high precipitation events, including Tropical Storm Ida.
35. Using median streamflow values as the best descriptor, during the P-R sampling LB streamflow volumes were highest in Winter and lowest in Summer.
36. Mean discharge recorded by the USGS gage from January 24, 2020 through June 30, 2022 was 27.32 cfs but was 45.24 cfs during the P-R sampling, confirming that the latter mostly took place when precipitation increased LB streamflow. Overall, during this 2.5-year period, about one-half of the mean daily LB discharge flows were less than 20 cfs and flows above 110 cfs rarely occurred.
37. When all available USGS streamflow records for LB (September 2008-September 2012; July 2014-September 2015; January 2020-January 2023) were examined, the mean daily discharge was 29.46 cfs.
38. During P-B sampling, LB streamflow increased rapidly following precipitation, which was followed by a corresponding decrease to more baseline levels in subsequent days.
39. All but two correlations among all the WQ parameters and LB streamflow in the P-R sampling were highly significant. Correlation coefficients were numerically greater than found previously with the T-B data.
40. Besides the expected high correlation between water temperature and DO, the highest correlation coefficient of -0.902 was between specific conductance and LB streamflow. The negative sign indicated that when discharge increases, specific conductance decreases, which was likely due to dilution of dissolved ions. Specific conductance and nitrate were both positively correlated (r = 0.724), also an indication of similar effects occurring for both under all LB flow conditions.
41. WQ parameters during the P-B sampling generally showed the same seasonal patterns as those during the T-B sampling.
42. A plot of specific conductance and LB streamflow data showed a curvilinear or power function relationship with a rapid decrease occurring in specific conductance that leveled off at higher streamflow levels. This implied that there is a proportional and linear decrease in specific conductance as LB discharge increases. This was likely due to dilution of ions in LB, which became offset by increasing sediments and ionic loading at higher flows. A natural logarithmic transformation applied to these data showed a negative linear fit.
43. Highest nitrate concentrations occurred in Spring, which also had the greatest range in values; Winter had the lowest concentrations. The Spring mean was significantly greater than the other seasons, which were not different from one another.
44. Higher nitrate concentrations were associated with lower LB streamflow levels and vice versa.
45. Nitrate concentration observations were placed into various hourly periods before and after discrete rainfall events. They were highest prior to the start of precipitation and up to 3 h later. The +1-3 h period after precipitation showed the greatest variability. The two following periods (+5-15 h and +20-32 h) had similar means, indicating some stabilization had occurred in nitrate concentration. The smallest mean nitrate concentrations occurred some 38-49 h after precipitation. Thereafter, nitrate concentrations mostly returned levels found at the start of each quarterly sampling.
46. As found with specific conductance, a plot of nitrate concentration versus LB streamflow showed a curvilinear or power function relationship, albeit with more scatter of the data. There was a wide range of nitrate values (0.04-1.00 mg/L) when LB streamflow was less than about 30 cfs, but no nitrate concentrations exceeded about 0.35 mg/L at higher flows. When a natural logarithmic

transformation was applied to these data, there was a significant, proportional negative linear decrease in nitrate concentration as streamflow increased.

47. There are confounding factors associated with how nitrate concentrations vary in relation to precipitation and streamflow as sources of nitrate in streams include mixtures of soil nitrate and ammonium fertilizers; wastewater discharges (e.g., septic systems), animal wastes; and atmospheric deposition. Some of these sources could be in the form of organic nitrogen and ammonia. Likely atmospheric deposition and nonpoint sources of nitrate in stormwater discharges would increase concentrations relatively quickly upon rainfall, but groundwater movements may lag as would soil sources, the movements of which may also depend upon prevailing soil moisture levels. At some point, large precipitation events increasing streamflow volumes will then also decrease nitrate concentrations through dilution effects.
48. An important goal of the NRWC WQ study was to evaluate the flux (i.e., discharge) of nitrogen into the NR from its major tributary streams and comparing our results to that of Mullaney (2013), who conducted comprehensive studies of nutrients in NR tributaries during August 2008 through February 2012. Mullaney sampled at the same or at locations very close to NRWC stations at several sites in LB (our stations 6, 3, and 1), CMB-L, OMB, and SB.
49. NRWC nitrate concentrations were like those reported by Mullaney from his long-term (August 2008-February 2012) study. At LB station 1, NRWC mean values were 0.37 mg/L (T-B) and 0.30 (P-R) and his was 0.35 mg/L. At OMB, the NRWC mean was 0.18 mg/L versus his 0.16 mg/L. The largest difference was at SB, where our T-B sampling mean was 0.20 mg/L and his was 0.09 mg/L.
50. Mullaney measured more nitrogen constituents than did this study, including total ammonia + organic nitrogen, and his nitrate-nitrogen values also included nitrite in his calculations of total nitrogen discharge. However, based on scientific literature and the WQ values observed in our study streams, there was likely little available nitrite in LB that would have increased NRWC nitrate-nitrogen values.
51. Having no measure of total ammonia + organic nitrogen, I used Mullaney's long-term study mean concentration of 0.27 mg/L in NRWC calculations of total nitrogen flux at LB station 1.
52. I calculated the flux of nitrogen using nitrate concentration data from both the T-B and P-R sampling programs with the long-term mean LB streamflow values of 29.5 cfs. I also computed mean May-June values for both nitrate concentration (0.30 mg/L) and LB streamflow (25 cfs) to compare these values with those reported in Mullaney (2013).
53. Mullaney made total nitrogen discharge calculations at all his stations based on single days of sampling in early June 2005, when streamflow volumes were relatively low. He reported a total nitrogen concentration of 0.72 mg/L at LB station 1, whereas NRWC estimates were 0.57-0.67 mg/L.
54. Mullaney (2013) found that total ammonia + organic nitrogen dominated the nitrogen constituents in OMB and SB, whereas nitrate predominated in LB. His data confirmed that nitrate concentrations in lower CMB are somewhat higher than they are in the middle portions of LB, but these higher concentrations are likely offset by a lower streamflow volume in CMB when considering nitrogen flux within these streams.
55. Besides at the LB dam (station 1), for his flux estimates, Mullaney measured flow volumes at upstream stations in LB as well as in CMB, OMB, and SB. His total nitrogen loading in LB increased when going downstream from station 6 (12.9 or 28.5 lbs per day) to 1 (28.2 kg or 62.1 lbs per day). NRWC calculations for station 1 ranged from 41.0 kg (90.2 lbs) to 46.1 kg (101.4 lbs) per day. His

higher nitrogen concentration at station 1 was offset by his lower streamflow measurement of 16 cfs used in the loading calculation for that station, resulting in a smaller nitrogen flux estimate.

56. NRWC calculated values may be more indicative of nitrogen flux from LB into the NR as they were based on long-term mean values for both total nitrogen and LB streamflow.
57. Mullaney's calculations showed relatively low nitrogen loading into the NR from both OMB and SB, with 5.0 kg (11.1 lbs) per day for the former and 3.1 kg (6.9 lbs) per day for the latter. As such, LB contributes about 78-80% of the nitrogen input to the NR from its three main surface tributaries.
58. Based on NRWC water temperature data, all sections of LB and OMB classify as a cool-water stream and SB as a cold-water stream with respect to CT trout species habitat as defined in Beauchene et al. (2016). However, maximum water temperatures in all LB segments (22.9-24.5^{o}C) during the June-August period fell well within the warm-water stream classification. No increasing trend was found in peak summer water temperatures during this study, so the thermal regime in LB appears to have been stable in recent years. However, persistent water temperature increases occurring in the future may degrade these streams as suitable trout habitat.
59. Data from a CT DEEP citizen science program called Stream Riffle Bioassessment by Volunteers (RBV) showed somewhat equivocal results with respect to WQ. RBV sampling at LB sites in most years indicated good WQ, but there was more uncertainty in CMB, OMB, and SB. Results for the latter sites may have been affected by locational issues affecting sampling as well as fewer years sampled. The NRWC WQ sampling in these streams as well as the presence of brook trout reported in CT DEEP and other surveys indicate that they continue to support desirable native fish and macroinvertebrate communities.

CONCLUSIONS

Ten years of sampling in four NR tributary streams demonstrated that WQ parameter values have been consistent in supporting desirable aquatic life forms. This notion is supported by data available from other sampling programs conducted by CT DEEP and other professional scientists, and through citizen science programs, such as RBV assessments. Water temperatures appear to have remained relatively stable in recent years, although warmer summers and any increasing trend over time may affect the suitability of these streams for trout, particularly in LB. DO concentrations are mostly high and show relatively high temperature-dependent percent saturation levels. In the few instances when low DO concentrations were observed during dry summers at station CMB-U, fish were present, indicating no adverse effects. Although water in these streams has been consistently acidic, pH values are not within ranges that would affect aquatic organisms. Variability found in pH during precipitation-related sampling may reflect acidic rain and other terrestrial inputs resulting from rainfall.

During the precipitation-related sampling, highest LB streamflows mostly occurred in Winter with fewest during Summer. Most rainfall events increased streamflow for several days, but the flow eventually returned to approximately the same levels present before the precipitation started. During our sampling, most WQ parameters were highly correlated among themselves and with streamflow values. When about 8 years of daily LB streamflow records available from the USGS were examined, a mean daily flow of 29.46 cfs was calculated. About one-half of the daily mean discharge values were less than 20 cfs with few daily mean discharge values greater than 110 cfs.

Specific conductance values decreased with increasing streamflow in LB. This relationship implies that when changes occur in streamflow, they produce a proportional and linear change in specific conductance values with rapid decreases occurring under increasing stream discharge volumes. This also indicates that the ionic composition producing the conductivity becomes diluted when stream water volumes become larger. This process continues proportionately until flow volumes become large enough that specific conductance values finally level off, perhaps due to increasing presence of sediments in high flows and, therefore, additional ionic loading. Specific conductance values and nitrate concentrations appear to vary similarly. Like specific conductance, nitrate concentrations exhibit a power curve relationship with streamflow values, with nitrate concentrations decreasing at higher stream flows. Nitrate concentrations showed a significant negative linear relationship with streamflow when a natural logarithmic transformation was applied.

Given the nutrient-related impairments noted for the NR by CT DEEP, the measurement of nitrate concentrations in the tributary streams were of great importance to the NRWC. Our organization as well as many others are concerned that increased nutrients entering the NR will result in increased algal blooms to the detriment of eelgrass and which may also exacerbate other environmental conditions, such as contributing to hypoxia in deeper waters of the river. As Mullaney (2013) reported in his comprehensive study of nitrogen in NR tributary streams, nitrate concentrations increased when proceeding downstream in LB from its upper reaches to the dam in Flanders, which is just upstream of the NR. This was also a finding of the NRWC study. This increase may be related to greater housing and commercial property development occurring in the downstream area of the LB watershed, where most properties discharge sanitary wastes into onsite septic systems having no nitrogen-reducing capability, and there are many untreated stormwater discharges. Lower CMB has a higher concentration of nitrate than does the upper reaches of LB. Similarly, this brook flows downstream through increased housing development as well as some small farms having crops and livestock. However, this input of nitrate is offset by a smaller water volume added from CMB this stream joins LB. On average, CMB contributes about 38% of the combined flows of these two streams and upper LB about 62%. Nitrate concentrations in OMB and SB were found to be lower than in LB and combined with their lower streamflow volumes, represent smaller inputs of nitrogen into the NR, which was also a finding of Mullaney (2013).

Calculations of nitrate concentrations in all streams except SB and nitrogen loading from LB into the NR were very comparable to results presented in Mullaney (2013) from his comprehensive study on nutrients in the NR tributaries. Thus, the results presented herein lend credibility to our work and affirm that the loading estimates are reasonably accurate. An important caveat, however, is that Mullaney's long-term mean concentrations of ammonia + organic nitrogen were used in NRWC flux calculations, as this constituent was not measured during our sampling. At least in lower LB, Mullaney found this constituent to have a concentration of less than one-half that of nitrite + nitrate-nitrogen, whereas he found it predominated in both OMB and SB. Mullaney calculated a discharge of 28.2 kg/day (62.1 lbs/day) of nitrogen from LB into the NR. His total nitrogen concentration of 0.72 mg/L was greater than the NRWC means of 0.57-0.67 mg/L. The three nitrogen flux calculations in the NRWC study ranged between 41.0 and 46.1 kg/day (90.2-101.4 lbs/day), but these were based on a larger mean LB streamflow discharge (25.0-29.5 cfs) as opposed to Mullaney's value of 16 cfs. Nonetheless, all these results provide estimates that can be useful in managing nitrogen inputs into the NR. Our goal should be to reduce prevailing nutrient loadings that might affect the ecology and biota of the Niantic River.

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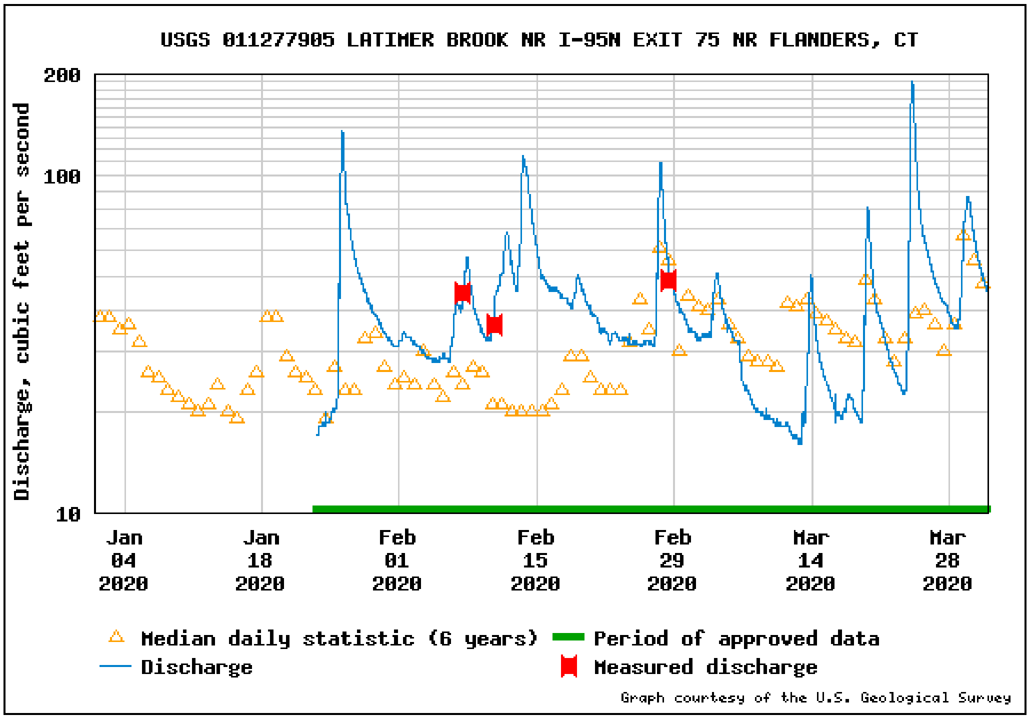
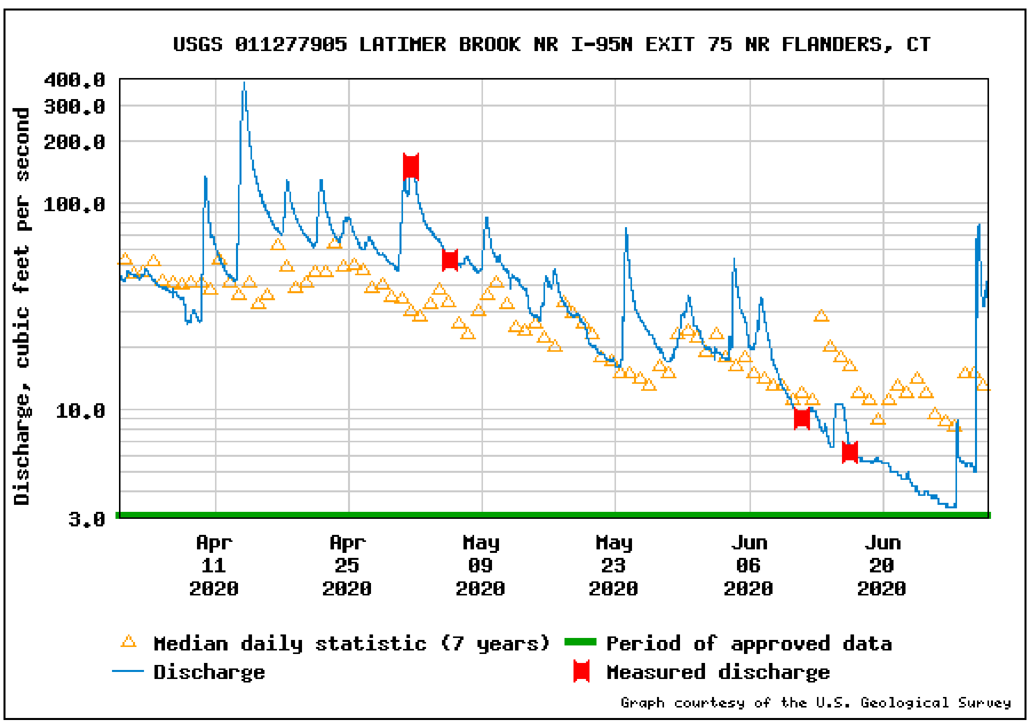
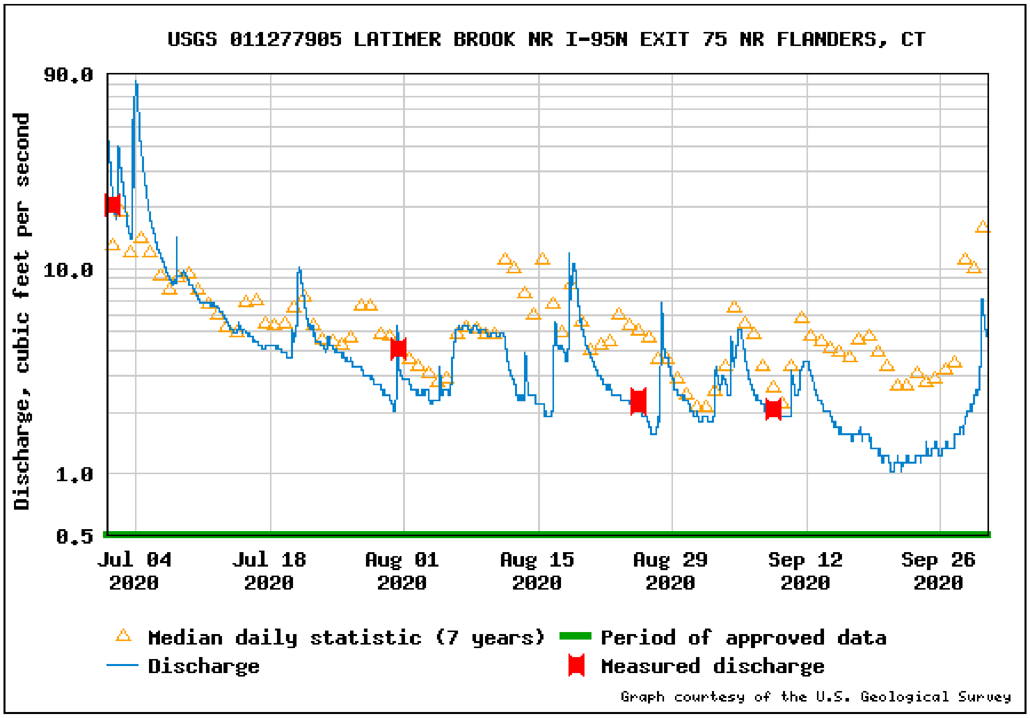
APPENDIX FIGURES



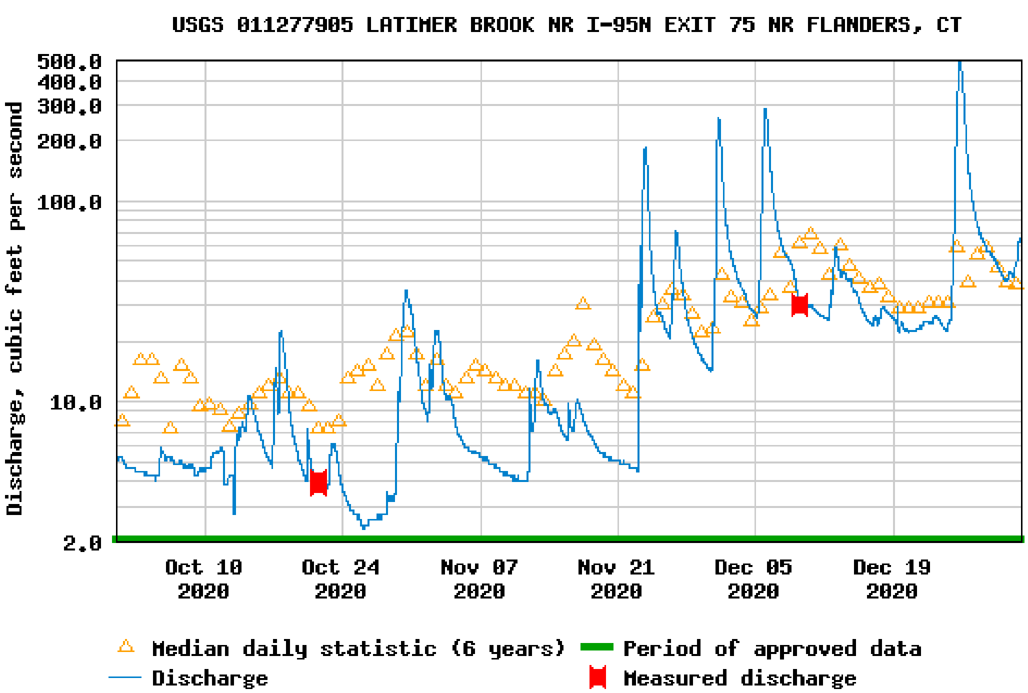
APPENDIX FIGURE 1. Discharge (cfs) as measured by the USGS gage in lower LB from January 1 through March 31, 2020 (USGS 2022).



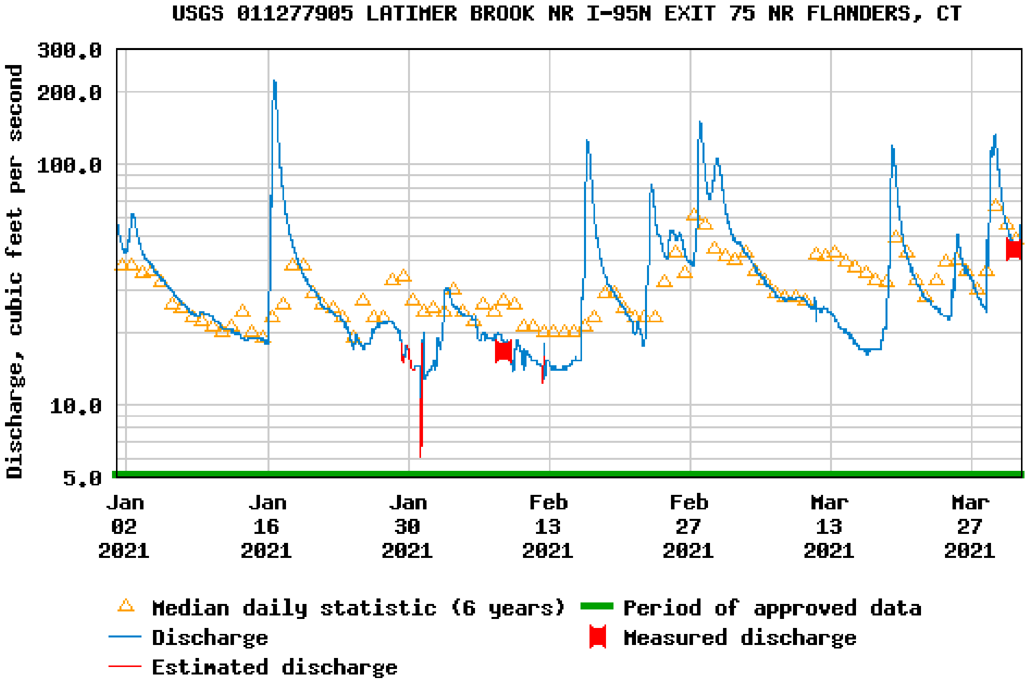
APPENDIX FIGURE 2. Discharge (cfs) as measured by the USGS gage in lower LB from April 1 through June 30, 2020 (USGS 2022).



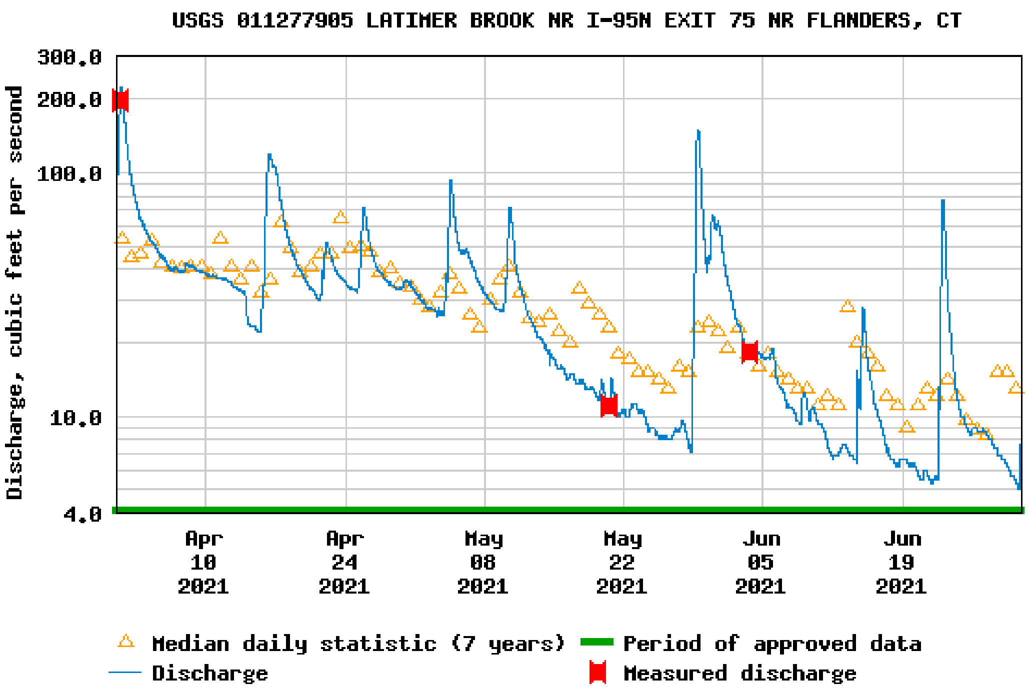
APPENDIX FIGURE 3 Discharge (cfs) as measured by the USGS gage in lower LB from July 1 through September 30, 2020 (USGS 2022).



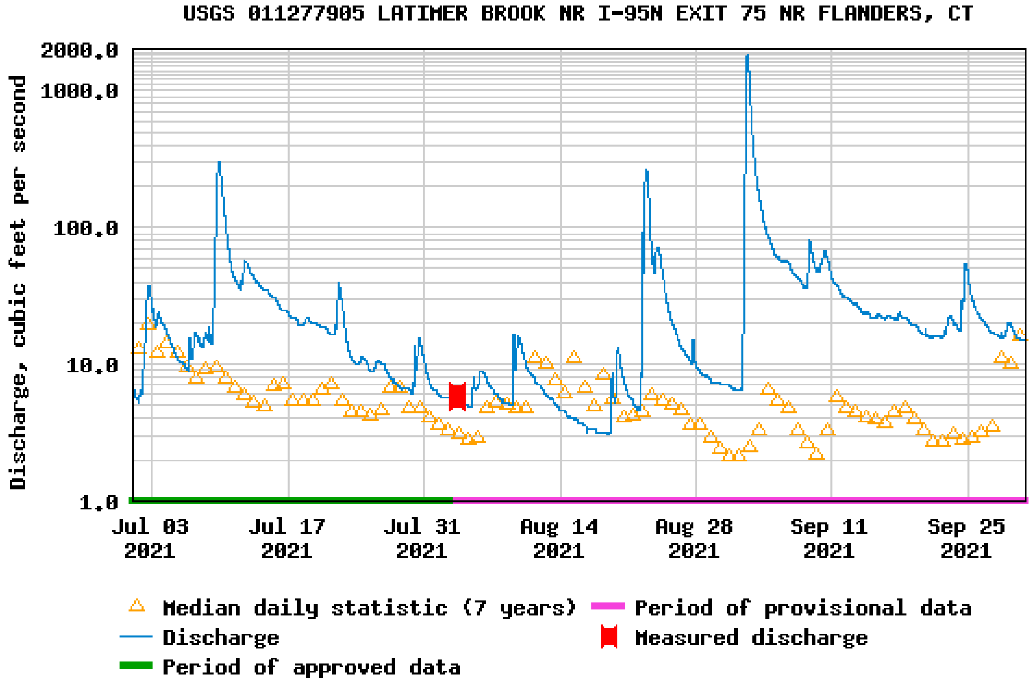
APPENDIX FIGURE 4 Discharge (cfs) as measured by the USGS gage in lower LB from October 1 through December 31, 2020 (USGS 2022).



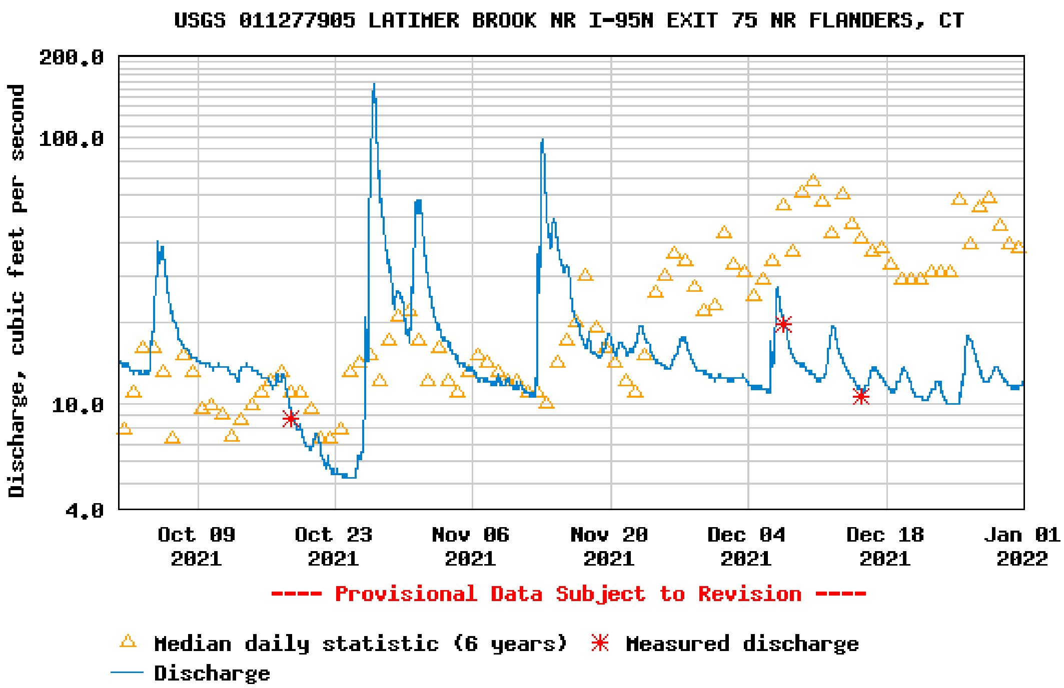
APPENDIX FIGURE 5. Discharge (cfs) as measured by the USGS gage in lower LB from January 1 through March 31, 2021 (USGS 2022).



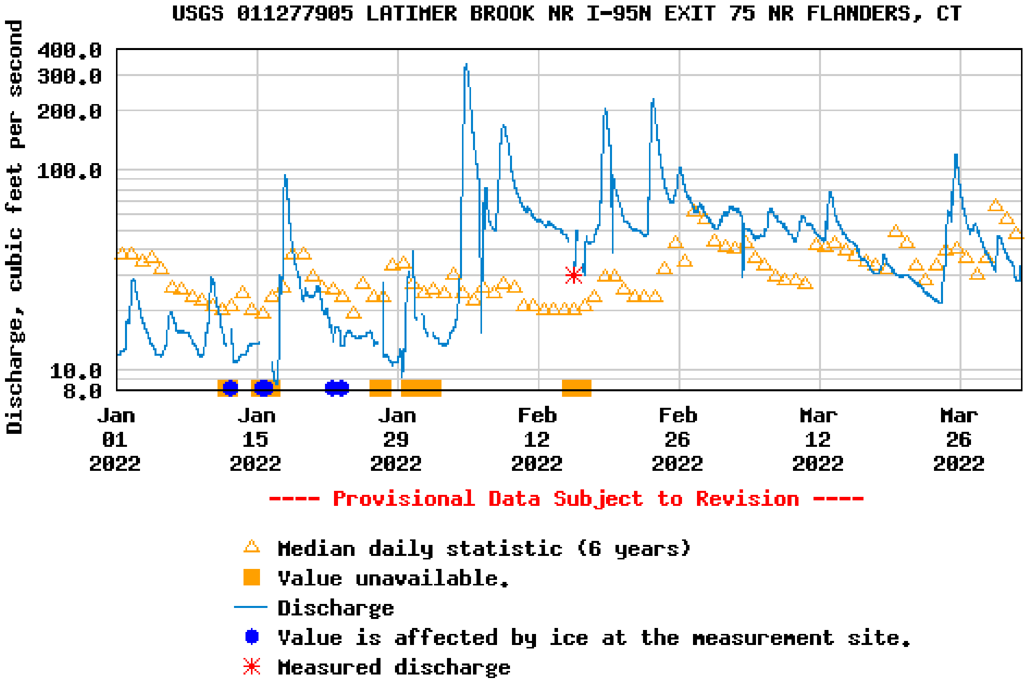
APPENDIX FIGURE 6. Discharge (cfs) as measured by the USGS gage in lower LB from April 1 through June 30, 2021 (USGS 2022).



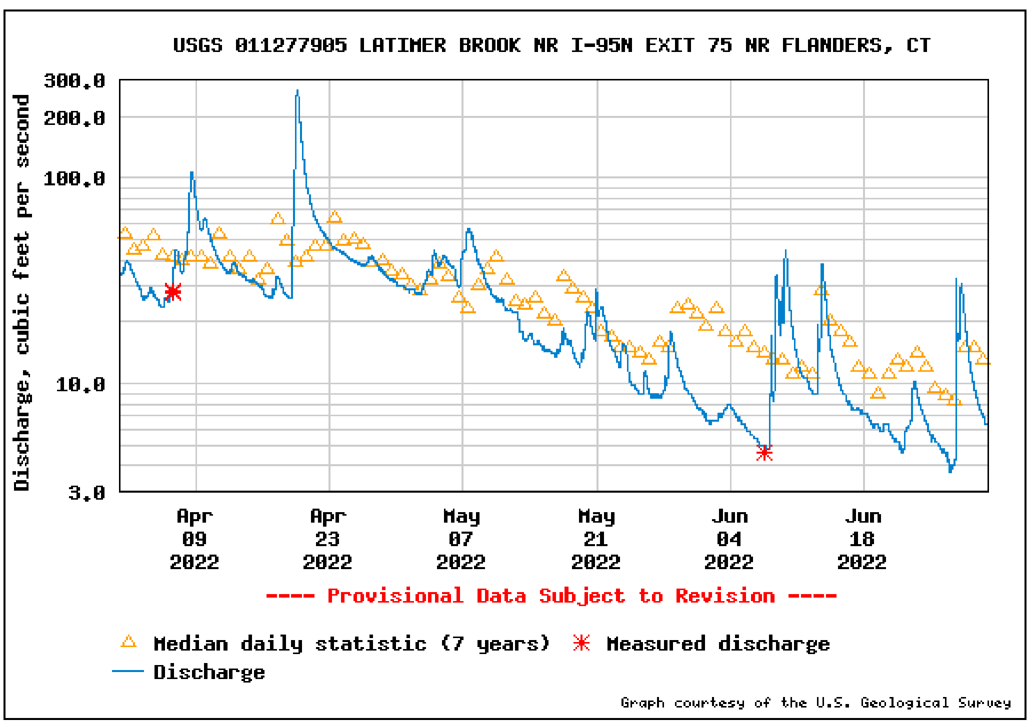
APPENDIX FIGURE 7. Discharge (cfs) as measured by the USGS gage in lower LB from July 1 through September 30, 2021 (USGS 2022). Data for August and September were considered provisional by USGS at the time of this writing.



APPENDIX FIGURE 8. Discharge (cfs) as measured by the USGS gage in lower LB from October 1 through December 31, 2021 (USGS 2022). All data were considered provisional by USGS at the time of this writing.



APPENDIX FIGURE 9. Discharge (cfs) as measured by the USGS gage in lower LB from January 1 through March 31, 2022 (USGS 2022). All data were considered provisional by USGS at the time of this writing.



APPENDIX FIGURE 10. Discharge (cfs) as measured by the USGS gage in lower LB from April 1 through June 30, 2022 (USGS 2022). All data were considered provisional by USGS at the time of this writing.

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