Water Quality of the Oyster River, New Hampshire, 2001-2011

Oyster River Water Testing Committee

Jim Colbert, Eric Fiegenbaum, Brian Gallagher, Jim Hornbeck, Tom Lee, Emily Poworoznek, and Carl Starr

February 2014

Acknowledgments: Sincere thanks to our partners for their hard work, technical advice, support (financial and otherwise), and encouragement: Jennifer Drociak, Ted Walsh, and Beth Malcolm at New Hampshire Department of Environmental Services Volunteer River Assessment Program (VRAP), Michelle Daley and Dr. William McDowell at the NH Water Resources Research Center, Wesley East at University of New Hampshire Water Utilities. Drs. Richard Carey, David Cedarholm, and William Arcieri commented on earlier versions of the report.

To obtain a copy of this report, see www.oysterriver.org

Thank You!

Special thanks are extended to the 78 individuals who have cheerfully volunteered their time and energy to monitor the Oyster River, 2001-2013:

Dan Abramson
Bill Arcieri
Haruka Asahina
Holly Bayley
Julia Belshaw
Darlene Brown
Bill Burtis
Tim Butler
Betsy Chadwick
Dick Cochran
Jim Colbert
Samantha Cuccaro
Greg DeCelles
Charlie Dingle
Brendan Fagan
Tony Federer
Eric Fiegenbaum
Barbara Flynn
Rita Freuder
Brian Gallagher
Ben Getchell
Filson Glanz
Tara Gonyer
Fred Greenberg
Shirley Greenberg
Liam Grenier
Cormac Griffin
Laura Hanna
Antoinette Hartgerink
Sarah Hatch
Harold Hocker
Kyle Hoffman
Jim Hornbeck
Ken Hult
Deb Johnson
Jeff Keyes
Craig Lee
Tom Lee
Meghan Laird
Seth Little
Sarah MacDougall
Nancy Marcotte
George Mattson
Barbara Maurer
Andrew Middleton
Bambi Miller
Douglas Miller
Tim Moore
Sarah Morris
John Nachilly
Michael O'Malley
Nancy Pape
Vaso Partinoudi
Paul Pepler
Laurie Potter
Emily Poworoznek
Evan Poworoznek
Eian Prohl
Don Quigley
Gloria Quigley
Suzanne Richardson
Stephanie Saporito
Lauren Schweizer
April Simnor
Robert Smith
Tucker Smith
Carl Starr
Sandi Straus
Katie Swan
Geoff Terragni
Kim Therrien
Christos Tsiamas
Devin Vandelinda
Matt Waisanen
John Wallace
Liz Willey
Larry Zeis
Difei Zhang

TABLE OF CONTENTS

WATER QUALITY OF THE OYSTER RIVER, NEW HAMPSHIRE, 2001-2011

Oyster River Water Testing Committee[1]

February 2014

EXECUTIVE SUMMARY

The Oyster River and its tributaries in southeastern New Hampshire have been monitored by volunteers since 2001 under purview of the New Hampshire Department of Environmental Services, Volunteer River Assessment Program. Data obtained have allowed establishment of baselines for selected water quality parameters, assessment of overall quality of water throughout the watershed, and the addressing of possible declines in water quality. This report presents comparisons of data among sampling locations and across time intervals for 11 years (2001-2011) and 21 sites along the main stem and tributaries of the Oyster River.

Specific conductance, a measure of dissolved ions in water, is typically less than 200 microsiemens per centimeter (µS/cm) in the main stem of the Oyster River, and varies with discharge. The State of New Hampshire considers 835 µS/cmas a “chronic”criterion for surface waters. Wendys, College, and Pettee tributaries were the only streams having specific conductance that occasionally approached or exceeded this value.

Individual ions sampled include chloride, sodium, phosphate, and various forms of nitrogen. With few exceptions, ions were well below levels of concern. Sodium and chloride are of interest due to sources in road salt. Mean chloride levels in Oyster River and its tributaries never exceeded 40 mg Cl/L, and individual values never exceeded the New Hampshire chronic criterion for surface waters of 230 mg Cl/L. Sodium mirrored the patterns of chloride. Highest levels of sodium and chloride occurred in tributary streams Wendys, College, and Pettee, helping explain their high specific conductances. Phosphate expressed as phosphorus was nearly always in the ideal range of <10 µg P/L, with the exception of a few measurements for Dube and Pettee tributaries. The various forms of nitrogen including ammonium, nitrate, dissolved organic nitrogen, and total dissolved nitrogen were generally low and in the ideal range for surface water. Elevated values occurred in tributaries, with Wendys having highest ammonium, and Wendys, Chesley, and College having highest nitrate.

Dissolved oxygen is a measure of the amount of oxygen in water and is important to survival of aquatic organisms. The New Hampshire class A surface water standard is a minimum of 0.6 mg O/L or 75% saturation. This value was usually exceeded in eight of ten sites along the main Oyster River, and in seven of ten tributaries. Failure to meet the standard could usually be tied to upstream conditions such

[1] **Jim Colbert, Eric Fiegenbaum, Brian Gallagher, Jim Hornbeck, Tom Lee, Emily Poworoznek, Carl Starr**

as beaver dams and wetlands. Dissolved oxygen varies over time depending upon temperature and flow rates.

Turbidity is a measure of the amount of suspended material in water, and is measured in Nephelometric Turbidity Units (NTU). New Hampshire standards for turbidity are vague, stating simply that turbidity shall not exceed naturally occurring conditions. Along the main stem of the Oyster River, mean turbidity values varied from lows of < 1 NTU at upstream sites to highs of between 4 and 7 NTU at downstream sites. Turbidity values seem to vary depending upon weather conditions and geologic surface materials. There do not seem to be significant anthropogenic impacts on turbidity, and turbidity values for Oyster River and its tributaries have shown a gradual decline over the 11-year sampling period.

pH is a measure of hydrogen activity in water and is measured on a scale of zero to 14 units. The New Hampshire class A surface water standard is between pH 6.5 and 8.0, unless naturally occurring. Several upstream locations fall below, or are more acid than, the state standard. This is likely due to organic wetlands and low soil buffer capacity. Highest pH values were found in downstream tributaries, but mean values for the highest was just slightly over pH 7, or well within the state standard.

Temperature is critical for aquatic life. Water temperatures varied by site, but a general trend was from warmest at upstream locations to cooler at downstream locations. Streams fed by ponds or wetlands tended to have higher water temperatures. Values appeared to be appropriate for surface waters in central New England.

Bacteria as measured by counts of *Escherichia coli* are an indicator of fecal contamination. Counts were generally low at main stem sites and most tributary sites. Over half the observations at most sites met New Hampshire class A water standard. However, counts at College Brook and Wendys Brook were consistently high, frequently exceeding the standard for class B water. Aside from these two sites the data do not suggest any chronic sources of fecal material.

During the 11-year sampling period, baselines have been established for water quality showing variability over time and location. The water quality at most sites on the main stem of the Oyster River and on its tributaries appears to be minimally affected by human activity. However, College Brook, Pettee Brook, Chesley Brook, and Wendys Brook have conductances and/or nutrient levels, and College Brook and Wendys Brook have bacteria counts suggesting possible impairment, and a need for further study.

INTRODUCTION

The Oyster River water monitoring project was established in 2001. The primary objective was to describe the quality of water in the Oyster River and its tributaries at many sites throughout the watershed, during different times of year, and over many years. Such descriptive data, we believed, would allow us to establish a water quality baseline against which future changes in water quality could be assessed. A secondary goal was to detect decline in water quality and, when such decline was ascribed to human activity, take action to ameliorate the decline. From its inception, the project has been a collaborative effort involving the following partners: Oyster River Watershed Association, University of New Hampshire (UNH) Water Utilities, New Hampshire Department of Environmental Services Volunteer River Assessment Program (DES VRAP), and the New Hampshire Water Resources Research Center (NH WRRC).

In this report we summarize and interpret some of the data collected from 2001 through 2011 with the hope that this synthesis will be used to better manage the Oyster River, its tributaries, and its watershed. Our specific objective is to summarize what we have learned about the following variables:

1) **Specific conductance:** a measure of the abundance of dissolved, ionic substances
2) **Individual ions:** chloride, sodium, phosphate, and various forms of nitrogen
3) **Dissolved oxygen**
4) **Turbidity:** a measure the amount of particulates suspended in the water column
5) **pH:** a measure of acidity (H^+ concentration)
6) **Water temperature**
7) **Bacteria** (counts of *Escherichia coli*): indicate possible presence of pathogenic bacteria

The summarized data were taken from 21 sites in the Oyster River watershed and were collected over 11 years, from 2001 through 2011.

SAMPLE SITES

From 2001 through 2011, we measured water quality at over 25 different sites in the Oyster River watershed. Sites were limited to the freshwater portion of the main stem and its tributaries, although some of the sites (i.e., those on Beards Creek and Johnson Creek) were located on tributaries that directly feed the estuarine portion of the river. In selecting sites we attempted to represent as many sub-watersheds, landscapes, soil parent materials, and land use types as possible.

For this report we analyzed data from 10 sites located on the Oyster River main stem and 11 sites located on tributaries (Tables 1 and 2, Figures 1 and 2). We have excluded all of the sites that were sampled in only one year. Specific conductance, dissolved oxygen, turbidity, pH, and water temperature – referred to here as "physical variables" – were measured every year but due to changing goals and perceptions of site value some *sites* were not measured in every year. Ions were only measured in some years; specifically 2001, 2002, 2005-2010; and, again, not all sites were sampled every year. Counts of *Escherichia coli*, a coliform bacteria that indicates fecal contamination, were made at most of the sites and years at which physical variables were sampled. Sites and years when the above variables were measured are listed in Tables 1 and 2.

Table 1. Years in which 10 sites on the main stem of the Oyster River were sampled for physical variables (specific conductance, dissolved oxygen, turbidity, pH and water temperature), *E. coli*, and ions. See Appendix A for site coordinates and elevations.

SITE NAME	SITE	PHYSICAL VARIABLES AND *E. COLI*	IONS
ROYALCREST	15C-OYS	2010, 2011	
SUGAR SHACK	15-OYS	2001-2009	2001, 2002, 2005-2009
ROUTE 125	13A-OYS	2001, 2010, 2011	2001, 2010
LEE CIRCLE	13-OYS	2001-2011	2001, 2002, 2005-2010
SNELL ROAD	11-OYS	2002, 2003, 2007*	2002, 2007
ROUTE 155	10-OYS	2001-2003, 2011	2001, 2002
GAGING STATION	9-OYS	2001-2011	2001, 2002, 2005-2010
MAST ROAD	8-OYS	2001-2011	2001, 2002, 2005-2010
FOOTBRIDGE	7-OYS	2001-2011	2001, 2002, 2005-2010
TIDAL DAM	5-OYS	2001-2006	2001, 2002

*no *E. coli* data sampled at 11-OYS in 2007.

Table 2. Years in which 11 sites on tributaries of the Oyster River were sampled for physical variables (specific conductance, dissolved oxygen, turbidity, pH and water temperature), *E. coli*, and ions. See Appendix A for site coordinates and elevations.

SITE NAME	SITE	PHYSICAL VARIABLES AND *E. COLI*	IONS
CALDWELL BROOK	01-CWL	2007*, 2010, 2011	2007, 2010
WHEELRIGHT	01-XBB	2001-2011	2001, 2002, 2005-2010
WENDYS BROOK	01-WDY	2008-2011	2008-2010
DUBE BROOK	01-DBE	2002-2011	2002, 2005-2010
CHESLEY BROOK	01-CSB	2001-2011	2001, 2002, 2005-2010
COLLEGE BROOK	00E-CGB	2007*, 2008-2011	2007-2010
HAMEL BROOK	01-HML	2001-2011	2001, 2002, 2005-2010
PETTEE BROOK	01-RSV	2001-2011	2001, 2002, 2005-2010
BEARDS CREEK	02-BRD	2001-2007	2001, 2002, 2005-2008
STOLWORTHY	02G-BRD	2008-2011	2009, 2010
JOHNSON CREEK	03-JNC	2001, 2004-2011	2001, 2006-2010

*no *E. coli* data sampled at 01-CWL and 00E-CGB in 2007.

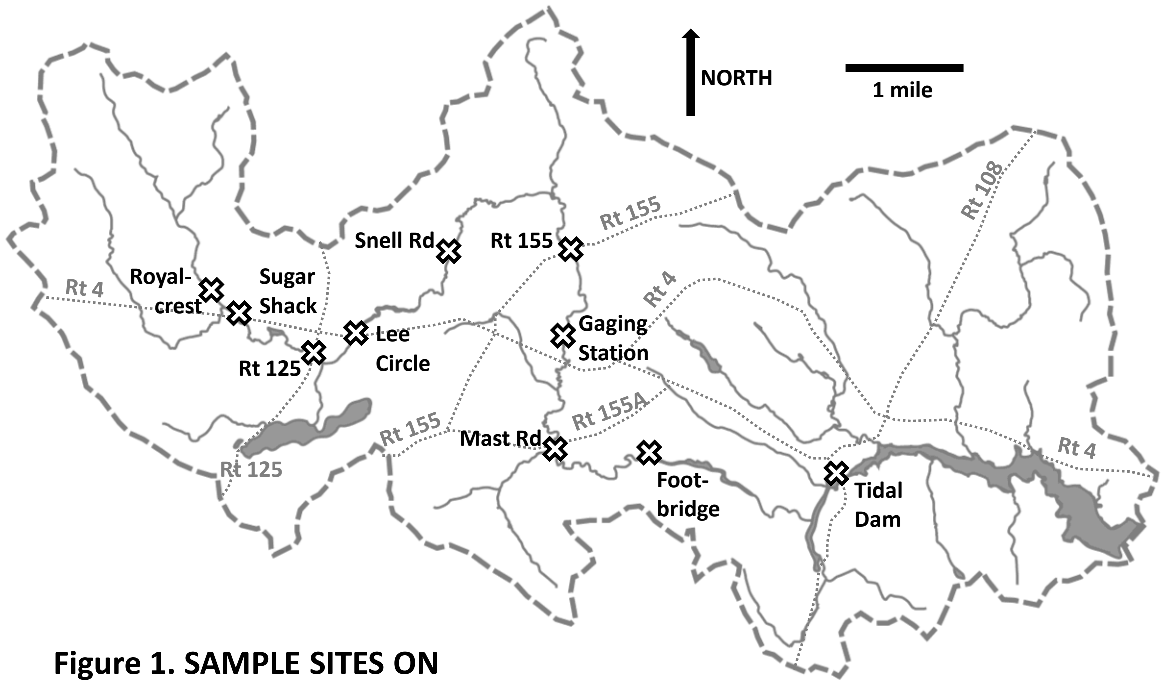


Figure 1. SAMPLE SITES ON
THE MAIN STEM OF THE OYSTER RIVER

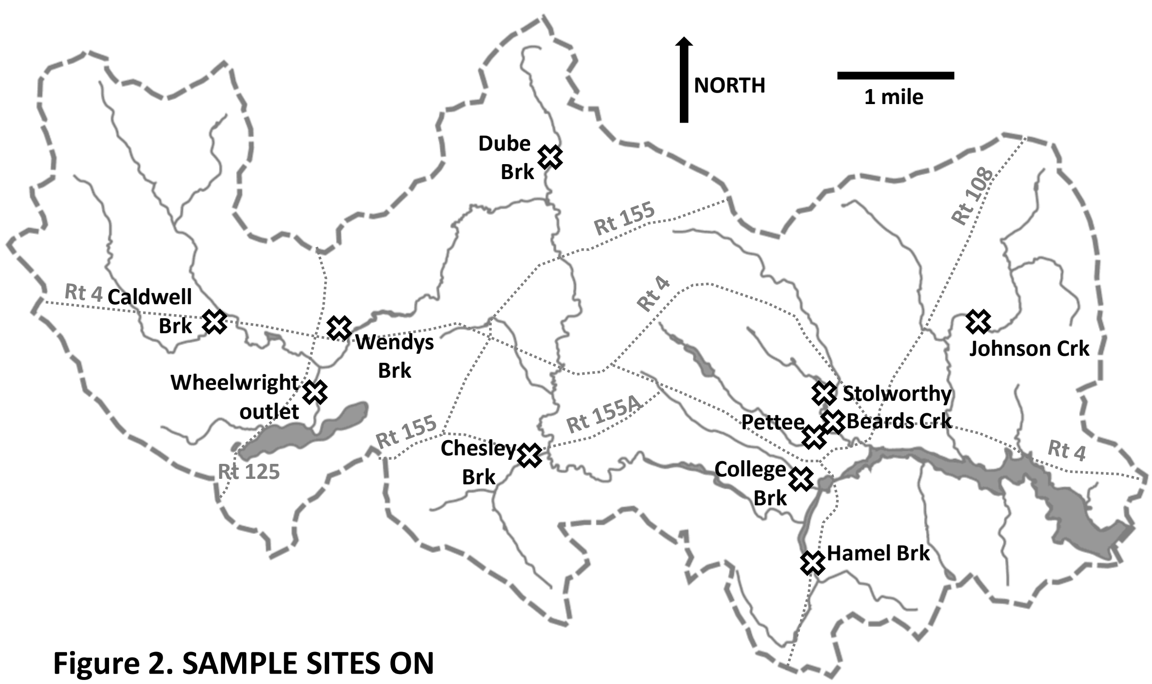


Figure 2. SAMPLE SITES ON
OYSTER RIVER TRIBUTARIES

METHODS

1. FIELD AND LABORATORY PROCEDURES

Specific conductance, dissolved oxygen, turbidity, pH, and water temperature were measured at each of 12-17 field sites from three and eight times per year, usually at monthly intervals. Variables were measured using instruments provided by the New Hampshire Department of Environmental Services Volunteer River Assessment Program (DES VRAP) or the Oyster River Watershed Association. Water samples were taken and instruments were operated by volunteers trained annually by VRAP staff. Sampling generally occurred between 8:00 a.m. and noon, and strictly followed EPA-approved VRAP protocol described by documents available at the VRAP web site: http://des.nh.gov/organization/divisions/water/wmb/vrap/categories/publications.htm.

Water samples for ion analysis were collected and filtered once by volunteers, frozen, and later analyzed for amounts of chloride; sodium; phosphorus in phosphate; nitrogen in nitrate, ammonium, and dissolved organic nitrogen (DON); and total dissolved nitrogen (TDN). Amounts of calcium, magnesium, potassium, sulfate, and dissolved organic carbon were also estimated, but these data are not presented here. All chemical analyses were done in the New Hampshire Water Resources Research Center (NH WRRC) laboratory at the University of New Hampshire (Dr. William H. McDowell). Analytical methods are summarized at: http://www.wrrc.unh.edu/analytical-services-prices. Ions were not sampled every year. In years when ions were sampled, from one to five sets were taken per year at various times between April and October.

Water samples for *E. coli* analysis were collected on a single day within one week of a sample of the VRAP physical variables. Samples were taken between 6 and 11 am. Samples were poured into sterilized bottles and kept in an ice-filled cooler. By noon on the same day samples were taken to the DES laboratory in Concord NH for analysis. VRAP procedures were followed throughout (see web site above for VRAP protocol).

Discharge (water flow) data at the USGS gaging station on Old Concord Road (now Sherburne Road) in Lee NH were obtained from the USGS web site: http://waterdata.usgs.gov/nh/nwis/uv/?site_no=01073000.

2. DATA ANALYSIS

Analysis of Physical and Chemical Variables Specific conductance, dissolved oxygen, turbidity, pH, water temperature, and the concentrations of chloride, sodium, phosphorus, and forms of nitrogen were dependent variables, and these were analyzed in relation to three independent variables: site, year, and month. For analysis of ion concentrations, a fourth variable, discharge at the Oyster River gaging station, was added. Relationships between each dependent variable and the independent variables were first examined graphically. On the basis of these analyses some dependent variables were log transformed to assure that the assumptions of parametric statistics were met. For each dependent variable, we then compared different predictive models involving various combinations of independent variables. For specific conductance, dissolved oxygen, turbidity, pH, and water temperature the three models were: 1) site, year, month; 2) site, year; 3) year; 4) site. Models for ions included discharge at the gaging station as a fourth independent variable. Models were run using least squares regression in the statistical software JMP Pro 10 (Statistical Analysis System, Cary, North Carolina). Models were then compared as to residuals and coefficients of variation. The model with the lowest AIC_c (Akaike Information Criterion, corrected) was selected as the "best" model. This model was then used to estimate ***adjusted mean*** and ***standard error*** of the dependent variable at each site, year, or month. ***Adjusted means are simply estimates of the mean value of a dependent variable, say specific conductance, for different levels of a dependent variable, say years, removing the effects of the other variables (month and site in this example).***

Adjusted means of specific conductance, dissolved oxygen, turbidity, pH, and water temperature, were generated by site (removing effects of year and month), year (removing effects of site and month), and month (removing effects of year and site). Adjusted means for ion concentrations were estimated only for site (holding year, month, and discharge constant), as not all years and months were represented in the sample (this was due to sampling that was less frequent than for the physical variables).

Graphs of Physical and Chemical Variables In this report, results for all of the measured physical and chemical variables – specific conductance, dissolved oxygen, turbidity, pH, water temperature, and the concentrations of chloride, sodium, phosphorus, and forms of nitrogen – are usually presented as *column graphs*. Invariably, these graphs present the *adjusted means* and *standard errors* of the dependent variable.

Analysis of Bacteria Data Bacteria (*E. coli*) data were summarized only by site. For each site we determined the number of samples that met class A state standards (≤ 153 counts/100 ml), class B state standards (≤ 406 cts/100 ml), and neither class A nor class B standards (> 406 cts/100 ml). (For state *E. coli* standards see New Hampshire Volunteer River Assessment Program [2011].) We also determined the number of samples that exceeded 1000 cts/100 ml and 10,000 cts/100 ml. We then calculated for each site the percentages of samples that met class A standards, met class B standards, met neither class A nor class B standards, exceeded 1000 cts/100 ml, and exceeded 10,000 counts/100 ml. No statistical analyses were run on these data.

RESULTS AND INTERPRETATION

1. SPECIFIC CONDUCTANCE

Specific conductance, a measure of the quantity of dissolved substances, varied significantly among sites, among years, and among months, and this was true for sites on the main stem of the river as well as tributaries.

Main Stem Conductance at main stem sites (Fig. 3) generally increased from upstream to downstream, with Royalcrest having an adjusted mean of only 57 / uS cm and the Tidal Dam having the highest adjusted mean (183 µS/cm). While individual observations of conductance on specific dates were sometimes above 200 µS/cm, none of the site means exceeded this value.

Tributaries In contrast to main stem sites, specific conductance varied greatly among tributary sites (Fig.4). Seven of 11 tributary sites had adjusted mean values above 200 µS/cm, higher than any of the main stem sites. With the exception of Wendy's Brook, sites with values > 200 µS/cmwere downstream of the Durham Reservoir. Three sites, Wendys Brook, Pettee Brook, and College Brook, had high mean values (> 400 µS/cm). These three tributaries lie within urban settings having extensive impervious surface

Figure 3. MAIN STEM - CONDUCTANCE BY SITE

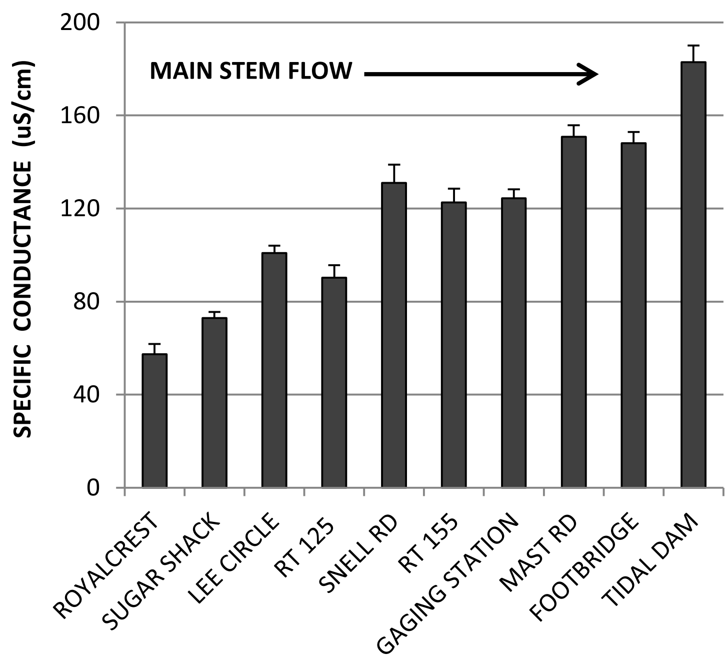
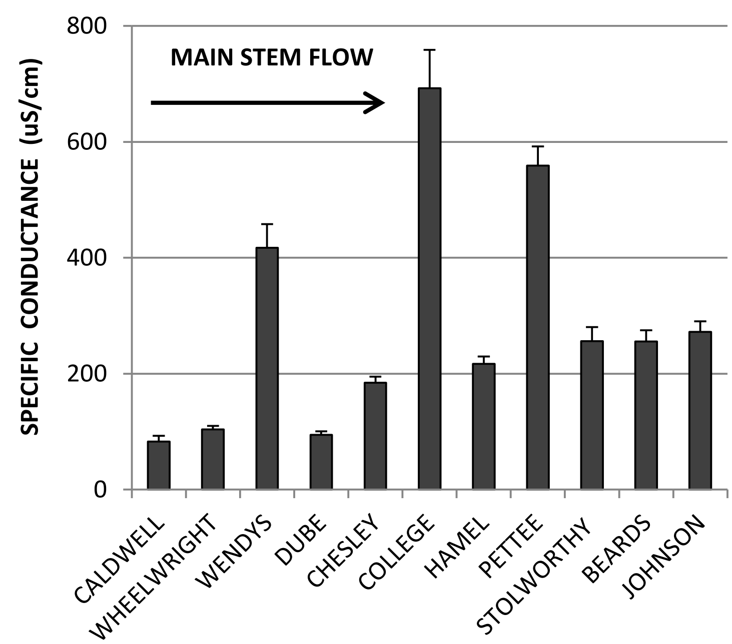


Figure 4. TRIBUTARIES- CONDUCTANCE BY SITE



and high road density. Four upstream tributary sites, Caldwell, Wheelwright, Dube, and Chesley, all had low mean conductance (< 200 µS/cm).

The US Environmental Protection Agency has established a relationship between specific conductance and chloride concentrations. Specific conductance values of 835 µS/cmare associated with chloride levels (230 mg Cl/L) that, when continuously applied, negatively impact aquatic life (Daley et al. 2009, New Hampshire VRAP 2011). In our 11-year sample of 602 individual observations at main stem sites, values never exceeded 835 µS/cm. However, of 676 individual observations at tributary sites, 52 (7.7%) were ≥ 835 µS/cm. Values ≥ 835 µS/cmonly occurred at Wendys Brook, College Brook, and Pettee Brook.

Patterns in Time There were significant differences in specific conductance among years from 2001 through 2011. This was true for main stem sites as well as tributaries (Fig. 5, 6). Adjusted means were highest in years 2001, 2002, and 2003, and were lower in all later years. While this pattern suggests a decline in specific conductance over time, there was no obvious temporal pattern after 2003. The high conductance values from 2001 through 2003 were almost certainly due to low discharge (water flow) in these years (see section on discharge, below).

Figure 5. MAIN STEM - CONDUCTANCE BY YEAR

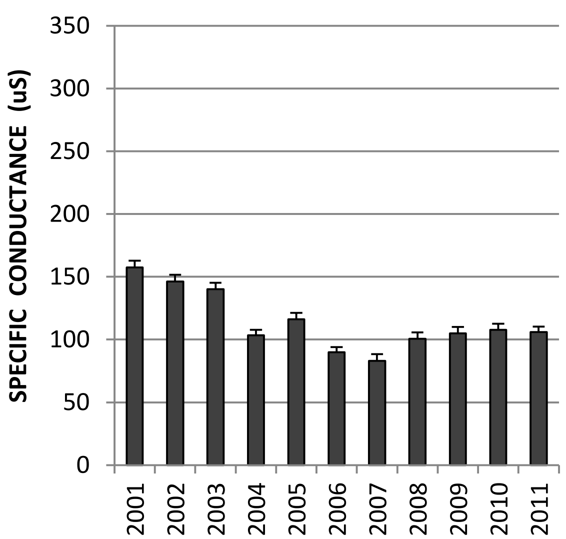
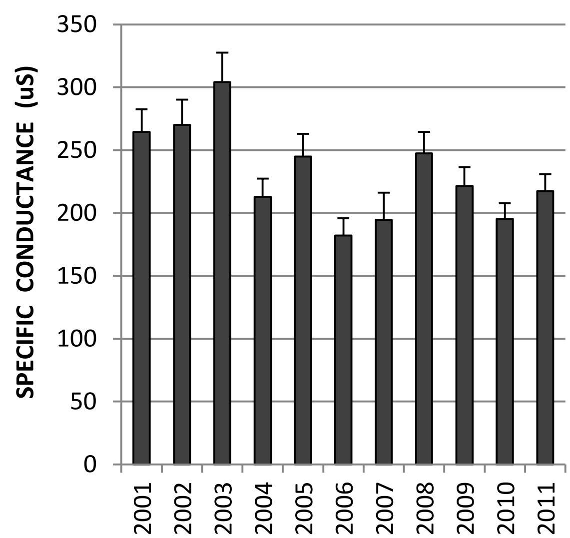
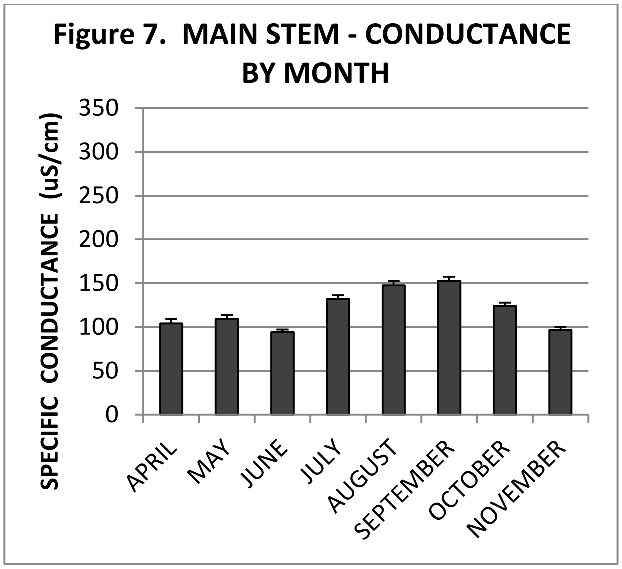
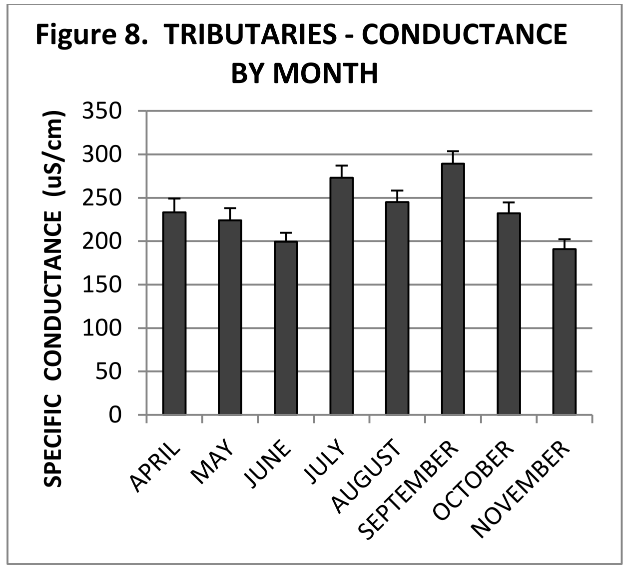


Figure 6. TRIBUTARIES - CONDUCTANCE BY YEAR



In addition to patterns among sites and years, there was a significant monthly pattern in specific conductance for both the main stem of the river and its tributaries (Fig. 7, 8). Specific conductance was greater in July, August, and September, and was lowest in November. This pattern was almost certainly related to discharge (water flow), which tended to be low in summer and early fall (see section on discharge, below).



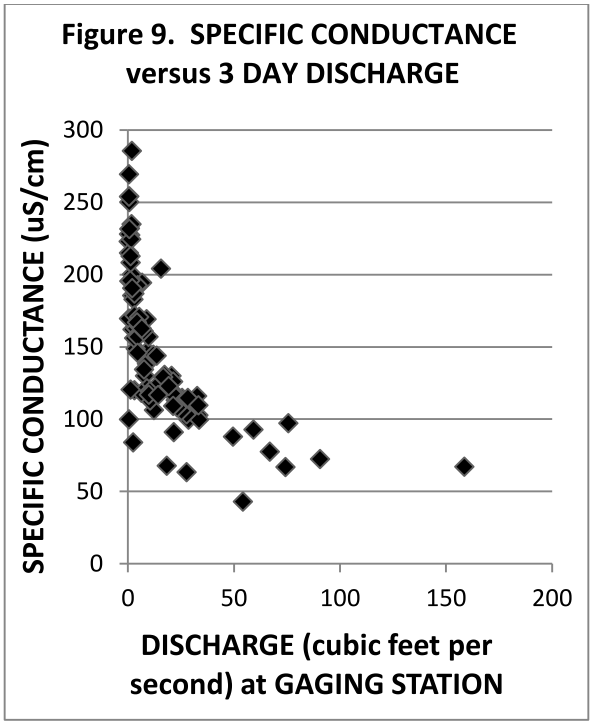


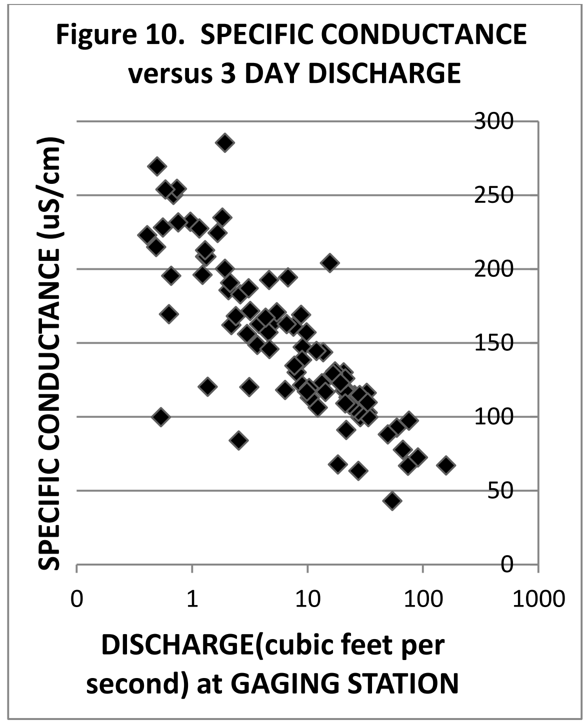
As seen in the charts above, specific conductance showed clear patterns across sites, years, and months. However, conductance also varied with discharge (rates of water flow). The relationship between conductance and discharge may explain, at least in part, the patterns of conductance across years and months as well as the generally higher values in tributaries compared to the main stem.

Discharge We have continuous measurements of discharge (water flow in cubic feet per second) at only one site in the Oyster River watershed, the USGS gaging station immediately north of Old Concord Road (now Sherburne Road) on the Lee-Durham border. (The NH DES code for this site is 09-OYS.) Discharge values from this site were obtained from the USGS National Water Information system (http://waterdata.usgs.gov/nh/nwis/uv/?site_no=01073000). Specifically, for every day that we had a measured conductance value at the gaging station, we determined the daily discharge for that day ("one day discharge"), for that day and the preceding day ("two day discharge"), and for that day and the preceding two days ("three day discharge"). Using regression analysis, specific conductance values at the gaging station site were related, separately, to these three estimates of discharge. The three-day discharge was most closely related to conductance, and so that variable was used in all subsequent analyses.

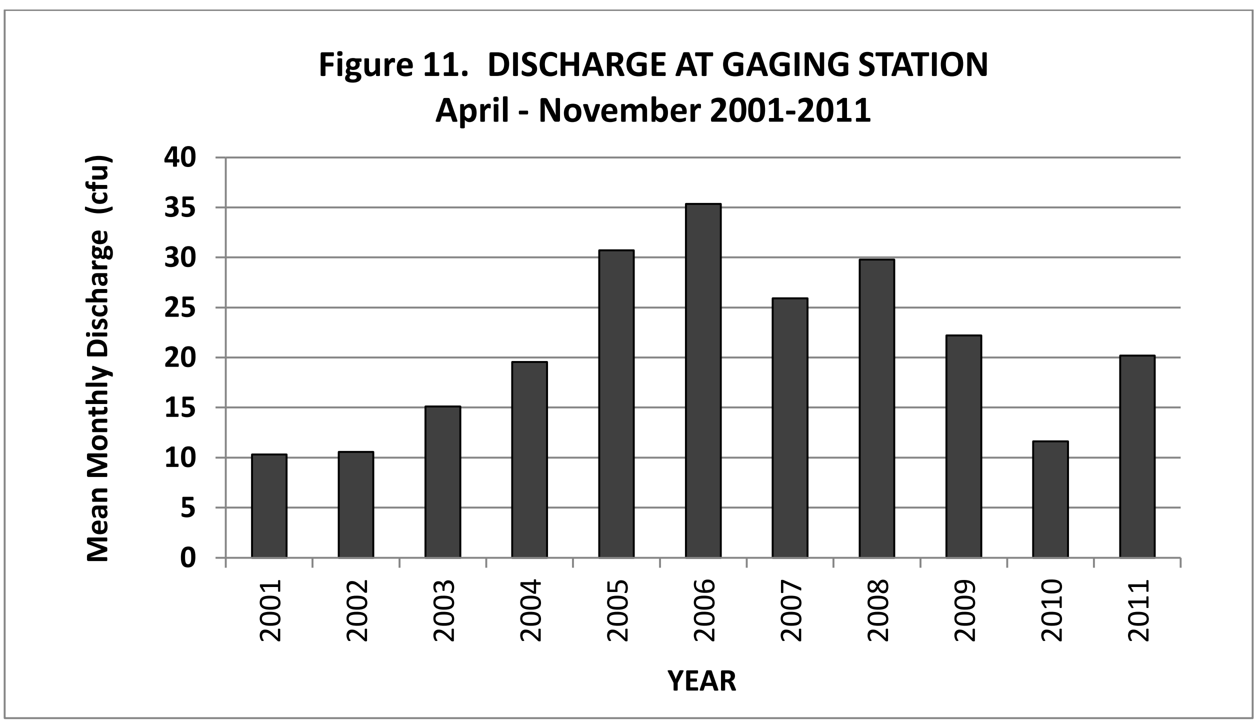
Specific conductance declined with three day discharge in a negative exponential fashion. Below, specific conductance is plotted versus discharge on both linear and log scales (Fig. 9, 10). The cause of the pattern is likely the dilution of dissolved substances during times of high water flow.

While we lack discharge values for sites other than the gaging station, it is likely that mean discharge at main stem sites exceeds discharge for the tributary sites. Thus, higher conductance in tributaries may be partially due to differences in discharge.

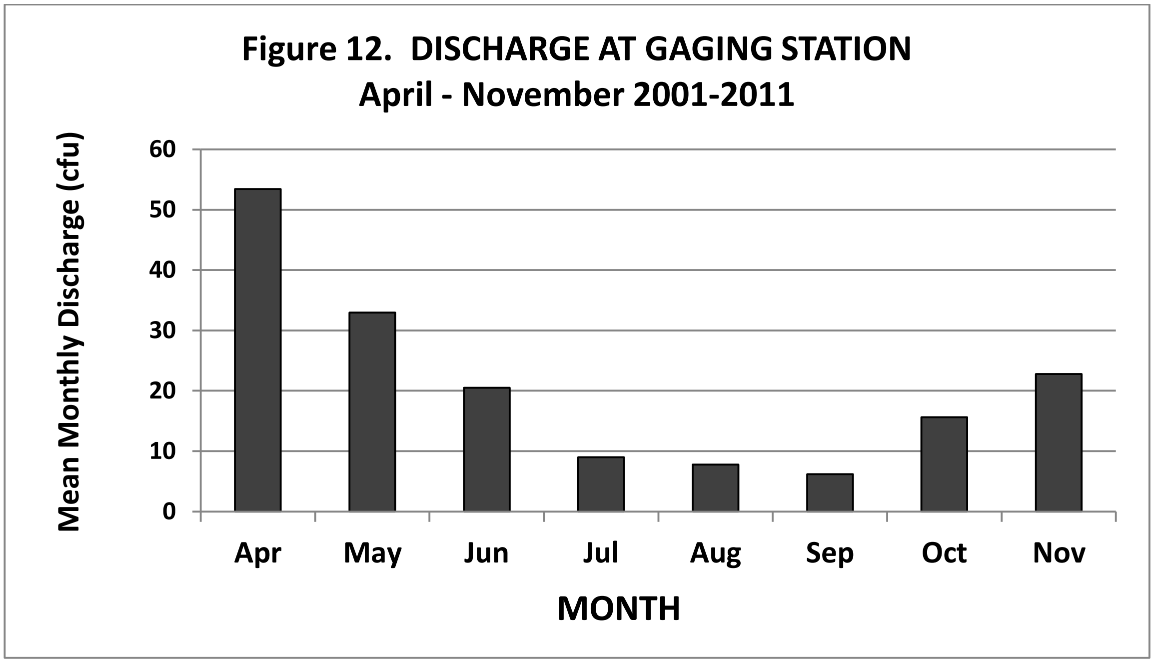




Mean monthly discharge for months covering our usual sampling time (April – November only) at the USGS gaging station was lowest in 2001, 2002, 2003, and 2010 (Fig. 11). The low flows in 2001-2003 generally correspond to high conductance values in those years, suggesting less dilution of dissolved substances in these years. One year, 2010 was anomalous; conductance in 2010 was low to intermediate despite low discharge in that year.



Mean monthly discharge at the USGS gaging station was lowest in July, August, and September, corresponding to high specific conductance in those months (Fig. 12). Presumably, dissolved substances were diluted during April, May, October, and November, when discharge was higher.

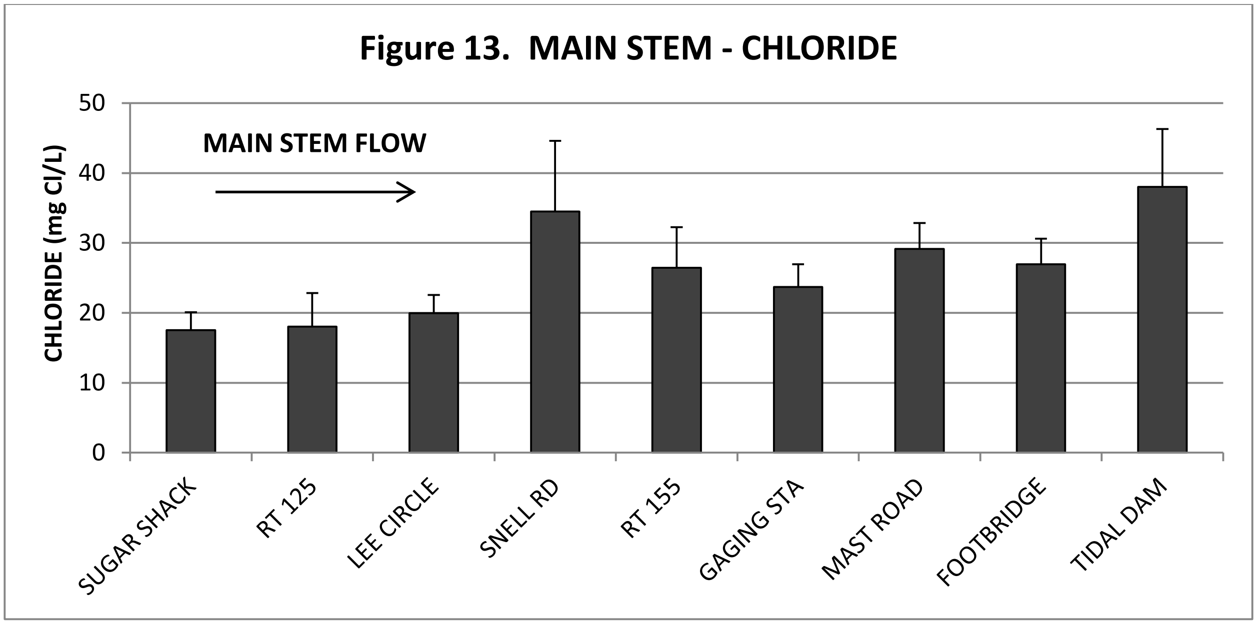


2. INDIVIDUAL IONS

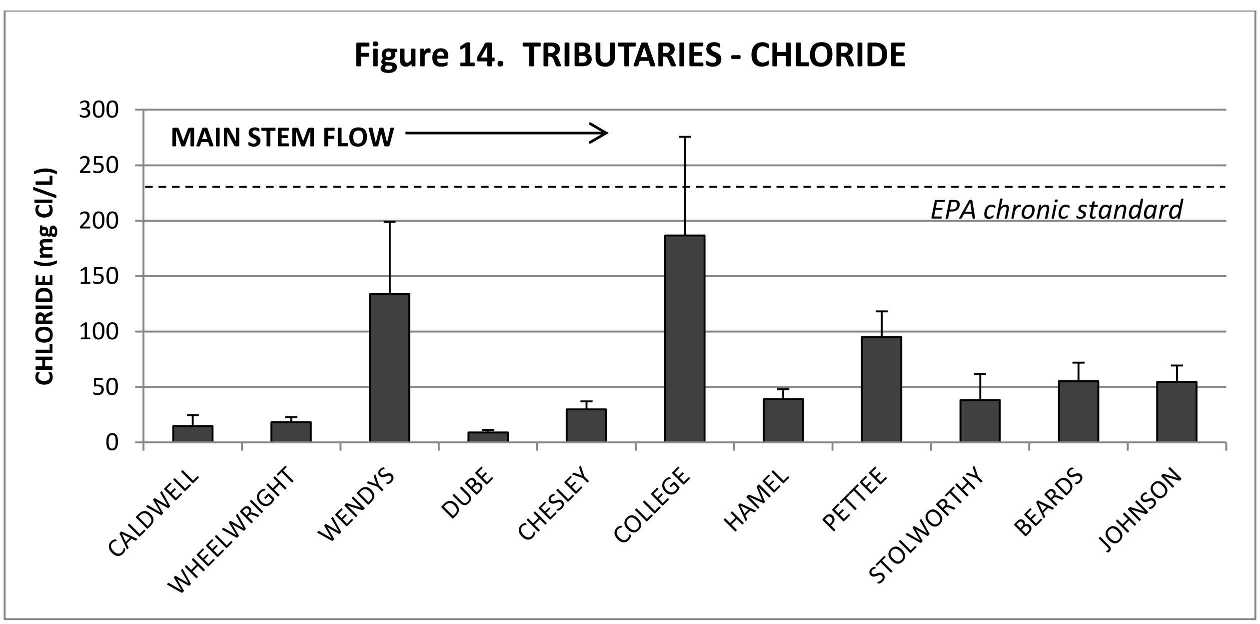
Specific conductance indicates the *overall* abundance of dissolved substances in a water sample, but does not tell us anything about the abundance of individual substances. Here, we look at concentrations of individual ionic forms. In our 11-year monitoring program, ions were sampled much less frequently than conductance and so sample sizes were smaller and inferences correspondingly weaker. In the results that follow, ionic concentrations are presented by site only. Statistical analysis (least squared multiple regression) factored out the effects of year, month, and discharge.

a) CHLORIDE

Main Stem Chloride, which often enters streams through road salt, can be toxic at high concentrations. Adjusted means of chloride (Cl^-) concentration varied significantly among main stem sites (Fig. 13). On the main stem, mean chloride levels from 2001 through 2011 never exceeded 40 mg Cl/L, although some individual values were higher. Even these individual values, however, never exceeded 100 mg Cl/L at any site, and so chloride levels at all sites were below the New Hampshire state “chronic” standard of 230 mg Cl/L (New Hampshire VRAP 2011). Main stem sites upstream of Snell Road had the lowest mean chloride concentrations (< 20 mg Cl/l), while Snell Road and all downstream sites had higher means.



Tributaries Adjusted means of chloride (Cl-) concentration also varied significantly among tributary sites (Fig. 14). Three tributaries, College Brook, Pettee Brook, and Wendy's Brook, had mean chloride concentrations >70 mg Cl/L, with College Brook the highest at 141 mg Cl/L. These three sites also showed high variability in chloride values over time, as indicated by high standard errors, and they occasionally reported chloride values over 200 mg Cl/L, with the state standard of 230 mg Cl/L exceeded at both College Brook (2 of 6 observations) and Pettee Brook (1 of 18 observations). If we ignore these three sites, the remaining tributary sites had chloride concentrations that were higher in the downstream portion of the watershed than in upstream areas.



b) SODIUM

Sodium, which with chloride often enters streams through road salt, can also be toxic at high concentrations. Sodium (Na^+) levels varied significantly among main stem sites (Fig. 15) and among tributary sites (Fig. 16). Patterns across sites, however, were almost identical to those of chloride for both the main stem and tributaries (see below).

Figure 15. MAIN STEM - SODIUM

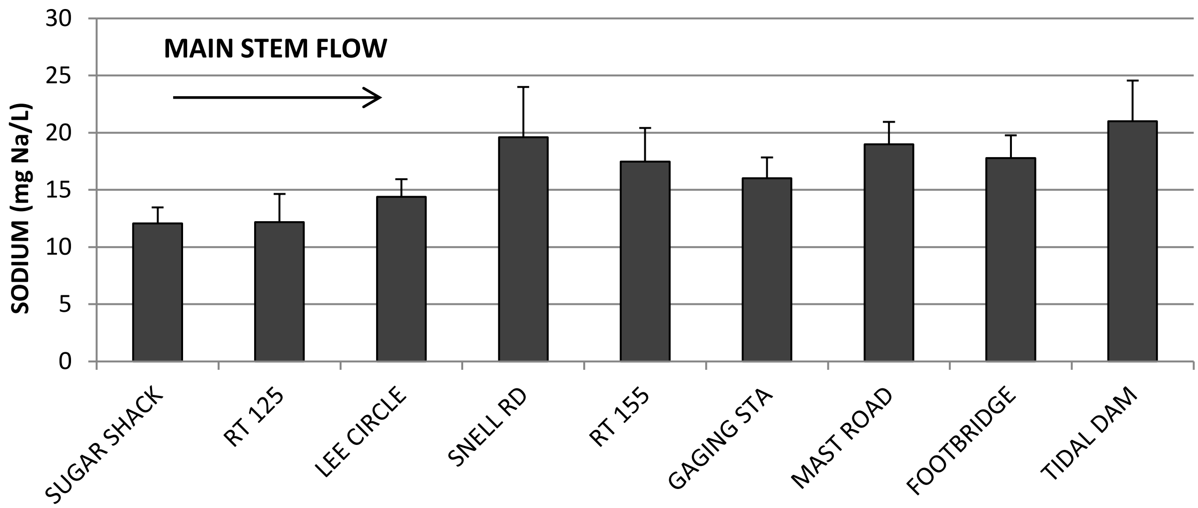
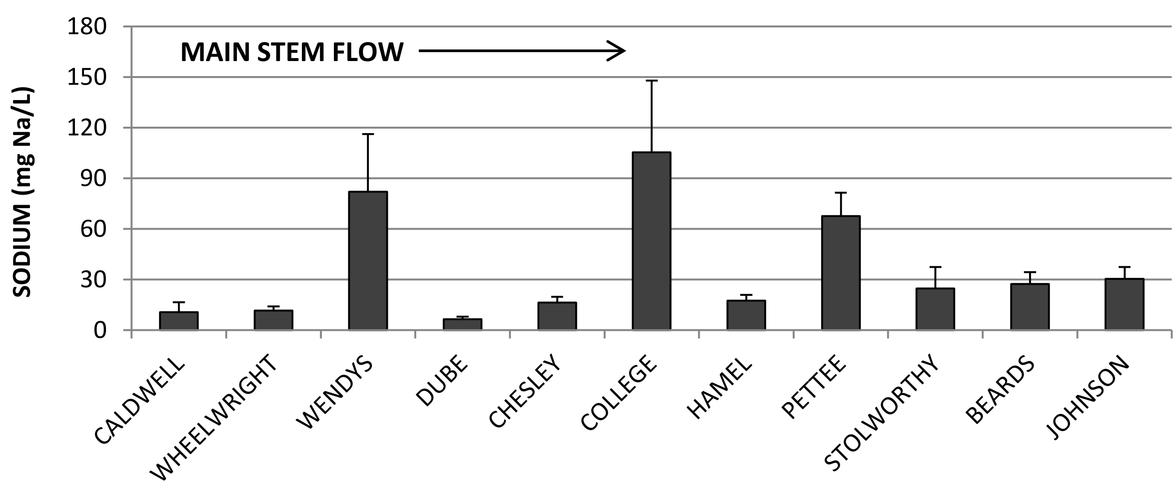


Figure 16. TRIBUTARIES - SODIUM

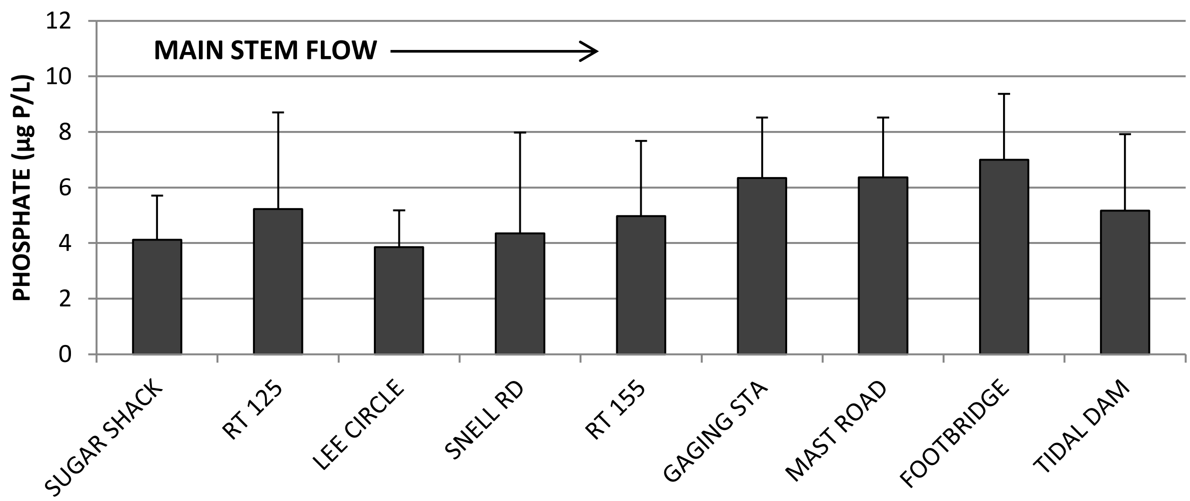


The source of most of the sodium and chloride in New Hampshire streams is road salt (sodium chloride, NaCl; Daley et al. 2009). Sodium and chloride concentrations were highest in College Brook, Pettee Brook, and Wendys Brook, and generally in the downstream areas of the watershed. These sites have high levels of impervious surface and high road density, and thus probably receive greater amounts of road salt via runoff (Daley et al. 2009). Chloride, sodium, and specific conductance show nearly identical patterns across sites, a relationship that has been established statewide by Daley et al. (2009) and New Hampshire Department of Environmental Services (New Hampshire VRAP 2011). It is likely that chloride concentration is the primary driver behind the patterns of conductance (Daley et al. 2009).

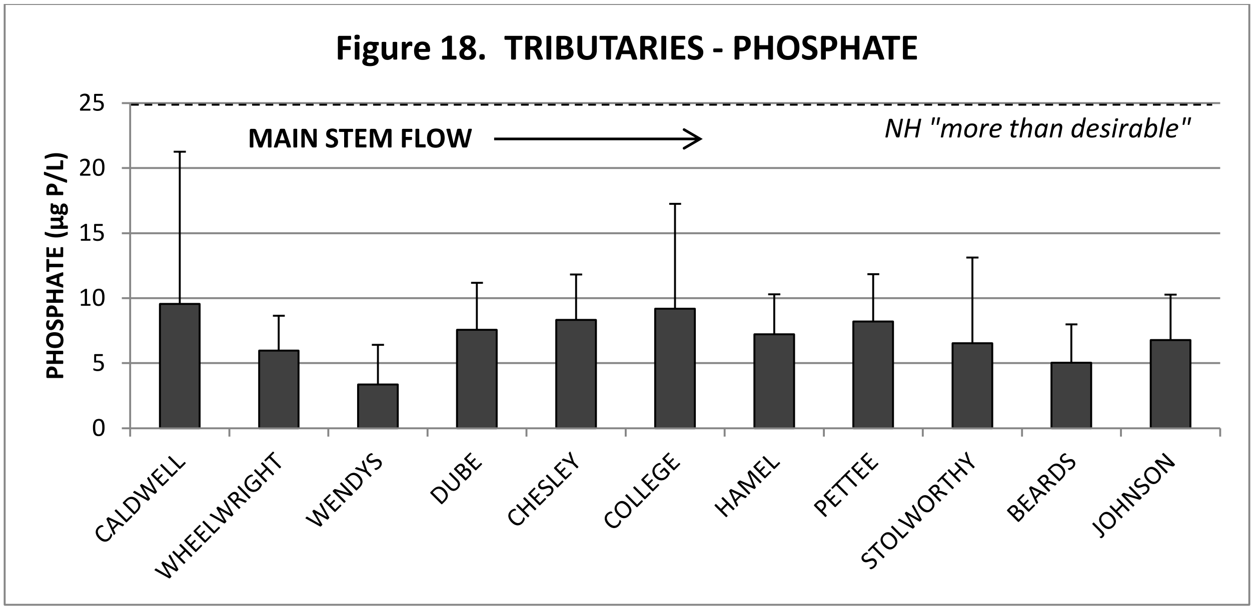
c) PHOSPHATE

Phosphorus is the limiting factor in the growth of algae in temperate, freshwater ecosystems. Consequently, high levels of phosphorus (usually in the form of phosphate, PO_4^{+3}) results in algal blooms and eutrophication. Mean phosphorus levels (adjusted means) at all Oyster River sites were low, < 10 µg/L. New Hampshire DES regards levels of phosphorus < 10 µg P/L as “ideal” (New Hampshire VRAP 2011). Phosphorus concentrations at main stem sites increased slightly but significantly from upstream to downstream (Fig. 17). They declined, however, downstream of the footbridge site (in College Woods), perhaps due to loss to sediment or uptake by vegetation in the Oyster River reservoir and Mill Pond. Phosphorus concentration did not vary significantly among tributary sites (Fig. 18).

Figure 17. MAIN STEM - PHOSPHATE

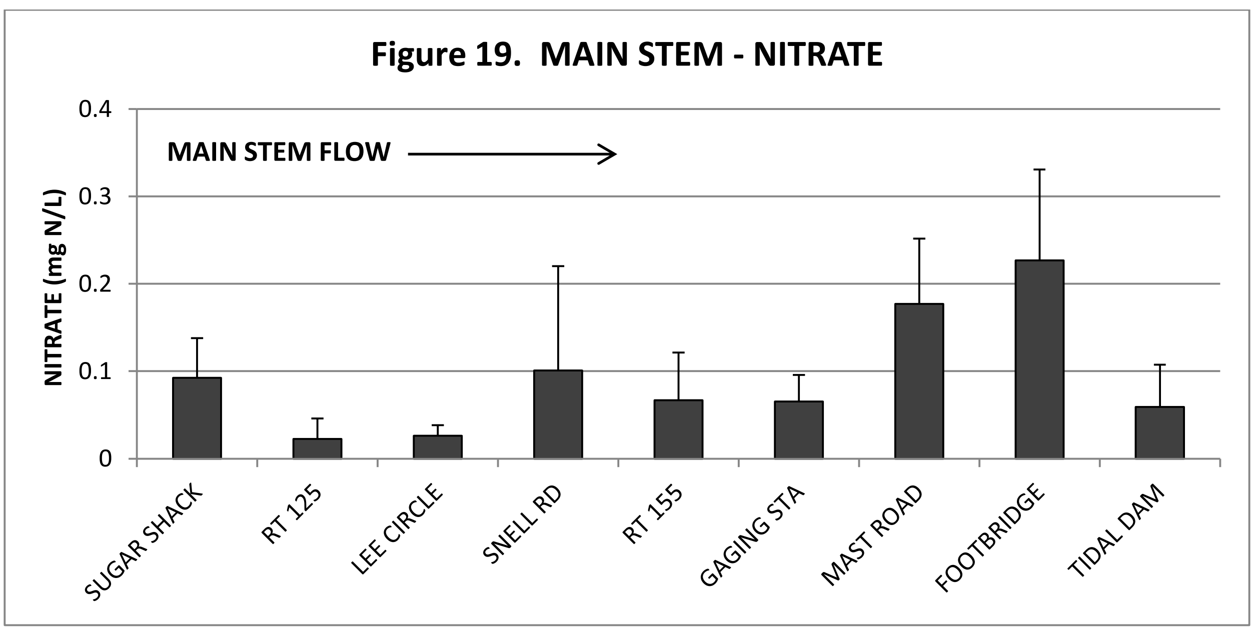


While adjusted means of phosphorus were low, there were a few individual observations with phosphorus concentrations that NH DES would classify as “more than desirable” (> 25 µg P/L). Of 120 phosphate measurements from main stem sites, only one (at the Route 125 site) exceeded 25 µg P/L. Of 135 phosphate measurements from tributary sites, only four (2 each at Dube and Pettee Brooks) exceeded 25 µg P/L.



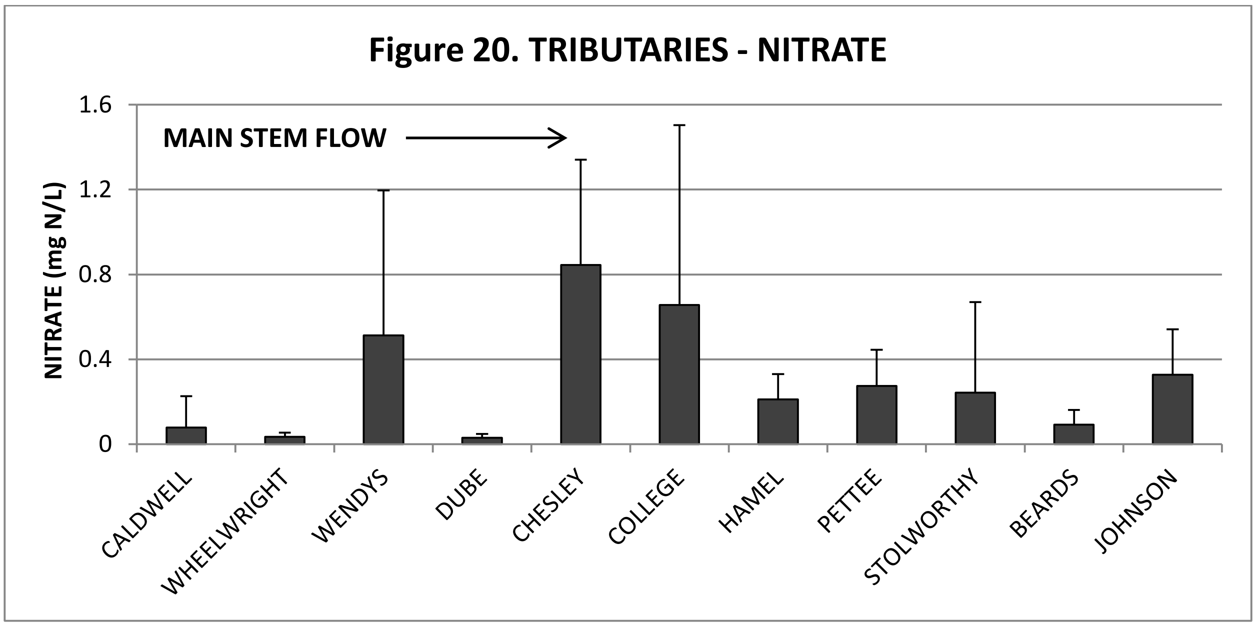
d) NITRATE

Main Stem Nitrate enters streams naturally from rainwater and leaching from soils. Septic systems are also a source. Adjusted mean nitrogen levels in nitrate (NO_3^-) were very low (< 0.1 mg N/L) at most main stem sites (Fig. 19). There was significant variation among sites, however, with highest values (~0.2 mg N/L) at two 'downstream' sites, Mast Road, and Footbridge.



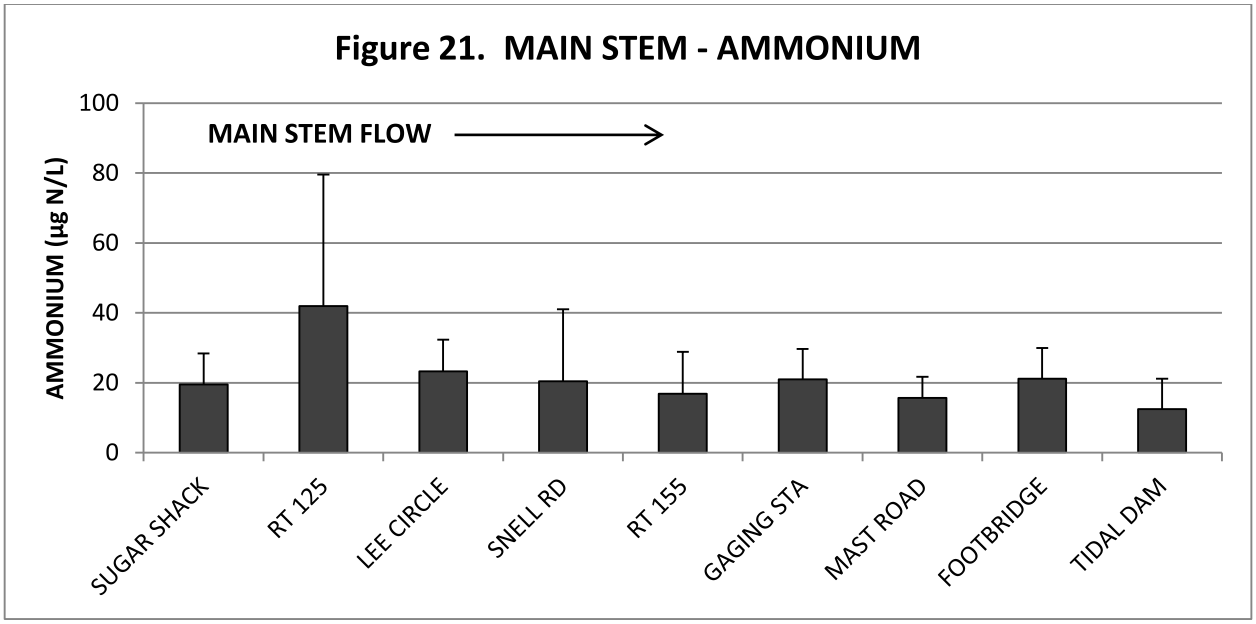
Tributaries Nitrate-N levels were generally higher at tributary sites than main stem sites, with mean values > 0.4 mg N/L at three sites, Wendys, College, and Chesley Brooks (Fig. 20). At Wendys Brook and College Brook high nitrate-N levels could be due to non-point sources associated with the urbanized environments and high population densities (Daley et al.) that characterize these sub-watersheds. The high nitrate-N at the more rural Chesley Brook is more difficult to explain, but may be connected to the agricultural activities in the upper reaches of this watershed (Dubrovsky et al. 2010, p. 55).

For the most part, nitrate values at our sites were not high relative to streams in the region or across the lower 48 states (Dubrovsky et al. 2010, pp. 52-55). Our nitrate-N concentrations were very similar to those reported from the nearby Lamprey River (Daley et al.). Based on data collected nationwide from 1992-2004, the typical 'background' level for nitrate-N in streams in undeveloped areas is 0.24 mg N/L, which is *higher* than at most of our sites. Chesley, College, and Wendys Brooks have mean values consistent with mixed-use or urban landscapes (Dubrovsky et al. 2010, p. 55) that have high population density (Daley et al.).

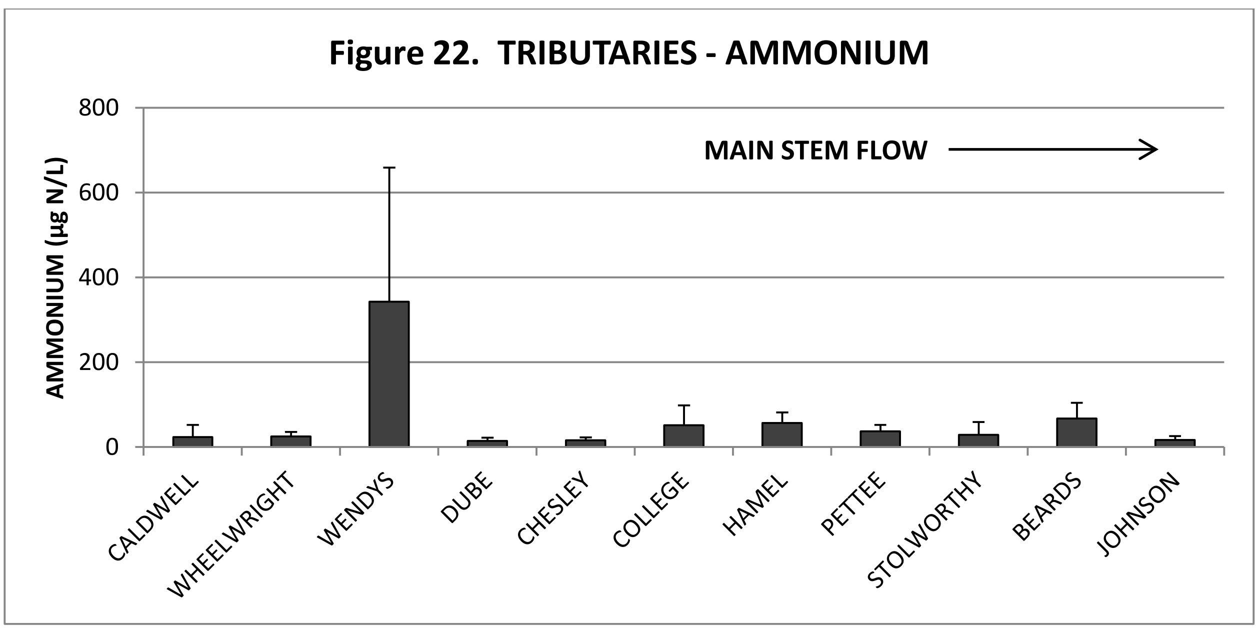


e) AMMONIUM

Nitrogen in ammonium (NH_4^+) is typically present at much lower concentrations than nitrogen in ammonium or in organic compounds (Dubrovsky et al. 2010, pp. 55 and 114). Unsurprisingly, then, ammonium-N was present at very low concentrations at Oyster River main stem sites and did not vary significantly among them (Fig. 21). The highest mean value (42 µl N/L) at Route 125 (just south of Lee Traffic Circle) was based on a small sample (n=6) that included one unusually high value.



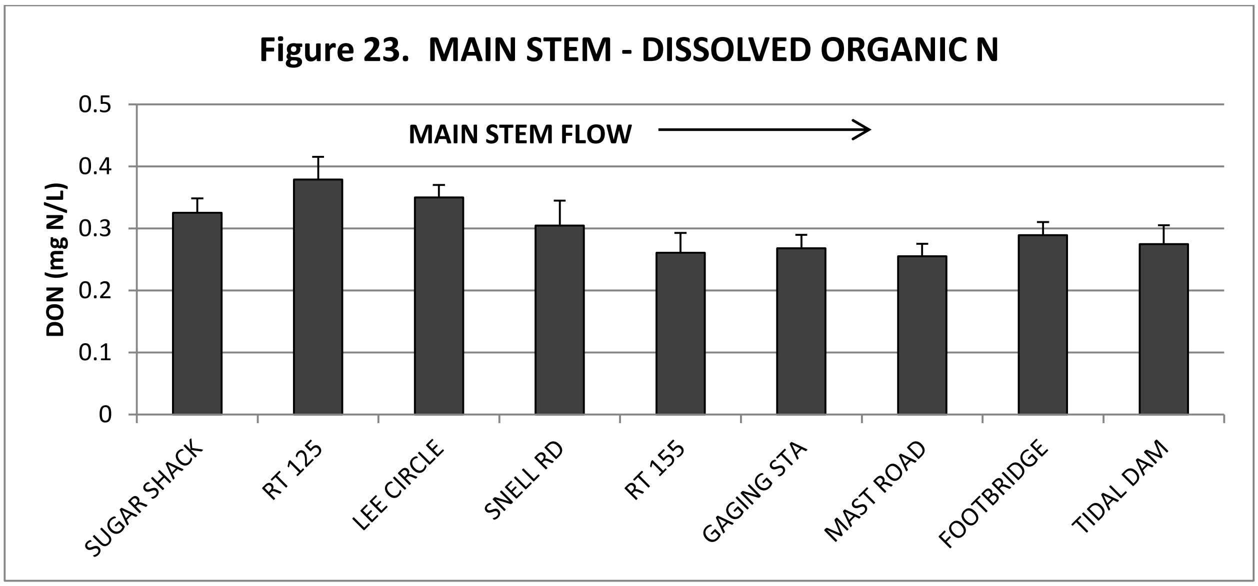
Ammonium-N was similarly low at most Oyster River tributary sites (Fig. 22), but there was significant variation among sites with Wendys Brook having a very high adjusted mean. While the sample was small at Wendys Brook – only 6 observations – all six values were > 100 µl N/L and one was > 600 µl N/L.



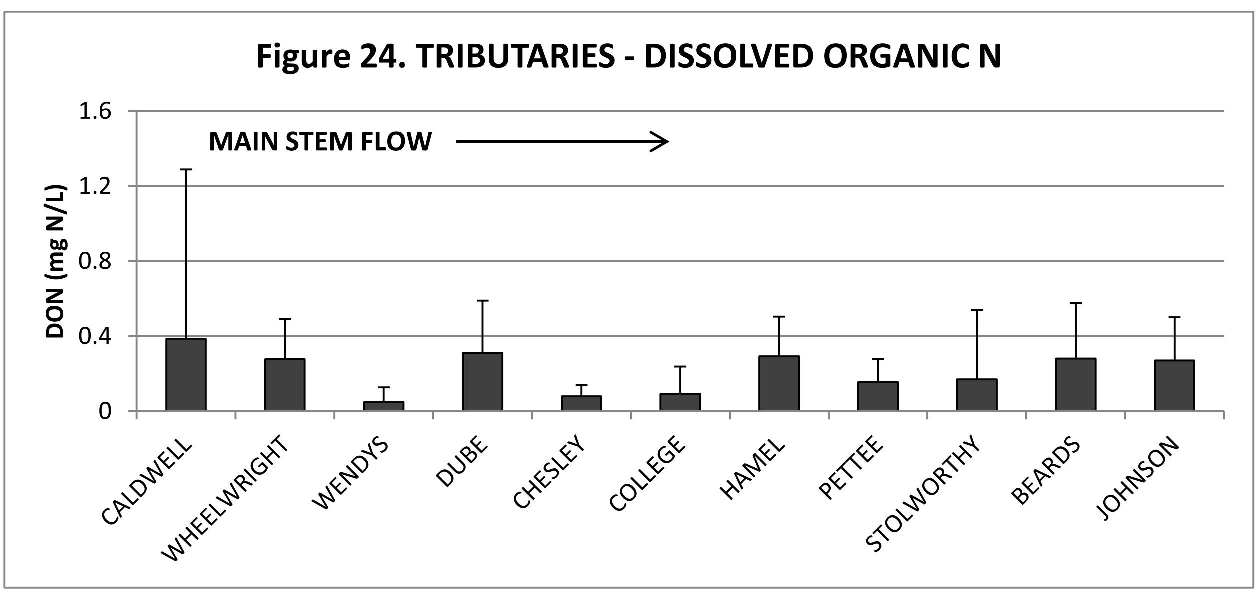
The high ammonium levels at Wendys Brook were high, not only relative to other Oyster River sites, but also high relative to nitrate and dissolved organic N at the Wendys Brook site. Given that ammonium concentrations tend to be low in streams, and that ammonium tends to decline rapidly after introduction to a stream (Peterson et al. 2001), there was likely a source of ammonium upstream from our Wendys Brook sample site. The source could be the small wetland complex northwest of Lee Circle, or could be a faulty septic unit in this vicinity, perhaps associated with the large shopping complex northwest of Lee Circle. The unusually high bacteria (*E. coli*) counts we have frequently observed at the Wendys Brook site suggest the latter. New Hampshire Department of Environmental Services has been advised of the ammonium/*E. coli* problem upstream of our Wendys Brook site and, presumably, appropriate action is pending.

f) DISSOLVED ORGANIC NITROGEN (DON)

Mean dissolved organic nitrogen (DON) was always < 0.4 mg N/L, although there was significant variation from site to site along the main stem and among tributary sites (Fig. 23). On the main stem, DON declined from > 0.3 mg N/L in the four upstream sites to < 0.3 mg N/L in the five downstream sites.

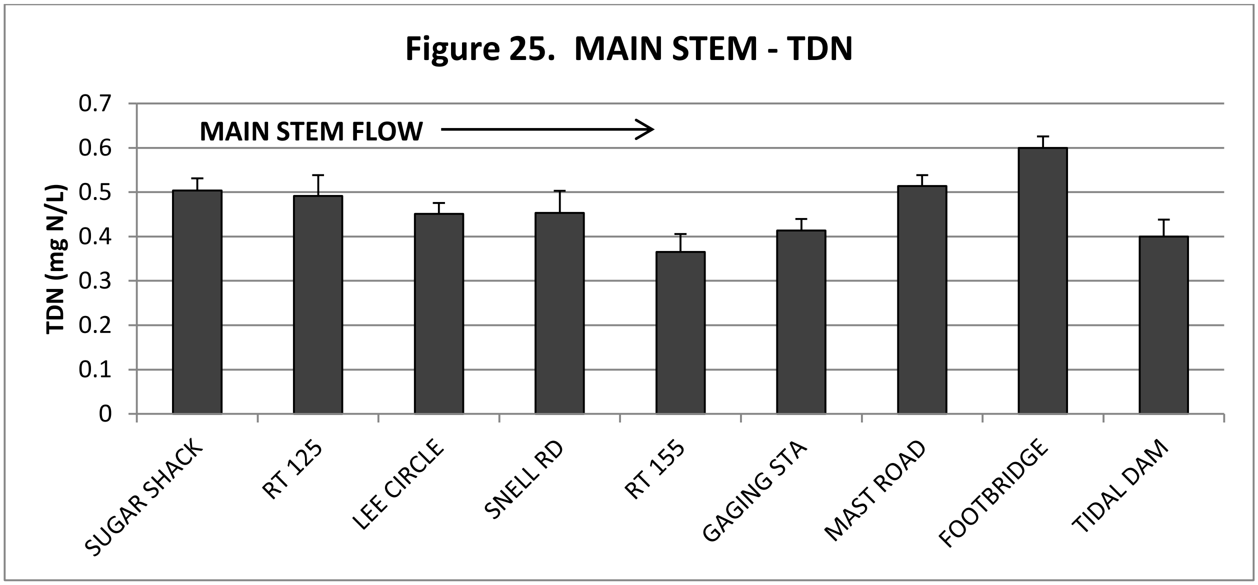


Among the tributary sites, three sites – Wendys, Chesley, and College Brooks – had the lowest DON concentrations (Fig. 24). These sites also had the highest concentrations of nitrate-N.

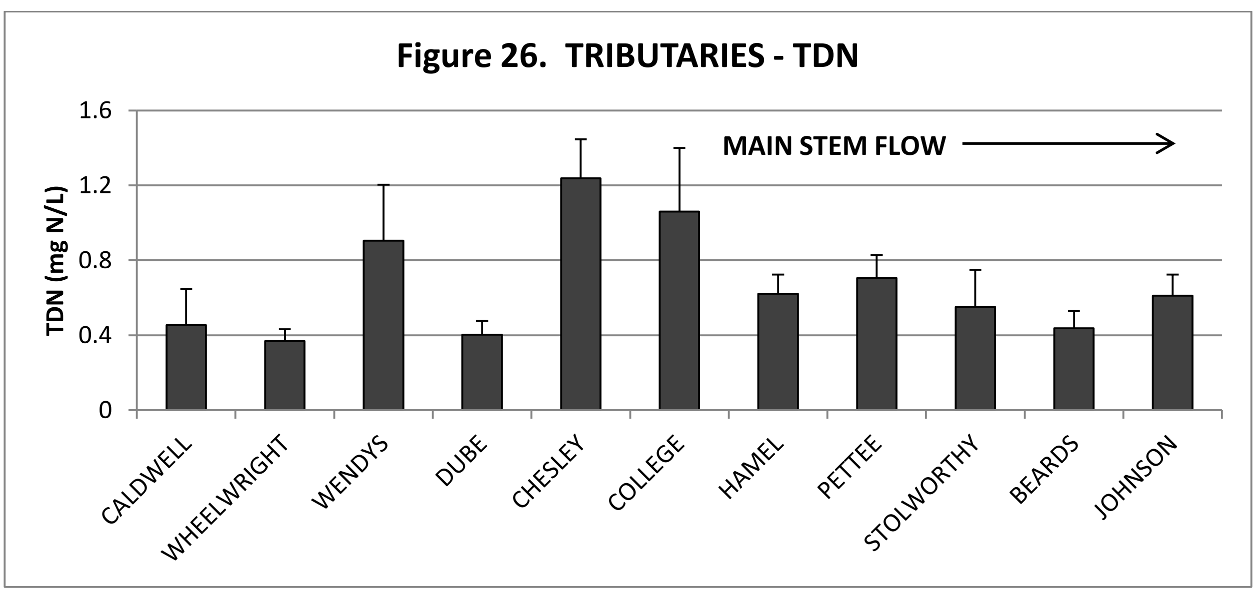


g) TOTAL DISSOLVED NITROGEN (TDN)

Total dissolved nitrogen (TDN) reflected the individual patterns of the various forms of dissolved nitrogen, especially nitrate. Among the main stems sites (Fig. 25), high values at Mast Road and Footbridge coincided with high nitrate-N levels there (see above).



Among tributary sites (Fig. 26), highest TDN values were associated with Wendys, Chesley, and College Brooks, again coinciding with previously described patterns of nitrate-N. The dominant influence of nitrate in influencing TDN is due to the greater variability of nitrate among all sites as compared with that of dissolved organic nitrogen (DON; see next section, 'Nitrogen by form').



h) NITROGEN BY FORM

Simultaneous comparison of patterns of different forms of nitrogen across main stem sites (Fig. 27, 28) shows that these sites were consistently dominated by DON, but that variation among sites in overall nitrogen concentrations (TDN) were indeed influenced by the greater variance in nitrate (Fig. 27).

Figure 27. MAIN STEM - NITROGEN (mgN/L)

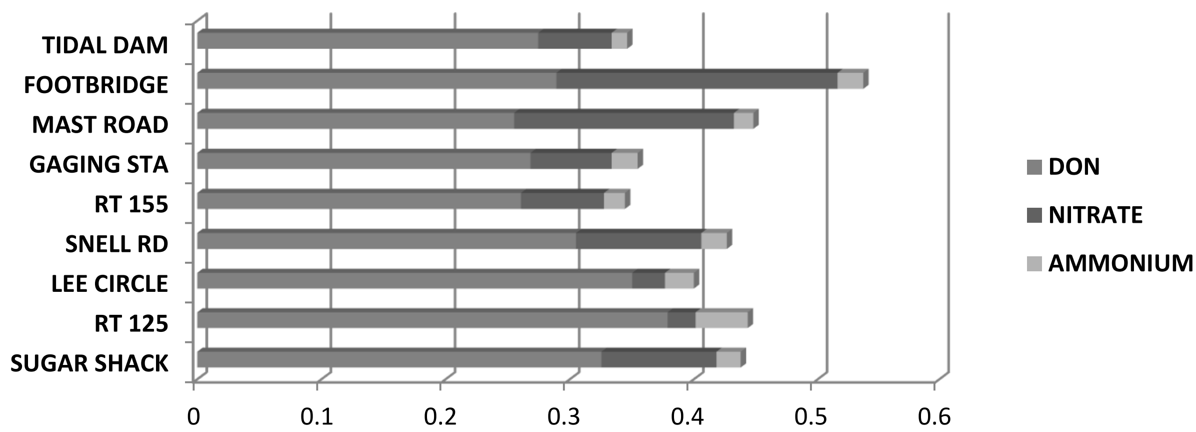
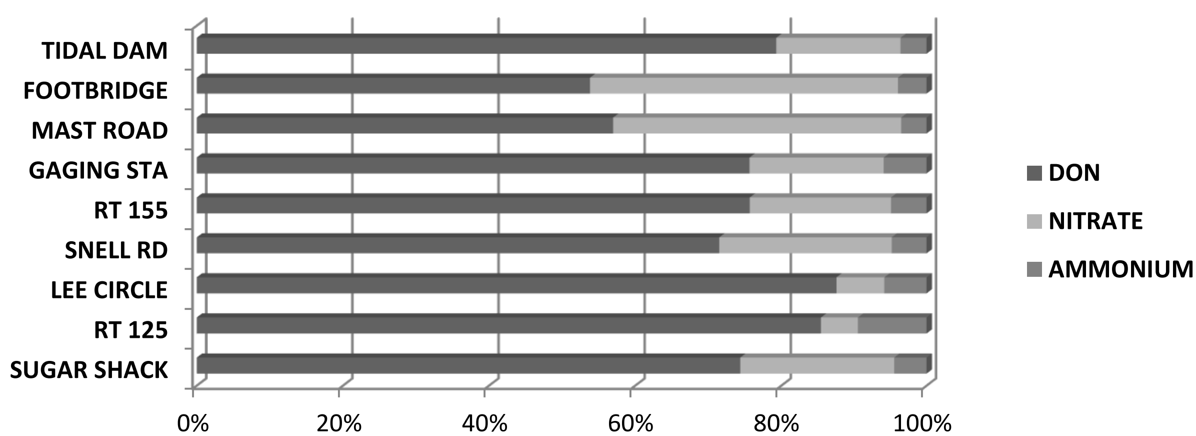


Figure 28. MAIN STEM - NITROGEN %



In contrast, tributary sites (Fig. 29, 30) varied greatly not only in TDN, but in the contributions of the different forms of N. Similar to the main stem sites, some tributaries (Beards Creek at Coe Drive, Hamel Brook, Dube Brook, Wheelwright pond outlet, and Caldwell Brook) were dominated by DON. Beards Creek at the Stolworthy site, Johnson Creek, Pettee Brook, College Brook, and Chesley Brook, however, were dominated by nitrate. Wendys Brook was dominated by nitrate-N, but also had unusual levels of ammonium (Fig. 29, 30).

Figure 29. TRIBUTARIES - NITROGEN (mg N/L)

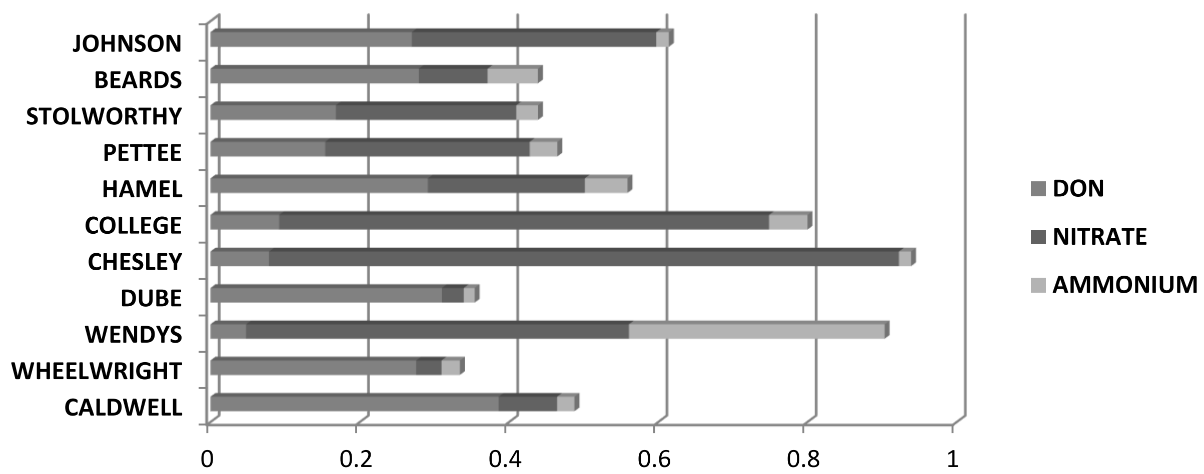
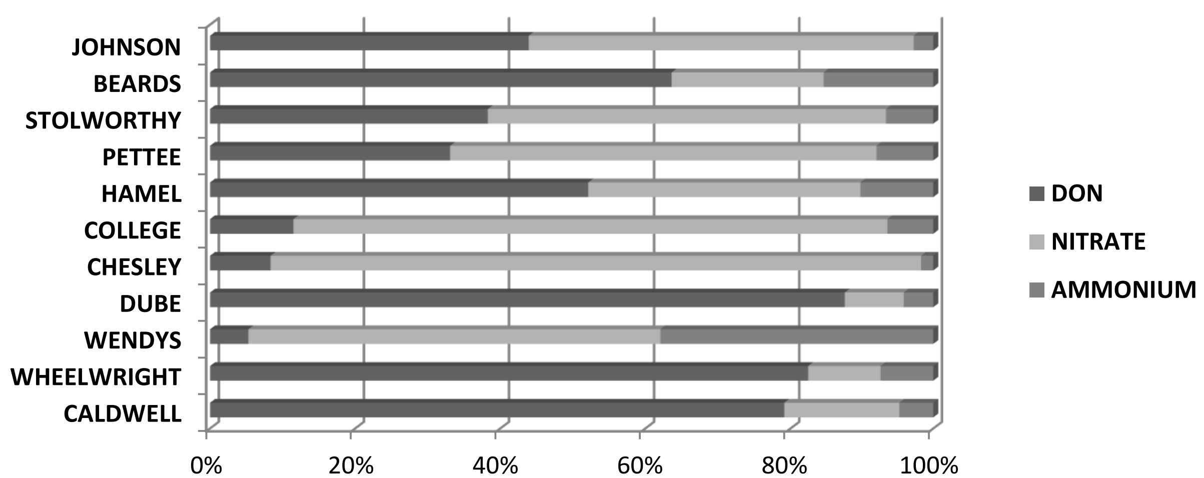


Figure 30. TRIBUTARIES - NITROGEN %



3. DISSOLVED OXYGEN

Oxygen, an essential element for all life, is made available to aquatic creatures as dissolved O_2. Dissolved oxygen is measured in two ways. Simple concentration can be measured as milligrams of oxygen per liter of water (mg O/L). The amount of oxygen that can dissolve in water, however, is limited by water temperature, with maximum oxygen concentration ('saturation') decreasing as temperature warms. To remove the effect of water temperature on oxygen concentration, the amount of dissolved oxygen is expressed as the percent of the saturation concentration, or '% saturation'.

In most rivers and streams, oxygen concentration and % saturation are affected by discharge. During times of high discharge, turbulence and resultant mixing of air with water assure that dissolved oxygen levels are high. When discharge is low, and much water resides in pools with little water movement, oxygen lost to living organisms is not readily replaced.

Data from the USGS gaging station at Sherburne Road in Lee (09-OYS) shows that, as the amount of discharge increases, dissolved oxygen concentrations expressed in mg/L increase (Figures 31, 32). We measured discharge as the mean flow rate on the day of sampling and the two previous days. Figure 31 plots discharge on a linear scale. Figure 32 plots discharge on a log scale.

Figure 31. DISSOLVED OXYGEN (mg/L) vs 3 DAY DISCHARGE

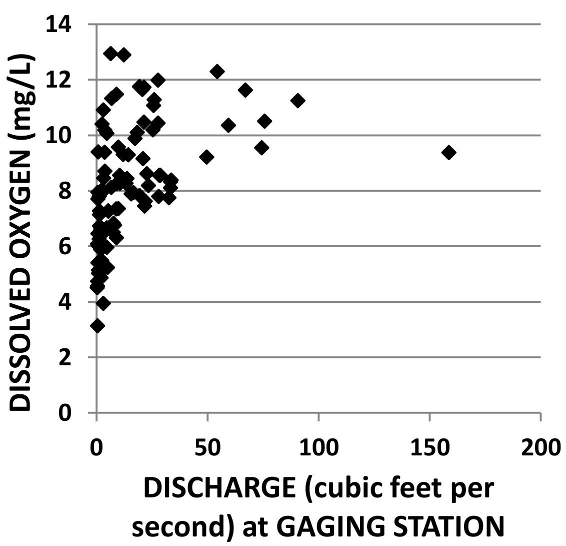
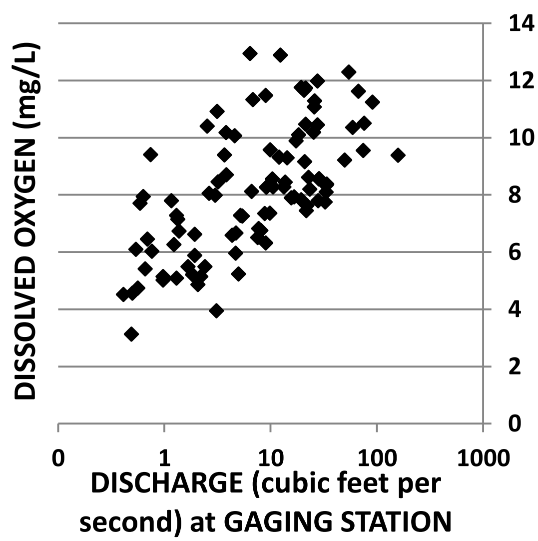
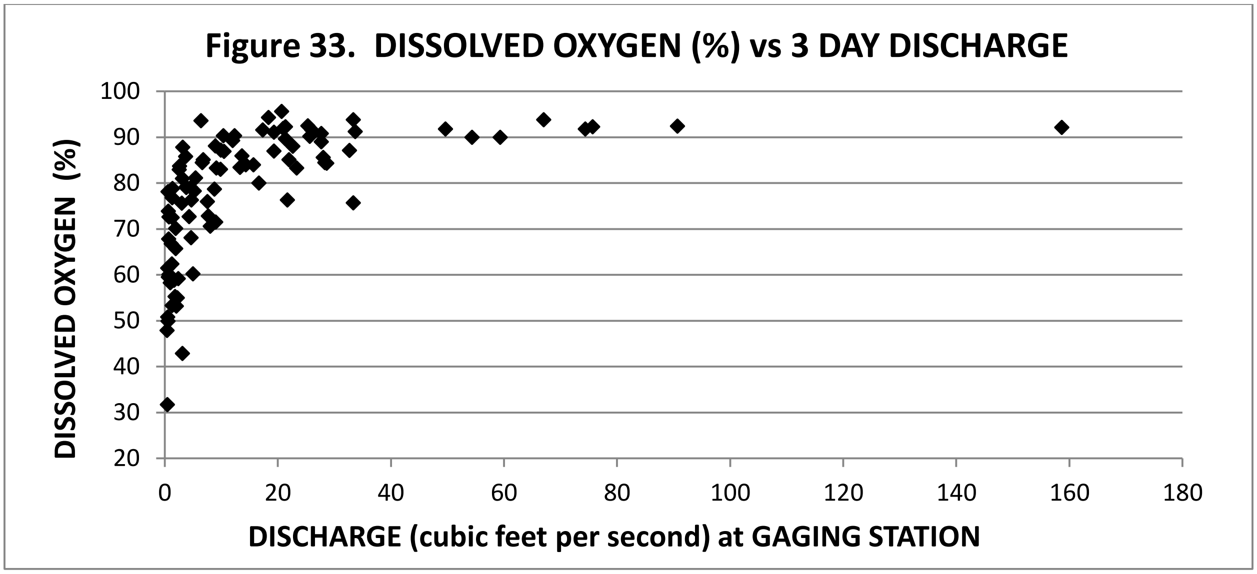


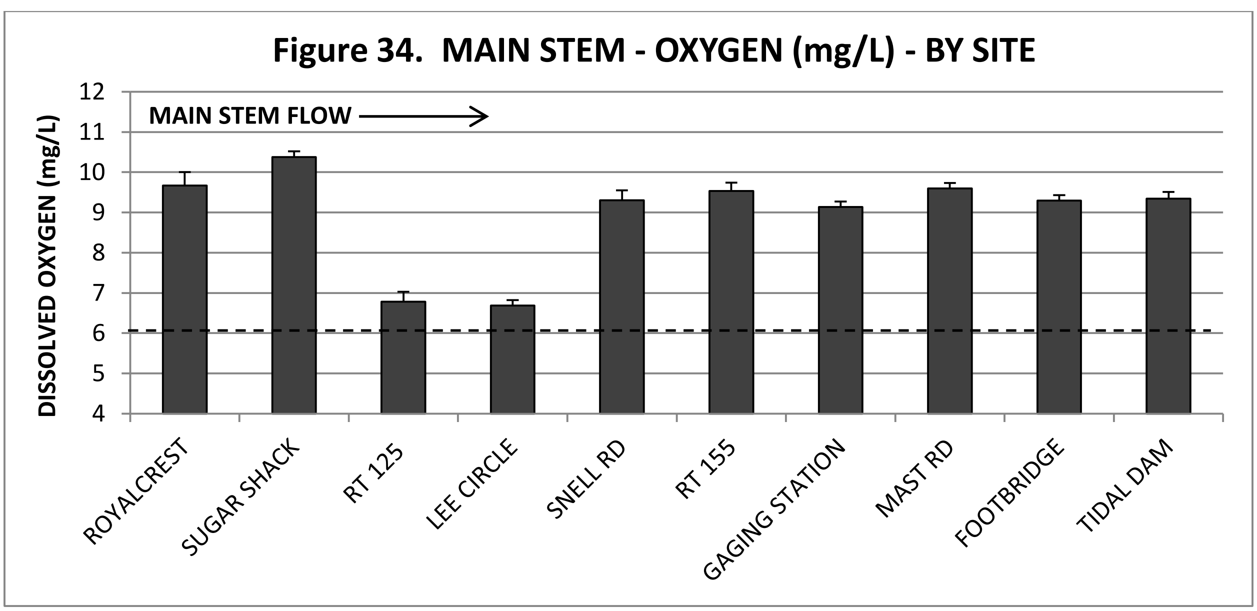
Figure 32. DISSOLVED OXYGEN (mg/L) vs 3 DAY DISCHARGE

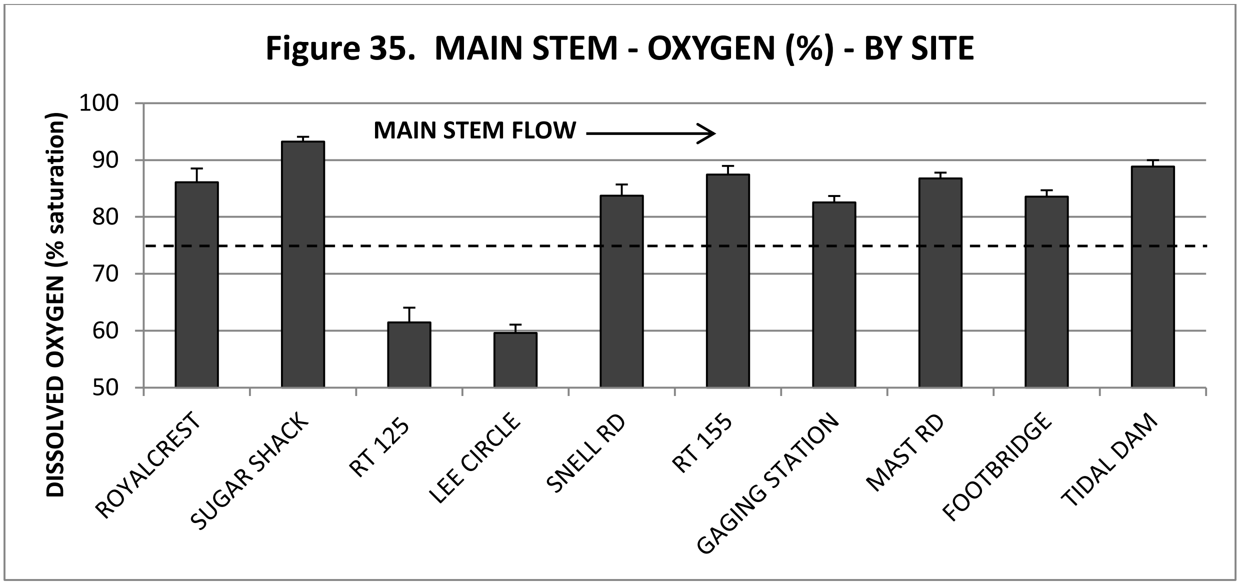


When dissolved oxygen measured as % saturation is plotted against discharge (Figure 33; below), it is clear that, at high levels of discharge, levels of dissolved oxygen approach saturation.

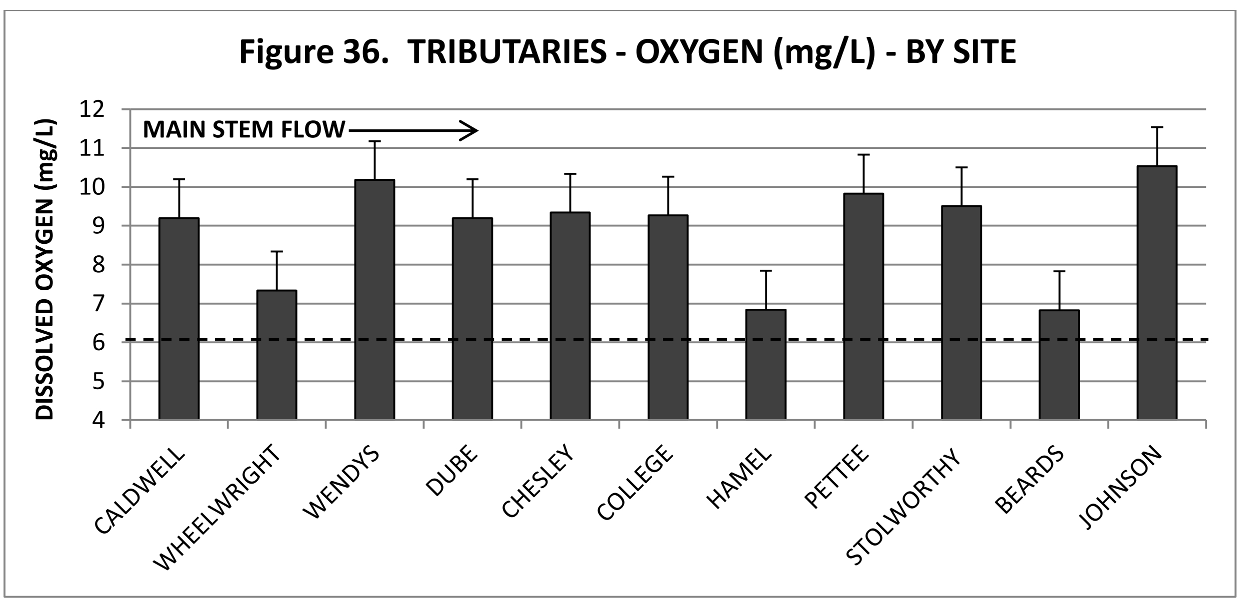


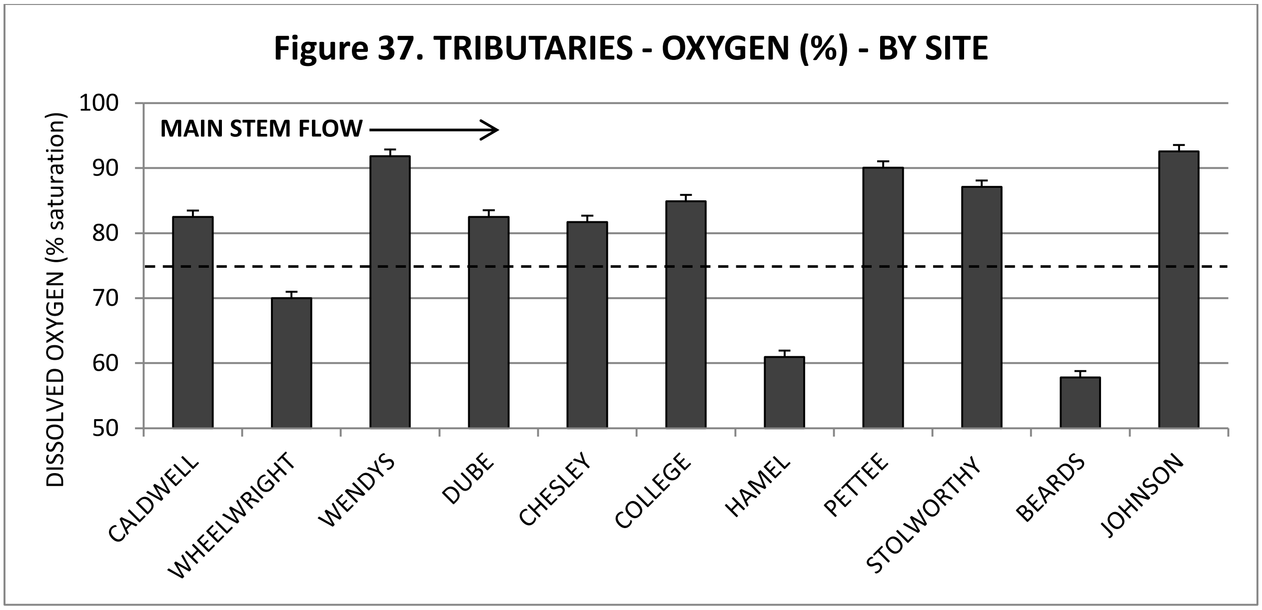
Main Stem Mean dissolved oxygen expressed as either mg/L or % saturation varied significantly among the 10 main stem sites (Fig. 34, 35). Dissolved oxygen was high, > 9 mg/L and > 80% of saturation, at eight sites but means at Route 125 and Lee Circle, sites only 0.37 miles (0.6 km) apart, were much lower. These low mean values exceeded the state standard for mg O/L (6 mg O/L) but were below the state standard for % saturation (75%; New Hampshire VRAP 2011). Low dissolved O_2 at these two sites is likely caused by natural processes. Both sites are located downstream of red maple-shrub swamps that may owe their origin to beaver dams. Over the 11 years of this study, there were beaver dams within a few meters upstream and downstream of the Lee Circle site (OYS-13). Low oxygen levels in such swamps results from two factors: (1) slow-moving water with little turbulence, providing little opportunity for water at depth to come in contact with air; and (2) oxygen uptake by aquatic decomposers consuming the extensive pool of detritus (dead plant material). At these low O_2 sites there is no evidence of anthropogenic sources of oxygen depletion, such as organic wastes or nutrient addition.



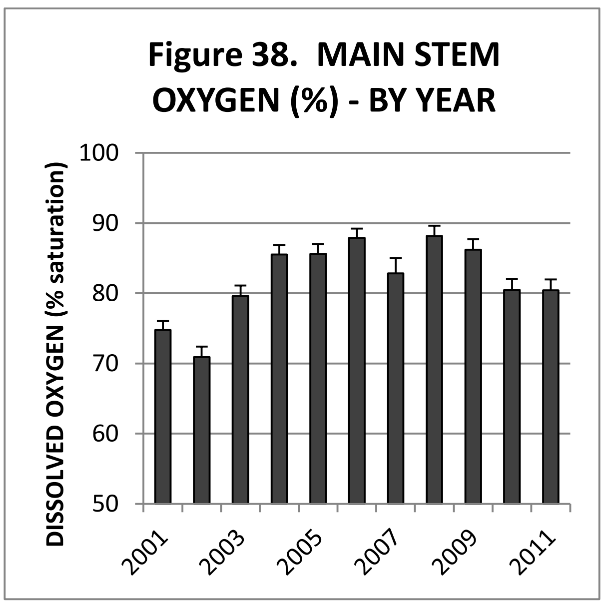


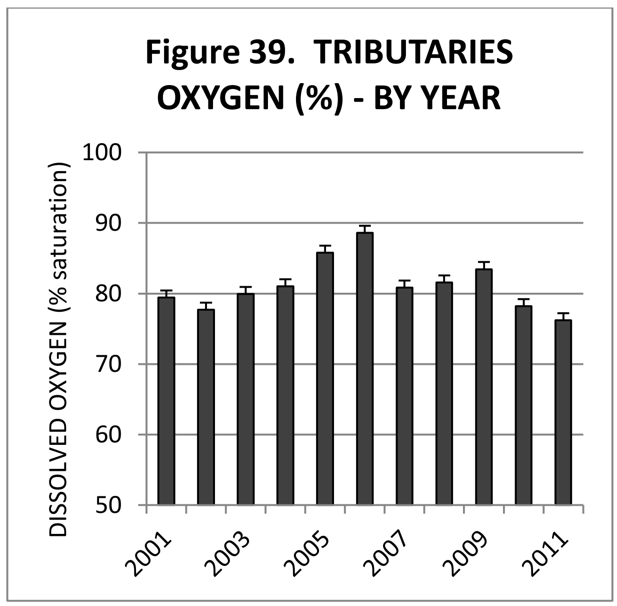
Tributaries Mean dissolved oxygen also varied significantly among tributary sites (Fig. 36, 37). As with main stem sites, dissolved oxygen at tributary sites was generally high, with only three of 10 sites falling below the state standard of 75% saturation. As was the case with the main stem sites reporting low oxygen, natural processes are likely responsible for low oxygen in these tributary sites. The Wheelwright site is about 100 m downstream from Wheelwright Pond and the area between the site and the pond is swampy, with low discharge. The Hamel Brook site lies downstream of a wet meadow with high organic content and low discharge, and the Beards Creek site is immediately downstream of a cattail marsh. At all of these sites, low rates of oxygen accumulation and high rates of biological oxygen demand are likely. That wetlands were the primary driver of low oxygen at the Beards Creek site is supported by the fact that the Stolworthy site (02G-BRD), which samples the same stream as the Beards Creek site (02-BRD but immediately *above* the cattail marsh, had high mean oxygen levels (> 9 mg O/L).



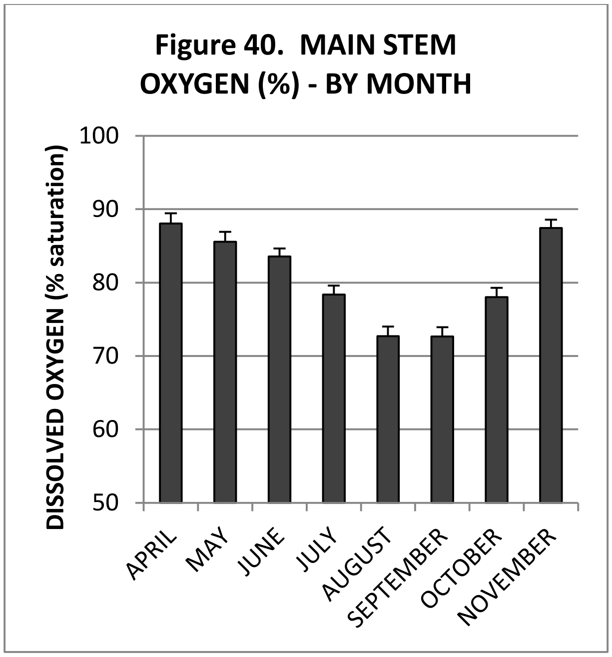


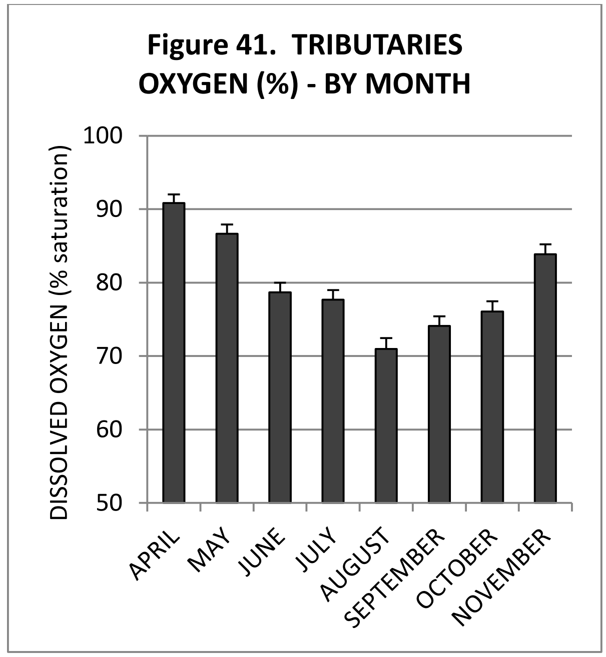
Patterns in Time Dissolved oxygen expressed as mg/L or % saturation varied significantly over the 11 years of the study, and this was true for both main stem and tributary sites (Fig. 38, 39). Dissolved oxygen was generally lower in years of low flow (i.e., 2001 to 2003, 2010, 2011; see Fig. 11).





Oxygen expressed as mg/L and % saturation varied significantly across the months of the year, from April to November, and this was true for both main stem and tributary sites (Fig. 40, 41). Dissolved oxygen was generally lower in months of low flow (i.e., July, August, September; see Fig. 12).



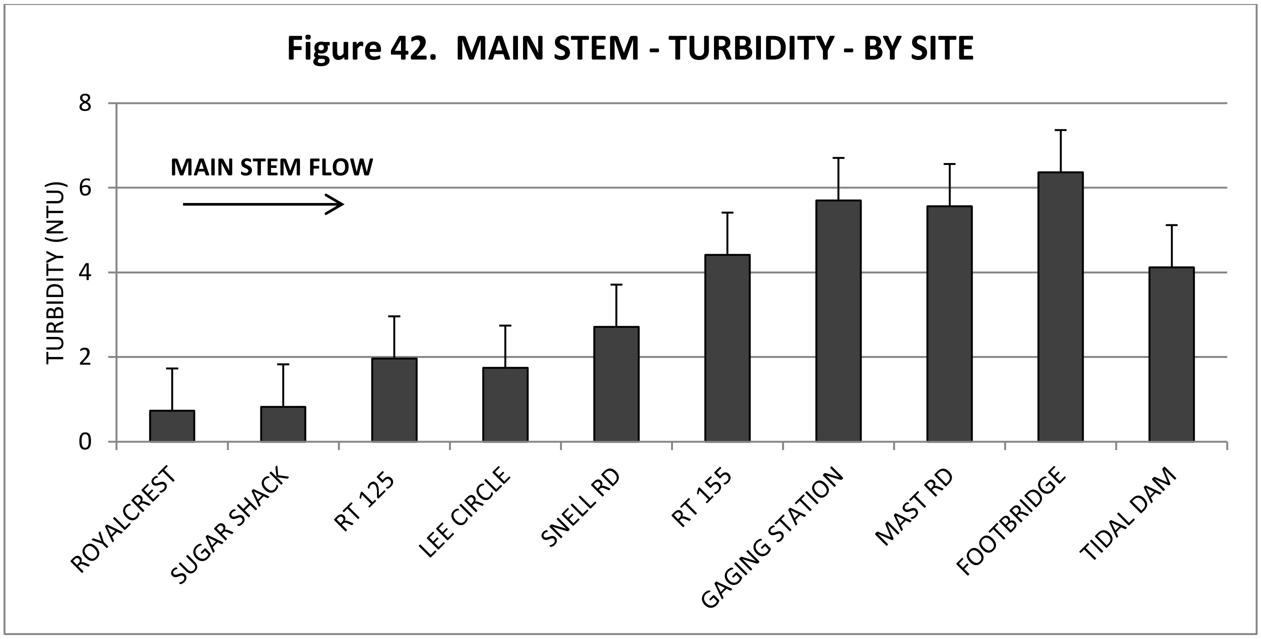


4. TURBIDITY

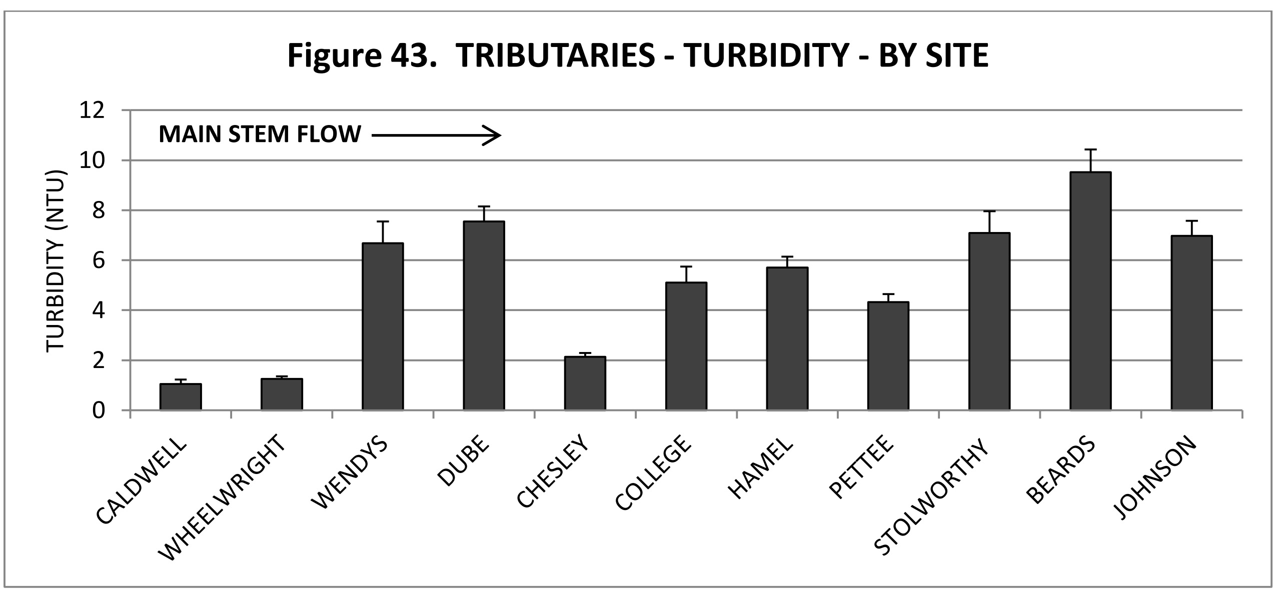
Turbidity measures the quantity of particles suspended in the water. Particles may be silt, clay, algal cells, other micro-organisms, and fragments of dead plant and animal material (detritus). High levels of turbidity may impair water quality. Turbidity is measured in nephalometric turbidity units (NTU).

Main Stem Mean turbidity was generally low (< 7 NTU) at the main stem sites, but it varied significantly among them (Fig. 42). Turbidity was lowest (< 1 NTU) at the upstream sites, Royalcrest and Sugar Shack, and increased progressively downstream, with highest values (> 5 NTU) at Gaging Station, Mast Road, and Footbridge. The last site before tidewater, the Tidal Dam, had intermediate turbidity (~4NTU). As the state standard for turbidity is somewhat vague (New Hampshire VRAP 2011) the extent to which our data comply is difficult to assess.

The pattern of increased turbidity downstream probably exists for two reasons. First, discharge rates and velocity of water generally increase downstream, and greater flow means greater ability of water to carry sediment. Second, there is a change in geologic surface materials across the watershed. Upstream, west of Lee Circle, surface materials are mainly sandy outwash and till, dominated by sand and gravel, materials which are not easily moved by flowing water. East of Route 125 and downstream, there are extensive deposits of marine silt and clay. These materials are easily suspended in flowing water. Anthropogenic inputs do not seem to influence any of the main stem sites at present.



Tributaries Mean turbidity also varied significantly among tributary sites (Fig. 43). Two streams that feed the upstream portion of the river, Caldwell Brook and the outlet from Wheelwright Pond, had very low turbidities (< 1 NTU), as did spring-fed Chesley Brook (~1 NTU). Wendys Brook, Dube Brook, Beards Creek (sampled at two sites, Beards and Stolworthy), and Johnson Creek, all had mean turbidities > 6 NTU. None of the tributaries seem to have significant anthropogenic inputs and the mean values reported here are not unusually high. As with main stem sites, vagueness of the state standard for turbidity (New Hampshire VRAP 2011) makes it difficult to know the extent to which our data comply. However, streams from areas with greater human impact (e.g., College Brook, Pettee Brook, Wendy's Brook) did not have the highest turbidities while Dube Brook, which drained an undeveloped watershed, had one of the higher mean turbidities. Thus, high turbidity values do not appear to be due to human impact.



Patterns in Time Average turbidity varied significantly by year and by month in both the main stem and the tributaries (Fig. 44-47). On the main stem, turbidity was greater in the first five years of the study and about 20% lower in the last six years. A similar pattern existed on the tributaries with the exception of low turbidity in 2001. Unlike specific conductance and dissolved oxygen concentration, turbidity was not associated with annual discharge at the gaging station (09-OYS; compare Fig. 44, 45 with Fig. 11).

Figure 44. MAIN STEM TURBIDITY - BY YEAR

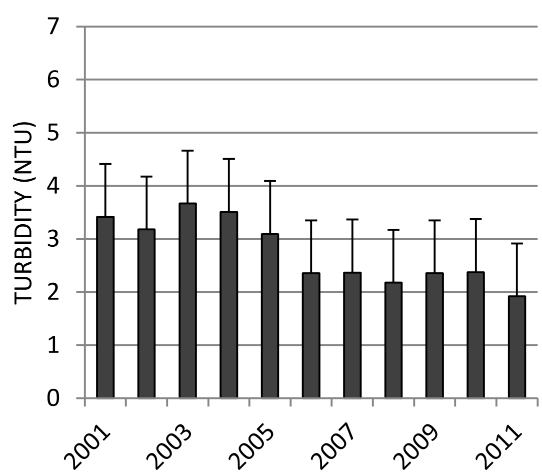
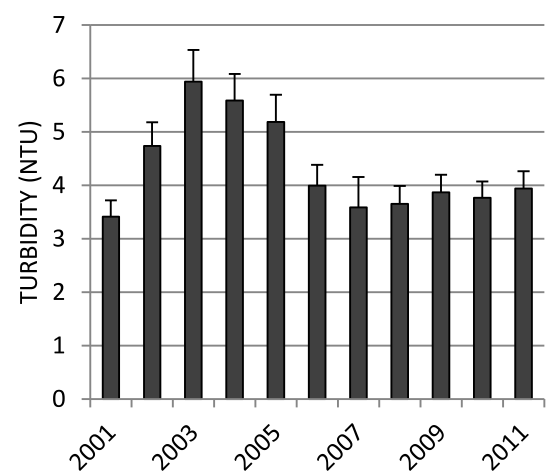


Figure 45. TRIBUTARIES TURBIDITY - BY YEAR



Mean turbidity was low in spring and fall and high from June through September (Fig. 46, 47). It is possible that high summer turbidities are due to greater biological activity at that time, with greater densities of planktonic microbes, especially planktonic algae, as well as increased movement of stream invertebrates and vertebrates causing suspension of mineral and detrital particles.

Figure 46. MAIN STEM TURBIDITY - BY MONTH

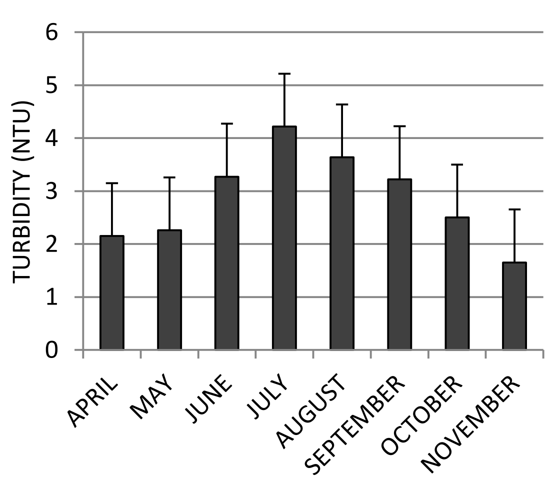
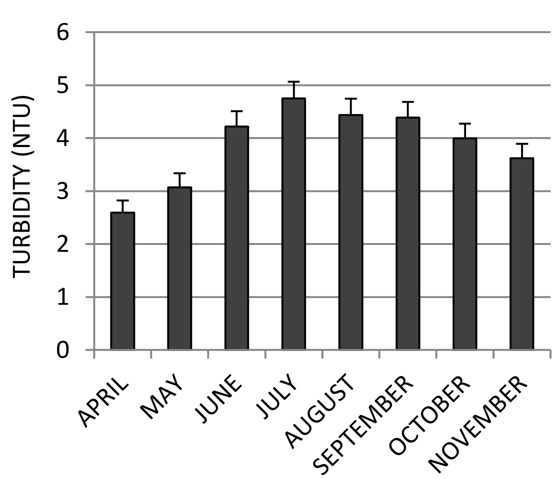


Figure 47. TRIBUTARIES TURBIDITY - BY MONTH

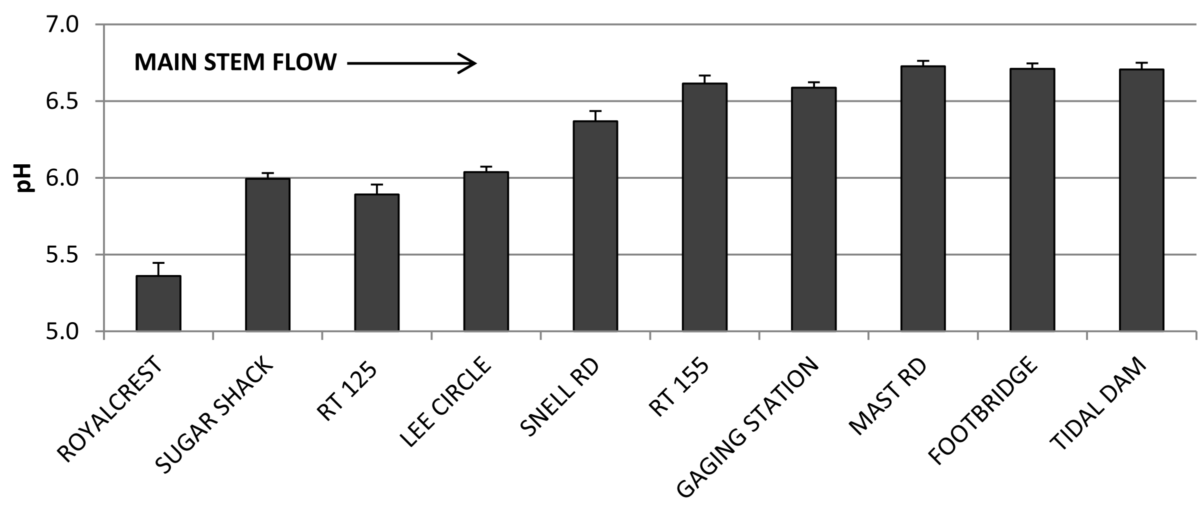


5. pH

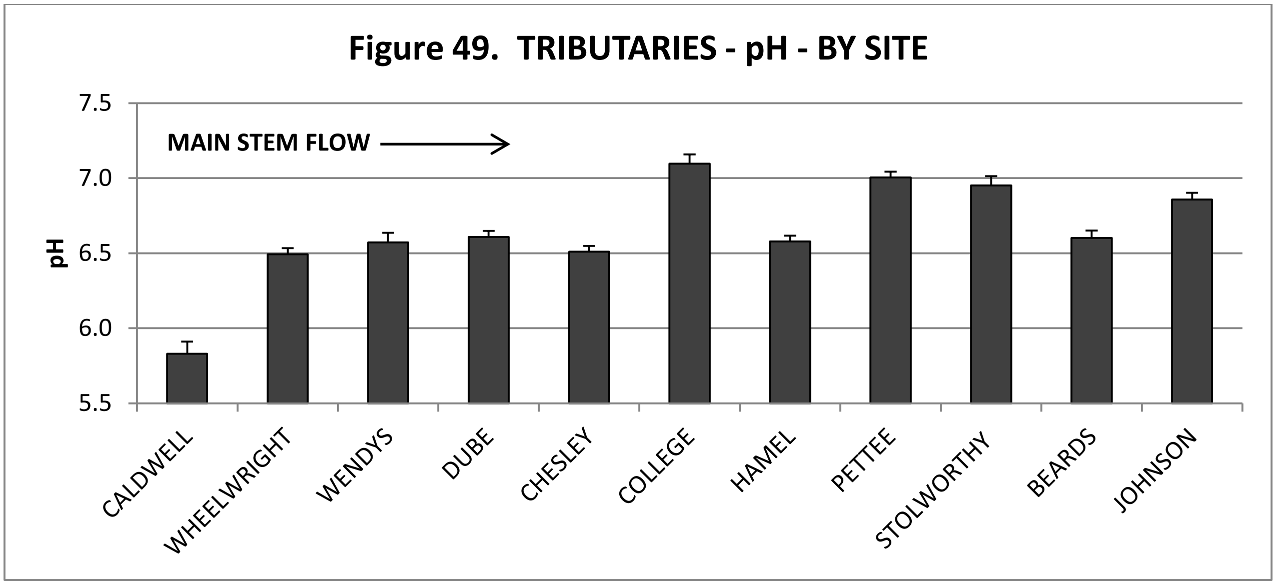
pH measures the quantity of hydrogen ions in the water. Low pH means greater acidity, high pH means less acidity. A pH of 7 indicates neutrality. pH affects (and reflects) many other aspects of water biogeochemistry. In New Hampshire most streams are acidic and some are extremely acidic, often due to natural causes. The state standard is 6.5 to 8.0, "unless naturally occurring" (New Hampshire VRAP 2011), but pristine New Hampshire streams may have pH below 4.5. pH < 4.5 is associated with a change in stream fauna and flora; some organisms are incapable of persisting in these streams.

Main Stem Mean pH varied significantly among main stem sites (Fig. 48). Mean pH was lowest at Royalcrest (<5.4), intermediate at Sugar Shack, Route 125, and Lee Circle (5.8-6.1) and high (> 6.3) at all six remaining sites, all of which were downstream. Low values at the upstream sites may be due to (1) presence of extensive wetlands with organic soils (decomposition of detritus liberates organic acids, such as tannic and humic acids), (2) low levels of calcium and other buffering cations due to low cation exchange capacities of the outwash and sandy till soils that dominate the western portion of the watershed. The Oyster River at Royalcrest lies just below a set of wetlands with Atlantic white-cedar present; such wetlands are known to have acid, organic soils. Mean pH values well below 6.5 occur in relatively pristine areas of the watershed and thus are probably "naturally occurring".

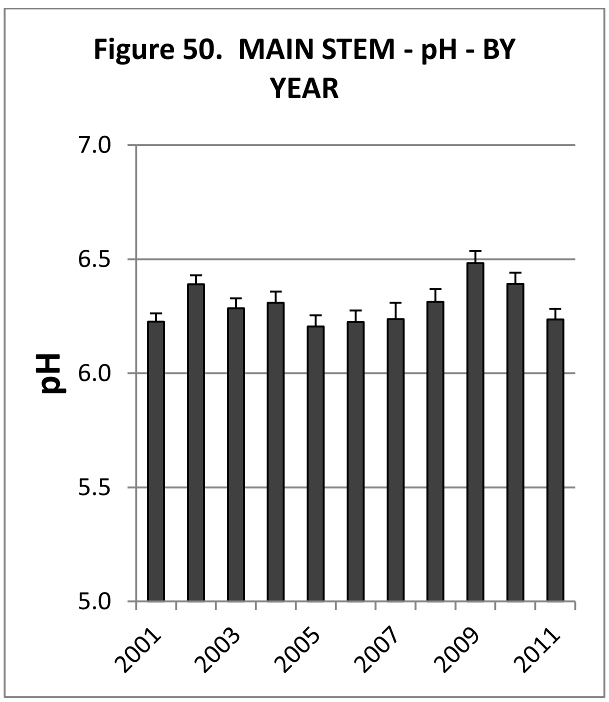
Figure 48. MAIN STEM - pH - BY SITE

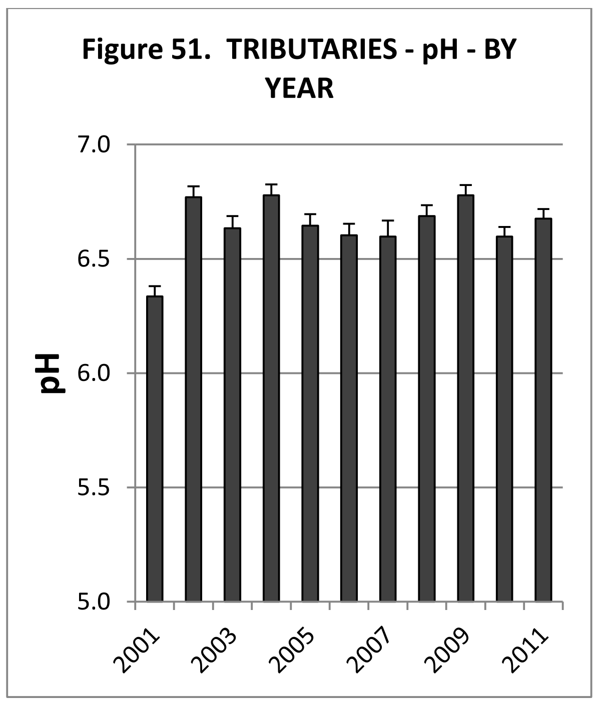


Tributaries Mean pH also varied significantly among tributary sites (Fig. 49). Low pH of Caldwell Brook, located in the western, upstream portion of the watershed is likely due to organic wetlands and low soil buffering capacities. Highest pH values were found in College and Pettee Brooks, the former being the only site to show a mean pH > 7. These two sites are highly urbanized and impacted streams.

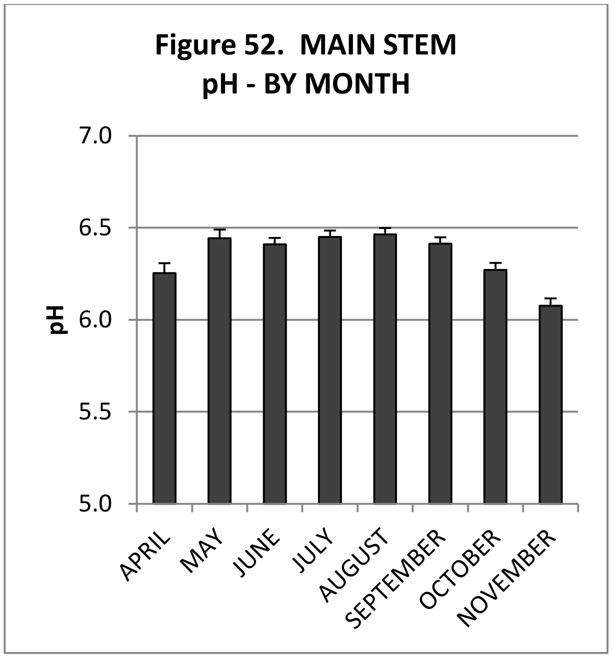


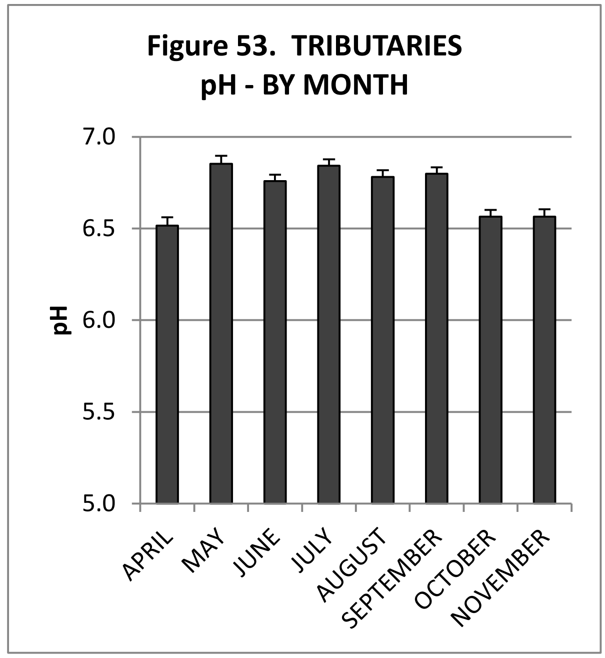
Patterns in Time Mean pH varied significantly among years and across months within years (Fig. 50-53). Mean pH varied slightly and erratically over the 11 years of the study, with no obvious relationship to annual discharge.





For main stem and tributary sites, pH varied less than half a unit over the eight months for which data were available (Fig. 53, 53). pH was lower in April, October, and November, and higher May through September.

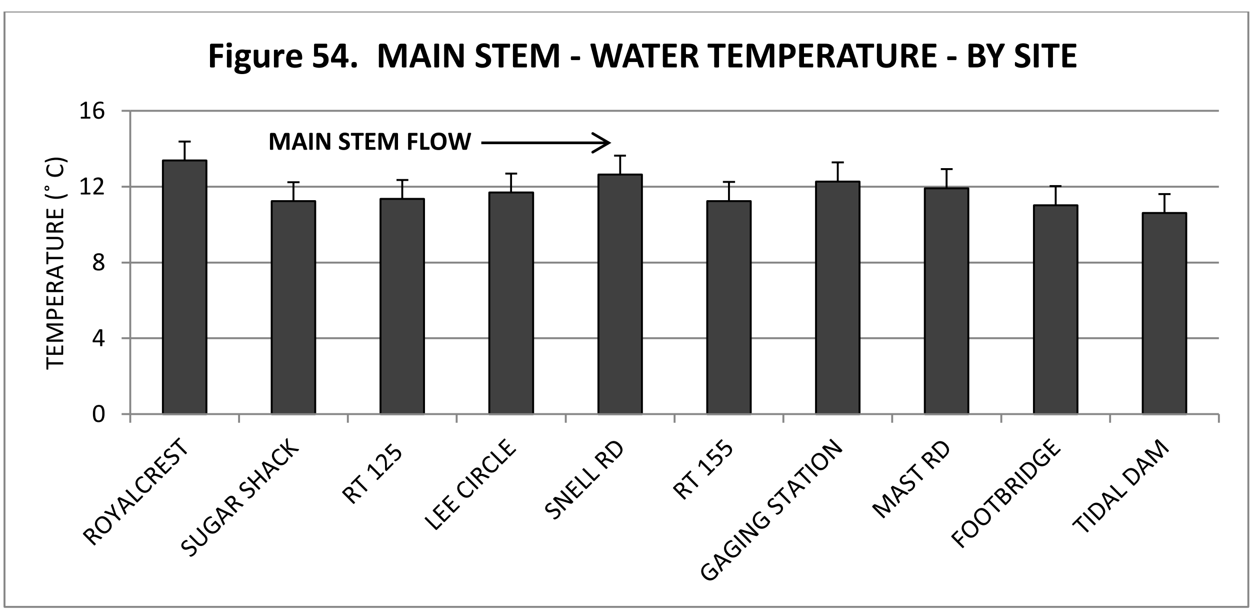




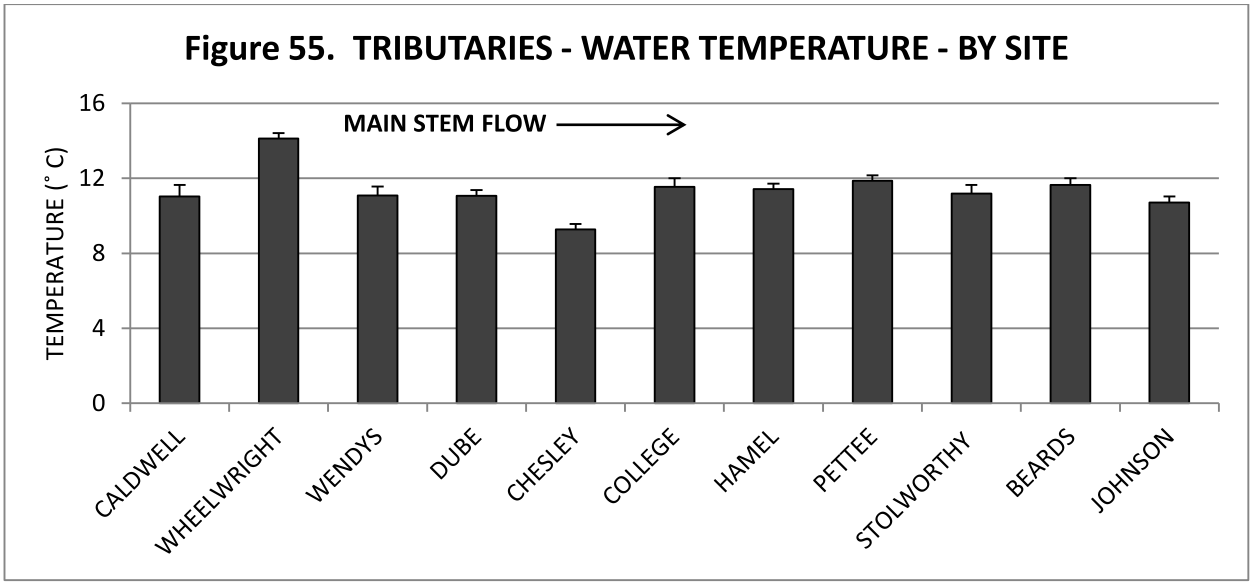
6. WATER TEMPERATURE

Water temperature is influenced by air temperature and thus by year to year and month to month variation in air temperature. It is also affected by solar radiation, which varies seasonally and with the presence or absence of a forest canopy. Shaded areas generally have cooler water temperatures in summer compared to unshaded areas. Water tempearture may also be affected by water source, with spring-fed streams having cooler summer temperatures compared to streams fed by surface waters. Streams draining shallow lakes or wetlands will also tend to have higher summer temperatures.

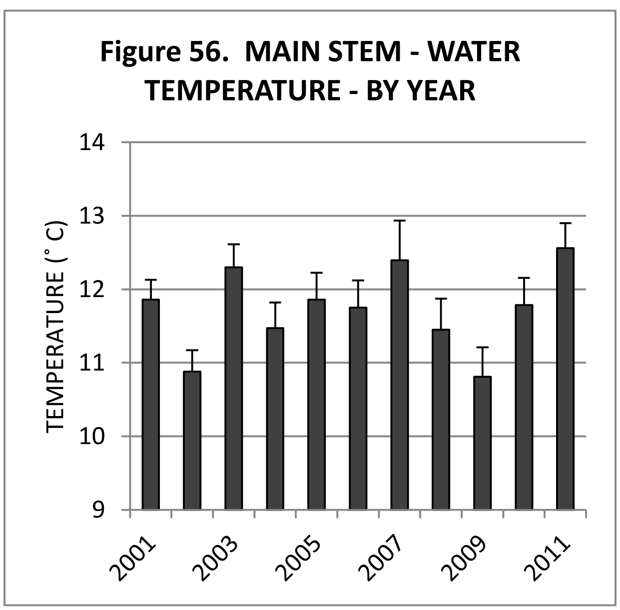
Main Stem Mean water temperature varied significantly across main stem sites (Fig. 54). Temperatures were greatest at Royalcrest and lowest at the Tidal Dam, with little variation in between.

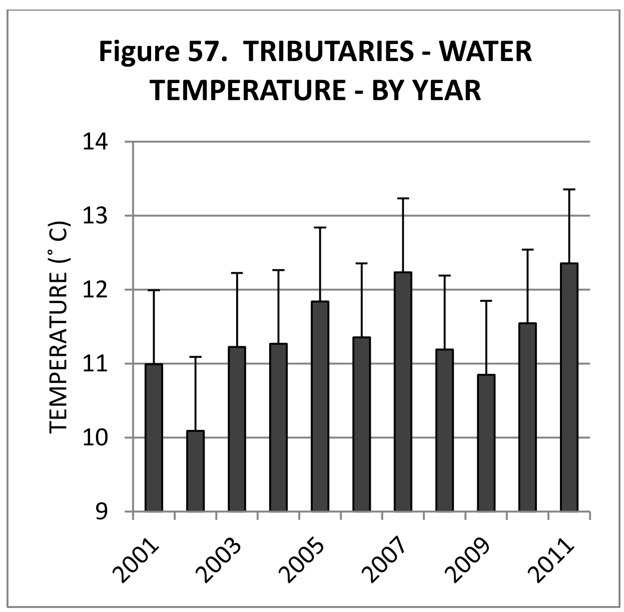


Tributaries Mean temperatures varied significantly across tributary sites (Fig. 55). The warm temperatures at Wheelwright are likely due to the fact that this stream drains Wheelwright Pond. Given the natural outlet of this pond, with sun-warmed surface waters contributing to the stream in summer, this pattern is not surprising. Chesley Brook's cooler mean temperature is likely due to its water source: springs just upstream from the sample site.

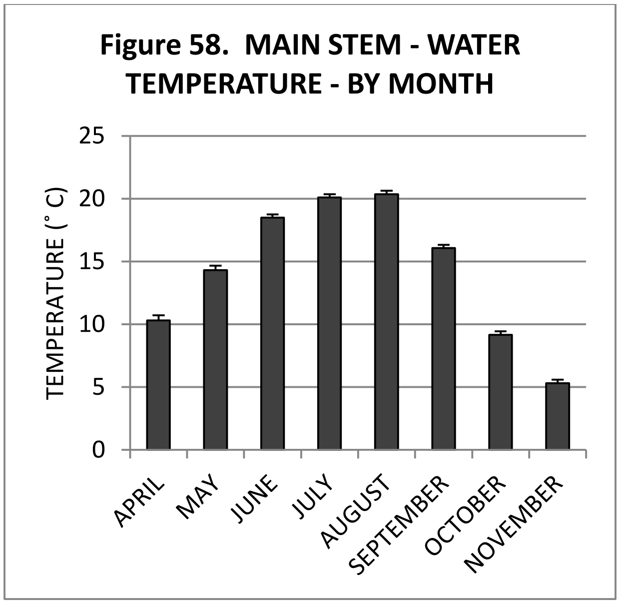


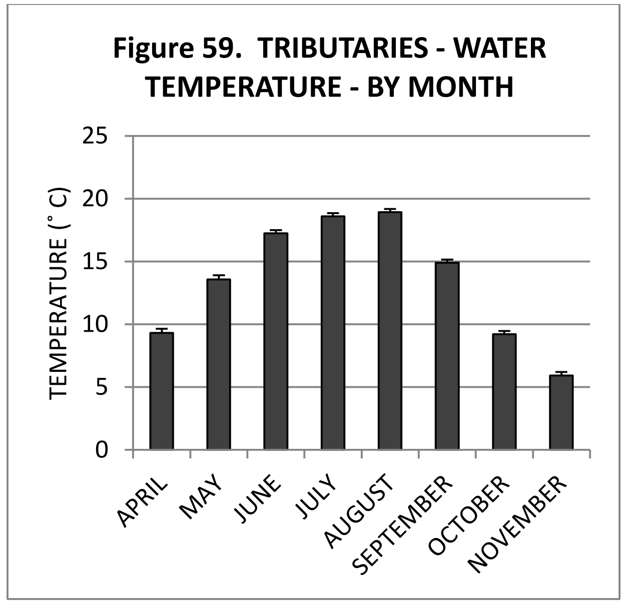
Patterns in Time Mean water temperature varied significantly across the 11 years of the study and the pattern was similar for main stem and tributary sites (Fig. 56, 57). 2002 and 2009 were relatively cool years, 2007 and 2011 were relatively warm.





Unsurprisingly, water temperatures varied seasonally, with warmer temperatures in June through August (Fig. 58, 59).





7. BACTERIA (*E. coli*)

Main Stem The Snell Road site (11-OYS) site was dropped due to small sample size (n = 9 samples). For each of the nine remaining main stem sites, more than half of the observed *E. coli* counts were in the NH class A category (≤ 153 counts/100 ml; Table 3). Between 8 and 30% of observations at each site were in class B. All sites, however, had at least 6% of observations *below* grade B standards (> 406 cts/100 ml, Table 3), and seven of nine sites reported at least one value > 1,000 cts/100 ml. The data do not suggest any chronic source of fecal material. Occasional high levels of *E. coli*, such as those observed in these sites, could result from local fecal deposition by wildlife or periods of high river flow REF.

While none of the main stem sites show chronic *E. coli* contamination, the three sites with the lowest percent of observations in the class A category (08-OYS, Mast Road; 09-OYS, Gaging Station; and 10-OYS, Route 155; Table 3), were also the only sites with > 10% of samples having values > 1,000 cts/100 ml. These three sites were located sequentially over about a 2.5 mile reach of river that runs from Route 155 to Route 155A (Mast Road) along the Lee-Durham town line. It is not clear, however, why this section of river should have more bacterial contamination than other sections of the main stem.

Tributaries The tributary sites showed much greater variation in *E. coli* counts among sites than did main stem sites. While Wheelwright (01-XBB) had 77% samples in class A, higher than that of any other site in the watershed, only five of 11 tributary sites had more than half their observations meet the class A standard, and all 11 sites had at least one observation with over 1,000 cts/100 ml (Table 3). Three of 11 tributaries reported at least one observation over 10,000 cts/100 ml.

Two tributary sites, Wendy's Brook (01-WDY) and College Brook (00E-CGB), reported high bacteria counts with unusual frequency. Both sites met class A water quality standards for only 5% of observations, and more than half the observations from these sites met neither class A nor class B standards (Table 3). At Wendys Brook, which drains the Lee Traffic Circle area, 90% of observations failed to meet class A or B standards, and 75% exceeded 1,000 cts/100 ml. The high *E. coli* counts at Wendys Brook, coupled with the high levels of nitrogen found at this site, especially in the form of ammonia (see section of this report on nitrogen), suggest direct and chronic contamination by fecal matter, perhaps by a faulty sewage processing unit.

Table 3. Percent of Oyster River bacteria (*E. coli*) observations (counts/100 ml) taken from 2001-2011 meeting the New Hampshire state standard for class A water (≤ 153 cts/100 ml), class B water (≤ 406 cts/100 ml), and neither class (> 406 cts/100 ml. Also shown is the percentage of observations with greater than 1000 cts/100 ml. Wendys and College Brooks are bolded to highlight the extreme values.

MAIN STEM SITES	**Site**	**# obser-vations per site**	**% class A**	**% class B**	**% > 406**	**% > 1,000**
ROYALCREST	15C-OYS	10	80	10	10	0
SUGAR SHACK*	15-OYS	45	71	16	13	4
ROUTE 125	13A-OYS	16	75	19	6	0
LEE CIRCLE	13-OYS	54	63	28	9	7
ROUTE 155	10-OYS	18	56	22	22	22
GAGING STATION	09-OYS	54	57	30	13	11
MAST ROAD	08-OYS	54	52	28	20	11
FOOTBRIDGE	07-OYS	54	76	9	15	9
TIDAL DAM	05-OYS	40	83	8	10	5
** includes Jennison (14-OYS)*		MEAN:	68	19	13	8

TRIBUTARY SITES	**Site**	**# obser-vations per site**	**% class A**	**% class B**	**% > 406**	**% > 1,000**
CALDWELL BROOK	01-CWL	10	70	20	10	10
WHEELRIGHT	01-XBB	52	77	13	10	2
WENDYS BROOK	**01-WDY**	**20**	**5**	**5**	**90**	**75**
DUBE BROOK	01-DBE	49	51	27	22	10
CHESLEY BROOK	01-CSB	54	67	19	15	9
COLLEGE BROOK	**00E-CGB**	**20**	**5**	**30**	**65**	**40**
HAMEL BROOK	01-HML	54	30	31	39	11
*PETTEE BROOK	01-RSV	54	24	41	35	15
BEARDS CREEK	02-BRD	34	29	18	53	15
STOLWORTHY	02G-BRD	20	50	10	40	25
JOHNSON CREEK	03-JNC	45	42	31	27	7
**also known as Reservoir Brook*		MEAN:	41	22	37	20

CONCLUSION

Mean levels of dissolved oxygen, turbidity, pH and temperature all varied significantly across sites on the main stem and tributaries of the Oyster River. These water quality metrics also varied significantly over months and years. However, despite this variation, most values fell within NH state standards. Unusually low levels of oxygen and pH could be explained by natural phenomena. Main stem sites with low oxygen, such as those near the Lee Traffic Circle, for example, were associated with still waters usually having large amounts of oxygen demanding detritus. Sites with low pH, such as Royalcrest, were associated with wetlands having organic soils and with areas having poorly buffered mineral soils. The high pH values in College and Pettee Brooks, however, may be related to the urbanization of the watersheds drained by these streams.

Levels of dissolved substances in the main stem of the Oyster River and most of its tributaries were relatively low in comparison to state water quality standards and other water bodies in undeveloped watersheds. Specific conductances were typically less than 200 µS/cm. Conductance decreased exponentially with increasing discharge, and higher conductances were associated with years (2001, 2002, 2003) and months (July-September) of low discharge.

Concentrations of chloride and sodium ions were correlated with specific conductance, with low values at main stem sites and at most tributary sites. Three tributary sites, however, College Brook, Pettee Brook, and Wendys Brook, reported mean conductances ≥ 400 µS/cm and chloride concentrations ≥ 90 mg/L, with individual values that occasionally exceeded what are considered stressful levels. High conductances and chloride levels in these streams were likely due to road salt deposition on extensive impermeable surfaces.

Concentrations of nitrogen in nitrate, ammonium, and organic forms were generally low throughout the watershed. Compared to other sites in the watershed, nitrate levels in Chesley, Wendys, and College Brooks were high, as were ammonium levels in Wendys Brook. N-levels in these streams were what would be expected for streams in mixed rural-urban landscapes. The high ammonium levels in Wendys Brook, combined with high chloride and nitrate levels there, represent an unusual combination of potential stressors and, thus, may be a concern.

Counts of *E. coli*, an indicator of fecal contamination, were generally low at main stem sites and some tributaries. Over half the observations at most sites met the NH standards for class A water. However, E. coli counts at College Brook and Wendys Brook are chronically high. The high counts at Wendys Brook coupled with high levels of ammonia nitrogen suggest the possible failure of a sewage processing unit in the vicinity of this site. As chronically high E. coli counts may be a hazard to human health, the situation at Wendys Brook deserves immediate attention.

Long-term studies of water quality should allow detection of directional decline or improvement in water quality over time. Although the mean values of specific conductance, dissolved oxygen, turbidity, pH, temperature, and most ions varied significantly over the 11 years of the study, the only variable that showed *directional* change was turbidity. The trend toward lower turbidity over the duration of the study should, if anything, be viewed as a positive trend.

The water quality at most sites on the main stem of the Oyster River and on its tributaries appears to be unimpaired or minimally impaired by human activity. Three tributaries, however, (College Brook, Pettee Brook, and Wendys Brook) have conductances and nutrient levels typical of streams impacted by urbanization (Paul and Meyer 2001). These tributaries should be monitored closely to document any further deterioration, and should be targeted for remediation or restoration. The unusually high bacteria counts and ammonia levels at Wendys Brook call for immediate response.

LITERATURE CITED

Daley, M.L., Potter, J.D., and McDowell, W.H. 2009. Salinization of urbanizing New Hampshire streams and groundwater: effects of road salt and hydrologic variability. Journal of the North American Benthos Society 28(4):929-940.

Daley, M.L., McDowell, W.H. and Lesser, T.R. Linking surface water quality to landscape characteristics in the Lamprey River watershed. NH WRRC Fact Sheet.

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton, P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.M., Sprague, L.A., Wilber, W.G. 2010. The Quality of Our Nation’s Water—Nutrients in the Nation’s Streams and Groundwater, 1992–2004. National Water-Quality Assessment Program, Circular 1350, U.S.

New Hampshire Volunteer River Assessment Program (VRAP). 2011. Interpreting VRAP water quality monitoring parameters. State of New Hampshire, Dept. of Environmental Services, VRAP.

Paul, M.J., and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333–365

Peterson, B.J., Wilfred M. Wollheim, W.M., Mulholland, P.J., Webster, J.R., Meyer, J.L., Tank, J.L., Martõ, E., Bowden, W.B., Valett, M., Hershey, A.M., McDowell, W.H., Dodds, W.K., Hamilton, S.K., Gregory, S., Morrall, D.D. 2001. Control of nitrogen export from watersheds by headwater streams. Science 292: 86-90.

APPENDIX A. Oyster River site names, codes, coordinates (latitude and longitude), and elevations. Datum = WGS84.

Table A1. Site names, NH DES site codes, coordinates, and elevations of 10 sampling sites on the main stem of the Oyster River.

SITE NAME	SITE	LATITUDE (°N)	LONGITUDE (°W)	ELEVATION (m)
ROYALCREST	15C-OYS	43.152511	71.022427	48
SUGAR SHACK	15-OYS	43.151457	71.019246	43
ROUTE 125	13A-OYS	43.146652	71.007283	40
LEE CIRCLE	13-OYS	43.148581	71.000437	39
SNELL ROAD	11-OYS	43.160742	70.982660	32
ROUTE 155	10-OYS	43.158446	70.964740	23
GAGING STATION	9-OYS	43.148383	70.965605	21
MAST ROAD	8-OYS	43.134923	70.967452	18
FOOTBRIDGE	7-OYS	43.133226	70.549577	15
TIDAL DAM	5-OYS	43.131000	70.918881	2

Table A2. Site names, NH DES site codes, coordinates, and elevations of 11 sampling sites on tributaries of the Oyster River.

SITE NAME	SITE	LATITUDE (°N)	LONGITUDE (°W)	ELEVATION (m)
CALDWELL BROOK	01-CWL	43.151205	71.022819	49
WHEELRIGHT	01-XBB	43.143116	71.005888	40
WENDYS BROOK	01-WDY	43.149192	71.003171	40
DUBE BROOK	01-DBE	43.169291	70.967091	32
CHESLEY BROOK	01-CSB	43.133535	70.970408	20
COLLEGE BROOK	00E-CGB	43.129847	70.923354	6
HAMEL BROOK	01-HML	43.119200	70.922432	7
PETTEE BROOK	01-RSV	43.135407	70.923100	10
BEARDS CREEK	02-BRD	43.138777	70.920303	2
STOLWORTHY	02G-BRD	43.140550	70.920387	2
JOHNSON CREEK	03-JNC	43.149456	70.890153	8