Acknowledgments

OARS wishes to thank our many dedicated volunteers for their work in the field and on our Board and advisory committees. We’d especially like to thank our 2016 water quality volunteers: Kim Burke, Katelyn Burke, David Downing, Susan Erickson, Lisa Fierce, Betsey Gardstein, Lucy Kirshner, Jason Kupperschmidt, Selene Hewes, Laurie LaBrecque, Adam Last, Shiamin Melville, Michal Mueller, Anu Paras, Pam Rockwell, Isaac Rockwell, David Rogers, Joe Rogers, Ragini Seth, Cheryl Silverberg, Joanne Ward, and Fred Yen.

For scientific review and editorial help, thanks to Cindy Delpapa of the Massachusetts Division of Ecological Restoration and Alison Field-Juma of OARS.

We greatly appreciate the support for our water quality sampling program from the towns of Maynard, Concord, Stow, Wayland, and Acton. The National Park Service, through the Sudbury-Assabet-Concord Wild and Scenic River Stewardship Council, Cedar Tree Foundation, and MA Department of Environmental Protection, provided significant financial support to the monitoring program for which we are grateful. We would also like to thank ERM Foundation and Suasco CISMA for their support. In-kind services were provided by U.S. Environmental Rental Corporation of Waltham. We also thank the OARS members whose membership dues and donations made this work possible.

Author: Suzanne Flint, OARS Staff Scientist

Available on line at: http://www.oars3rivers.org/river/waterquality/reports


Cover pictures clockwise from top left: pickerel weed flower; staff gage at Hop Brook, Northborough (August); Rapid Response team’s canoe; petiole of water chestnut
Table of Contents

Abstract ........................................................................................................................................... 1
Introduction ...................................................................................................................................... 1
Water Quality Sampling .................................................................................................................. 6
  Water Quality Sampling Methods .............................................................................................. 6
  River Reaches and Tributaries .................................................................................................... 8
  Precipitation and Streamflow ..................................................................................................... 9
  Water Quality Results ............................................................................................................... 13
  Summer Nutrient Trends 1992 - 2016 .................................................................................. 21
  Water Quality and Stream Health Index Calculations ........................................................... 28
Aquatic Plant Biomass Sampling .................................................................................................. 31
  Biomass Survey Methods ........................................................................................................ 31
  Biomass Results ....................................................................................................................... 32
Summary ........................................................................................................................................ 36
References ....................................................................................................................................... 39
Glossary of Terms .......................................................................................................................... 42
Appendix I: Water Quality Designations for the SuAsCo Rivers and Streams ....................... 46
Appendix II: Streamflow Data from USGS Gages .................................................................... 48
Appendix III: Data Quality Notes .............................................................................................. 49
Appendix IV: Water Quality Data ................................................................................................ 51
Appendix V: Aquatic Plant Biomass Survey Data 2005 - 2016 .................................................. 52

Figures and Tables

Figure 1: Sudbury, Assabet, and Concord River Watershed and 2016 Sampling Sites .......... 5
Figure 2: Groundwater Levels (USGS Monitoring Well Acton, MA) ...................................... 10
Figure 3: Average Daily Discharge / Reporting Period 2016 .................................................... 10
Figure 4: Mean Daily Streamflows, Assabet River, 2016 .......................................................... 11
Figure 5: Mean Daily Streamflows, Sudbury River, 2016 ......................................................... 12
Figure 6: Temperatures in Tributaries and Assabet Headwater ............................................... 16
Figure 7: Median Dissolved Oxygen Measurements .................................................................. 18
Figure 8: Median Total Phosphorus Concentrations (Summers 2007- 2016) ....................... 19
Figure 9: Median Nitrate Concentrations (Summers 2008- 2016) .......................................... 19
Figure 10: TSS by River Section, 2015 ...................................................................................... 20
Figure 11: Chlorophyll-α at Sudbury River Sites ....................................................................... 21
Figure 12: Summer Total Phosphorus in Upper and Lower Assabet Mainstem ..................... 23
Figure 13: Summer Nitrates in Upper and Lower Assabet Mainstem ..................................... 24
Figure 14: Summer Total Phosphorus at Assabet Headwater & Tributaries ............................ 25
Figure 15: Summer Nitrates at Assabet Headwater Site and Tributaries ................................ 26
Figure 16: Annual Load Total Phosphorus from WWTPs ......................................................... 27
Figure 17: Total Annual Flow from WWTPs ........................................................................... 27
Figure 18: Class vs. Biomass Wet Weight .................................................................................. 32
Figure 19: Total Floating Aquatic Plant Biomass Wet Weight .................................................. 32
Figure 20: Total Floating Biomass, Ben Smith, August 26, 2016 .......................................... 33
Figure 21: Total Floating Biomass, Gleasondale Impoundment, August 25, 2016 ................. 34
Figure 22: Total Floating Biomass, Hudson Impoundment, August 29, 2016 ....................... 35

WQ Final Report 2016
Table 1: Water Quality Sampling Sites 2016 ................................................................. 4
Table 2: Sampling and Analysis Methods ........................................................................ 6
Table 3: Water Quality Standards and Guidance ............................................................... 7
Table 4: Reference Conditions for Ecoregion XIV (59) Streams ....................................... 7
Table 5: StreamStats Drainage Basin Statistics ................................................................. 8
Table 6: Hydrographic and Precipitation Data 2016 .......................................................... 9
Table 7: 2016 Mean Daily Flows at USGS Gages ............................................................. 10
Table 8: Mainstem Reach and Tributary Statistics ............................................................ 14
Table 10: Dissolved Oxygen Violations ............................................................................ 17
Table 11: NH Chlorophyll Categories .............................................................................. 20
Table 12: Sites for Nutrient Trends Analysis .................................................................... 21
Table 13: Stream Health Index Readings ......................................................................... 29
Table 14: Water Quality Index Readings ........................................................................... 30

Appendices

I: Water Quality Designations for the SuAsCo Rivers and Streams
II: Streamflow Data from USGS Gages
III: Data Quality Notes
IV: Water Quality Data (available upon request)
V: Aquatic Plant Biomass Survey Data
Abstract

This report covers the water quality and streamflow data collected between March 2016 and November 2016, summarizes the findings of a trends analysis for total phosphorus and nitrates concentrations between 1993 and 2016, and presents aquatic plant biomass data collected in 2016.


Introduction

The combined Assabet, Sudbury, and Concord River watershed is about 399 square miles in eastern Massachusetts and is within EPA’s Nutrient Ecoregion XIV subregion 59, the Eastern Coastal Plain. The mainstem rivers, particularly the Assabet, suffer from cultural eutrophication caused by excess nutrients coming from point and non-point sources and from the soft sediments. During the growing season excess nutrients, phosphorus in particular, fuel nuisance algal and macrophytic plant growth which interferes with recreational use of the rivers and causes large daily variations in dissolved oxygen concentrations and pH, making poor habitat for aquatic life. When the algae and plants decay (whenever they are exposed on the river banks and/or at the end of the growing season) they generate strong sewage-like odors, can dramatically lower dissolved oxygen levels in the water column and impair aesthetics and use of the rivers.

Under the federal Clean Water Act (Section 305b), states are required to evaluate the condition of the state’s surface and ground waters with respect to their ability to support designated uses (such as fishing and swimming) as defined in each of the state’s surface water quality standards. In their 2014 assessment, Massachusetts Department of Environmental Protection (MA DEP, 2014) lists all sections of the Assabet and Concord Rivers, from the Assabet River Reservoir (A1 Impoundment) in Westborough to the confluence with the Merrimack River in Lowell, on the Impaired Waters List—Category 5, “Waters Requiring a TMDL” for a variety of impairments. A Total Maximum Daily Loading Study (TMDL) for nutrients on the Assabet River was completed in 2004. The Sudbury River upstream of the Fruit Street bridge in Hopkinton/Westborough is listed as Category 3, “No uses assessed.” All sections of the Sudbury River from Fruit Street downstream to the confluence with the Assabet in Concord are listed as Category 5, impaired for metals. Seven of the tributaries in the basin are also listed as Category 5 Waters (MA DEP, 2014): Eames Brook (cause unknown, taste/odor, noxious aquatic plants), Hop Brook in Marlborough/ Sudbury (nutrients, pathogens, dissolved oxygen, and noxious aquatic plants), Pantry Brook (pathogens), Elizabeth Brook (cause unknown), Nashoba Brook (fisheries bioassessment), and River Meadow Brook (pathogens). Mill Brook in Concord is listed as Category 4c Waters, “Impairment not caused by a pollutant.” Other tributaries are listed as either Category 2 (“Attaining some uses; other uses not assessed”) or Category 3 (“No Uses Assessed”).

The findings of the Assabet River Total Maximum Daily Load for Total Phosphorus study (ENSR 2001, MA DEP 2004) confirmed that the majority of the nutrients entering the Assabet were coming from the wastewater treatment plants that discharge treated effluent to the river. In
particular, treatment plants are the major source of ortho-phosphorus (the bioavailable form of phosphorus) throughout the year. While non-point sources contribute nutrients, they contributed significantly less than point sources over the growing season. The 2004 study concluded that reductions in nutrient loads from both point and non-point sources would be required to restore the Assabet River to Class B conditions. MA DEP and EPA adopted a two-phased adaptive management plan to reduce phosphorus loads in the Assabet. In Phase I, lower total phosphorus discharge limits were required at the four major wastewater treatment plants (WWTPs). As a part of Phase I, ways of limiting nutrient flux from the nutrient-rich sediments which accumulate in the slower moving and impounded river sections were studied. The Assabet River, Massachusetts, Sediment and Dam Removal Feasibility Study (ACOE 2010) examined sediment dredging, dam removal, and lower winter phosphorus discharge limits as ways of controlling the annual phosphorus loading from the sediments. The study concluded that: (1) dredging would achieve, at best, short-term improvements; (2) phosphorus discharge from the WWTPs in the winter contributes to the annual phosphorus budget for the Assabet and, therefore, decreased winter phosphorus discharge limits would be another way to control phosphorus loading to the system; and (3) that dam removal plus the Phase 1 WWTPs phosphorus discharge reductions would almost meet the goal of reducing the sediment phosphorus contribution by 90 percent (MA DEP 2004), achieving an estimated 80 percent reduction. The study commented that, “due to the large size of the impoundment, if the Ben Smith dam were to stay in place, significant biomass growth would continue to occur, resulting in existing levels of sediment phosphorus flux in both the entire length of the Ben Smith impoundment, and continuing downstream to the Powdermill impoundment, and beyond.”

Upgrades to all four municipal wastewater treatment plants that discharge to the Assabet River were completed as of the spring of 2012: Hudson in September 2009, Maynard in spring 2011, Marlborough Westerly and Westborough in the spring of 2012. With the upgrades complete, all the treatment plants meet summer total phosphorus discharge limits of 0.1 mg/L and a winter limit of 1.0 mg/L. The Marlborough Easterly plant discharging to Hop Brook (tributary to the Sudbury River) finished required upgrades by spring 2015.

A natural streamflow regime (i.e. range, duration, and timing of streamflows) throughout the year is critical to supporting fish and other aquatic life. Baseflow, the flow of groundwater into the streams, is particularly critical during the summer and is essential to diluting the effluent discharged to the river. For the nutrient load reductions proposed in the state’s TMDL to be effective in restoring water quality in the mainstem, the existing baseflow in the river and its tributaries must be preserved and, if possible, augmented. The water resources of the area are under the strain of an increasing demand for water supply and centralized wastewater treatment, which results in the net loss of water from many sub-basins and reduced baseflow in the mainstem and tributaries.

Invasive aquatic plants are also a problem throughout the watershed. The Sudbury River has a long history of invasive water chestnut (Trapa natans) problems and efforts to remediate those problems. Significant water chestnut infestations are also on the Concord River, particularly in the Billerica impoundment, and the Assabet River, particularly in the Stow sections of the river. Other invasive aquatic plants include Eurasian milfoil, fanwort, curly leaf pondweed, and European water clover.
Because of these problems, OARS (formerly the Organization for the Assabet River) conducts water quality, streamflow, and aquatic plant biomass monitoring on the mainstems and large tributaries of the Assabet, Sudbury, and Concord rivers. Without the support and work of its volunteers, OARS would not be able to conduct such an extensive monitoring program. The summer of 2016 was OARS’ 25th consecutive summer collecting data at mainstem Assabet River sites, including the longest standing sites below each major wastewater treatment plant, its 15th year collecting data at tributary sites, its 13th year collecting data at mainstem Concord River sites, its 7th summer collecting Sudbury River data, and its 12th year assessing aquatic plant biomass in the large impoundments of the Assabet River. Water quality data collected under OARS’ Quality Assurance Project Plan for OARS’ Water Quality and Quantity Monitoring Program (approved May 2016 to cover the 2016-2018 field seasons) and previous Quality Assurance Project Plans may be used by EPA and DEP in making regulatory decisions (OARS, 2016b). The goals of OARS’ monitoring program remain: to understand long-term trends in the condition of the rivers and their tributaries, provide sound scientific information to evaluate and support regulatory decisions that affect the rivers, and to promote stewardship of the rivers through volunteer participation in the project.

The data collected are also used to characterize fish habitat conditions in the main tributary sub-basins. Streamflow and habitat availability data were collected at seven tributary sites (Assabet headwaters, Hop Brook, North Brook, Elizabeth Brook, Danforth Brook, Nashoba Brook, and River Meadow Brook) to calculate OARS’ “Stream Health Index” readings for those streams (described at http://www.oars3rivers.org/our-work/monitoring/interpret-data).
## Table 1: Water Quality Sampling Sites 2016

<table>
<thead>
<tr>
<th>Waterbody / Section</th>
<th>Site Location</th>
<th>Town</th>
<th>OARS Site #</th>
<th>SARIS #</th>
<th>Months Sampled</th>
<th>Lat/Long (d/m/s)</th>
<th>Measurements WQ</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concord River</td>
<td>Rogers Street</td>
<td>Lowell</td>
<td>CND-009</td>
<td>46500</td>
<td>Mar, May – Sept, Nov</td>
<td>42°38’ 08.89&quot; / -71°18’ 06.45&quot;</td>
<td>√ (USGS)</td>
<td></td>
</tr>
<tr>
<td>Concord River</td>
<td>Lowell Street</td>
<td>Billerica</td>
<td>CND-045</td>
<td>46500</td>
<td>June - Aug</td>
<td>42°35’35.5&quot; / -71°17’ 20.04&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Concord River</td>
<td>Rte 225</td>
<td>Bedford</td>
<td>CND-110</td>
<td>46500</td>
<td>June - Aug</td>
<td>42°30’33.0&quot; / -71°18’ 48.6&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Concord River</td>
<td>Lowell Rd. Bridge</td>
<td>Concord</td>
<td>CND-161</td>
<td>46500</td>
<td>Mar, May – Sept, Nov</td>
<td>42°27’ 58.56&quot; / -71°21’ 20.43&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sudbury River</td>
<td>Rte 62 / Boat House</td>
<td>Concord</td>
<td>SUD-005</td>
<td>47650</td>
<td>Mar, May – Sept, Nov</td>
<td>42°27’ 29.8&quot; / -71°21’ 58.8&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sudbury River</td>
<td>Sherman Bridge Rd.</td>
<td>Wayland</td>
<td>SUD-064</td>
<td>47650</td>
<td>May - Sept</td>
<td>42°23’ 47.21&quot; / -71°21’ 50.00&quot;</td>
<td>√ (USGS)</td>
<td></td>
</tr>
<tr>
<td>Sudbury River</td>
<td>River Road</td>
<td>Wayland</td>
<td>SUD-086</td>
<td>47650</td>
<td>May - Sept</td>
<td>42°22’ 25.26&quot; / -71°22’ 55.17&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sudbury River</td>
<td>Route 20</td>
<td>Wayland</td>
<td>SUD-096</td>
<td>47650</td>
<td>May – Sept</td>
<td>42°21’ 48&quot; / -71°22’ 28&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sudbury River</td>
<td>Sudbury Landing</td>
<td>Framingham</td>
<td>SUD-144</td>
<td>47650</td>
<td>May - Sept</td>
<td>42°19’ 32.1&quot; / -71°23’ 50.8&quot;</td>
<td>(USGS)</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Lower</td>
<td>Route 2</td>
<td>Concord</td>
<td>ABT-026</td>
<td>46775</td>
<td>Mar, May – Sept, Nov</td>
<td>42°27’ 56.96&quot; / -71°23’ 27.92&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Lower</td>
<td>Rte 62 / Canoe access</td>
<td>Acton</td>
<td>ABT-063</td>
<td>46775</td>
<td>June - Aug</td>
<td>42°26’ 28.29&quot; / -71°25’ 48.65&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Lower</td>
<td>Rte 62/ USGS Gage</td>
<td>Maynard</td>
<td>ABT-077</td>
<td>46775</td>
<td>Mar, May – Sept, Nov</td>
<td>42°25’ 56.00&quot; / -71°26’ 58.55&quot;</td>
<td>(USGS)</td>
<td></td>
</tr>
<tr>
<td>Assabet River/ Impound.</td>
<td>White Pond Road</td>
<td>Stow/Maynard</td>
<td>ABT-095</td>
<td>46775</td>
<td>June – Aug</td>
<td>42°25’23.6&quot; / -71°28’ 29.5&quot;</td>
<td>in-situ</td>
<td></td>
</tr>
<tr>
<td>Assabet River/Impound.</td>
<td>Sudbury Road</td>
<td>Stow</td>
<td>ABT-134</td>
<td>46775</td>
<td>June – Aug</td>
<td>42°24’41.8&quot; / -71°30’ 30.0&quot;</td>
<td>in-situ</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Upper</td>
<td>Rte 62 / Glesondale</td>
<td>Stow</td>
<td>ABT-144</td>
<td>46775</td>
<td>June - Aug</td>
<td>42°24’ 16.26&quot; / -71°31’ 34.70&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Upper</td>
<td>Cox Street</td>
<td>Hudson</td>
<td>ABT-162</td>
<td>46775</td>
<td>June – Aug</td>
<td>42°23’59.1&quot; / -71°32’45.0&quot;</td>
<td>in-situ</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Upper</td>
<td>Robin Hill Road</td>
<td>Marlborough</td>
<td>ABT-238</td>
<td>46775</td>
<td>June – Aug</td>
<td>42°20’ 42.61&quot; / -71°36’ 50.92&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Assabet River / Upper</td>
<td>Route 9</td>
<td>Westborough</td>
<td>ABT-301</td>
<td>46775</td>
<td>Mar, May – Sept, Nov</td>
<td>42°16’ 59.61&quot; / -71°38’ 19.44&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Assabet River/ Headwater</td>
<td>Mill Road</td>
<td>Westborough</td>
<td>ABT-312</td>
<td>46775</td>
<td>Mar, May-Sept, Nov</td>
<td>42°16’26&quot; / -71°37’ 56&quot;</td>
<td>OARS</td>
<td></td>
</tr>
<tr>
<td>River Meadow Brook</td>
<td>Thorndike Street</td>
<td>Lowell</td>
<td>RVM-005</td>
<td>46525</td>
<td>June - Aug</td>
<td>42°37’ 54.54&quot; / -71°18’ 30.70&quot;</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Nashoba Brook</td>
<td>Commonwealth Av.</td>
<td>Concord</td>
<td>NSH-002</td>
<td>unnamed</td>
<td>Mar, May – Sept, Nov</td>
<td>42°27’ 32.05&quot; / -71°23’ 49.35&quot;</td>
<td>√ (USGS)</td>
<td></td>
</tr>
<tr>
<td>Nashoba Brook</td>
<td>Wheeler Lane</td>
<td>Acton</td>
<td>NSH-047</td>
<td>46875</td>
<td>Mar, May – Sept, Nov</td>
<td>42°30’ 46.71&quot; / -71°24’ 15.83&quot;</td>
<td>(USGS)</td>
<td></td>
</tr>
<tr>
<td>Elizabeth Brook</td>
<td>White Pond Road</td>
<td>Stow</td>
<td>ELZ-004</td>
<td>47125</td>
<td>Mar, May – Sept, Nov</td>
<td>42°25’ 36.96&quot; / -71°29’ 07.01&quot;</td>
<td>√ (USGS)</td>
<td></td>
</tr>
<tr>
<td>Danforth Brook</td>
<td>Rte 85</td>
<td>Hudson</td>
<td>DAN-013</td>
<td>47275</td>
<td>Mar, May – Sept, Nov</td>
<td>42°24’ 13.65&quot; / -71°34’ 28.64&quot;</td>
<td>√ (USGS)</td>
<td></td>
</tr>
<tr>
<td>North Brook</td>
<td>Pleasant St.</td>
<td>Berlin</td>
<td>NTH-009</td>
<td>47375</td>
<td>Mar, May – Sept, Nov</td>
<td>42°21’ 25.67&quot; / -71°37’ 45.48&quot;</td>
<td>OARS</td>
<td></td>
</tr>
<tr>
<td>Hop Brook</td>
<td>Otis Street</td>
<td>Northborough</td>
<td>HOP-011</td>
<td>47600</td>
<td>Mar, May – Sept, Nov</td>
<td>42°17’ 31.27&quot; / -71°39’ 27.04&quot;</td>
<td>√ (USGS)</td>
<td></td>
</tr>
<tr>
<td>Hop Brook</td>
<td>Landham Road</td>
<td>Sudbury</td>
<td>HBS-016</td>
<td>47825</td>
<td>May - Sept</td>
<td>42°21’ 26.5&quot; / -71°24’ 11.7&quot;</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1: Sudbury, Assabet, and Concord River Watershed and 2016 Sampling Sites
Water Quality Sampling

Water Quality Sampling Methods
Trained volunteers and OARS staff monitored water quality at sites throughout the watershed (Table 1, Figure 1). Each site is assigned a three letter prefix for the waterbody name plus a three number designation indicating river miles above its confluence with the next stream. Water quality monitoring was conducted one Sunday each month in March, May, June, July, August, September, and November. Because of funding limitations, not all sites are sampled each month: in November and March, only the flow gaged sites and top and bottom of the main rivers were sampled; in May through September, Sudbury River sites were included; all sites were sampled in the summer months (June, July, and August); from May to September additional in-situ readings were taken at three sites within impounded Assabet River areas in Stow and Hudson (ABT-162, ABT-134, and ABT-095). From May to September (the growing season) monitoring is conducted between 5:00 am and 8:30 am, to capture the diurnal low in dissolved oxygen readings. In the non-growing season when dissolved oxygen does not vary as dramatically over the day, monitoring is conducted between about 6:00 am and 1:00 pm. Streamflow was calculated from stage readings of OARS’ gages using stage/discharge rating curves developed in cooperation with the United States Geological Survey (USGS) or recorded from the USGS real-time gage web pages.

Nutrient and suspended solids samples were taken using bottles supplied by the state certified laboratory under contract with OARS and were stored in the dark on ice during transport from the field to the lab. Samples were delivered to the laboratory within 24 hours of collection and analyzed within their respective hold-times. Chlorophyll-a samples were delivered to the laboratory within 4 hours of sampling and analyzed within their hold-times. In-situ readings of temperature, dissolved oxygen, pH, and conductivity were taken using multi-function YSI 6000-series meters (pre- and post-calibration done by OARS staff). To ensure that samples were representative of the bulk flow of the river in wadeable free-running sections, bottle samples and meter readings were taken from the main flow of the river at mid-depth where possible. Ten percent of the samples taken were duplicate field samples and 10% were field blanks of distilled water. Table 2, below, summarizes the parameters measured, laboratory methods and equipment used. Detailed descriptions of sampling methods and quality control measures are available in Quality Assurance Project Plan for OARS’ Water Quality and Quantity Monitoring Program (OARS, 2016b).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Analysis Method #</th>
<th>Equipment Range/Reporting Limits</th>
<th>Sampling Equipment</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>---</td>
<td>-5 to 45 degrees C</td>
<td>YSI 6000-series</td>
<td>---</td>
</tr>
<tr>
<td>pH</td>
<td>---</td>
<td>0 to 14 units</td>
<td>YSI 6000-series</td>
<td>---</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>---</td>
<td>0 to 50 mg/L</td>
<td>YSI 6000-series</td>
<td>---</td>
</tr>
<tr>
<td>Conductivity</td>
<td>---</td>
<td>0 to 1000 µS/cm</td>
<td>YSI 6000-series</td>
<td>---</td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>SM 2540D</td>
<td>1 mg/L</td>
<td>bottle</td>
<td>Nashoba Analytical</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>SM4500-P-E</td>
<td>0.01 mg/L</td>
<td>bottle</td>
<td>Nashoba Analytical</td>
</tr>
<tr>
<td>ortho-Phosphate</td>
<td>SM4500-P-E</td>
<td>0.01 mg/L</td>
<td>bottle</td>
<td>Nashoba Analytical</td>
</tr>
<tr>
<td>Nitrates</td>
<td>EPA 300.0</td>
<td>0.05 mg/L</td>
<td>bottle</td>
<td>Nashoba Analytical</td>
</tr>
<tr>
<td>Ammonia</td>
<td>SM4500-NH3-D</td>
<td>0.1 mg/L</td>
<td>bottle</td>
<td>Nashoba Analytical</td>
</tr>
<tr>
<td>Chlorophyll – a</td>
<td>SM 10200 H</td>
<td>2.00 µg/L – 100 µg/L</td>
<td>bottle</td>
<td>Alpha Analytical</td>
</tr>
</tbody>
</table>

Water quality measurements were compared with the Massachusetts Water Quality Standards (MA DEP, 2013). All segments of the Assabet are designated Class B/warm water fisheries.
River from the confluence of the Assabet and Sudbury to the Billerica drinking water withdrawal is designated Class B warm water fishery/treated drinking water supply. From the Billerica withdrawal to Rogers Street in Lowell, the Concord is designated Class B warm water fishery and the last segment (below OARS’ last sampling site) from Rogers Street in Lowell to its confluence with the Merrimack which is designated Class B (CSO)/warm water fishery. The Sudbury River from the outlet of Cedar Swamp Pond to Fruit Street, Hopkinton (not monitored as part of this project) is designated Class B/Oustanding Resource Water. From Fruit Street to the outlet of Saxonville Pond, Framingham, the Sudbury is designated Class B/warm water fishery. From the outlet of Saxonville Pond to its confluence with the Assabet, the Sudbury is designated Class B/aquatic life. All of the tributary streams assessed in this project are designated Class B waters. (For a full list of SuAsCo stream segment designations, see Appendix I.)

The MA Division of Fisheries and Wildlife lists 34 tributary streams in the basin as Coldwater Fisheries Resources (MA DFW, 2016) and MA DEP designates two tributary streams (an unnamed tributary of the Assabet River and the upper portion of Jackstraw Brook) as cold water fisheries (MA DEP, 2013). Since these and other tributary streams support or have supported cold water fisheries (Schlotterbeck 1954) it is useful to compare tributary dissolved oxygen and temperature measurements with cold water fisheries standards. For nutrient concentrations (where the Massachusetts standard is narrative) results were compared with EPA “Gold Book” total phosphorus criteria (US EPA, 1986) (Table 3) and with summertime data for Ecoregion XIV subregion 59 (US EPA, 2000) (Table 4).

Table 3: Water Quality Standards and Guidance for Use Support (MA DEP 2013)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard / Guidance Class B</th>
<th>Standard / Guidance Class B &quot;Aquatic Life&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen</td>
<td>≥ 5.0 mg/l for warm water fisheries, ≥ 6.0 mg/l for cold water fisheries</td>
<td>≥ 5.0 mg/l at least 16 hours of any 24-hour period and ≥ 3.0 mg/l at any time</td>
</tr>
<tr>
<td>pH</td>
<td>6.5 – 8.3 inland waters</td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td>&quot;control cultural eutrophication&quot; / Gold Book standard TP &lt; 0.05 mg/L for rivers entering a lake or impounded section</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>≤ 28.3°C and Δ &lt; 2.8°C for warm water fisheries, ≤ 20.0°C and Δ &lt; 1.7°C for cold water fisheries</td>
<td>≤ 29.4°C and Δ ≤ 2.8°C</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>&quot;free from floating, suspended and settleable solids in concentrations and combinations that would impair any use assigned to this Class&quot;</td>
<td></td>
</tr>
<tr>
<td>Aesthetics</td>
<td>All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Reference Conditions for Ecoregion XIV (59) Streams (US EPA 2000)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Phosphorus</td>
<td>25 μg/L</td>
<td>50 μg/L</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>0.44 mg/L</td>
<td>0.74 mg/L</td>
</tr>
<tr>
<td>NO2 + NO3</td>
<td>0.34 mg/L</td>
<td>0.43 mg/L</td>
</tr>
<tr>
<td>Chlorophyll a (Spec A method)</td>
<td>2.00 μg/L **</td>
<td>4.00 μg/L **</td>
</tr>
</tbody>
</table>

* EPA, 2000
** chlorophyll-a data is available only for subregion 63
River Reaches and Tributaries
All the sites tested for nutrients were in relatively free-flowing sections, where the water column is assumed to be well-mixed. In addition, three sites were added in 2014 for in-situ measurements within impounded sections of the river (ABT-162, ABT-134 and ABT-095). For data analysis, the sites are divided into sections (Table 1): (1) the upper Assabet mainstem, (2) the lower Assabet mainstem, (3) the Concord River mainstem, (4) the Sudbury River mainstem, (5) the Assabet headwater and all tributary sites (except HOP-016), and (5) “impounded” sites on the Assabet River. Because the headwaters site ABT-312 (Mill Street, Westborough) is upstream of the first wastewater treatment plant discharge, it is reported separately from the other Assabet River mainstem sites. Sites HOP-011 (Hop Brook), NTH-009 (North Brook), DAN-013 (Danforth Brook), ELZ-004 (Elizabeth Brook), NSH-047 (Nashoba Brook in Acton), and NSH-002 (Nashoba Brook) are all on tributaries to the Assabet River; RVM-005 (River Meadow Brook at Lowell) is on the largest tributary to the Concord River. HBS-016 (Hop/Landham Brook in Sudbury), a tributary to the Sudbury River, is reported separately from the other tributaries because it receives the discharge from the Marlborough Easterly wastewater treatment plant. Table 5 lists tributary and mainstem basin characteristics calculated using USGS’s StreamStats program.

Table 5: StreamStats Drainage Basin Statistics

<table>
<thead>
<tr>
<th>Headwater &amp; Tributary Streams</th>
<th>Statistics at Mouth of Tributary&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mainstem Rivers</th>
<th>Statistics near Mouth of River&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latitude/Longitude at Mouth of Tributary</td>
<td>Drainage Area (sq.mi.)</td>
<td>Stratified Drift Area (sq.mi.)</td>
</tr>
<tr>
<td>Assabet at Maynard St., Westboro</td>
<td>42.2741/-71.6322</td>
<td>6.79</td>
<td>1.64</td>
</tr>
<tr>
<td>Cold Harbor Brook, Northboro</td>
<td>42.3238/-71.6413</td>
<td>6.86</td>
<td>1.97</td>
</tr>
<tr>
<td>Danforth/ Mill Brook, Hudson</td>
<td>42.3897/-71.5666</td>
<td>7.17</td>
<td>2.06</td>
</tr>
<tr>
<td>Elizabeth Brook, Stow</td>
<td>42.4217/-71.4776</td>
<td>19.09</td>
<td>6.93</td>
</tr>
<tr>
<td>Fort Meadow Brook, Hudson</td>
<td>42.3975/-71.5169</td>
<td>6.25</td>
<td>1.76</td>
</tr>
<tr>
<td>Hop Brook, Northboro/Shrewsbury</td>
<td>42.2887/-71.6449</td>
<td>7.87</td>
<td>2.09</td>
</tr>
<tr>
<td>Hop Brook, Sudbury</td>
<td>42.3627/-71.3733</td>
<td>22.0</td>
<td>13.4</td>
</tr>
<tr>
<td>Nashoba Brook, Concord</td>
<td>42.4592/-71.3942</td>
<td>48.05</td>
<td>19.05</td>
</tr>
<tr>
<td>North Brook, Berlin</td>
<td>42.3576/-71.6188</td>
<td>16.89</td>
<td>4.12</td>
</tr>
<tr>
<td>River Meadow Brook, Lowell</td>
<td>42.6318/-71.3087</td>
<td>26.32</td>
<td>16.18</td>
</tr>
<tr>
<td>Assabet River, Concord</td>
<td>42.4652/-71.3596</td>
<td>177.81</td>
<td>73.00</td>
</tr>
<tr>
<td>Sudbury River, Concord</td>
<td>42.4637/-71.3578</td>
<td>162</td>
<td>49.13</td>
</tr>
<tr>
<td>Concord River, Lowell</td>
<td>42.6351/-71.3015</td>
<td>400.0</td>
<td>197.97</td>
</tr>
</tbody>
</table>

<sup>a</sup>Calculated using USGS’s StreamStats program (http://ststdmamrl.er.usgs.gov/streamstats/)

<sup>b</sup>Slope is the mean basin slope calculated from the slope of each grid cell in the designated sub-basin.
**Precipitation and Streamflow**

The watershed and region were affected by drought in 2016. Based on seven indices (Standardized Precipitation Index, Crop Moisture Index, Keetch-Byram Drought Index, Precipitation, Groundwater levels, Streamflow levels, and Index Reservoir levels (MA EEA, 2013)), MA EEA declared a “drought watch” for the Central and Northeast regions of the state in June 2016. In July 2016 the “watch” was raised to a “warning,” which continued through December 2016.

Precipitation, and the associated increased stormwater runoff and streamflow changes, are correlated with concentrations of total suspended solids, total phosphorus, and nitrate/nitrites. For the purposes of this project, sampling dates were classified by visual inspection of the hydrograph of the nearest available real-time USGS gage as rising, falling, or flat hydrograph (Table 6). Flow at the Sudbury River gage in Framingham is sometimes affected by dam manipulations upstream. Samples collected on a rising hydrograph are likely to include “first flush” runoff and the associated pollutants.

Sampling events that were preceded by more than 0.1 inches of rain (the standard definition of a “wet” weather sampling) are highlighted. Rainfall data (Table 6) was downloaded from the National Weather Service’s Worcester Airport station (http://www7.ncdc.noaa.gov/CDO/cdo).

**Table 6: Hydrographic and Precipitation Data 2016**

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>Hydrograph at USGS gage</th>
<th>Precip (inches) before sampling day</th>
<th>Precip. (inches) 24 - 48 hrs. before sampling day</th>
<th>Precip. (inches) sampling day (inc. hrs. after sampling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-Mar-2016</td>
<td>Peak (Assabet River at Maynard)</td>
<td>Peak (Sudbury at Framingham)</td>
<td>Rising (Concord at Lowell)</td>
<td>0.73</td>
</tr>
<tr>
<td>22-May-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Falling (Sudbury at Framingham)</td>
<td>Falling (Concord at Lowell)</td>
<td>0</td>
</tr>
<tr>
<td>19-Jun-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Flat (Sudbury at Framingham)</td>
<td>Falling (Concord at Lowell)</td>
<td>0</td>
</tr>
<tr>
<td>17-Jul-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Flat (Sudbury at Framingham)</td>
<td>Flat (Concord at Lowell)</td>
<td>0</td>
</tr>
<tr>
<td>20-Jul-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Flat (Sudbury at Framingham)</td>
<td>Flat (Concord at Lowell)</td>
<td>0</td>
</tr>
<tr>
<td>21-Aug-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Flat (Sudbury at Framingham)</td>
<td>Flat (Concord at Lowell)</td>
<td>0.28</td>
</tr>
<tr>
<td>18-Sep-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Flat (Sudbury at Framingham)</td>
<td>Flat (Concord at Lowell)</td>
<td>0.02</td>
</tr>
<tr>
<td>13-Nov-2016</td>
<td>Falling (Assabet River at Maynard)</td>
<td>Falling (Sudbury at Framingham)</td>
<td>Falling (Concord at Lowell)</td>
<td>0</td>
</tr>
</tbody>
</table>

Streamflow has a direct impact on the concentration of nutrients and suspended solids in the water column and the availability of aquatic habitat, and an indirect impact on water temperature, dissolved oxygen concentration, pH, and conductivity. Streamflows measured at the Assabet River gage in Maynard include effluent discharges from three of the four municipal wastewater treatment plants on the river; the three treatment plants discharged a combined average of 14.9 cfs/day to the river from May to October 2016 (EPA, 2017). While daily average wastewater discharge volume varies
Figure 2 shows groundwater levels compared with historic mean and maximum (deepest) levels from the USGS monitoring well in Acton (USGS 422812071244401 MA-ACW 158 ACTON, MA) over two years. From June to December 2016, groundwater levels were close to the record lows. Changes in groundwater levels reflect precipitation and evapo-transpiration rates and, in turn, affect baseflow to the streams.

Streamflow has a direct impact on the concentration of nutrients and suspended solids in the water column and the availability of aquatic habitat, and an indirect impact on water temperature, dissolved oxygen concentration, pH, and conductivity. Streamflows measured at the Assabet River gage in Maynard include effluent discharges from three of the four municipal wastewater treatment plants on the river; the three treatment plants discharged a combined average of 14.9 cfs/day to the river from May to October 2016 (EPA, 2017). While daily average wastewater discharge volume varies
with changing groundwater levels and rainfall amounts (due to inflow and infiltration), the variation is relatively small compared with the variation in streamflow at the gages used. Figure 3 shows the combined average daily discharge by month for the three upstream WWTPs for 2016.

Figures 4 & 5 and shows mean daily streamflows (for the year and for May to Oct) at the Assabet River and Sudbury River gages compared with the historic mean of the daily streamflows and the minimum daily flows for the period of record (calculated through the end of 2015). For comparison, the combined average daily discharge for the three upstream Assabet WWTPs is also shown on graph of summer Assabet streamflows.

In 2016, daily streamflows at all four USGS full-time gages were primarily below the 50th percentile throughout the year. New record minimum flows (for the period of record) were set at all four USGS full-time gages in the watershed (Table 7). Note that the Assabet River gage record period starts before the wastewater treatment plants were constructed and includes the drought of the 1960s, which may explain the difference in the number of record minimum flow days in 2016 at Assabet gage (3 days) in comparison to the Sudbury (78 days), and the Concord (50 days).

Table 7: 2016 Mean Daily Flows at USGS Gages Compared with Record

<table>
<thead>
<tr>
<th>USGS Gage Location</th>
<th>Period of Record</th>
<th>Days ≤ 10th Percentile Flows</th>
<th>Days ≤ Historic Min. Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assabet River, Maynard</td>
<td>1941-2016</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>Sudbury River, Saxonville</td>
<td>1979-2016</td>
<td>143</td>
<td>78</td>
</tr>
<tr>
<td>Concord River, Lowell</td>
<td>1936-2016</td>
<td>147</td>
<td>50</td>
</tr>
<tr>
<td>Nashoba Brook, Acton</td>
<td>1963-2016</td>
<td>147</td>
<td>55</td>
</tr>
</tbody>
</table>
Figure 4: Mean Daily Streamflows, Assabet River, 2016

Mean Daily Streamflows, Jan - Dec 2016
USGS Assabet River Gage, Maynard, MA

Mean Daily Streamflows, May - Oct 2016
USGS Assabet River Gage, Maynard, MA

Legend:
- Historic Mean Daily Flow
- Historic Min Flow (thru 2015)
- Mean Daily Flow
- Flow on OARS Sampling Date
- WWTP Average Daily Discharge
Figure 5: Mean Daily Streamflows, Sudbury River, 2016
Hydrographs for the Concord River gage in Lowell, and the Nashoba Brook gage in Acton (see Appendix II) show similar patterns to the Subury River’s gage. Flow at the Nashoba Brook gage was zero on 13 days. Monthly streamflows were also recorded at five tributary monitoring sites and near the Assabet River headwaters, above the first wastewater discharge (data in Appendix IV).

Water Quality Results

Reach and tributary statistics are summarized in Table 8, below. Individual parameters are discussed below.
Table 8: Mainstem Reach and Tributary Statistics

<table>
<thead>
<tr>
<th>Date</th>
<th>Reach</th>
<th># Sites</th>
<th>Time</th>
<th>Temp (°C)</th>
<th>DO % Sat</th>
<th>DO Conc (mg/L)</th>
<th>Cond (µS/cm)</th>
<th>pH</th>
<th>TSS (mg/L)</th>
<th>TP (mg/L)</th>
<th>ortho-P (mg/L)</th>
<th>NO3 (mg/L)</th>
<th>NH3 (mg/L)</th>
<th>Chl (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-Mar-16</td>
<td>Upper Assabet Mainstem</td>
<td>1</td>
<td>Single reading</td>
<td>3:21 PM</td>
<td>12.50</td>
<td>97.2</td>
<td>10.34</td>
<td>568</td>
<td>7.05</td>
<td>2</td>
<td>0.18</td>
<td>0.16</td>
<td>3.3</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Lower Assabet Mainstem</td>
<td>2</td>
<td>Median</td>
<td>1:36 PM</td>
<td>9.76</td>
<td>98.4</td>
<td>11.15</td>
<td>341</td>
<td>7.03</td>
<td>2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.82</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Sudbury Mainstem</td>
<td>2</td>
<td>Median</td>
<td>12:05 PM</td>
<td>9.28</td>
<td>98.3</td>
<td>11.26</td>
<td>375</td>
<td>7.13</td>
<td>4</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.34</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Concord Mainstem</td>
<td>2</td>
<td>Median</td>
<td>11:29 AM</td>
<td>9.59</td>
<td>98.8</td>
<td>11.25</td>
<td>369</td>
<td>7.09</td>
<td>4.5</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.52</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Headwater &amp; Tribs</td>
<td>7</td>
<td>Median</td>
<td>3:02 PM</td>
<td>11.44</td>
<td>98.4</td>
<td>10.72</td>
<td>255</td>
<td>7.09</td>
<td>1</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.2</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>22-May-16</td>
<td>Upper Assabet Mainstem</td>
<td>1</td>
<td>Single reading</td>
<td>7:30 AM</td>
<td>15.69</td>
<td>84.2</td>
<td>8.34</td>
<td>735</td>
<td>7.33</td>
<td>2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.4</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Lower Assabet Mainstem</td>
<td>2</td>
<td>Median</td>
<td>7:12 AM</td>
<td>17.87</td>
<td>89.0</td>
<td>8.42</td>
<td>552</td>
<td>7.29</td>
<td>3.5</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.4</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Assabet Impounded Sites</td>
<td>3</td>
<td>Median</td>
<td>7:09 AM</td>
<td>17.49</td>
<td>88.2</td>
<td>8.58</td>
<td>562</td>
<td>7.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sudbury Mainstem</td>
<td>5</td>
<td>Median</td>
<td>6:53 AM</td>
<td>17.69</td>
<td>91.3</td>
<td>8.4</td>
<td>503</td>
<td>7.25</td>
<td>6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.11</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Concord Mainstem</td>
<td>2</td>
<td>Median</td>
<td>6:50 AM</td>
<td>17.90</td>
<td>89.1</td>
<td>8.45</td>
<td>518</td>
<td>7.39</td>
<td>5.5</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.31</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Headwater &amp; Tribs</td>
<td>8</td>
<td>Median</td>
<td>7:17 AM</td>
<td>16.39</td>
<td>93.6</td>
<td>9.07</td>
<td>418</td>
<td>7.38</td>
<td>3</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.14</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Hop Brook, Sudbury</td>
<td>1</td>
<td>Single reading</td>
<td>6:21 AM</td>
<td>16.55</td>
<td>51.0</td>
<td>4.99</td>
<td>460</td>
<td>6.94</td>
<td>0.5</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.74</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>19-Jun-16</td>
<td>Upper Assabet Mainstem</td>
<td>3</td>
<td>Median</td>
<td>7:23 AM</td>
<td>18.88</td>
<td>87.5</td>
<td>8.11</td>
<td>863</td>
<td>7.24</td>
<td>2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>6.2</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Lower Assabet Mainstem</td>
<td>3</td>
<td>Median</td>
<td>6:25 AM</td>
<td>21.66</td>
<td>92.4</td>
<td>8.11</td>
<td>660</td>
<td>7.53</td>
<td>1</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.5</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Assabet Impounded Sites</td>
<td>3</td>
<td>Median</td>
<td>7:34 AM</td>
<td>22.02</td>
<td>84.7</td>
<td>7.45</td>
<td>822</td>
<td>7.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sudbury Mainstem</td>
<td>5</td>
<td>Median</td>
<td>6:27 AM</td>
<td>22.52</td>
<td>84.3</td>
<td>7.25</td>
<td>712</td>
<td>7.01</td>
<td>10</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.14</td>
<td>&lt;0.1, 11</td>
</tr>
<tr>
<td></td>
<td>Concord Mainstem</td>
<td>4</td>
<td>Median</td>
<td>7:01 AM</td>
<td>22.61</td>
<td>91.0</td>
<td>7.87</td>
<td>637</td>
<td>7.44</td>
<td>6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.6</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Headwater &amp; Tribs</td>
<td>8</td>
<td>Median</td>
<td>7:33 AM</td>
<td>19.21</td>
<td>82.4</td>
<td>7.72</td>
<td>511</td>
<td>7.22</td>
<td>7</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.14</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Hop Brook, Sudbury</td>
<td>1</td>
<td>Single reading</td>
<td>7:10 AM</td>
<td>19.19</td>
<td>39.8</td>
<td>3.68</td>
<td>603</td>
<td>6.95</td>
<td>6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.86</td>
<td>0.11</td>
</tr>
<tr>
<td>17-Jul-16</td>
<td>Upper Assabet Mainstem</td>
<td>3</td>
<td>Median*</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>8.7</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Lower Assabet Mainstem</td>
<td>3</td>
<td>Median*</td>
<td>6:55 AM</td>
<td>25.73</td>
<td>75.1</td>
<td>6.08</td>
<td>940</td>
<td>7.66</td>
<td>8</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.69</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Assabet Impounded Sites</td>
<td>3</td>
<td>Median*</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sudbury Mainstem</td>
<td>5</td>
<td>Median</td>
<td>6:55 AM</td>
<td>27.32</td>
<td>81.2</td>
<td>6.42</td>
<td>828</td>
<td>7.09</td>
<td>9</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.08</td>
<td>&lt;0.1, 16.3</td>
</tr>
<tr>
<td></td>
<td>Concord Mainstem</td>
<td>4</td>
<td>Median</td>
<td>6:53 AM</td>
<td>26.73</td>
<td>86.9</td>
<td>6.93</td>
<td>831</td>
<td>7.48</td>
<td>7</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.44</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Headwater &amp; Tribs</td>
<td>8</td>
<td>Median*</td>
<td>7:30 AM</td>
<td>24.20</td>
<td>60.4</td>
<td>5.12</td>
<td>585</td>
<td>7.23</td>
<td>5.5</td>
<td>0.03</td>
<td>0.02</td>
<td>0.23</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Hop Brook, Sudbury</td>
<td>1</td>
<td>Single reading</td>
<td>7:15 AM</td>
<td>25.70</td>
<td>8.3</td>
<td>0.66</td>
<td>678</td>
<td>6.9</td>
<td>6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>6.1</td>
<td></td>
</tr>
</tbody>
</table>
Table 8 (continued)

<table>
<thead>
<tr>
<th>Reach</th>
<th>Sites</th>
<th>statistic</th>
<th>Time</th>
<th>Temp (°C)</th>
<th>DO %</th>
<th>DO Conc (mg/L)</th>
<th>Cond (μS/cm)</th>
<th>pH</th>
<th>TSS (mg/L)</th>
<th>TP (mg/L)</th>
<th>ortho-P (mg/L)</th>
<th>NO3 (mg/L)</th>
<th>NH3 (mg/L)</th>
<th>Chl (μg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Assabet Mainstem</td>
<td>3</td>
<td>Median*</td>
<td>7:57 AM</td>
<td>21.61</td>
<td>86.1</td>
<td>7.56</td>
<td>1140</td>
<td>7.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assabet Impounded Sites</td>
<td>3</td>
<td>Median*</td>
<td>6:06 AM</td>
<td>22.26</td>
<td>80.2</td>
<td>6.95</td>
<td>958</td>
<td>7.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Assabet Mainstem</td>
<td>1</td>
<td>Single reading*</td>
<td>6:49 AM</td>
<td>25.38</td>
<td>84.2</td>
<td>6.88</td>
<td>1106</td>
<td>7.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headwater &amp; Tribs</td>
<td>4</td>
<td>Median*</td>
<td>7:59 AM</td>
<td>19.28</td>
<td>48.8</td>
<td>4.35</td>
<td>349</td>
<td>7.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Assabet Mainstem</td>
<td>3</td>
<td>Median</td>
<td>7:42 AM</td>
<td>23.03</td>
<td>71.1</td>
<td>6.08</td>
<td>1128</td>
<td>7.31</td>
<td>1</td>
<td>0.02</td>
<td>0.01</td>
<td>5.5</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Assabet Impounded Sites</td>
<td>3</td>
<td>Median</td>
<td>6:32 AM</td>
<td>22.79</td>
<td>75.1</td>
<td>6.21</td>
<td>1053</td>
<td>7.81</td>
<td>3</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.3</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Sudbury Mainstem</td>
<td>5</td>
<td>Median</td>
<td>6:22 AM</td>
<td>24.94</td>
<td>52.4</td>
<td>4.38</td>
<td>844</td>
<td>7.28</td>
<td>11</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.03</td>
<td>&lt;0.1</td>
<td>15.4</td>
</tr>
<tr>
<td>Concord Mainstem</td>
<td>4</td>
<td>Median</td>
<td>7:02 AM</td>
<td>24.86</td>
<td>71.8</td>
<td>6.00</td>
<td>948</td>
<td>7.70</td>
<td>6.5</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.44</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Headwater &amp; Tribs</td>
<td>8</td>
<td>Median</td>
<td>7:29 AM</td>
<td>22.34</td>
<td>57.5</td>
<td>4.76</td>
<td>561</td>
<td>7.04</td>
<td>3</td>
<td>0.02</td>
<td>0.02</td>
<td>0.28</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Hop Brook, Sudbury</td>
<td>1</td>
<td>Single reading</td>
<td>6:58 AM</td>
<td>22.31</td>
<td>6.8</td>
<td>0.60</td>
<td>755</td>
<td>6.93</td>
<td>9</td>
<td>0.12</td>
<td>0.08</td>
<td>0.03</td>
<td>0.11</td>
<td>3.4</td>
</tr>
<tr>
<td>Upper Assabet Mainstem</td>
<td>1</td>
<td>Single reading</td>
<td>8:17 AM</td>
<td>20.37</td>
<td>76.6</td>
<td>6.88</td>
<td>1503</td>
<td>7.25</td>
<td>2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>14.5</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Lower Assabet Mainstem</td>
<td>2</td>
<td>Median</td>
<td>8:13 AM</td>
<td>19.80</td>
<td>74.6</td>
<td>6.78</td>
<td>948</td>
<td>7.54</td>
<td>3</td>
<td>0.013</td>
<td>0.013</td>
<td>1.22</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Sudbury Mainstem</td>
<td>5</td>
<td>Median</td>
<td>8:23 AM</td>
<td>20.27</td>
<td>75.6</td>
<td>6.75</td>
<td>1350</td>
<td>7.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concord Mainstem</td>
<td>2</td>
<td>Median</td>
<td>7:41 AM</td>
<td>19.69</td>
<td>75.5</td>
<td>6.90</td>
<td>865</td>
<td>7.29</td>
<td>8</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.11</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Headwater &amp; Tribs</td>
<td>8</td>
<td>Median</td>
<td>8:18 AM</td>
<td>19.15</td>
<td>90.0</td>
<td>8.51</td>
<td>919</td>
<td>7.37</td>
<td>21</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>3.05</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Hop Brook, Sudbury</td>
<td>1</td>
<td>Single reading</td>
<td>8:15 AM</td>
<td>17.02</td>
<td>63.1</td>
<td>6.06</td>
<td>415</td>
<td>7.34</td>
<td>5.5</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>0.12</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Upper Assabet Mainstem</td>
<td>1</td>
<td>Single reading</td>
<td>9:43 AM</td>
<td>13.11</td>
<td>100.3</td>
<td>10.59</td>
<td>878</td>
<td>7.49</td>
<td>0.5</td>
<td>0.17</td>
<td>0.13</td>
<td>13.4</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Lower Assabet Mainstem</td>
<td>2</td>
<td>Median</td>
<td>8:56 AM</td>
<td>6.44</td>
<td>102.9</td>
<td>12.62</td>
<td>634</td>
<td>7.56</td>
<td>1.5</td>
<td>0.03</td>
<td>&lt;0.01</td>
<td>2.65</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Sudbury Mainstem</td>
<td>2</td>
<td>Median</td>
<td>7:01 AM</td>
<td>6.65</td>
<td>92.3</td>
<td>11.28</td>
<td>533</td>
<td>7.46</td>
<td>2.8</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.18</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Concord Mainstem</td>
<td>2</td>
<td>Median</td>
<td>8:47 AM</td>
<td>6.81</td>
<td>102.4</td>
<td>12.46</td>
<td>508</td>
<td>7.28</td>
<td>5</td>
<td>0.03</td>
<td>&lt;0.01</td>
<td>0.89</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>Headwater &amp; Tribs</td>
<td>7</td>
<td>Median</td>
<td>9:10 AM</td>
<td>5.14</td>
<td>94.0</td>
<td>12.00</td>
<td>289</td>
<td>7.52</td>
<td>2</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>0.25</td>
<td>&lt;0.1</td>
<td></td>
</tr>
</tbody>
</table>

NA = not sampled / not recorded
NR = data censored
* In-situ measurements for Upper Assabet sites, Assabet impounded sites, one Lower Assabet site, and 4 tributary sites were repeated on 20-July
Water Temperature, pH, and Conductivity

In-situ readings (including dissolved oxygen, water temperature, pH, and conductivity) in the summer months (May to Sept) were taken between about 5:30 am and 9:00 am, when dissolved oxygen concentrations are expected to be at their lowest for the day. Readings during the non-growing season (November and March) were taken between 8:00 am and 6:00 pm. Summary statistics for all in-situ readings are in Table 8 (above) and full data set is in Appendix IV.

Water temperatures at all sites met Class B warm water fisheries standard (28.3°C) on all of the regular testing dates in 2016.

Many of the tributary streams support or have supported cold water fisheries; therefore, tributary and headwater temperature readings are compared with the cold water standard (20.0°C). The recommended single-reading maxima for brook trout is 20.0°C and for brown trout is 23.9°C. In 2016, most sites exceeded 20.0°C in July and August; three sites exceeded 23.9°C in July and one site exceeded 23.9°C in August. Danforth Brook was not sampled in August because it was dry.

Figure 6: Temperatures in Tributaries and Assabet Headwater

The pH readings in ranged from 6.62 to 8.53 SU in 2016, with one site above the Class B standard on July 20th (ABT-095 pH reading 8.53 SU).

Conductivity is an indirect indicator of pollutants such as effluent, non-point source runoff (especially road salts) and erosion. EPA (http://water.epa.gov/type/rsl/monitoring/vms59.cfm) studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range
between 150 and 500 µS/cm. The range of mainstem conductivity readings was from 340 µS/cm to 1503 µS/cm in 2016 with the highest reading at Assabet at Rte 9 (ABT-301) in September. Among the tributary streams, conductivity ranged from 141–1648 µS/cm: the lowest reading was recorded at Danforth Brook in Sept; highest readings were recorded at RVM-005 in September (1648 µS/cm).

Dissolved Oxygen
Dissolved oxygen (DO) concentrations during the growing season are generally lowest between 5 am and 8 am after plant and microbial respiration has removed oxygen from the water column overnight. Low minimum DO concentrations and large diurnal variations in DO can indicate eutrophic conditions. Summary statistics for DO readings are in Table 8 and full data are in Appendix I. DO readings at the “impounded” sites (ABT-162, ABT-134, and ABT-095) were not substantially different from readings up and downstream of those sections. Water quality standards (WQS) violations (<5.0 mg/L for Class B; < 3.0 mg/L for Class B Aquatic Life for mainstem Sudbury sites) observed during the regular sampling are listed in Table 9. Note that low DO measurements may not constitute a violation of WQS if caused by natural conditions.

<table>
<thead>
<tr>
<th>Date</th>
<th>Site</th>
<th>Dissolved Oxygen (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/22/2016</td>
<td>HBS-016</td>
<td>4.99</td>
</tr>
<tr>
<td>6/19/2016</td>
<td>ELZ-004</td>
<td>4.30</td>
</tr>
<tr>
<td>6/19/2016</td>
<td>HBS-016</td>
<td>3.68</td>
</tr>
<tr>
<td>7/17/2016</td>
<td>HBS-016</td>
<td>0.66</td>
</tr>
<tr>
<td>7/17/2016</td>
<td>NSH-047</td>
<td>3.89</td>
</tr>
<tr>
<td>7/17/2016</td>
<td>NSH-002</td>
<td>3.17</td>
</tr>
<tr>
<td>7/20/2016</td>
<td>ABT-162</td>
<td>4.35</td>
</tr>
<tr>
<td>7/20/2016</td>
<td>DAN-013</td>
<td>3.37</td>
</tr>
<tr>
<td>7/20/2016</td>
<td>ELZ-004</td>
<td>3.16</td>
</tr>
<tr>
<td>8/21/2016</td>
<td>ABT-026</td>
<td>4.64</td>
</tr>
<tr>
<td>8/21/2016</td>
<td>ELZ-004</td>
<td>3.98</td>
</tr>
<tr>
<td>8/21/2016</td>
<td>HBS-016</td>
<td>0.60</td>
</tr>
<tr>
<td>8/21/2016</td>
<td>NSH-047</td>
<td>2.53</td>
</tr>
<tr>
<td>8/21/2016</td>
<td>NSH-002</td>
<td>1.00</td>
</tr>
<tr>
<td>9/18/2016</td>
<td>DAN-013</td>
<td>2.01</td>
</tr>
<tr>
<td>9/18/2016</td>
<td>HBS-016</td>
<td>0.77</td>
</tr>
<tr>
<td>9/18/2016</td>
<td>NSH-002</td>
<td>3.63</td>
</tr>
<tr>
<td>9/18/2016</td>
<td>NTH-009</td>
<td>4.61</td>
</tr>
</tbody>
</table>

For comparison between years and sections, Figure 7 shows median summer (June, July, and August) dissolved oxygen measurements for mainstem and tributary sections in 2009 - 2016. Hop Brook at Landham Road, Sudbury, has consistently low dissolved oxygen concentrations. The orange line indicates the minimum Class B water quality standard (5.0mg/l) and the red line indicates the minimum Class B Aquatic Life water quality standard (3.0mg/L).
Figure 7: Median Dissolved Oxygen Measurements

![Median Dissolved Oxygen Concentrations - Summers 2007-2016 Assabet, Sudbury, Concord, and Tributaries](image)

**Nutrients and Suspended Solids**

Summary statistics for nutrient concentrations are in Table 8 (pages 14-15). Median summer nutrient concentrations are shown (Figures 8 and 9) for the upper and lower Assabet mainstem reaches (see Table 1 for reach definitions), Sudbury mainstem sites, Concord mainstem sites, combined Assabet headwaters and tributary sites, and Hop Brook in Sudbury. This analysis includes all the sites sampled in 2016 (not just the long-term sites used in the trend analysis, below).

In 2016, the median summer TP concentration (0.02 mg/L), of all the Assabet River mainstem sites below the first wastewater discharge (Westborough WWTP) was below the EPA “Gold Book” recommendation (0.05 mg/L) and the Ecoregion reference condition for TP of 0.025 mg/L. The median summer NO3 concentration of all the Assabet mainstem sites was 1.5 mg/L, more than 4 times the Ecoregion reference condition of 0.34 mg/L.

The median summer TP concentration in the Concord River mainstem was 0.02 mg/L (below the Ecoregion reference condition and EPA “Gold Book” recommendation). The median summer nitrate concentration was 0.45 mg/L, slightly above the Ecoregion reference condition.

The median summer TP concentration in the Sudbury River was 0.02 mg/L (below the Ecoregion reference condition and EPA “Gold Book” recommendation); the median nitrate concentration was 0.08 mg/L (below the Ecoregion reference condition). The median summer TP concentration of the tributaries of all three rivers (excluding Hop Brook, Sudbury) was <0.01 mg/L. Hop Brook, Sudbury, which is affected by the wastewater discharge from Marlborough.
Easterly WWTP, and had a median summer TP concentration (0.07 mg/L) above both the “Gold Book” recommended concentration and the Ecoregion reference condition for total phosphorus.

Figure 8: Median Total Phosphorus Concentrations (Summers 2007-2016)

![Median Total Phosphorus Concentrations - Summers 2007-2016](image)

Figure 9: Median Nitrate Concentrations (Summers 2008-2016)

![Median Nitrate Concentrations - Summers 2007-2016](image)
Median total suspended solids (TSS) concentrations by section are shown in Figure 10. The highest single reading of TSS was in Nashoba Brook (NSH-047) in June (58 mg/L), which may have been sediment from the stream bottom in the sample since the stream was very shallow.

Figure 10: TSS by River Section, 2015

Chlorophyll a
Chlorophyll a is the principle photosynthetic pigment in algae and vascular plants; chlorophyll a concentrations give an estimate of the biomass of planktonic algae in the river and is one indicator of eutrophication. Rivers, like the Assabet, whose vegetation is dominated by larger rooted and floating aquatic plants may have low chlorophyll a concentrations although they are eutrophic. There is no numeric standard for chlorophyll in Massachusetts waters. The New Hampshire Department of Environmental Services categorizes chlorophyll a concentrations in rivers as follows (http://www2.des.state.nh.us/OneStop/docs/river_parm_desc.pdf):

Table 10: NH Chlorophyll Categories

<table>
<thead>
<tr>
<th>Chlorophyll a Categories</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 μg/L</td>
<td>Excellent</td>
</tr>
<tr>
<td>3 – 7 μg/L</td>
<td>Good</td>
</tr>
<tr>
<td>7 – 15 μg/L</td>
<td>Less than desirable</td>
</tr>
<tr>
<td>&gt; 15 μg/L</td>
<td>Nuisance</td>
</tr>
</tbody>
</table>

Chlorophyll a was measured on the Sudbury River and Hop Brook/Sudbury, in June, July, and August (Figure 11). (The Concord and Assabet Rivers are not sampled for chlorophyll a.) Concentrations ranged from <2.00 to 27.5 μg/L with 10 readings in the “less-than-desirable” to “nuisance” range. The highest reading was at the downstream-most Sudbury site, SUD-005. The upstream-most site (SUD-144) was in the “excellent” range on all three dates tested.
**Summer Nutrient Trends 1992 - 2016**

Summer (June, July, and August only) trends in nutrient concentrations in the two most-stable nutrient parameters (total phosphorus and nitrates) for the longest term sites was extended to include 2016. Sites that are less than 0.1 river miles apart and where there are no significant changes (e.g., tributaries joining) were considered the same. Table 11 lists the long-term sites used and their sections. Box plots for Assabet River sites are shown for 1997–2016 (omitting 1992–1997 data because of graphing software limitations).

**Table 11: Sites for Nutrient Trends Analysis**

<table>
<thead>
<tr>
<th>Section</th>
<th>Sites</th>
<th>Years Sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assabet Headwater</td>
<td>ABT-311 &amp; ABT-312</td>
<td>1992-2011 (ABT-311); 2012 – 2016 (ABT-312)</td>
</tr>
<tr>
<td>Middle Assabet</td>
<td>ABT-144*</td>
<td>1992 – 2016</td>
</tr>
<tr>
<td>Lower Assabet</td>
<td>ABT-077</td>
<td>1992-2016</td>
</tr>
<tr>
<td></td>
<td>ABT-026</td>
<td>1992-2016</td>
</tr>
<tr>
<td>Tributary Streams</td>
<td>HOP-011</td>
<td>2002-2016</td>
</tr>
<tr>
<td></td>
<td>NTH-009</td>
<td>2002-2016</td>
</tr>
<tr>
<td></td>
<td>DAN-013</td>
<td>2002-2016</td>
</tr>
<tr>
<td></td>
<td>ELZ-004</td>
<td>2002-2016</td>
</tr>
<tr>
<td></td>
<td>NSH-002</td>
<td>1995-2016</td>
</tr>
<tr>
<td>Lower Concord</td>
<td>CND-009</td>
<td>2004 - 2016</td>
</tr>
</tbody>
</table>

* ABT-144 site was moved from above to below the Gleasondale dam in 2002
Total phosphorus in the upper and lower Assabet River mainstem sites is shown in Figure 12 (note that the y-axis scale is different in the two graphs). Nitrate concentrations for the upper and lower Assabet River mainstem sites are shown in Figure 13. Total phosphorus and nitrate concentrations in the Assabet headwater site and five tributaries of the Assabet River are shown in Figures 14 and 15. The last of the wastewater treatment plant upgrades (needed, in part, to meet the lower phosphorus discharge limits stipulated in their 2005 permits) were completed by the spring of 2012.

The statistical significance of apparent summer trends in water quality were evaluated using a single season Mann-Kendall test (Helsel, 2006) computed on concentration and on flow-weighted concentration (using a locally weighted scatterplot smooth; LOWESS) and two date ranges (“all dates” 1993–2016 and “late” 1999–2016) where sufficient data were available. Assabet River streamflows from the USGS Assabet River gage in Maynard were used for the LOWESS smooth for the Assabet River sites; streamflows from the USGS Concord River gage in Lowell were used for the LOWESS smooth for the Concord River site. The test statistics are shown below each figure. (Full test statistics are in Appendix VI). Results were deemed significant for $p < 0.05$ with absolute value of Kendall tau $> 0.20$.

Otherwise, statistically significant trends were similar to previous findings:

- decreasing total phosphorus concentrations in the Assabet River (upper and middle sections) for both date ranges assessed
- decreasing ortho-phosphorus concentrations in the Assabet River (upper, middle and lower sections) between 1999 and 2016 (the only date range assessed for this parameter)
- weakly decreasing ortho-phosphorus concentrations in the Assabet tributaries and lower Concord River site (CND-009) in Lowell
- weakly increasing flow-weighted nitrate concentrations in the upper, middle, and lower Assabet for the whole date range assessed and in flow-weighted concentrations in the upper and middle Assabet in the later date range
- decreasing trends in nitrate concentrations in the tributaries
- nitrate concentrations in the Assabet Headwater site appeared to have a sharp decrease between 2006 and 2007 and then remained similar from 2007–2016
- increasing dissolved oxygen concentrations in the upper Assabet between 1999 and 2016; weakly increasing DO concentrations in the lower Assabet for the whole range of dates

No significant trends were found in streamflow at the Assabet River USGS gage on sampling dates for either range of dates tested.
Figure 12: Summer Total Phosphorus in Upper and Lower Assabet Mainstem

### Upper ABT
- **Concentration**
  - 1993-2016: $-0.661$, $-6616$, $-11.67$, $0.0000$, downward
  - 1999-2016: $-0.564$, $-3260$, $-8.656$, $0.0000$, downward
- **Flow-weighted**
  - 1993-2016: $-0.596$, $-5970$, $-10.53$, $0.0000$, downward
  - 1999-2016: $-0.549$, $-3238$, $-8.596$, $0.0000$, downward

### Middle ABT
- **Concentration**
  - 1993-2016: $-0.735$, $-1879$, $-9.132$, $0.0000$, downward
  - 1999-2016: $-0.621$, $-888$, $-6.662$, $0.0000$, downward
- **Flow-weighted**
  - 1993-2016: $-0.644$, $-1646$, $-7.997$, $0.0000$, downward
  - 1999-2016: $-0.549$, $-786$, $-5.857$, $0.0000$, downward

### Lower ABT
- **Concentration**
  - 1993-2016: $-0.593$, $-6107$, $-10.55$, $0.0000$, downward
  - 1999-2016: $-0.480$, $-2273$, $-7.374$, $0.0000$, downward
- **Flow-weighted**
  - 1993-2016: $-0.552$, $-5679$, $-9.809$, $0.0000$, downward
  - 1999-2016: $-0.444$, $-2567$, $-6.814$, $0.0000$, downward
### Summer Nitrates in Upper and Lower Assabet Mainstem

#### Upper Assabet Mainstem (ABT-301 & ABT-237)

<table>
<thead>
<tr>
<th>Section</th>
<th>Type</th>
<th>All dates</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>years</td>
<td>tau</td>
</tr>
<tr>
<td>Upper ABT</td>
<td>conc.</td>
<td>1993-2016</td>
<td>0.102</td>
</tr>
<tr>
<td>Upper ABT</td>
<td>flow-weighted</td>
<td>1993-2016</td>
<td>0.211</td>
</tr>
<tr>
<td>Middle ABT</td>
<td>conc.</td>
<td>1993-2016</td>
<td>0.166</td>
</tr>
<tr>
<td>Middle ABT</td>
<td>flow-weighted</td>
<td>1993-2016</td>
<td>0.352</td>
</tr>
<tr>
<td>Lower ABT</td>
<td>conc.</td>
<td>1993-2016</td>
<td>0.146</td>
</tr>
<tr>
<td>Lower ABT</td>
<td>flow-weighted</td>
<td>1993-2016</td>
<td>0.151</td>
</tr>
</tbody>
</table>

**NST** = no significant trend

---

### Nitrates - Mann-Kendall test statistics

**Figure 13:** Summer Nitrates in Upper and Lower Assabet Mainstem

- **Upper Assabet Mainstem (ABT-301 & ABT-237)**
- **Middle Assabet Mainstem (ABT-077 & ABT-026)**

**Data Range:** 1997-2016

- **Upper ABT conc.** (1993-2016): tau = 0.102, s = 859, z = 1.727, p = 0.0841, Trend = NST
- **Upper ABT flow-weighted** (1993-2016): tau = 0.211, s = 1767, z = 3.555, p = 0.0004, Trend = weak up
- **Middle ABT conc.** (1993-2016): tau = 0.166, s = 357, z = 1.972, p = 0.0486, Trend = weak up
- **Middle ABT flow-weighted** (1993-2016): tau = 0.352, s = 756, z = 4.178, p = 0.0000, Trend = upward
- **Lower ABT conc.** (1993-2016): tau = 0.146, s = 1261, z = 2.481, p = 0.0131, Trend = weak up
- **Lower ABT flow-weighted** (1993-2016): tau = 0.151, s = 1302, z = 2.56, p = 0.0105, Trend = weak up

- **NST** = no significant trend
Figure 14: Summer Total Phosphorus at Assabet Headwater & Tributaries

<table>
<thead>
<tr>
<th>Section Type</th>
<th>All dates</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>years</td>
<td>tau</td>
</tr>
<tr>
<td>Headwater ABT conc.</td>
<td>1993-2016</td>
<td>-0.011</td>
</tr>
<tr>
<td>Headwater ABT flow-weighted</td>
<td>1993-2016</td>
<td>0.019</td>
</tr>
<tr>
<td>Tributaries conc.</td>
<td>1993-2016</td>
<td></td>
</tr>
<tr>
<td>Tributaries flow-weighted</td>
<td>1993-2016</td>
<td></td>
</tr>
</tbody>
</table>

NST = no significant trend
Figure 15: Summer Nitrates at Assabet Headwater Site and Tributaries

<table>
<thead>
<tr>
<th>Section</th>
<th>Type</th>
<th>All dates</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>years</td>
<td>tau</td>
</tr>
<tr>
<td>Headwater ABT</td>
<td>conc.</td>
<td>1993-2016</td>
<td>-0.200</td>
</tr>
<tr>
<td>Headwater ABT</td>
<td>flow-weighted</td>
<td>1993-2016</td>
<td>-0.230</td>
</tr>
<tr>
<td>Tributaries</td>
<td>conc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tributaries</td>
<td>flow-weighted</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For comparison with in-stream conditions, wastewater treatment plant total phosphorus loads from 2007 to 2016 (from EPA’s Discharge Monitoring Report (DMR) Pollutant Loading Tool. EPA, 2017) are shown (Figure 16) for the WWTPs discharging to the Assabet River. Improvements in phosphorus removal dramatically reduced TP concentrations and total annual loads from the Assabet wastewater treatment plants between 2007 and about 2013. Total annual discharge flows decreased slightly (Figure 17) over the same time period; in 2016 total annual discharge flows were lower than previous years, perhaps because of the drought affecting the region in 2016.

Figure 16: Annual Load Total Phosphorus from WWTPs

![Annual Load Total Phosphorus from WWTPs 2007 - 2016](image)

Figure 17: Total Annual Flow from WWTPs

![Total Annual Flow from WWTPs 2007 - 2016](image)
Water Quality and Stream Health Index Calculations

The Stream Health Index was used to assess conditions at six of the tributary stream sites for each of the monthly (May to Sept) sampling results (Table 12). The Water Quality Index (a sub-index of the overall Stream Health Index) was also used to assess water quality at selected mainstem sites (Table 13) and Hop Brook, Sudbury, which don’t have streamflow data available.

OARS’ Stream Health Index is designed to characterize summertime fish habitat conditions in the small streams of the watershed. A full description of the index is available on the OARS webpage. Briefly, an index brings information from multiple data sources together into a single number, like a grade, that can be understood at a glance. As such, an index is a useful tool in making water quality, habitat and streamflow data accessible to the public and in assessing spatial and temporal trends.

For the Stream Health Index, measurements of streamflow, groundwater levels, channel flow status, dissolved oxygen, temperature, pH, total phosphorus, nitrates, and total suspended solids are scored from 1 (worst) to 100 (best). Streamflow data are scored against minimum summertime streamflow recommendations of several standard-setting methods. Water quality metrics are scored against published fish tolerances, Massachusetts surface water quality standards, and EPA criteria. Nutrient concentrations are scored against expected conditions for Ecoregion XIV. Channel flow status is scored using EPA’s Rapid Bioassessment Protocol. For all tributary stream sites, which support or have supported cold-water fish populations, temperature and dissolved oxygen readings were compared with Class B cold water standards. For mainstem Assabet and Concord sites, temperature and DO readings were compared with Class B warm water standards and Sudbury sites were compared with Class B “Aquatic Life” standards. These parameter scores are aggregated to give streamflow, water quality and habitat availability index scores; these three index scores are then aggregated into an overall stream health index. For posting, the index score was converted to a description: excellent (81–100), good (61–80), fair (41–60), poor (21–40), and very poor (1–20).

Tributary Stream Health Index: The lowest scoring months were July, August, and September 2016, when streamflows were very low. Streamflows at Danforth, Nashoba, and North Brook sites were below the rating curves at times during the summer.

Water Quality Index: Table 13 shows Water Quality Index readings for selected sites on the mainstem Assabet, Sudbury and Concord Rivers and on Hop Brook in Sudbury. At the Assabet River sites, nitrates were the lowest scoring parameters, driving the overall WQI score. The upper Assabet site, below the Westborough WWTP scored “very poor” on all dates tested because nitrate concentrations were high. The Assabet in Maynard scored “good” on all dates tested; nitrates were the lowest scoring parameter. The Concord River at Lowell Road, Concord (CND-161), generally scored “good,” with nitrates and total suspended solids the lowest scoring parameters. Nitrates at the Concord River site at Rogers Street, Lowell (CND-009) was the lowest-scoring parameter on all dates tested; water quality was rated “fair” to “poor” from June to September. Sudbury River sites were generally “good” to “excellent” with dissolved oxygen (during low flows) and total suspended solids the lowest scoring parameters. Dissolved oxygen was the lowest scoring parameters at the Hop Brook site in Sudbury, and overall water quality scored “very poor” in July, August, and September.
### Table 12: Stream Health Index Readings – Summer 2016

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assabet River Headwater, Mill Rd., Westborough (ABT-312)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>100</td>
<td>49</td>
<td>73</td>
<td>68</td>
<td>83</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>63</td>
<td>88</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>100</td>
<td>66</td>
<td>76</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>DO</td>
<td>89</td>
<td>76</td>
<td>83</td>
<td>74</td>
<td>82</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>63</td>
<td>68</td>
<td>66</td>
<td>42</td>
<td>65</td>
</tr>
<tr>
<td>Streamflow</td>
<td>75</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Groundwater</td>
<td>69</td>
<td>59</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Habitat</td>
<td>75</td>
<td>25</td>
<td>30</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Stream Health Index</td>
<td>78</td>
<td>23</td>
<td>22</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Danforth Brook, Rte 85, Hudson (DAN-013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>85</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>63</td>
<td>71</td>
<td>82</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>76</td>
<td>83</td>
<td>62</td>
<td>76</td>
<td>70</td>
</tr>
<tr>
<td>DO</td>
<td>85</td>
<td>77</td>
<td>48</td>
<td>40</td>
<td>68</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>71</td>
<td>43</td>
<td>28</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Streamflow</td>
<td>94</td>
<td>40</td>
<td>27</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Groundwater</td>
<td>69</td>
<td>59</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Habitat</td>
<td>80</td>
<td>70</td>
<td>45</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Stream Health Index</td>
<td>83</td>
<td>25</td>
<td>3</td>
<td>dry</td>
<td>7</td>
</tr>
<tr>
<td>Hop Brook, Civic Street, Northborough (HOP-011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>85</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>63</td>
<td>71</td>
<td>82</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>76</td>
<td>83</td>
<td>62</td>
<td>76</td>
<td>70</td>
</tr>
<tr>
<td>DO</td>
<td>85</td>
<td>77</td>
<td>48</td>
<td>40</td>
<td>68</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>71</td>
<td>43</td>
<td>28</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Streamflow</td>
<td>94</td>
<td>40</td>
<td>27</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Groundwater</td>
<td>69</td>
<td>59</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Habitat</td>
<td>80</td>
<td>70</td>
<td>45</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Stream Health Index</td>
<td>83</td>
<td>25</td>
<td>3</td>
<td>dry</td>
<td>7</td>
</tr>
<tr>
<td>Nashoba Br., Commonwealth Ave, W. Concord (NSH-002)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>63</td>
<td>97</td>
<td>76</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>71</td>
<td>19</td>
<td>100</td>
<td>63</td>
</tr>
<tr>
<td>TSS</td>
<td>83</td>
<td>32</td>
<td>30</td>
<td>46</td>
<td>25</td>
</tr>
<tr>
<td>DO</td>
<td>90</td>
<td>80</td>
<td>15</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>54</td>
</tr>
<tr>
<td>Temp</td>
<td>55</td>
<td>27</td>
<td>11</td>
<td>30</td>
<td>54</td>
</tr>
<tr>
<td>Streamflow</td>
<td>30</td>
<td>56</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Groundwater</td>
<td>69</td>
<td>59</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Habitat</td>
<td>70</td>
<td>80</td>
<td>30</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>Stream Health Index</td>
<td>59</td>
<td>62</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Nashoba Brook, Wheeler Ave, Acton (NSH-047)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>79</td>
<td>100</td>
<td>72</td>
<td>50</td>
<td>78</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>53</td>
<td>50</td>
<td>63</td>
<td>82</td>
</tr>
<tr>
<td>TSS</td>
<td>76</td>
<td>12</td>
<td>49</td>
<td>49</td>
<td>59</td>
</tr>
<tr>
<td>DO</td>
<td>78</td>
<td>65</td>
<td>27</td>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>pH</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>68</td>
<td>52</td>
<td>25</td>
<td>46</td>
<td>64</td>
</tr>
<tr>
<td>Streamflow</td>
<td>80</td>
<td>24</td>
<td>7</td>
<td>9</td>
<td>NR</td>
</tr>
<tr>
<td>Groundwater</td>
<td>69</td>
<td>59</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Habitat</td>
<td>95</td>
<td>80</td>
<td>36</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Stream Health Index</td>
<td>83</td>
<td>44</td>
<td>23</td>
<td>16</td>
<td>NR</td>
</tr>
<tr>
<td>North Brook, Whitney Ave, Berlin (NTH-009)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>94</td>
<td>89</td>
<td>100</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>70</td>
<td>76</td>
<td>53</td>
<td>83</td>
<td>76</td>
</tr>
<tr>
<td>DO</td>
<td>91</td>
<td>70</td>
<td>69</td>
<td>45</td>
<td>59</td>
</tr>
<tr>
<td>pH</td>
<td>99</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>74</td>
<td>51</td>
<td>11</td>
<td>27</td>
<td>61</td>
</tr>
<tr>
<td>Streamflow</td>
<td>100</td>
<td>NR</td>
<td>38</td>
<td>NR</td>
<td>11</td>
</tr>
<tr>
<td>Groundwater</td>
<td>69</td>
<td>59</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Habitat</td>
<td>85</td>
<td>70</td>
<td>55</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Stream Health Index</td>
<td>84</td>
<td>NR</td>
<td>45</td>
<td>NR</td>
<td>31</td>
</tr>
</tbody>
</table>

Key:
- 81 – 100 = Excellent
- 61 – 80 = Good
- 41 – 60 = Fair
- 21 – 40 = Poor
- 1 – 20 = Very Poor
### Table 13: Water Quality Index Readings – Selected Mainstem Sites, Summer 2016

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assabet at Rte 9 Westboro (ABT-301)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TP</td>
<td>71</td>
<td>57</td>
<td>71</td>
<td>82</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>83</td>
<td>83</td>
<td>83</td>
<td>96</td>
<td>83</td>
</tr>
<tr>
<td>DO</td>
<td>89</td>
<td>87</td>
<td>82</td>
<td>65</td>
<td>74</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>100</td>
<td>100</td>
<td>93</td>
<td>86</td>
<td>98</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>20</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Assabet at Rte 27 Maynard (ABT-077)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>24</td>
<td>29</td>
<td>45</td>
<td>31</td>
<td>38</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>82</td>
<td>100</td>
<td>100</td>
<td>82</td>
</tr>
<tr>
<td>TSS</td>
<td>70</td>
<td>70</td>
<td>51</td>
<td>70</td>
<td>24</td>
</tr>
<tr>
<td>DO</td>
<td>88</td>
<td>72</td>
<td>68</td>
<td>71</td>
<td>97</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>100</td>
<td>90</td>
<td>64</td>
<td>81</td>
<td>100</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>62</td>
<td>64</td>
<td>78</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td>Concord at Lowell Rd Concord (CND-161)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>100</td>
<td>40</td>
<td>57</td>
<td>48</td>
<td>29</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>82</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>66</td>
<td>70</td>
<td>51</td>
<td>70</td>
<td>24</td>
</tr>
<tr>
<td>DO</td>
<td>89</td>
<td>72</td>
<td>68</td>
<td>71</td>
<td>97</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>100</td>
<td>90</td>
<td>64</td>
<td>81</td>
<td>100</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>90</td>
<td>69</td>
<td>69</td>
<td>74</td>
<td>52</td>
</tr>
<tr>
<td>Concord at Rogers St Lowell (CND-009)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>46</td>
<td>31</td>
<td>14</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>71</td>
<td>50</td>
<td>63</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>62</td>
<td>44</td>
<td>26</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>DO</td>
<td>92</td>
<td>89</td>
<td>77</td>
<td>57</td>
<td>83</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>100</td>
<td>88</td>
<td>65</td>
<td>77</td>
<td>100</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>76</td>
<td>59</td>
<td>35</td>
<td>41</td>
<td>27</td>
</tr>
<tr>
<td>Sudbury at Sudbury Landing Framingham (SUD-144)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>87</td>
<td>92</td>
<td>100</td>
<td>87</td>
<td>68</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>83</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>DO</td>
<td>97</td>
<td>88</td>
<td>65</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>91</td>
<td>93</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>100</td>
<td>88</td>
<td>59</td>
<td>77</td>
<td>100</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>94</td>
<td>96</td>
<td>89</td>
<td>83</td>
<td>88</td>
</tr>
<tr>
<td>Sudbury at Main St. Concord (SUD-005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>71</td>
<td>100</td>
<td>82</td>
<td>100</td>
</tr>
<tr>
<td>TSS</td>
<td>56</td>
<td>51</td>
<td>51</td>
<td>49</td>
<td>56</td>
</tr>
<tr>
<td>DO</td>
<td>100</td>
<td>83</td>
<td>69</td>
<td>49</td>
<td>80</td>
</tr>
<tr>
<td>pH</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temp</td>
<td>100</td>
<td>88</td>
<td>59</td>
<td>77</td>
<td>100</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>88</td>
<td>78</td>
<td>74</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Hop Brook at Landham Rd Sudbury (HBS-016)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO3</td>
<td>41</td>
<td>37</td>
<td>100</td>
<td>100</td>
<td>28</td>
</tr>
<tr>
<td>TP</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>38</td>
<td>71</td>
</tr>
<tr>
<td>TSS</td>
<td>100</td>
<td>62</td>
<td>62</td>
<td>53</td>
<td>83</td>
</tr>
<tr>
<td>DO</td>
<td>44</td>
<td>24</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>pH</td>
<td>98</td>
<td>98</td>
<td>96</td>
<td>97</td>
<td>91</td>
</tr>
<tr>
<td>Temp</td>
<td>67</td>
<td>51</td>
<td>8</td>
<td>31</td>
<td>57</td>
</tr>
<tr>
<td>Water Quality Index</td>
<td>65</td>
<td>44</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

**Key:**

- 81 – 100 = Excellent
- 61 – 80 = Good
- 41 – 60 = Fair
- 21 – 40 = Poor
- 1 – 20 = Very Poor
Aquatic Plant Biomass Sampling
Three large impoundments of the Assabet River, Massachusetts, were visually surveyed for aquatic plant biomass using a grid-based system between mid-August and early September each year starting in 2007. Goals of the ongoing project are to assess the nature and extent of aquatic plant biomass in the major impoundments of the Assabet River to add to the multi-year database to assess changes in the river’s condition and assess progress in achieving the TMDL goal (MA DEP, 2004): “a substantial reduction in total biomass of at least 50% from July 1999 values is considered a minimum target for achieving designated uses.”

Biomass Survey Methods
These surveys have focused on three large impoundments of the Assabet River, as the most eutrophic areas of the river. Impoundment locations include: (1) Hudson impoundment (off Rte 85), Hudson, about 0.5 miles upstream from the dam at Rte. 85; (2) Gleasondale impoundment, Stow, about 0.6 miles upstream from the dam near Rte. 62; and (3) Ben Smith impoundment, Maynard, about 0.7 miles upstream from the dam near Rte. 62/117.

The rivers are divided into observation grids, extending the grid system originally developed by USGS for MassDEP duckweed monitoring in 2007 (USGS 2011). Using this method, visual observations were conducted by OARS staff from a kayak or canoe, at the peak of the growing season each summer starting in 2007. Observations were recorded in the field using hand-held GIS/GPS devices (Spectra Precision MobileMappers). A viewing tube (“Aquascope”) and/or plant rake was used in some locations to help estimate the percent volume of the water column filled with plants and identification of species. At each grid cell the following observations were recorded:

- water depth (measured with weighted tape)
- visual assessments of
  - total percent coverage of floating plants
  - percent coverage of duckweed (Lemna minor) ignoring the other floating plants
  - percent volume of the grid’s water column filled with submerged plants
  - percent coverage of emergent plants
- dominant and other species in each category (floating, submerged, and emergent)
- presence of invasive species

To compare conditions between years and between impoundments, total wet weight of the floating plant biomass was calculated for each impoundment. Field estimates of total floating plant cover were converted to consistent classes (0 = 0% coverage, 1 = 1–25% coverage, 2 = 25–50% coverage, 3 = 50–75% coverage, 4 = 75–99% coverage, 5 = 100% coverage); the total grid surface area (from GIS) for each class was summed for each impoundment; finally, total floating biomass wet weight was calculated using conversion factors developed by OARS (Figure 18). Caveat: these conversion factors were developed on mixture of floating and rooted aquatic plants, so biomass is relative, i.e. comparable within this analysis but not with other analyses.
Figure 18: Class vs. Biomass Wet Weight

![Graph showing Class vs. Biomass](image18)

**Biomass Results**

The calculated wet weight of total floating biomass for the Hudson, Gleasondale, and Ben Smith impoundments from 2007 to 2016 is shown in Figure 19. Because aquatic plant growth is strongly affected by summer weather conditions, mean of the monthly mean air temperatures for May to August (from the National Weather Service Worcester Regional Airport station) are also shown. This survey is semi-quantitative, shows some inter-annual variation that coincides with variation in summer air temperature and rainfall, and is subject to changes in dominant vegetation type that are not adequately accounted for in the general biovolume to biomass conversion.

Figure 19: Total Floating Aquatic Plant Biomass Wet Weight

![Graph showing Total Floating Aquatic Plant Biomass](image19)

Figures 20-22 show floating plant biomass in the Ben Smith, Gleasondale, and Hudson impoundments in 2016. The camera icon indicates the approximate position of the inset photo.
Figure 20: Total Floating Biomass, Ben Smith, August 26, 2016
Figure 21: Total Floating Biomass, Gleasondale Impoundment, August 25, 2016
Figure 22: Total Floating Biomass, Hudson Impoundment, August 29, 2016
Summary

This report presents the water quality, streamflow, and aquatic plant biomass data OARS collected on the Assabet, Sudbury, and Concord Rivers and tributary streams in 2016 (March, May, June, July, August, September, and November) and extends the trend analysis of the nutrient data for the longest-running sites in the Assabet River watershed.

The watershed and region were affected by drought in 2016. Based on seven indices (Standardized Precipitation Index, Crop Moisture Index, Keetch-Byram Drought Index, Precipitation, Groundwater levels, Streamflow levels, and Index Reservoir levels (MA EEA, 2013)), MA EEA declared a “drought watch” for the Central and Northeast regions of the state in June 2016. In July 2016 the “watch” was raised to a “warning,” which continued through December 2016.

In 2016, daily streamflows at all four USGS full-time gages were primarily below the 50th percentile throughout the year. New record minimum flows (for the period of record) were set at all four USGS full-time gages in the watershed. Note that the Assabet River gage record period starts before the wastewater treatment plants were constructed and includes the drought of the 1960s, which may explain the difference between the number of record minimum flow days in 2016 at Assabet gage (3) in comparison to the Sudbury (78), and the Concord (50).

“Wet” sampling events (i.e., preceded by more than 0.1 inches of rain) in 2016 were March and August. Despite the 0.28 inches of rain in the 24-48 hours preceding the August 21st sampling the hydrographs at all four USGS gages were essentially flat that day.

Water temperatures at all sites met Class B warm water fisheries standard (28.3°C) on all of the regular testing dates in 2016. Many of the tributary streams support or have supported cold water fisheries; therefore, tributary and headwater temperature readings are also compared with the cold water standard. The recommended single-reading maxima for brook trout is 20.0°C and for brown trout is 23.9°C. In 2016, all tributary sites tested had water temperatures above 20.0°C in July and August. Hop Brook (HBS-016), Nashoba Brook (NSH-002), and North Brook (NTH-009) exceeded 23.9°C in July. In August, the sampling site at Danforth Brook (DAN-013) was dry, and therefore not tested.

The pH readings in ranged from 6.62 to 8.53 SU in 2016, with one site above the Class B standard on July 20th (ABT-095 pH reading 8.53 SU).

The range of mainstem conductivity readings was from 340 μS/cm to 1503 μS/cm in 2016 with the highest reading at Assabet at Rte 9 (ABT-301) in September. Among the tributary streams, conductivity ranged from 141–1648 μS/cm: the lowest reading was recorded at Danforth Brook in September; highest readings were recorded at River Meadow Brook (RVM-005) in September (1648 μS/cm).

Dissolved oxygen concentrations at the mainstem sites met Water Quality Standards of ≥ 5.0 mg/L for Class B or ≥ 3.0 mg/L for Class B Aquatic Life on all sampling dates except ABT-162 in July and ABT-026 in August. However, with very low streamflows, DO concentrations in the tributary streams
failed to meet Water Quality Standards on 16 occasions. (See Table 10, page 17.) The lowest DO reading was at Hop Brook (HBS-016) on August 21st (0.60 mg/L).

**Nutrients and suspended solids** In 2016, the median summer TP concentration (0.02 mg/L), of all the Assabet River mainstem sites below the first wastewater discharge (Westborough WWTP) was below the EPA “Gold Book” recommendation (0.05mg/L) and the Ecoregion reference condition for TP of 0.025 mg/L. The median summer NO3 concentration of all the Assabet mainstem sites was 1.5 mg/L, more than 4 times the Ecoregion reference condition of 0.34 mg/L.

The median summer TP concentration in the Concord River mainstem was 0.02 mg/L (below the Ecoregion reference condition and EPA “Gold Book” recommendation). The median summer nitrate concentration was 0.45 mg/L, slightly above the Ecoregion reference condition. 

The median summer TP concentration in the Sudbury River was 0.02 mg/L (below the Ecoregion reference condition and EPA “Gold Book” recommendation); the median nitrate concentration was 0.08 mg/L (below the Ecoregion reference condition).

The median summer TP concentration of the tributaries of all three rivers (excluding Hop Brook, Sudbury) was <0.01 mg/L. Hop Brook, Sudbury, which is affected by the wastewater discharge from Marlborough Easterly WWTP, and had a median summer TP concentration (0.07 mg/L) above both the “Gold Book” recommended concentration and the Ecoregion reference condition for total phosphorus.

The highest single reading of total suspended solids was in Nashoba Brook (NSH-047) in June (58 mg/L), which may have been sediment from the stream bottom in the sample since the stream was very shallow.

**Chlorophyll a** was measured on the Sudbury River and Hop Brook/Sudbury, in June, July, and August. Concentrations ranged from <2.00 to 27.5 µg/L with 10 readings in the “less-than-desirable” to “nuisance” range. The highest reading was at the downstream-most Sudbury site, SUD-005. The upstream-most site (SUD-144) was in the “excellent” range on all three dates tested.

**Nutrient Trends:** The analysis of summer (June, July, and August) nutrient concentration trends in the two most-stable nutrient parameters (total phosphorus and nitrates) was extended to include 2016. Two date ranges were assessed: 1993–2016 (“all dates”), and 1999–2016 (“late”). Statistically significant trends were similar to previous findings:

- decreasing total phosphorus concentrations in the Assabet River (upper and middle sections) for both date ranges assessed
- decreasing ortho-phosphorus concentrations in the Assabet River (upper, middle and lower sections) between 1999 and 2016 (the only date range assessed for this parameter)
- weakly decreasing ortho-phosphorus concentrations in the Assabet tributaries and lower Concord River site (CND-009) in Lowell
- weakly increasing flow-weighted nitrate concentrations in the upper, middle, and lower Assabet for the whole date range assessed and in flow-weighted concentrations in the upper and middle Assabet in the later date range
- decreasing trends in nitrate concentrations in the tributaries
- nitrate concentrations in the Assabet Headwater site appeared to have a sharp decrease between 2006 and 2007 and then remained similar from 2007–2016
- increasing dissolved oxygen concentrations in the upper Assabet between 1999 and 2016; weakly increasing DO concentrations in the lower Assabet for the whole range of dates

No significant trends were found in dissolved oxygen and no significant trends were found in streamflow at the Assabet River USGS gage on sampling dates.

**Tributary Stream Health Index:** Stream Health Index scores were calculated for small streams where flow data was collected: Assabet River headwater, Hop Brook in Northborough, North Brook in Berlin, Danforth Brook in Hudson, and Nashoba Brook in Concord and in Acton. The lowest scoring months were July - September, when streamflows were very low. There were a number of sampling dates when the full Stream Health Index could not be calculated because streamflows were below the sites stage/flow rating curve or were dry.

**Water Quality Index:** Water Quality Index (WQI) scores were calculated for selected sites on the mainstem Assabet, Sudbury and Concord Rivers and on Hop Brook in Sudbury. At the two Assabet River mainstem sites nitrates were the lowest scoring parameters. The upper Assabet site, below the Westborough WWTP scored “very poor” May through September, with nitrates scoring the lowest. The Assabet in Maynard generally scored “good.” The Concord River in Concord generally scored “good,” with nitrates and total suspended solids the lowest scoring parameters. The Concord River in Lowell scored “fair” in June and August, but “poor” in July and September, with nitrates the lowest scoring parameter. Sudbury River sites were generally “good” to “excellent” with dissolved oxygen and total suspended solids the lowest scoring parameters. Dissolved oxygen followed by total phosphorus and temperature were the lowest scoring parameters at the Hop Brook site in Sudbury, and the brook scored “very poor” in July, August and September.

The wet weight of total floating biomass was calculated for the Ben Smith, Gleasondale, and Hudson impoundments. This survey is semi-quantitative, shows some inter-annual variation that coincides with variation in summer air temperature and rainfall, and is subject to changes in dominant vegetation type that are not adequately accounted for in the general biovolume to biomass conversion. Therefore it will likely take a much longer dataset to determine whether the eutrophication of the impounded sections of the Assabet has improved in response to reductions in total phosphorus discharged from the wastewater treatment plants.
References


OAR. 2009a. Quality Assurance Project Plan for StreamWatch: OAR’s Water Quality and Quantity Monitoring Program (approved 7/20/09)


Glossary of Terms

**Adaptive Management:** the process by which new information about a watershed is incorporated into the watershed management plan. Ideally, adaptive management is a combination of research, monitoring, and practical management that allows "learn by doing." It is a useful tool because of the uncertainty about how ecosystems function and how management affects ecosystems. More: [http://www.epa.gov/owow/watershed/wacademy/wam/step5.html](http://www.epa.gov/owow/watershed/wacademy/wam/step5.html)

**Ammonia (NH₃):** a form of nitrogen available for uptake by plants and microorganisms. Sources include the breakdown of organic nitrogen in sediments and untreated sewage. Other sources of ammonia include: fertilizer, home cleaning products and food processing. While ammonia can be readily utilized by plants, high concentrations of ammonia are directly toxic to aquatic life. A secondary effect of increased ammonia occurs when bacteria oxidize the NH₃ to NO₃, a process called nitrification, consuming four atoms of oxygen for every atom of nitrogen converted. This process can dramatically lower dissolved oxygen in the water.

**Baseflow:** the flow of water from aquifers into the streambed. In natural systems in New England baseflow makes up most of the river flow during the summer.

**Channel Flow Status:** an estimation of the amount of the streambed that is covered with water. Method from the EPA Rapid Bioassessment Protocol.

**Class B:** Massachusetts Class B, sometimes referred to as “fishable, swimmable,” is one of the state’s designations of “appropriate water uses to be achieved and protected” under the federal Clean Water Act. For more information about the federal requirements on water quality standards: [http://water.epa.gov/scitech/swguidance/standards/index.cfm](http://water.epa.gov/scitech/swguidance/standards/index.cfm). For the Massachusetts Surface Water Quality Standards: [http://www.mass.gov/dep/service/regulations/314cmr04.pdf](http://www.mass.gov/dep/service/regulations/314cmr04.pdf).

**Conductivity:** the ability of the water to conduct an electrical charge. Conductivity is a rough indicator of the presence of pollutants such as: wastewater from wastewater treatment plants or septic systems; non-point source runoff (especially road salts); and soil erosion. Reported in microSiemens per centimeter (µS/cm), conductivity is measured by applying a constant voltage to one nickel electrode and measuring the voltage drop across 1 cm of water. The flow of electrical current (I) through the water is proportional to the concentration of dissolved ions in the water - the more ions, the more conductive the water and the higher the “conductivity.” Since conductivity in water is also temperature dependent the results are often reported as “specific conductivity,” which is the raw conductivity measurement adjusted to 25° C.

**Dissolved Oxygen:** the presence of oxygen gas molecules (O₂) in the water, reported as percent saturation (% sat) or in milligrams per liter (mg/L). The concentration of dissolved oxygen (DO) in the water column provides a direct indication of the water’s ability to support aquatic life like fish and macroinvertebrates. Aquatic plants and bacteria in the sediments remove dissolved oxygen from the water when they respire (plants respire mainly at night). Therefore, the lowest dissolved oxygen concentrations of the day occur in the early in the morning. During the day plants add oxygen to the water column through photosynthesis. Both extreme (low or high) DO concentrations and large changes in DO concentrations over the day (diurnal variation) are damaging to the habitat.
**Ecoregion**: An area over which the climate is sufficiently uniform to permit development of similar ecosystems on sites that have similar properties. According to EPA, the ecoregions are “designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components.” More information on the New England Ecoregions: [http://www.epa.gov/wed/pages/ecoregions/new_eng_eco.htm](http://www.epa.gov/wed/pages/ecoregions/new_eng_eco.htm)

**Eutrophic**: abundant in nutrients and having high rates of productivity frequently resulting in oxygen depletion below the surface layer.

**Eutrophication and Cultural Eutrophication**: Eutrophication is the enrichment of bodies of fresh water by inorganic plant nutrients (e.g. nitrate, phosphate). It may occur naturally but can also be the result of human activity (cultural eutrophication from fertilizer runoff and sewage discharge) and is particularly evident in slow-moving rivers and shallow lakes.

**Hydrograph**: A graph showing stage, flow, velocity, or other property of water with respect to time. More hydrographic definitions: [http://water.usgs.gov/wsc/glossary.html#TOC](http://water.usgs.gov/wsc/glossary.html#TOC)


**Impoundment**: A body of water contained by a barrier such as a dam; characterized by an inlet and an outlet stream.

**Mainstem**: The main channel of a river, as opposed to the streams and smaller rivers that feed into it.

**Mesotrophic**: having a nutrient loading resulting in moderate productivity.

**Nitrogen**: a major nutrient supporting plant growth. Nitrogen is measured in its various forms as nitrate (NO$_3$), nitrite (NO$_2$), ammonia (NH$_3$), and total Kjeldahl nitrogen (TKN). Total nitrogen is calculated as the sum of TKN and nitrates. Available nitrogen, calculated as the sum of nitrate and ammonia, gives a measure of the nitrogen readily available for absorption by plants. Once absorbed, nitrogen is incorporated into proteins, amino acids, nucleic acids, and other molecules. Although most aquatic plant growth in rivers is limited by the availability of phosphorus, increased nitrogen availability can also lead to algal blooms.

**Oligotrophic**: having a small supply of nutrients, low production of organic matter, low rates of decomposition, and high dissolved oxygen in the lower layers of the water column.

**Phosphorus**: Plants need nutrients to grow; in particular they need a balance of phosphorus (P) and nitrogen (N). Phosphorus is measured as total phosphorus (TP) and ortho-phosphate (ortho-P; soluble inorganic phosphate, the form required by plants). In most fresh waters, the concentration of phosphorus available to plants is low enough that the plants cannot grow at their maximum rate. But in water bodies like the Assabet, where human activities add phosphorus to the environment, the added phosphorus allows much greater growth of aquatic plants (eutrophic conditions).
**pH**: the negative log of the hydrogen ion concentration in water, a measure of the acidity of water. pH is measured on a logarithmic scale from 1 to 14, with 1 being very acidic, 7 being neutral, and 14 being very basic. Extreme pHs, in either direction, can be toxic to fish and other aquatic life and play a role in the behavior of other pollutants such as heavy metals in the environment. Changes in pH can be the result of acid rain/snow, chemicals entering the waterways, or algal blooms.

**Sediment phosphorus flux**: the exchange of phosphorus between the sediment layer and the overlying water column. Whether the sediments are a nutrient sink or source depends on the composition of the sediments and the condition of the overlying water column. Particularly, under anoxic conditions, phosphorus tends to be released from the sediments.

**Stage and streamflow** measure the amount of water in the river. Stage is the height of the water above the riverbed, and is read at staff gages on the mainstem river and at sites on six tributaries. Streamflow (also called discharge) is the volume of water passing a given point in the river (reported in cubic feet per second, “cfs”). Streamflow is measured on the mainstem Assabet in Maynard, Sudbury in Framingham, and Concord in Lowell at USGS gages and is reported on the USGS web page. Streamflow on the tributary streams is calculated from staff gage readings taken by OARS volunteers using a rating curve.

**Stage-discharge rating (aka “rating curve”)**: the relationship between stage (water height) and discharge (streamflow). The rating curve is determined empirically by making a series of streamflow measurements at different stages and analyzing the graphed results (figure below).

![Stage-discharge rating](image)

**Temperature** affects the ecosystem in a number of ways: many organisms, especially cool water fish, are sensitive to high temperatures; the solubility of oxygen is lower in warmer water, decreasing the supply of dissolved oxygen; algae, weeds, and pathogenic microorganisms can all grow faster in warmer water.

**TMDL**: Total Maximum Daily Loading, defined under the federal Clean Water Act, is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. More: [http://www.epa.gov/owow/tmdl/overviewoftmdl.html](http://www.epa.gov/owow/tmdl/overviewoftmdl.html)
Total suspended solids (TSS): the amount of silt, clay, organic material and algae in the water. Sources include erosion and the solids in effluent. Once in the water column, suspended solids are transported downstream and settle gradually, along with decaying plant matter, to form thick organic-rich sediments in the slower sections of the river.

Tributary: A stream or river whose water flows into a larger stream, river, or lake.
# Appendix I: Water Quality Designations for the SuAsCo Rivers and Streams

Excerpted from 314 CMR 4.00 : DIVISION OF WATER POLLUTION CONTROL

<table>
<thead>
<tr>
<th><strong>Sudbury River</strong></th>
<th><strong>Concord River</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boundary</strong></td>
<td><strong>Mile Point</strong></td>
</tr>
<tr>
<td>Source to Fruit Street Bridge, Hopkinton</td>
<td>29.1</td>
</tr>
<tr>
<td>Fruit Street Bridge to Outlet to Saxonville Pond</td>
<td>29.1 - 16.2</td>
</tr>
<tr>
<td>Outlet Saxonville Pond to Hop Brook confluence</td>
<td>16.2 - 10.6</td>
</tr>
<tr>
<td>Hop Brook confluence to Assabet River confluence</td>
<td>10.6 - 0.00</td>
</tr>
<tr>
<td>Denney Brook, Jackstraw Brook, Picadilly Brook, Rutters Brook and Whitehall Brook</td>
<td></td>
</tr>
<tr>
<td>Hop Brook source to Sudbury River confluence</td>
<td>9.7 – 0.0</td>
</tr>
<tr>
<td><strong>Confluence of the Assabet and Sudbury to Billerica water supply intake</strong></td>
<td>31.8 - 30.4</td>
</tr>
<tr>
<td><strong>Billerica water supply intake to Rogers St.</strong></td>
<td>30.4 – 12.4</td>
</tr>
<tr>
<td><strong>Rogers Street to confluence Merrimack River</strong></td>
<td>12.4 – 0.0</td>
</tr>
</tbody>
</table>

---

*WQ Final Report 2016 - Appendix I*
<table>
<thead>
<tr>
<th>Stream Name</th>
<th>SARIS #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranberry Brook</td>
<td>8247885</td>
</tr>
<tr>
<td>Danforth Brook</td>
<td>8247275</td>
</tr>
<tr>
<td>Flagg Brook</td>
<td>8247225</td>
</tr>
<tr>
<td>Great Brook</td>
<td>8247175</td>
</tr>
<tr>
<td>Hayward Brook</td>
<td>8248000</td>
</tr>
<tr>
<td>Hog Brook</td>
<td>8247325</td>
</tr>
<tr>
<td>Hop Brook (1)</td>
<td>8247600</td>
</tr>
<tr>
<td>Hop Brook (2)</td>
<td>8247825</td>
</tr>
<tr>
<td>Howard Brook</td>
<td>8247525</td>
</tr>
<tr>
<td>Jackstraw Brook</td>
<td>8248475</td>
</tr>
<tr>
<td>Landham (Allowance) Brook</td>
<td>8247900</td>
</tr>
<tr>
<td>Nagog Brook</td>
<td>8246900</td>
</tr>
<tr>
<td>North Brook</td>
<td>8247375</td>
</tr>
<tr>
<td>Piccadilly Brook</td>
<td>8248450</td>
</tr>
<tr>
<td>Pine Brook</td>
<td>8247950</td>
</tr>
<tr>
<td>Rawson Hill Brook</td>
<td>8247575</td>
</tr>
<tr>
<td>Run Brook</td>
<td>8247875</td>
</tr>
<tr>
<td>Second Division Brook</td>
<td>8247075</td>
</tr>
<tr>
<td>Sheepsfall Brook</td>
<td>8247250</td>
</tr>
<tr>
<td>UNT to A-1 Site (1) (Nourse Brook)</td>
<td>8247627</td>
</tr>
<tr>
<td>UNT to A-1 Site (2)</td>
<td>8247628</td>
</tr>
<tr>
<td>UNT to Assabet River</td>
<td>8247260</td>
</tr>
<tr>
<td>UNT to Cranberry Brook</td>
<td>8247886</td>
</tr>
<tr>
<td>UNT to Great Brook</td>
<td>8247180</td>
</tr>
<tr>
<td>UNT to Hog Brook</td>
<td>8247327</td>
</tr>
<tr>
<td>UNT to Hop Brook</td>
<td>8247879</td>
</tr>
<tr>
<td>UNT to Hop Brook (2, 1; Trout Brook)</td>
<td>8247830</td>
</tr>
<tr>
<td>UNT to Hop Brook (2, 3)</td>
<td>8247855</td>
</tr>
<tr>
<td>NT to Nashoba Brook</td>
<td>8246876</td>
</tr>
<tr>
<td>UNT to North Brook</td>
<td>8247435</td>
</tr>
<tr>
<td>UNT to Pine Brook</td>
<td>8247965</td>
</tr>
<tr>
<td>UNT to Second Division Brook</td>
<td>8247076</td>
</tr>
<tr>
<td>UT (NOURSE BROOK)</td>
<td>8248530</td>
</tr>
<tr>
<td>Wrack Meadow Brook</td>
<td>8247440</td>
</tr>
</tbody>
</table>
Appendix II: Streamflow Data from USGS Gages
(see Fig. 4 for Assabet and Sudbury River Mean Daily Streamflows)

Mean Daily Streamflows: Concord River USGS gage, Lowell, MA

Mean Daily Streamflows: Nashoba Brook USGS gage, Acton, MA
Appendix III: Data Quality Notes

OARS’ data quality objectives and data qualifiers are listed below. When streamflows from OARS gages are reported as “>”, the streamflow is above the ranged of the gage’s rating curve. Full QC details are available in OARS’ Quality Assurance/Quality Control documents on request.

Data Qualifiers

<table>
<thead>
<tr>
<th>Data Qualifiers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>not sampled or not reported</td>
</tr>
<tr>
<td>P</td>
<td>provisional data (QA/QC not yet performed)</td>
</tr>
<tr>
<td>Q</td>
<td>data met most but not all QA/QC requirements</td>
</tr>
<tr>
<td>NR</td>
<td>not reported/ data censored</td>
</tr>
</tbody>
</table>

Qualified or censored data for 2016 includes:

<table>
<thead>
<tr>
<th>Date</th>
<th>Parameter</th>
<th>Qualified/ Censored</th>
<th>Sites</th>
<th>Problem / Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/19/16</td>
<td>Cond</td>
<td>Qualified</td>
<td>RVM-005</td>
<td>Reading higher than highest standard (&gt;1000μS/cm)</td>
</tr>
<tr>
<td>7/17/16</td>
<td>Dissolved oxygen, temp, cond, pH</td>
<td>Qualified</td>
<td>ABT-237, ABT-301, ABT-312, HOP-011</td>
<td>Readings taken after 10am. All reading re-taken on 7/20/16.</td>
</tr>
<tr>
<td>7/17/16</td>
<td>Dissolved oxygen</td>
<td>Censored</td>
<td>ABT-077, ABT-095, ABT-134, ABT-144, ABT-162</td>
<td>DO failed post-field calibration check</td>
</tr>
<tr>
<td>7/17/16</td>
<td>Cond</td>
<td>Qualified</td>
<td>ABT-095, ABT-134, ABT-144, ABT-162, ABT-237, ABT-301, HOP-011, RVM-005</td>
<td>Reading higher than highest standard (&gt;1000μS/cm)</td>
</tr>
<tr>
<td>8/21/16</td>
<td>Cond</td>
<td>Qualified</td>
<td>ABT-026, ABT-062, ABT077, ABT-095, ABT-134, ABT-144, ABT-237, ABT-301, RVM-005</td>
<td>Reading higher than highest standard (&gt;1000μS/cm)</td>
</tr>
<tr>
<td>9/18/16</td>
<td>Cond</td>
<td>Qualified</td>
<td>ABT-077, ABT-095, ABT-134, ABT-162, ABT-301, HOP-011, RVM-005, SUD-144</td>
<td>Reading higher than highest standard (&gt;1000μS/cm)</td>
</tr>
<tr>
<td>All dates</td>
<td>Streamflow</td>
<td>Qualified</td>
<td>NSH-002, DAN-013, NTH-009, HOP-011, ABT-312</td>
<td>Rating curves have not be re-checked</td>
</tr>
</tbody>
</table>
### Data Quality Objectives

<table>
<thead>
<tr>
<th>Instrument/Laboratory</th>
<th>Parameter</th>
<th>Data Quality Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>Field Precision</td>
<td>Lab Precision&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Instrument/Laboratory</strong></td>
<td><strong>Parameter</strong></td>
<td><strong>Temperature</strong></td>
</tr>
<tr>
<td>YSI 6000-series Thermistor probe</td>
<td>temperature</td>
<td>± 1 °C</td>
</tr>
<tr>
<td>YSI 6000-series Glass Electrode</td>
<td>pH</td>
<td>± 0.2 S.U. at pH 7.00</td>
</tr>
<tr>
<td>YSI 6000-series Rapid Pulse</td>
<td>DO</td>
<td>± 5% at 100% saturation</td>
</tr>
<tr>
<td>YSI 6000-series 4-electrode cell</td>
<td>Conductivity</td>
<td>± 50 µS/cm at 0 and 1000 µS/cm</td>
</tr>
<tr>
<td>Nashoba Analytical</td>
<td>TSS</td>
<td>85-115% recovery of lab fortified blank</td>
</tr>
<tr>
<td>Nashoba Analytical</td>
<td>TP</td>
<td>85-115% recovery of lab fortified blank</td>
</tr>
<tr>
<td>Nashoba Analytical</td>
<td>ortho – P</td>
<td>85-115% recovery of lab fortified blank</td>
</tr>
<tr>
<td>Nashoba Analytical</td>
<td>NO3</td>
<td>85-115% recovery of lab fortified blank</td>
</tr>
<tr>
<td>Nashoba Analytical</td>
<td>NH3</td>
<td>85-115% recovery of lab fortified blank</td>
</tr>
<tr>
<td>Alpha Analytical</td>
<td>Chlorophyll &lt;i&gt;a&lt;/i&gt;</td>
<td>75 – 125% recovery of lab QC sample (with known Chl &lt;i&gt;a&lt;/i&gt; content)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Lab Precision for field parameters is evaluated by comparing side-by-side meter readings in a bucket of river water.
Appendix IV: Water Quality Data
(contact OARS for full data set)
## Appendix V: Aquatic Plant Biomass Survey Data 2005 - 2016

<table>
<thead>
<tr>
<th>Section</th>
<th>Class 0 Wet Wt (kg)</th>
<th>Class 1 Wet Wt (kg)</th>
<th>Class 2 Wet Wt (kg)</th>
<th>Class 3 Wet Wt (kg)</th>
<th>Class 4 Wet Wt (kg)</th>
<th>Class 5 Wet Wt (kg)</th>
<th>Total Wet Wt (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hudson Impoundment</td>
<td>2005: 14359</td>
<td>9529</td>
<td>11424</td>
<td>2297</td>
<td>4593</td>
<td>7907</td>
<td>18597</td>
</tr>
<tr>
<td></td>
<td>2006: 27233</td>
<td>6617</td>
<td>3337</td>
<td>3923</td>
<td>7846</td>
<td>4491</td>
<td>12823</td>
</tr>
<tr>
<td></td>
<td>2007: 23466</td>
<td>10020</td>
<td>12464</td>
<td>16708</td>
<td>33415</td>
<td>3623</td>
<td>10344</td>
</tr>
<tr>
<td></td>
<td>2008: 46928</td>
<td>20038</td>
<td>2442</td>
<td>2432</td>
<td>4864</td>
<td>2385</td>
<td>6810</td>
</tr>
<tr>
<td></td>
<td>2009: 32268</td>
<td>13778</td>
<td>10903</td>
<td>2453</td>
<td>4906</td>
<td>1241</td>
<td>3542</td>
</tr>
<tr>
<td></td>
<td>2010: 28152</td>
<td>12021</td>
<td>328</td>
<td>389</td>
<td>5638</td>
<td>11276</td>
<td>3330</td>
</tr>
<tr>
<td></td>
<td>2011: na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>2012: 4268</td>
<td>5064</td>
<td>23204</td>
<td>27520</td>
<td>5861</td>
<td>11723</td>
<td>3071</td>
</tr>
<tr>
<td></td>
<td>2013: 6091</td>
<td>1405</td>
<td>13083</td>
<td>15516</td>
<td>5776</td>
<td>11551</td>
<td>8919</td>
</tr>
<tr>
<td></td>
<td>2014: 2582</td>
<td>6041</td>
<td>16239</td>
<td>19259</td>
<td>3417</td>
<td>6835</td>
<td>5187</td>
</tr>
<tr>
<td></td>
<td>2015: 11269</td>
<td>4812</td>
<td>14562</td>
<td>3918</td>
<td>7837</td>
<td>15675</td>
<td>44752</td>
</tr>
<tr>
<td></td>
<td>2016: 3005</td>
<td>4961</td>
<td>12369</td>
<td>14670</td>
<td>0</td>
<td>3298</td>
<td>9418</td>
</tr>
<tr>
<td></td>
<td>2005: 28956</td>
<td>15603</td>
<td>2873</td>
<td>3408</td>
<td>444</td>
<td>887</td>
<td>648</td>
</tr>
<tr>
<td></td>
<td>2006: 45966</td>
<td>8586</td>
<td>944</td>
<td>1119</td>
<td>417</td>
<td>8341</td>
<td>1178</td>
</tr>
<tr>
<td></td>
<td>2007: 5600</td>
<td>18872</td>
<td>4219</td>
<td>5004</td>
<td>4770</td>
<td>9540</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2008: 15954</td>
<td>22617</td>
<td>4799</td>
<td>5692</td>
<td>1081</td>
<td>2162</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2009: 45010</td>
<td>4741</td>
<td>6890</td>
<td>8172</td>
<td>7976</td>
<td>15951</td>
<td>3823</td>
</tr>
<tr>
<td></td>
<td>2010: 14329</td>
<td>11016</td>
<td>6351</td>
<td>7533</td>
<td>11656</td>
<td>23311</td>
<td>8779</td>
</tr>
<tr>
<td></td>
<td>2011: 17858</td>
<td>22043</td>
<td>591</td>
<td>701</td>
<td>3657</td>
<td>7314</td>
<td>1073</td>
</tr>
<tr>
<td></td>
<td>2012: 10212</td>
<td>9231</td>
<td>20419</td>
<td>24217</td>
<td>6242</td>
<td>12483</td>
<td>4728</td>
</tr>
<tr>
<td></td>
<td>2013: 26352</td>
<td>15806</td>
<td>6088</td>
<td>7220</td>
<td>1000</td>
<td>1999</td>
<td>3198</td>
</tr>
<tr>
<td></td>
<td>2014: 2643</td>
<td>16961</td>
<td>25551</td>
<td>30303</td>
<td>2047</td>
<td>4093</td>
<td>1511</td>
</tr>
<tr>
<td></td>
<td>2015: 12746</td>
<td>16638</td>
<td>13520</td>
<td>16035</td>
<td>1067</td>
<td>2133</td>
<td>7439</td>
</tr>
<tr>
<td></td>
<td>2016: 0</td>
<td>9901</td>
<td>26492</td>
<td>31421</td>
<td>4817</td>
<td>9635</td>
<td>7202</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ben Smith Impoundment</th>
<th>Class 0 Wet Wt (kg)</th>
<th>Class 1 Wet Wt (kg)</th>
<th>Class 2 Wet Wt (kg)</th>
<th>Class 3 Wet Wt (kg)</th>
<th>Class 4 Wet Wt (kg)</th>
<th>Class 5 Wet Wt (kg)</th>
<th>Total Wet Wt (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005: 15675</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2006: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2007: 15675</td>
<td>7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
</tr>
<tr>
<td>2008: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2009: 15675</td>
<td>7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
</tr>
<tr>
<td>2010: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2011: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2012: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2013: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2014: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2015: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
<tr>
<td>2016: 7202</td>
<td>7439</td>
<td>1511</td>
<td>4728</td>
<td>12483</td>
<td>13498</td>
<td>11581</td>
<td>43799</td>
</tr>
</tbody>
</table>
### Total Area (sq. meters) by Coverage Class; Calculated Wet Weight

<table>
<thead>
<tr>
<th>Section</th>
<th>Class 0 Wet Wt (kg)</th>
<th>Class 1 Wet Wt (kg)</th>
<th>Class 2 Wet Wt (kg)</th>
<th>Class 3 Wet Wt (kg)</th>
<th>Class 4 Wet Wt (kg)</th>
<th>Class 5 Wet Wt (kg)</th>
<th>Total Wet Wt (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gleasondale Impoundment</td>
<td>2005</td>
<td>24626</td>
<td>1991</td>
<td>850</td>
<td>2056</td>
<td>2438</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>12402</td>
<td>6518</td>
<td>2783</td>
<td>3523</td>
<td>4179</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>0</td>
<td>19821</td>
<td>8464</td>
<td>6015</td>
<td>7134</td>
<td>3937</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>2293</td>
<td>24230</td>
<td>10346</td>
<td>3619</td>
<td>4292</td>
<td>1869</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>19768</td>
<td>0</td>
<td>9029</td>
<td>3855</td>
<td>3061</td>
<td>3631</td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>9355</td>
<td>0</td>
<td>9656</td>
<td>4123</td>
<td>3365</td>
<td>3991</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>7226.6</td>
<td>0</td>
<td>16156</td>
<td>6898</td>
<td>2856</td>
<td>3387</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>8105.9</td>
<td>0</td>
<td>8338</td>
<td>3561</td>
<td>6315</td>
<td>7491</td>
</tr>
<tr>
<td></td>
<td>2016</td>
<td>5206.3</td>
<td>0</td>
<td>15306</td>
<td>6536</td>
<td>5026.5</td>
<td>5961</td>
</tr>
</tbody>
</table>

Conversion Factors (based on mean OARS field measurements and trend line):
Biomass (g/m²): Class 0 = 0 g/m²; Class 1 = 427 g/m²; Class 2 = 1186 g/m²; Class 3 = 2000 g/m²; Class 4 = 2855 g/m²; Class 5 = 3782 g/m².

Area * class conversion factor /1000 = total wet weight in kilograms.