OARS

FOR THE ASSABET SUDBURY & CONCORD RIVERS

Water Quality Monitoring Program Final Report: 2016 Field Season

January 2017

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.

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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

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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.

Water quality reports for 1999–2015 (OAR 2000b, OAR 2001, OAR 2002, OAR 2003b, OAR 2004, OAR 2005, OAR 2006b, OAR 2007, OAR 2009, OARS 2011, OARS 2013, OARS 2015, OARS 2016) and 2005 biomass sampling project (OAR 2006a) are available on OARS' website (http://www.oars3rivers.org/river/waterquality/reports). Full data is available upon request.

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 phosphorous 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.

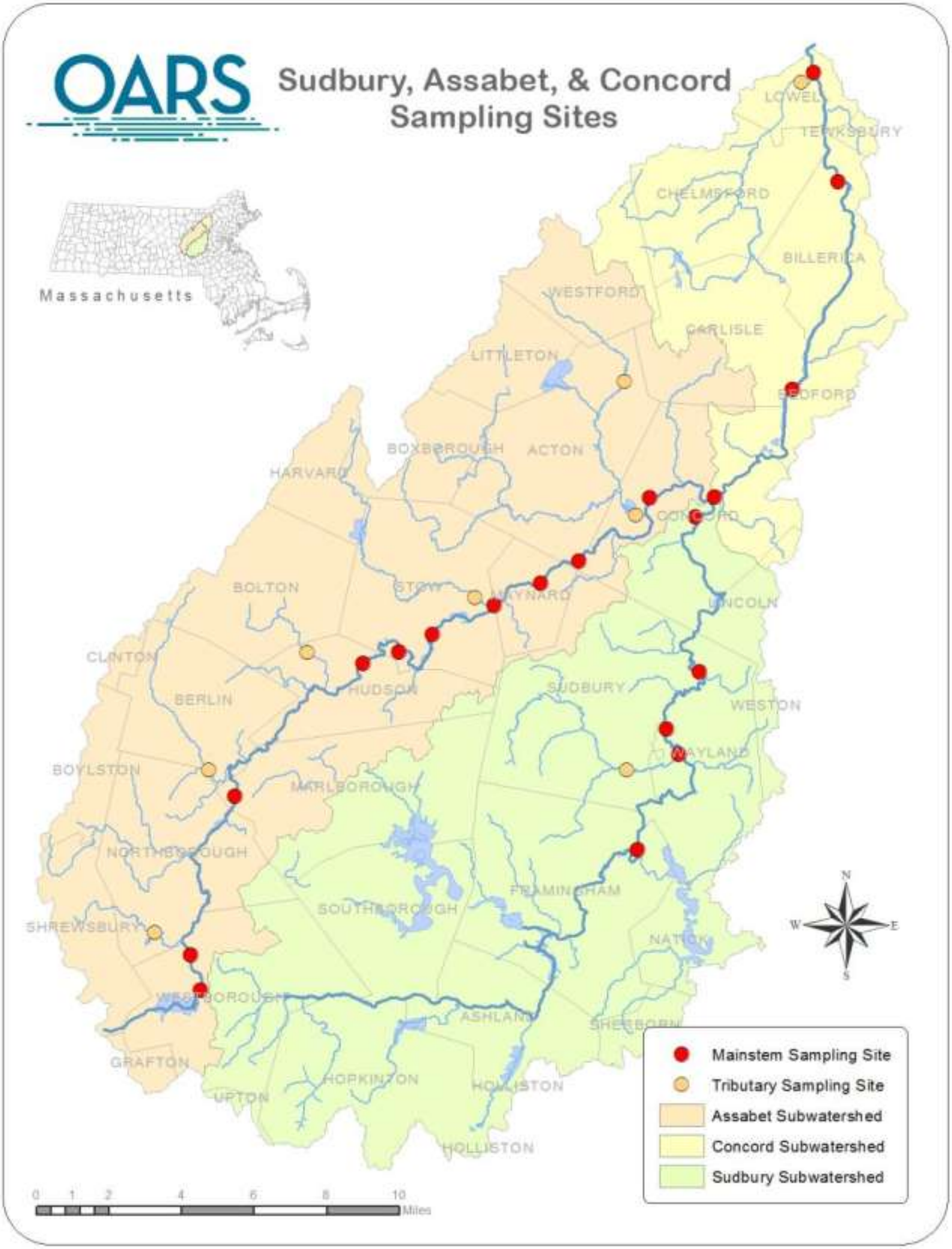
Because of these problems, OARS (formerly the Organization for the Assabet River) conducts water quality, streamflow, and aquatic plant biomass monitoring on the mainstems and large tributaries of the Assabet, Sudbury, and Concord rivers. Without the support and work of its volunteers, OARS would not 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

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

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 5:00am 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 2: Sampling and Analysis Methods

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

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. The Concord

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/Outstanding 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)

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

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

Nutrient Parameter	Aggregate Nutrient Ecoregion XIV (subregion 59) Reference Conditions* (25th percentile of June - September data)	Aggregate Nutrient Ecoregion XIV (subregion 59) Reference Conditions* (50th percentile of June - September data)
Total Phosphorus	25 μg/L	50 μg/L
Total Nitrogen	0.44 mg/L	0.74 mg/L
NO2 + NO3	0.34 mg/L	0.43 mg/L
Chlorophyll *a* (Spec A method)	2.00 μg/L **	4.00 μg/L **

* 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, (4) 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

	Statistics at Mouth of Tributary[a]				
Headwater & Tributary Streams	Latitude/Longitude at Mouth of Tributary	Drainage Area (sq.mi.)	Stratified Drift Area (sq.mi.)	% area stratified drift	Slope [b] (%)
Assabet at Maynard St., Westboro	42.2741/-71.6322	6.79	1.64	24.15	3.61
Cold Harbor Brook, Northboro	42.3238/-71.6413	6.86	1.97	28.72	5.01
Danforth/ Mill Brook, Hudson	42.3897/-71.5666	7.17	2.06	28.73	3.58
Elizabeth Brook, Stow	42.4217/-71.4776	19.09	6.93	36.30	3.73
Fort Meadow Brook, Hudson	42.3975/-71.5169	6.25	1.76	28.16	3.77
Hop Brook, Northboro/Shrewsbury	42.2887/-71.6449	7.87	2.09	26.56	3.57
Hop Brook, Sudbury	42.3627/-71.3733	22.0	13.4	61.14	2.44
Nashoba Brook, Concord	42.4592/-71.3942	48.05	19.05	39.65	2.29
North Brook, Berlin	42.3576/-71.6188	16.89	4.12	24.39	4.38
River Meadow Brook, Lowell	42.6318/-71.3087	26.32	16.18	61.47	1.91
Mainstem Rivers	**Statistics near Mouth of River[a]**				
Assabet River, Concord	42.4652/-71.3596	177.81	73.00	41.06	3.01
Sudbury River, Concord	42.4637/-71.3578	162	49.13	30.33	2.52
Concord River, Lowell	42.6351/-71.3015	400.0	197.97	49.49	2.63

[a] Calculated using USGS's StreamStats program (http://ststdmamrl.er.usgs.gov/streamstats/)
[b] 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

	Hydrograph at USGS gage			Precip (inches) before sampling day	
Sampling Date	Assabet River at Maynard	Sudbury at Framingham	Concord at Lowell	Precip. (inches) 24 - 48 hrs. before sampling day	Precip. (inches) sampling day (inc. hrs. after sampling)
17-Mar-2016	**Peak**	**Peak**	**Rising**	**0.73**	**0.13**
22- May-2016	Falling	Fallling	Falling	0	0
19-Jun-2016	Falling	Flat	Falling	0	0
17-Jul-2016	Falling	Flat	Flat	0	0
20-Jul-2016	Falling	Flat	Flat	0	0.03
21-Aug-2016	**Falling**	**Flat**	**Flat**	**0.28**	**0**
18- Sep-2016	Falling	Flat	Flat	0.02	0
13-Nov-2016	Falling	Falling	Falling	0	0

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 upsteam 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 comparision, the combined average daily discharge for the three upstream Assabet WWTPs is also shown on graph of summer Assabet streamflows.

Figure 2: Groundwater Levels (USGS Monitoring Well Acton, MA)

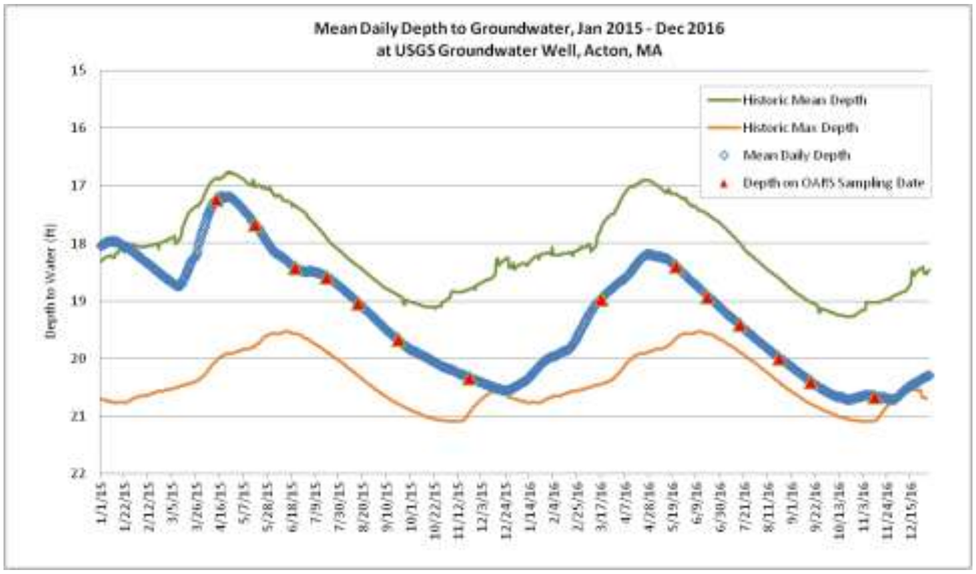
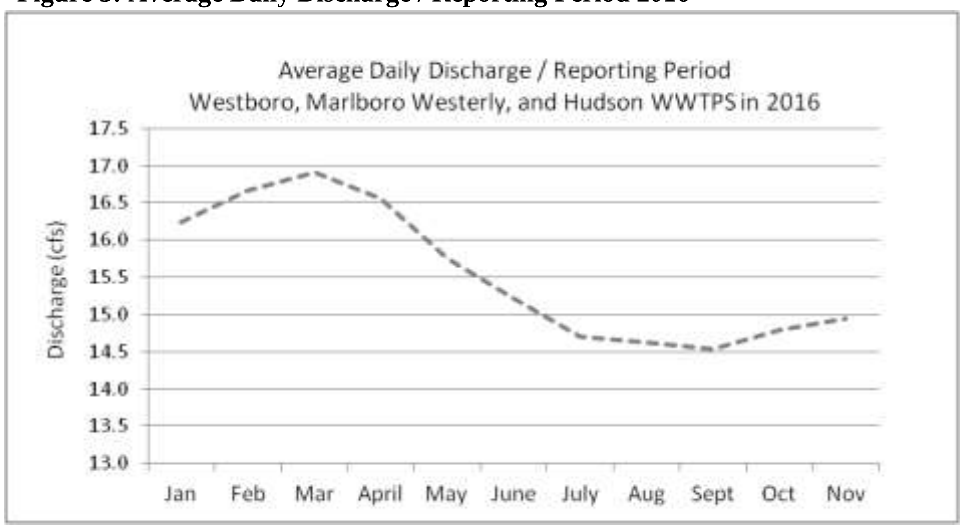


Figure 3: Average Daily Discharge / Reporting Period 2016

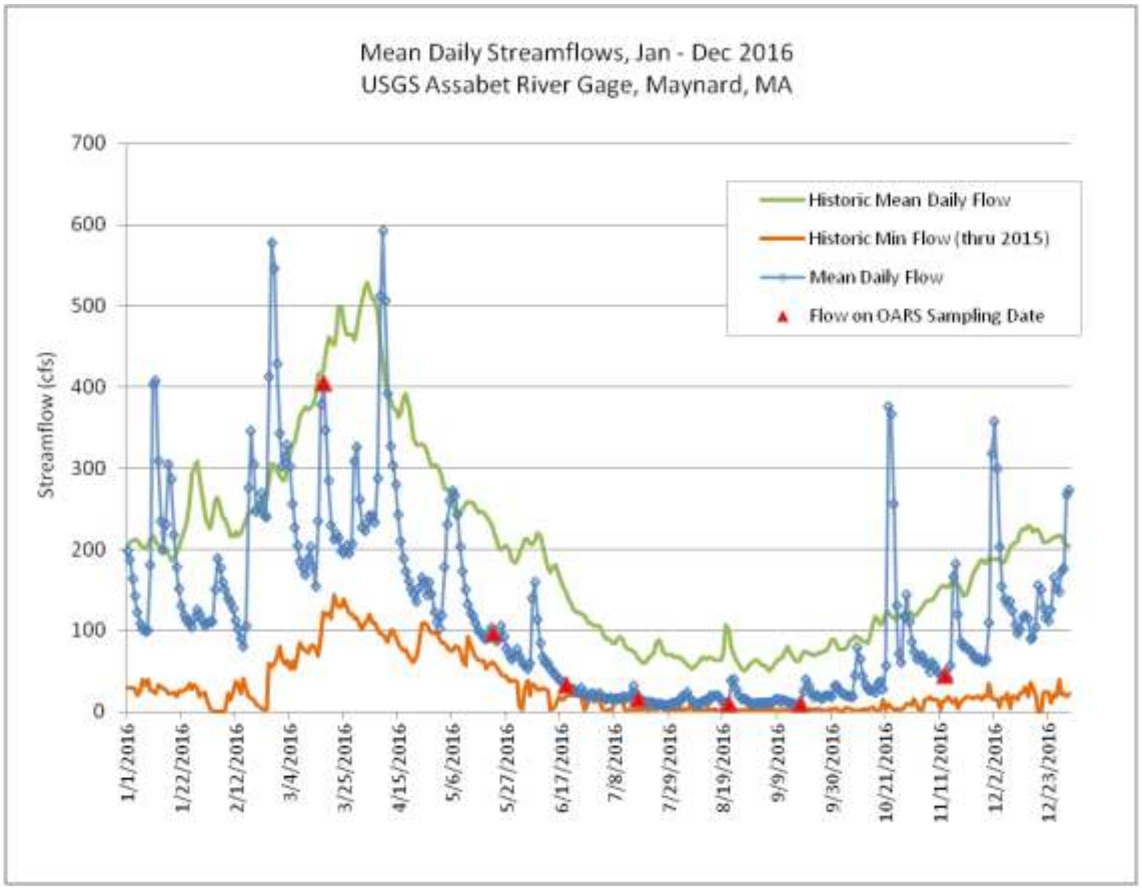


In 2016, daily streamflows at all four USGS full-time gages were primarily below the 50th percentile throughout the year. New record minimum flows (for the period of record) were set at all four USGS full-time gages in the watershed (Table 7). Note that the Assabet River gage record period starts before 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

USGS Gage Location	Period of Record	Days ≤ 10th Percentile Flows	Days ≤ Historic Min. Flow
Assabet River, Maynard	1941-2016	90	3
Sudbury River, Saxonville	1979-2016	143	78
Concord River, Lowell	1936-2016	147	50
Nashoba Brook, Acton	1963-2016	147	55

Figure 4: Mean Daily Streamflows, Assabet River, 2016



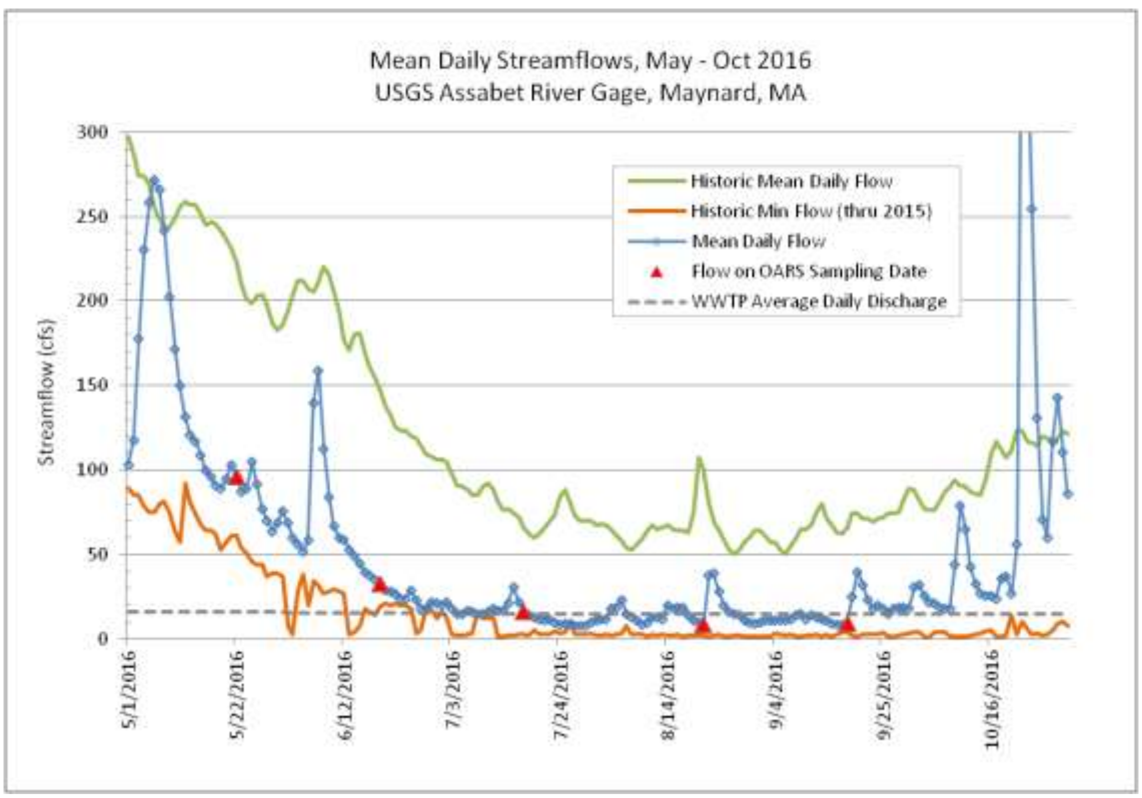
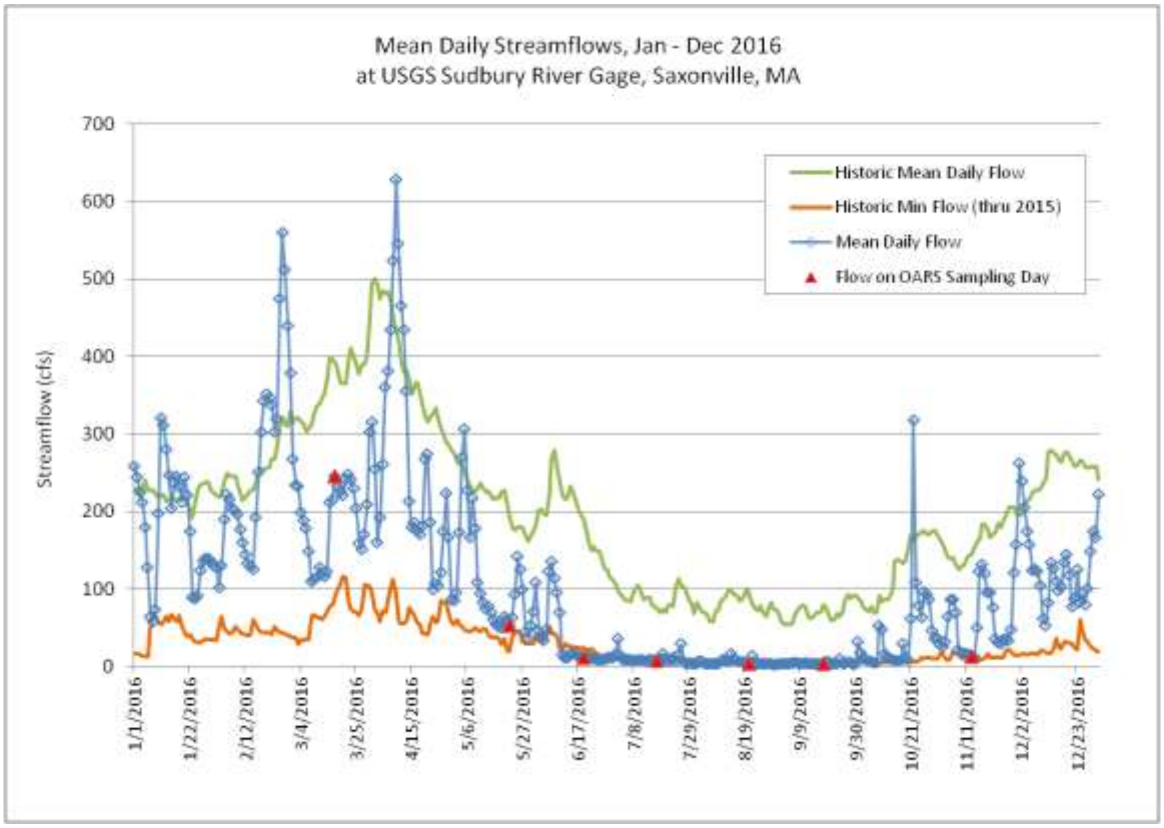
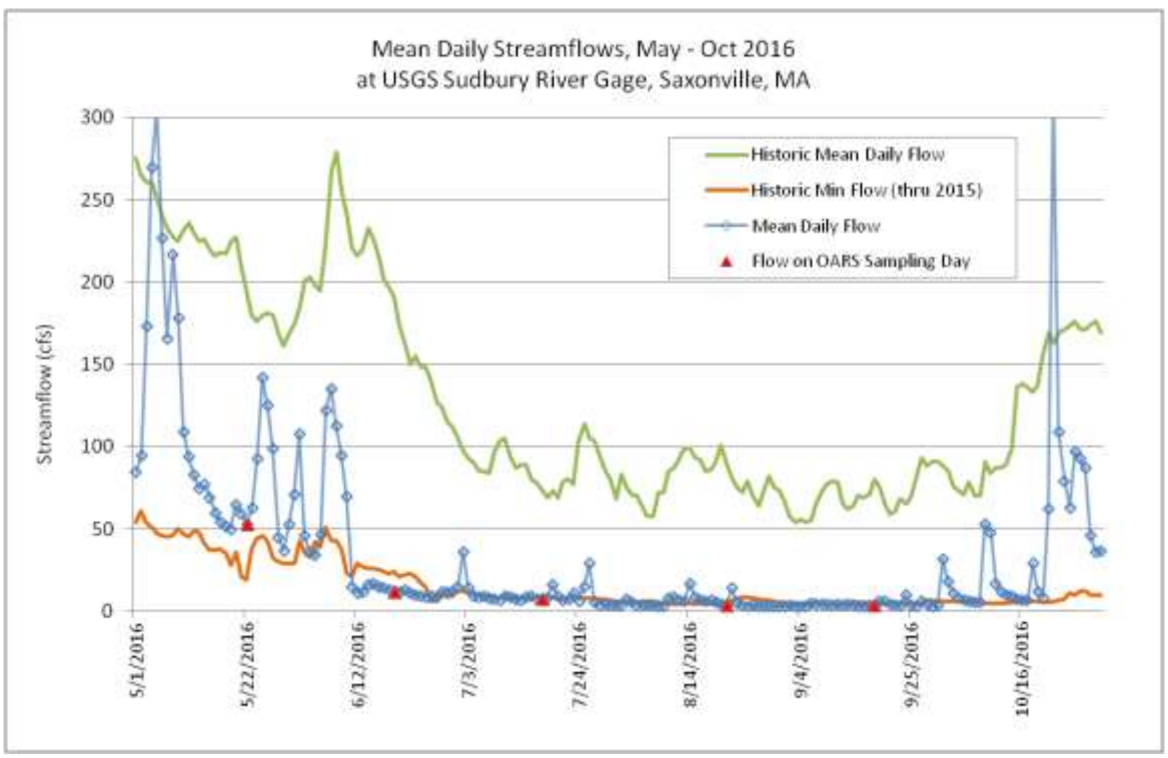


Figure 5: Mean Daily Streamflows, Sudbury River, 2016





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

	Reach Statistics 2016 (calculated on 1/2 detection level where sample is Below Detection Limit)														
	Reach	# Sites	statistic	Time	Temp (˚C)	DO % Sat	DO Conc (mg/L)	Cond (µS/cm)	pH	TSS (mg/L)	TP (mg/L)	ortho-P (mg/L)	NO3 (mg/L)	NH3 (mg/L)	Chl (µg/L)
17-Mar-16	Upper Assabet Mainstem	1	Single reading	3:21 PM	12.50	97.2	10.34	568	7.05	2	0.18	0.16	3.3	0.1	
	Lower Assabet Mainstem	2	Median	1:36 PM	9.76	98.4	11.15	341	7.03	2	< 0.01	< 0.01	0.82	<0.1	
	Sudbury Mainstem	2	Median	12:05 PM	9.28	98.3	11.26	375	7.13	4	< 0.01	< 0.01	0.34	<0.1	
	Concord Mainstem	2	Median	11:29 AM	9.59	98.8	11.25	369	7.09	4.5	< 0.01	< 0.01	0.52	<0.1	
	Headwater & Tribs	7	Median	3:02 PM	11.44	98.4	10.72	255	7.09	1	< 0.01	< 0.01	0.2	<0.1	
22-May-16	Upper Assabet Mainstem	1	Single reading	7:30 AM	15.69	84.2	8.34	735	7.33	2	0.03	< 0.01	6	<0.1	
	Lower Assabet Mainstem	2	Median	7:12 AM	17.87	89.0	8.42	552	7.29	3.5	< 0.01	< 0.01	1.4	<0.1	
	Assabet Impounded Sites	3	Median	7:09 AM	17.49	88.2	8.58	562	7.29						
	Sudbury Mainstem	5	Median	6:53 AM	17.69	91.3	8.4	503	7.25	6	< 0.01	< 0.01	0.11	<0.1	
	Concord Mainstem	2	Median	6:50 AM	17.90	89.1	8.45	518	7.39	5.5	< 0.01	< 0.01	0.31	<0.1	
	Headwater & Tribs	8	Median	7:17 AM	16.39	93.6	9.07	418	7.38	3	< 0.01	< 0.01	0.14	<0.1	
	Hop Brook, Sudbury	1	Single reading	6:21 AM	16.55	51.0	4.99	460	6.94	0.5	0.01	< 0.01	0.74	<0.1	
19-Jun-16	Upper Assabet Mainstem	3	Median	7:23 AM	18.88	87.5	8.11	863	7.24	2	0.05	< 0.01	6.2	<0.1	
	Lower Assabet Mainstem	3	Median	6:25 AM	21.66	92.4	8.11	660	7.53	1	0.04	< 0.01	1.5	<0.1	
	Assabet Impounded Sites	3	Median	7:34 AM	22.02	84.7	7.45	822	7.42						
	Sudbury Mainstem	5	Median	6:27 AM	22.52	84.3	7.25	712	7.01	10	0.04	< 0.01	0.14	<0.1	11
	Concord Mainstem	4	Median	7:01 AM	22.61	91.0	7.87	637	7.44	6	0.03	< 0.01	0.6	<0.1	
	Headwater & Tribs	8	Median	7:33 AM	19.21	82.4	7.72	511	7.22	7	0.04	< 0.01	0.14	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:10 AM	19.19	39.8	3.68	603	6.95	6	0.07	0.06	0.86	0.11	<2.00
17-Jul-16	Upper Assabet Mainstem	3	Median*	NR	NR	NR	NR	NR	NR	2	0.01	0.01	8.7	<0.1	
	Lower Assabet Mainstem	3	Median*	6:55 AM	25.73	75.1	6.08	940	7.66	8	0.02	< 0.01	0.69	<0.1	
	Assabet Impounded Sites	3	Median*	NR	NR	NR	NR	NR	NR						
	Sudbury Mainstem	5	Median	6:55 AM	27.32	81.2	6.42	828	7.09	9	0.02	< 0.01	0.08	<0.1	16.3
	Concord Mainstem	4	Median	6:53 AM	26.73	86.9	6.93	831	7.48	7	< 0.01	< 0.01	0.44	<0.1	
	Headwater & Tribs	8	Median*	7:30 AM	24.20	60.4	5.12	585	7.23	5.5	0.03	0.02	0.23	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:15 AM	25.70	8.3	0.66	678	6.9	6	0.07	0.06	0.05	<0.1	6.1

Table 8 (continued)

	Reach Statistics 2016 (calculated on 1/2 detection level where sample is BDL)														
	Reach	# Sites	statistic	Time	Temp (°C)	DO % Sat	DO Conc (mg/L)	Cond (µS/cm)	pH	TSS (mg/L)	TP (mg/L)	ortho-P (mg/L)	NO3 (mg/L)	NH3 (mg/L)	Chl (µg/L)
20-Jul-16	Upper Assabet Mainstem	3	Median*	7:57 AM	21.61	86.1	7.56	1140	7.39						
	Assabet Impounded Sites	3	Median*	6:06 AM	22.26	80.2	6.95	958	7.56						
	Lower Assabet Mainstem	1	Single reading*	6:49 AM	25.38	84.2	6.88	1106	7.71						
	Headwater & Tribs	4	Median*	7:59 AM	19.28	48.8	4.35	349	7.65						
21-Aug-16	Upper Assabet Mainstem	3	Median	7:42 AM	23.03	71.1	6.08	1128	7.31	1	0.02	0.01	5.5	<0.1	
	Lower Assabet Mainstem	3	Median	6:32 AM	22.79	75.1	6.21	1053	7.81	3	< 0.01	< 0.01	1.3	<0.1	
	Assabet Impounded Sites	3	Median	7:21 AM	24.65	71.2	5.82	1090	7.81						
	Sudbury Mainstem	5	Median	6:22 AM	24.94	52.4	4.38	844	7.28	11	0.02	< 0.01	0.03	<0.1	15.4
	Concord Mainstem	4	Median	7:02 AM	24.86	71.8	6.00	948	7.70	6.5	0.02	< 0.01	0.44	0.12	
	Headwater & Tribs	8	Median	7:29 AM	22.34	57.5	4.76	561	7.04	3	0.02	0.02	0.28	<0.1	
	Hop Brook, Sudbury	1	Single reading	6:58 AM	22.31	6.8	0.60	755	6.93	9	0.12	0.08	0.03	0.11	3.4
18-Sep-16	Upper Assabet Mainstem	1	Single reading	8:17 AM	20.37	76.6	6.88	1503	7.25	2	< 0.01	< 0.01	14.5	<0.1	
	Lower Assabet Mainstem	2	Median	8:13 AM	19.80	74.6	6.78	948	7.54	3	0.013	0.013	1.22	<0.1	
	Sudbury Mainstem	5	Median	8:23 AM	20.27	75.6	6.75	1350	7.55						
	Concord Mainstem	2	Median	7:41 AM	19.69	75.5	6.90	865	7.29	8	0.02	< 0.01	0.11	<0.1	
	Headwater & Tribs	8	Median	8:18 AM	19.15	90.0	8.51	919	7.37	21	< 0.01	< 0.01	3.05	<0.1	
	Hop Brook, Sudbury	1	Single reading	8:15 AM	17.02	63.1	6.06	415	7.34	5.5	0.01	< 0.01	0.12	<0.1	
13- Nov-16	Upper Assabet Mainstem	1	Single reading	9:43 AM	13.11	100.3	10.59	878	7.49	0.5	0.17	0.13	13.4	<0.1	
	Lower Assabet Mainstem	2	Median	8:56 AM	6.44	102.9	12.62	634	7.56	1.5	0.03	< 0.01	2.65	<0.1	
	Sudbury Mainstem	2	Median	7:01 AM	6.65	92.3	11.28	533	7.46	2.8	0.02	< 0.01	0.18	0.11	
	Concord Mainstem	2	Median	8:47 AM	6.81	102.4	12.46	508	7.28	5	0.03	< 0.01	0.89	<0.1	
	Headwater & Tribs	7	Median	9:10 AM	5.14	94.0	12.00	289	7.52	2	0.01	< 0.01	0.25	<0.1	

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

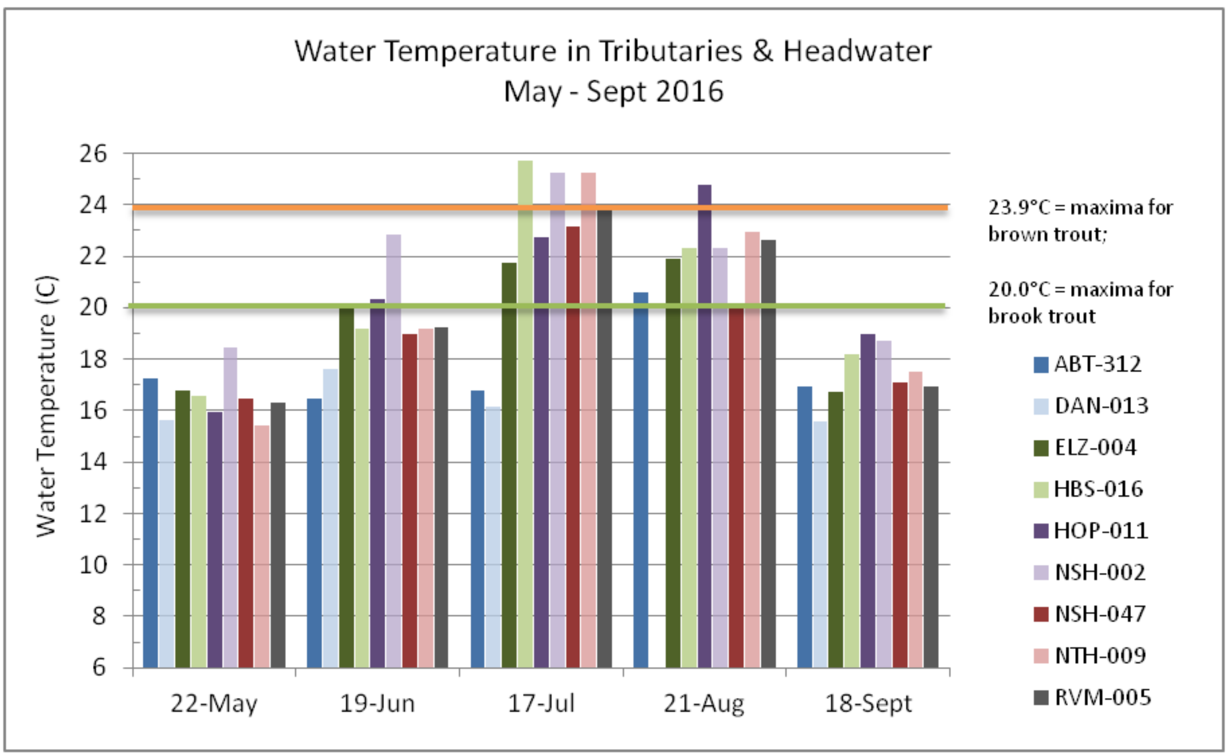
Water Temperature, pH, and Conductivity

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

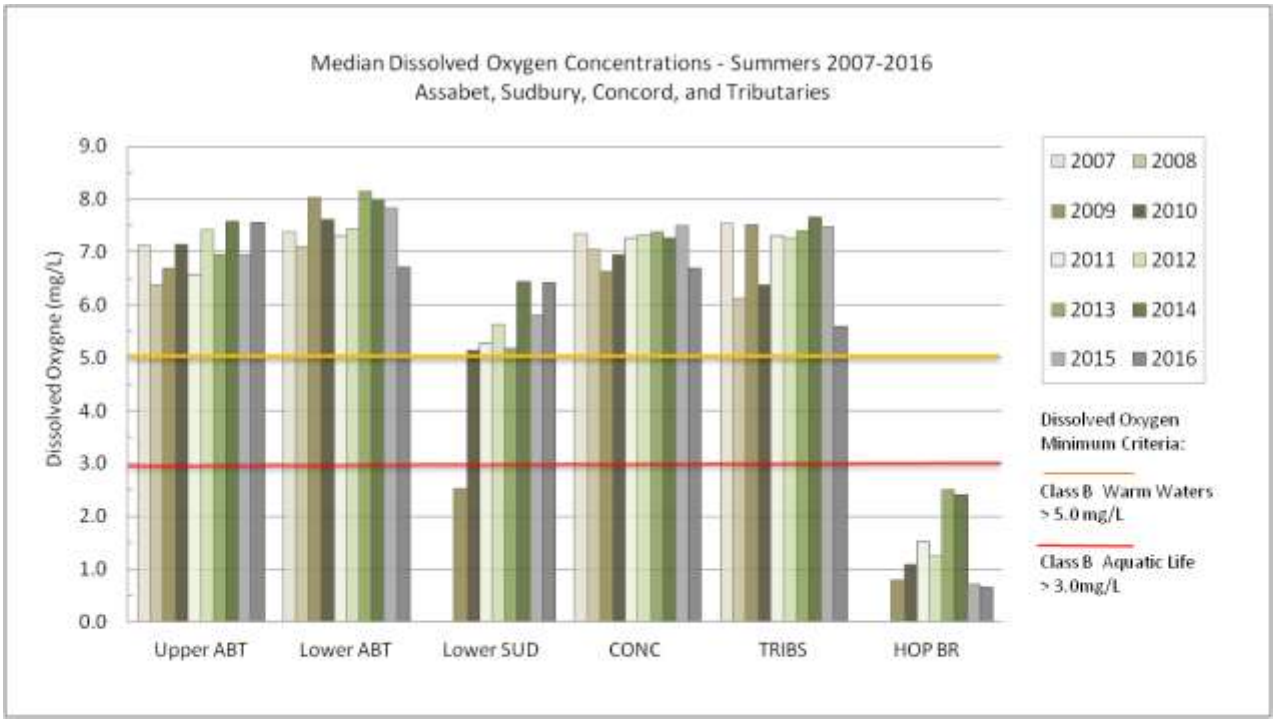
Dissolved oxygen (DO) concentrations during the growing season are generally lowest between 5 am and 8 am after plant and microbial respiration has removed oxygen from the water column overnight. Low minimum DO concentrations and large diurnal variations in DO can indicate eutrophic conditions. Summary 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 9: Dissolved Oxygen Violations

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

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



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 (0.05mg/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.

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

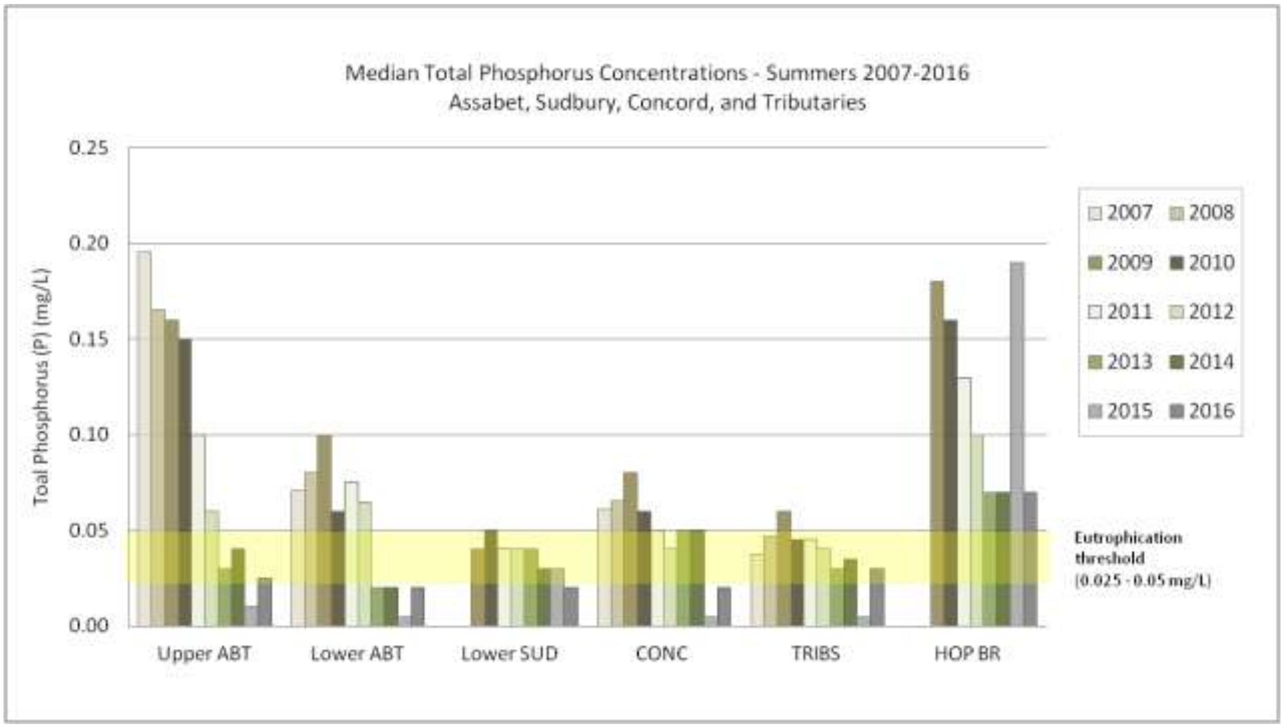
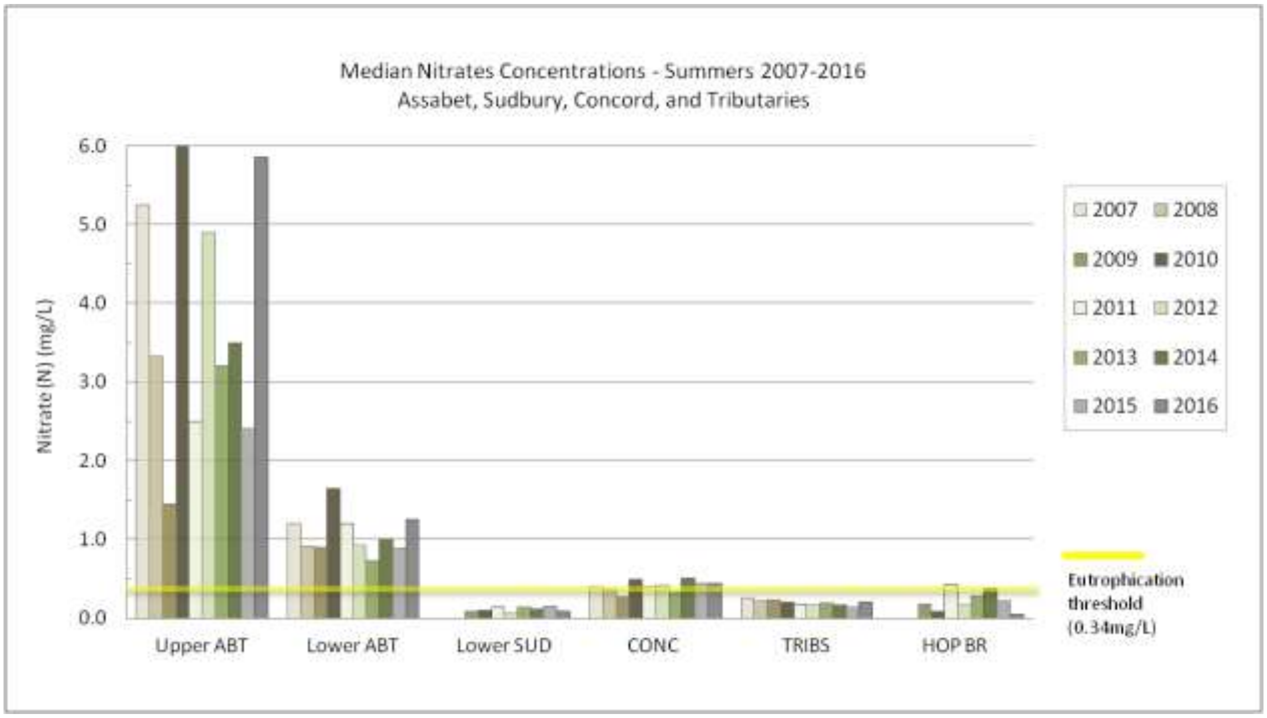
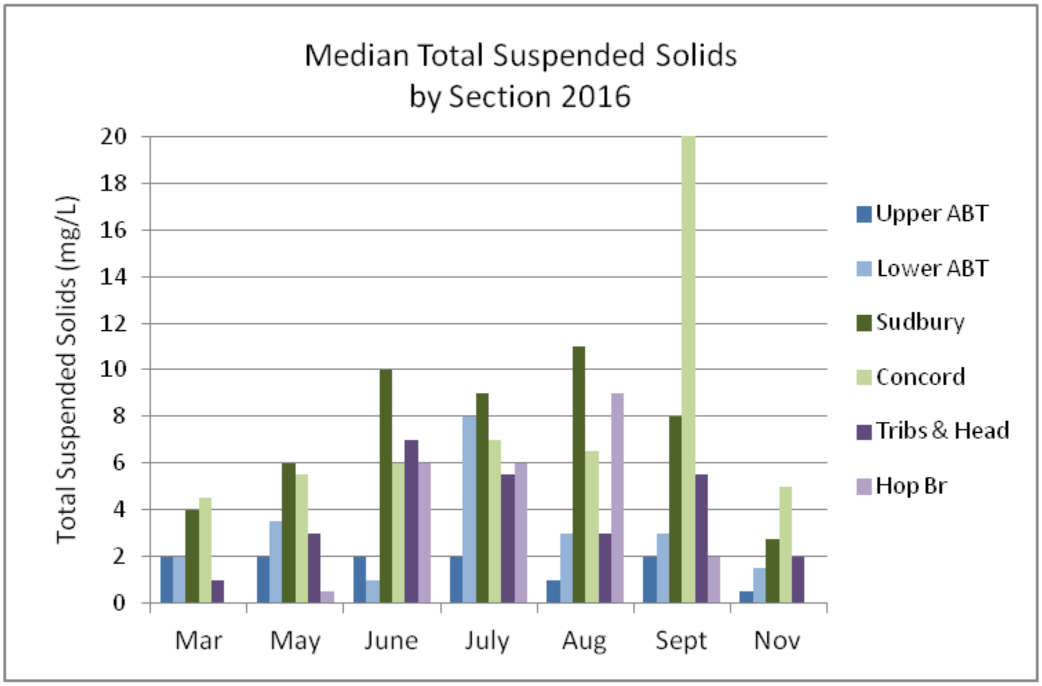


Figure 9: Median Nitrate Concentrations (Summers 2008- 2016)



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

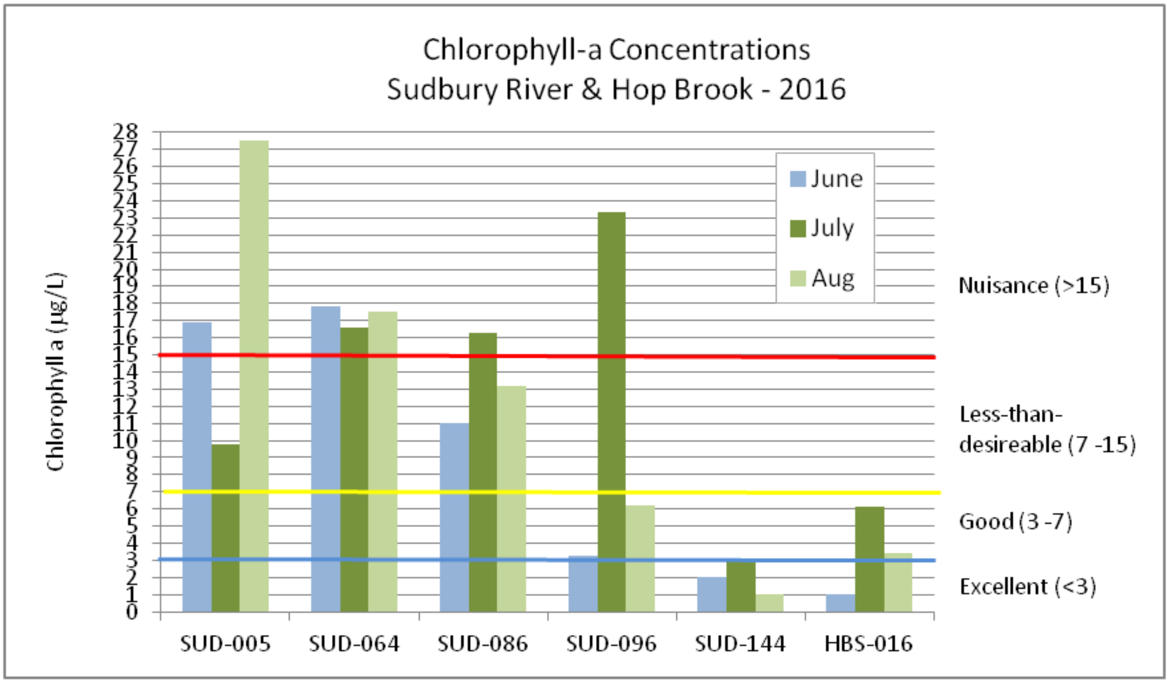
Chlorophyll *a* is the principle photosynthetic pigment in algae and vascular plants; chlorophyll *a* concentrations give an estimate of the biomass of planktonic algae in the river and is one indicator of eutrophication. Rivers, like the Assabet, whose vegetation is dominated by larger rooted and floating 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

Chlorophyll *a* Categories	
< 3 µg/L	Excellent
3 – 7 µg/L	Good
7 – 15 µg/L	Less than desirable
> 15 µg/L	Nuisance

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-desireable" 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.

Figure 11: Chlorophyll-*a* at Sudbury River Sites



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

Section	Sites	Years Sampled
Assabet Headwater	ABT-311 & ABT-312	1992-2011 (ABT-311); 2012 – 2016 (ABT-312)
Upper Assabet	ABT-301	1992 – 2016
	ABT-238 & ABT-237	1992 – 2005 (ABT-238); 2006-2016 (ABT-237)
Middle Assabet	ABT-144*	1992 – 2016
Lower Assabet	ABT-077	1992-2016
	ABT-026	1992-2016
Tributary Streams	HOP-011	2002-2016
	NTH-009	2002-2016
	DAN-013	2002-2016
	ELZ-004	2002-2016
	NSH-002	1995-2016
Lower Concord	CND-009	2004 - 2016

** 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.

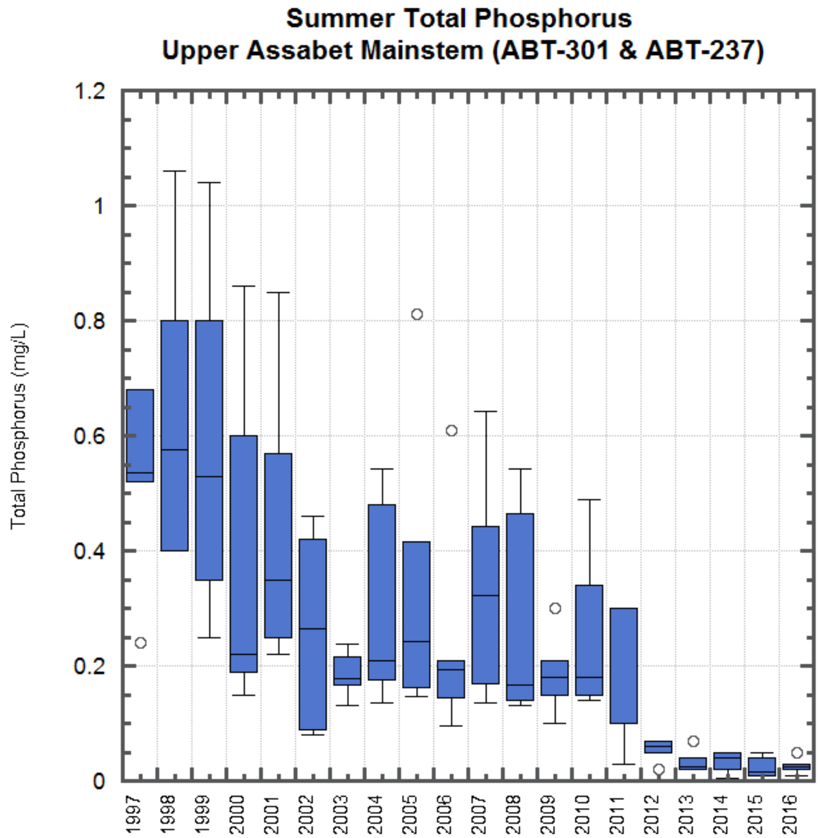
The statistical significance of apparent summer trends in water quality were evaluated using a single season Mann-Kendall test (Helsel, 2006) computed on concentration and on flow-weighted concentration (using a locally weighted scatterplot smooth; LOWESS) and two date ranges ("all dates" 1993–2016 and "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.

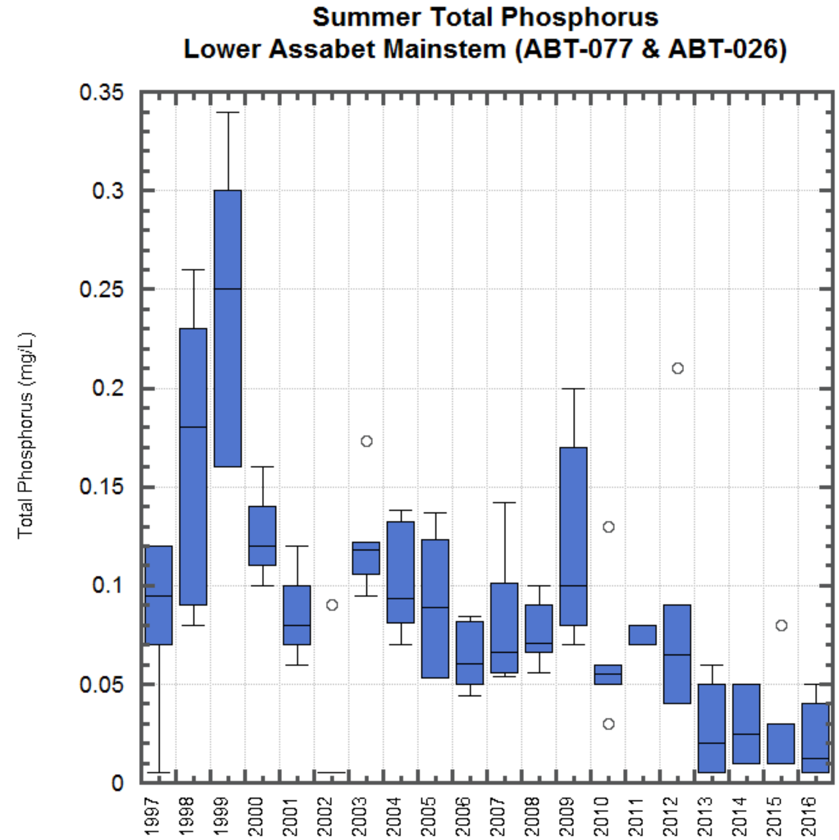
Otherwise, statistically significant trends were similar to previous findings:

- 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.

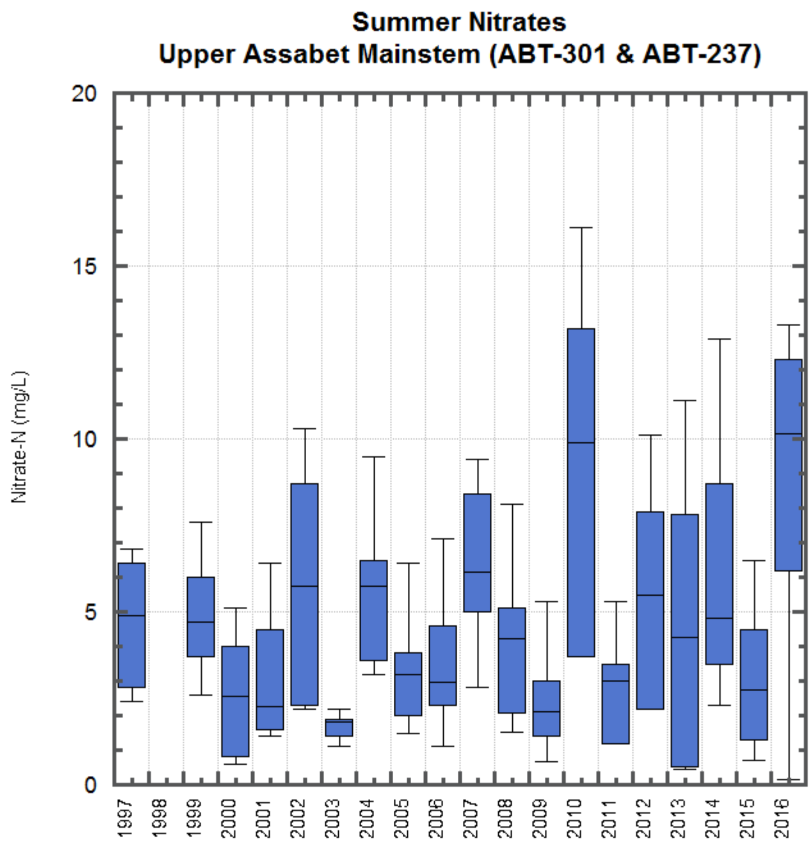
Figure 12: Summer Total Phosphorus in Upper and Lower Assabet Mainstem

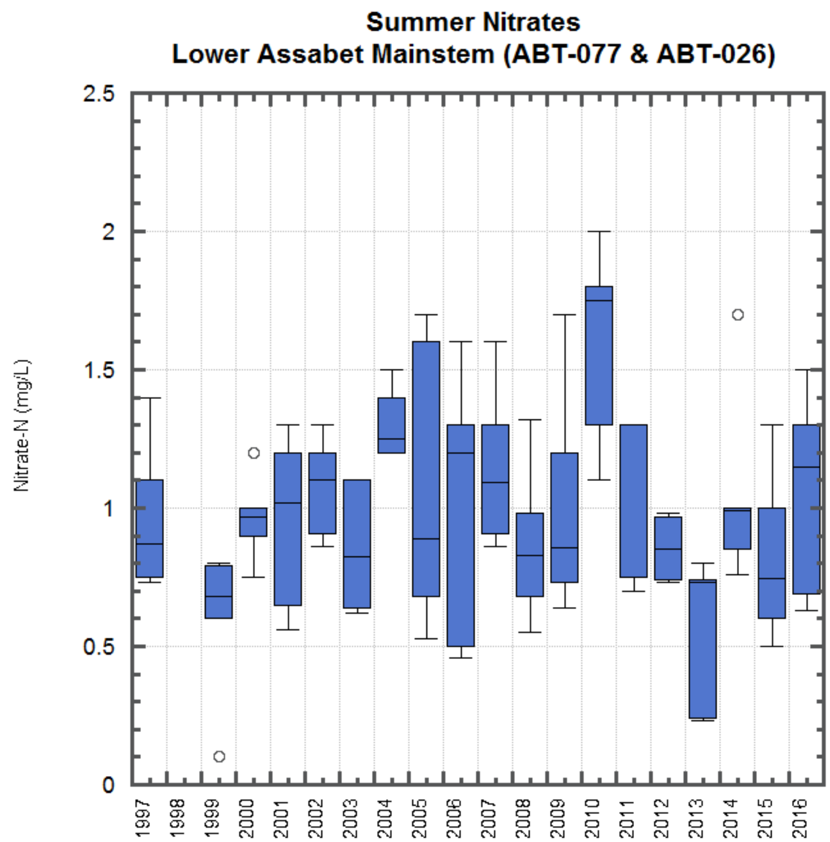




		Total Phosphorus - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Upper ABT	conc.	1993-2016	-0.661	-6616	-11.67	0.0000	downward	1999-2016	-0.564	-3260	-8.656	0.0000	downward
Upper ABT	flow-weighted	1993-2016	-0.596	-5970	-10.53	0.0000	downward	1999-2016	-0.560	-3238	-8.596	0.0000	downward
Middle ABT	conc.	1993-2016	-0.735	-1879	-9.132	0.0000	downward	1999-2016	-0.621	-888	-6.662	0.0000	downward
Middle ABT	flow-weighted	1993-2016	-0.644	-1646	-7.997	0.0000	downward	1999-2016	-0.549	-786	-5.857	0.0000	downward
Lower ABT	conc.	1993-2016	-0.593	-6107	-10.55	0.0000	downward	1999-2016	-0.480	-2273	-7.374	0.0000	downward
Lower ABT	flow-weighted	1993-2016	-0.552	-5679	-9.809	0.0000	downward	1999-2016	-0.444	-2567	-6.814	0.0000	downward

Figure 13: Summer Nitrates in Upper and Lower Assabet Mainstem

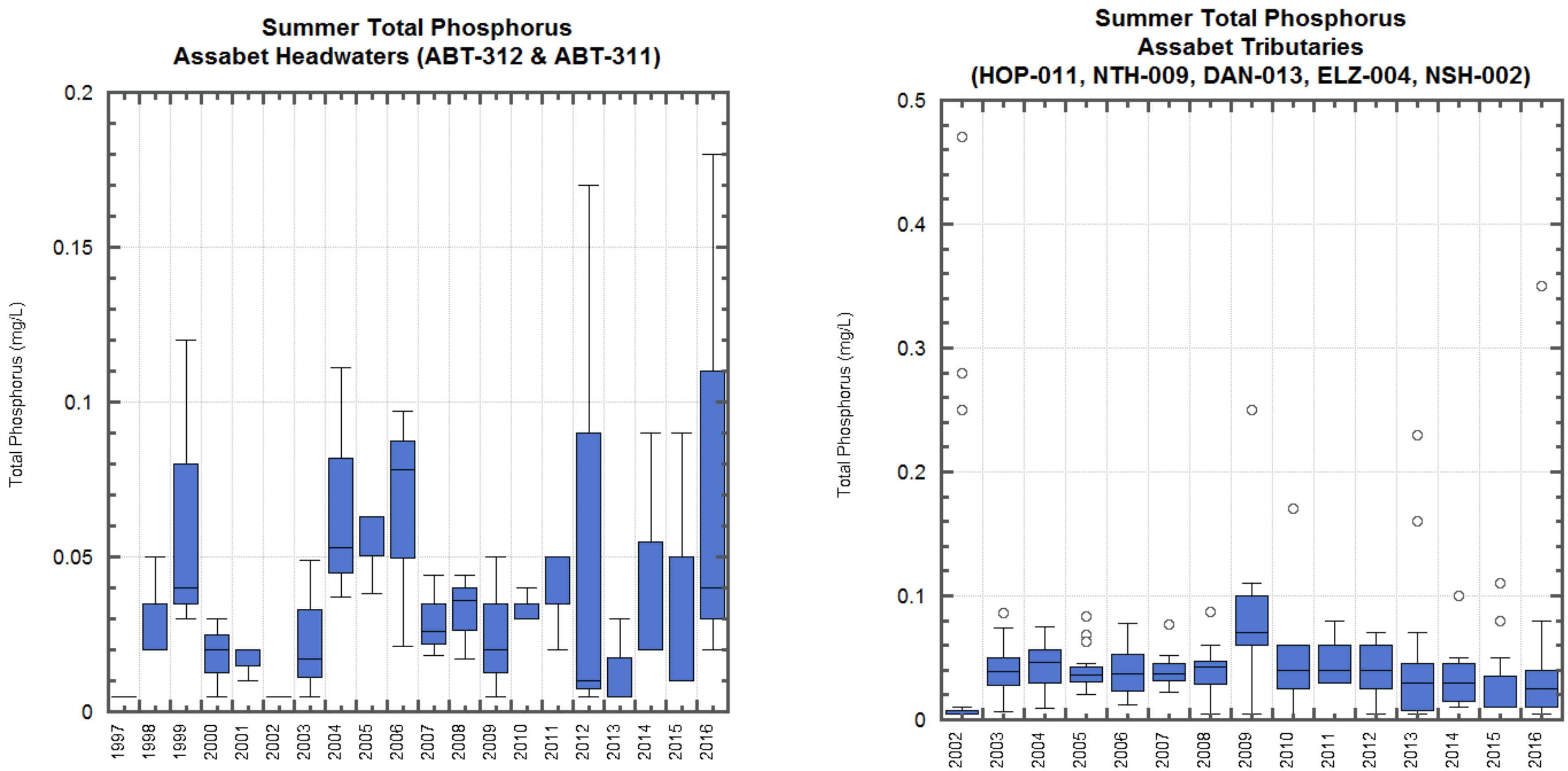




		Nitrates - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Upper ABT	conc.	1993-2016	0.102	859	1.727	0.0841	NST	1999-2016	0.118	682	1.809	0.0705	NST
Upper ABT	flow-weighted	1993-2016	0.211	1767	3.555	0.0004	weak up	1999-2016	0.216	1250	3.317	0.0001	weak up
Middle ABT	conc.	1993-2016	0.166	357	1.972	0.0486	weak up	1999-2016	0.106	152	1.128	0.2595	NST
Middle ABT	flow-weighted	1993-2016	0.352	756	4.178	0.000	upward	1999-2016	0.249	357	2.656	0.0079	weak up
Lower ABT	conc.	1993-2016	0.146	1261	2.481	0.0131	weak up	1999-2016	0.033	193	0.511	0.6096	NST
Lower ABT	flow-weighted	1993-2016	0.151	1302	2.56	0.0105	weak up	1999-2016	0.006	32	0.082	0.9344	NST

NST = no significant trend

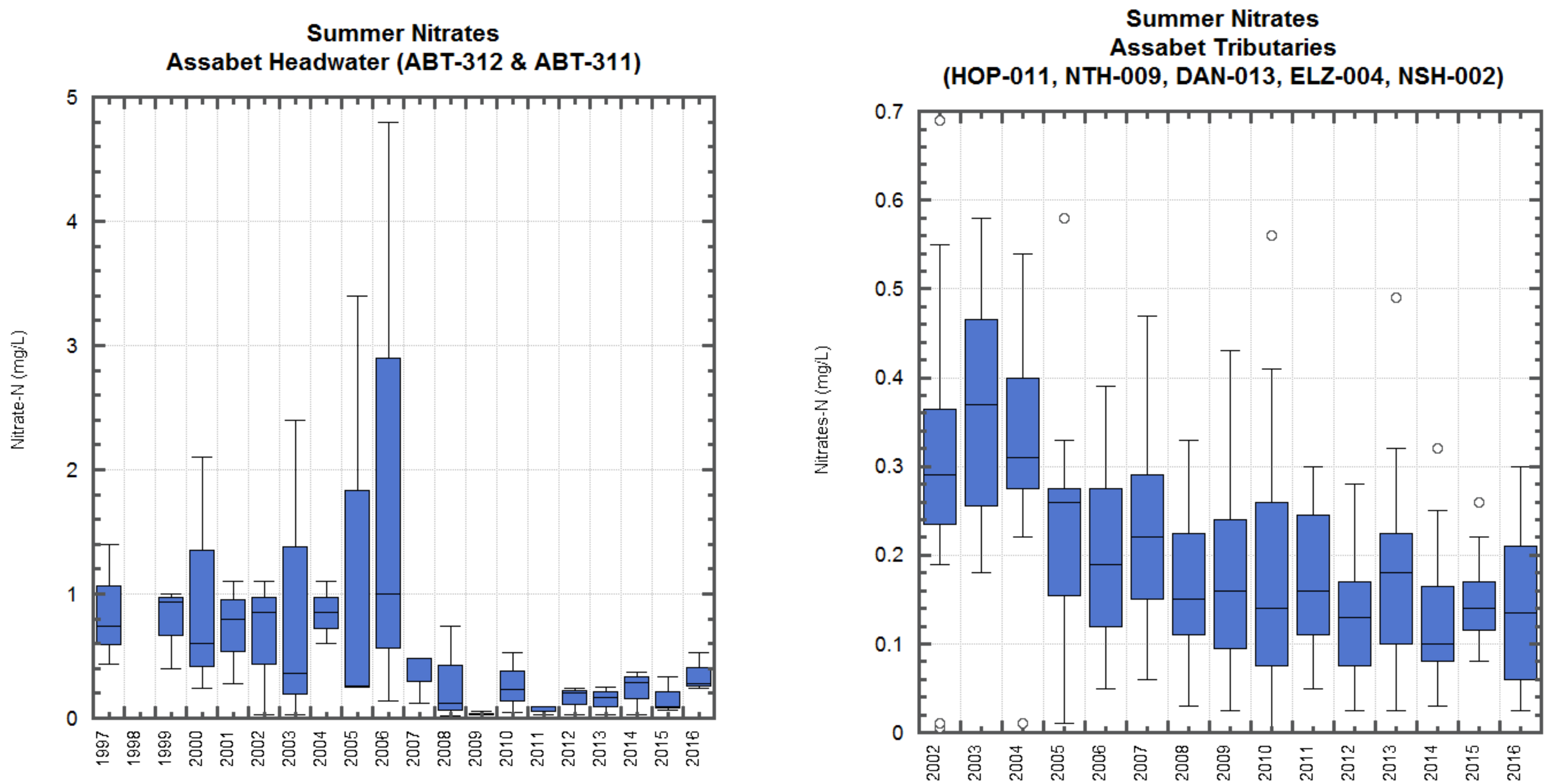
Figure 14: Summer Total Phosphorus at Assabet Headwater & Tributaries



		Total Phosphorus - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Headwater ABT	conc.	1993-2016	-0.011	-35	-0.139	0.8891	NST	1999-2016	0.003	6.0	0.03	0.9762	NST
Headwater ABT	flow-weighted	1993-2016	0.019	63	0.253	0.8003	NST	1999-2016	0.001	1.0	0.00	1.0000	NST
Tributaries	conc.							2002-2016	-0.072	-1868	-1.614	0.1065	NST
Tributaries	flow-weighted							2002-2016	-0.022	-585	-0.504	0.6142	NST

NST = no significant trend

Figure 15: Summer Nitrates at Assabet Headwater Site and Tributaries



		Nitrates - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Headwater ABT	conc.	1993-2016	-0.200	-554	-2.533	0.0113	weak down	1999-2016	-0.306	-598	-3.548	0.0004	downward
Headwater ABT	flow-weighted	1993-2016	-0.230	-637	-2.91	0.0036	weak down	1999-2016	-0.458	-894	-5.298	0.0000	downward
Tributaries	conc.							2002-2016	-0.301	-7854	-6.784	0.0000	downward
Tributaries	flow-weighted							2002-2016	-0.273	-7128	-6.152	0.0000	weak down

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

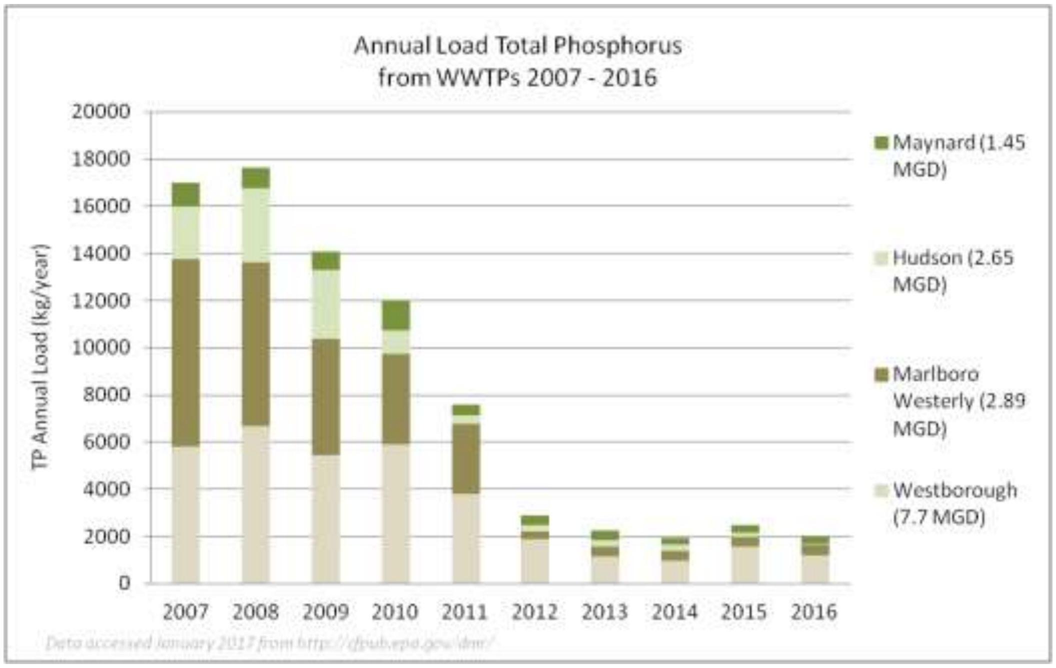
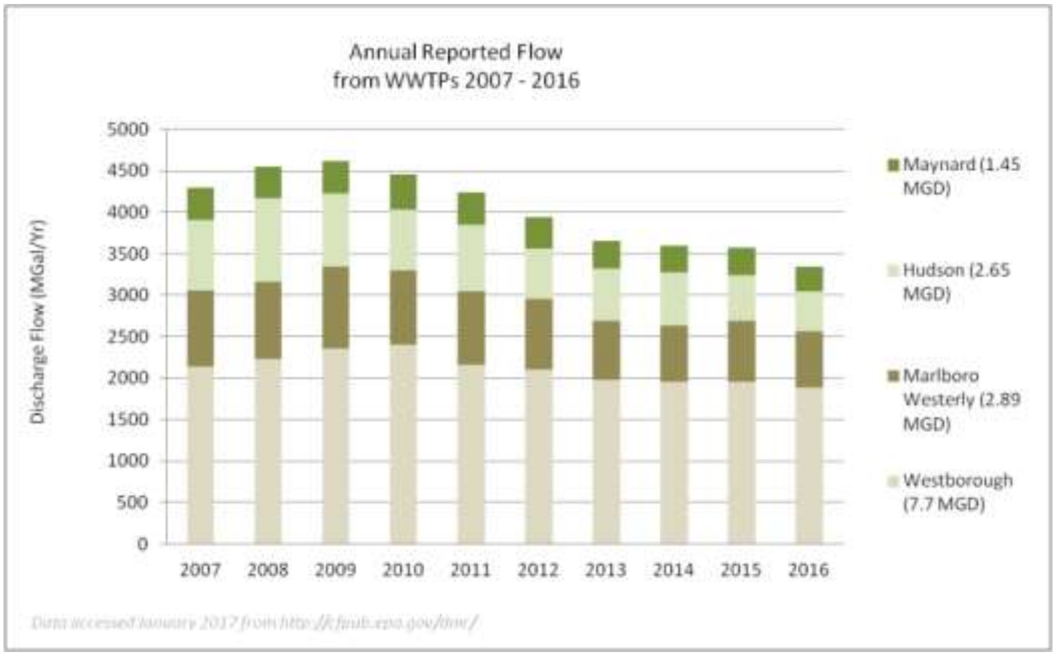


Figure 17: Total Annual Flow from WWTPs



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

	Stream Health Index Readings – 2016				
	5/22/2016	6/19/2016	7/17/2016	8/21/2016	9/18/2016
Assabet River Headwater, Mill Rd., Westborough (ABT-312)					
NO3	100	49	73	68	83
TP	100	63	30	82	100
TSS	100	38	66	76	100
DO	89	76	83	74	82
pH	100	100	100	100	100
Temp	63	68	66	42	65
Streamflow	75	8	6	6	7
Groundwater	69	59	48	35	24
Habitat	75	25	30	15	20
Stream Health Index	78	23	22	17	19
Danforth Brook, Rte 85, Hudson (DAN-013)					
NO3	100	78	79	dry	100
TP	100	47	100	dry	47
TSS	44	51	100	dry	56
DO	93	85	18	dry	1
pH	100	94	100	dry	85
Temp	73	60	70	dry	73
Streamflow	100	18	1	dry	1
Groundwater	69	59	48	dry	24
Habitat	90	15	1	dry	5
Stream Health Index	83	25	3	dry	7
Hop Brook, Otis Street, Northborough (HOP-011)					
NO3	85	100	100	100	100
TP	100	63	71	82	100
TSS	76	83	62	76	70
DO	85	77	48	40	68
pH	100	100	100	99	100
Temp	71	43	28	15	52
Streamflow	94	40	27	19	16
Groundwater	69	59	48	35	24
Habitat	80	70	45	40	50
Stream Health Index	81	61	43	34	35
Nashoba Br., Commonwealth Ave, W. Concord (NSH-002)					
NO3	63	97	76	100	97
TP	100	71	19	100	63
TSS	83	32	30	46	25
DO	90	80	15	1	23
pH	100	100	100	99	100
Temp	55	27	11	30	54
Streamflow	30	56	NR	NR	NR
Groundwater	69	59	48	35	24
Habitat	70	85	30	35	25
Stream Health Index	59	62	NR	NR	NR
Nashoba Brook, Wheeler Ave, Acton (NSH-047)					
NO3	79	100	72	50	78
TP	100	53	50	63	82
TSS	76	12	49	49	59
DO	78	65	27	4	65
pH	99	100	100	99	100
Temp	68	52	25	46	64
Streamflow	80	24	7	6	NR
Groundwater	69	59	48	35	24
Habitat	95	80	35	30	30
Stream Health Index	83	44	23	16	NR
North Brook, Whitney Ave, Berlin (NTH-009)					
NO3	94	89	100	1	100
TP	100	100	100	100	100
TSS	70	76	53	83	76
DO	91	70	69	45	38
pH	100	92	100	100	100
Temp	74	51	11	27	61
Streamflow	100	NR	38	NR	11
Groundwater	69	59	48	35	24
Habitat	85	70	55	10	60
Stream Health Index	84	NR	45	NR	31

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

	Water Quality Index Readings				
Site / Parameter	5/22/2016	6/19/2016	7/17/2016	8/21/2016	9/18/2016
Assabet at Rte 9 Westboro (ABT-301)					
NO3	4	1	1	1	1
TP	71	57	71	82	100
TSS	83	83	83	96	83
DO	89	87	82	65	74
pH	100	100	100	100	100
Temp	100	100	93	86	98
Water Quality Index	20	6	6	6	6
Assabet at Rte 27 Maynard (ABT-077)					
NO3	24	29	45	31	38
TP	100	57	100	100	82
TSS	70	100	100	96	83
DO	96	87	75	73	81
pH	100	100	100	100	100
Temp	100	93	90	87	98
Water Quality Index	62	64	78	68	72
Concord at Lowell Rd Concord (CND-161)					
NO3	100	40	57	48	29
TP	100	82	100	100	100
TSS	66	70	51	70	24
DO	88	72	68	71	97
pH	100	100	100	100	100
Temp	100	90	64	81	100
Water Quality Index	90	69	69	74	52
Concord at Rogers St Lowell (CND-009)					
NO3	46	31	14	14	6
TP	100	71	50	63	100
TSS	62	44	26	56	56
DO	92	89	77	57	83
pH	100	100	100	91	100
Temp	100	88	65	77	100
Water Quality Index	76	59	35	41	27
Sudbury at Sudbury Landing Framingham (SUD-144)					
NO3	87	92	100	87	68
TP	100	100	100	100	100
TSS	83	100	100	100	100
DO	97	88	65	50	75
pH	100	100	91	93	100
Temp	100	100	89	97	100
Water Quality Index	94	96	89	83	88
Sudbury at Main St. Concord (SUD-005)					
NO3	100	100	100	100	100
TP	100	71	100	82	100
TSS	56	51	51	49	56
DO	100	83	69	49	80
pH	100	100	100	100	100
Temp	100	88	59	77	100
Water Quality Index	88	78	74	70	85
Hop Brook at Landham Rd Sudbury (HBS-016)					
NO3	41	37	100	100	28
TP	100	50	50	38	71
TSS	100	62	62	53	83
DO	44	24	1	1	1
pH	98	98	96	97	91
Temp	67	51	8	31	57
Water Quality Index	65	44	5	5	6

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

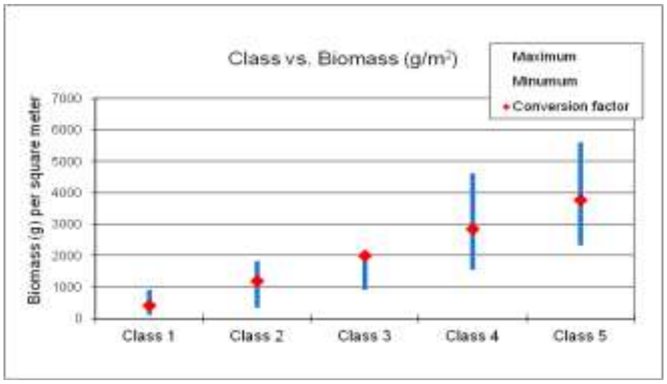
These surveys have focused on three large impoundments of the Assabet River, as the most eutrophic areas of the river. Impoundment locations include: (1) Hudson impoundment (off Rte 85), Hudson, about 0.5 miles upstream from the dam at Rte. 85; (2) Gleasondale impoundment, Stow, about 0.6 miles upstream 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.

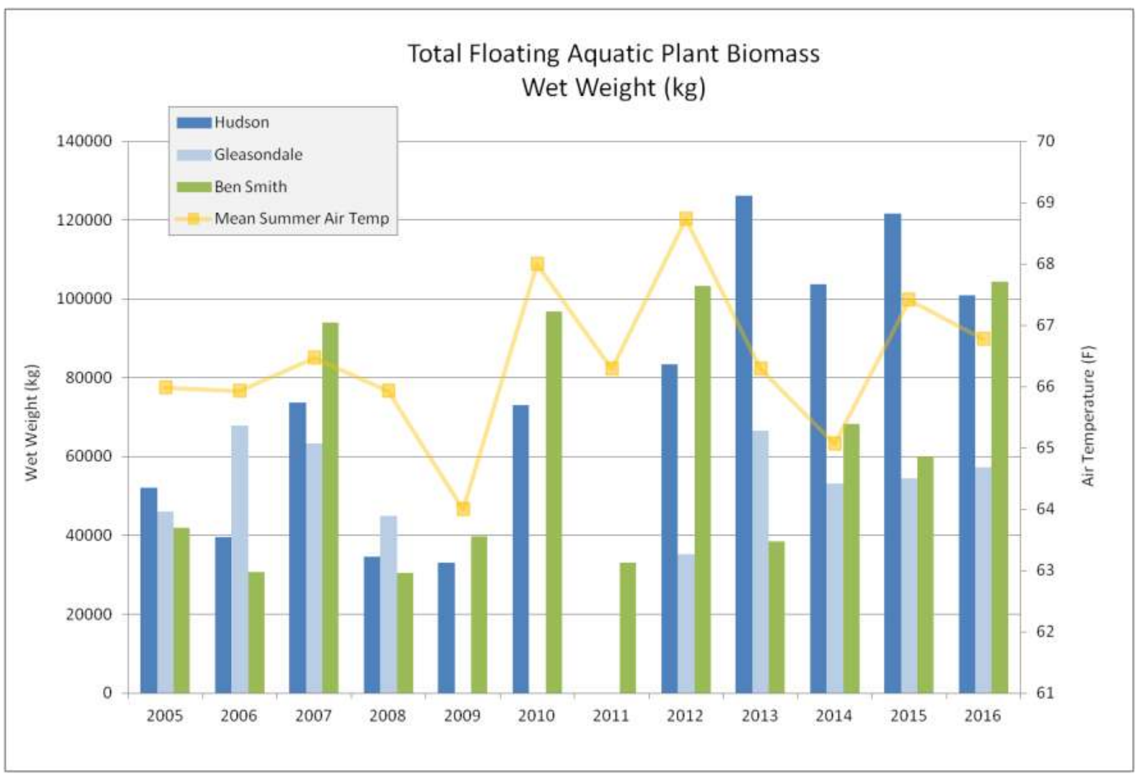
Figure 18: Class vs. Biomass Wet Weight



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



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

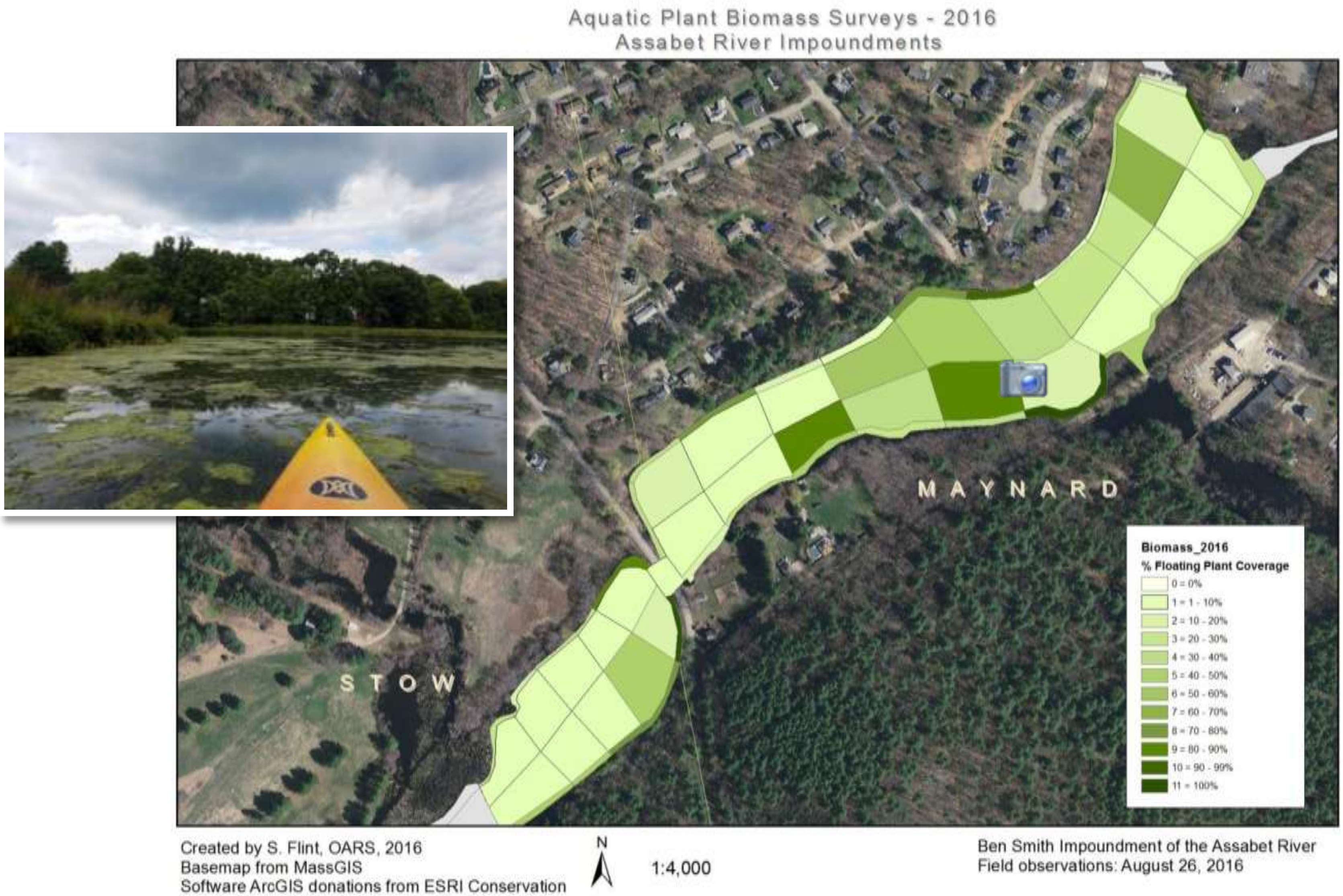


Figure 21: Total Floating Biomass, Gleasondale Impoundment, August 25, 2016

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-desireable" 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.

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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

Ammonia (NH_3): 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 NH_3 to NO_3, 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. For the Massachusetts Surface Water Quality Standards: 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 (O_2) 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

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

Gold Book: EPA's 1986 publication of recommended water quality standards. http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/upload/2009_01_13_criteria_goldbook.pdf

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.

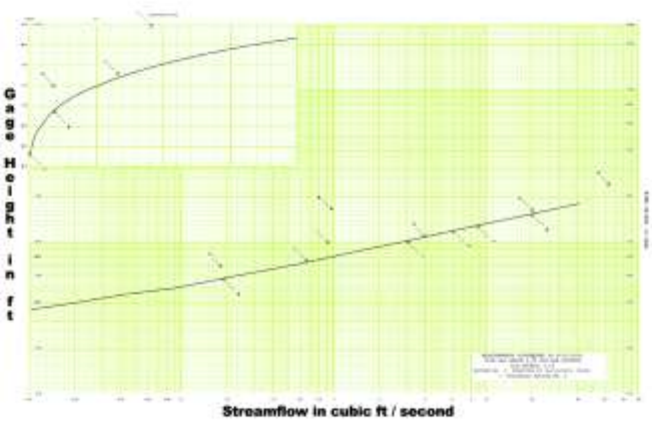
Phosphorus: Plants need nutrients to grow; in particular they need a balance of phosphorus (P) and nitrogen (N). Phosphorus is measured as **total phosphorus** (TP) and **ortho-phosphate** (ortho-P; soluble inorganic phosphate, the form required by plants). In most fresh waters, the concentration of 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).



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

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
http://www.mass.gov/eea/docs/dep/water/laws/i-thru-z/tblfig.pdf

Sudbury River			
Boundary	Mile Point	Class	Qualifiers
Source to Fruit Street Bridge, Hopkinton	29.1	B	Warm Water Outstanding Resource Water
Fruit Street Bridge to Outlet to Saxonville Pond	29.1 - 16.2	B	Warm Water High Quality Water
Outlet Saxonville Pond to Hop Brook confluence	16.2 - 10.6	B	Aquatic Life High Quality Water
Hop Brook confluence to Assabet River confluence	10.6 - 0.00	B	Aquatic Life
Denney Brook, Jackstraw Brook, Picadilly Brook, Rutters Brook and Whitehall Brook		B	Outstanding Resource
Hop Brook source to Sudbury River confluence	9.7 – 0.0	B	Warm water
Concord River			
Confluence of the Assabet and Sudbury to Billerica water supply intake	15.4 – 5.9	B	Warm Water Treated Water Supply
Billerica water supply intake to Rogers St.	5.9 – 1.0	B	Warm Water
Rogers Street to confluence Merrimack River	1.0 – 0.0	B	Warm Water CSO
Assabet River			
Source to Westborough WWTF	31.8 - 30.4	B	Warm Water High Quality Water
Westborough WWTF to outlet of Boones Pond	30.4 – 12.4	B	Warm Water
Outlet Boones Pond to confluence with Sudbury River	12.4 – 0.0	B	Warm Water

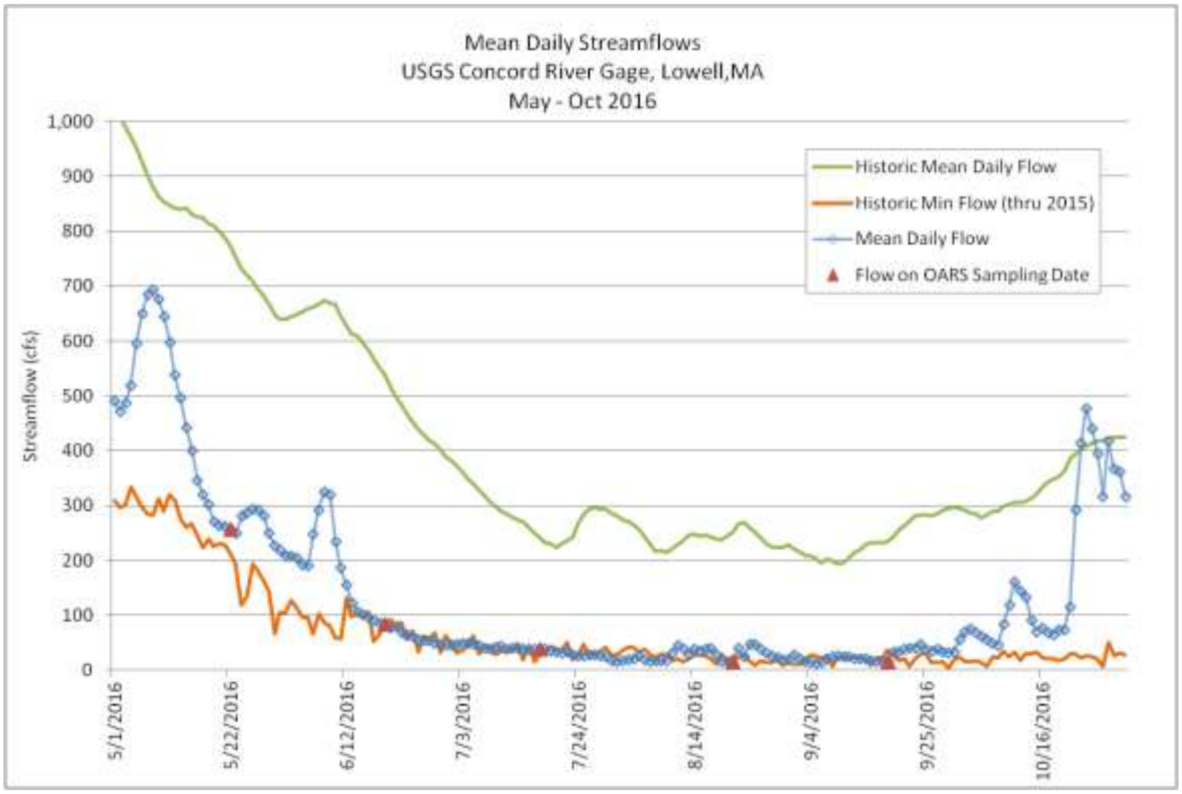
Massachusetts Division of Fisheries and Wildlife List of Coldwater Fishery Resources in the Concord (SuAsCo) basin (http://www.mass.gov/eea/agencies/dfg/dfw/wildlife-habitat-conservation/coldwater-fish-resources-list.html)

Stream Name	SARIS #
Cranberry Brook	8247885
Danforth Brook	8247275
Flagg Brook	8247225
Great Brook	8247175
Hayward Brook	8248000
Hog Brook	8247325
Hop Brook (1)	8247600
Hop Brook (2)	8247825
Howard Brook	8247525
Jackstraw Brook	8248475
Landham (Allowance) Brook	8247900
Nagog Brook	8246900
North Brook	8247375
Piccadilly Brook	8248450
Pine Brook	8247950
Rawson Hill Brook	8247575
Run Brook	8247875
Second Division Brook	8247075
Sheepsfall Brook	8247250
UNT to A-1 Site (1) (Nourse Brook)	8247627
UNT to A-1 Site (2)	8247628
UNT to Assabet River	8247260
UNT to Cranberry Brook	8247886
UNT to Great Brook	8247180
UNT to Hog Brook	8247327
UNT to Hop Brook	8247879
UNT to Hop Brook (2, 1; Trout Brook)	8247830
UNT to Hop Brook (2, 3)	8247855
NT to Nashoba Brook	8246876
UNT to North Brook	8247435
UNT to Pine Brook	8247965
UNT to Second Division Brook	8247076
UT (NOURSE BROOK)	8248530
Wrack Meadow Brook	8247440

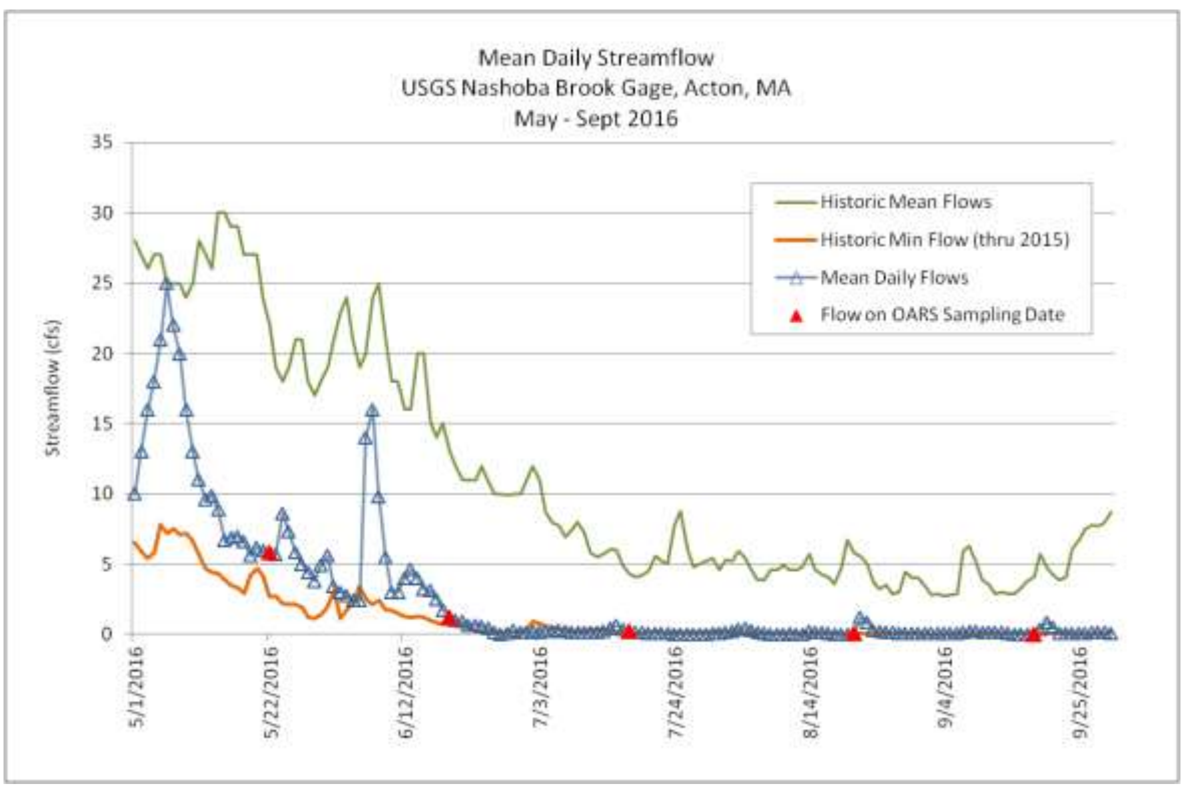
Appendix II: Streamflow Data from USGS Gages

(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

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

Qualified or censored data for 2016 includes:

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

Data Quality Objectives

Instrument/ Laboratory	Parameter	Data Quality Objectives			
		Accuracy	**Field Precision**	**Lab Precision**[a]	**Field Blank Cleanliness**
YSI 6000-series Thermistor probe	temperature	± 1 °C	< 10% RPD	< 10% RPD	na
YSI 6000-series Glass Electrode	pH	± 0.2 S.U. at pH 7.00	± 0.5 S.U.	± 0.5 S.U.	na
YSI 6000-series Rapid Pulse	DO	± 5% at 100% saturation	< 10% RPD or < 20% RPD if <4.0 mg/L	< 10% RPD	na
YSI 6000-series 4-electrode cell	Conductivity	± 50 µS/cm at 0 and 1000 µS/cm	< 20% RPD or < 30% RPD if <250 µS/cm	< 20% RPD	na
Nashoba Analytical	TSS	85-115% recovery of lab fortified blank	< 30% RPD or < ± 1 mg/L if < 2 mg/L	< 20% RPD	BDL
Nashoba Analytical	TP	85-115% recovery of lab fortified blank	< 20% RPD or ± 0.01 mg/L if <0.030 mg/L	< 20% RPD	BDL
Nashoba Analytical	ortho – P	85-115% recovery of lab fortified blank	< 20% RPD or ± 0.01 mg/L if <0.030 mg/L	< 20% RPD	BDL
Nashoba Analytical	NO3	85-115% recovery of lab fortified blank	< 30% RPD	< 20% RPD	BDL
Nashoba Analytical	NH3	85-115% recovery of lab fortified blank	< 30% RPD	< 20% RPD	BDL
Alpha Analytical	Chlorophyll *a*	75 – 125% recovery of lab QC sample (with known Chl *a* content)	< 20% RPD or ± 2.0 if < 15 µg/L	< 20% RPD	BDL

[a] 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

		Total Area (sq. meters) by Coverage Class; Calculated Wet Weight												
Section		Class 0	Wet Wt (kg)	Class 1	Wet Wt (kg)	Class 2	Wet Wt (kg)	Class 3	Wet Wt (kg)	Class 4	Wet Wt (kg)	Class 5	Wet Wt (kg)	Total Wet Wt (kg)
Hudson Impoundment	2005	14359	0	22317	9529	9632	11424	2297	4593	2770	7907	4917	18597	52050
	2006	27233	0	15496	6617	2813	3337	3923	7846	4491	12823	2334	8828	39451
	2007	0	0	23466	10020	10510	12464	16708	33415	3623	10344	1984	7505	73749
	2008	2350	0	46928	20038	2059	2442	2432	4864	2385	6810	136	515	34670
	2009	11137	0	32268	13778	9193	10903	2453	4906	1241	3542	0	0	33129
	2010	8856	0	28152	12021	328	389	5638	11276	1166	3330	12151	45956	72972
	2011	na		na		na		na		na		na		
	2012	4268	0	11859	5064	23204	27520	5861	11723	3071	8767	8028	30360	83434
	2013	6091	0	3291	1405	13083	15516	5776	11551	8919	25465	19132	72357	126295
	2014	2582	0	14147	6041	16239	19259	3417	6835	5187	14811	15018.5	56800	103746
	2015	0	0	11269	4812	12278	14562	3918	7837	15675	44752	13149	49731	121694
	2016	3005	0	11618	4961	12369	14670	0	0	3298	9418	19013	71910	100959
Ben Smith Impoundment	2005	28956	0	36541	15603	2873	3408	444	887	648	1851	5339	20193	41942
	2006	45966	0	20107	8586	944	1119	4171	8341	1178	3364	2436	9212	30622
	2007	5600	0	44197	18872	4219	5004	4770	9540	0	0	16015	60568	93984
	2008	15954	0	52967	22617	4799	5692	1081	2162	0	0	0	0	30470
	2009	45010	0	11103	4741	6890	8172	7976	15951	3823	10914	0	0	39778
	2010	14329	0	25799	11016	6351	7533	11656	23311	8779	25065	7888	29831	96756
	2011	17858	0	51623	22043	591	701	3657	7314	1073	3062	0	0	33120
	2012	10212	0	21619	9231	20419	24217	6242	12483	4728	13498	11581	43799	103230
	2013	26352	0	37015	15806	6088	7220	1000	1999	3198	9132	1148	4343	38500
	2014	2643	0	39721	16961	25551	30303	2047	4093	1511	4313	3329	12590	68260
	2015	12746	0	38965	16638	13520	16035	1067	2133	7439	21239	1065	4028	60073
	2016	0	0	23186	9901	26492	31421	4817	9635	7202	20562	8708	32934	104451

Appendix V (cont)		Total Area (sq. meters) by Coverage Class; Calculated Wet Weight												
Section		Class 0	Wet Wt (kg)	Class 1	Wet Wt (kg)	Class 2	Wet Wt (kg)	Class 3	Wet Wt (kg)	Class 4	Wet Wt (kg)	Class 5	Wet Wt (kg)	Total Wet Wt (kg)
Gleasondale Impoundment (2009 – 2011 not assessed)	2005	24626	0	1991	850	2056	2438	0	0	2011	5742	9797	37053	46083
	2006	12402	0	6518	2783	3523	4179	0	0	4112	11739	12993	49138	67838
	2007	0	0	19821	8464	6015	7134	3937	7874	728	2080	9979	37741	63293
	2008	2293	0	24230	10346	3619	4292	1869	3738	6003	17139	2467	9329	44845
	2013	19768	0	9029	3855	3061	3631	198	395	4766	13606	3659	13840	35327
	2013	9355	0	9656	4123	3365	3991	3143	6285	4738	13528	10224	38666	66594
	2014	7226.6	0	16156	6898	2856	3387	3522	7045	4979	14216	5741	21714	53260
	2015	8105.9	0	8338	3561	6315	7491	7017	14036	3989	11389	4764	18018	54494
	2016	5206.3	0	15306	6536	5026.5	5961	2507	5015	3832.0	10940	7591	28711	57164

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.