OARS

FOR THE ASSABET SUDBURY & CONCORD RIVERS

Water Quality Monitoring Program
Final Report: 2012-2013 Field Seasons

April 2014

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Table of Contents

Figures and Tables

Abstract

This report covers the water quality and streamflow data collected between March 2012 and November 2013, summarizes the findings of a trends analysis for total phosphorus and nitrates concentrations between 1993 and 2013, and presents aquatic plant biomass data collected in 2012 and 2013.

Water quality reports and data for 1999 – 2011 (OAR 2000b, OAR 2001, OAR 2002, OAR 2003b, OAR 2004, OAR 2005, OAR 2006b, OAR 2007, OAR 2009, OARS 2011, OARS 2012) and 2005 biomass sampling project (OAR 2006a) are available on OARS' website (http://www.oars3rivers.org/river/waterquality/reports).

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 entering the river. During the growing season these 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 2012 assessment, Massachusetts Department of Environmental Protection (MA DEP, 2012) 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 Water, "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 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 for metals. Seven of the tributaries in the basin are also listed as Category 5 Waters (MA DEP, 2012): 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 Loading 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 study concluded that reductions in nutrient loads from both point and non-point sources will 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 imposed 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) is required to be upgraded by May 31, 2015.

Flow, particularly baseflow, is critical to supporting fish and other aquatic life in the mainstem river and tributaries 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.

Because of these problems, OARS (formerly the Organization for the Assabet River) conducts water quality, streamflow, and 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 2013 was OARS' 22nd consecutive summer collecting data at mainstem Assabet River sites, including the longest standing sites below each major wastewater treatment plant, its 12th year collecting data at tributary sites, its 10th year collecting data at mainstem Concord River sites, its 5th summer collecting Sudbury River data, and its 9th 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 2013) and previous Quality Assurance Project Plans may be used by EPA and DEP in making regulatory decisions. The goals of OARS' monitoring program remain: to understand long-term trends in the condition of the river and its tributaries, provide sound scientific information to evaluate regulatory decisions that affect the river, and to promote stewardship of the river 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).

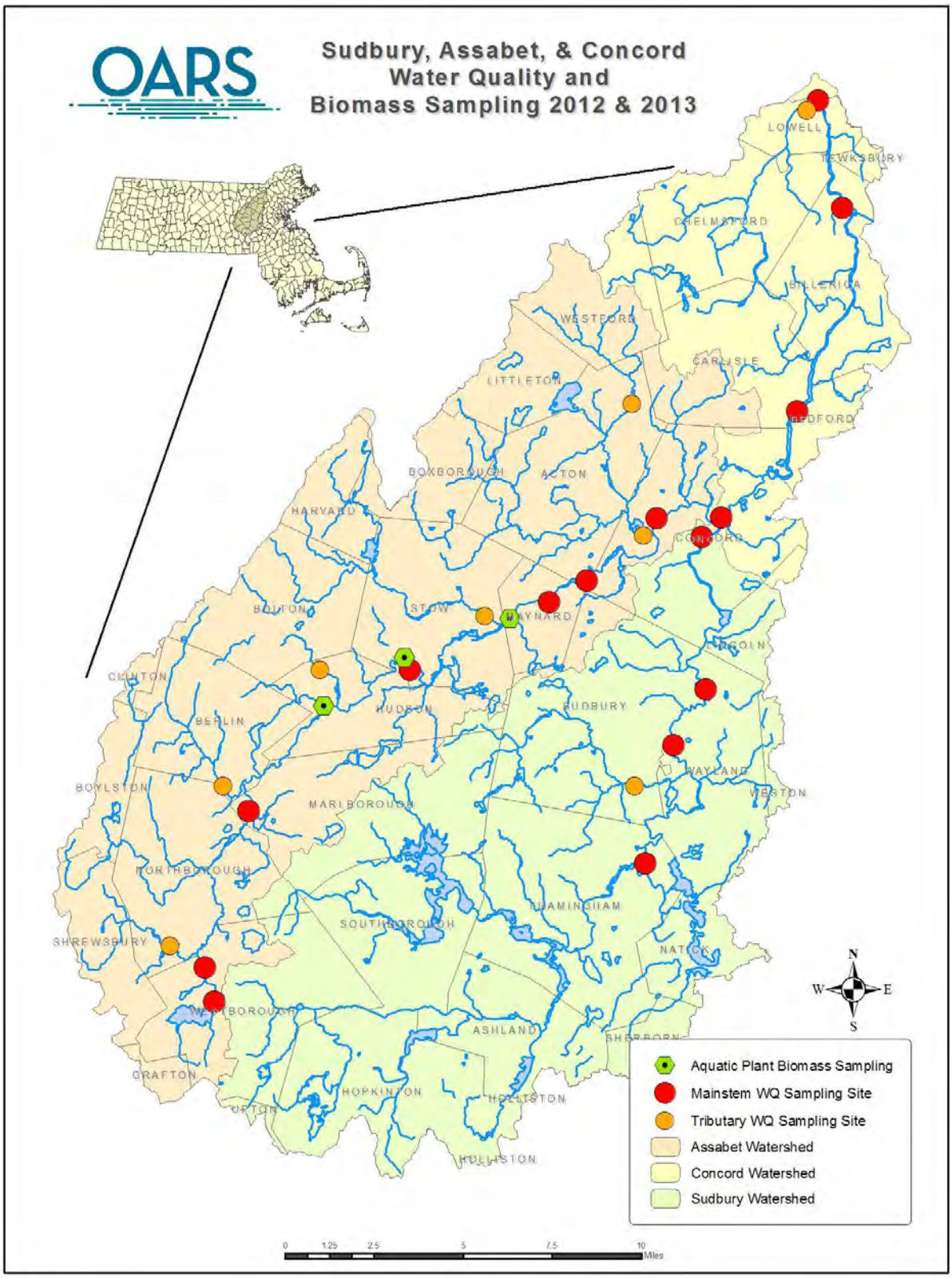
Table 1: Water Quality Sampling Sites 2012 & 2013

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[a]	Wayland	SUD-096	47650	May – Sept	42° 21' 48"/ -71° 22'28"	√	
Sudbury River	Pelham Island Road[a]	Wayland	SUD-098	47650	May - Sept	42°21' 33.3" / - 71°22' 09.1"	√	
Sudbury River	Sudbury Landing	Framingham	SUD-144	47650	May - Sept	42°19' 32.1" /- 71°23' 50.8"	√	(USGS)
Assabet River / Lower	Lowell Road	Concord	ABT-010	46500	June - Aug	42°28' 12.43"/- 71°21' 44.65"	√	
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 / Upper	Rte 62 / Gleasondale	Stow	ABT-144	46775	June - Aug	42°24' 16.26"/ -71°31' 34.70"	√	
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	Maynard Street [b]	Westborough	ABT-311	46775	Mar, May – Sept, Nov	42°16' 26.07"/ -71°37' 57.34"	√	OARS
Assabet River/ Headwater	Mill Road[b]	Westborough	ABT-312	46775	Mar, May-Sept, Nov	42°16' 26"/ -71°37' 56"	√	OARS
River Meadow Brk	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"	√	

[a] The site at Pelham Island Road (SUD-098) was moved downstream to Rte 20 (SUD-096) in August 2012 when the bridge at Pelham Island Road was under construction. SUD-098 is upstream of the confluence of Hop Brook with the Sudbury River, and SUD-096 is just downstream of the confluence.

[a] The site at Maynard Street, Westborough (ABT-311) was moved upstream to Mill Road, Westborough (ABT-312) in May 2012 to use the USGS-installed staff gage at that site.

Figure 1: Sudbury, Assabet, and Concord River Watershed and 2012 & 2013 Sampling Sites



Water Quality Sampling 2012 – 2013

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 rivermiles above its confluence with the next stream. Water quality monitoring (grab samples*, in-situ* measurements, and observations) was conducted one Sunday each month in March, May, June, July, August, September, and November of 2013 and 2013. Because of funding limitations, not all sites are sampled each month: in November and March, only the gaged sites and mainstem top and bottom of the rivers (ABT-301, ABT-026, CND-161, CND-005, SUD-144, and SUD-005) 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 (the growing season) monitoring is conducted between 5:00am and 8:30am, 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 6:00am and 1:00pm. Streamflow was calculated from the stage readings of OARS' gages using stage/discharge rating curves developed in cooperation with USGS or recorded from the USGS real-time gage webpages.

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 twenty four 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 *the Quality Assurance Project Plan for StreamWatch: OAR's Water Quality and Quantity Monitoring Program* (OAR 2009a, approved 7/20/09) and *Quality Assurance Project Plan for OAR's Lower Sudbury River Water Quality Monitoring Program* (OAR 2009b, approved 8/14/09), and the *Quality Assurance Project Plan for OARS' Water Quality and Quantity Monitoring Program* (OARS 2013, approved June 2013).

Table 2: Sampling and Analysis Methods

Parameter	Analysis Method #	Equipment Range/ Reporting Limits	Sampling Equipment	Laboratory
Temperature	---	-5 – 45 degrees C	YSI 6000-series	---
pH	---	0 to 14 units	YSI 6000-series	---
Dissolved oxygen	---	0 - 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 30 tributary streams in the basin as Coldwater Fisheries Resources 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. Since these and other tributary streams support or have supported cold water fisheries (Schlotterbeck 1954) and 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 the EPA "Gold Book" total phosphorus criteria (US EPA, 1986) (Table 3) and with summertime data for Ecoregion XIV subregion 59 streams (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 an 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 $\Delta \leq$ 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 were in relatively free-flowing sections, where the water column is assumed to be well-mixed. 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, and (4) the Assabet headwater and all tributary sites (Table 1). 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.

Water Quality Results

Reach and tributary statistics are summarized in Table 6, below. Full monthly summaries of the water quality data are attached in Appendix II. Individual parameters are discussed below.

Table 6: Mainstem Reach and Tributary Statistics – 2012 & 2013

	Reach Statistics 2012 (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)
11 & 12-March-2012	Upper Assabet Mainstem	1	Single reading	7:02 AM	6.99	87.5	10.62	322	7.11	2	0.19	0.14	3	<0.1	
	Lower Assabet Mainstem	2	Median	9:26 AM	4.20	102.0	13.29	337	7.19	3.3	0.06	0.01	1	<0.1	
	Sudbury Mainstem	2	Median	8:42 AM	6.50	101.0	12.39	292	6.96	3.5	0.03	<0.01	0.42	<0.1	
	Concord Mainstem	2	Median	9:50 AM	6.12	107.1	13.25	292	7.14	3.8	0.04	<0.01	0.57	<0.1	
	Headwater & Tribs	7	Median	9:16 AM	3.85	96.7	12.73	149	7.06	1.5	0.04	<0.01	0.22	<0.1	
	Hop Brook, Sudbury	1	Single reading	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
13-May-2012	Upper Assabet Mainstem	1	Single reading	7:22 AM	15.97	95.4	9.21	252	7.26	6.5	0.03	<0.01	1.1	<0.1	
	Lower Assabet Mainstem	2	Median	6:15 AM	16.24	92.6	9.08	259	7.08	7	0.08	<0.01	0.51	0.1	
	Sudbury Mainstem	5	Median	6:33 AM	15.40	90.2	9.01	215	6.99	3	0.03	<0.01	0.15	0.1	
	Concord Mainstem	2	Median	6:54 AM	16.25	88.6	8.64	289	7.07	4	0.03	0.01	0.38	<0.1	
	Headwater & Tribs	8	Median	7:15 AM	16.49	79.6	7.76	303	6.89	4.5	0.02	<0.01	0.14	0.1	
	Hop Brook, Sudbury	1	Single reading	6:49 AM	15.08	40.2	4.05	301	6.67	<1	0.04	0.02	1.1	0.1	
17-June-2012	Upper Assabet Mainstem	3	Median	7:43 AM	17.92	82.3	7.78	539	7.24	2	0.07	<0.01	2.2	<0.1	
	Lower Assabet Mainstem	3	Median	7:01 AM	20.34	88.5	7.99	383	7.34	7.8	0.1	0.02	0.94	<0.1	
	Sudbury Mainstem	5	Median	6:29 AM	20.53	71.4	6.4	397	6.95	9.5	0.02	<0.01	0.07	<0.1	5.95
	Concord Mainstem	4	Median	7:24 AM	21.07	87.9	7.82	370	7.205	9	0.06	0.01	0.40	<0.1	
	Headwater & Tribs	8	Median	7:40 AM	18.71	93.3	8.31	357	7.19	3.5	0.05	0.01	0.27	<0.1	
	Hop Brook, Sudbury	1	Single reading	6:51 AM	17.70	20.5	1.95	363	6.76	1.5	0.08	0.04	0.16	<0.1	<2.00
15-July-2012	Upper Assabet Mainstem	3	Median	7:25 AM	21.76	60.7	5.32	861	7.29	2	0.06	0.02	5.3	<0.1	
	Lower Assabet Mainstem	3	Median	6:45 AM	25.25	78.9	6.39	575	7.51	4	0.04	0.02	0.94	<0.1	
	Sudbury Mainstem	5	Median	6:30 AM	25.29	67.4	5.33	503	7.22	11	0.04	0.01	0.05	<0.1	7.34
	Concord Mainstem	4	Median	7:07 AM	26.80	75.8	6.09	524	7.35	15	0.06	0.02	0.47	<0.1	
	Headwater & Tribs	8	Median	7:17 AM	23.60	79.8	6.645	383	7.33	9.3	0.06	0.01	0.18	0.1	
	Hop Brook, Sudbury	1	Single reading	7:03 AM	22.92	14.6	1.25	460	6.95	6	0.1	0.06	0.72	0.1	3.95

	Reach Statistics 2012 (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)
19-August-2012	Upper Assabet Mainstem	3	Median	7:35 AM	20.45	75.8	6.93	476	7.23	2	0.05	0.04	2.2	<0.1	
	Lower Assabet Mainstem	3	Median	6:34 AM	22.69	85.0	7.35	382	7.41	3	0.06	0.03	0.74	<0.1	
	Sudbury Mainstem	5	Median	6:32 AM	22.80	58.5	5.07	392	6.85	8	0.04	0.03	0.06	<0.1	6.08
	Concord Mainstem	4	Median	7:11 AM	24.33	92.5	7.73	445	7.44	12	0.04	0.02	0.39	<0.1	
	Headwater & Tribs	8	Median	7:15 AM	20.49	81.7	7.07	328	7.1	2.5	0.04	0.02	0.10	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:15 AM	20.01	10.3	0.94	391	6.70	12	0.24	0.15	0.13	<0.1	4.27
23-Sept-2012	Upper Assabet Mainstem	1	Single reading	7:38 AM	19.32	75.8	6.94	988	7.16	1.5	0.04	0.01	12	<0.1	
	Lower Assabet Mainstem	2	Median	7:42 AM	18.3	79.7	7.48	611	7.57	6.75	0.015	<0.01	1.8	<0.1	
	Sudbury Mainstem	5	Median	7:32 AM	18.39	88.4	8.28	379	7.21	6.5	0.01	<0.01	0.12	<0.1	
	Concord Mainstem	2	Median	7:37 AM	19.16	92.6	8.55	510	7.50	6.5	0.02	<0.01	0.87	<0.1	
	Headwater & Tribs	8	Median	7:59 AM	16.88	84.1	8.11	328	7.25	2	0.01	<0.01	0.11	<0.1	
	Hop Brook, Sudbury	1	Single reading	8:13 AM	16.11	41.4	4.07	397	6.75	1	0.04	0.01	0.7	<0.1	
15-Nov-2012	Upper Assabet Mainstem	1	Single reading	11:10 AM	12.27	99.9	10.67	688	7.44	6	0.20	0.18	10.8	<0.1	
	Lower Assabet Mainstem	2	Median	5:21 AM	7.35	102.0	12.26	337	7.45	1.8	0.02	0.02	1.9	0.1	
	Sudbury Mainstem	2	Median	6:42 AM	7.79	93.95	11.19	267	7.63	3.3	0.01	<0.01	0.21	<0.1	
	Concord Mainstem	2	Median	4:09 AM	7.49	90.65	10.86	300	7.14	5.8	0.02	<0.01	0.49	<0.1	
	Headwater & Tribs	7	Median	9:50 AM	5.32	92.7	11.68	202	7.32	1.5	<0.01	<0.01	0.19	<0.1	
	Hop Brook, Sudbury	1	Single reading	12:05 PM	5.37	83.9	10.60	276	7.52	1	0.02	0.01	0.97	<0.1	

NA = not sampled / not recorded

	Reach Statistics 2013 (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)
28-March-2013	Upper Assabet Mainstem	1	Single reading	11:06 AM	7.84	103.5	12.28	428	7.16	1.5	<0.01	<0.01	4.4	<0.1	
	Lower Assabet Mainstem	2	Median	12:56 PM	6.98	107.9	13.09	315	7.23	3.5	<0.01	<0.01	1.1	<0.1	
	Sudbury Mainstem	2	Median	11:45 AM	6.38	103.4	12.69	345	7.27	1.5	<0.01	<0.01	0.37	<0.1	
	Concord Mainstem	2	Median	10:38 AM	6.75	106.5	12.99	339	7.15	2.0	<0.01	<0.01	0.58	<0.1	
	Headwater & Tribs	6	Median	11:35 AM	6.16	102.5	12.93	195	7.01	1.5	<0.01	<0.01	0.34	<0.1	
	Hop Brook, Sudbury	1	Single reading	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
19-May-2013	Upper Assabet Mainstem	1	Single reading	7:27 AM	15.27	78.3	7.83	692	7.34	3.5	0.06	0.04	6.9	<0.1	
	Lower Assabet Mainstem	2	Median	7:17 AM	17.33	88.5	8.48	461	7.32	4.8	0.02	<0.01	1.4	<0.1	
	Sudbury Mainstem	5	Median	6:50 AM	17.53	86.6	8.19	493	7.18	12.0	<0.01	<0.01	0.17	<0.1	
	Concord Mainstem	2	Median	7:02 AM	17.34	90.8	8.70	480	7.24	22.3	<0.01	<0.01	0.57	<0.1	
	Headwater & Tribs	8	Median	7:20 AM	15.86	87.3	8.73	447	7.17	4.8	<0.01	<0.01	0.25	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:35 AM	15.22	52.1	5.20	443	7.03	2.0	0.02	0.01	0.49	<0.1	
16-June-2013	Upper Assabet Mainstem	3	Median	7:38 AM	17.36	79.4	7.46	299	6.77	4.0	0.03	0.02	0.45	<0.1	
	Lower Assabet Mainstem	3	Median	6:30 AM	17.86	90.8	8.61	248	6.76	7.5	0.06	0.04	0.24	<0.1	
	Sudbury Mainstem	5	Median	6:47 AM	18.64	52.7	4.93	310	6.55	2.0	0.04	<0.01	0.14	<0.1	4.61
	Concord Mainstem	4	Median	7:19 AM	18.57	69.5	6.49	263	6.67	6.3	0.07	0.013	0.16	<0.1	
	Headwater & Tribs	8	Median	7:29 AM	16.92	87.4	8.53	213	6.70	2.8	0.03	<0.01	0.13	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:22 AM	17.26	35.1	3.37	293	6.59	1.0	0.07	0.03	0.43	<0.1	1
21-July-2013	Upper Assabet Mainstem	3	Median	8:00 AM	23.84	72.5	6.24	812	7.31	0.5	0.04	0.02	4.7	<0.1	
	Lower Assabet Mainstem	3	Median	6:30 AM	27.79	85.5	6.85	614	7.49	1.5	0.02	0.01	0.80	<0.1	
	Sudbury Mainstem	5	Median	6:35 AM	27.88	59.6	4.61	585	7.01	6.0	0.06	0.03	0.17	<0.1	8.54
	Concord Mainstem	4	Median	7:00 AM	28.96	86.4	6.60	533	7.27	8.0	0.06	0.01	0.42	<0.1	
	Headwater & Tribs	8	Median	7:28 AM	25.16	78.6	6.25	425	6.98	2.8	0.05	0.03	0.23	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:13 AM	24.92	20.6	1.67	528	6.95	4.5	0.13	0.11	0.14	0.12	nr

	Reach Statistics 2013 (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)
18-August-2013	Upper Assabet Mainstem	3	Median	7:45 AM	20.16	77.4	6.98	729	7.48	2.5	0.02	<0.01	3.8	<0.1	
	Lower Assabet Mainstem	3	Median	6:30 AM	20.72	85.5	7.72	490	7.45	1.5	<0.01	<0.01	0.73	<0.1	
	Sudbury Mainstem	5	Median	6:30 AM	22.00	71.2	6.11	493	7.01	5.0	<0.01	<0.01	0.10	<0.1	6.55
	Concord Mainstem	4	Median	6:52 AM	22.83	90.2	7.72	457	7.29	7.5	<0.01	<0.01	0.39	<0.1	
	Headwater & Tribs	8	Median	7:21 AM	19.57	82.2	7.58	413	7.16	3.0	<0.01	<0.01	0.28	<0.1	
	Hop Brook, Sudbury	1	Single reading	7:06 AM	18.80	26.9	2.50	431	6.80	11.5	0.04	0.03	0.28	<0.1	NA
22-Sept-2013	Upper Assabet Mainstem	1	Single reading	8:00 AM	20.21	81.8	7.38	909	7.37	2.0	0.05	0.01	10.6	<0.1	
	Lower Assabet Mainstem	2	Median	8:07 AM	19.00	83.9	7.78	516	7.43	3.0	0.01	<0.01	1.40	<0.1	
	Sudbury Mainstem	5	Median	7:39 AM	19.15	81.7	7.58	490	7.32	8.5	0.03	<0.01	0.17	<0.1	
	Concord Mainstem	2	Median	7:40 AM	19.19	92.5	8.53	588	7.49	10.0	0.04	<0.01	1.13	<0.1	
	Headwater & Tribs	8	Median	8:06 AM	17.82	89.0	8.37	328	7.24	2.8	0.02	<0.01	0.23	<0.1	
	Hop Brook, Sudbury	1	Single reading	8:10 AM	17.25	40.9	3.92	474	7.01	4.0	0.07	0.04	0.49	<0.1	
10-Nov-2013	Upper Assabet Mainstem	1	Single reading	8:39 AM	13.08	78.3	8.21	766	7.47	1.5	0.44	0.29	11.4	<0.1	
	Lower Assabet Mainstem	2	Median	7:55 AM	6.71	94.7	11.55	464	7.18	1.5	0.07	<0.01	3.0	<0.1	
	Sudbury Mainstem	2	Median	9:05 AM	7.70	96.1	11.44	359	7.63	1.8	0.04	<0.01	0.14	<0.1	
	Concord Mainstem	2	Median	8:34 AM	7.36	95.4	11.45	403	7.43	3.5	0.02	0.01	1.30	<0.1	
	Headwater & Tribs	7	Median	8:36 AM	6.02	92.7	11.24	199	7.22	1.0	0.06	<0.01	0.18	<0.1	
	Hop Brook, Sudbury	1	Single reading	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Precipitation and Streamflow

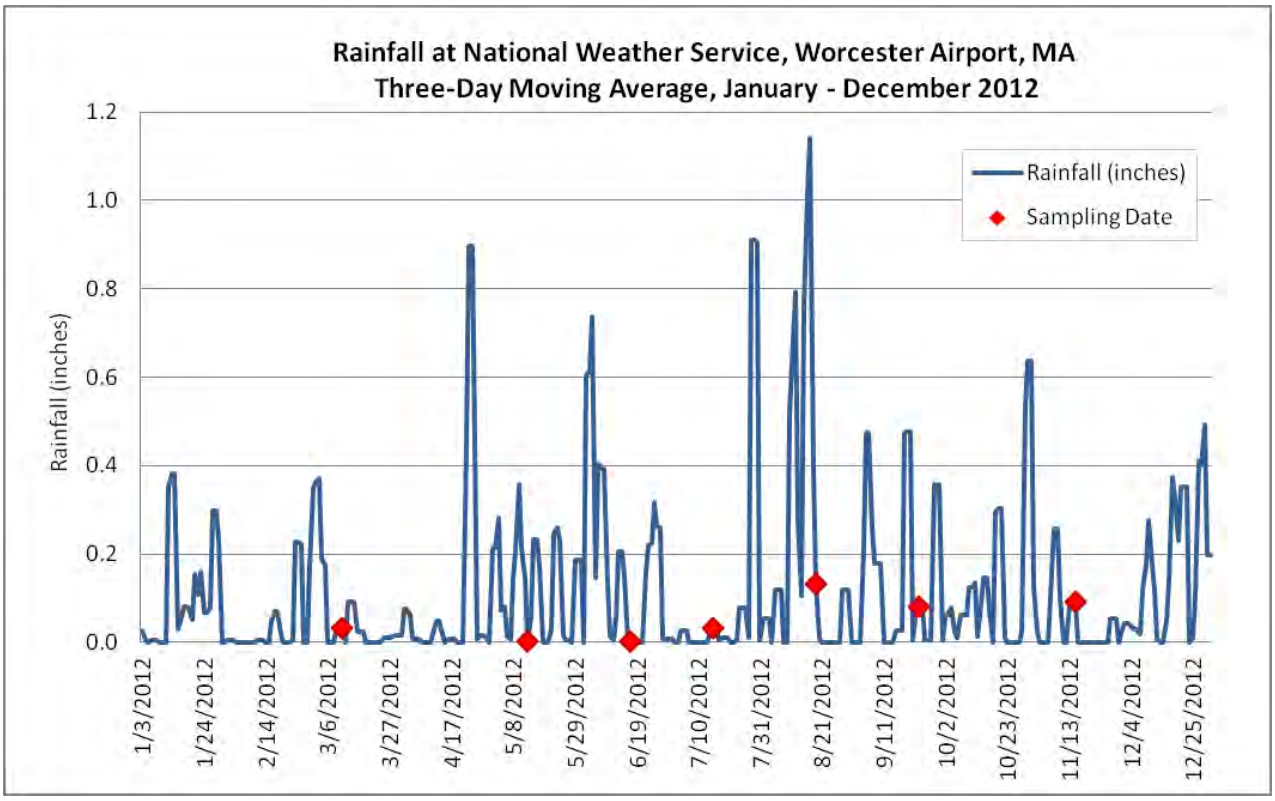
Precipitation, and the associated increased stormwater runoff and streamflow changes, are correlated with concentrations of total suspended solids, total phosphorus, and nitrate/nitrites. For the purposes of this project, sampling dates were classified by visual inspection of the hydrograph of the nearest available real-time USGS gage as rising, falling, or flat hydrograph (Table 7). Note that flow at the Sudbury River gage in Framingham is sometimes affected by dam manipulations upstream. Samples collected on a rising or peak hydrograph are likely to include "first flush" stormwater runoff and the associated pollutants.

Sampling events that were preceded by more than 0.1 inches of rain are highlighted; the rainfall on September 22, 2013 occurred after sampling. Rainfall data was downloaded from the National Weather Service's Worcester Airport station (http://www7.ncdc.noaa.gov/CDO/cdo) (Table 7 and Figure 2). Figure 2 shows the three-day moving average of the rainfall.

Table 7: Hydrograph and precipitation preceding and on sampling days 2012 & 2013

	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)
3/11/2012	falling	falling	peak	0.08	0
5/13/2012	falling	falling	peak	0	0
6/17/2012	falling	falling	falling	0	0
7/15/2012	flat	falling	falling	0.07	0.01
8/19/2012	falling	falling	peak	0.40	0
9/23/2012	flat	falling	falling	0.24	0.01
11/15/2012	falling	falling	falling	0.26	0
3/28/2013	falling	falling	falling	0	0.02
5/19/2013	falling	falling	falling	0	0.09
6/16/2013	peak	peak	rising	0.88	0
7/21/2013	falling	falling	falling	0.15	0
8/18/2013	falling	falling	falling	0	0
9/22/2013	flat	falling	falling	0.01	0.49
11/10/2013	flat	flat	flat	0	0.02

Figure 2: NWS rainfall data three-day moving averages (2012 and 2013)



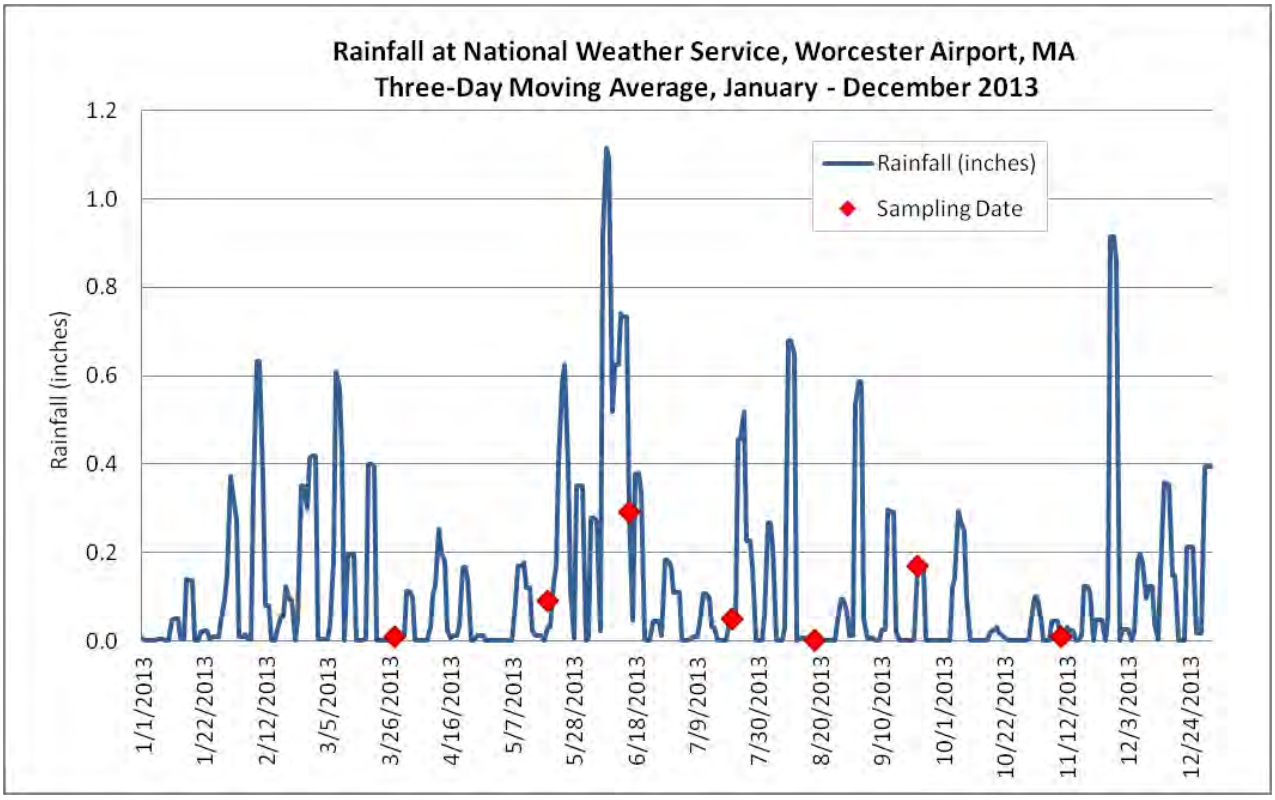
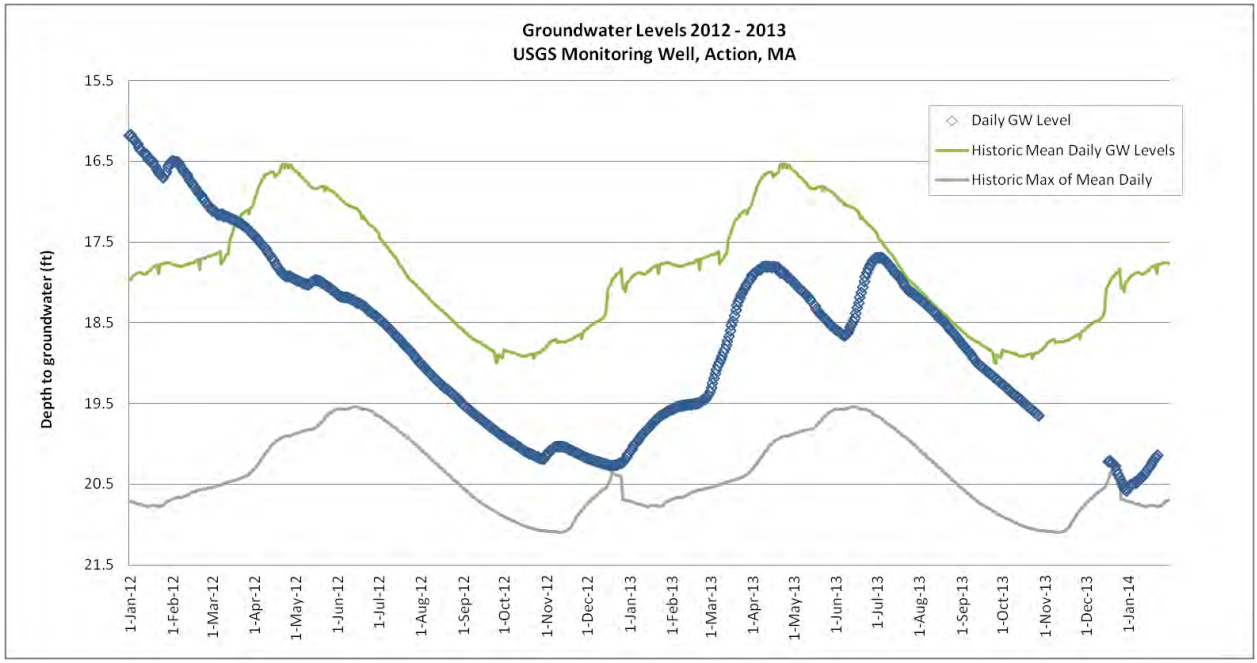


Figure 3 shows groundwater levels from the USGS monitoring well in Acton (USGS 422812071244401 MA-ACW 158 ACTON, MA). Changes in groundwater levels reflect precipitation and evapo-transpiration rates and, in turn, affect baseflow to the streams. Groundwater levels were below the historic mean levels between March 2012 and June 2013, near the mean levels in July 2013, and below the mean from mid-August to the end of the year.

Figure 3: Groundwater levels (USGS Monitoring well Acton, MA) 2012 & 2013

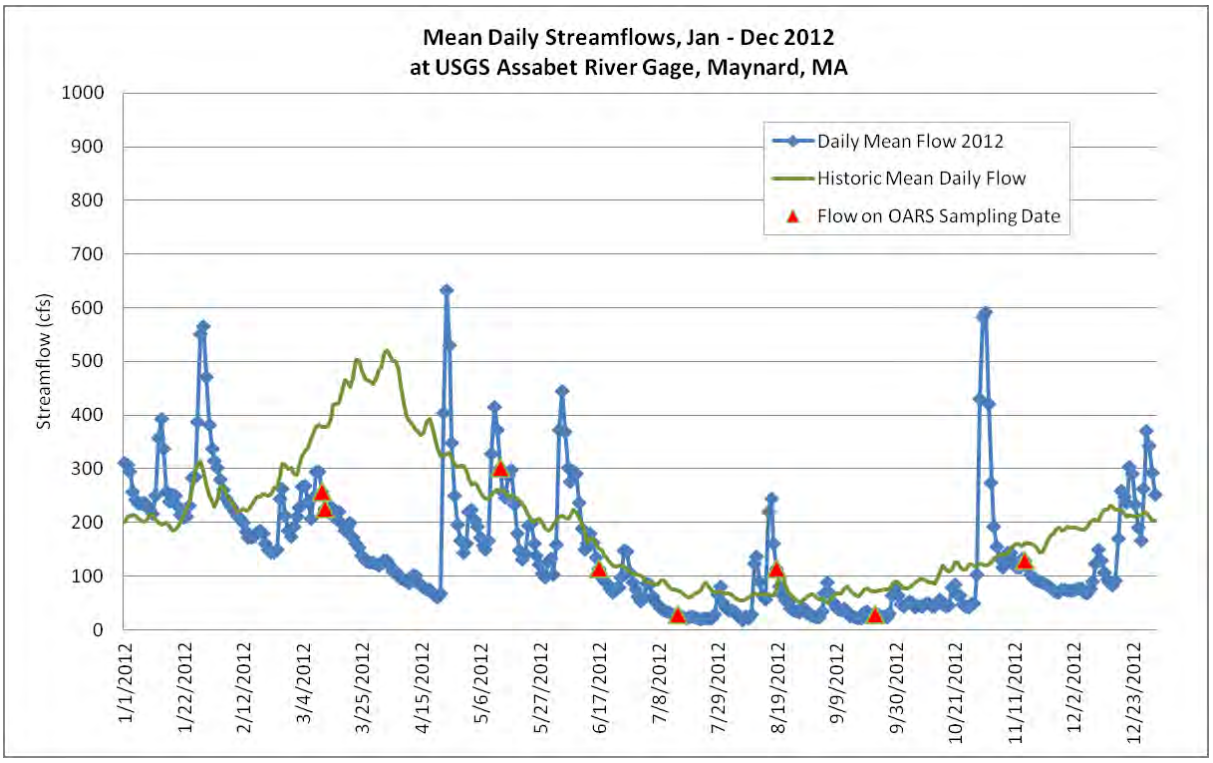


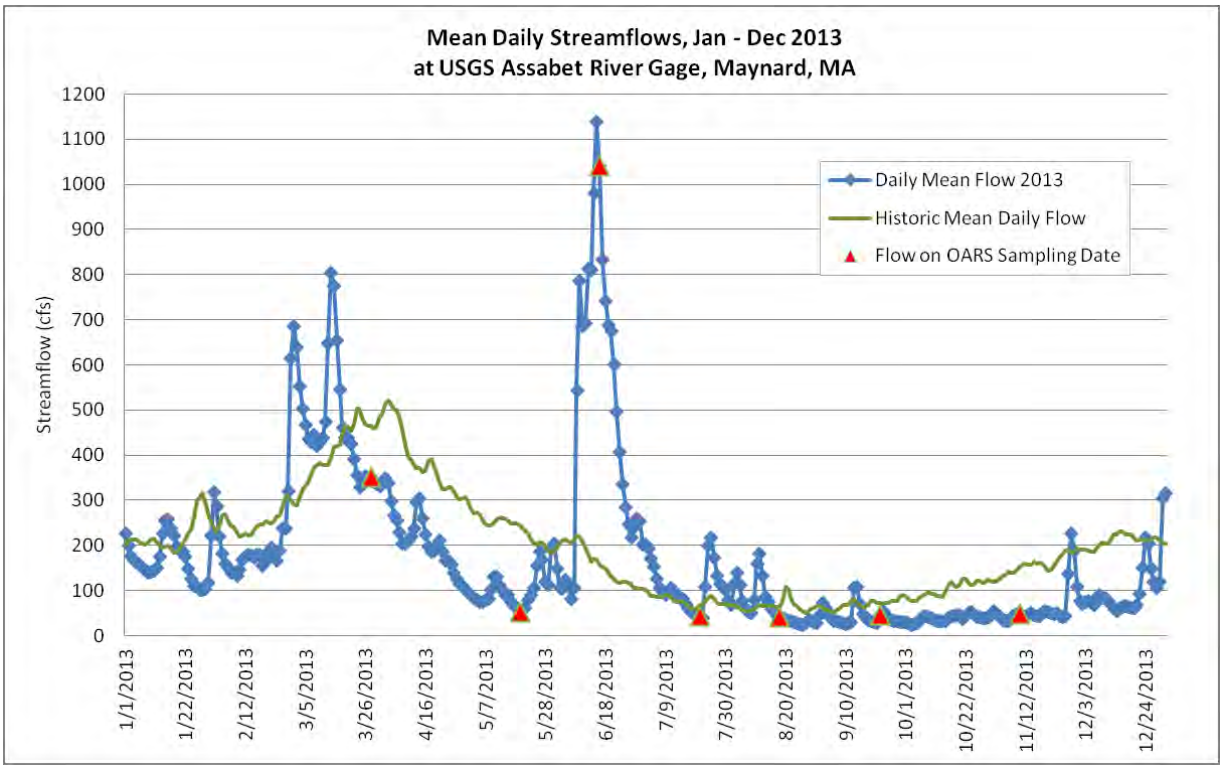
Streamflow has a direct impact on the concentration of nutrients and suspended solids in the water column and the availability of aquatic habitat, and an indirect impact on water temperature, dissolved oxygen concentration, pH, and conductivity. Note that streamflows measured at the Assabet River gage in Maynard include effluent discharges from three of the four municipal wastewater treatment plants on the river. Figure 4 shows mean daily streamflows at the Assabet River gage in Maynard compared with the historic mean of the daily streamflows (calculated on the period of record for the gage) for 2012 and 2013.

Streamflows at the Assabet River gage were lower than the historic mean for much of 2012 and 2013 except for May and early June of 2012 and March, June and July of 2013. Hydrographs for the Concord River gage in Lowell, the Sudbury River gage in Saxonville/Framingham, and the Nashoba Brook gage in Acton (see Appendix I) show similar patterns to the Assabet River's.

Monthly streamflows were also recorded at seven tributary monitoring sites and near the Assabet River headwaters, above the first wastewater discharge (data in Appendix I).

Figure 4: Mean Daily Streamflows Assabet River: 2012 and 2013





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 1:00 pm. Summary statistics for all in-situ readings are in Table 6 (above) and full data set is in Appendix A.

Water temperatures at all sites met Class B warm water fisheries standard (28.3°C) on all of the regular testing dates in 2012. In July 2013 six mainstem sites exceeded 28.3°C (ABT-062, SUD-064, CND-110, CND-045 and CND-005).

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 2012, the majority of the headwater/tributary sites tested had water temperatures exceeding 20.0°C in July and August. In 2013, all headwater/tributary sites exceeded 23.9°C in July; two sites exceeded 20.0°C in August.

The pH readings in ranged from 6.50 to 7.92 SU in 2012, meeting Class B standards on all regular testing dates. In 2013 pH readings ranged from 6.49 to 8.00 SU; the only site failing to meet Class B standards was SUD-064 in June 2013. Mid-afternoon readings on July 22, 2013 showed the highest pH on the Assabet River at White Pond Road, Maynard.

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 93 µS/cm to 1276 µS/cm in 2012. For 2012: the lowest reading (98 µS/cm) was recorded at Danforth Brook in March; highest readings were recorded at RVM-005 in July (1276 µS/cm) and September (1019 µS/cm) and ABT-301 in July (1100 µS/cm), August (1178 µS/cm), and Sept (988 µS/cm). For 2013 pH readings ranged between 116 µS/cm and 1122 µS/cm. For 2013: the lowest reading was recorded at North Brook in June; the highest readings were recorded at ABT-301 in July (1122 µS/cm) and September (909 µS/cm) and at RVM-005 in July (961 µS/cm).

Dissolved Oxygen

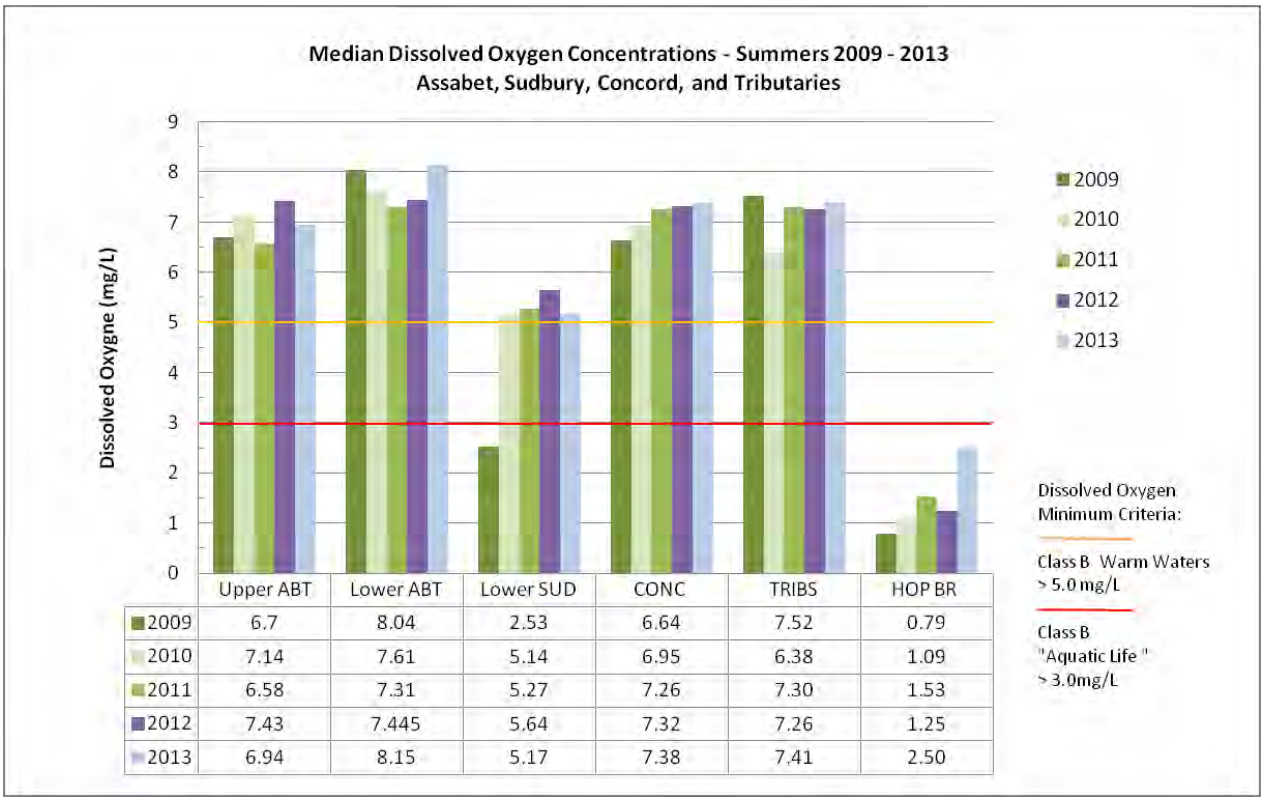
Dissolved oxygen (DO) concentrations during the growing season are generally lowest between 5am and 8am after plant and microbial respiration has removed oxygen from the water column overnight. Low minimum DO concentrations and large diurnal variations in DO can indicate eutrophic conditions. Summary statistics for DO readings are in Table 6 and full data are in Appendix I. 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) are listed in Table 8. Note that low DO measurements may not constitute a violation of WQS if caused by natural conditions.

Table 8: Dissolved Oxygen Violations

Dissolved Oxygen Violations of WQS 2012 & 2013		
Date	Site	Dissolved Oxygen (mg/L)
5/13/2012	HBS-016	4.05
6/17/2012	HBS-016	1.95
7/15/2012	HOP-011	4.48
	ELZ-004	3.92
	HBS-016	1.25
8/19/2012	HBS-016	0.94
9/23/2012	HBS-016	4.07
6/16/2013	CND-161	4.44
	HBS-016	3.37
7/21/2013	ELZ-004	4.31
	HBS-016	1.67
8/18/2013	HBS-016	2.50
9/22/2013	HBS-016	3.92

For comparison between years and sections, Figure 5 shows median summer (June, July, and August) dissolved oxygen measurements for mainstem and tributary sections in 2009 - 2013. Hop Brook at Landham Road, Sudbury, has consistently low dissolved oxygen concentrations. The orange line indicates the Class B water quality standard (5.0mg/l) and the red line indicates the Class B Aquatic Life water quality standard (3.0mg/L). Note that these measurements are taken in free-flowing sections; dissolved oxygen in the impounded section would likely be lower.

Figure 5: Dissolved Oxygen Measurements (median summer) 2009 – 2013



	Upper ABT	Lower ABT	Lower SUD	CONC	TRIBS	HOP BR
2009	6.7	8.04	2.53	6.64	7.52	0.79
2010	7.14	7.61	5.14	6.95	6.38	1.09
2011	6.58	7.31	5.27	7.26	7.30	1.53
2012	7.43	7.445	5.64	7.32	7.26	1.25
2013	6.94	8.15	5.17	7.38	7.41	2.50

Nutrients and Suspended Solids

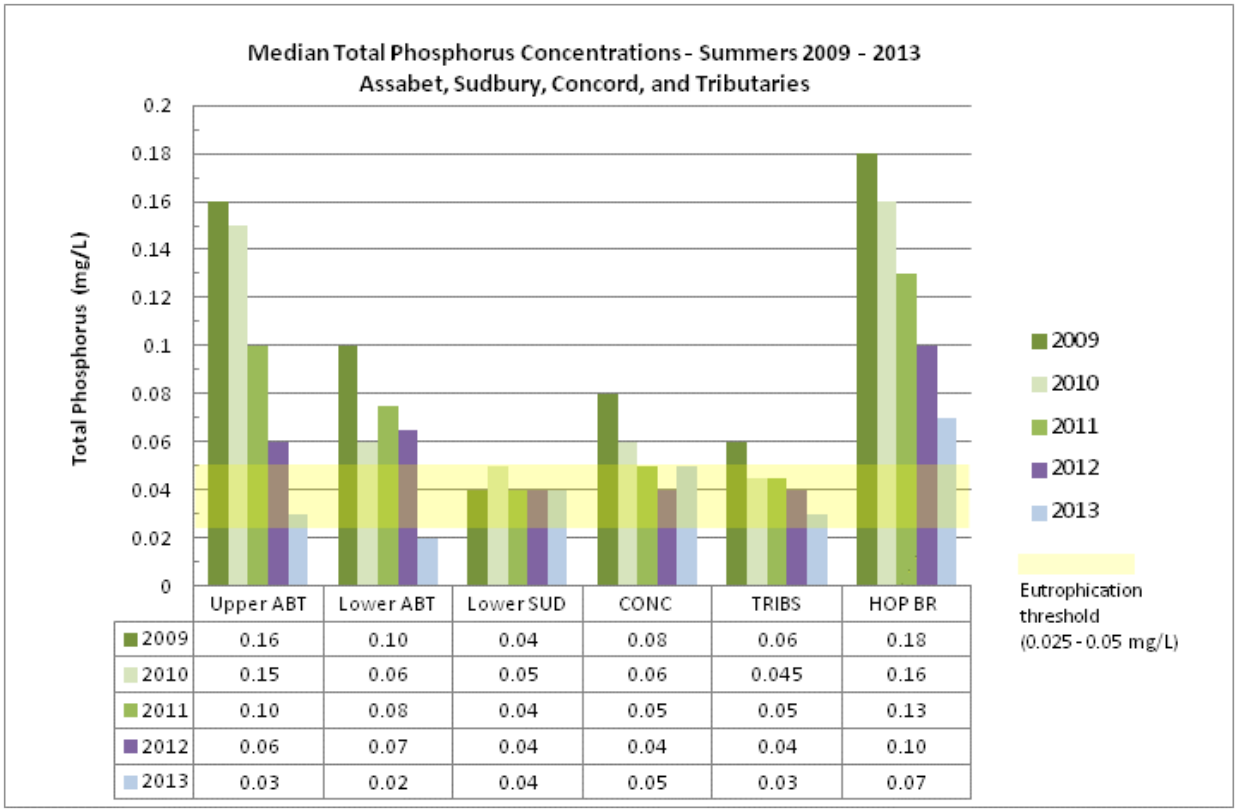
Summary statistics for nutrient concentrations are in Table 6, above. Median summer nutrient concentrations are shown (Figures 6 and 7)for the upper and lower Assabet mainstem reaches (see Table 1 for reach definitions), Sudbury mainstem sites, Concord mainstem sites, combined Assabet headwaters and tributary sites, and Hop Brook in Sudbury.

In 2013, median total phosphorus concentrations along the Assabet River mainstem below the first wastewater discharge (Westborough WWTP) were, for the first time since OARS has been monitoring, below the EPA "Gold Book" recommendation (0.05 mg/L TP), but slightly above the Ecoregion reference condition for TP (0.025 mg/L). Median nitrate concentrations on in the upper Assabet mainstem were 9-14 times the Ecoregion reference condition in 2012 and 2013, and in the lower Assabet mainstem were 2-3 times the Ecoregion reference condition.

Median total phosphorus concentrations in the Concord River mainstem were 0.04 mg/L and 0.05mg/L in 2012 and 2013, respectively (above the Ecoregion reference condition, but below the EPA "Gold Book" recommendation.) Nitrate concentrations were 0.42mg/L and 0.32 mg/L in 2012 and 2013.

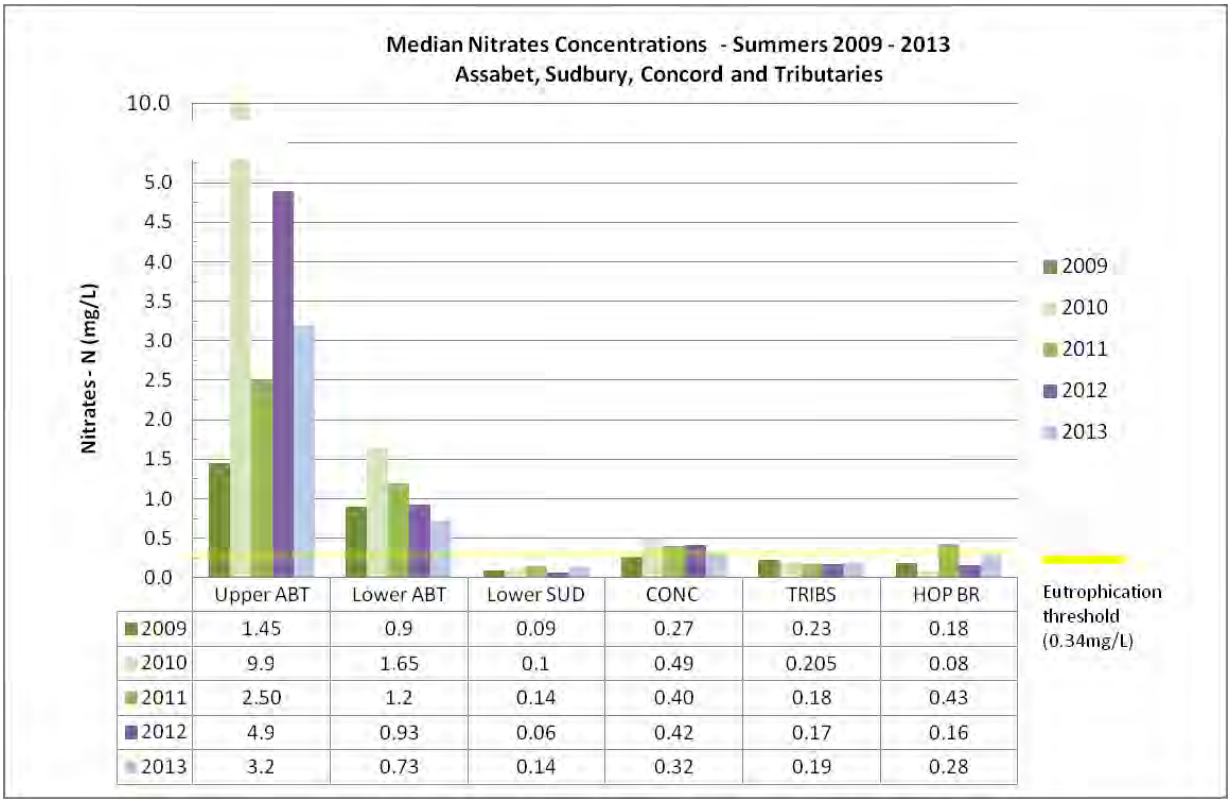
Median TP concentrations in the Sudbury River and in the tributaries of all three rivers (excluding Hop Brook, Sudbury) were slightly elevated: above 0.025mg/L but below 0.05mg/L. Hop Brook, Sudbury, which is affected by the wastewater discharge from Marlborough Easterly WWTP, and has total phosphorus concentrations 3-4 times the recommended concentrations.

Figure 6: Median Total Phosphorus Concentrations (Summers 1999- 2013)



	Upper ABT	Lower ABT	Lower SUD	CONC	TRIBS	HOP BR
2009	0.16	0.10	0.04	0.08	0.06	0.18
2010	0.15	0.06	0.05	0.06	0.045	0.16
2011	0.10	0.08	0.04	0.05	0.05	0.13
2012	0.06	0.07	0.04	0.04	0.04	0.10
2013	0.03	0.02	0.04	0.05	0.03	0.07

Figure 7: Median Nitrate Concentrations (Summers 2009- 2013)



	Upper ABT	Lower ABT	Lower SUD	CONC	TRIBS	HOP BR
2009	1.45	0.9	0.09	0.27	0.23	0.18
2010	9.9	1.65	0.1	0.49	0.205	0.08
2011	2.50	1.2	0.14	0.40	0.18	0.43
2012	4.9	0.93	0.06	0.42	0.17	0.16
2013	3.2	0.73	0.14	0.32	0.19	0.28

Chlorophyll a

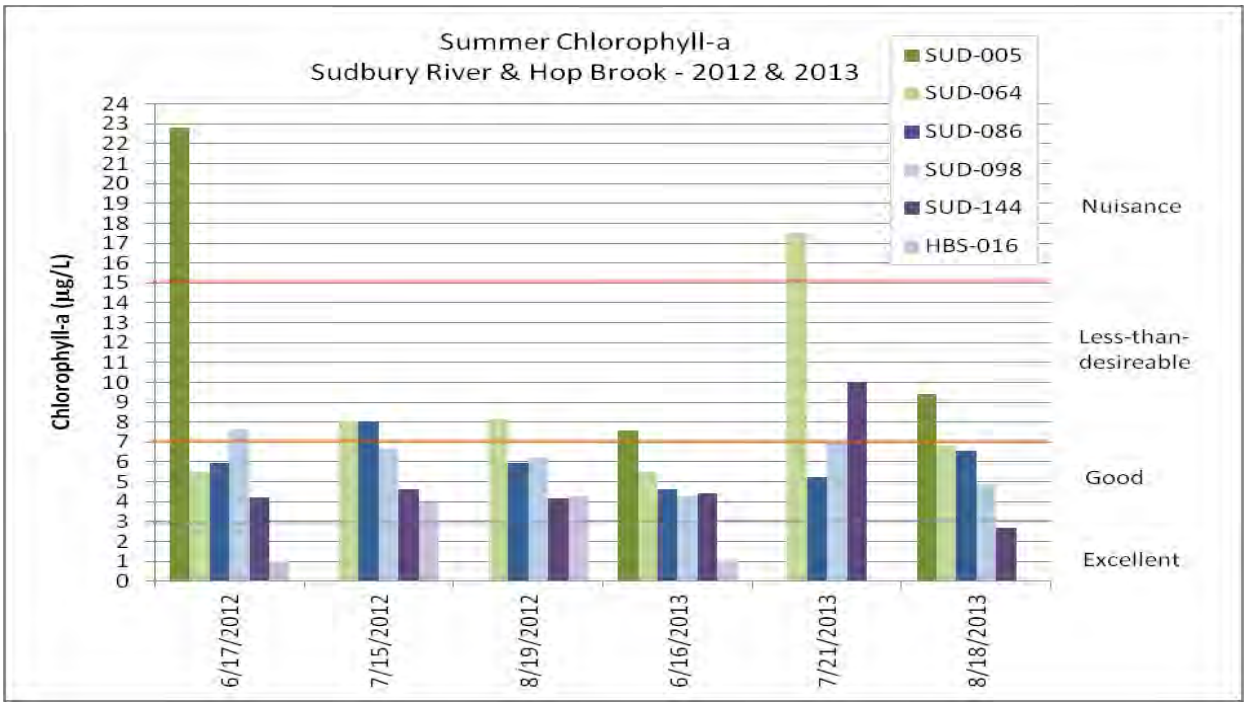
Chlorophyll *a* is the principle photosynthetic pigment in algae and vascular plants; chlorophyll *a* concentrations gives an estimate of the biomass of planktonic algae in the river and is one indicator of eutrophication. Rivers, like the Assabet, whose vegetation is dominated by larger rooted and floating aquatic plants may have low chlorophyll a concentrations although they are eutrophied. Chlorophyll *a* was measured in the Sudbury River and Hop Brook in Sudbury in June, July, and August each year. 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 9: 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. (The Concord and Assabet Rivers are not sampled for chlorophyll *a* because of budget constraints.) Concentrations ranged from <2 to 22.8 µg/L with most readings in the "good" to "excellent" range. The highest readings, falling into the "nuisance" range, were at SUD-005 (22.8 µg/L in June 2012) and SUD-064 at 17.5.0 µg/L in July 2013).

Figure 8: Chlorophyll-*a* at Sudbury River sites – 2012 & 2013



Fish Kill & Additional Readings – July 2013

OARS staff followed up reports of fish kills with additional YSI in-situ water quality readings on two occasions in July 2013 (full data in Appendix V).

In the first week of July, there were (unconfirmed) reports of fish kills along the Sudbury River. OARS staff took in-situ readings on July 2 at sampling sites on the Sudbury mainstem and on Hop Brook, Sudbury. Dissolved oxygen levels (Figure 9) were below the Class B Aquatic Life standard (3.0 mg/L) from River Road (SUD-086) to Rte 62 Concord (SUD-005), and very low on Hop Brook. Since streamflows in the previous three weeks were high (2 – 10 times the historic mean flows), it is possible that de-oxygenated water was coming into the river from the flood plains.

On July 20, 2013, a fish kill was documented in the Stow section of the Assabet River mainstem by OARS volunteers (Figure 10). In-situ readings were taken mid-afternoon on July 22 to check water temperatures upstream and downstream of the fish kill. Readings (Figure 11) showed the highest water temperature (30.21 °C), dissolved oxygen (201.9%) and pH (9.40 SU) in the surface waters at White Pond Road, downstream of the fish kill. It is likely that the fish kill was the result of a combination of stresses including the high water temperatures.

Figure 9: Dissolve Oxygen, Sudbury River, 7/2/2013

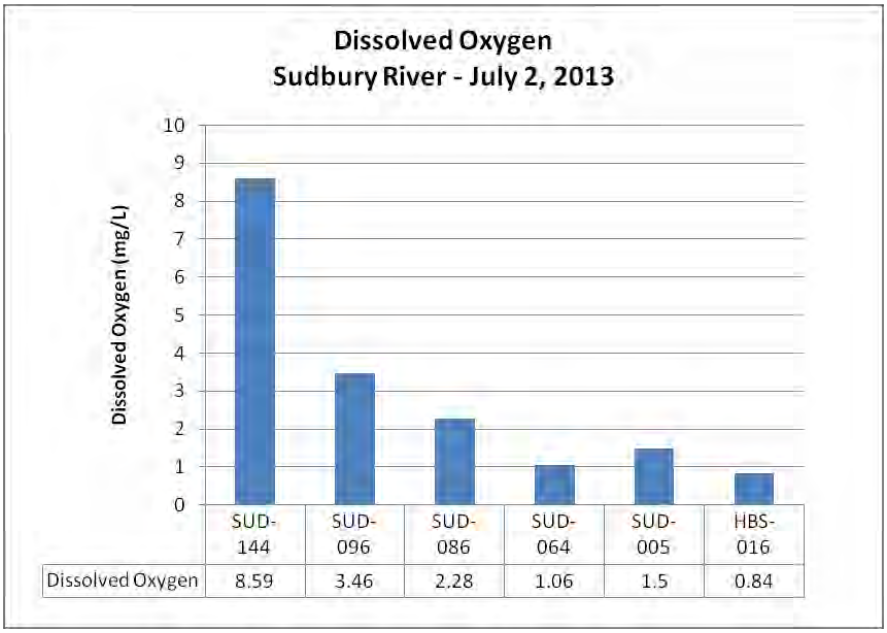
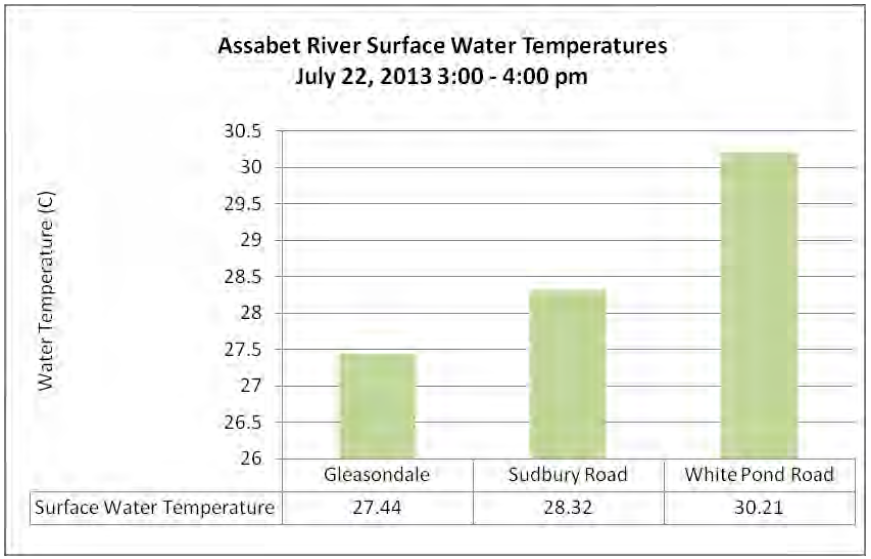


Figure 10: Fish kill on the Assabet River, Stow, July 20, 2013

Figure 11: Surface Water Temperature, Assabet River, 7/22/2013



Summer Nutrient Trends 1992 - 2013

Summer (June, July, and August only) trends in nutrient concentrations in the two most-stable nutrient parameters (total phosphorus and nitrates) were examined for the longest term sites that have remained essentially unchanged. Sites used are list in Table 10. 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. Box plots for Assabet River sites are shown for 1994 – 2013 (omitting 1993 data because of graphing software limitations).

Table 10: Sites for Nutrient Trends Analysis

Section	Sites	Years Sampled
Assabet Headwater	ABT-311 & ABT-312	1992-2011; 2012 - 2013
Upper Assabet	ABT-301	1992 – 2013
	ABT-238 & ABT-237	1992 – 2005; 2006-2013
Middle Assabet	ABT-144*	1992 – 2013
Lower Assabet	ABT-077	1992-2013
	ABT-026	1992-2013
Tributary Streams	HOP-011	2002-2013
	NTH-009	2002-2013
	DAN-013	2002-2013
	ELZ-004	2002-2013
	NSH-002	1995-2013

** ABT-144 site was moved from above to below the Gleasondale dam in 2002*

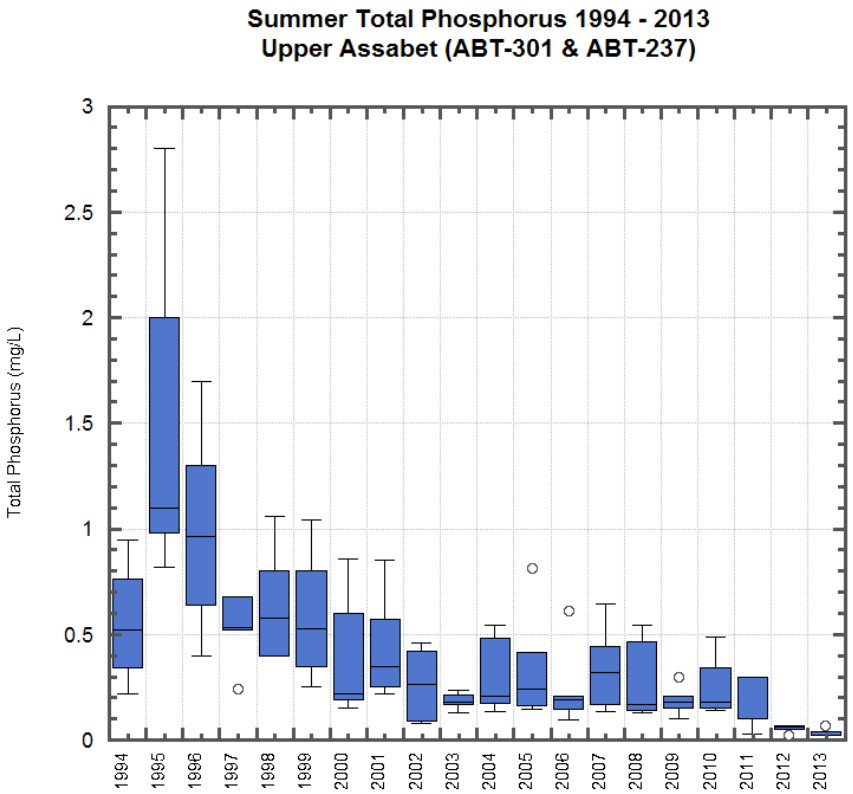
Total phosphorus in the upper and lower Assabet River mainstem sites is shown in Figure 12 (note that the y-axis scale is different in the two graphs). Nitrate concentrations for the upper and lower Assabet River mainstem sites are shown in Figure 13. Total phosphorus and nitrate concentrations in the Assabet headwater site and five tributaries of the Assabet River are shown in Figures 14 and 15. Average summer TP concentrations for each Assabet River section are shown in Table 11 for 2007 – 2013 (the years immediately preceding and during the recent upgrades in phosphorus removal at the wastewater treatment plants discharging to the Assabet). The last of the upgrades were completed by the spring of 2012.

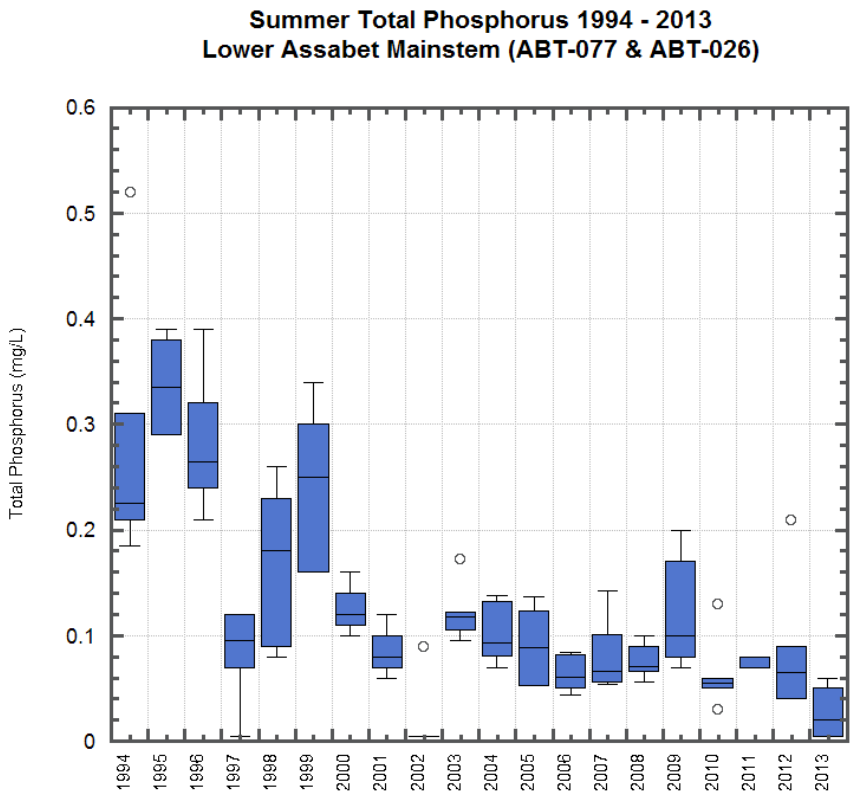
Table 11: Average Summer TP Concentrations - Assabet River

Average Summer Total Phosphorus Concentrations (mg/L)							
	2007	2008	2009	2010	2011	2012	2013
Assabet (all long-term sites)	0.18	0.16	0.16	0.14	0.11	0.07	0.03
Assabet Headwater (1 site)	0.03	0.03	0.03	0.03	0.04	0.06	0.01
Upper Assabet (2 sites)	0.34	0.27	0.19	0.25	0.16	0.06	0.03
Lower Assabet (2 sites)	0.08	0.08	0.12	0.06	0.07	0.09	0.04

The statistical significance of apparent summer trends in water quality were evaluated using a single season Mann-Kendall test (Helsel, 2006) for concentration and flow-weighted concentration and two date ranges ("all dates" 1993 - 2013 and "late" 1999 - 2013) where sufficient data were available. 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.

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

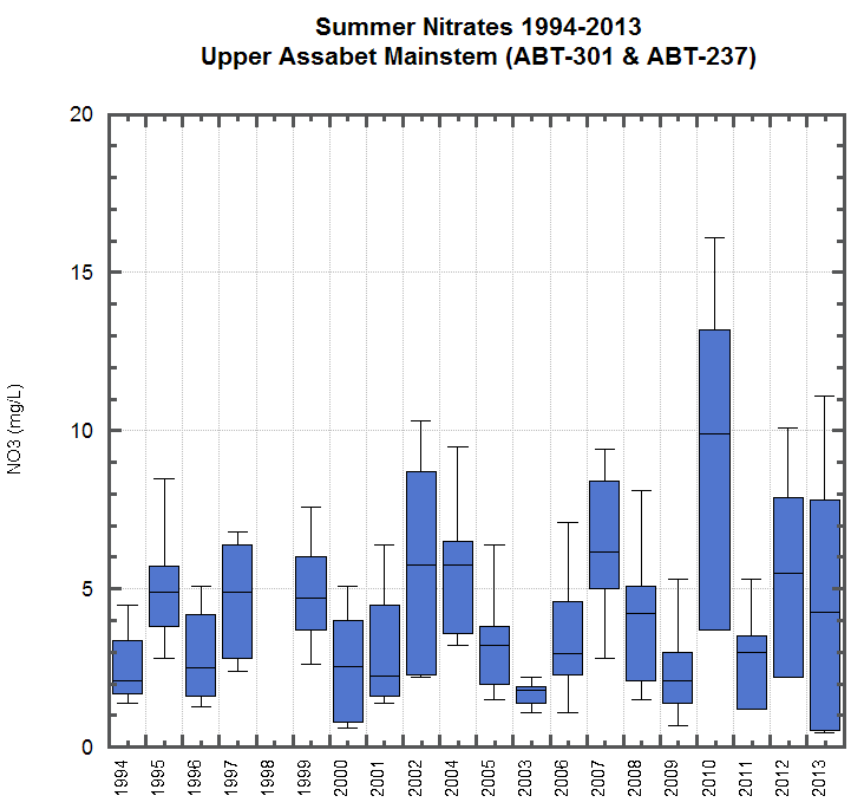


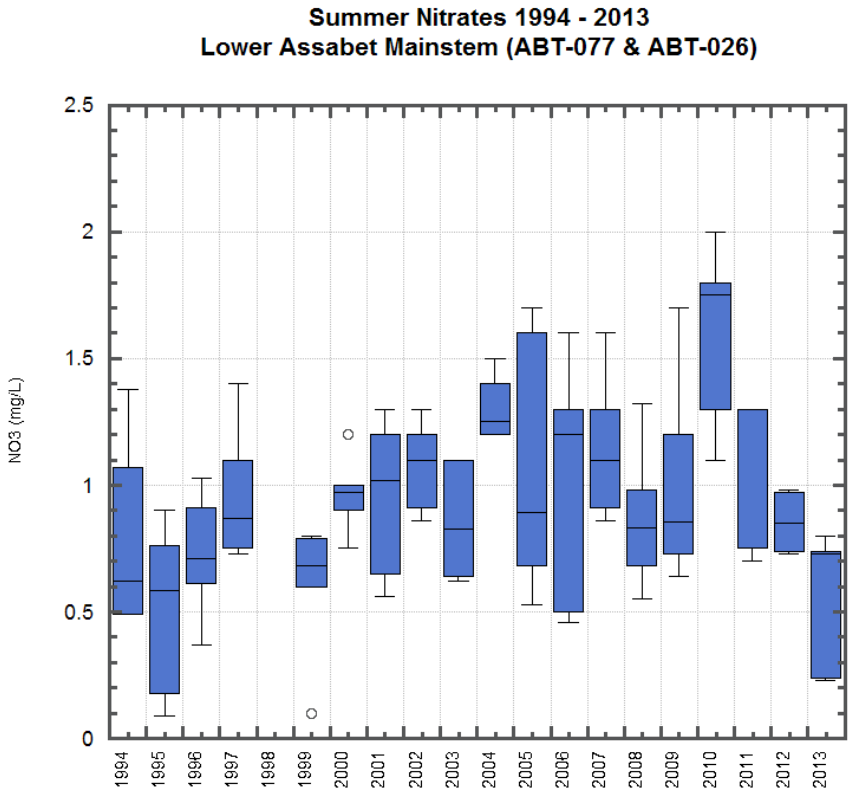


		Total Phosphorus - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Upper ABT	conc.	1993-2013	-0.59	-4499	-9.72	0.0000	downward	1999-2013	-0.438	-1755	-6.115	0.0000	downward
Upper ABT	flow-weighted	1993-2013	-0.503	-3834	-8.28	0.000	downward	1999-2013	-0.344	-1376	-4.794	0.0000	downward
Lower ABT	conc.	1993-2013	-0.527	-4147	-8.75	0.000	downward	1999-2013	-0.356	-1427	-4.977	0.0000	downward
Lower ABT	flow-weighted	1993-2013	-0.473	-3728	-7.86	0.000	downward	1999-2013	-0.35	-1402	-4.884	0.0000	downward

NST = no significant trend

Figure 13: Summer Nitrates in Upper and Lower Assabet Mainstem

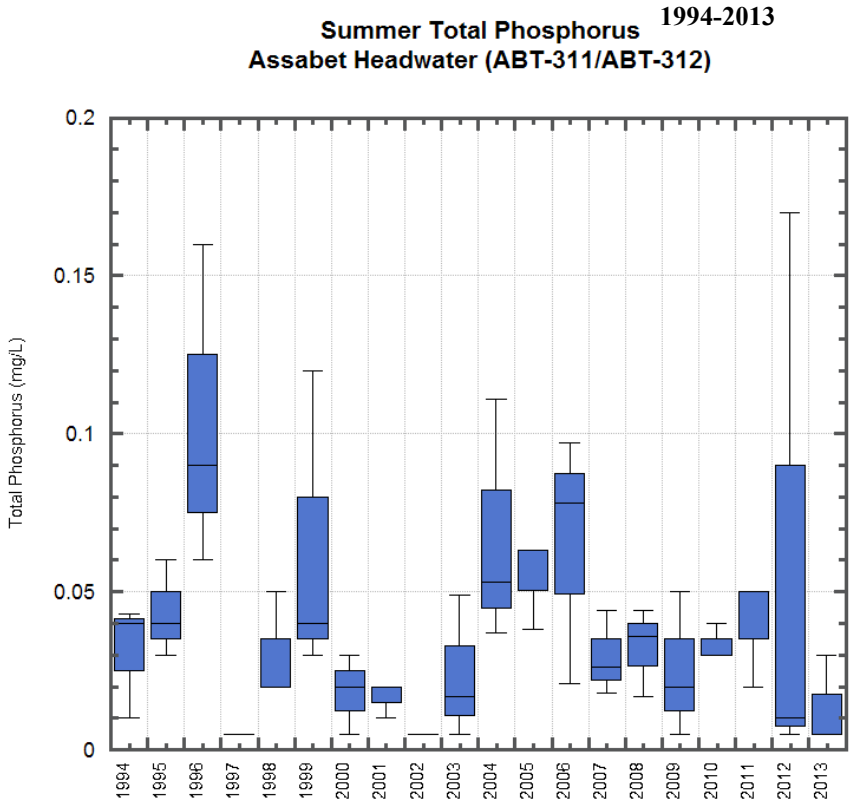


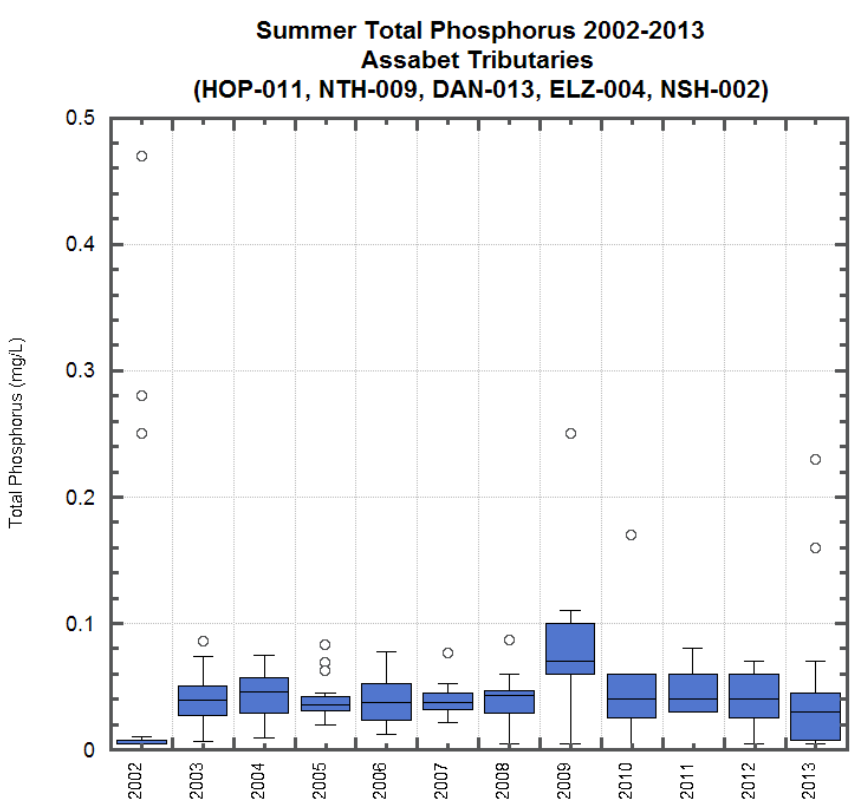


		Nitrates - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Upper ABT	conc.	1993-2013	-0.107	-839	-1.77	0.0771	NST	1999-2013	0.07	434	1.089	0.2760	NST
Upper ABT	flow-weighted	1993-2013	0.242	1670	3.883	0.0001	upward	1999-2013	0.234	1453	3.652	0.0003	upward
Lower ABT	conc.	1993-2013	0.179	1150	2.817	0.0048	upward	1999-2013	0.06	241	0.838	0.4018	NST
Lower ABT	flow-weighted	1993-2013	0.227	1462	3.579	0.003	upward	1999-2013	0.102	408	1.419	0.1559	NST

NST = no significant trend

Figure 14: Summer Total Phosphors at Assabet Headwater & Tributaries

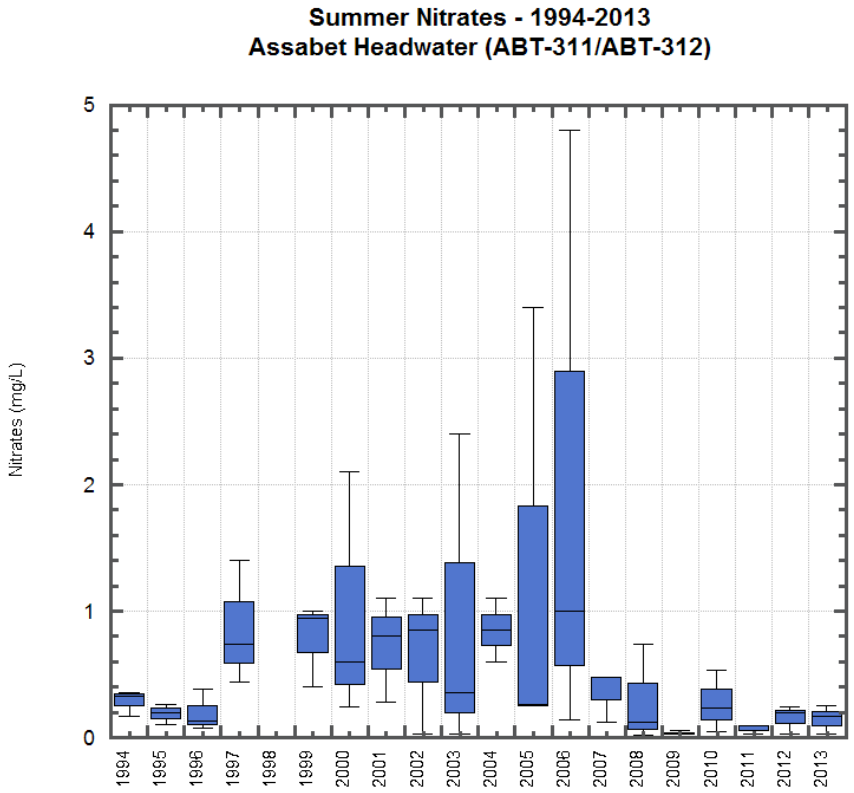


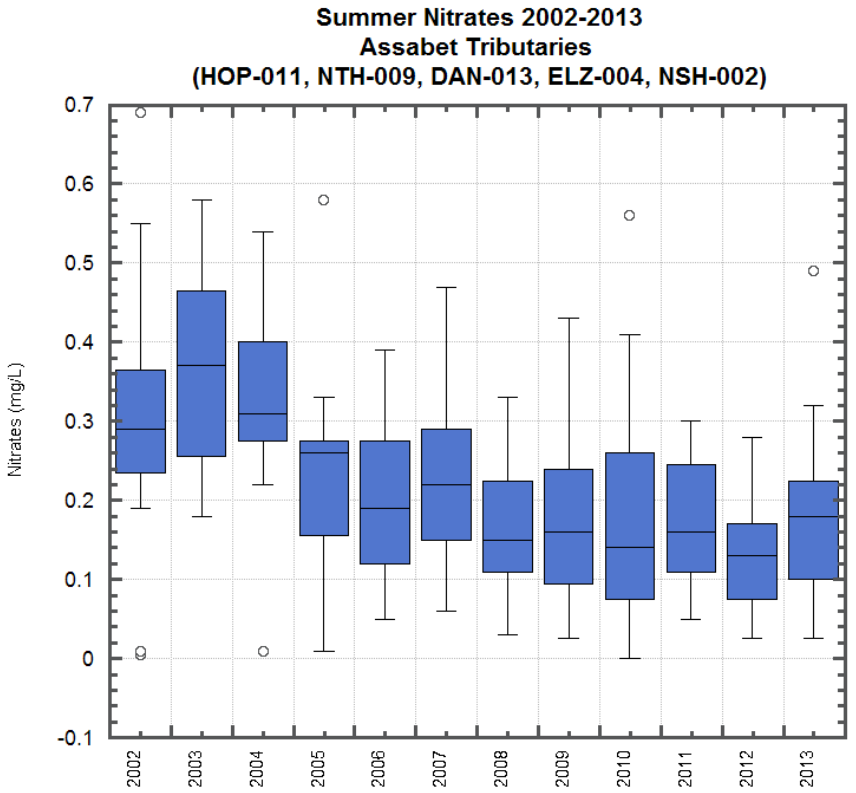


		Total Phosphorus - Mann-Kendall test statistics											
Section	Type	All dates						Late					
		years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Headwater ABT	conc.	1993-2013	0.02	52	0.248	0.804	NST	1999-2013	-0.006	-8	-0.052	0.0958	NST
Headwater ABT	flow-weighted	1993-2013	-0.018	-47	-0.23	0.822	NST	1999-2013	0.027	38	0.276	0.7824	NST
Tributaries	conc.							2002-2013	0.777	1227	1.531	0.1257	NST
Tributaries	flow-weighted							2002-2013	0.126	2002	2.498	0.0125	upward

NST = no significant trend

Figure 15: Summer Nutrients 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.	1993-2013	-0.205	-440	-2.43	0.015	downward	1999-2013	-0.354	-507	-3.784	0.0002	downward
Headwater ABT	flow-weighted	1993-2013	-0.132	-283	-1.56	0.1185	NST	1999-2013	-0.444	-636	-4.739	0.0000	downward
Tributaries	conc.							2002-2013	-0.308	-4960	-6.143	0.0000	downward
Tributaries	flow-weighted							2002-2013	-0.317	-5045	-6.3	0.0000	downward

NST = no significant trend

Statistically significant trends included: decreasing trends in total phosphorus concentrations in the Assabet River (upper and lower sections) for both date ranges assessed; increasing trend in flow-weighted nitrate concentrations in the upper Assabet; an increasing trend in flow-weighted total phosphorus concentrations in tributary streams; decreasing trends in nitrate concentrations in the tributaries and the Assabet headwater site. No significant trends were found in dissolved oxygen or streamflow at the Assabet River USGS gage on sampling dates.

For comparison, wastewater treatment plant total phosphorus loads from 2007 to 2011 (the latest data available from EPA's Discharge Monitoring Report (DMR) Pollutant Loading Tool. EPA, 2014) are shown (Figure 16) for the WWTPs discharging to the Assabet River. Improvements in phosphorus removal reduced TP concentrations and total annual loads from the Assabet wastewater treatment plants between 2007 and 2011, while total annual discharge flows did not changed substantially (Figure 17).

Figure 16: Annual Load Total Phosphorus from WWTPs 2007 - 2011

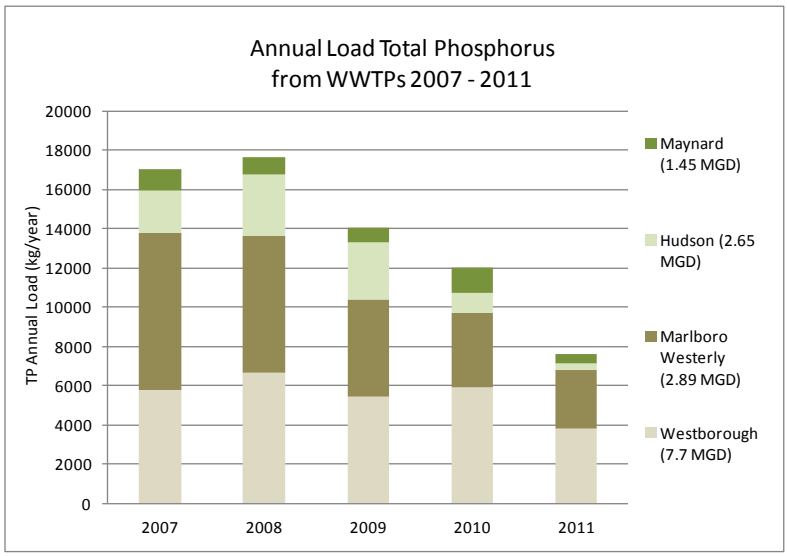
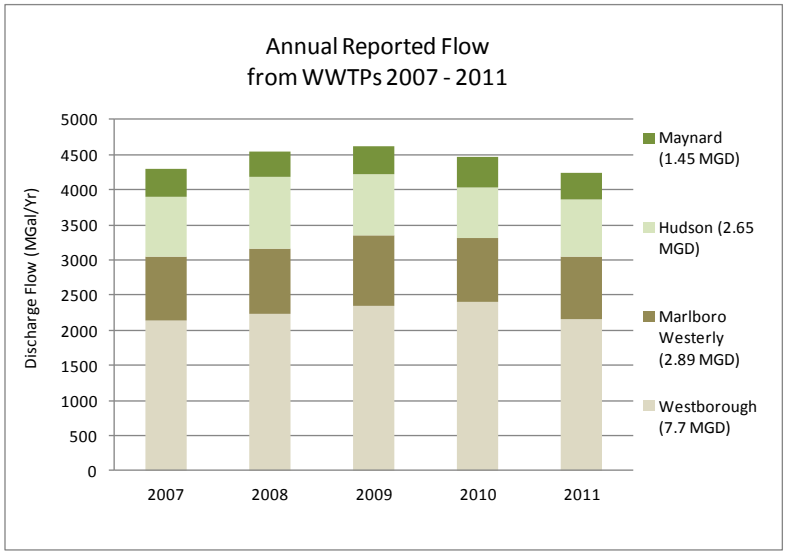


Figure 17: Total Annual Flow from WWTPs 2007 - 2011



Water Quality and Stream Health Index Calculations

The Stream Health Index was used to assess conditions at seven of the tributary stream sites for each of the monthly sampling results (Table 11). 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 12) 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). In 2009, the index calculation was updated to use nitrates (instead of total nitrogen, since TKN is no longer being analyzed) and to include Class B "Aquatic Life" standards for dissolved oxygen and temperature in the Water Quality Index for the Sudbury River mainstem sites. 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 2012 and July 2013, with the heat wave in July 2013 driving stream temperatures up. Streamflows in June 2013 were above the highest measured flow on the rating curves for the established flow gages (i.e. cannot be correlated with a flow volume).

Water Quality Index: Table 12 shows Water Quality Index readings for selected sites on the mainstem Assabet, Sudbury and Concord Rivers and on Hop Brook in Sudbury. Nitrates were the lowest scoring parameters, driving the overall WQI score, at the Assabet River sites. In previous years both total phosphorus and nitrates have been the lowest scoring parameters at the Assabet sites. At the Concord River sites, nitrates and total suspended solids were the lowest scoring parameters (although higher scoring than at the Assabet sites). Dissolved oxygen and total suspended solids were generally the lowest scoring parameter at the Sudbury River sites below Saxonville. Dissolved oxygen was the lowest scoring parameters at the Hop Brook site in Sudbury.

Table 12: Stream Health Index Readings – Summer 2012 & 2013

	Stream Health Index Readings – 2012 & 2013									
	5/13/12	6/17/12	7/18/12	8/19/12	9/23/12	5/19/13	6/16/13	7/21/13	8/18/13	9/22/13
Assabet River Headwater, Mill Rd., Westborough										
Water Quality Index	88	84	33	62	79	84	83	60	71	75
Flow Index	86	29	20	56	19	63	81	19	32	21
Habitat Index	95	65	35	70	60	90	100	50	30	35
Stream Health Index	90	49	28	62	36	77	87	33	38	34
Danforth Brook, Rte 85, Hudson										
Water Quality Index	88	77	64	71	82	NA	85	50	56	65
Flow Index	86	NA	18	55	21	53	81	54	26	40
Habitat Index	90	75	25	90	40	55	100	60	30	70
Stream Health Index	88	NA	27	69	35	NA	88	55	34	54
Hop Brook, Otis Street, Northborough										
Water Quality Index	78	74	41	65	67	75	69	6	70	84
Flow Index	86	83	45	67	75	70	NA	60	53	54
Habitat Index	85	85	40	75	69	75	100	60	40	70
Stream Health Index	83	80	42	69	62	73	NA	14	51	67
Nashoba Br., Commonwealth Ave, W. Concord										
Water Quality Index	80	67	31	57	86	76	75	6	72	87
Flow Index	86	83	54	66	44	81	NA	82	78	65
Habitat Index	100	85	65	75	40	75	100	85	95	75
Stream Health Index	88	77	45	65	51	77	NA	15	81	75
Nashoba Brook, Wheeler Ave, Acton										
Water Quality Index	74	52	51	62	67	70	75	37	63	63
Flow Index	86	82	18	63	40	80	81	70	66	45
Habitat Index	100	95	85	90	70	85	100	95	95	95
Stream Health Index	85	71	35	69	55	78	84	58	72	62
North Brook, Whitney Ave, Berlin										
Water Quality Index	86	81	46	68	79	81	85	26	73	81
Flow Index	86	83	64	64	44	76	81	56	64	54
Habitat Index	100	80	55	90	45	80	100	50	50	80
Stream Health Index	90	81	54	73	52	79	88	39	61	69

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 Summers 2012 & 2013

Assabet at Rte 9 Westboro (ABT-301)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	1.1	0.03	6.5	9.21	7.26	15.97	64
6/17/12	7.9	0.07	2	7.78	7.23	17.92	8
7/15/12	10.1	0.06	2	4.86	7.24	21.53	6
8/19/12	5.7	0.02	2	5.90	7.09	20.45	21
9/23/12	12	0.04	1.5	6.94	7.16	19.32	6
5/19/13	6.9	0.06	3.5	7.83	7.34	15.27	14
6/16/13	0.53	0.02	4	7.46	6.95	18.37	76
7/21/13	11.1	0.07	2.5	6.24	7.31	22.63	6
8/18/13	7.8	0.02	3.5	6.98	7.48	20.23	9
9/22/13	10.6	0.05	2	7.38	7.37	20.21	6

Assabet at Rte 27 Maynard (ABT-077)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	0.52	0.08	5.5	9.22	7.05	16.42	69
6/17/12	0.89	0.08	4	8.59	7.31	21.21	63
7/15/12	0.81	0.04	2.5	6.39	7.66	25.96	64
8/19/12	0.73	0.09	2	7.30	7.20	22.69	64
9/23/12	2.1	0.02	7.5	7.48	7.67	18.75	52
5/19/13	1.4	0.02	3	8.79	7.37	17.67	64
6/16/13	0.24	0.06	7.5	8.15	6.76	17.66	73
7/21/13	0.8	0.02	1	6.00	7.49	27.79	65
8/18/13	0.73	<0.01	2	7.72	7.45	20.06	76
9/22/13	1.3	<0.01	2	7.96	7.47	19.17	67

Concord at Lowell Rd Concord (CND-161)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	0.15	0.02	5	8.51	7.10	16.16	86
6/17/12	0.06	0.03	7.5	7.26	7.23	21.11	80
7/15/12	0.5	0.04	4.5	6.10	7.31	26.20	66
8/19/12	<0.05	0.03	6	6.24	7.28	23.58	78
9/23/12	0.44	0.02	6	8.55	7.51	19.11	77
5/19/13	0.31	<0.01	36	8.64	7.26	17.42	60
6/16/13	<0.05	0.03	2.5	4.44	6.59	18.87	74
7/21/13	0.46	0.05	7.5	6.33	7.13	28.06	62
8/18/13	0.44	<0.01	3.5	7.17	7.24	22.18	79
9/22/13	1.3	0.04	6	8.67	7.54	19.44	61

Key:	81 – 100 = Excellent	61 – 80 = Good	41 – 60 = Fair	21 – 40 = Poor	1 – 20 = Very Poor

Concord at Rogers Street Lowell (CND-009)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	0.6	0.04	3	8.76	7.03	16.33	74
6/17/12	0.48	0.16	13	8.26	7.23	21.03	58
7/15/12	1	0.09	10	6.08	7.36	26.71	53
8/19/12	0.55	0.03	14	7.89	7.59	24.52	65
9/23/12	1.3	0.02	7	8.55	7.48	19.20	62
5/19/13	0.82	<0.01	8.5	8.75	7.22	17.26	70
6/16/13	0.2	0.07	11	7.83	6.73	18.44	70
7/21/13	0.59	0.06	9	NA	7.28	28.71	NA
8/18/13	0.77	<0.01	7	7.90	7.23	22.81	70
9/22/13	0.95	0.04	14	8.39	7.43	18.94	61

Sudbury at Saxonville Framingham (SUD-144)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	0.28	<0.01	5	9.53	7.08	15.27	86
6/17/12	0.22	<0.01	1	8.26	7.23	19.58	93
7/15/12	0.1	0.02	1	6.37	7.25	24.31	88
8/19/12	0.07	0.02	3	8.36	7.16	23.10	88
9/23/12	0.15	<0.01	<1	9.16	7.26	18.05	98
5/19/13	0.31	<0.01	2	8.93	7.37	16.49	88
6/16/13	0.2	0.03	3.5	10.45	7.00	17.53	85
7/21/13	0.17	0.04	<1	8.11	7.30	26.23	82
8/18/13	0.14	<0.01	<1	7.96	7.29	20.95	96
9/22/13	0.15	0.03	7	8.29	7.17	19.15	82

Sudbury at Sherman Bridge Rd, Wayland (SUD-064)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	0.08	0.02	2	6.17	6.72	16.82	87
6/17/12	0.07	0.02	9.5	5.74	6.85	20.81	78
7/15/12	<0.05	0.04	12	5.88	7.22	26.35	70
8/19/12	0.06	0.04	8	4.36	6.50	22.80	69
9/23/12	0.10	<0.01	7	8.28	7.27	18.41	88
5/19/13	0.13	<0.01	31	8.19	7.06	18.01	67
6/16/13	0.06	0.04	2	3.82	6.49	19.31	72
7/21/13	0.15	0.08	18.5	4.61	7.01	29.00	56
8/18/13	0.09	<0.01	11.5	6.11	7.01	22.91	79
9/22/13	0.17	0.05	24.5	8.21	7.38	19.94	65

Key:	81 – 100 = Excellent	61 – 80 = Good	41 – 60 = Fair	21 – 40 = Poor	1 – 20 = Very Poor

Sudbury at Rte 62, Concord (SUD-005)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	0.14	0.02	4.5	7.76	7.03	16.49	86
6/17/12	<0.05	0.05	10	7.24	7.01	21.74	75
7/15/12	<0.05	0.04	8.5	5.33	7.25	27.54	69
8/19/12	<0.05	0.04	17	5.36	6.90	24.13	67
9/23/12	<0.05	0.01	6.5	8.29	7.20	19.06	88
5/19/13	0.05	<0.01	12	9.43	7.25	18.07	84
6/16/13	<0.05	0.04	2.5	3.40	6.58	19.28	69
7/21/13	<0.05	0.06	10.5	4.32	6.92	28.29	62
8/18/13	<0.05	<0.01	9.5	6.54	7.08	23.07	81
9/22/13	<0.05	0.03	10.5	7.58	7.33	19.71	79

Hop Brook at Landham Road, Sudbury (HBS-016)	Water Quality Parameter Reading						Water Quality Index Reading
	NO3	TP	TSS	DO	pH	Temp	
5/13/12	1.1	0.04	<1	4.05	6.67	15.08	52
6/17/12	0.16	0.08	1.5	1.95	6.76	17.70	6
7/15/12	0.72	0.1	6	1.25	6.95	22.92	5
8/19/12	0.13	0.24	12	0.94	6.70	20.01	5
9/23/12	0.7	0.04	1	4.07	6.75	16.11	55
5/19/13	0.49	0.02	2	5.20	7.03	15.22	68
6/16/13	0.43	0.07	1	3.37	6.59	17.26	46
7/21/13	0.14	0.13	4.5	1.67	6.95	24.92	5
8/18/13	0.28	0.04	11.5	2.50	6.80	18.80	16
9/22/13	0.49	0.07	4	3.92	7.01	17.25	52

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 Septemeber 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

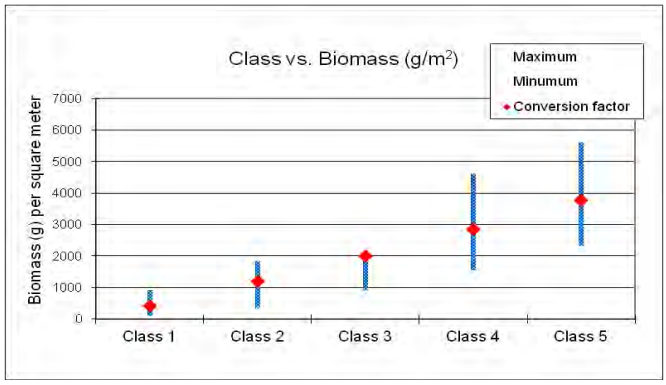
These surveys have focused on three large impoundments of the Assabet River, as the most eutrophied areas of the river. Impoundment locations include: (1) Hudson impoundment (off Rte 85), Hudson, about 0.5 miles upstream from the dam at Rte 85; (2) Gleasondale impoundment, Stow, about 0.6 miles upstream 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 Assabet River was 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. From 2007 – 2011, grid cells were located in the field using a printed map with the grids and GPS coordinates for the centroid of each grid cell. In 2012, the data collection was conducted using Magellan MobileMapper-6 GPS unit with ESRI ArcPad and data input screens designed for the study. The MobileMapper allows data input in the field and more accurate identification of grid cell locations and size. The size of a grid cell can be estimated in the field by paddling from edge to edge, observing the current GPS point location. 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. Date, observer's initials, and starting time for the survey, were recorded for each field session. At each grid cell the following information was 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 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.

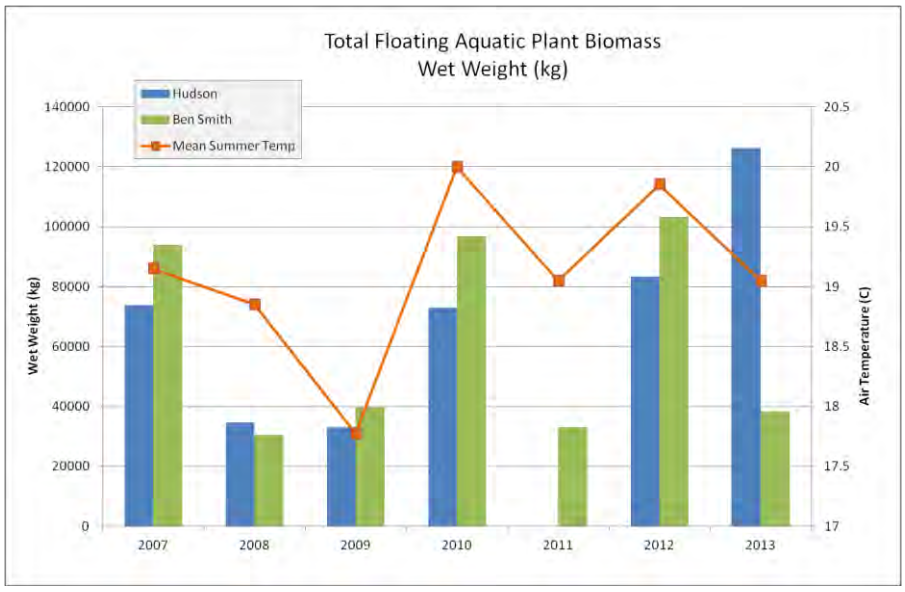
Figure 18: Class vs. biomass wet weight



Biomass Results

The calculated wet weight of total floating biomass for the Ben Smith and Hudson impoundments from 2007 to 2013 is shown in Figure 19. (The Gleasondale impoundment was not sampled consistently and is not shown.) Because aquatic plant growth appears to be strongly affected by weather conditions over the summer, mean of the daily average summer air temperatures (from the National Weather Service Worcester Regional Airport station) are also shown. The variation in total floating biomass coincides with the variation in average summer temperature (an indicator of overall summer conditions including rainfall and temperature). From 2007 to 2012, total floating biomass in the Ben Smith and Hudson impoundments tended to track together; but in 2013 biomass in the Ben Smith impoundment was considerably reduced in comparison with the upstream Hudson impoundment; however, some rooted species that reach the surface may be contributing to high percent "cover" ratings in the Hudson impoundment.

Figure 19: Total Floating Aquatic Plant Biomass Wet Weight 2007 - 2013.



Figures 20 to 23 show conditions in the Ben Smith and Hudson impoundments in 2012 and 2013, the summers since upgrades to the Assabet wastewater treatment plants were finished and total phosphorus concentrations in the water column have decreased.

Figure 20: Total Floating Biomass Cover, Ben Smith 8/29/12 (camera icon indicates picture location).

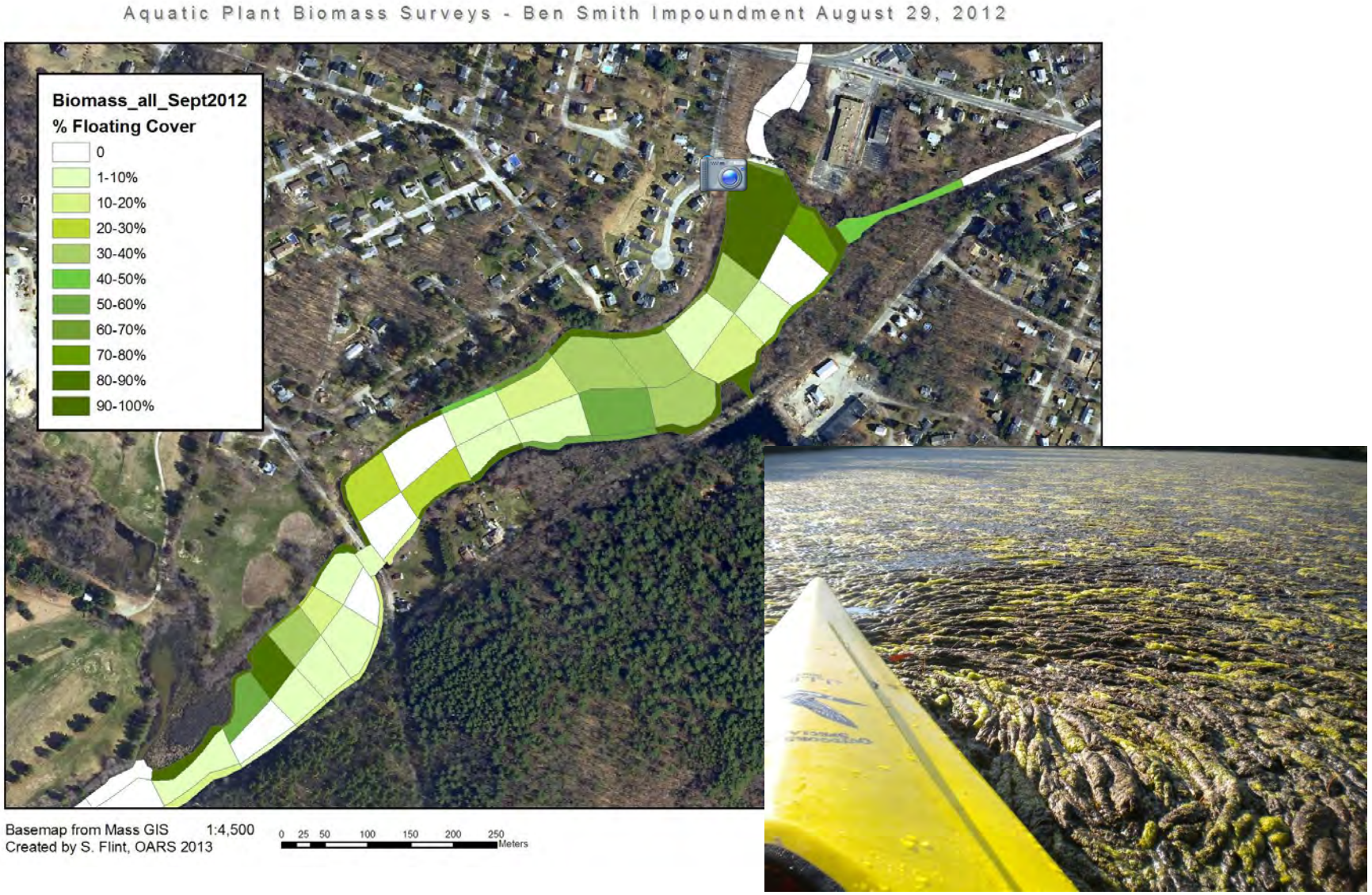


Figure 21: Total Floating Biomass - Ben Smith Impoundment 8/22/13

Figure 22: Total Floating Biomass - Hudson Impoundment 9/13/12

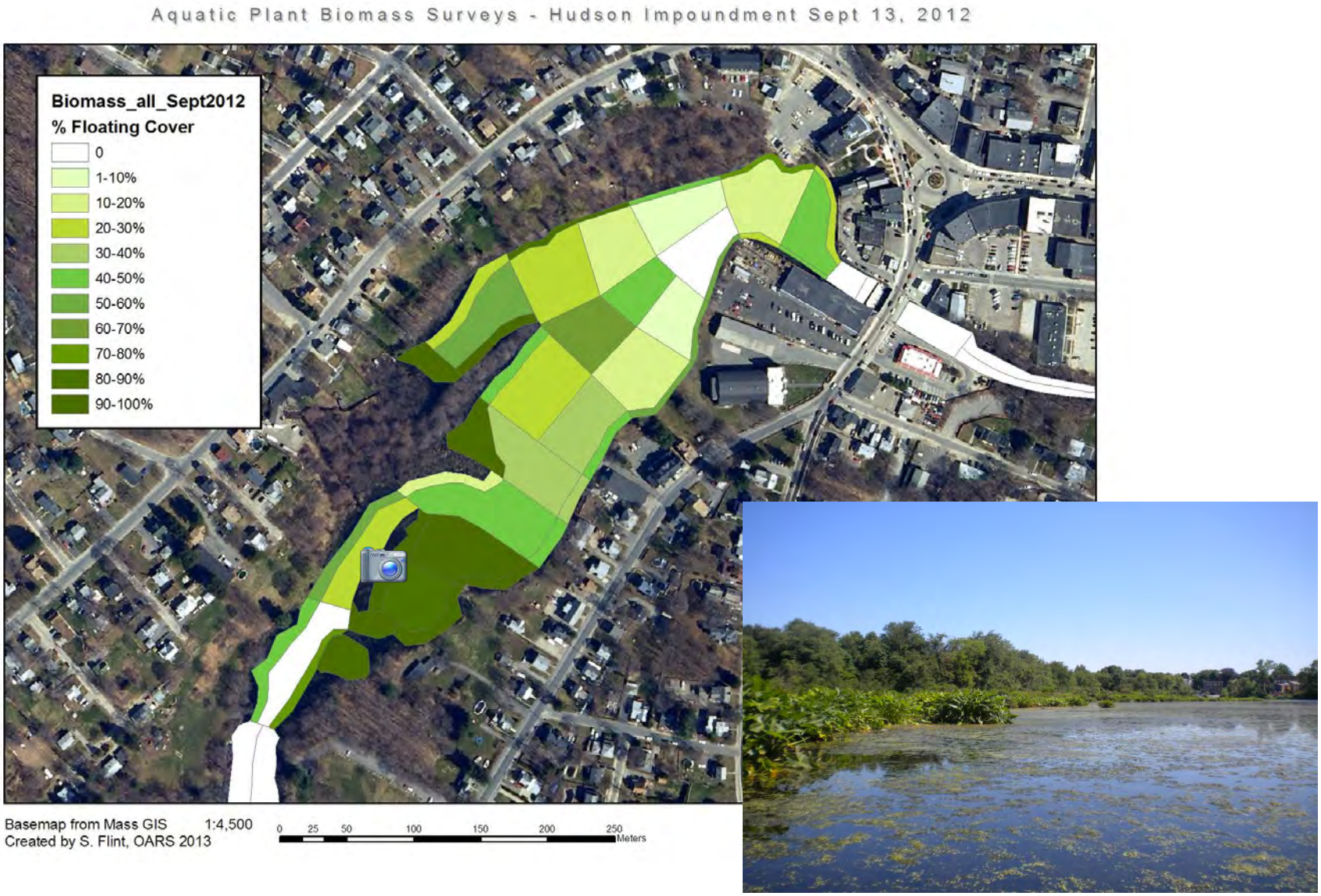
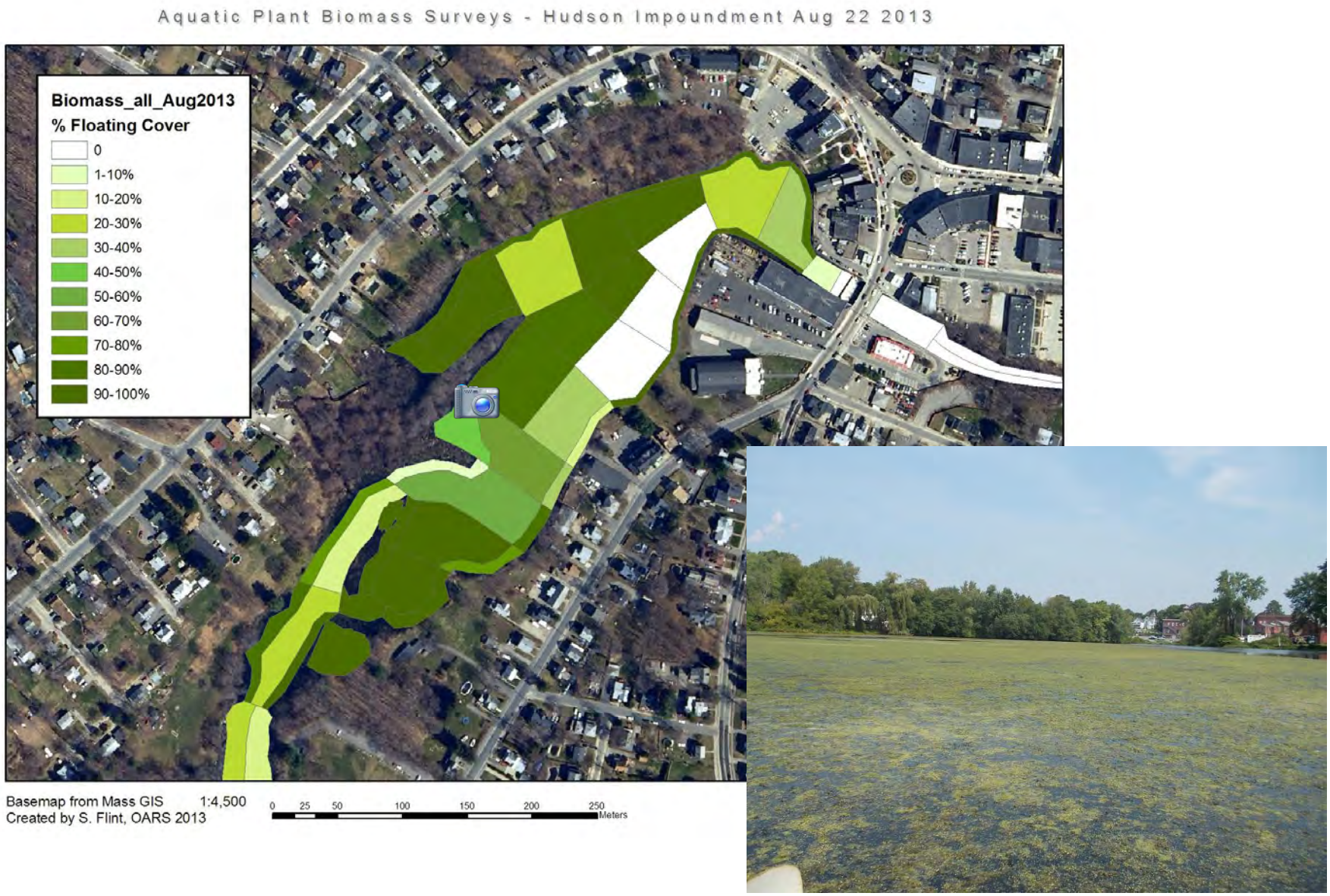


Figure 23: Total Floating Biomass - Hudson Impoundment 8/22/13



Summary

This report presents the monthly water quality, streamflow, and aquatic plant biomass data OARS collected on the Assabet, Sudbury, and Concord Rivers and tributary streams in 2012 and 2013 (March, May, June, July, August, September, and November) and presents a trends analysis of the nutrient data from the longest-running sites in the Assabet River watershed.

"**Wet" sampling events** (i.e. preceded by more than 0.1 inches of rain) in 2012 included August 19th, September 23rd, and November 11th; in 2013 wet sampling events included June 16th and July 21st. The remaining nine sampling events were dry. Streamflows at the Assabet River gage were lower than the historic mean for much of 2012 and 2013 except for May and early June of 2012 and March, June and July of 2013. Notably, June 2013 had about twice the average rainfall for the month. Hydrographs for the Concord River gage in Lowell, the Sudbury River gage in Saxonville/Framingham, and the Nashoba Brook gage in Acton (see Appendix I) show similar patterns to the Assabet River's.

Water temperatures at all sites met Class B warm water fisheries standard (28.3°C) on all of the regular testing dates in 2012. In July 2013 six mainstem sites exceeded 28.3°C (ABT-062, SUD-064, CND-110, CND-045 and CND-005).

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 2012, the majority of the headwater/tributary sites tested had water temperatures exceeding 20.0°C in July and August. In 2013, all headwater/tributary sites exceeded 23.9°C in July; two sites exceeded 20.0°C in August.

Additional temperature readings were taken following a fish kill on the Assabet River in Stow reported on July 20, 2013. Readings showed the highest water temperature (30.21 °C), dissolved oxygen (201.9%) and pH (9.40 SU) in the surface waters at White Pond Road, downstream of the fish kill. It is likely that the fish kill was the result of a combination of stresses including the high water temperatures.

The **pH** readings in ranged from 6.50 to 7.92 SU in 2012, meeting Class B standards on all regular testing dates. In 2013 pH readings ranged from 6.49 to 8.00 SU; the only site failing to meet Class B standards was SUD-064 in June 2013. Mid-afternoon readings on July 22, 2013 showed the highest pH on the Assabet River at White Pond Road, Maynard.

The range of mainstem **conductivity** readings was from 93 µS/cm to 1276 µS/cm in 2012. For 2012: the lowest reading (98 µS/cm) was recorded at Danforth Brook in March; highest readings were recorded at RVM-005 in July (1276 µS/cm) and September (1019 µS/cm) and ABT-301 in July (1100 µS/cm), August (1178 µS/cm), and Sept (988 µS/cm). For 2013 pH readings ranged between 116 µS/cm and 1122 µS/cm. For 2013: the lowest reading was recorded at North Brook in June; the highest readings were recorded at ABT-301 in July (1122 µS/cm) and September (909 µS/cm) and at RVM-005 in July (961 µS/cm).

Dissolved oxygen on the Assabet River and Sudbury River met Class B and Class B Aquatic Life standards on all regular sampling days. The Concord River at Lowell Road failed to meet Class B (5.0 mg/L) on June 16, 2013. Hop Brook at Landham Road, Sudbury, has consistently low dissolved oxygen concentrations, failing to meet Class B standards on nine of ten sampling dates; the lowest reading at that site was 0.94 mg/L on August 19, 2012. Low dissolved oxygen levels were also measured following reports of a fish kill on the Sudbury River in early July 2013. Dissolved oxygen levels were below the Class B Aquatic Life standard (3.0 mg/L) from River Road (SUD-086) to Rte 62 Concord (SUD-005), and very low on Hop Brook (HBS-016). Since streamflows in the previous three weeks were high (2 – 10 times the historic mean flows), it is possible that de-oxygenated water was coming into the river from the flood plains.

In 2013, median **total phosphorus** concentrations along the Assabet River mainstem below the first wastewater discharge (Westborough WWTP) were, for the first time since OARS has been monitoring, below the EPA "Gold Book" recommendation (0.05 mg/L TP), but slightly above the Ecoregion reference condition for TP (0.025 mg/L). Median **nitrate** concentrations on in the upper Assabet mainstem were 9-14 times the Ecoregion reference condition in 2012 and 2013, and in the lower Assabet mainstem were 2-3 times the Ecoregion reference condition. Median total phosphorus concentrations in the Concord River mainstem were 0.04 mg/L and 0.05mg/L in 2012 and 2013, respectively. Nitrate concentrations were 0.42mg/L and 0.32 mg/L in 2012 and 2013. Median TP concentrations in the Sudbury River and in the tributaries of all three rivers (excluding Hop Brook, Sudbury) were slightly elevated: above 0.025mg/L but below 0.05mg/L. Hop Brook, Sudbury, which is affected by the wastewater discharge from Marlborough Easterly WWTP, and has total phosphorus concentrations 3-4 times the recommended concentrations.

Summer (June, July, and August only) **trends in nutrient concentrations** in the two most-stable nutrient parameters (total phosphorus and nitrates) were examined for the longest term sites that have remained essentially unchanged. Statistically significant trends included: decreasing trends in total phosphorus concentrations in the Assabet River (upper and lower sections) for both date ranges assessed; increasing trend in flow-weighted nitrate concentrations in the upper Assabet; an increasing trend in flow-weighted total phosphorus concentrations in tributary streams; decreasing trends in nitrate concentrations in the tributaries and the Assabet headwater site. No significant trends were found in dissolved oxygen throughout the river or in streamflow at the Assabet River USGS gage on sampling dates.

Tributary Stream Health Index: The lowest scoring months were July 2012 and July 2013, with the heat wave in July 2013 driving stream temperatures up. Streamflows in June 2013 were above the highest measured flow on the rating curves for the established flow gages (i.e. cannot be correlated with a flow volume). **Water Quality Index**: Water Quality Index readings were calculated for selected sites on the mainstem Assabet, Sudbury and Concord Rivers and on Hop Brook in Sudbury. Nitrates were the lowest scoring parameters, driving the overall WQI score, at the Assabet River sites. In previous years both total phosphorus and nitrates have been the lowest scoring parameters at the Assabet sites. At the Concord River sites, nitrates and total suspended solids were the lowest scoring parameters (although higher scoring than at the Assabet sites). Dissolved oxygen and total suspended solids were generally the lowest scoring parameter at the Sudbury River sites below Saxonville. Dissolved oxygen was the lowest scoring parameters at the Hop Brook site in Sudbury.

Aquatic plant biomass (wet weight): 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 Septemeber each year starting in 2007. Total floating biomass wet weights were calculated for two most-consistently surveyed impoundments, Hudson and Ben Smith, from 2007 to 2013. The variation in total floating biomass coincides with the variation in average summer temperature (an indicator of overall summer conditions including rainfall and temperature). From 2007 to 2012, total floating biomass in the Ben Smith and Hudson impoundments tended to track together; but in 2013 biomass in the Ben Smith impoundment was considerably reduced in comparison with the upstream Hudson impoundment; however, some rooted species that reach the surface may be contributing to high percent "cover" ratings in the Hudson impoundment. Because the survey is semi-quantitative and shows high inter-annual variation that coincides with variation in summer temperature, it will take a longer dataset to detemine whether the eutrophication of the impounded sections of the Assabet have improved with 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.

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.

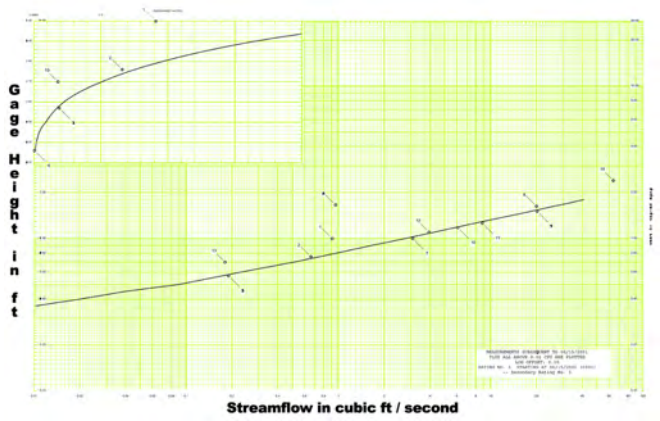
Oligotrophic: having a small supply of nutrients, low production of organic matter, low rates of decomposition, and high dissolved oxygen in the lower layers of the water column.

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.

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 at several points along the mainstem river and at sites on eight 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 and Concord Rivers at the USGS gages in Maynard and Lowell, respectively, and reported on the USGS web page. Streamflow on the tributary streams is calculated using a rating curve from staff gage readings taken by OARS volunteers.

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

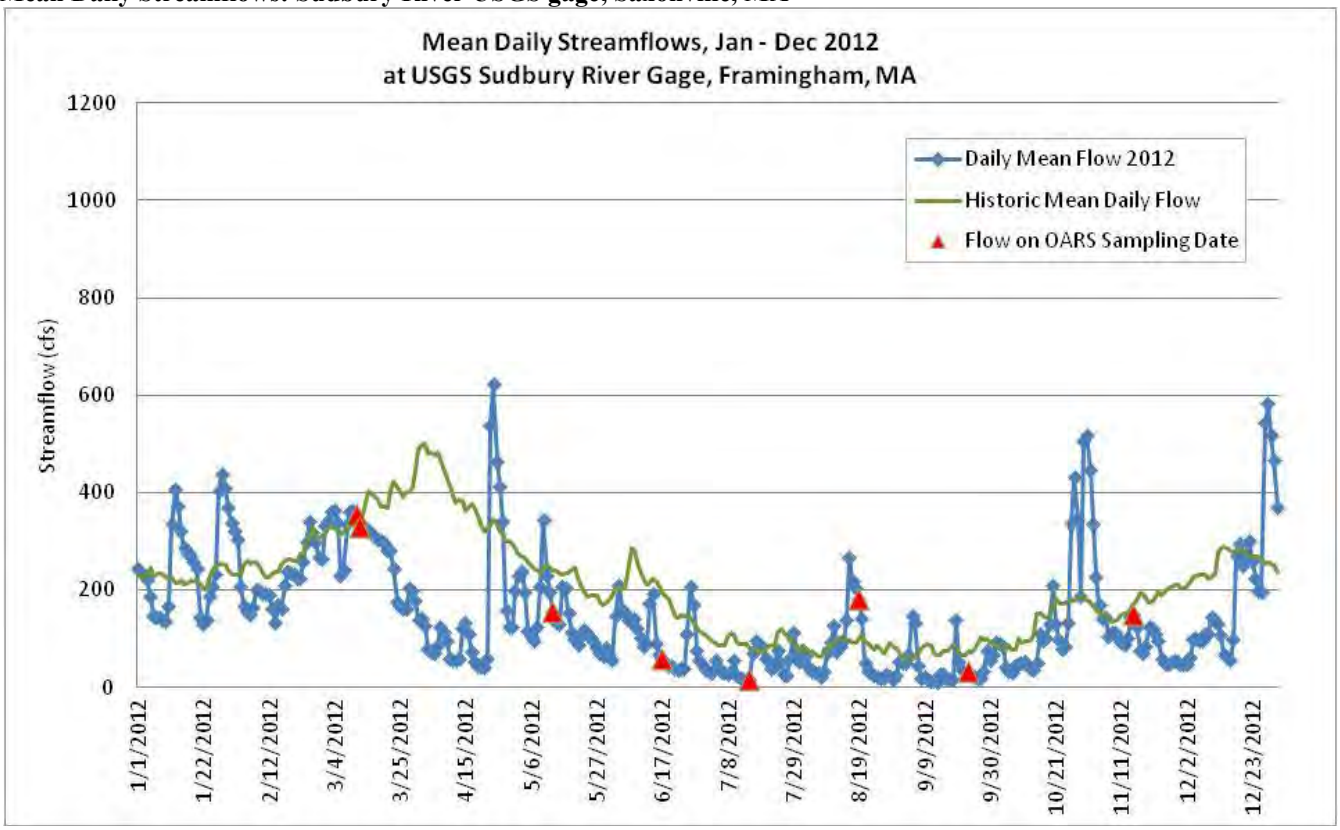
Excerpted from 314 CMR 4.00 : DIVISION OF WATER POLLUTION CONTROL
http://www.mass.gov/eea/docs/dep/water/laws/i-thru-z/tblfig.pdf

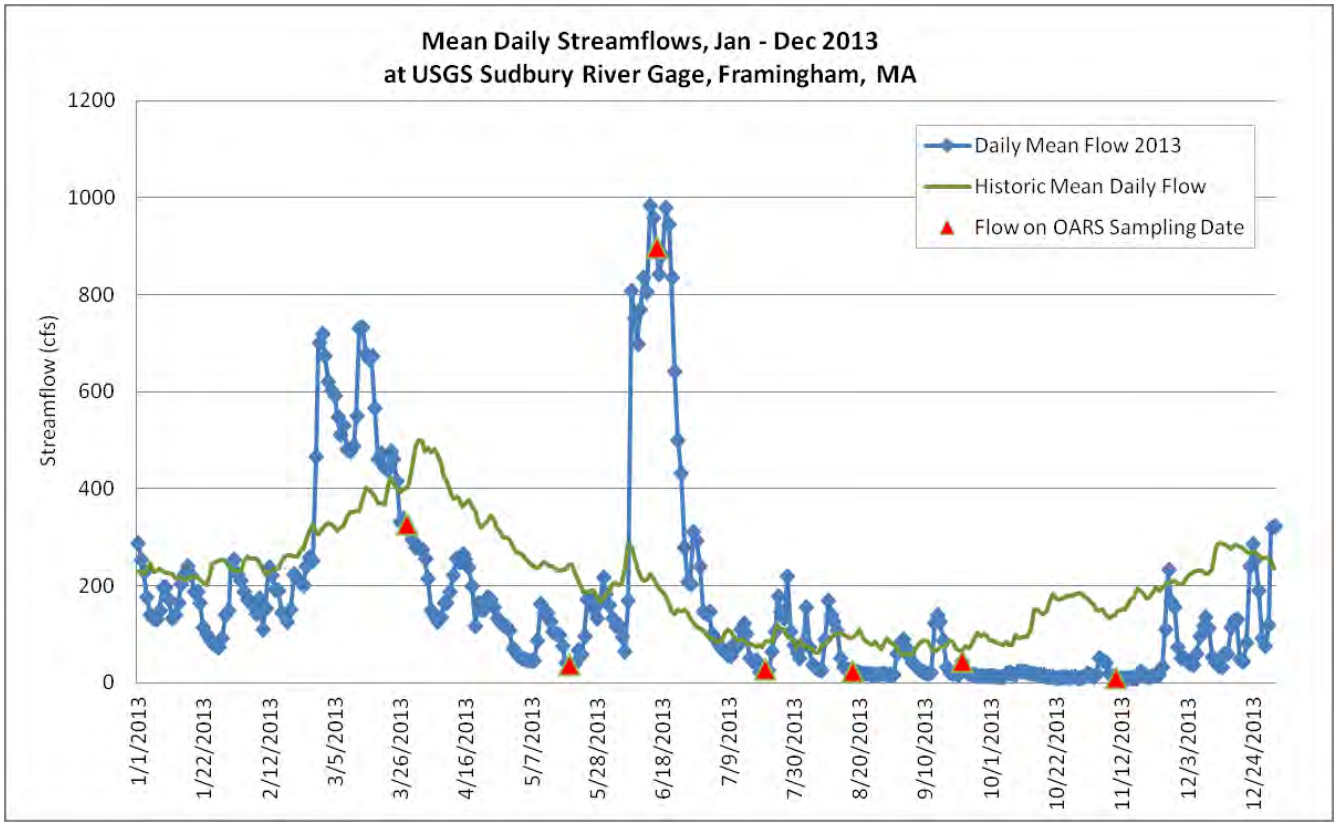
SuAsCo River Basin

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
Tributaries			
Unnamed tributary to Assabet River	entire length		Cold Water
Jackstraw Brook Source to Upton Rd 1st crossing south of Hopkinton Rd.			Cold Water

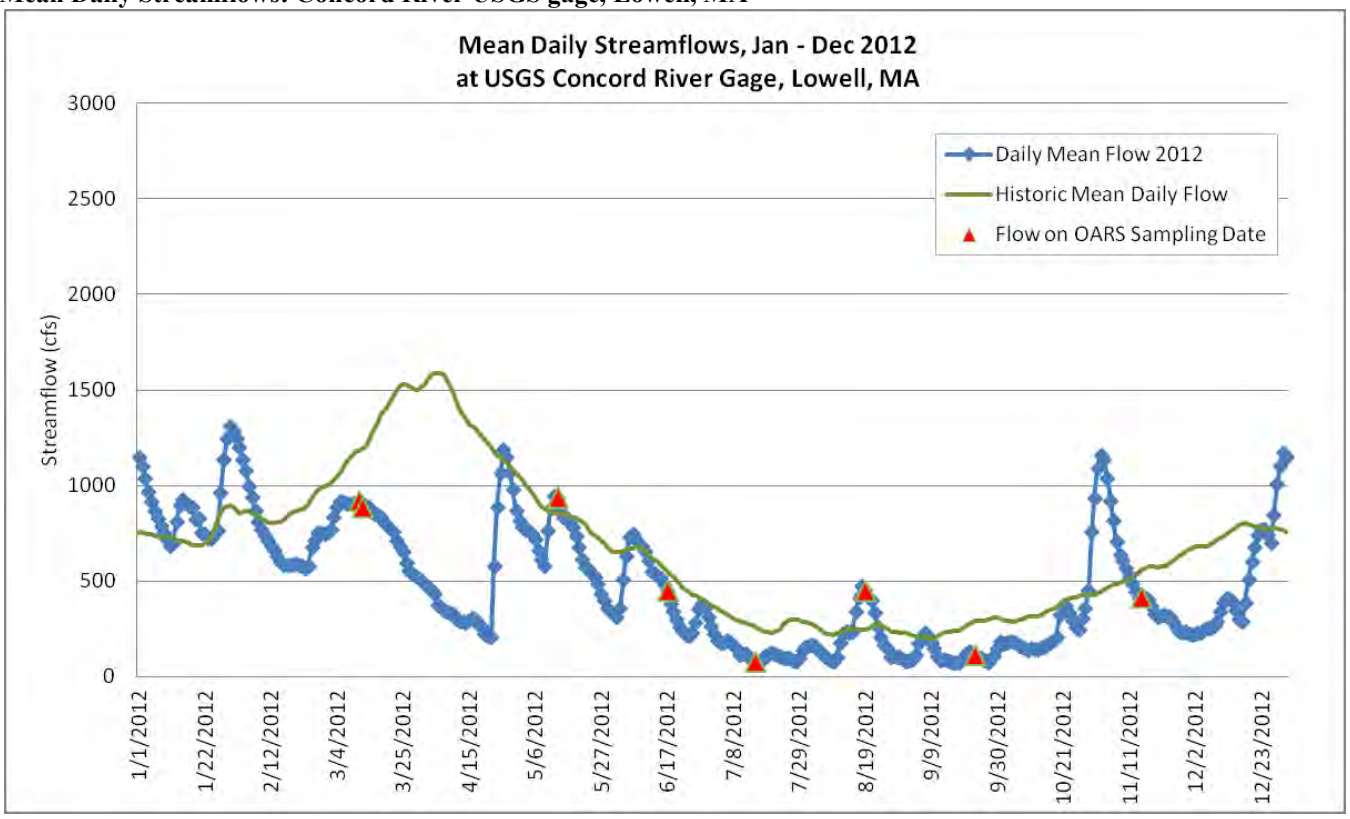
Appendix II: Streamflow Data from USGS Gages

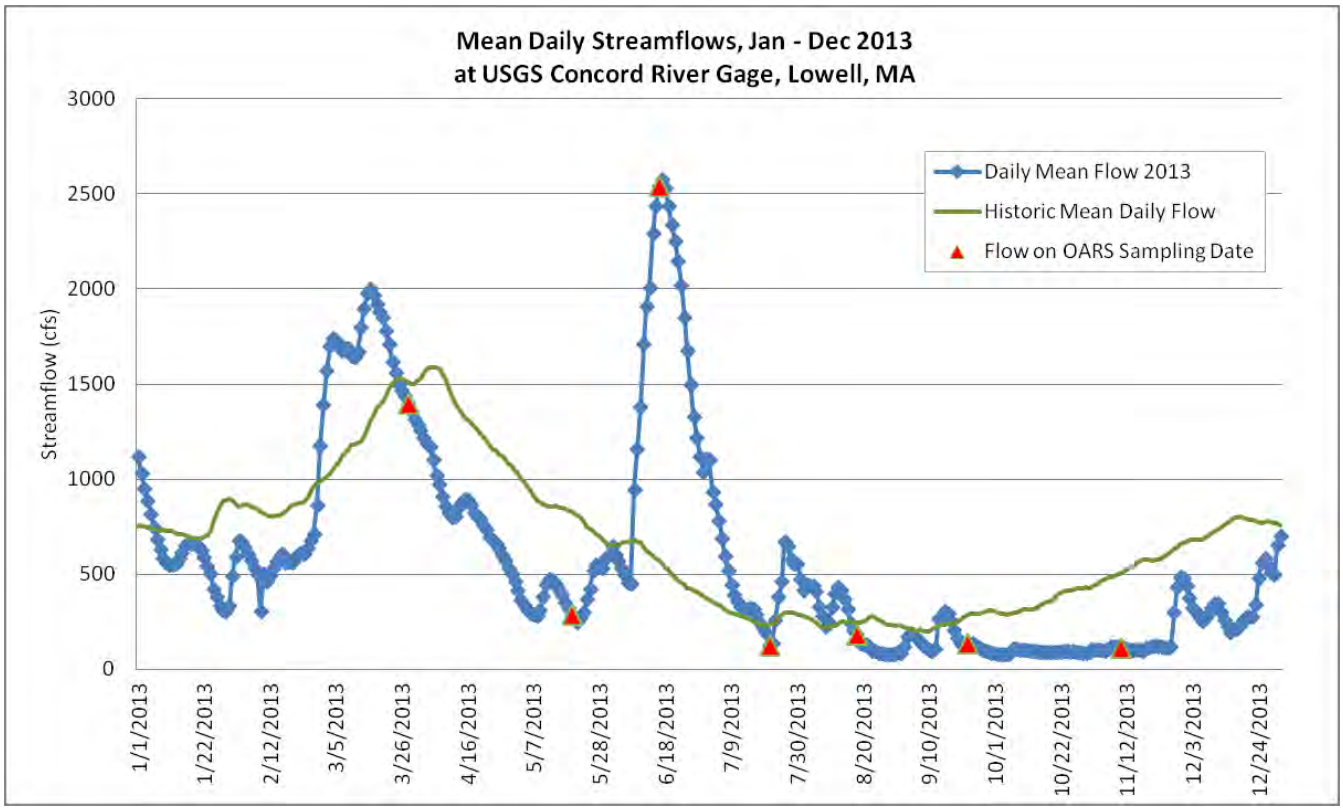
Mean Daily Streamflows: Sudbury River USGS gage, Saxonville, MA



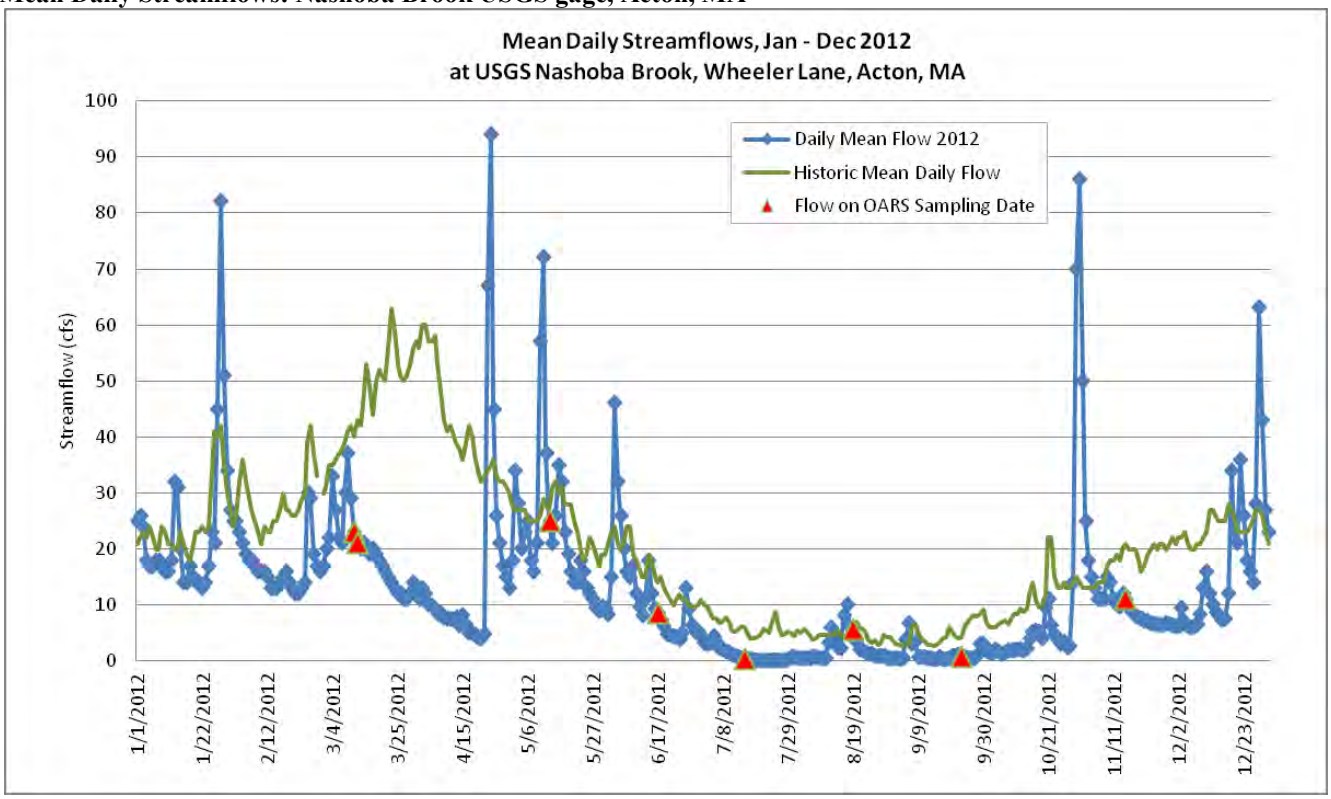


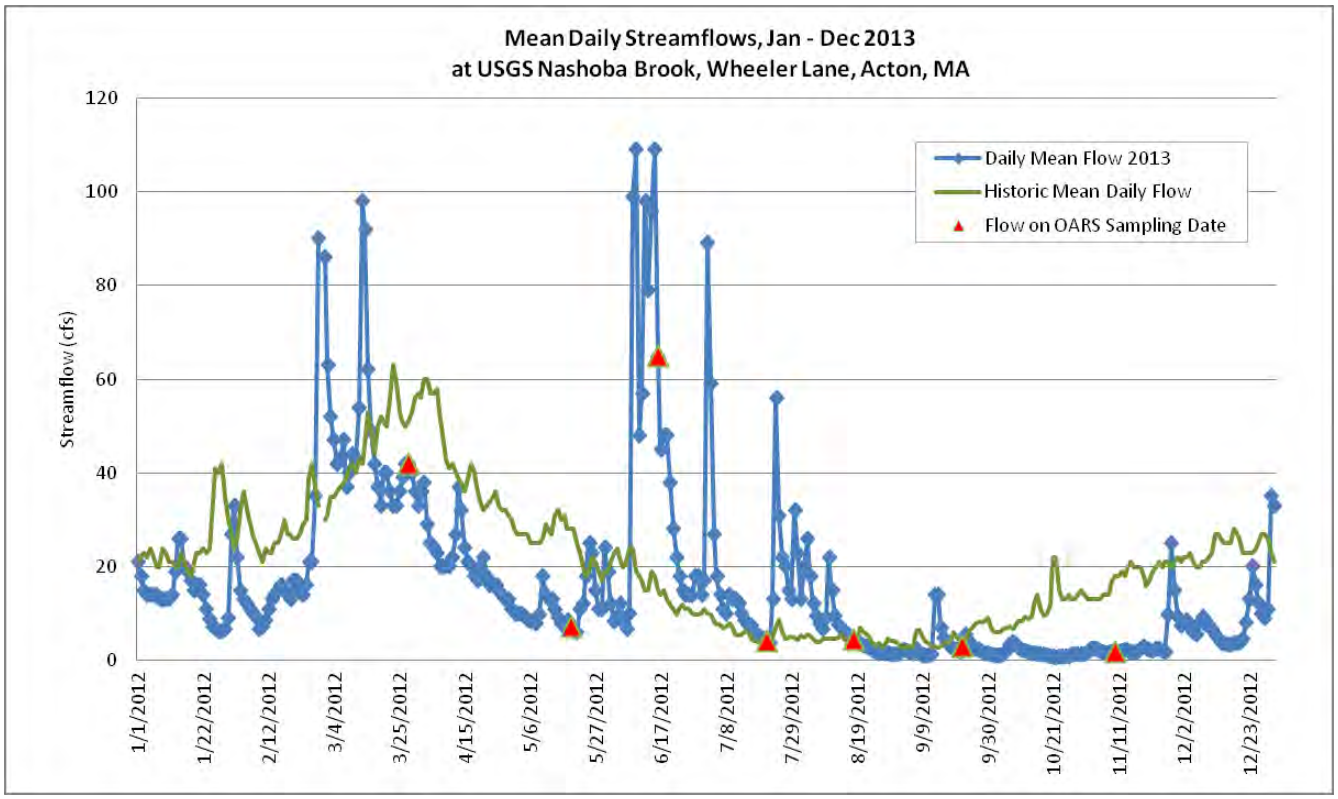
Mean Daily Streamflows: Concord River USGS gage, Lowell, MA





Mean Daily Streamflows: Nashoba Brook USGS gage, Acton, MA





Appendix III: Data Quality Notes

OARS' data quality objectives (Table 12) and data qualifiers are listed below (Table 13). Full QC details are available in OARS' Quality Assurance/Quality Control documents on request.

Data Qualifiers

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

Qualified or censored data for 2012 and 2013 includes:

Date	Parameter	Qualified/ Censored	Sites	Problem
May 13, 2102	TP	Q	all	one laboratory spike recovery 118%
June 17, 2012	TSS	Q	all	one field duplicate RPD 105%
July 15, 2012	TSS	Q	all	two field duplicates RPDs 79% and 80%
Aug 15, 2012	TP	Q	all	two field dups. RPDs 40% and 33%
Sept 23, 2012	TP	Q	all	one field dup. RPD 67%
May 19, 2013	TSS	censored	CND-161	samples "silty" and field duplicate RPD 100%
May 19, 2013	NO3	censored	CND-161	samples "silty" and field duplicate RPD 45%
June 16, 2013	TSS	Q	all	one field dup. RPD 46%
July 21, 2013	TSS	Q	all	one field dup. RPD 46%
Aug 18, 2013	TP	Q	all	one laboratory dup. RPD 29%
Sept 22, 2013	TP	Q	all	one field dup. RPD 40% two lab dups. RPD 67% and 50%
Nov 10, 2013	TP	Q	all	one field dup. RPD 164%
all dates	flow	NA	ELZ-004	staff gage is loose and needs replacement

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

Appendix V: Additional Readings – July 2014

		DateTime	Water Temp	DO %	DO Conc	Cond	pH	Total Depth	Reading Depth
Water Body	Site	M/D/Y	C	%	mg/L	uS/cm		ft	ft
Sudbury River & Hop Brook	SUD-144	7/2/2013 16:46	25.36	453	104.7	8.59	7.16	nr	1
	SUD-096	7/2/2013 16:16	25.64	472	42.4	3.46	6.63	nr	1
	SUD-086	7/2/2013 15:57	25.79	464	28.0	2.28	6.57	nr	1
	SUD-064	7/2/2013 15:41	26.05	459	13.0	1.06	6.45	nr	1
	SUD-005	7/2/2013 17:19	26.44	450	18.6	1.50	6.54	nr	1
	HBS-016	7/2/2013 16:37	24.60	468	10.1	0.84	6.66	nr	1
Assabet River	ABT-144	7/22/2013 15:03	27.44	99.1	7.82	835	7.64	0.5	0.5
	Sudbury Road, Stow	7/22/2013 15:14	28.32	80.2	6.23	804	7.39	4	0.5
	Sudbury Road, Stow	7/22/2013 15:15	27.68	75.0	5.89	795	7.32	4	3
	White Pond Road, Maynard	7/22/2013 15:44	30.21	201.9	15.18	698	9.40	5	0.5
	White Pond Road, Maynard	7/22/2013 15:42	29.02	190.4	14.61	719	9.21	5	4

Appendix VI: Mann-Kendall test statistics on long term-nutrient data (NST = no statistically significant trend)

Mann –Kendall test statistics for total phosphorus

	Section	Type	All dates						Late					
			years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Total phosphorus	Upper ABT	conc.	1993-2013	-0.59	-4499	-9.72	0.0000	downward	1999-2013	-0.438	-1755	-6.115	0.0000	downward
	Upper ABT	flow-weighted	1993-2013	-0.503	-3834	-8.28	0.000	downward	1999-2013	-0.344	-1376	-4.794	0.0000	downward
	Middle ABT	conc.	1993-2013	-0.69	-1341	-8.0	0.000	downward	1999-2013	-0.517	-512	-5.002	0.0000	downward
	Middle ABT	flow-weighted	1993-2013	-0.60	-1169	-6.28	0.000	downward	1999-2013	-0.46	-455	-4.441	0.0000	downward
	Lower ABT	conc.	1993-2013	-0.53	-4147	-8.75	0.000	downward	1999-2013	-0.356	-1427	-4.977	0.0000	downward
	Lower ABT	flow-weighted	1993-2013	-0.47	-3728	-7.86	0.000	downward	1999-2013	-0.35	-1402	-4.884	0.0000	downward
	Headwater ABT	conc.	1993-2013	0.02	52	0.248	0.804	NST	1999-2013	-0.006	-8	-0.052	0.0958	NST
	Headwater ABT	flow-weighted	1993-2013	-0.02	-47	-0.23	0.822	NST	1999-2013	0.027	38	0.276	0.7824	NST
	NSH-002	conc.	1995-2013	0.084	130	0.918	0.359	NST	2002-2013	0.021	13	0.165	0.9692	NST
	NSH-002	flow-weighted	1995-2013	0.121	186	1.308	0.191	NST	2002-2013	0.163	103	1.389	0.1647	NST
	Tributaries	conc.							2002-2013	0.077	1227	1.531	0.1257	NST
	Tributaries	flow-weighted							2002-2013	0.126	2002	2.498	0.0125	upward
	CND-009	conc.							2004-2013	0.053	23	0.394	0.6939	NST
	CND-009	flow-weighted							2004-2013	0.092	40	0.696	0.0487	NST
ortho- phosphorus	Upper ABT	conc.							1999-2013	-0.375	-1437	-5.181	0.0000	downward
	Upper ABT	flow-weighted							1999-2013	-0.329	-1260	-4.539	0.0000	downward
	Middle ABT	conc.							1999-2013	-0.523	-495	-4.997	0.0000	downward
	Middle ABT	flow-weighted							1999-2013	-0.525	-497	-5.017	0.0000	downward
	Lower ABT	conc.							1999-2013	-0.415	-1589	-5.773	0.0000	downward
	Lower ABT	flow-weighted							1999-2013	-0.394	-1510	-5.44	0.0000	downward
	Headwater ABT	conc.							1999-2013	-0.0.41	-56	-0.434	0.6641	NST
	Headwater ABT	flow-weighted							1999-2013	-0.0.59	-81	-0.614	0.5393	NST
	NSH-002	conc.							1999-2013	0.066	62	0.625	0.5317	NST
	NSH-002	flow-weighted							1999-2013	0.02	19	0.182	0.8550	NST
	Tributaries	conc.							2002-2013	-0.09	-1438	-1.817	0.0699	NST
	Tributaries	flow-weighted							2002-2013	-0.035	-550	-0.685	0.4932	NST
	CND-009	conc.							2004-2013	-0.287	-125	-2.235	0.0254	downward
	CND-009	flow-weighted							2004-2013	-0.299	-130	-2.302	0.0213	downward

			Mann –Kendall test statistics											
	Section	Type	All dates						Late					
			years	tau	s	z	p	Trend	years	tau	s	z	p	Trend
Nitrates	Upper ABT	conc.	1993-2013	-0.11	-839	-1.77	0.0771	NST	1999-2013	0.07	434	1.089	0.2760	NST
	Upper ABT	flow-weighted	1993-2013	0.242	1670	3.883	0.0001	upward	1999-2013	0.234	1453	3.652	0.0003	upward
	Middle ABT	conc.	1993-2013	0.103	165	1.13	0.2584	NST	1999-2013	0.011	11	0.098	0.9220	NST
	Middle ABT	flow-weighted	1993-2013	0.407	650	4.468	0.000	upward	1999-2013	0.274	271	2.641	0.0083	upward
	Lower ABT	conc.	1993-2013	0.179	1150	2.817	0.0048	upward	1999-2013	0.06	241	0.838	0.4018	NST
	Lower ABT	flow-weighted	1993-2013	0.227	1462	3.579	0.003	upward	1999-2013	0.102	408	1.419	0.1559	NST
	Headwater ABT	conc.	1993-2013	-0.205	-440	-2.43	0.015	downward	1999-2013	-0.354	-507	-3.784	0.0002	downward
	Headwater ABT	flow-weighted	1993-2013	-0.132	-283	-1.56	0.1185	NST	1999-2013	-0.444	-636	-4.739	0.0000	downward
	NSH-002	conc.	1995-2013	-0.192	-235	-1.96	0.050	downward	2002-2013	-0.252	-159	-2.157	0.0310	downward
	NSH-002	flow-weighted	1995-2013	-0.237	-290	-2.42	0.0156	downward	2002-2013	-0.24	-151	-2.043	0.0410	downward
	Tributaries	conc.							2002-2013	-0.308	-4960	-6.143	0.0000	downward
	Tributaries	flow-weighted							2002-2013	-0.317	-5045	-6.3	0.0000	downward
	CND-009	conc.							2004-2013	0.018	8	0.125	0.9005	NST
	CND-009	flow-weighted							2004-2013	0.041	18	0.303	0.7616	NST
Dissolved Oxygen (%)	Upper ABT	conc.							1999-2013	0.112	450	1.566	0.1175	NST
	Upper ABT	flow-weighted							1999-2013	0.059	236	0.819	0.4126	NST
	Middle ABT	conc.							1999-2013	-0.131	-130	-1.262	0.2069	NST
	Middle ABT	flow-weighted							1999-2013	-0.106	-105	-1.017	0.3090	NST
	Lower ABT	conc.	1993-2013	0.332	2374	5.384	0.000	upward	1999-2013	0.128	512	1.782	0.0748	NST
	Lower ABT	flow-weighted	1993-2013	0.282	2021	4.56	0.000	upward	1999-2013	0.111	444	1.544	0.1220	NST
	Headwater ABT	conc.							1999-2013	-0.143	-205	-1.523	0.1280	NST
	Headwater ABT	flow-weighted							1999-2013	-0.159	-228	-1.694	0.0900	NST
	NSH-002	conc.							2002-2013	0.19	120	1.621	0.1050	NST
	NSH-002	flow-weighted							2002-2013	0.195	123	1.662	0.0965	NST
	Tributaries	conc.							2002-2013	0.073	1157	1.443	0.1491	NST
	Tributaries	flow-weighted							2002-2013	0.097	1546	1.928	0.0538	NST
	CND-009	conc.							2004-2013	-0.021	-9	-0.143	0.8865	NST
	CND-009	flow-weighted							2004-2013	-0.047	-19	-0.338	0.7356	NST
FLOW	ABT-077	flow	1993-2013	0.099	193	1.139	0.254	NST	1999-2013	0.09	89	0.861	0.3890	NST

NST = no statistically significant trend

Appendix VII: Aquatic Plant Biomass Survey Data

		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
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