

Blackstone River Water Quality Monitoring Program

2018 Sampling Season Report



Prepared for

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Upper Blackstone Clean Water

by

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Front cover photo: Rice City Pond sampling site in Uxbridge, MA, October 2019, by Upper Blackstone Clan Water staff

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1.0 Introduction

In 2012, the Upper Blackstone Water Pollution Abatement District (Upper Blackstone) initiated a voluntary program to monitor river quality in response to treatment plant upgrades and subsequent treatment process refinements. This report presents water quality data collected on behalf of Upper Blackstone along the mainstem of the Blackstone River between April and November 2018. It includes a brief overview of trends in total phosphorus, total nitrogen, chlorophyll-a, and periphyton data observed since the start of the sampling program in 2012. Hydrologic data for the period 2012-2018 are also presented. Additional details of periphyton sampling are available under separate cover from Normandeau Associates¹. More detailed technical information regarding the sampling program is available from the Field Sampling Plan and the Quality Assurance Project Plan (QAPP) for this project. Water quality reports and factsheets for each sampling season are available upon request. The Blackstone River water quality data collected as part of Upper Blackstone's monitoring program are publicly available by request to Karla Sangrey (email: ksangrey@ubcleanwater.org) or via download through the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI, www.cuahsi.org) Hydrologic Information System (HIS) database and servers (data.cuahsi.org), which are sponsored by the National Science Foundation.

2.0 Background

The Blackstone River watershed encompasses an area of approximately 480 mi² in central Massachusetts and northern Rhode Island. The watershed lies within EPA's Nutrient Ecoregion XIV, subregion 59, the Eastern Coastal Plain. The river flows from its headwaters in the hills above Worcester, MA, through Woonsocket, RI, and finally joins the Seekonk River in Pawtucket, RI, just below the Slater Mill Dam. The Seekonk River discharges into the Providence River, which flows into Narragansett Bay. Six major tributaries (the Quinsigamond, Mumford, West, Mill, Peters, and Branch rivers) as well as many smaller tributaries join the mainstem of the Blackstone River. The watershed includes over 1,300 acres of lakes and ponds. Reservoirs in the northwest portion of the basin are used for the City of Worcester water supply.

Several U.S. Geological Survey (USGS) streamflow gaging sites are located in the watershed, and hourly precipitation data are available for several locations in and near the watershed from the National Weather Service (NWS) National Centers for Environmental Information (NCEI). The Blackstone River is one of the largest contributors of freshwater to Narragansett Bay, providing on average almost one quarter of the freshwater flow to the Bay (Ries, 1990; Ely, 2002; Save the Bay, 2006), and plays an important role in the health of the Bay.

The Blackstone River Valley is acknowledged as the "Birthplace of the American Industrial Revolution." Over its 48-mile run towards Narragansett Bay, the Blackstone drops approximately 440 feet (Shanahan, 1994; BRNHC, 2006), a steeper gradient than the Colorado River (Arizona Humanities Council, 2006). The Blackstone River and its watershed were transformed from a farming area in colonial days into one of the 19th century's great industrial areas due to this hydraulic potential, starting with the first milldam built by Samuel Slater at the outlet of the river in 1793. Water-powered textile mills proliferated up and

¹ Blackstone River 2018 Periphyton and Benthic Macroinvertebrate Study Final Report (Normandeau Associates, Inc., 2019)

down the river, and at one point, the river had almost one dam for every mile along its run. The historical significance of the river has been recognized at both local and federal levels. In 1986, an Act of Congress established the John H. Chafee Blackstone River Valley National Heritage Corridor. In 1998, the Blackstone was designated as an American Heritage River. In 2002, it was one of eight rivers included in an urban river restoration pilot study led by the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (ACOE). In 2014, the Blackstone River Valley National Historical Park was established as the 402nd park in the national park system.

There are nine wastewater treatment facilities (WWTFs) that discharge into the Blackstone River and its tributaries, Table 1. The largest, in terms of volume, is the Upper Blackstone (UB). There are twenty named dams remaining along the mainstem of the Blackstone River. The locations of the WWTFs and remaining dams along the mainstem of the Blackstone River are shown in Table 1 based on river mile. The outlet of the Blackstone River in Pawtucket, RI, is denoted as river mile zero, with river mile increasing in the upstream direction. The locations of federally regulated and controlled (licensed by the Federal Energy Regulatory Commission [FERC]) and minor dams along the river elevation profile are depicted in Figure 1. The industrial past of the Blackstone River, urbanization, and a high population density have resulted in a legacy of complex water quality issues.

In 2003, Upper Blackstone requested the Massachusetts Water Resources Research Center (MaWRRC) at UMass Amherst and CDM Smith to initiate a watershed assessment study to improve understanding of these complex dynamics. The study included river monitoring in 2005 and 2006, historical data analysis, and modeling to evaluate trends in river quality as well as management opportunities for improving water quality and aquatic habitat throughout the basin. Upper Blackstone has supported additional water quality data collection in 2010 and 2011, and since 2012 has supported consistent year to year water quality monitoring at several sampling locations along the mainstem Blackstone River to support the assessment of the river's response to reduced nutrient concentrations in the wastewater treatment plant effluent. While Upper Blackstone's monitoring program has always followed strict sample collection and analysis procedures, sampling was conducted under a Quality Assurance Project Plan (QAPP) approved by the Massachusetts Department of Environmental Protection (MassDEP) from 2014 - 2016. A newly approved QAPP covers sampling in 2017 – 2019. Having the approved QAPP in place allows MassDEP to use the data in the agency's watershed assessments.

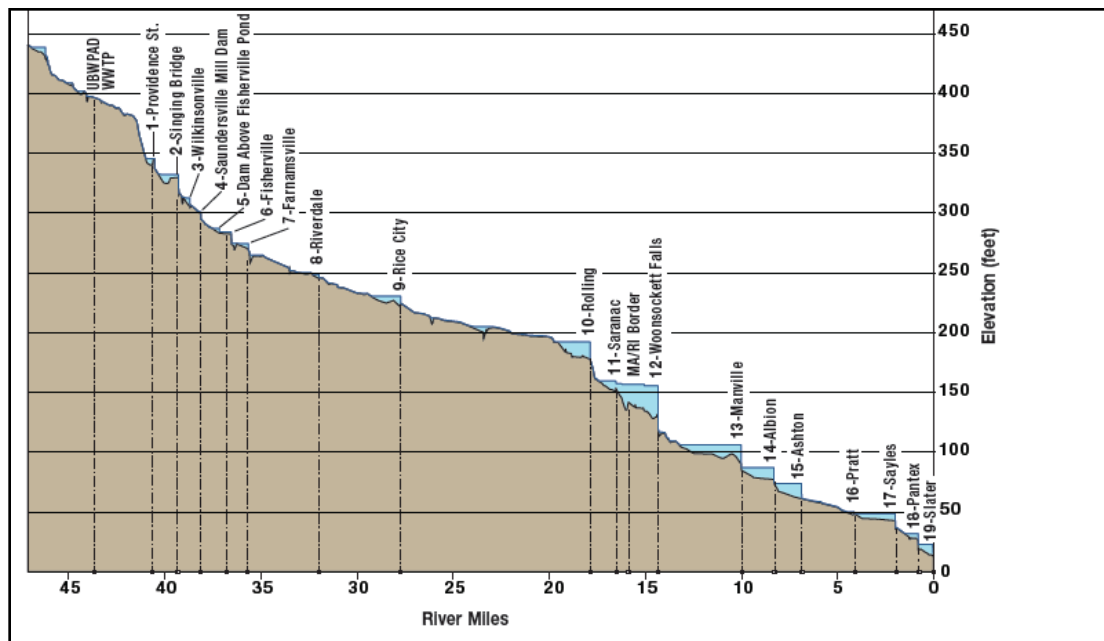


Figure 1: River elevation profile

Table 1: Dams, sampling sites, and tributaries on the Blackstone River mainstem (adapted from Wright et al., 2001)

Mile	Description	Mile	Description
0	Slater Mill Dam	27.8	Rice City Pond Dam
0	Slater Mill Dam, Pawtucket, RI (RMSD)	27.8	Below Rice city Pond Sluice Gates, Hartford St., Uxbridge, MA (W1779)
0.8	Pawtucket Hydro Dam	29.2	Northbridge WWTF
1.8	Abbot Run	31.9	Riverdale Hydro Dam
2	Central Falls Dam	33.4	USGS gage near Sutton St. Bridge, Northbridge, MA (W0767)
4.1	Lonsdale Dam	35.4	Grafton WWTF
6.3	Rte 116 Bikepath Bridge, Pawtucket, RI (R116)	35.6	Farnumsville Hydro Dam
6.8	Ashton Dam	36.3	Route 122A, Grafton, MA (W1242)
8.2	Albion Dam	36.5	Fisherville Dam
9.9	Manville Dam	36.6	Quinsigamond River
12.4	Woonsocket WWTF	38	Depot St., Sutton, MA (Depot)
12.8	Hamlet Ave. Dam	38.7	Saundersville Dam
13.1	Peters River	39.2	Wilkinsonville Dam
15.5	Thundermist Hydro Dam	39.8	Singing Dam
15.5	State Line, RI (RMSL)	41	Millbury Electric Dam
16.5	Blackstone Dam	42.7	Central Cemetery, Millbury, MA (W1258)
17.4	Branch River	43.9	McCracken Rd Dam
17.8	Tupperware Dam	44.4	Upper Blackstone WWTF
19.2	Mill River	44.6	Below confluence with UB effluent (UBWPAD2)
22	Uxbridge WWTF	45.2	New Millbury St bridge, Worcester, MA (W0680)
24.2	West River	46.4	Worcester CSO
25.9	Mumford River	46.6	Mill Brook/Middle River Confluence & USGS gaging station 01109730

Sampling sites, Tributaries, WWTFs, FERC dams, Minor dams/ impoundments

3.0 Blackstone Water Quality Sampling Program

In 2018, the river monitoring program included monthly water quality sampling for nutrients and chlorophyll-a. Three Rhode Island sites were co-sampled with the Narragansett Bay Commission (NBC). Monthly sampling was conducted from April through November. Three synoptic periphyton sampling surveys were conducted in coordination with Normandeau Associates to capture a more in-depth “snapshot” of river biological response to water quality during low flow river conditions. Periphyton sampling was performed at four sampling locations over a short period (1 - 2 days) of relatively steady hydrologic conditions in July, August, and September.

Sampling locations for routine and periphyton monitoring were selected based on several criteria, in order to:

- Provide reference data for the river above and below the confluence with Upper Blackstone’s effluent channel;
- Correspond with locations monitored by MassDEP in 2008;
- Correspond with long-term monitoring locations maintained by NBC;
- Build upon Upper Blackstone sampling efforts that were first initiated in 2004;
- Provide information on both run-of-river and impounded sites along the river;
- Provide information on both the nutrient and biological status of the river; and
- Build a database to facilitate identification of temporal trends in water quality within the river.

Although this is Upper Blackstone’s monitoring program, the data collected as part of this water quality-monitoring program are generally denoted “UMass 2018 data” in graphs and tables to avoid potential confusion with 1) the location where Upper Blackstone effluent enters the Blackstone River and 2) the river monitoring location immediately downstream of this confluence. A brief overview of Upper Blackstone’s monitoring programs is presented in the sections below. Detailed descriptions of sampling methods, quality control measures, and additional technical details are available in yearly field sampling plans and the project QAPP (approved by MassDEP in 2017), available upon request. A brief summary of sample collection and processing is provided in Appendix A. Laboratory methods and detection limits are provided in Appendix B.

3.1 Overview

Monitoring locations and data collection type are summarized in Table 2 and on Figure 2. Monthly water quality sampling for nutrients and chlorophyll-a are conducted from April through November generally every four weeks at nine sites along the mainstem of the Blackstone River, including three Rhode Island sites that are co-sampled with NBC. Periphyton sampling is performed three times a year, in July, August, and September, at three of the nutrient sampling sites plus one additional site sampled by MassDEP in 2008.

Table 2: Blackstone River 2018 sampling sites

Site ID#	Site Name	Lat	Lon	River Mile ²	HSPF Reach ²	Sampling Details ³
¹ RSMD	Slater Mill Dam, Pawtucket, RI	41.877	-71.382	0.0	200	N
¹ R116	Rte 116 Bikepath Bridge, Pawtucket, RI	41.938	-71.434	6.3	228	N
¹ RMSL	State Line, RI	42.010	-71.529	15.5	268	N
W1779	Below Rice City Pond Sluice Gates, Hartford St., Uxbridge, MA	42.097	-71.622	27.8	326	N
W0767	USGS gage near Sutton St. Bridge, Northbridge, MA	42.154	-71.653	33.4	348	N
W1242	Route 122A, Grafton, MA	42.177	-71.688	36.3	360	N
Depot	Depot St., Sutton, MA	42.177	-71.720	38.0	--	P
W1258	Central Cemetery, Millbury, MA	42.194	-71.766	42.7	392	NP
UBWPAD2 ⁴	Confluence Site, Millbury, MA	42.206	-71.781	44.6	402	NP
W0680 ⁵	New Millbury St bridge, Worcester, MA	42.228	-71.787	45.2	414	NP

¹ Locations of co-sampling with NBC

² Corresponding river mile and model reach in Blackstone River HSPF model: *Blackstone River HSPF Water Quality Model Calibration Report* (CDM Smith and UMass, August 2008) and the *Blackstone River HSPF Water Quality Model Calibration Report Addendum* (CDM Smith and UMass, October 2011).

³ Sampling Types: N = 9 sites, nutrients & chlorophyll-a 1 event/4-weeks; P = 4 sites, Periphyton event/month July - Sept.

⁴ Site replaced original confluence site (UBWPAD) in 2013

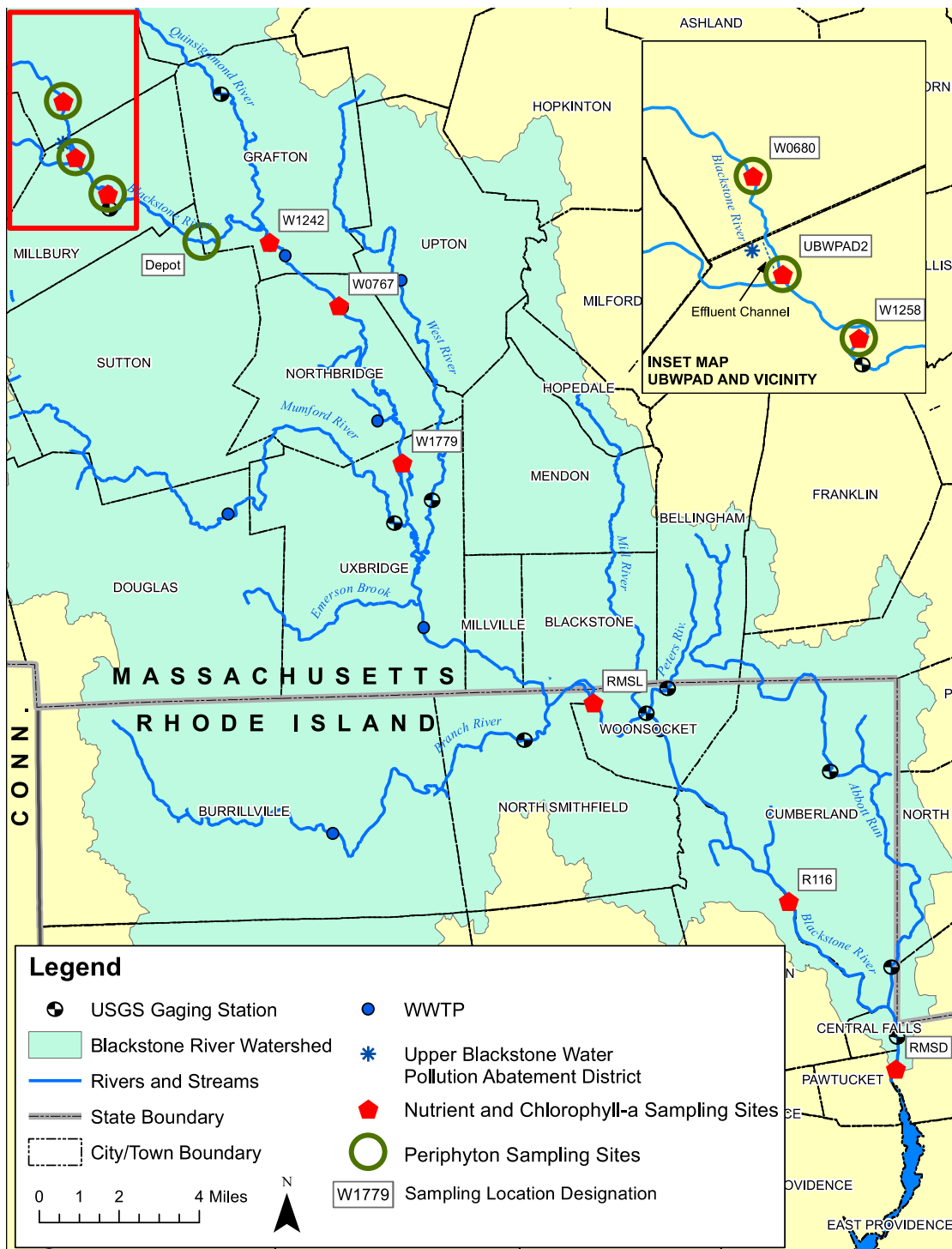


Figure 2: Blackstone River 2018 nutrient, chlorophyll-a, and periphyton sampling sites.

⁵ W0680 is located between the Worcester CSO discharge and UBWPAD2.

3.2 Sampling Dates and Data Collected

Sampling dates for the nutrient, chlorophyll-a, and periphyton monitoring program are summarized in Table 3 for 2018.

Table 3: 2018 river nutrient and periphyton sampling dates

Site ID#	25-April, 2018 ^a	24-May, 2018 ^a	20-June, 2018 ^a	11-12 July, 2018 ^b	18-July, 2018 ^a	09-10 August, 2018 ^b	16-August, 2018 ^a	04-05 September, 2018 ^b	12-September, 2018 ^a	24-October, 2018 ^a	07-November, 2018 ^a
RSMD	X	X	X		X		X		X	X	X
R116	X	X	X		X		X		X	X	X
RMSL	X	X	X		X		X		X	X	X
W1779	X	X	X		X		X		X	X	X
W0767	X	X	X		X		X		X	X	X
W1242	X	X	X		X		X		X	X	X
DEPOT ^e				X		X		X			
W1258 ^e	X	X	X	X	X	X	X	X	X	X	X
UBWPAD2 ^e	X	X	X	X	X	X	X	X	X	X	X
W0680 ^e	X	X	X	X	X	X	X	X	X	X	X

Notes: ^a Nutrient + chlorophyll-a monthly sampling dates

^b Periphyton sampling dates

X - Data collection completed

Samples collected for nutrient analysis are analyzed for total ammonia nitrogen (TAM), total nitrite-nitrate nitrogen (NO₂₃), either total Kjeldahl nitrogen (TKN) or total nitrogen (TN) depending on the analysis laboratory, total orthophosphate (TOP), total phosphorus (TP), total suspended solids (TSS), and chlorophyll-a (chl-a), Table 4. Additional water samples are collected for analysis of chlorophyll-a and TP during the week of periphyton sampling. Samples collected at the three sites co-sampled with NBC are also analyzed for dissolved nutrients. Samples are analyzed at Upper Blackstone's laboratory, NBC's laboratory, the UMass Environmental Analysis Laboratory (EAL), and/or the UMass Dartmouth (UMD) laboratory depending on the parameter as noted in the table.

Table 4: 2018 river sampling program analytes and laboratories

Parameter	Upper Blackstone Lab	NBC Lab	UMass EAL	UMD Lab
Dissolved Ammonia (dTAM)	--	Apr – Nov 3 RI Sites	--	Apr – Nov All sites
Dissolved Nitrite/Nitrate (dNO ₂₃)	--	Apr – Nov 3 RI Sites	--	Apr – Nov All sites
Total Dissolved Nitrogen (TDN)	--	Apr – Nov 3 RI Sites	--	Apr – Nov All sites
Total Nitrogen (TN)	--	--	--	Calculated
Particulate Organic Nitrogen (PON)	--	--	--	Apr – Nov All sites
Dissolved Orthophosphate (DOP) – 3 RI Sites	Apr – Nov 3 RI Sites	Apr – Nov 3 RI Sites	--	--
Total Orthophosphate (TOP)	Apr – Nov All sites	--	--	--
Total Dissolved Phosphorus (DP) – 3 RI Sites	--	--	Apr – Nov 3 RI Sites	--
Total Phosphorus (TP)	--	--	Apr – Nov All sites	--
Total Suspended Solids (TSS)	Apr – Nov All sites	Apr – Nov 3 RI Sites	--	--
Chlorophyll-a (chl-a)	--	--	Apr – Nov All sites	--
Periphyton Chlorophyll-a			Jun-Nov 4 MA Sites	

4.0 Sampling Season Environmental Conditions

Precipitation, temperature, and streamflow influence how the river and bay systems respond to inputs of nutrients. In wet years, the WWTF effluent comprises a smaller fraction of the river volume, and nutrients from WWTF effluent and other sources tend to be flushed from the river system more quickly, reducing the opportunity for algal growth in impoundments. For example, when flows are $\sim 4,000$ cfs² at Woonsocket, RI, it takes a “parcel” of water approximately two days to travel from the Blackstone headwaters at river mile 46.6 to the outlet. Large storm events can also scour the streambed, washing periphyton and macrophytes downstream. Conversely, in dry years, in-stream nutrient concentrations tend to be higher. Lower stream water depths enhance the penetration of light to the stream bottom, and lower flows reduce scour, providing conditions more amenable for periphyton growth. The time it takes for water to move from the headwaters to the outlet of the river greatly increases, to approximately 30 days, when river flows are near ~ 85 cfs³ at Woonsocket, RI, providing conditions that promote the growth of algae in impoundments. A cold spring tends to maintain the snowpack and keep river and impoundment temperatures below conditions amenable for algal and periphyton growth. Warmer air temperatures result in higher water temperatures, which in turn promote algal and periphyton growth.

Data describing the 2018 environmental conditions are presented in this section. Precipitation and air temperature data are presented in Section 4.1, followed by a summary of the river streamflow conditions in Section 4.2. Section 4.3 provides a brief summary of the potential relative impacts of these conditions on river quality compared to previous sampling years.

4.1 Precipitation and Air Temperature

Snowfall records are available from the National Weather Service (NWS) since 1892 for Worcester (Worcester Regional Airport, KOHR and New Bedford Regional Airport, KTAN). This 124-year record is summarized in Figure 3 based on published monthly data. Snowfall accumulations from the winters of 2011 – 2012 through 2017 - 2018 are highlighted due to their potential influence on the subsequent sampling season results. The seven sampling seasons span the range of typical snow accumulation, ranging from a total of 30.1 inches (winter of 2011-2012) to 119.7 inches (winter of 2014- 2015). The historical ranking of each sampling year in terms of snow accumulation is summarized in Table 5. The 2018 sampling season was preceded by the eleventh snowiest winter on record, with 96.1 inches of snowfall.

² A flow of 4,000 cfs is exceeded $\sim 1\%$ of the time at the Woonsocket stream gaging station

³ 85 cfs is the lowest average discharge over a period of seven days that occurs on average once every 10 years (7Q10) at the Woonsocket stream gaging station

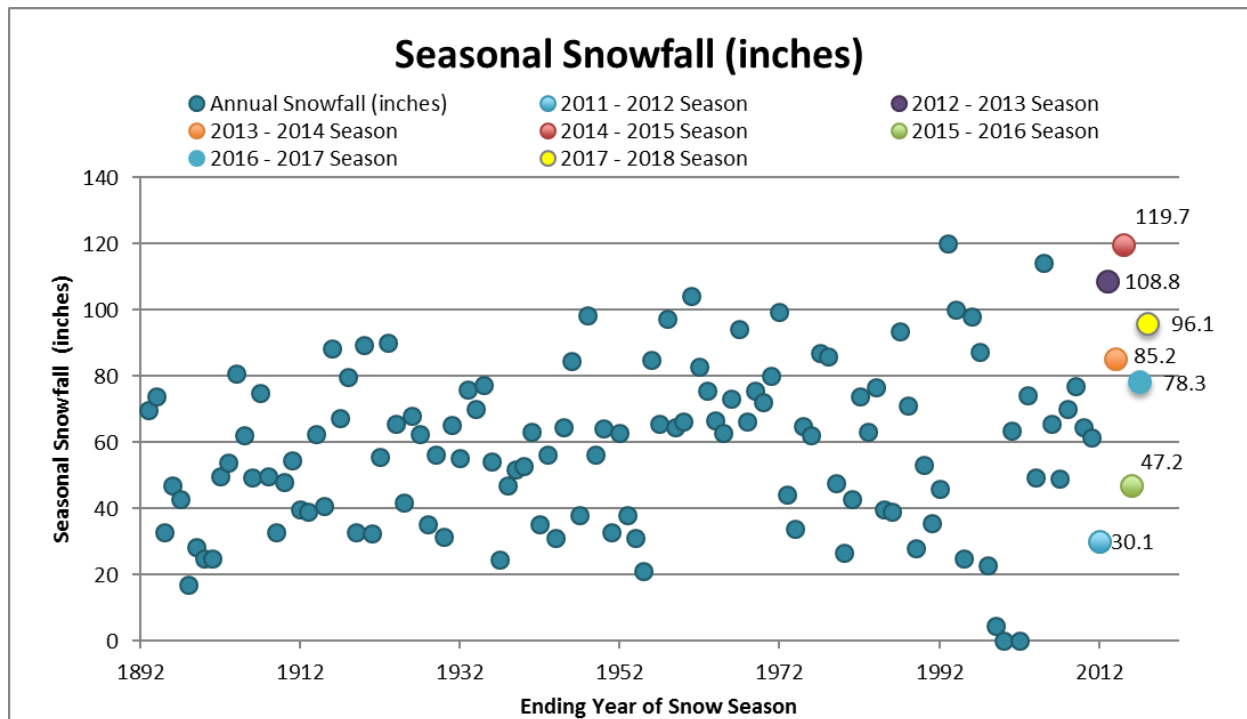


Figure 3: Seasonal snowfall (inches) in Worcester from 1893 through 2018, inclusive

(Note: year plotted is end of snow season)

Table 5: Snowfall totals winters 2011-2012 to 2017-2018

	Snow (in)	Rank in 124 years of record (1 = snowiest)
Winter 2011 - 12	30.1	113 th
Winter 2012 – 13	108.8	4 th
Winter 2013 – 14	85.2	20 th
Winter 2014 – 15	119.7	2 nd
Winter 2015 – 16	47.2	86 th
Winter 2016 - 17	78.3	27 th
Winter 2017 - 18	96.1	11 th

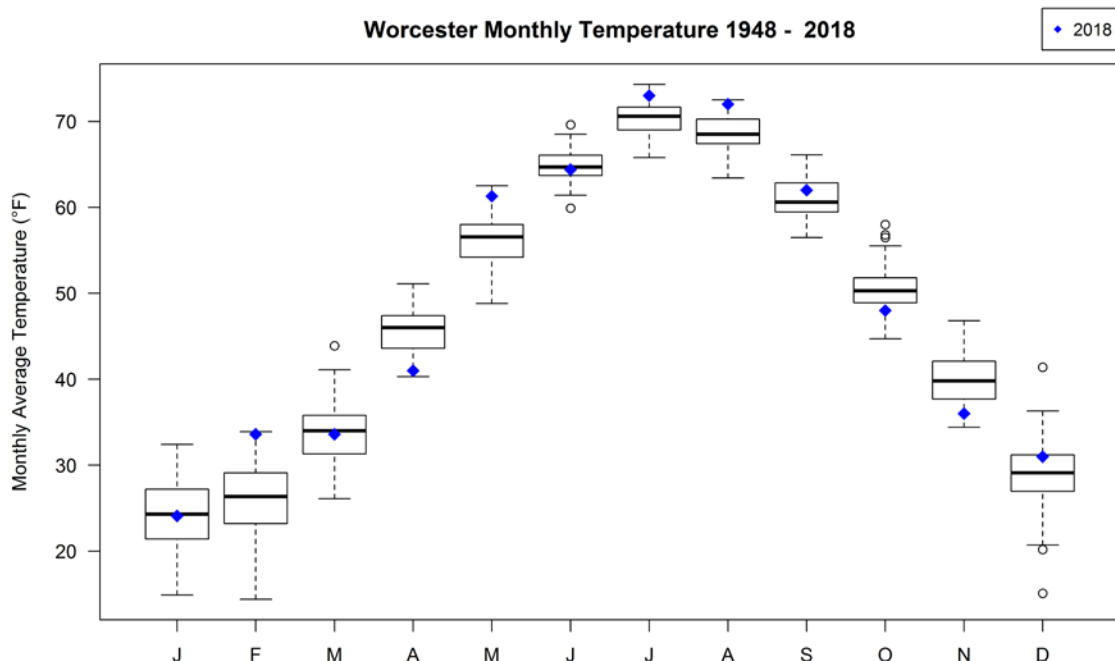


Figure 4: Worcester monthly air temperatures 1948 - 2018

Air temperature data for Worcester are available from the NWS starting in 1948. Monthly average temperature data since 1948 are summarized on Figure 4 as a boxplot, with the data for 2018 shown with blue diamonds. The box plots provide a summary of the distribution of the data, with the box showing the first quartile, median, and third quartile, and the whiskers showing 1.5 times the interquartile range above the upper quartile and below the lower quartile of the data. The small black circles above and below the whiskers represent observed data that are statistically considered “outliers.” The winter (e.g., January-March) of 2017 - 2018 was variable: normal in January and March, but much warmer in February. Unlike in 2017, the month of April was quite cold compared to historical data, though May was warmer than historical median by a comparable amplitude (~5°F). Temperatures in June were normal, followed by warmer than average in July and August. While the monthly average temperature in September reached the upper quartile of historical data, in October and November it dipped below the lower quartile, only to reach the upper quartile again in December.

Figure 5 presents three statistics to summarize monthly temperature conditions since routine sampling began in 2012. The average mean temperature (black solid line) is determined based on the average daily temperature for each day in the given month. The average low temperature (solid blue line) is determined based on the average of the low temperatures observed on each day in the given month while the average high temperature (solid red line) is determined based on the average of the high temperatures observed on each day. These data are plotted against the published normal monthly data for each statistic, based on the 30-year period from 1981 to 2010, shown as a dashed line of the same color. Instances where the solid line falls above the dashed line indicate warmer than typical conditions, whereas instances where the solid line falls below indicate cooler than normal conditions. The 2018 sampling season was preceded by an average winter compared to previous sampling years, while the sampling season was warmer than those of recent sampling years.

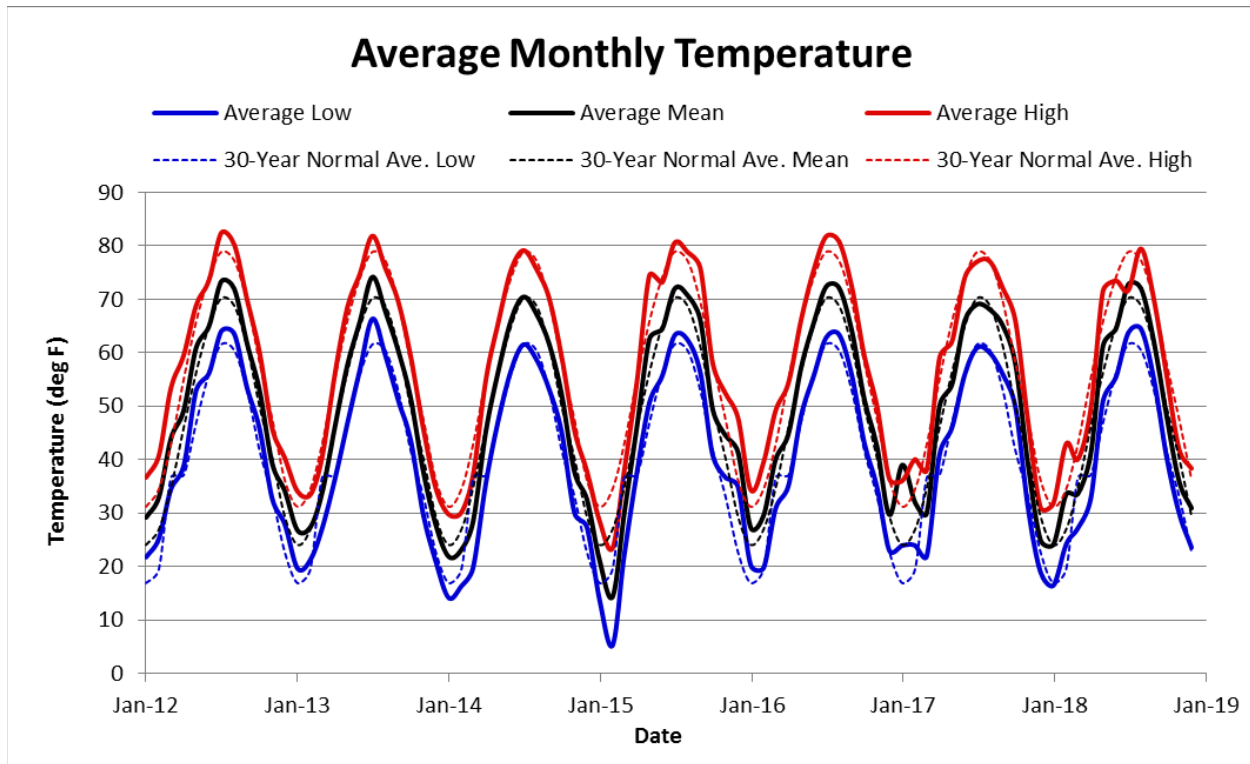


Figure 5: Average monthly low, mean, and high air temperature values observed since 2012

Notes: Observed values for each month (solid lines) are compared to the normal for the month (dashed lines) based on NWS monthly data for Worcester from 1981 – 2010, available online: www.ncdc.noaa.gov/cdo-web/datasets#GHCND

Annual precipitation totals for Worcester (Regional Airport KOHR) from the NWS since 1949 are shown on Figure 6, with the years since routine sampling began in 2012 noted with their associated accumulation. The annual precipitation in 2018, 62.4 inches, was notably higher than the average of the observed values since 1949 (47.6 inches). Figure 7 summarizes monthly precipitation conditions since sampling began in 2012, shown as a solid green line, compared to published normals from the NWS based on the 30-year period 1981 – 2010, shown as a dashed green line. There is significant variability in monthly precipitation year-to-year and month-to-month, but almost every month in 2018 saw larger precipitation amounts than average, particularly in summer and fall.

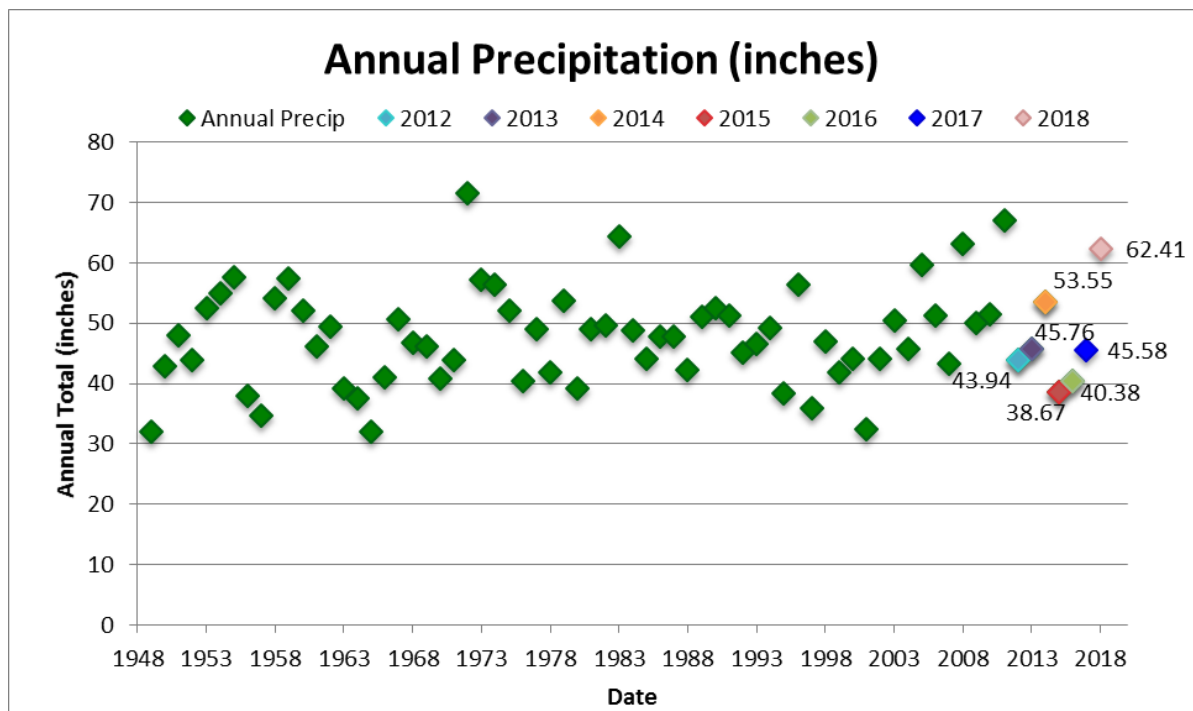


Figure 7: Annual precipitation (inches) in Worcester since 1949

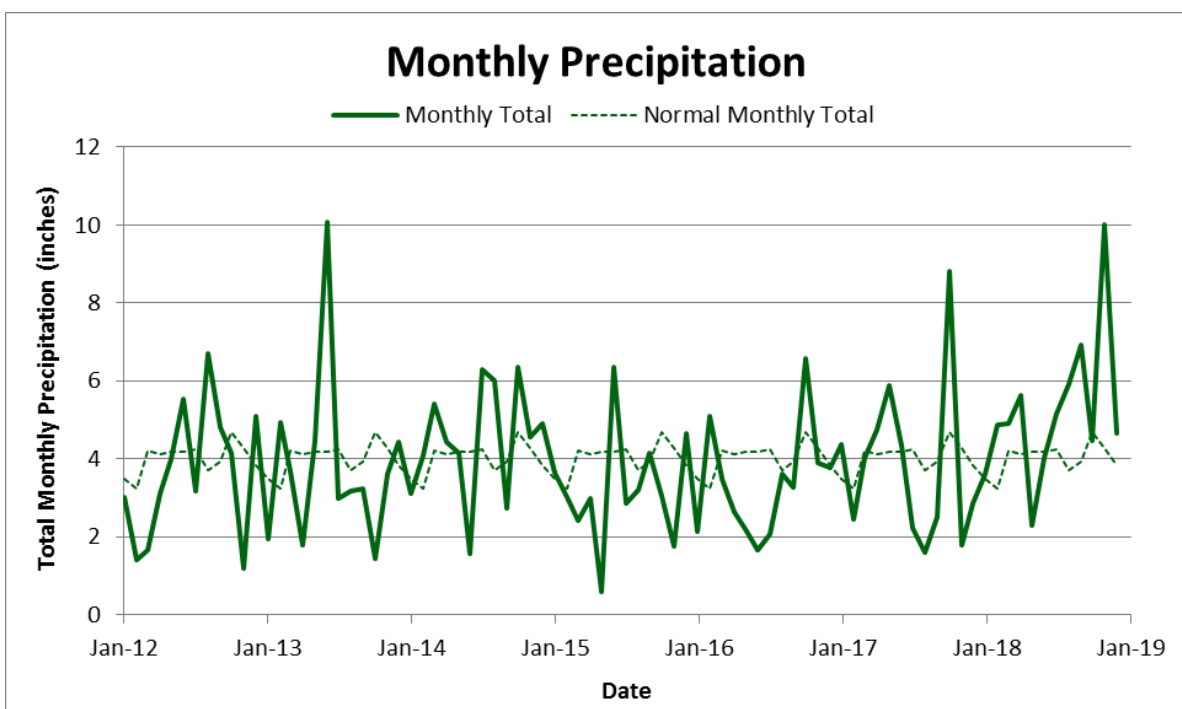


Figure 6: Monthly precipitation totals 2012-2018 compared to normal monthly totals

Notes: Observed totals for each month (solid line) are compared to the normal for the month (dashed lines) based on NWS monthly data for Worcester from 1981 – 2010

Monthly precipitation totals since 1949 for Worcester are summarized using boxplots on Figure 8. Data for 2018 are represented by blue diamonds. Rainfall totals were higher than the historical median every month except May. Additional monthly precipitation condition data for the 2018 sampling years compared to the NWS 30-year normal are provided in Appendix C.

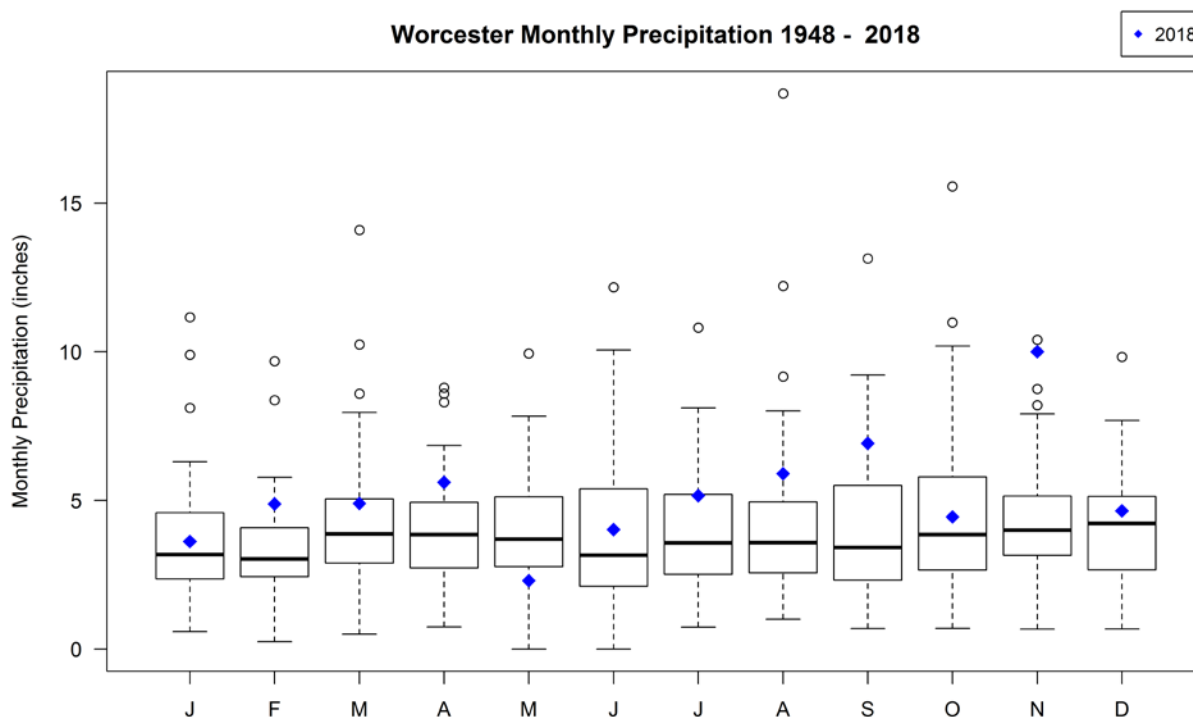


Figure 8: Worcester monthly precipitation 1948 - 2018

Daily precipitation data as measured at the Worcester Airport are plotted on Figure 9 for 2018. The precipitation on sampling dates is highlighted. Cumulative precipitation for the year is also plotted and compared against the historical data, calculated as the cumulative sum of 50th percentile daily normal for Worcester from 1981 - 2010. Total precipitation was 62.4 inches in 2018. Cumulative rainfall in 2018 was higher than the historical cumulative until early June, then lower than historically for about two months, and in early September cumulative precipitation returned to levels higher than historical ones.

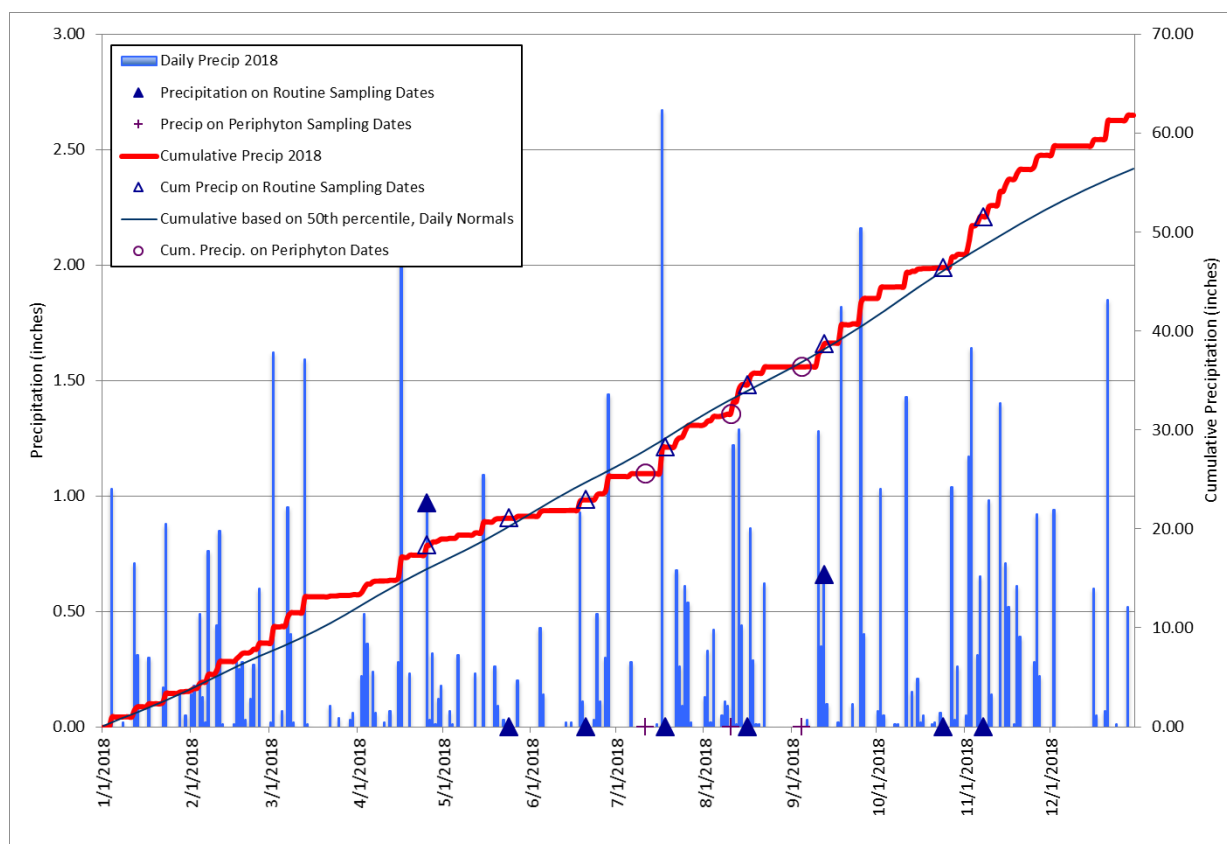


Figure 9: 2018 sampling season daily precipitation at Worcester Airport (KORH) compared against 50th percentile daily normal precipitation

The occurrence of precipitation relative to the occurrence of routine sampling can have an impact on the measured levels of in-stream constituents such as nutrients, chlorophyll-a, and periphyton. Sampling day and antecedent precipitation conditions are summarized in Table 6 for all routine sampling dates in 2018. Most routine sampling in 2018 occurred on days with little to no precipitation, except on April 25th and September 12th (no precipitation in RI on September 12). Significant rainfall (>0.5 inches) occurred during the week prior to sampling in June, July, August, September and November 2018, and the day prior to both the July and November sampling dates. There was a particularly high amount of rain the day prior to the July sampling (2.67 inches). While it is not possible to fully account for the impacts of rainfall on results, stream sampling results can be summarized and reviewed based on the prevailing streamflow conditions on the sampling days. This issue is addressed further in the next sections.

Table 6: Day-of and antecedent precipitation on routine sampling dates in 2018

Sampling Date	Precipitation in Worcester, MA (NWS Station KORH) - inches			
	Day Of	1-day Prior	Total over 3-days Prior	Total over 7-days Prior
25 April	0.97	0.00	0.00	0.23
24 May	0.00	0.00	0.03	0.38
20 June	0.00	0.11	1.04	1.08
18 July	0.00	2.67	2.68	2.68
16 August	0.00	0.00	1.73	3.05
12 September	0.66	0.35	1.63	1.66
24 October	0.00	0.06	0.08	0.14
7 November	0.00	0.65	0.96	3.82

4.2 Streamflow Conditions

Blackstone River Streamflow conditions during the 2018 sampling season are described in this section. It should be noted that some of the USGS streamflow data were still considered provisional at the time they were accessed for compilation of this report. Data are considered provisional until they undergo a formal review by USGS staff. During the formal review, small adjustments to the data may be made based on the most up-to-date field quality control data, particularly for very high or low streamflows. As a result, the data presented here might vary slightly from the final approved data.

Monthly average streamflow data collected by the USGS at Millbury, MA, since July 2002 are summarized on Figure 10 as a boxplot, with the data for 2018 depicted with blue diamonds. Data for the USGS gage at Woonsocket, RI, collected since March 1929, are similarly presented on Figure 11. Monthly streamflows for each month of the routine sampling season are compared against the median, average and minimum monthly data for both Millbury and Woonsocket in Table 7. Streamflows were above or at the median value until July, when they progressively got higher, rising even above the 1.5 times the upper quartile starting in September at Woonsocket. In November, streamflow was significantly above average.

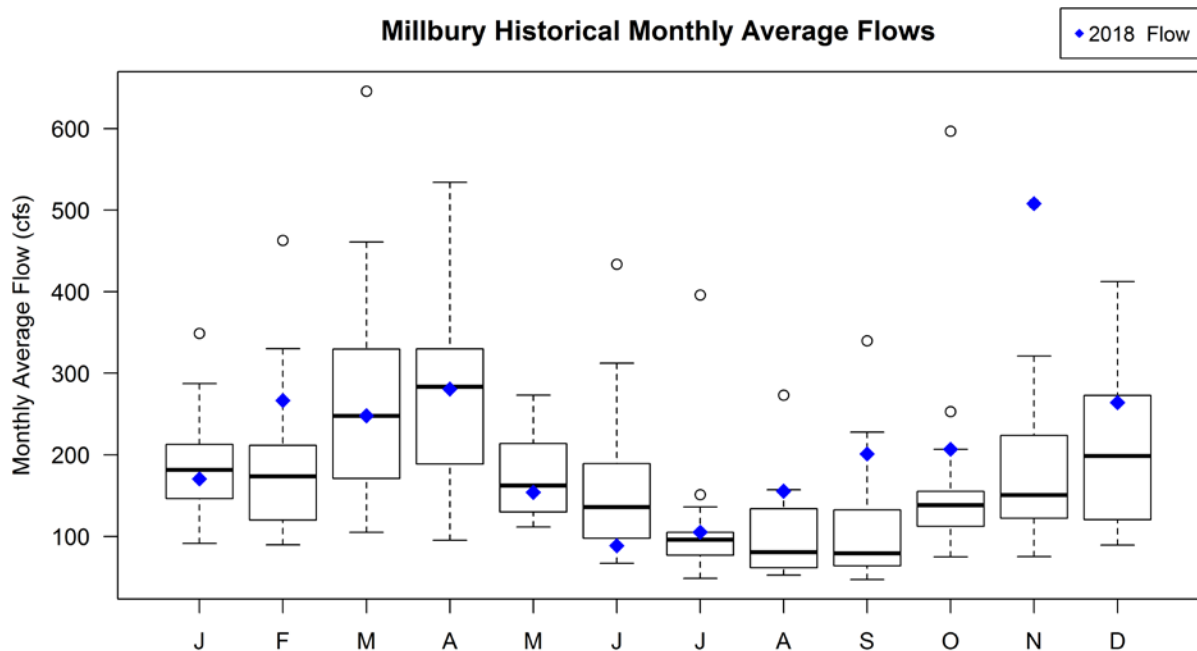


Figure 10: Millbury, MA, USGS gaging station 01109730 historical monthly average streamflows, 2003 - 2018

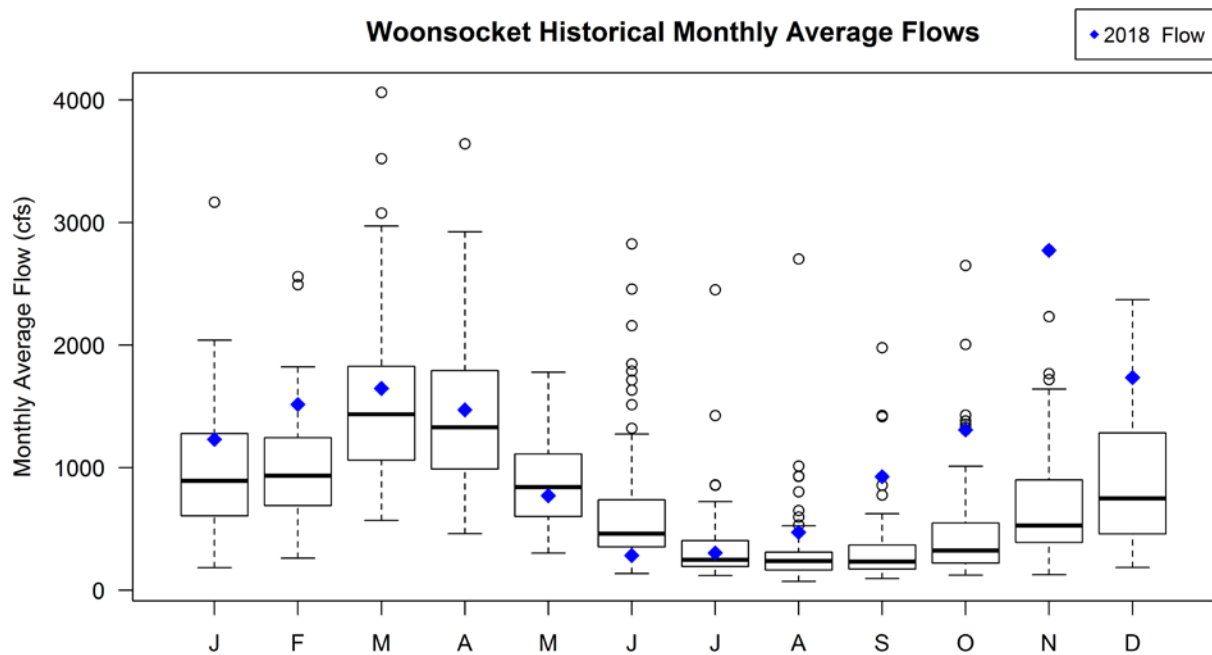


Figure 11: Woonsocket, RI, USGS gaging station historical monthly average streamflows, 1930 – 2018

Table 7: Mean monthly streamflows in 2018 compared to median, mean, and minimum¹

Millbury (cfs)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
<i>2018 Monthly Q_{ave}</i>	281	154	89	105	156	201	207	508
Median 2003 - 2018	283	162	136	96	80	79	138	151
Average 2003 - 2018	277	171	166	112	102	112	167	184
Minimum 2003 - 2018	95	112	67	49	53	47	75	75
Woonsocket (cfs)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
<i>2018 Monthly Q_{ave}</i>	1472	771	284	304	473	926	1308	2774
Median 1930 - 2018	1330	841	462	248	239	233	324	528
Average 1930 - 2018	1435	877	649	342	309	329	475	696
Minimum 1930 – 2018	461	303	137	120	72	95	123	127

¹Monthly streamflows at Millbury started in July 2002, thus statistics do not include 2012

The lowest average discharge over a period of seven days that occurs on average once every 10 years (7Q10) is around 85 cfs at Woonsocket. This is a streamflow condition that is often utilized in regulations. Because of its still relatively short period of record (July 2002 – 2018), 7Q10 flow has not been officially computed for the Millbury gage by the USGS, but the data may be utilized to generate an estimate. Millbury 7Q10 conditions are estimated to be around 38 cfs. Average 7-day flows (7Q) did not fall below 7Q10 conditions at either Millbury or Woonsocket in 2018. For reference, average daily streamflows at Woonsocket and Millbury for each day two weeks prior to periphyton sampling are provided in Appendix C, along with the 7-day average streamflows for the week prior, for comparison against the 7Q10 conditions noted. Table 8 summarizes the minimum 7Q flows observed at Millbury and Woonsocket since routine sampling began.

Table 8: Minimum 7-day average streamflows by year since routine sampling began

	Minimum 7Q (cfs)	
Year	Millbury	Woonsocket
2012	49	152
2013	51	127
2014	47	74
2015	42	58
2016	37	64
2017	40	107
2018	50	131
7Q10	38 ^a	85

Notes: ^a Estimated

Mean daily streamflows measured at Millbury and Woonsocket are compared to historic mean daily streamflows on Figures 12 and 13 for the 2018 sampling season. The solid blue line represents the observed daily mean streamflow for the given year, while the solid red line represents the historic mean daily streamflow. The dates of routine sampling are indicated by green triangles, while periphyton sampling dates are noted with purple crosses. It has already been noted that monthly streamflows were high throughout the last two-thirds of the 2018 sampling season. While daily streamflows were below average historical conditions in May and June, and average in October, streamflows were above average on all the other sampling dates in 2018.

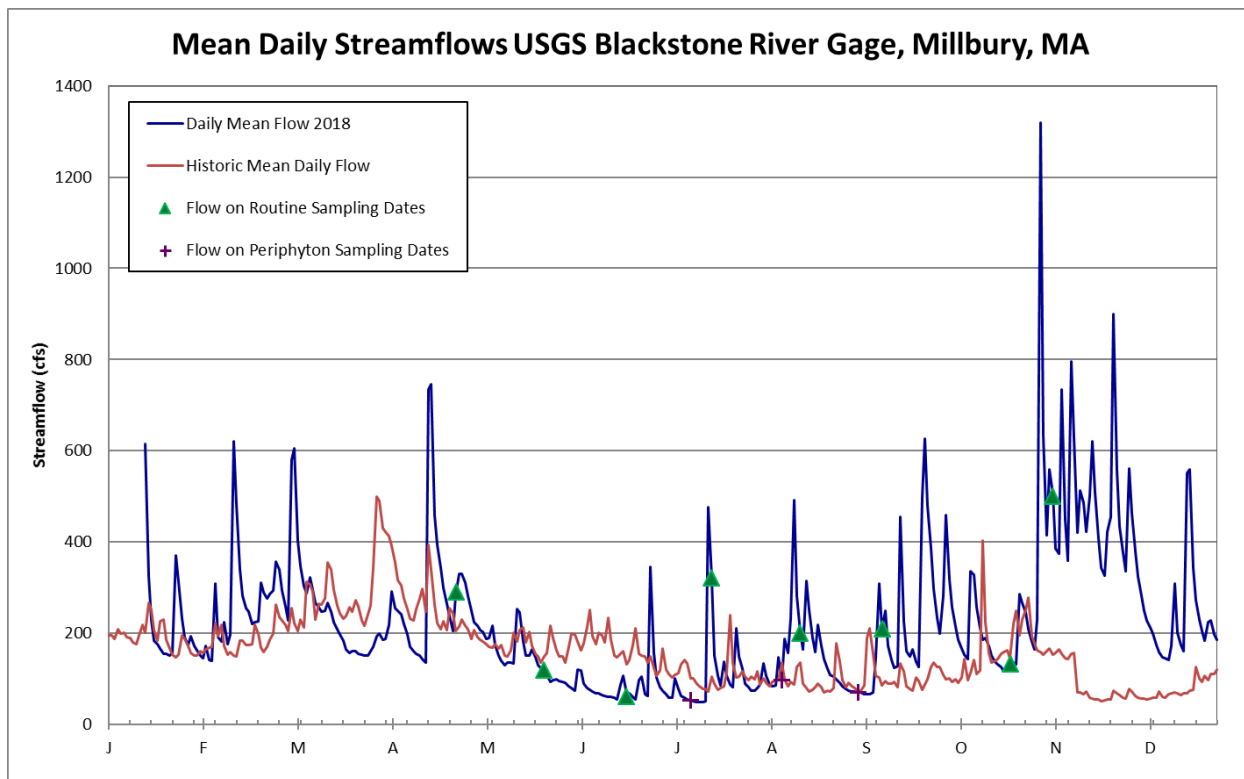


Figure 12: 2018 mean daily streamflows at USGS Millbury, MA stream gage

(Notes: Historical Mean Daily streamflow data through 2018)

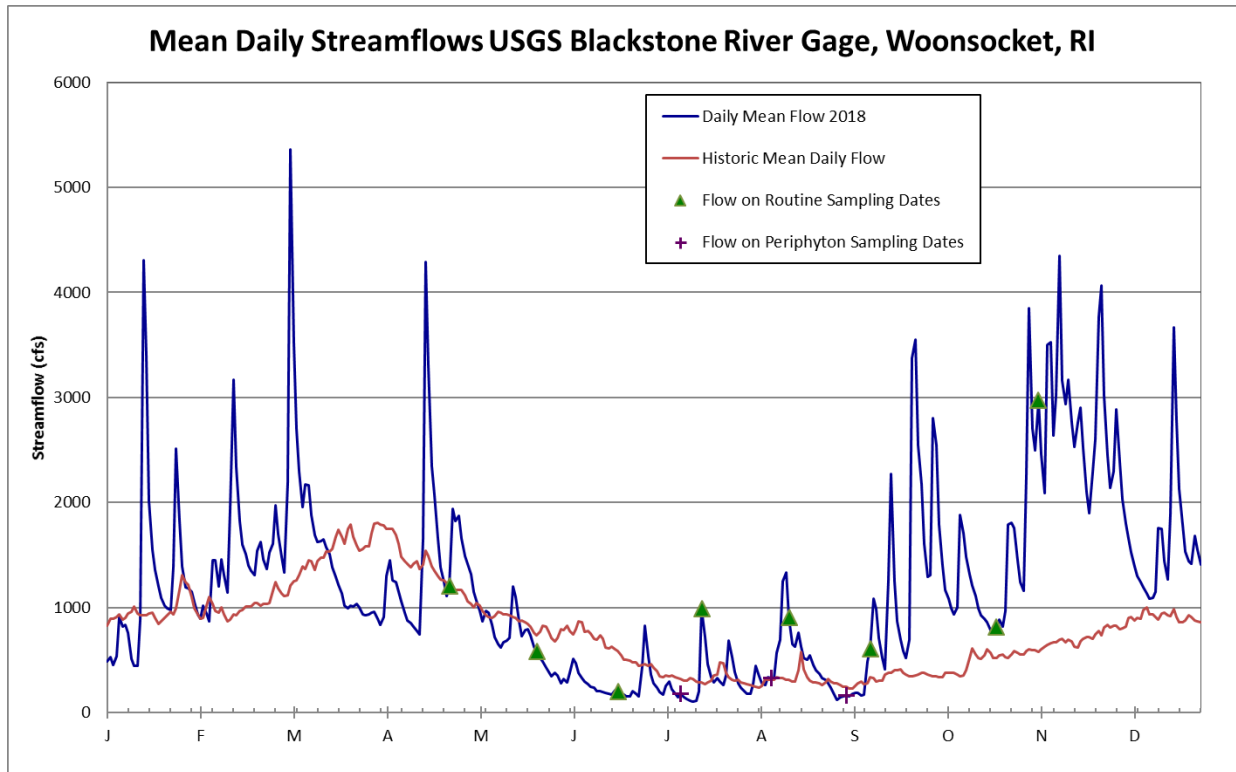


Figure 13: 2018 mean daily streamflows at USGS 01112500 Woonsocket, RI gage

(Notes: Historical Mean Daily streamflow data through 2018)

Table 9 provides routine sampling day streamflow data from the figures in tabular format, compared to the mean daily discharge for that day based on the historical record. Note that the historical mean daily discharge is for a specific *day* of the month, rather than the month as a whole. As such, the values reported in Table 9 may differ from the monthly mean.

Table 9: Routine sampling day-of streamflow conditions 2018

Sampling Date	Woonsocket, RI – USGS Station 01112500			Millbury, MA – USGS Station 01109730		
	2018 Mean Daily Q (cfs)	^b Historical Mean Daily Q (cfs)	% of normal	2018 Mean Daily Q (cfs)	^b Historical Mean Daily Q (cfs)	% of Normal
25 April ^a	1200	1230	98%	291	205	142%
24 May ^a	579	736	79%	119	149	80%
20 June ^a	199	582	34%	61	131	47%
18 July ^a	985	285	346%	321	104	309%
16 August ^a	902	307	294%	200	136	147%
12 September ^a	602	335	180%	209	86	243%
24 October ^a	811	520	156%	133	145	92%
7 November ^a	2970	577	515%	500	152	329%

Notes: ^a Nutrient + chlorophyll-a monthly sampling dates

^b Historical Mean Daily Q (cfs) based on data through 2018

4.3 Environmental Conditions Summary

There were no clear trends in 2018 average monthly temperatures, when compared to previous years. For some months, 2018 values were at or below the median value; in other months 2018 monthly average temperatures exceeded median and upper quartile values based on the period of record.

The year, 2018, was by all accounts a very wet year. Snowfall amounts were the third highest since 2012, and rainfall was the highest in the same period of time. Consequently, streamflow was unusually high for the last two-thirds of the sampling season. Only in April was streamflow low relative to average conditions on the day of sampling. The impact of these mixed conditions on stream water quality is discussed in the next section.

5.0 Upper Blackstone Effluent

Upper Blackstone facility seasonal permit limits⁴ for total phosphorus (TP) and total nitrogen (TN) are listed in Table 10. Upper Blackstone has been taking steps to comply with the 2008 permit limits. These steps include:

- Implementation of interim measures to further improve plant operation and control, and performance to result in more stable operation and improved effluent quality;

⁴ TP 'summer' limits are for April through October; TP 'winter' limits are for November through March.

TN 'summer' limits are for May through October; TN 'winter' limits are for November through April.

- Facilities Planning to evaluate necessary nutrient removal facility improvements to achieve 2008 permit limits, including development of future flows and loads and an Alternatives Analysis Screening and Evaluation, as well as an analysis of ancillary facilities;
- WWTF upgrade construction to implement successfully tested interim measures and to modernize facility SCADA and data collection systems (in progress);
- Design of phosphorus removal system to meet 2008 permit limits (in progress);

Table 10: Upper Blackstone 2008 permit limits

Total Phosphorus (mg/L)¹	
Apr – Oct (summer)	0.1 ²
Nov – Mar (winter)	1.0
Total Nitrogen (mg/L)	
May – Oct (summer)	5.0
Nov – Apr (winter)	Report

¹ Upper Blackstone effluent limits are typically listed in mg/L. The conversion is 1 mg/L = 1000 ppb.

² The 0.1 mg/L total phosphorus limit is a 60-day rolling average limit.

The facility is operated to remove nitrogen and phosphorus year-round, even though it has only a May – October seasonal nitrogen permit limit, and much less stringent wintertime limits for total phosphorus.

Figure 14 shows the actual effluent TN and TP annual average daily concentrations since 2006, and Table 11 summarizes TP and TN effluent concentrations by season, corresponding to the permit limits, since 2012.

Table 11: Upper Blackstone average permit season TP and TN effluent concentrations*

	2012	2013	2014	2015	2016	2017	2018
Total Phosphorus (mg/L)							
Apr – Oct (summer)	0.48	0.17	0.35	0.18	0.20	0.17	0.20
Nov – Mar (winter)	0.34	0.18	0.19	0.18	0.55	0.34	0.12
Total Nitrogen (mg/L)							
May – Oct (summer)	5.04	4.3	4.7	4.6	3.9	4.5	4.90
Nov – Apr (winter)	5.34	5.5	4.6	5.2	5.9	8.7	5.04

*Summer months are April-October of that year. Winter months are Nov-Dec of the previous year and Jan-Mar of that year

Percent reduction in average daily and yearly TP and TN effluent loads compared to plant performance are shown in Tables 12 and 13, respectively.

Table 12: Percent reduction in average daily TP and TN effluent loads compared to plant performance, 2006-2008

Year	TP	TN
2012	75%	56%
2013	88%	57%
2014	83%	59%
2015	87%	52%
2016	78%	54%
2017	85%	34%
2018	87%	43%

Table 13: Percent reduction in yearly TN and TP effluent load compared to plant performance 2006-2008

Year	TP (lb/yr)	TP % Reduction	TN (lb/yr)	TN % Reduction
2006 – 2008	153×10^3	--	1045×10^3	--
2012	38.3×10^3	75%	458×10^3	56%
2013	18.9×10^3	88%	452×10^3	57%
2014	25.6×10^3	83%	428×10^3	59%
2015	19.6×10^3	87%	499×10^3	52%
2016	33.9×10^3	78%	485×10^3	54%
2017	23.3×10^3	85%	690×10^3	34%
2018	19.6×10^3	87%	597×10^3	43%

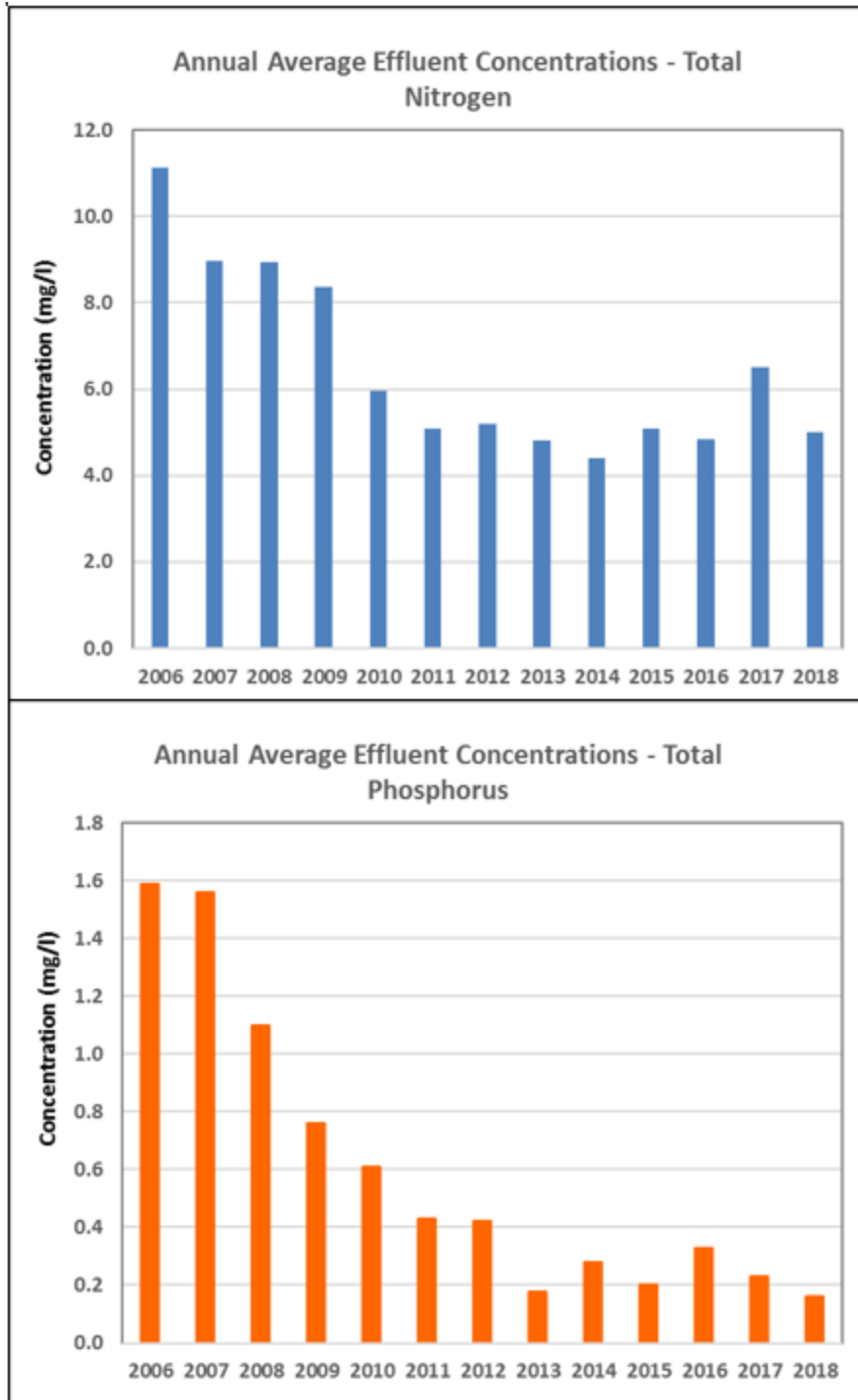


Figure 14: Annual average effluent total nitrogen and total phosphorus concentrations 2006 – 2018

Figure 15 shows the effluent TN and TP annual total loads since 2006, and seasonal loads for summer and winter for 2010-2018.

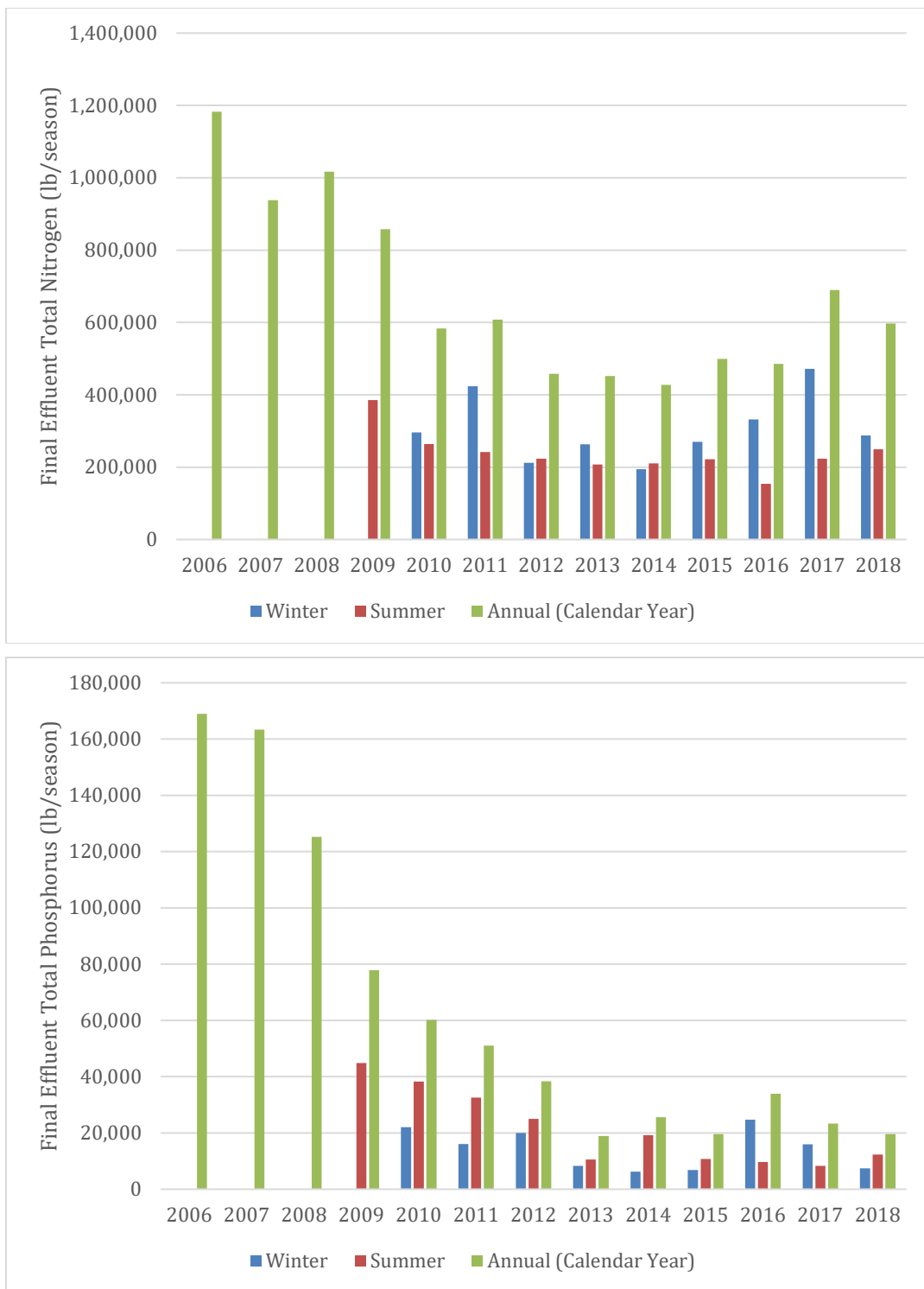


Figure 15: Total annual, winter permit, and summer permit total nitrogen and total phosphorus loads to the Blackstone River 2006 – 2018

Notes: 1. Summer refers to the period between April 1 and October 31 for TP and May 1 and October 31 for TN for the year noted. Winter refers to the period between November 1 of the prior year through March 31 of the current year for TP and April

30 of the current year for TN.
 2. Annual loads are on a calendar year basis, January 1 - December 31

The highest biological activity in the river typically occurs during the warmest months of the year, from June through September. It is thus also useful to identify year-to-year differences in effluent nutrient characteristics for this summer growing period, which may provide insight into river conditions captured by the monitoring program.

Effluent nutrient and flow data during each year from 2006 - 2018 were used to calculate the daily average concentration and load from June through September, Table 14. A boxplot of the daily data from June through September each year is shown on Figure 16 for concentrations and Figure 17 for loads from 2012 – 2018. The boxplots provide an indication of the day-to-day variability during the June – September growing period each year of the monitoring program.

Table 13: Average of the daily effluent nutrient characteristics during the June – September growing season in 2006 to 2017

Year	Effluent TP		Effluent TN	
	June – September Ave. Daily Conc. (mg/L)	June – September Ave. Daily Load (lb/d)	June – September Ave. Daily Conc. (mg/L)	June – September Ave. Daily Load (lb/d)
2006	1.7	403	NA	NA
2007	2.1	424	8.3	1,687
2008	1.5	421	8.0	2,178
2009	0.9	238	7.8	2,089
2010	1.0	237	6.1	1,346
2011	0.4	151	4.2	1,411
2012	0.4	99	4.6	1,094
2013	0.1	45	3.8	1,065
2014	0.5	114	4.8	1,104
2015	0.2	44	4.5	1,167
2016	0.2	43	3.8	782
2017	0.2	36	4.4	1,729
2018	0.2	53	4.8	1,280

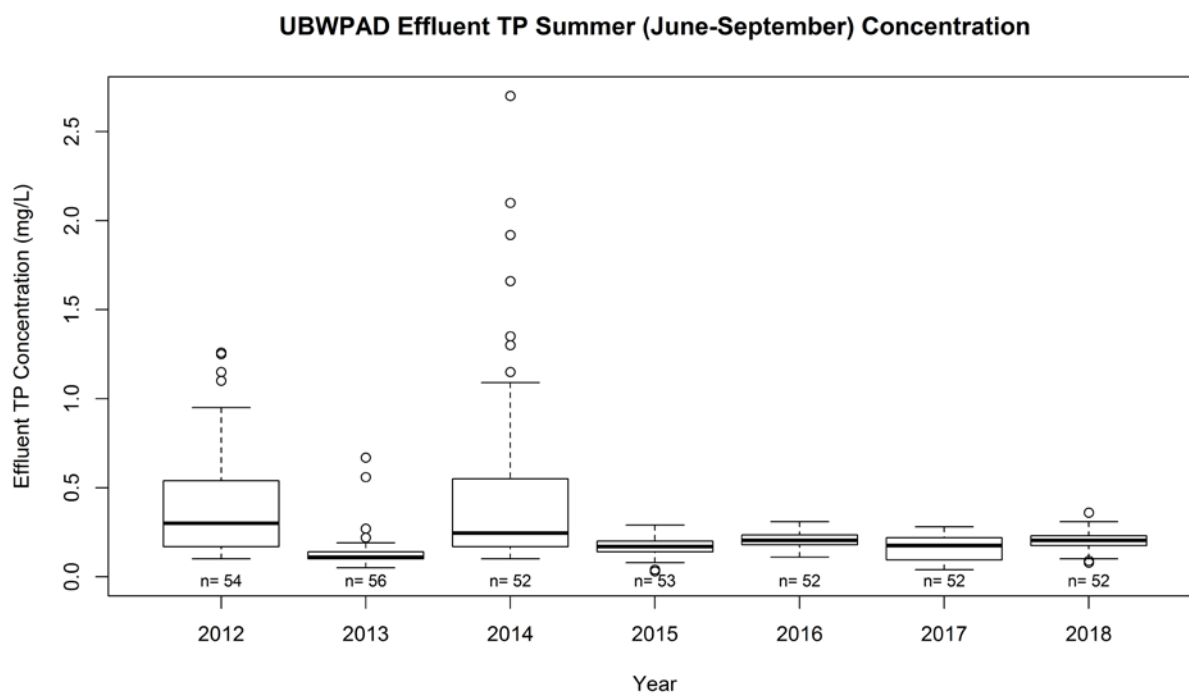
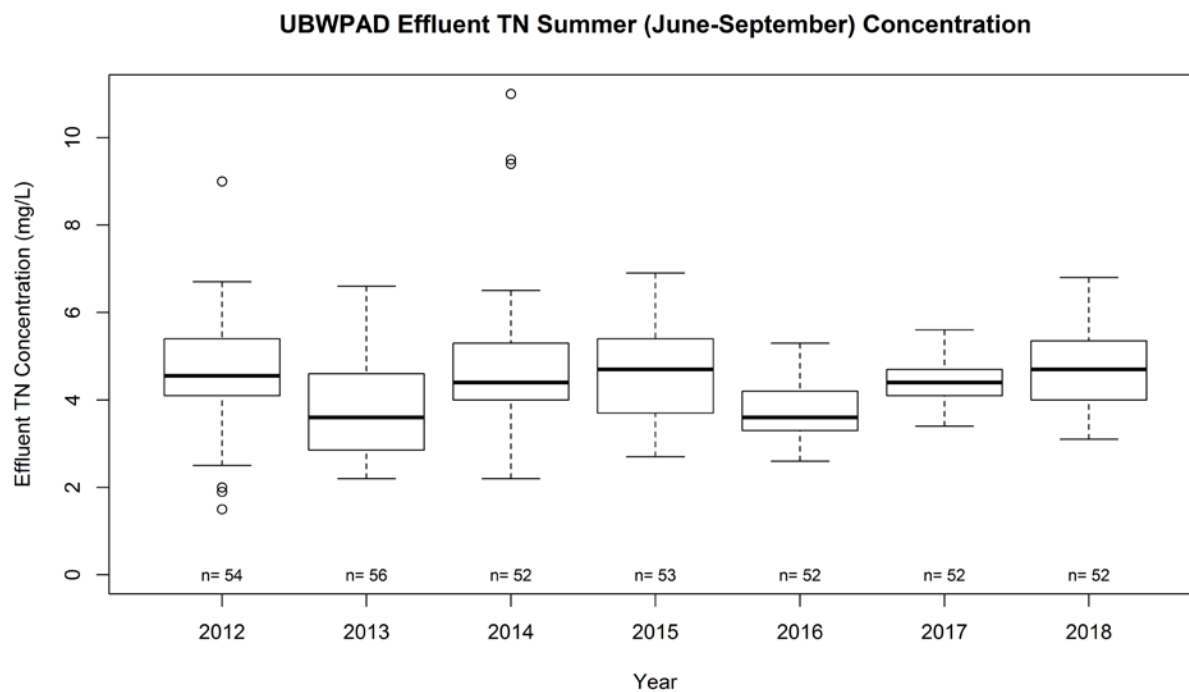


Figure 16: Upper Blackstone daily effluent TN and TP concentrations by year from June - September

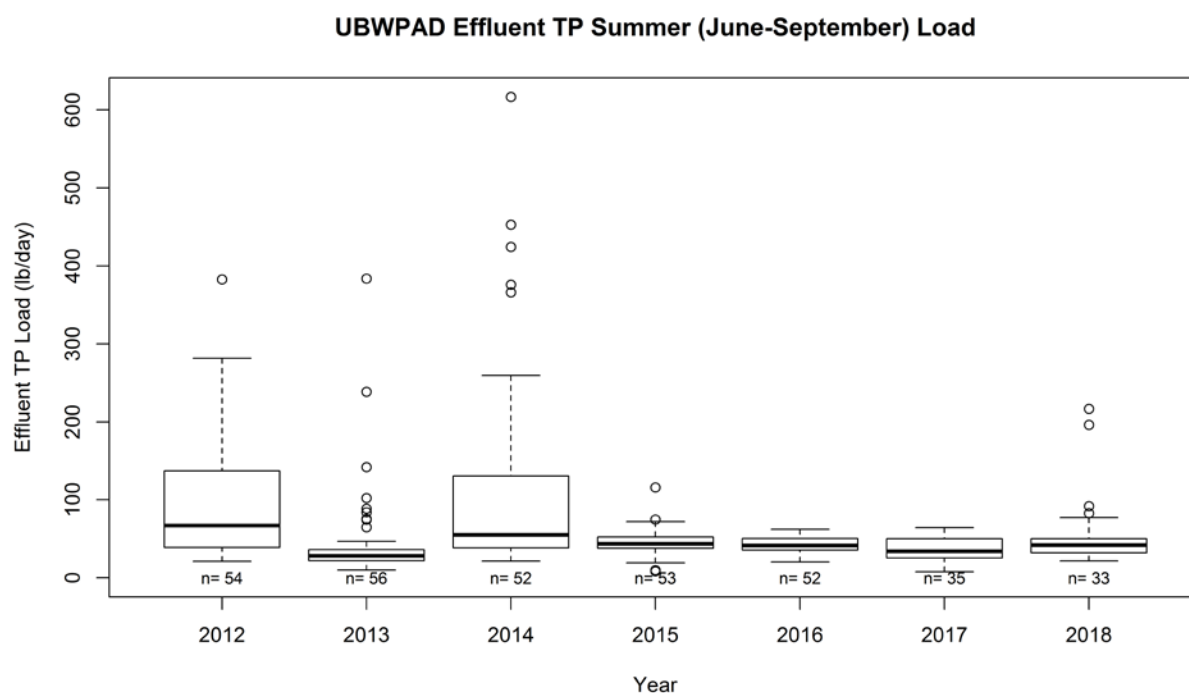
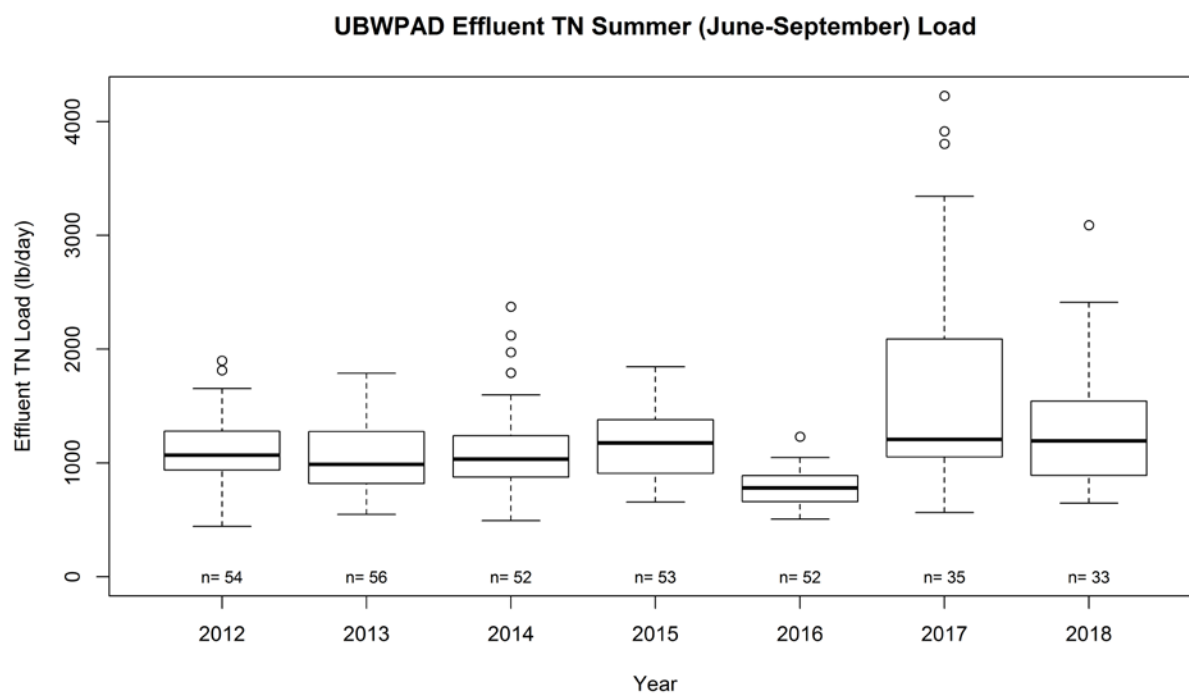


Figure 17: Upper Blackstone daily effluent TN and TP loads to the river by year from June - September

The interquartile range of daily TN effluent loads from June – September has been relatively constant since 2012 with the notable exception of 2016, when the summer interquartile of daily TN loads leaving the plant fell below that of previous years. Daily growing season TN loads in 2018 were similar to data from 2014 – 2017, although levels were slightly higher than in 2017. TP effluent loads during the summer growing season showed little day-to-day variability, as indicated by a small interquartile range in 2013 and 2015-2018, but larger variability in 2012 and 2014. Time series plots of effluent TP and TN characteristics, as well as effluent flow, are included in Appendix D.

Upper Blackstone’s effluent discharge can account for a significant percentage of the flow that exits the headwaters of the watershed. The average Upper Blackstone flow contributions to summer flows at Millbury on a daily basis since 2003 vary between 33% and 65% during the months of June through September. In 2018, Upper Blackstone flow contributed between 10% (minimum) and 68% (maximum) of the daily streamflow at Millbury, averaging 39% from June to September.

Upper Blackstone flow contributions during the growing season may also be summarized on a lumped volume basis, smoothing the data to account for the travel time between the confluence and the Millbury stream gage. These data may be compared to the volume entering the river from Upper Blackstone during the same time periods. This difference represents the “natural streamflow” in the river at the Millbury gage. On a volume basis the effluent comprised approximately 34% of the streamflow in the river at Millbury over the period June – August in 2018.

This contribution can be examined on a daily basis, and Table 15 lists calculated estimates of the relative contribution of Upper Blackstone effluent flow to the streamflow measured at the Millbury gage on each of the 2018 sampling days. On most sampling days, this calculated value was below 30%; however, in June (49%) and May (35%), the estimated contribution of effluent discharge to river streamflow was greater.

Table 14: Relative contributions by volume on sampling days 2018

Sampling Date	Upper Blackstone % of Millbury streamflow
4/25/2018	27%
5/24/2018	35%
6/20/2018	49%
7/18/2018	14%
8/16/2018	22%
9/12/2018	24%
10/24/2018	30%
11/7/2018	18%

6.0 Sampling Season Data for 2018

Routine monitoring was conducted monthly from April to October for nutrients and chlorophyll-a at nine in-stream locations. Nutrient sampling was conducted monthly, regardless of streamflow conditions. Thus, looking at the data as a whole can mask improvements in the river due to point load reductions, which have a greater impact during low streamflow conditions. In order to provide a more

focused look at the impact of plant facility improvements on river water quality, the data are presented in terms of both concentration and load. River streamflow data for each sampling date were available from two USGS gaging sites, located at Millbury, MA (USGS 01109730) and Woonsocket, RI (USGS 01112500). Observed sampling day streamflows at these locations were used to provide streamflow estimates for load calculations at each sampling location based on the simulation results from the HSPF model developed for the Blackstone River (UMass and CDM Smith, 2008). These calculated streamflows are generally comparable to taking area-weighted estimates. Further analyses were conducted by looking at streamflow-adjusted concentrations.

Periphyton sampling was conducted three times during the summer. The four sampling locations were all located in Massachusetts, including one upstream of the confluence with Upper Blackstone's effluent channel, and three downstream locations. Periphyton scrapings were analyzed for chlorophyll-a content as well as periphyton species and area coverage. While periphyton chlorophyll-a data are presented in this report, a complete report on periphyton data is available under separate cover from Normandeau Associates (Normandeau, 2019).

In this section, streamflow conditions on routine sampling days are first described. River water quality conditions are then summarized by presenting the TP, TN, chlorophyll-a, and periphyton results. In-stream data are reported as ppb in this report. To compare with effluent data from the previous sections, note that $1 \text{ mg/L} = 1000 \text{ ppb} = 1 \text{ } \mu\text{g/L}$.

6.1 Flow Conditions on Routine Sampling Days

Section 4.2 presented a discussion of monthly and day of sampling conditions in a general historical context with regards to streamflow. It is also of interest to directly compare streamflow conditions on sampling days. Data were subdivided into samples collected during low streamflow, average, and high streamflow conditions. Low streamflow conditions were defined as less than half of the average streamflow in a reach, high streamflow conditions were defined as greater than 1.5 times the average streamflow in a reach, and all other streamflows were categorized as average. Because distinct streamflow condition categories exist for each reach, it is possible for sampling sites along the river to have different streamflow categories for a given sampling date as effects of precipitation-runoff processes move through the basin. In such instances, sites close to the threshold were re-categorized to reflect the dominant streamflow condition category for the sampling date. Table 16 summarizes how the sampling events since 2012 were categorized by streamflow condition. Calculated mean streamflow at each sampling site is shown on Figure 18. The data for 2018 are shown as a purple line with round symbols. The historical data are drawn from data collected by MassDEP, USGS, RIDEM, URI/NBC, and UMass from 1997 – 2011.

The highest streamflow conditions on sampling days since routine monitoring began in 2012 occurred during the 2018 sampling season. In the subsequent discussion, TP and TN concentration data are similarly summarized based on streamflow condition for comparison against data from other time periods.

Table 15: Summary of streamflow conditions during routine monitoring
(L = low, A = average, H = high)

Year	April	May	June	July	August	September	October	November
2012	L	A	A	L	L	L	A/ L ¹	A
2013	A	L / A ¹	H	L	L	L	L	L
2014	A	A	L	L	L	L	L	L
2015	A	L	A	L	L	L	L	L
2016	A	L	L	L	L	L	L	L
2017	H/A ¹	A	H	L	L	L	A/ H / A ¹	A
2018	H	A	L	A/H ¹	A	A	A	H

¹ streamflow conditions on sampling dates during these months were too disparate to be classified as the same condition; variable conditions listed from downstream (left) to upstream (right)

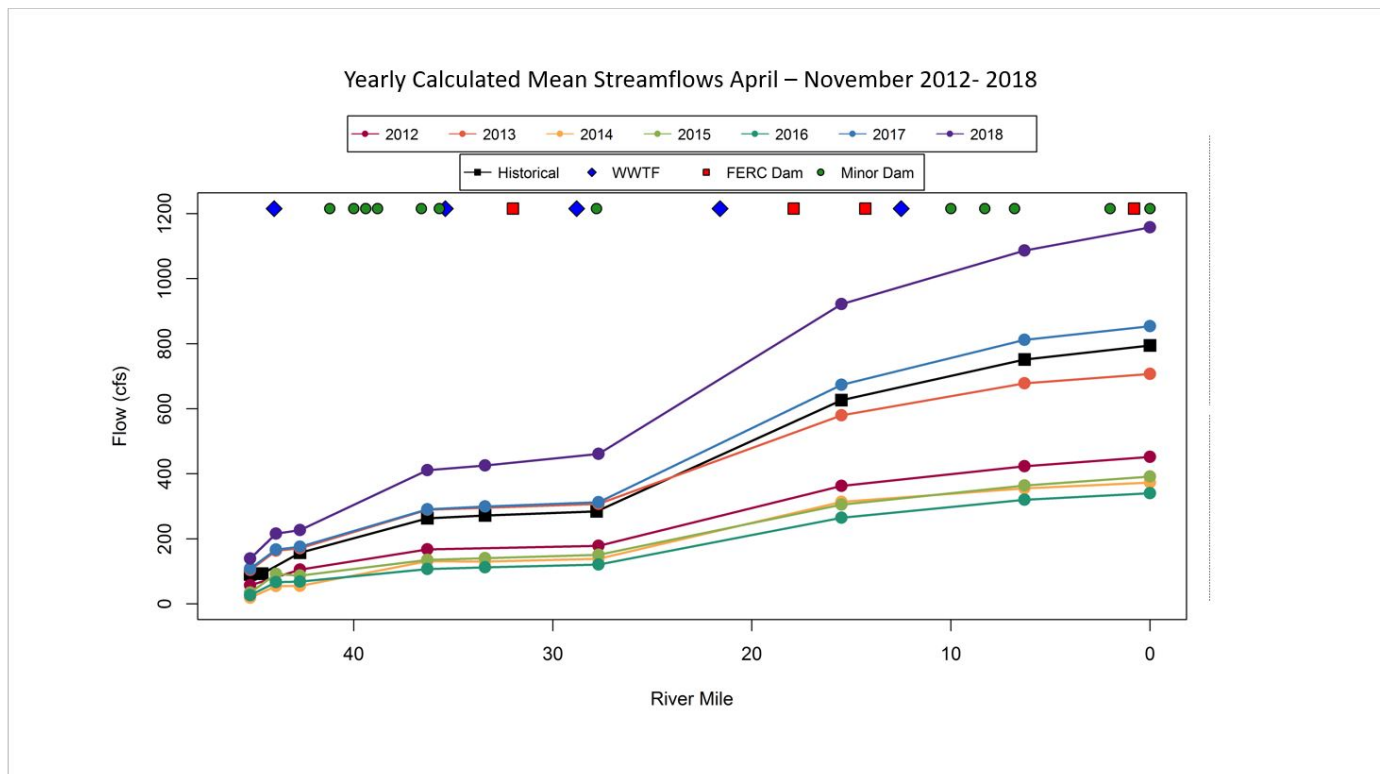


Figure 18: Comparison of average calculated streamflow conditions on sampling date by year

Historical data covers years 1997-2011

6.2 Routine Monitoring Data

Sampling data results for TP, TN, and chlorophyll-a are summarized in sections 6.2.1, 6.2.2, and 6.2.3, respectively, using a consistent series of plots and analyses. Sufficient data are now available to conduct a more robust trend analysis based on streamflow-weighted concentration data. Streamflow-weighted concentration trend analyses are presented for TP, TN, and chlorophyll-a in Section 6.1.4. Additional information on nitrogen and phosphorus subspecies, as well as laboratory QAQC data, is available upon request.

6.2.1. *Total Phosphorus*

Available TP concentration data for the Blackstone River since 1996 are summarized in Figure 19 using boxplots. Data for all sampling locations are grouped by year. While, in general, the same sample locations were surveyed 2012-2018, the concentrations from 1996 – 2008 period represent results of multiple individual sampling programs carried by Upper Blackstone and others and in many cases at different sampling locations. As explained previously, the median of the data for each year is shown by the dark bar in each box, the lower and upper quartile ($\pm 25\%$ around median) of the observed data are shown by the body of the box, the whiskers identify 1.5 times the interquartile range above the upper quartile and below the lower quartile of the data, and the small black circles above and below the whiskers represent observed data that are statistically considered “outliers.”

TP concentrations since Upper Blackstone upgrades came online in 2009 are less variable and are lower than historical concentrations. Upgrades to the plant have translated into improved river conditions. The TP concentrations observed during routine sampling in 2018 were characterized by the smallest interquartile range and median value compared to earlier sampling years, and outliers were low compared to 2017. The TP concentration data points identified as outliers in 2018 on Figure 20 are for W1779 and RSML in July and UBWPAD in June. The July routine sampling occurred following 2.67 inches of rain on the day prior (Table 6). The other identified outlier was for the UBWPAD2 sampling site and occurred during the June 20, 2018 routine sampling during a period of falling streamflows. The streamflow on that day at the USGS Millbury gage was only 61 cfs.

The mean summer (June – September) TP concentration at each sampling location in the Blackstone River is shown on Figure 21 for sampling data collected since 2012. Data are clustered by sampling site, plotted from the headwaters (left) to the outlet (right). Each year is shown as a different color, with 2018 in dark blue. At most sampling locations, average TP concentrations in 2018 were about average compared to other sampling years, though higher at sites RMSL and R116 (and slightly higher at UBWPAD2).

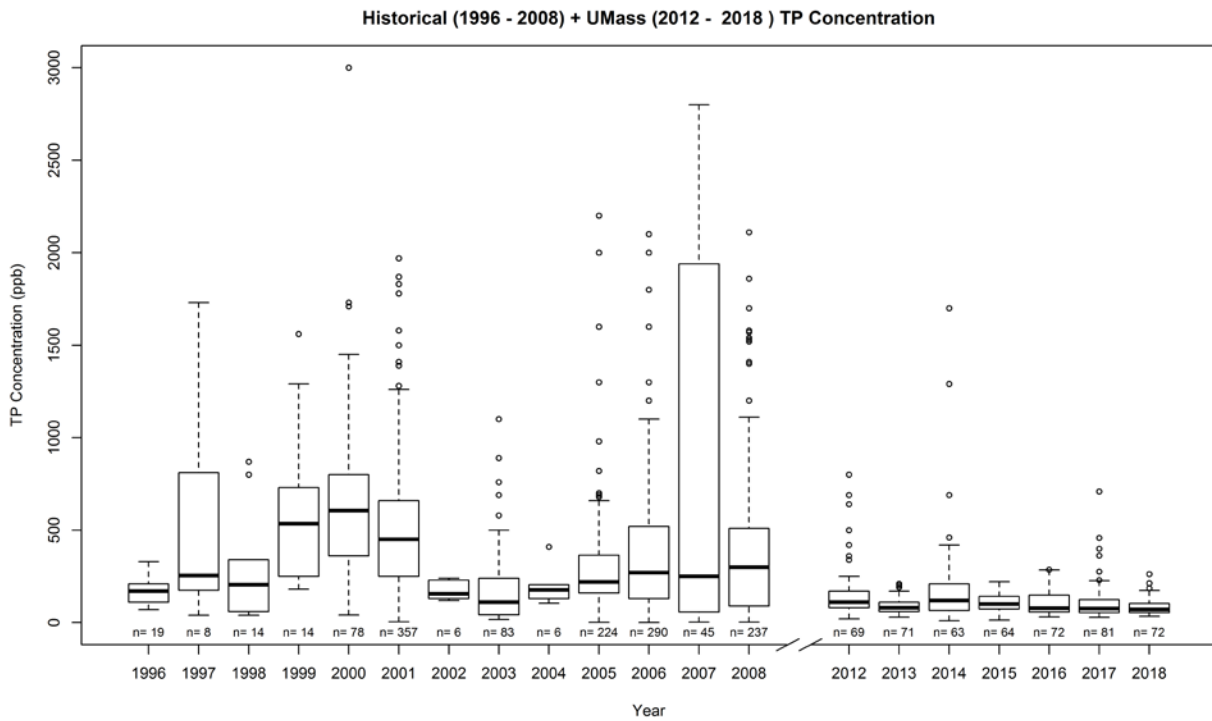


Figure 19: TP concentrations observed in the river 1996 – 2008 and 2012 – 2018

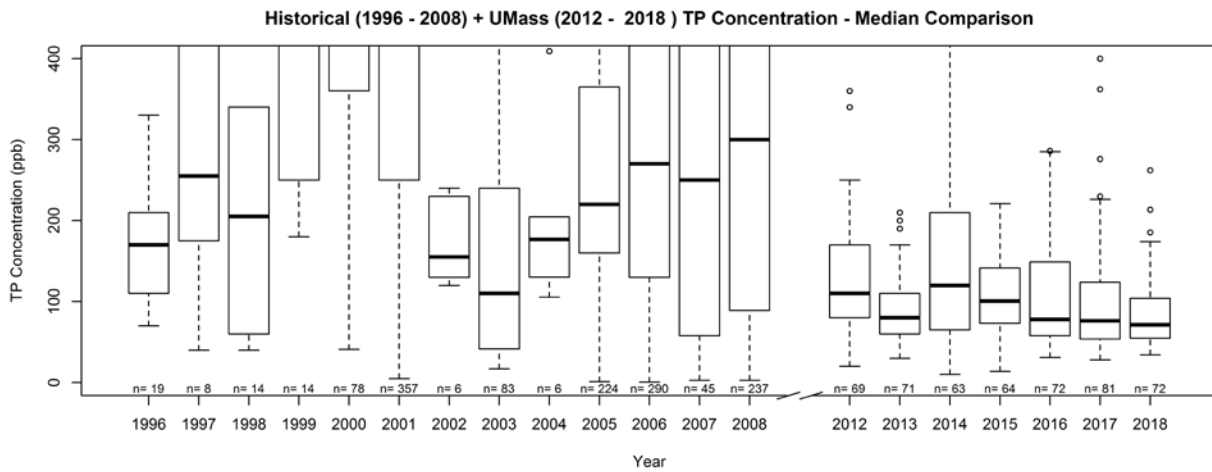


Figure 20: TP concentrations observed in the river 1996 – 2008 and 2012 – 2018

(Y-axis cut off at 400 ppb to make later years easier to read)

<i>TP (ppb)</i>	<i>W0680</i>	<i>UBWPAD 2</i>	<i>W1258</i>	<i>W1242</i>	<i>W0767</i>	<i>W1779</i>	<i>RMSL</i>	<i>R116</i>	<i>RMSD</i>
2012	76.7	115.0	260.0	178.0	178.0	216.0	162.5	117.5	90.0
2013	52.5	87.5	85.0	82.5	NA	145.0	87.5	72.5	70.0
2014	99.8	600.3	453.3	403.3	246.0	264.0	215.3	172.5	98.0
2015	71.0	130.3	133.0	80.8	105.5	137.3	86.0	76.0	82.3
2016	59.8	230.5	163.3	161.3	214.5	221.0	76.0	70.3	128.8
2017	55.0	152.3	131.4	111.6	157.2	166.1	82.7	74.2	90.5
2018	59.8	155.5	94.2	97.1	126.1	154.2	136.5	98.6	86.8

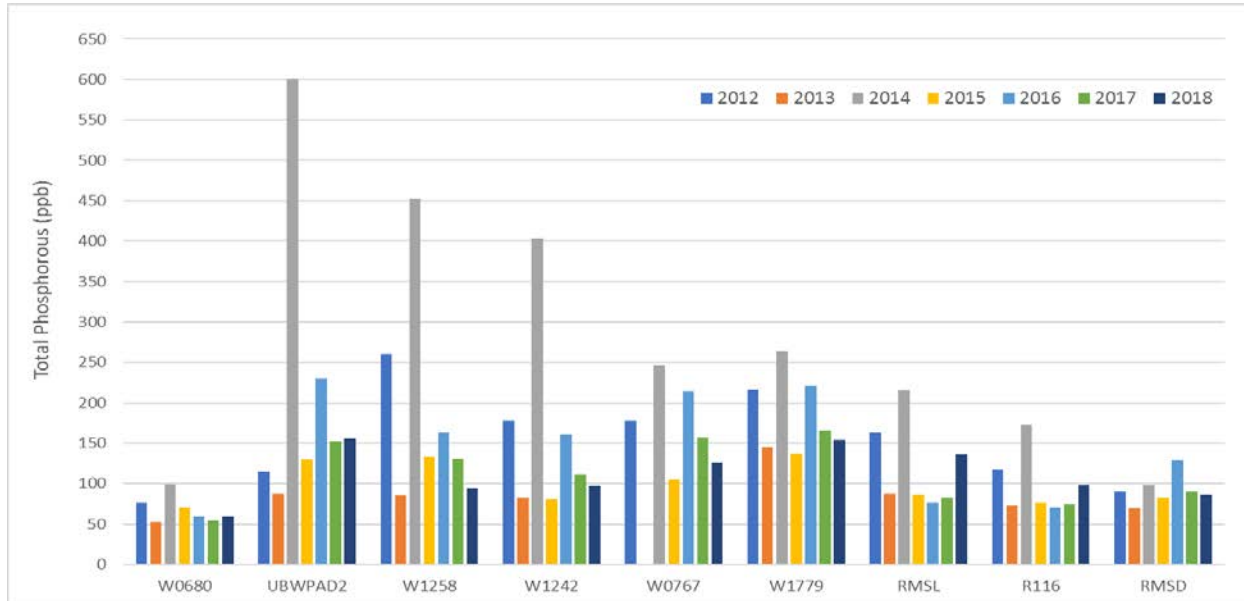


Figure 21: Mean summer (June – September) TP concentrations observed by site since 2012

The full range of TP concentrations observed at each site since 2012 is summarized in Figure 22, with sites plotted from the headwaters (left) to outlet (right) as above. Average concentrations in 2018 are indicated by blue diamonds. It should be noted that data collection at the UBWPAD site occurred from 2012 – 2013, when the site was moved to a better-mixed location downstream, UBWPAD2, where data collection started in 2013 and continues to this day. Average TP concentrations in 2018 fell within the interquartile range of values observed since 2012 at all sampling sites but were at the lower quartile limit for sampling locations W1258, W0767, and W1779.

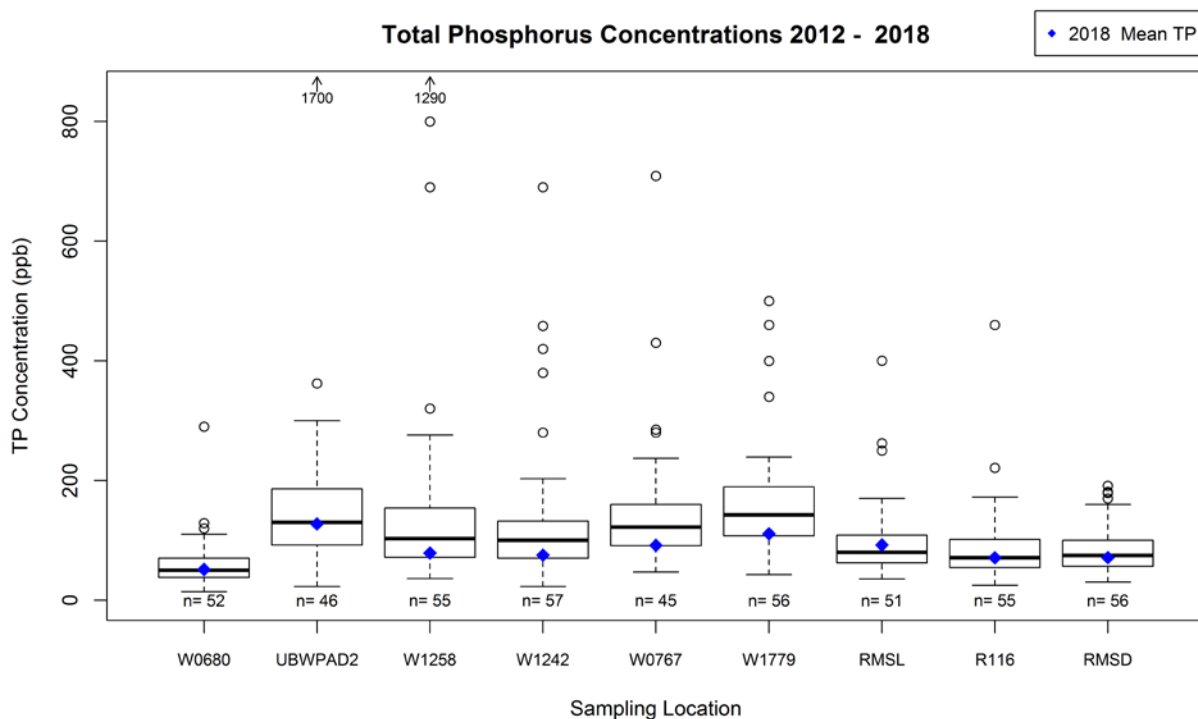


Figure 22: TP concentrations by site from 2012 - 2018

Average TP concentrations in 2012 – 2018 are compared to historical in Figure 23, plotted against river mile with headwater locations on the left (river mile 50) and the outlet on the right (river mile 0), analogous to the earlier plots where site name is indicated instead of river mile. The average low streamflow TP concentrations at the three RI sites were the lowest in 2017 since routine sampling began in 2012 and remained low in 2018. For the MA sampling locations, 2018 means were the lowest since 2012, and lower than all historical levels as well. Upper Blackstone's efforts to reduce effluent TP translate into reductions in stream TP levels during dry and wet conditions.

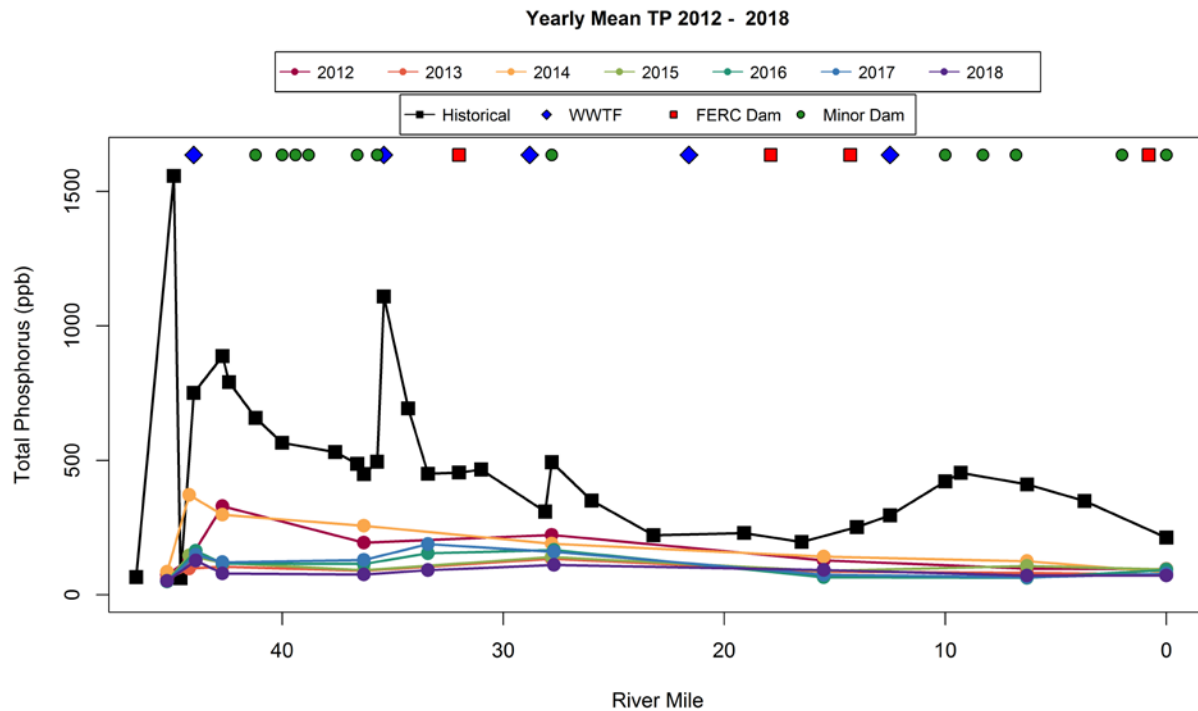


Figure 23: Along stream TP concentrations

Note that historical data are means for sites with >8 data points

Estimates of mass flux (or load) based on the observed concentrations and flow estimates provide more relevant information on the benefits of the plant upgrades for receiving waters, such as Narragansett Bay. Estimates of TP loads since 1996 in the Blackstone River are summarized in Figure 24 (zoomed in Figure 25). Data for all sampling locations along the river are grouped by year. There is an even larger reduction in TP load (versus concentration) in the river since Upper Blackstone upgrades came online in 2009. Average riverine loads since routine sampling started in 2012 are less variable and overall lower, though the median TP load is slightly higher in 2018 than in the past few years (most likely due to the higher water volumes this year). Calculated TP loads observed at each site since 2012 are summarized in Figure 26, with data for 2018 highlighted as before. High streamflows resulted in the 2018 average TP load (blue diamonds) falling above the interquartile range at all sampling locations. The greater river load is also notable in Figure 24 and Figure. Along stream average TP loads, Figure 26 and Figure 27, further illustrate the impact of streamflow conditions on load estimates. While TP concentrations were lowest in 2018, 2018 loads were among the highest since 2012, reflecting the high streamflows in the Blackstone River this year.

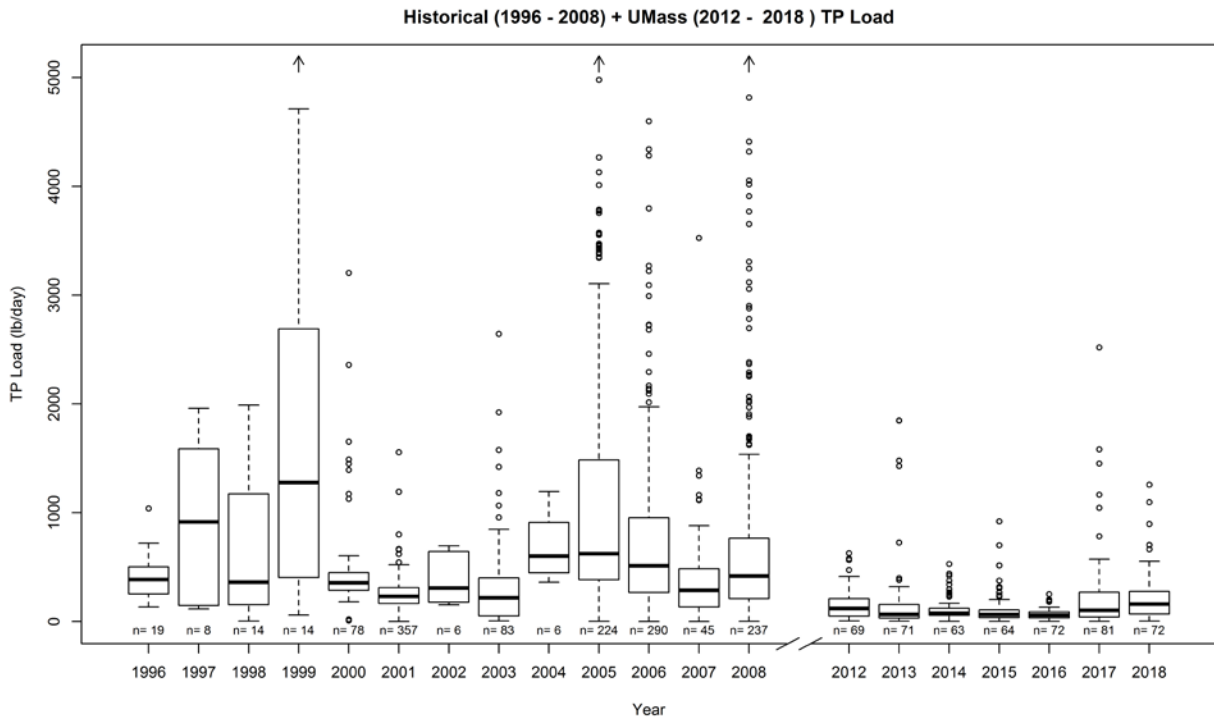


Figure 24: Summary of TP loads observed in the river 1996 – 2008 and 2012 – 2018
(note, additional extreme outliers not shown, as indicated by arrows)

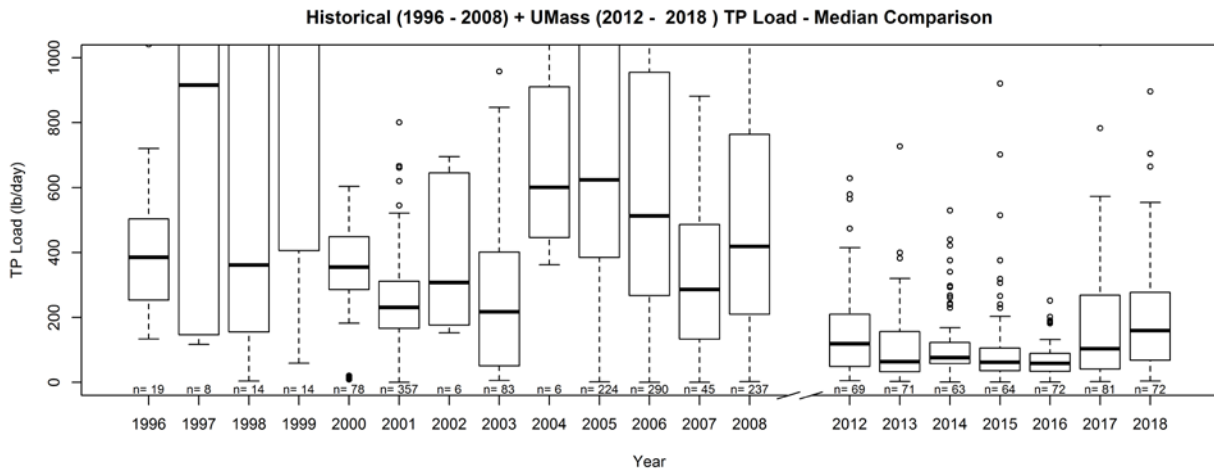


Figure 25: Summary of calculated TP loads based on streamflow estimates and reported concentrations for sampling days, 1996 – 2008 and 2012 – 2018

(Y-Axis truncated at 1500 lb/day to clarify differences in later years)

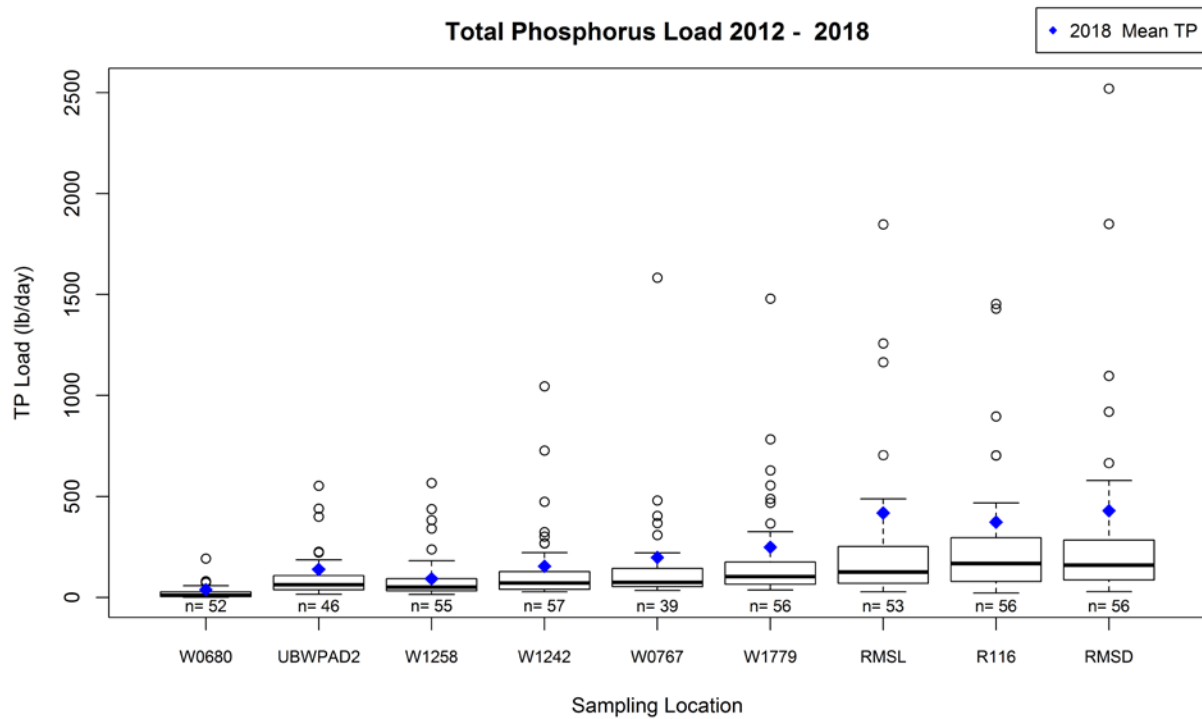


Figure 26: TP load data by site from 2012 - 2018

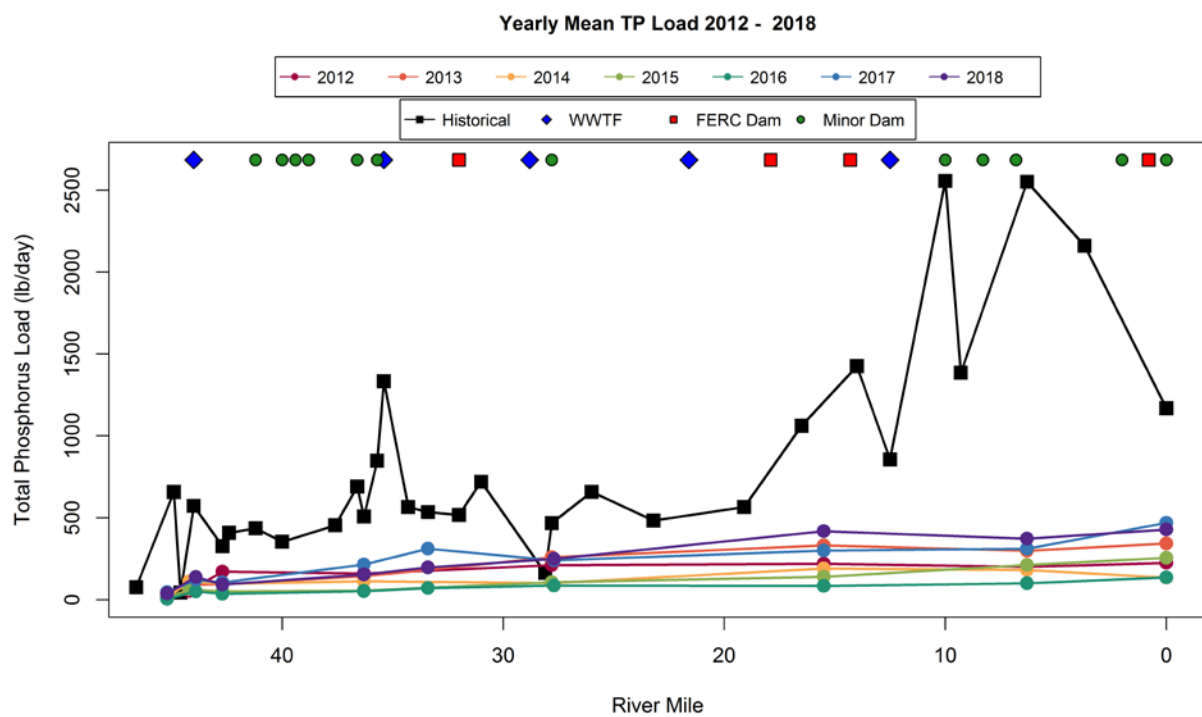


Figure 27: Mean TP Loads on Sampling Dates

In 2018, total phosphorus concentrations in the Blackstone River were below the MassDEP 2016 CALM screening threshold of 100 ppb 69% of the time, Figure 28. TP concentrations at UPWPAD2, the sampling site below the confluence with UB discharge, were below the MassDEP threshold in only 1 of 8 2018 samples (13%). TP concentrations were below MassDEP guidance values on 50% of the sampling days at W1779 at river mile 27.8; all other sites were below MassDEP guidance values at least 63% of the time.

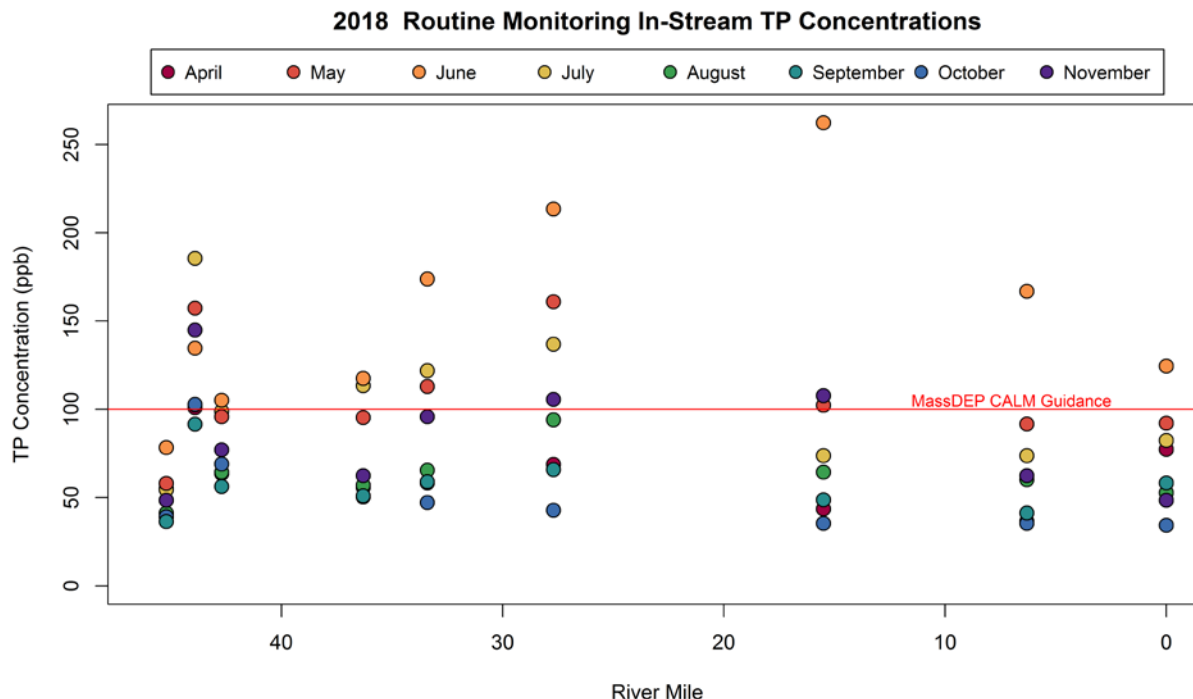


Figure 28: 2018 TP concentrations compared with MassDEP CALM guidance

6.2.2. Total Nitrogen

Available TN concentration data for the Blackstone River since 1996 are summarized in Figure 29. The 2008 permit limits reduced TN effluent concentrations by 40% during summer months. The impact of the new limits and associated plant upgrades which came online in 2009 is evident. The overall variability of in-stream concentrations has been reduced even though the median TN concentration has not changed significantly from pre- to post-upgrade. The TN concentration data points identified as outliers in 2018 on Figure 29 are associated with the falling limb of an event (6/20/18 and 10/24/18) during relatively low river flows with effluent contributing >30% of the streamflow. Two of the outliers are samples from the UBWPAD2 site (just downstream of the river confluence with the plant's effluent discharge channel) and the other is from the W1258 site (the next site downstream).

Since 2014, there has been a steady reduction in both the span and magnitude of the interquartile range of TN concentrations observed in the river. The upper quartile and median of observed TN concentrations in 2018 continue on this downward trend. Trends in TN are discussed further below.

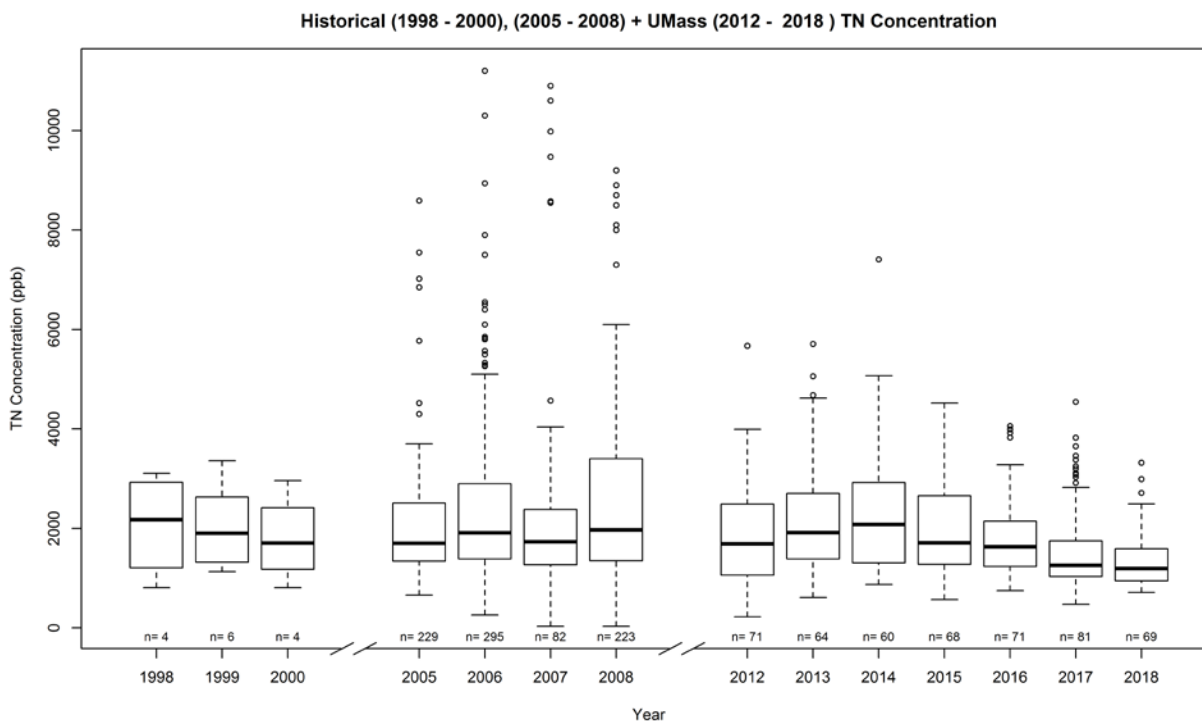


Figure 29: Summary of TN concentrations observed in the river, 1998 – 2000, 2005 – 2008, and 2012 – 2018

The mean summer (June – September) TN concentration at each sampling location in the Blackstone River is shown on Figure 30 for sampling data collected since 2012. Data are clustered by sampling site, plotted from the headwaters (left) to the outlet (right). Each year is shown as a different color, with 2017 in green. It should be noted that the apparent increase in mean summer TN concentrations at sampling site UBWPAD2, downstream of the confluence with Upper Blackstone’s effluent channel, from 2012 to 2013 is an artifact of relocation of the site further downstream to a more well-mixed location in 2013. The original site, included here for the year 2012, had lower values because it was not appropriately capturing the impacts of the effluent. In addition, site W0767 was not sampled in 2013. Mean summer TN concentrations observed in 2018 were lower than previous years at all sites except for the Rhode Island sites (Figure 30).

The full range of TN concentrations observed at each site since 2012 is summarized in Figure 31, with sites plotted from the headwaters (left) to outlet (right) as above.

Data for both the original UBWPAD site (2012 – 2013) and new site, UBWPAD2 (where data collection started in 2013 and continues) are included. Average TN concentrations in 2018 (depicted with blue diamonds) fell within or below the interquartile range of values observed since 2012 at all sampling

sites, and in fact the average TN concentration for most locations fell at or below the lower quartile (exceptions are UBWPAD2 and RMSL). TN concentration was always less in 2018 than the median of the data collected since 2012.

Average TN in 2012 – 2018 are compared to historical concentrations in Figure 32, plotted against river mile with headwater locations on the left (river mile 50) and the outlet on the right (river mile 0). A solid purple line with round symbol indicates data for 2018. The concentration data for 2018 is the lowest observed so far at all sites except the Rhode Island sites, where 2018 values are very close to the lowest values (seen in 2017). TN levels in the river have steadily decreased since 2012.

TN (ppb)	W0680	UBWPAD2	W1258	W1242	W0767	W1779	RMSL	R116	RMSD
2012	983.3	1127.5	2976.0	2366.0	2366.0	2184.0	1368.0	1432.0	1264.0
2013	1102.5	2440.0	2820.0	2225.0	NA	2192.5	1440.0	1497.5	1507.5
2014	1433.3	3590.0	3292.5	2763.8	3041.3	2399.8	1990.0	1801.3	1473.5
2015	1068.8	2993.3	2791.5	2083.8	2466.5	2018.0	1352.8	1653.8	1383.5
2016	1087.5	3120.0	2925.0	2420.0	2742.5	2332.5	1427.5	1407.5	1500.0
2017	1078.8	2920.4	2628.8	2152.6	2201.4	1830.4	1154.2	1126.8	1134.0
2018	820.3	2289.5	1705.5	1297.5	950.5	1673.8	1508.3	1371.0	1143.3

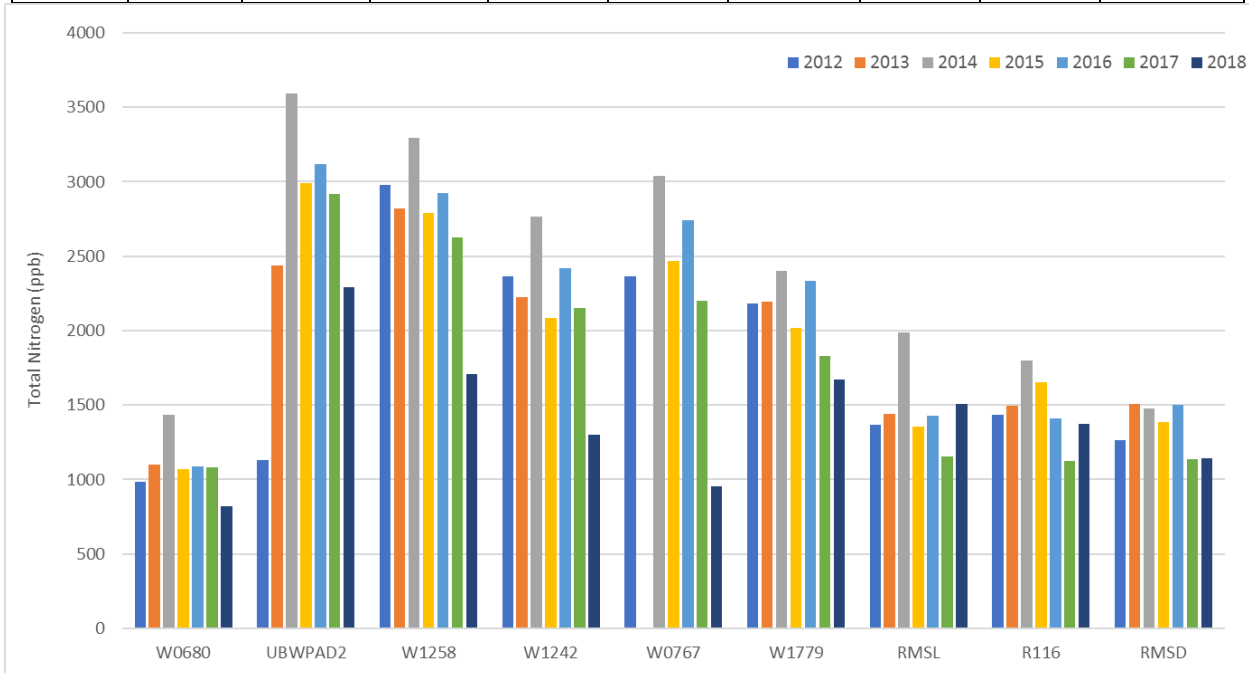


Figure 30: Mean summer (June – September) TN concentrations observed by site since 2012

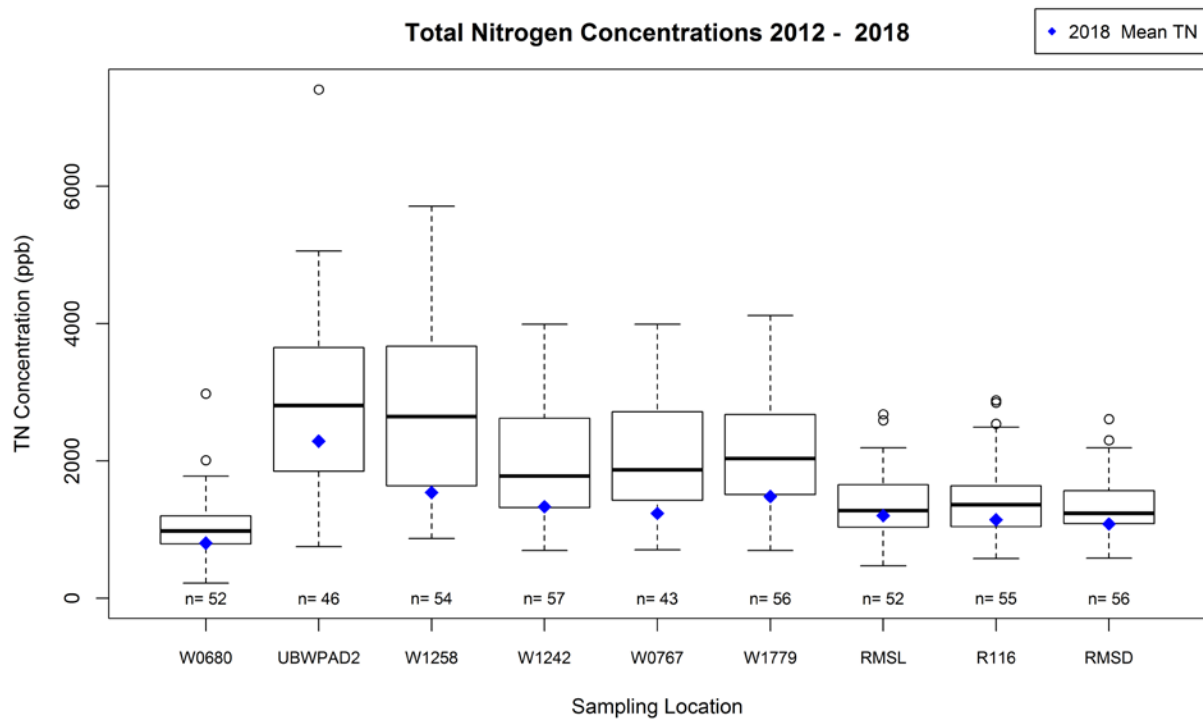


Figure 31: TN concentrations by sampling location from 2012 - 2018

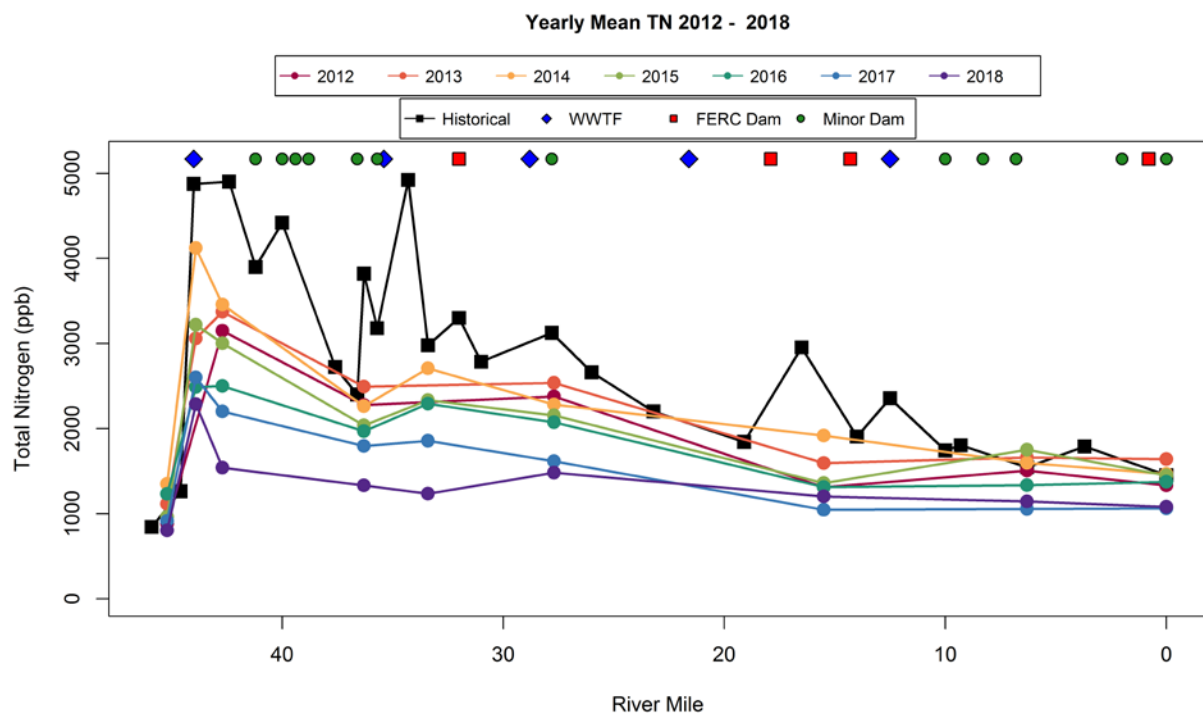


Figure 32: Along stream TN concentrations

Estimates of TN loads since 1996 in the Blackstone River are summarized in Figure 32. Data for all sampling locations along the river are grouped by year. The TN load data suggest a decrease in TN loads transported by the river since Upper Blackstone's upgrades were online in 2009. The interquartile range of observed TN loads from 2012 through 2018 are smaller than from 1999 through 2008. In 2018, TN load increases compared to recent years, which is likely attributable to above average Blackstone River streamflow.

The full range of TN loads observed at each site since 2012 is summarized in Figure 33, with data for 2018 highlighted as before. Loads in 2018 are clearly higher than they have been since 2012, falling on or above the upper quartile of observed values at every site (including upstream of the Upper Blackstone). While the interquartile range (body of box) of TN concentrations tended to decrease downstream (Figure 31), the interquartile range of TN loads (Figure 34) increased in the downstream direction, reflecting the impact of streamflow on the load estimate. This increase is more pronounced for TN than observed for TP. As the streamflow estimates utilized in the load calculation are the same for TN as for TP, the underlying cause is likely due to differences in the variability of TN and TP concentration in the downstream direction.

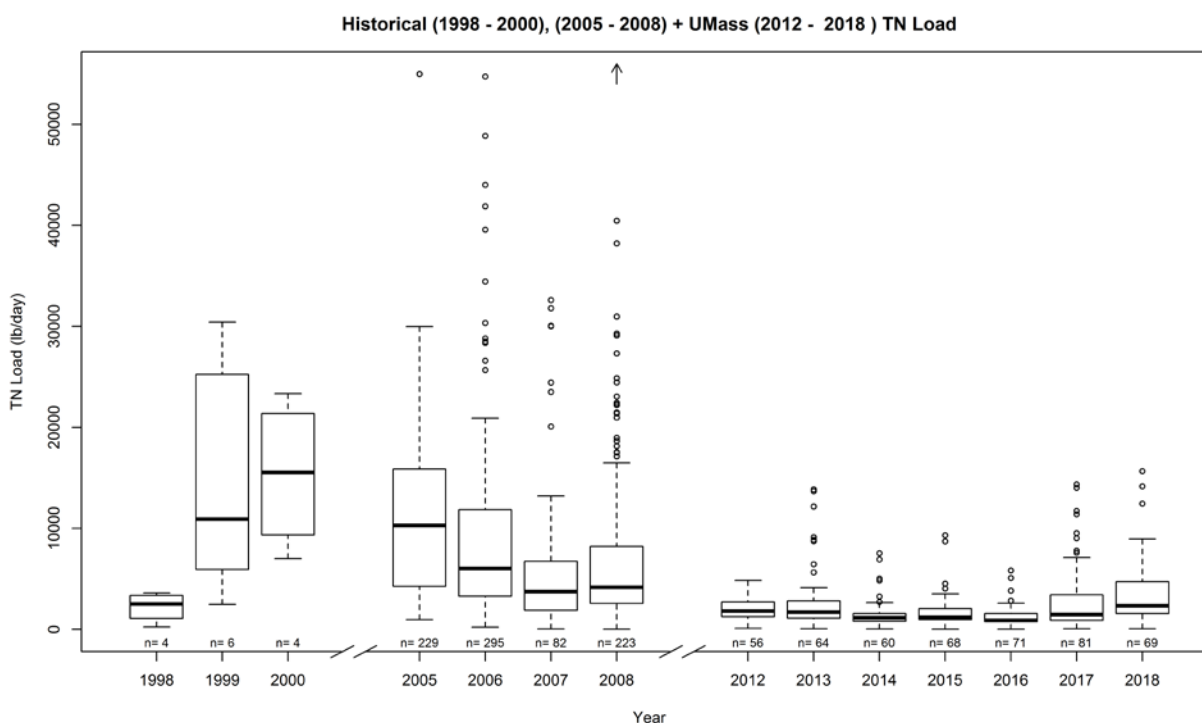


Figure 33: TN loads observed in the river 1998 – 2000, 2005 – 2008, and 2012 – 2018

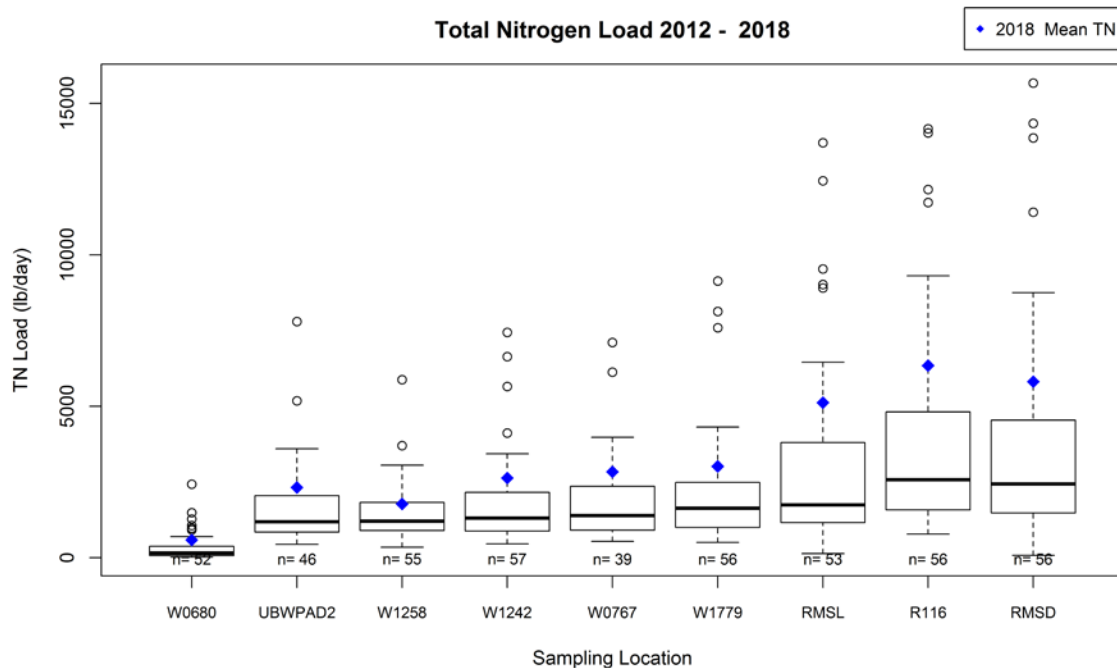


Figure 35: TN load data by sampling location 2012 - 2018

Along stream average TN loads, as summarized by year and site on Figure 35, show a departure in 2018 from recent years improvements in the river and for receiving waters. The average TN load in 2018, while clearly lower than that of historic data, is the highest at all sites since 2012.

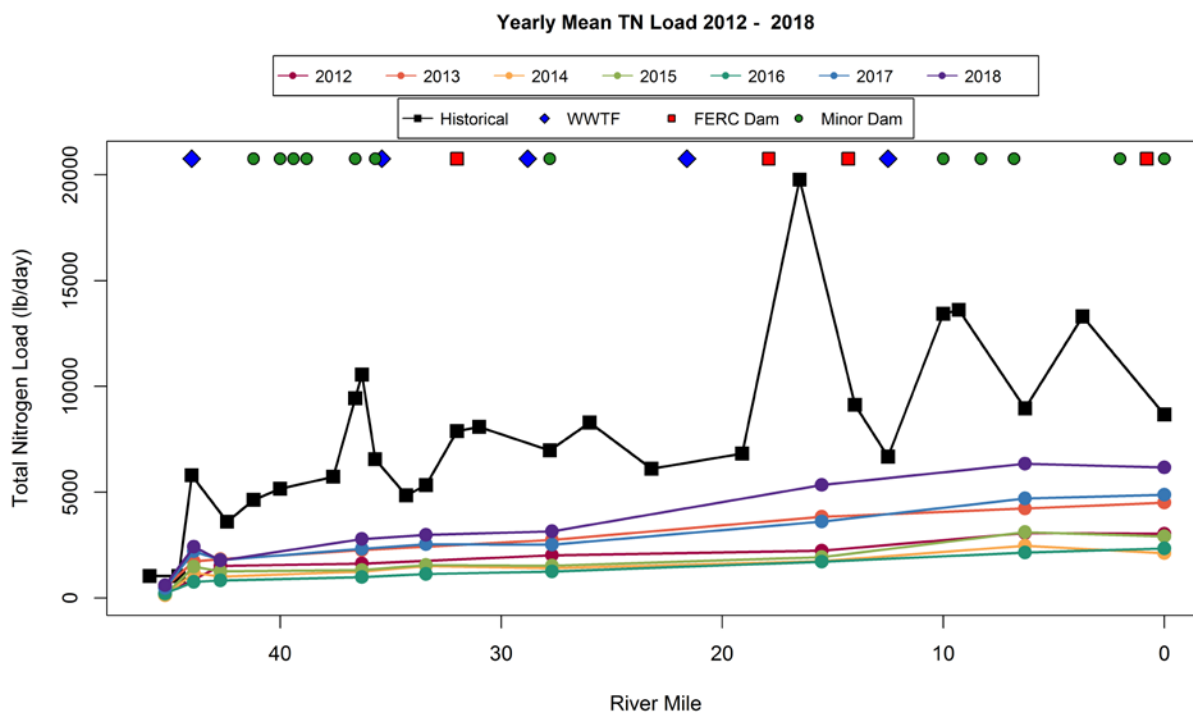


Figure 34: Along stream TN loads

6.2.3. Chlorophyll-a

Chlorophyll-a concentrations observed during the summer months (June – September) since 2012 are summarized by year in Figure 36. Overall, summertime chlorophyll-a levels in 2018 exhibited an interquartile range comparable to that observed in 2016. The average spread in values is comparable to that of previous years, though the median is higher than in all previous years except 2014 (the year of the plant upsets).

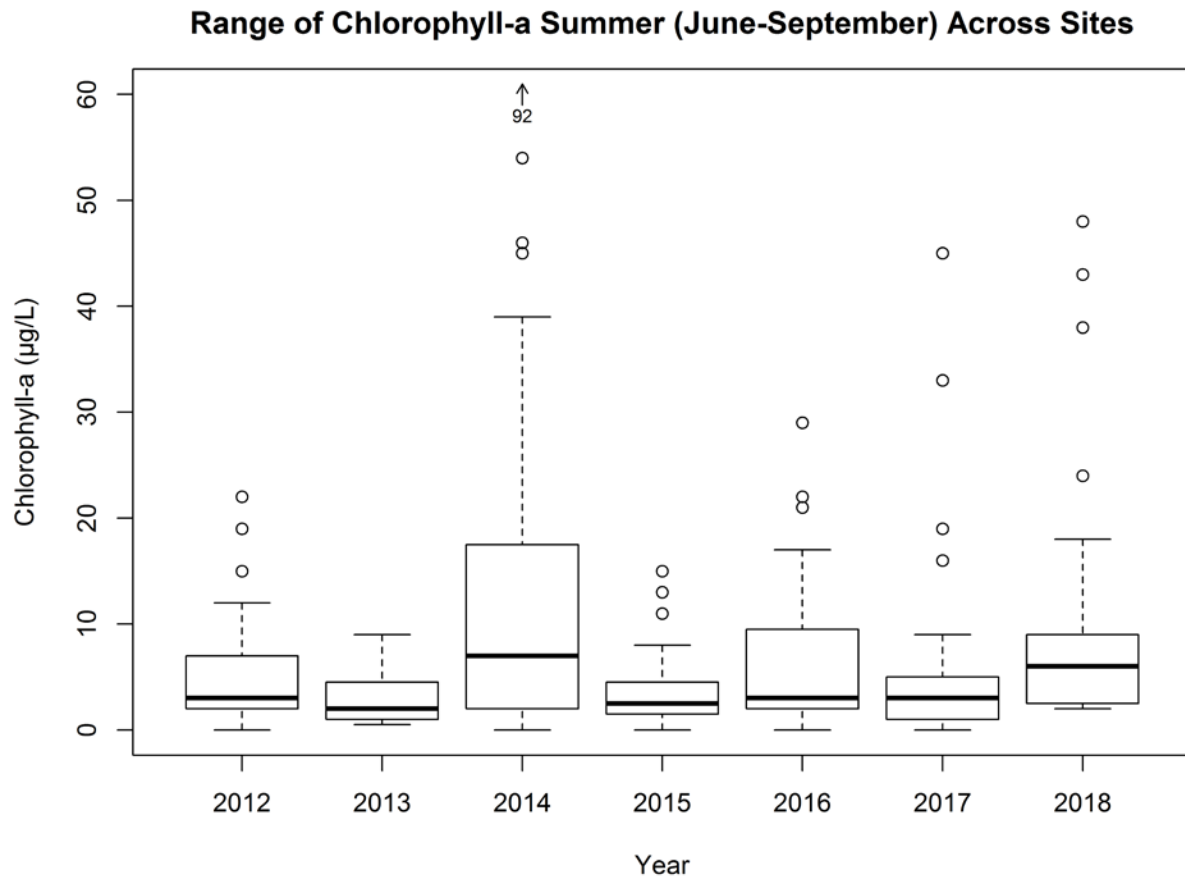


Figure 36: Chlorophyll-a concentrations observed during June, July, August, and September since 2012, summarized by year

The same data are summarized by site in Figure 37 for just the months of June – September, plotted from the headwaters (left) to the outlet (right). At individual sampling locations, mean summer concentrations in 2018 (blue diamonds) are higher than the median for all years except at W0767 and W1779. At the three most downstream sites, the mean values are much higher, exceeding even the upper quartile.

The mean summer (June – September) chlorophyll-a concentrations for each year and sampling location on the Blackstone River are also summarized on Figure 38. Data are clustered by sampling site, again plotted from the headwaters (left) to the outlet (right). In 2018, summertime chlorophyll-a levels were higher than historical data at all sites except at W0767 and W1779. In RI (sampling sites RMSL, R116 and

RMSD) mean summer levels of chlorophyll-a were much higher than last year, especially at the two most downstream sites.

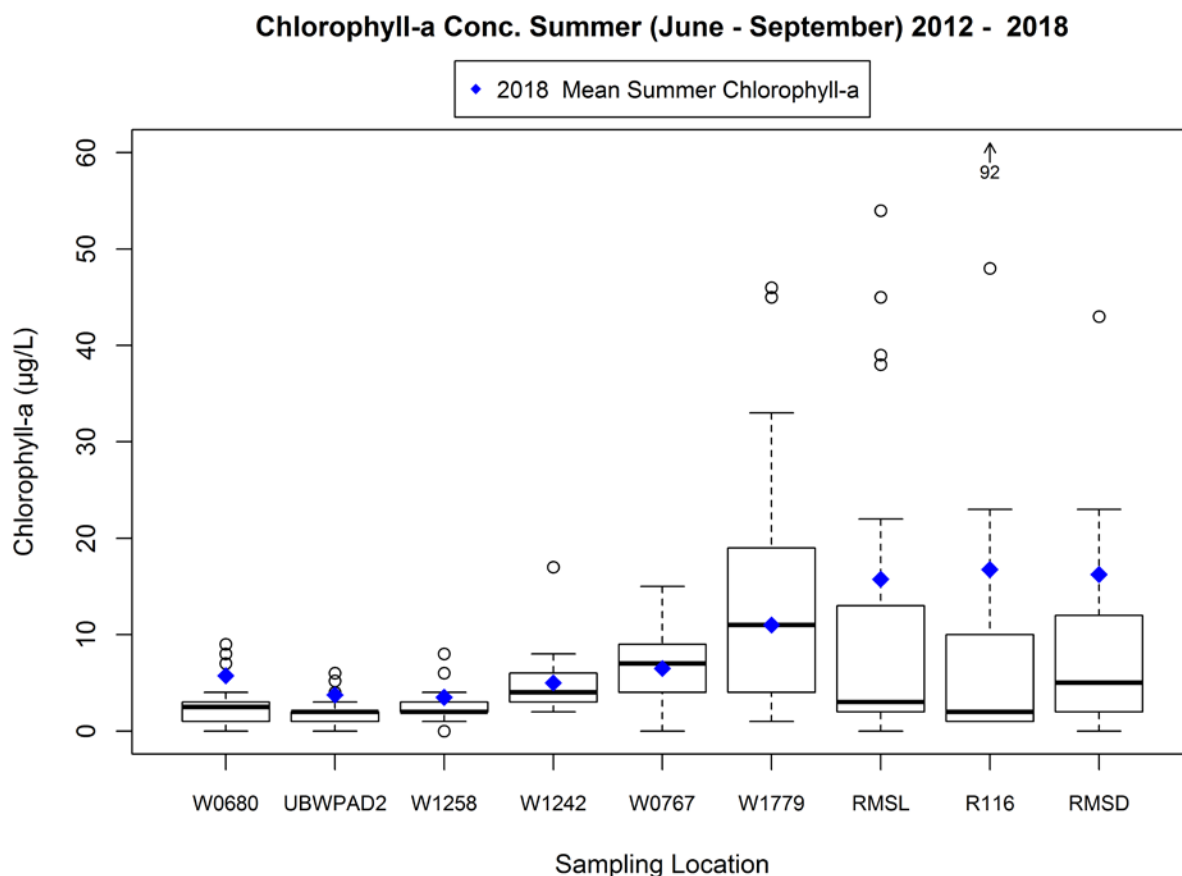


Figure 37: Chlorophyll-a concentrations observed during June, July, August, and September since 2012, summarized by sampling location

The average chlorophyll-a concentration data for 2018, Figure 38, though highest at the upper portion of the river, fall in the middle range starting at W1242 site and increase progressively toward the mouth of the river. The same trend is observed when looking at total chlorophyll data (Figure 39).

<i>Chl-a</i> ($\mu\text{g/L}$)	W0680	UBWPAD2	W1258	W1242	W0767	W1779	RMSL	R116	RMSD
2012	2.0	NA	1.3	3.5	1.3	7.8	7.5	7.5	9.3
2013	3.3	2.2	3.0	3.0	NA	3.3	3.0	3.3	4.0
2014	1.0	1.3	2.0	8.8	8.0	28.8	26.8	33.5	18.0
2015	2.0	1.3	2.0	3.3	4.5	7.8	7.0	2.5	3.0
2016	4.0	2.3	2.5	6.0	10.3	22.0	2.3	5.0	7.5
2017	3.6	1.6	2.0	4.6	7.8	17.8	10.4	1.4	1.2
2018	5.8	3.8	3.5	5.0	6.5	11.0	15.8	16.8	16.3

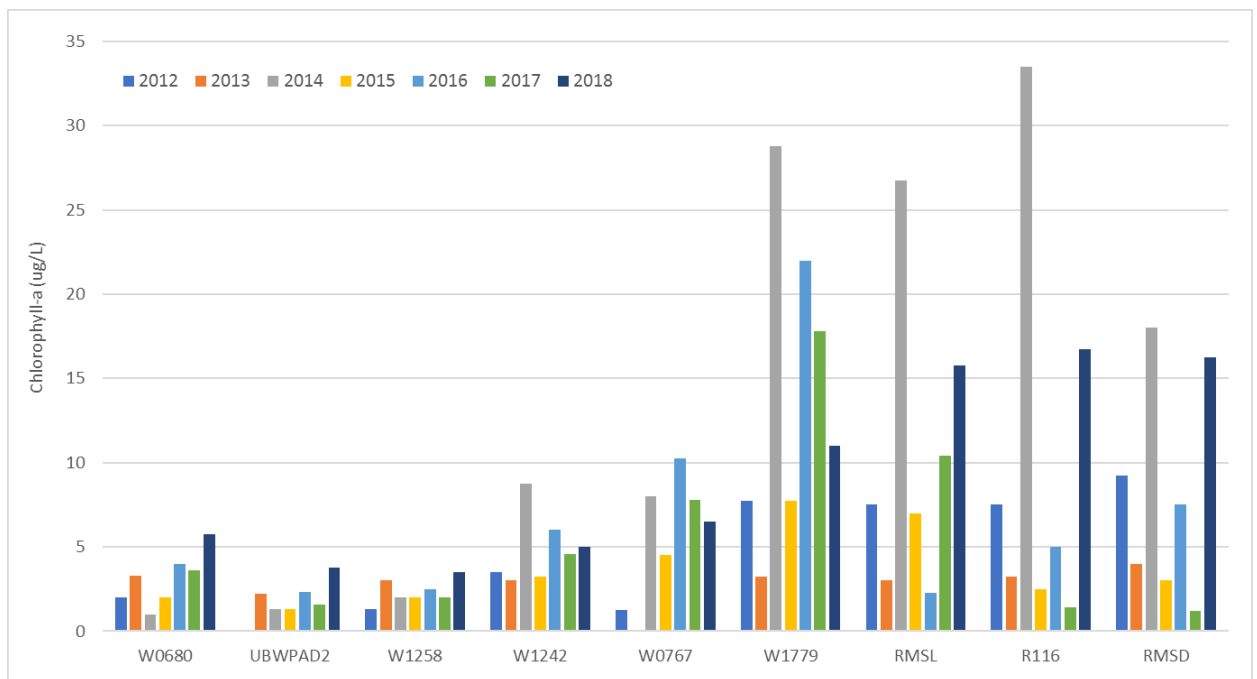


Figure 38: Mean summer (June – September) chlorophyll-a concentrations by site since 2012

The maximum chlorophyll-a concentrations observed at each sampling location follow a similar trend in 2018 compared to historical data, though the level drops at the most downstream site (Figure 39). 2018 levels increase steadily toward the mouth of the river, a trend that was not evident in previous years.

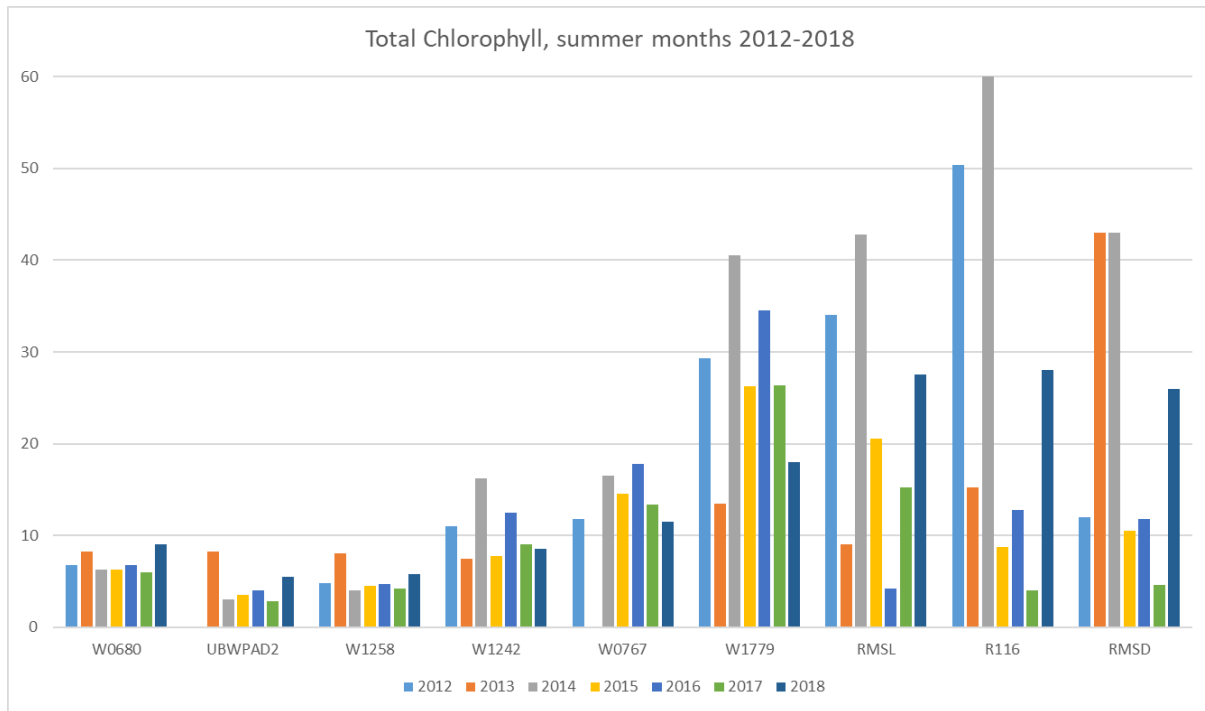


Figure 39: Mean summer (June – September) total chlorophyll concentrations by site since 2012

Average and maximum chlorophyll-a concentrations during low streamflows in 2012 – 2018 are compared to historical data during similar conditions in Figures 40 and 41, respectively. The data are again plotted from the headwaters (left) to the outlet (right). WWTF effluent discharge points along the river are indicated by the blue triangles along the top of the graph, while the locations of FERC dams are indicated by the red squares. The location of minor dams along the river are indicated by green circles. A solid black line with square symbols indicates historical data (between 2000-2006). 2018 data is graphed with a purple line. The highest average and maximum chlorophyll-a concentrations observed since 2012 at most sampling locations occurred in 2014.

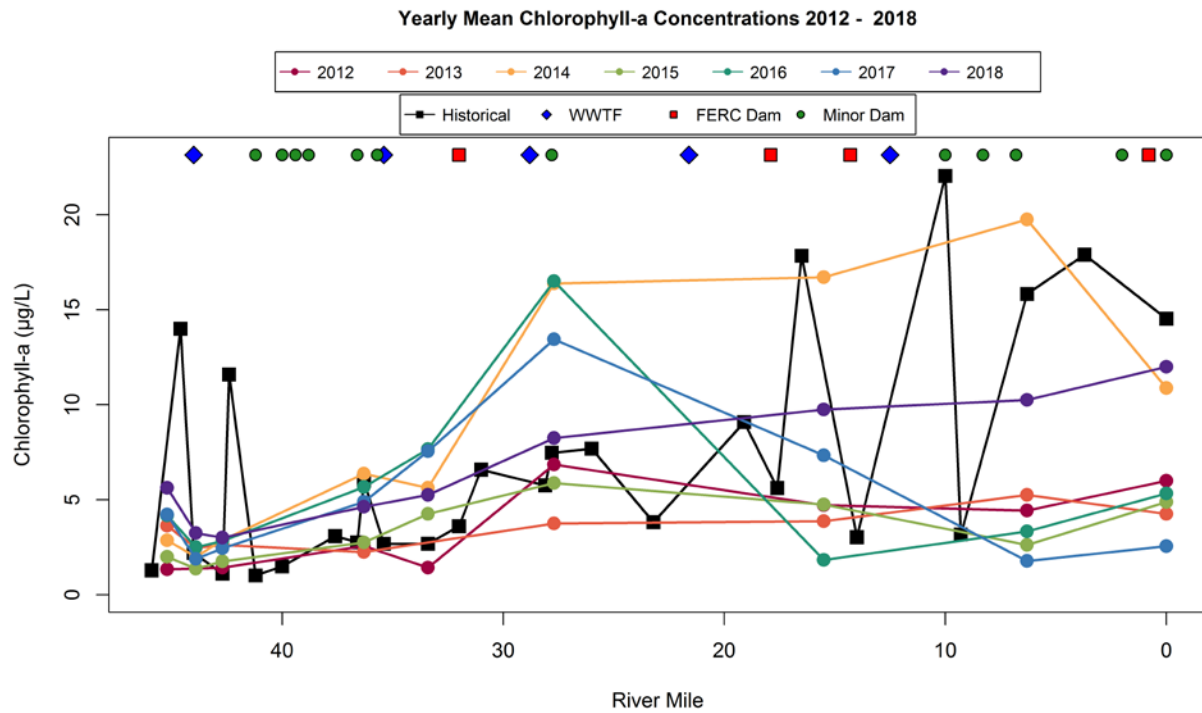


Figure 40: Along stream average chlorophyll-a levels

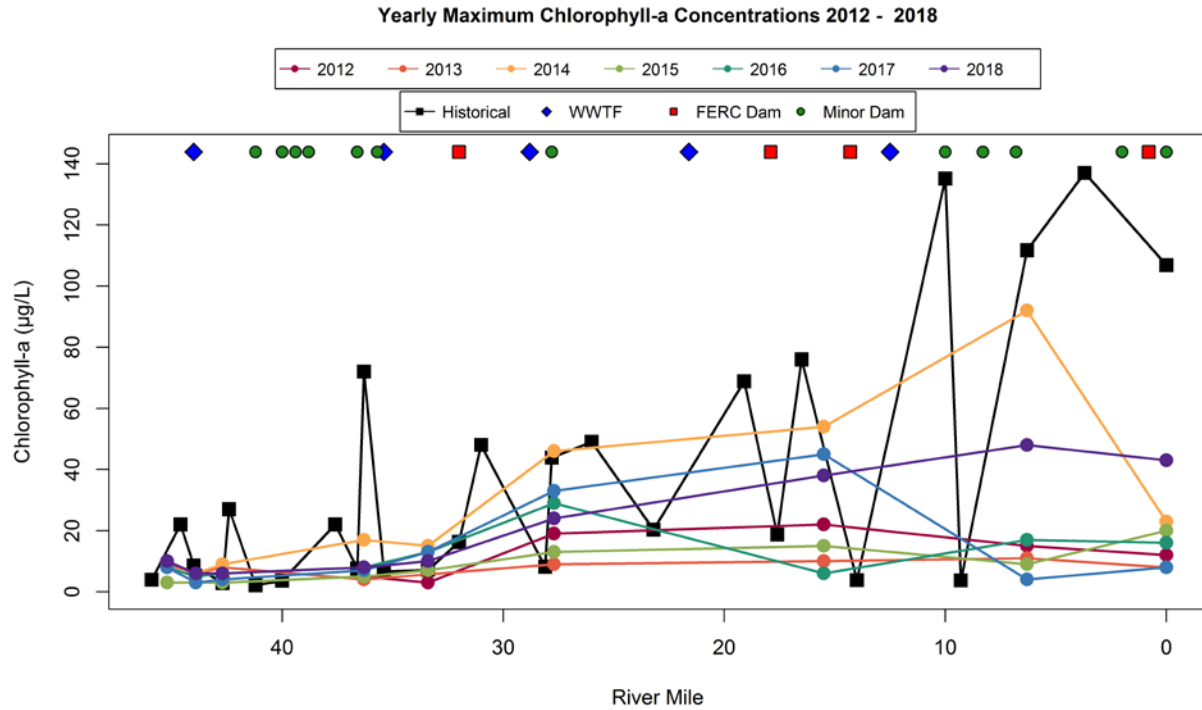


Figure 41: Along stream maximum chlorophyll-a levels

It appears that chlorophyll-a values increased in 2016 and have remained higher than in the past, at most sites. We will evaluate in 2019 whether this could be associated with a slight modification in sample preparation technique in the laboratory that was initiated in 2016.

In 2018, chlorophyll-a concentrations in the Blackstone River were below the MassDEP 2016 CALM screening threshold of 16 µg/L 90% of the time, Figure 42. Most concentrations above CALM guidance occurred at the four most downstream sites. Chlorophyll-a concentrations were below MassDEP CALM guidance values in 88% of the samples at W1779 and at R116, 75% of samples at RMSL, and 63% of samples at RSMD. The five upper river sites, including just below the confluence with UB discharge, were always below MassDEP CALM guidance.

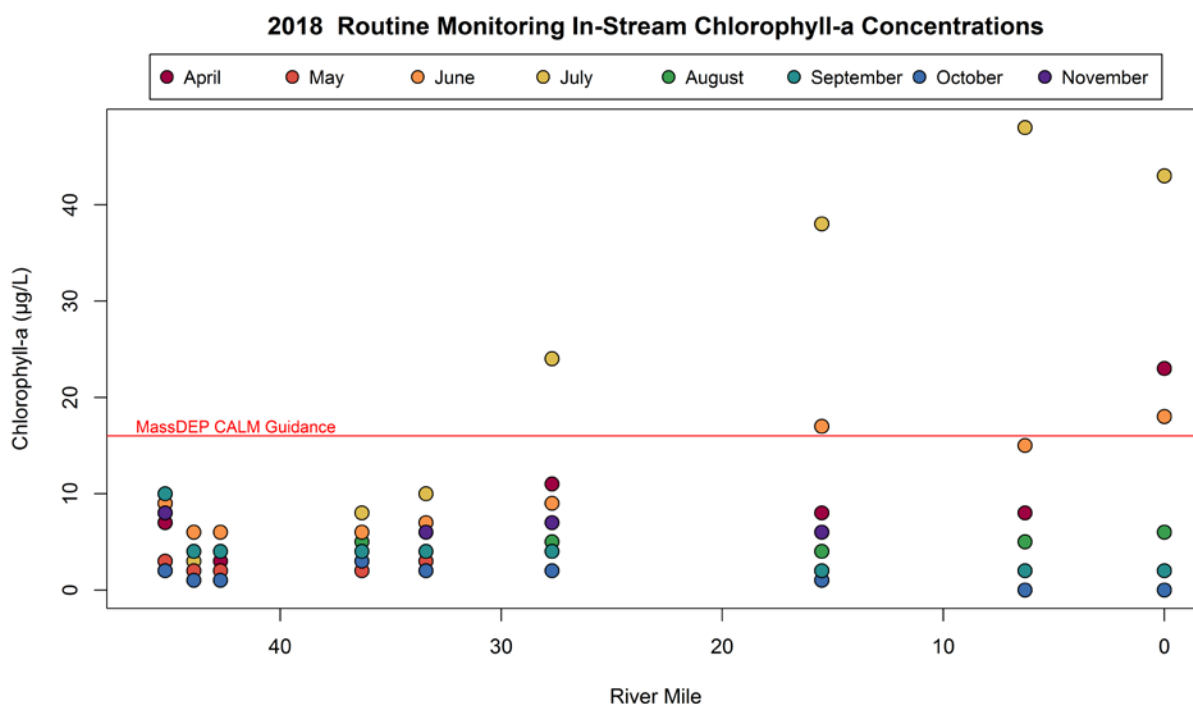


Figure 42: 2018 chlorophyll-a concentrations relative to MassDEP CALM guidance

6.2.4. Rice City Pond Study

In recent years (2014, 2016, and 2017), summer chlorophyll-a levels have been elevated at the Rice City Pond site in Uxbridge.

A limited but detailed investigation was conducted in the summer of 2018 to explore potential causes of these elevated chlorophyll-a levels. Three hypotheses were advanced:

1. A physical change at the sampling location, such as a change in tree canopy or channel configuration.

2. A sampling location that is not representative of the full streamflow of the river.
3. Variability in sampling or analytical techniques.

Field data sheets from 2013 through 2018 were consulted. Google Earth satellite photos dating back to 2013 were examined. Seven sites around site W1779 were sampled on August 21, 2018 and analyzed for chlorophyll-a. Sampling crews were questioned about the protocols they have been following at that site.

None of the above-mentioned hypotheses could satisfactorily explain the elevated chlorophyll-a levels. The only issue found was that there was a change in sampling protocol starting in 2016. A comparison of that protocol and the one used previously should be run in the next sampling season.

Based on the data collected in 2018, it is likely that variations in chlorophyll-a levels below Rice City Pond are caused by climatic variations from year to year. The site is directly downstream of a large shallow ponded body of water, which could be a source of increased algae during hot and dry summers.

Note that this trend did not continue in 2018, which supports the hypothesis that algae and chlorophyll-a levels in the Blackstone River depend on the magnitude and variability of its streamflow.

The full report for this study can be found in the Appendix F.

6.2.5. *Flow-weighted concentration trend analysis*

Correlations between streamflow and concentration make it difficult to identify trends in water quality without a more robust statistical analysis. However, streamflow-weighted concentrations, which account for differences in streamflow conditions, can be used to evaluate trends and to additionally account for the influence of location, season, or month on water quality.

Flow-weighted concentration was calculated based on a locally weighted scatterplot smooth (LOWESS) between concentration and streamflow. Streamflow-weighted concentrations are the residuals (e.g., the absolute value of the difference between the observed concentration and the LOWESS smooth).

Trends in water quality were then evaluated using a seasonal Mann-Kendall test (Helsel, 2006) computed on the streamflow-weighted concentration data collected since 2012. The trend analysis was conducted for each site individually by season. While the data set is limited due to the length of record, sufficient data were available to complete the analysis at all sampling locations, Tables 17-19. The Mann-Kendall analysis becomes more robust as more data become available. The analysis found:

- When all sites are considered together, there is a statistically significant decreasing trend at the 99% significance level in both TP and TN streamflow-weighted concentrations when the data are analyzed accounting for either season or month.
- Some sites also exhibit statistically significant decreasing trends in streamflow-weighted TP concentration. Decreasing trends in TP are noted when the data are grouped monthly at the Slater Mill Dam in Pawtucket, RI (RMSD) and Rice City Pond (W1779) sampling sites (95% significance level), and at the Route 122, Grafton (W1242) sampling site (90% level). When data are grouped by season, RMSD exhibits a decreasing trend at the 95% significance level, and R116 and W1242 show a decreasing trend at the 90% significance level.

- Decreasing trends in TN streamflow-weighted concentration are observed at either the 95% or 99% significance level at all sites except for the Sutton Street Bridge in Northbridge (W0767) and the most upstream site, W0680, when the data are grouped monthly. When the data are grouped seasonally, no trend is observed below the Upper Blackstone effluent confluence with the river, site UBWPAD2, in addition to W0767 and W0680, and the significance level at several sites decreases.
- Increasing trends in seasonal streamflow-weighted chlorophyll-a concentration data are observed when all sites are lumped together and the data are grouped by month (99% significance level) or when the data are grouped seasonally (95% significance level). Increasing trends when the individual site data are grouped monthly are observed at the 95% significance level at W1242, and at the 90% significance level at sites W1779, W0767, and W1258. When grouped seasonally, site W1258 is the only site where a positive trend is detected, at the 90% significance level.

Table 16: Streamflow-weighted seasonal trend analysis results for TP

Site	Point	Block	Significance	Trend
All Sites	Flow-weighted TP	Site+Month	>99%	Decreasing
RMSD	Flow-weighted TP	Month	>95%	Decreasing
R116	Flow-weighted TP	Month		
RMSL	Flow-weighted TP	Month		
W1779	Flow-weighted TP	Month	>95%	Decreasing
W0767	Flow-weighted TP	Month		
W1242	Flow-weighted TP	Month	>90%	Decreasing
W1258	Flow-weighted TP	Month		
UBWPAD2	Flow-weighted TP	Month		
W0680	Flow-weighted TP	Month		
All Sites	Flow-weighted TP	Site+Season	>99%	Decreasing
RMSD	Flow-weighted TP	Season	>95%	Decreasing
R116	Flow-weighted TP	Season	>90%	Decreasing
RMSL	Flow-weighted TP	Season		
W1779	Flow-weighted TP	Season		
W0767	Flow-weighted TP	Season		
W1242	Flow-weighted TP	Season	>90%	Decreasing
W1258	Flow-weighted TP	Season		
UBWPAD2	Flow-weighted TP	Season		
W0680	Flow-weighted TP	Season		

Table 18: Streamflow-weighted seasonal trend analysis results for TN

Site	Point	Block	Significance	Trend
All Sites	Flow-weighted TN	Site+Month	>99%	Decreasing
RMSD	Flow-weighted TN	Month	>95%	Decreasing
R116	Flow-weighted TN	Month	>99%	Decreasing
RMSL	Flow-weighted TN	Month	>90%	Decreasing
W1779	Flow-weighted TN	Month	>99%	Decreasing
W0767	Flow-weighted TN	Month		
W1242	Flow-weighted TN	Month	>99%	Decreasing
W1258	Flow-weighted TN	Month	>99%	Decreasing
UBWPAD2	Flow-weighted TN	Month		
W0680	Flow-weighted TN	Month		
All Sites	Flow-weighted TN	Site+Season	>99%	Decreasing
RMSD	Flow-weighted TN	Season	>95%	Decreasing
R116	Flow-weighted TN	Season	>95%	Decreasing
RMSL	Flow-weighted TN	Season	>90%	Decreasing
W1779	Flow-weighted TN	Season	>95%	Decreasing
W0767	Flow-weighted TN	Season		
W1242	Flow-weighted TN	Season	>95%	Decreasing
W1258	Flow-weighted TN	Season	>95%	Decreasing
UBWPAD2	Flow-weighted TN	Season		
W0680	Flow-weighted TN	Season		

Table 19: Streamflow-weighted seasonal trend analysis results for chlorophyll-a

Site	Point	Block	Significance	Trend
All Sites	Flow-weighted Chl-a	Site+Month	>99%	Increasing
RMSD	Flow-weighted Chl-a	Month		
R116	Flow-weighted Chl-a	Month		
RMSL	Flow-weighted Chl-a	Month		
W1779	Flow-weighted Chl-a	Month	>90%	Increasing
W0767	Flow-weighted Chl-a	Month	>90%	Increasing
W1242	Flow-weighted Chl-a	Month	>95%	Increasing
W1258	Flow-weighted Chl-a	Month	>90%	Increasing
UBWPAD2	Flow-weighted Chl-a	Month		
W0680	Flow-weighted Chl-a	Month		
All Sites	Flow-weighted Chl-a	Site+Season	>95%	Increasing
RMSD	Flow-weighted Chl-a	Season		
R116	Flow-weighted Chl-a	Season		
RMSL	Flow-weighted Chl-a	Season		
W1779	Flow-weighted Chl-a	Season		
W0767	Flow-weighted Chl-a	Season		
W1242	Flow-weighted Chl-a	Season		
W1258	Flow-weighted Chl-a	Season	>90%	Increasing
UBWPAD2	Flow-weighted Chl-a	Season		
W0680	Flow-weighted Chl-a	Season		

6.3 Periphyton Sampling

6.3.1. Sampling procedures and criteria

Normandeau Associates conducted periphyton sampling at four sites in July, August, and September of 2018. Three sampling sites (UBPWAD⁵, W1258, and Depot) are located in areas where the MassDEP conducted its periphyton sampling in 2008 (MassDEP and Beskenis, 2009). Three of the sampling sites (W0680, UBWPAD, and W1258) correspond with routine monthly sampling locations. Periphyton sampling occurs along the reach upstream and downstream of the location where the routine monthly surface water sample is collected. Normandeau has conducted periphyton sampling at all four sites since 2012.

Sampling was conducted based on the MassDEP Standard Operating procedures (SOPs) for Percent Cover and Periphyton Collection Determinations. At each station, two targeted riffle zones were established. Per Mass DEP protocol, the targeted riffles were intended to be 100 to 300 yards apart;

⁵ Periphyton sampling occurs along a stretch of the river that is representative of both routine sampling locations termed UBWPAD and UBWPAD2 and consistent with the MassDEP sampling location referred to as UBWPAD. Thus, the periphyton sampling location is simply termed UBWPAD, denoting this stretch.

however, this criterion was met only at the MID2 sampling location. Riffle habitat was limited at the other three sampling locations and the targeted riffle zones were located within 100 yards of each other. Efforts were made to select riffles with at least partially open canopy and cobble bottom, but professional judgment was used to select representative areas when station conditions did not completely meet these criteria.

Transects were spaced at least 5 meters apart and were selected to maintain habitat uniformity. Three sub-samples were collected from three cobbles, located on the left, middle, and right of each transect. A 1-inch diameter circle was scraped, scrubbed, and rinsed from each cobble utilizing a modified MassDEP sampling strip and SOP. The subsamples from transects 1 and 2 were combined into one composite sample, while subsamples from transects 3 and 4 were combined into a second composite sample, and each composite bottle was filled to 500 mL with bottled water. See Blackstone River Periphyton Report (Normandeau, 2019) for further details.

The collected scrapings were analyzed for chlorophyll-a content and reported as chlorophyll-a in mg/m². The value reported for each composite is the average of three separate filter determinations (e.g., ~50 mL aliquots filtered, then the filters processed for analysis, and the results of the three aliquots averaged). The final number presented is the average of all six aliquots, or the average of the two composite samples.

High streamflow conditions prior to periphyton sampling dates can impact results due to scour. MassDEP guidance requires a no-sampling period of two to three weeks following high streamflow events with a potential to cause scouring to ensure adequate time for the algal community to re-establish so that representative densities are present during sampling. MassDEP guidance utilizes three times (3x) the median average monthly streamflow as the criteria for potential scour. Table 20 summarizes the 3x median average monthly streamflow values for the USGS Millbury gage for the 2018 sampling season. The 3x median criteria utilized in 2018 were based on data from 2002 through 2017.

The sampling team draws upon additional guidance from the literature as well as best professional judgment when making sampling decisions. Specifically, additional consideration is given to:

- Three times the annual median average streamflow for the period of record, rather than three times the monthly median streamflow, as the metric for scour potential (see Biggs, 2000 and Clausen and Biggs, 1997)⁶. In 2018, this equated to a mean daily streamflow of 384 cfs at Millbury.
- Short periods of streamflow, rather than daylong or greater excursion, may also cause scour and impact periphyton densities. Data in the literature on the effects of streamflow velocity on biomass, however, are limited. One study in southeastern Australia suggests that streamflow velocities greater than 1.8 ft/s significantly impact filamentous chlorophytes (Ryder et al., 2006).
- In lieu of real-time velocity data, rough estimates of velocity calculated based on the observed discharge and stage at Millbury, paired with sampling reach width data collected by Normandeau, suggest that periphyton communities in the Blackstone River are acclimated to velocities associated with instantaneous streamflows up to ~400 cfs. Periphyton sampling preferentially

⁶ The Millbury period of record mean daily value (updated through 2017) is 128 cfs, resulting in a 3x median value equal to 384 cfs for this guidance in 2018. These values shift slightly each year, as new data are added and the values are updated.

does not take place for at least two weeks after an instantaneous streamflow value >400 cfs is recorded at Millbury.

To provide extra protection, if at all feasible, the sampling team tries to allow for at least a two-week period between when instantaneous streamflows rise above ~250 cfs, roughly the average of the mean daily 3x median monthly values for July, August, and September.

Table 17: Monthly mean daily summer discharge (cfs) for the USGS Millbury gage

(Median Period of Record mean daily value = 128 cfs; 3x = 384 cfs)

Year	June	July	August	September
2002 ^a	NA	54	56	72
2003	303	96	125	100
2004	80	98	88	165
2005	107	136	63	79
2006	312	103	76	74
2007	136	77	53	54
2008	114	151	143	228
2009	146	396	157	79
2010	114	61	66	47
2011	202	93	273	340
2012	136	68	105	88
2013	434	105	85	82
2014	80	77	68	70
2015	164	96	60	72
2016	67	49	59	49
2017	177	89	59	58
2018	89	105	156	201
Average^b	171	113	99	106
Median^b	136	96	76	79
3xMedian^b	408	287	227	236
Minimum^b	67	49	53	47

^a Data for 2002 were included as this is the earliest year included in the MassDEP evaluation of their 2008 data (Beskenis, 2009), however summary statistics are based only on 2003 through present as the June 2002 monthly average was not reported by USGS

^b Summary calculations based on data 2003 through 2017

The streamflow criteria data for periphyton sampling described above are summarized graphically for the 2018 sampling season compared to observed streamflows and sampling dates on Figure 43. The mean daily data as observed at the USGS Millbury gage are shown as orange dots, while the 15-minute streamflow data are shown by the solid blue line.

A line representing the MassDEP sampling guidance criteria of 3x the median daily streamflow for the month is included on the figure (July - green, August - purple, and September - red) for a two-week period prior to the periphyton sampling which occurred in that month, indicated by the purple crosses. The light blue, dotted horizontal line shown for the entire time period indicates 3x the median average daily streamflow for the period of record, while the red dashed line indicates the target instantaneous streamflow value of 250 cfs. In addition, the number of days in each month when mean daily streamflow exceeded three times the period of record median mean daily value for the USGS Millbury gage is summarized in Table 21. To further explore potential impacts of streamflow conditions on observed periphyton levels, antecedent rain, mean daily discharge, and daily instantaneous peak streamflow data are tabulated for 7 days prior to periphyton sampling in Table 22 for 2018. Key observations include:

- July 2018 sampling: no appreciable precipitation fell in the days preceding sampling, but there was a peak daily discharge of 898 cfs 13 days before sampling day (above the instantaneous streamflow target of 250 cfs and above the value of 3x median monthly streamflow criterion of 384 cfs).
- August 2018: sampling met all antecedent streamflow criteria, except for an instantaneous streamflow of 314 cfs occurring 5 days before sampling and an instantaneous streamflow of 329 cfs occurring 13 days before sampling. Both streamflows exceed the 250 cfs target instantaneous value.
- September 2018: sampling began 13 days after an instantaneous streamflow of 402 cfs.

In summary, in 2018 streamflows for two weeks prior to all three periphyton sampling events exceeded guidance criteria each of the sampling months. While these excursions may have resulted in some scour, overall periphyton sampling during 2018 are reflective of the best sampling opportunities available based on precipitation and streamflow conditions.⁷

⁷ For comparison purposes, figures and tables for flow conditions in 2012, 2013, 2014, 2015, 2016, 2017 and 2018 are provided in Appendix C and D.

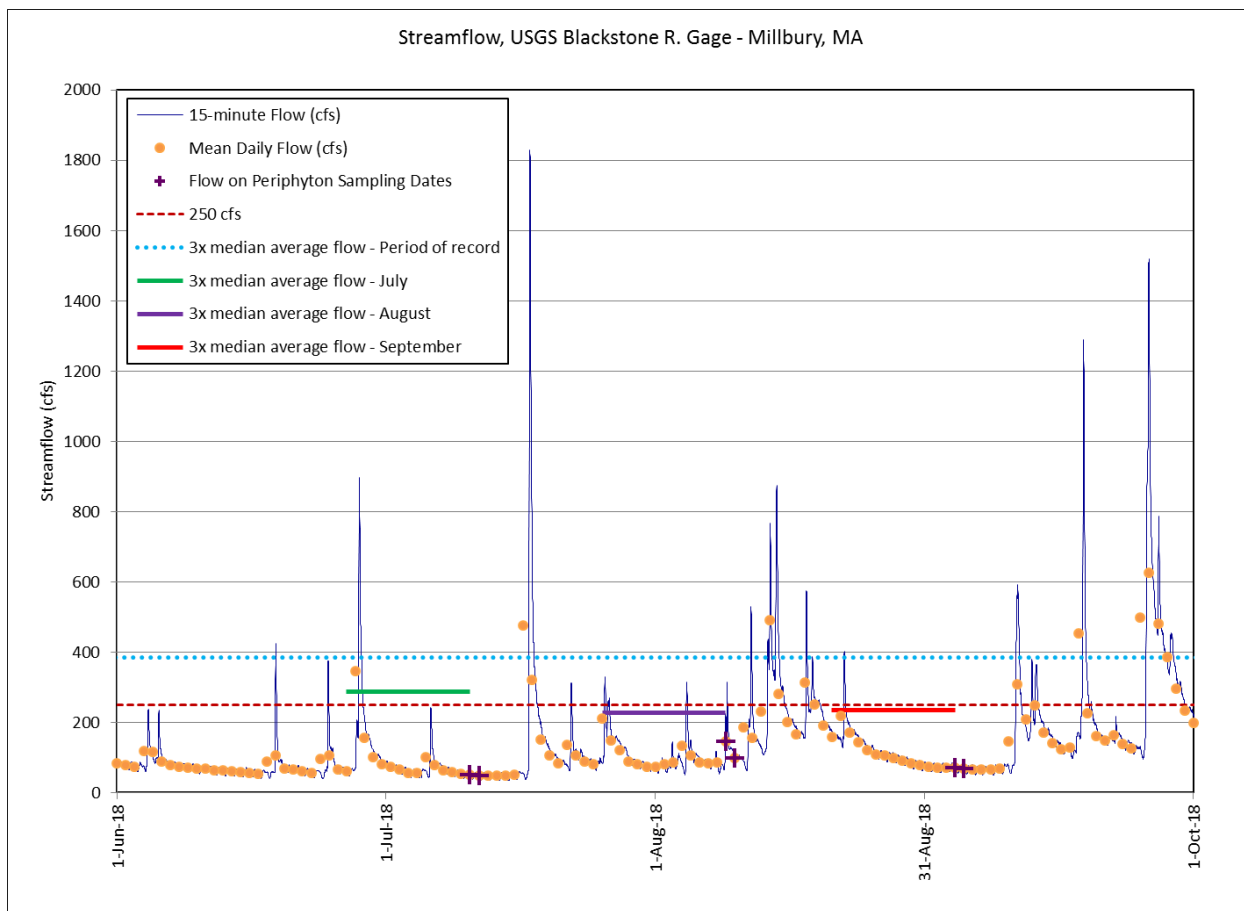


Figure 43: Summary of 2018 streamflows relative to periphyton sampling

Table 18: Number of days mean daily streamflow at Millbury exceeded 3x the period of record median

Year	June	July	August	September
2002	NA	0	0	0
2003	3	0	1	1
2004	0	1	0	4
2005	0	2	0	0
2006	8	0	0	0
2007	0	0	0	0
2008	1	1	0	2
2009	1	10	1	0
2010	0	0	0	0
2011	2	0	6	6
2012	0	0	1	0
2013	12	0	0	0
2014	0	0	0	0
2015	2	1	0	1
2016	0	0	0	0
2017	2	0	0	0
2018	0	1	1	4

Table 19: 2018 periphyton sampling antecedent rain and discharge conditions

2018 Date	Daily Precipitation, Worcester, MA (inches)	Mean Daily Discharge (cfs) – Millbury, MA	Peak Daily Discharge (cfs) – Millbury, MA
June 27	0.3	62	70
June 28	1.44	338	898
June 29	0.00	162	222
June 30	0.00	104	125
July 1	0.00	82	92
July 2	0.00	74	92
July 3	0.00	66	172
July 4	0.00	58	68
July 5	0.00	57	67
July 6	0.28	101	242
July 7	0.00	78	93
July 8	0.00	63	73
July 9	0.00	59	64
July 10	T	54	63
July 11	0.00	52	58
July 12	0.00	50	57
July 26	0.54	206	329
July 27	0.02	151	178
July 28	T	123	146
July 29	0.00	89	102
July 30	0.00	81	91
July 31	0.00	76	82
August 1	0.13	73	80
August 2	0.33	80	145
August 3	0.02	87	121
August 4	0.42	133	314
August 5	0.00	106	149
August 6	0.00	87	102
August 7	0.05	84	118
August 8	0.11	85	226
August 9	0.09	147	315

August 10	0.00	98	116
August 21	T	159	180
August 22	0.62	216	402
August 23	T	172	193
August 24	0.00	144	162
August 25	0.00	123	136
August 26	0.00	110	120
August 27	0.00	105	115
August 28	0.00	99	113
August 29	0.00	90	103
August 30	0.00	83	93
August 31	0.00	78	87
September 1	0.00	73	86
September 2	0.00	72	85
September 3	0.00	72	85
September 4	0.00	70	78
September 5	0.00	69	81

^a Periphyton sampling dates are shaded

6.3.2. Periphyton survey results

Periphyton chlorophyll-a survey results from 2012 - 2018⁸ and the 2008 MassDEP data are presented in Figure 44 as a simple boxplot, and are tabulated in Table 23. Periphyton chlorophyll-a levels in 2018 were about average compared to historical data at the most upstream site (W0680) and at Depot Street. At the UBWPAD and W1258 transects, periphyton chlorophyll-a levels were higher than average compared to historical data, falling near and above the third quartile, and higher than the MassDEP suggested guidance level of 200 mg/m².

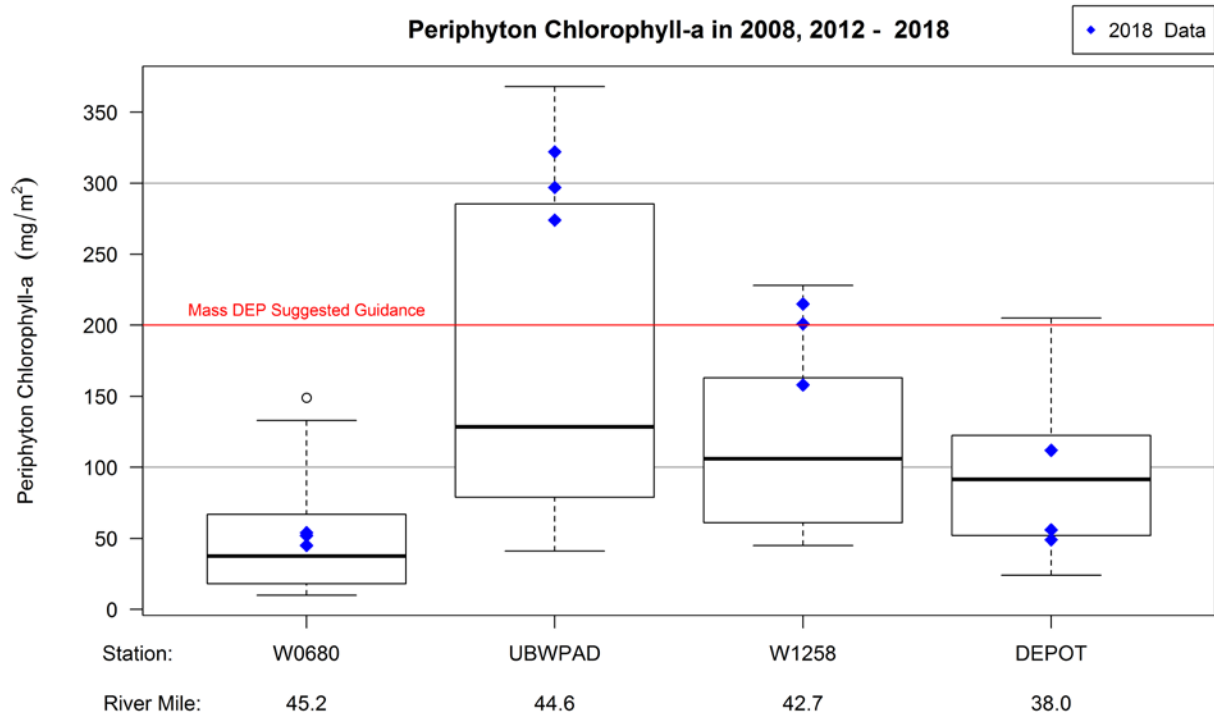


Figure 44: Range of periphyton chlorophyll-a at sampling sites in 2008, 2012 - 2018

⁸ In 2014, periphyton sampling was also conducted in June.

Table 20: Available periphyton chlorophyll-a data for the Blackstone River

Month	Site	Periphyton (Chlorophyll-a mg/m ²)							
		2008 ^a	2012	2013 ^b	2014	2015	2016	2017	2018
June	W0680	--	--	--	24	--	--	--	--
	UBWPAD	--	--	--	75	--	--	--	--
	W1258	--	--	--	110	--	--	--	--
	Depot	--	--	--	24	--	--	--	--
July	W0680	--	--	33 and 18	133	30	102	20	54
	UBWPAD	65	--	84 and 58	119	83	363	191	322
	W1258	51	--	59 and 78	62	59	137	107	215
	Depot	26	--	--	133	77	205	94	112
Aug.	W0680	--	15	14	107	23	60	36	45
	UBWPAD	--	41	42	189	113	366	237	297
	W1258	--	82	47	141	76	169	113	158
	Depot	--	37	--	107	55	178	89	49
Sept.	W0680	--	15	14	149	39	114	67	52
	UBWPAD	138	90	71	190	89	313	368	274
	W1258	105	59	60	168	91	228	176	201
	Depot	110	34	--	149	79	139	110	56

^aData collected by MassDEP (MassDEP and Beskenis, 2009)

^bIn 2013, periphyton was sampled twice in July, once in early July and once in late July

Boxplots of the periphyton chlorophyll-a data separated by site and year are presented in Figure 45. Boxplots of the periphyton chlorophyll-a data separated by site and month are shown in Figure 46, with the 2018 sampling results noted with blue diamonds.

At the three upstream sites (W0680, UBWPAD, and W1258), periphyton chlorophyll-a levels increased in 2018 compared to 2017, and were higher than the historical median each month. At the downstream (Depot) site, however, periphyton chlorophyll-a levels were lower than in the past four years, and near or below the historical medians. Again this year, the most elevated levels occurred downstream from the confluence, at the UBWPAD site. MassDEP utilizes 200 mg/m² as the target maximum periphyton chlorophyll-a level in rivers. All data collected in 2012 through 2015 fall below this target level, but values above the target level were observed in 2016, 2017, and 2018. In 2018, the 200 mg/m² target was exceeded five times, at least once each month and at sites UBWPAD and W1258. However, the limit was not even approached at sites W0680 and Depot.

For results of the periphyton survey, see the 2018 Normandeau report (Normandeau Associates Inc., 2019).

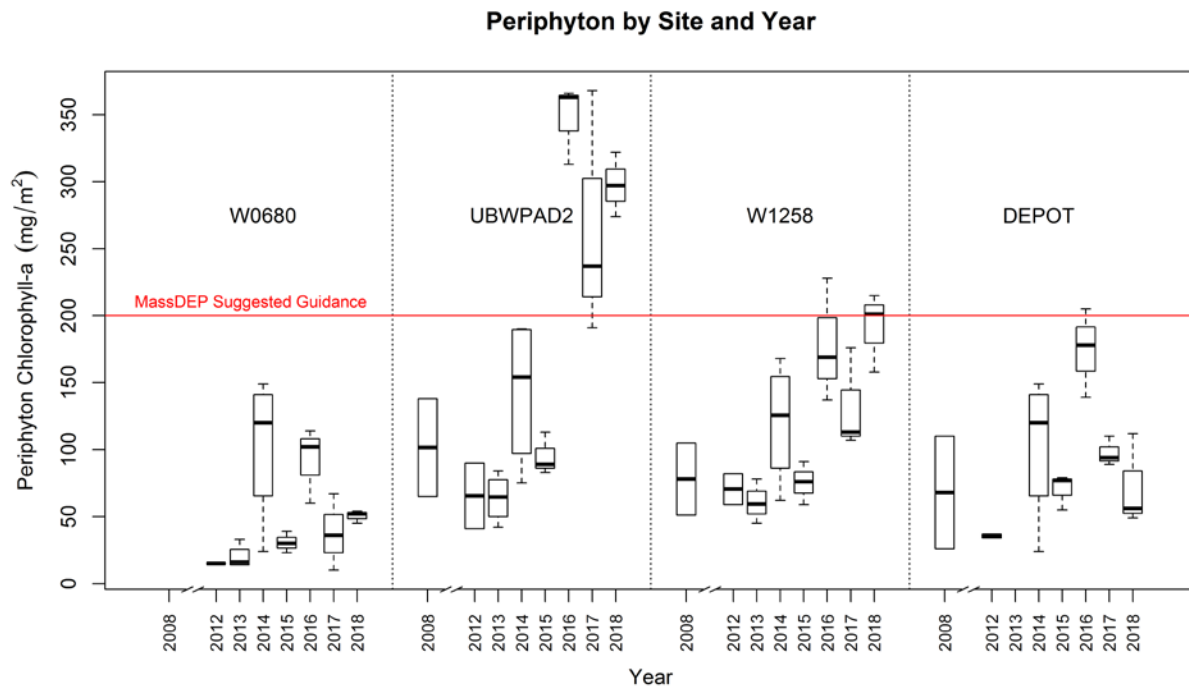


Figure 45: Summary of available periphyton chlorophyll-a data by sampling site and year

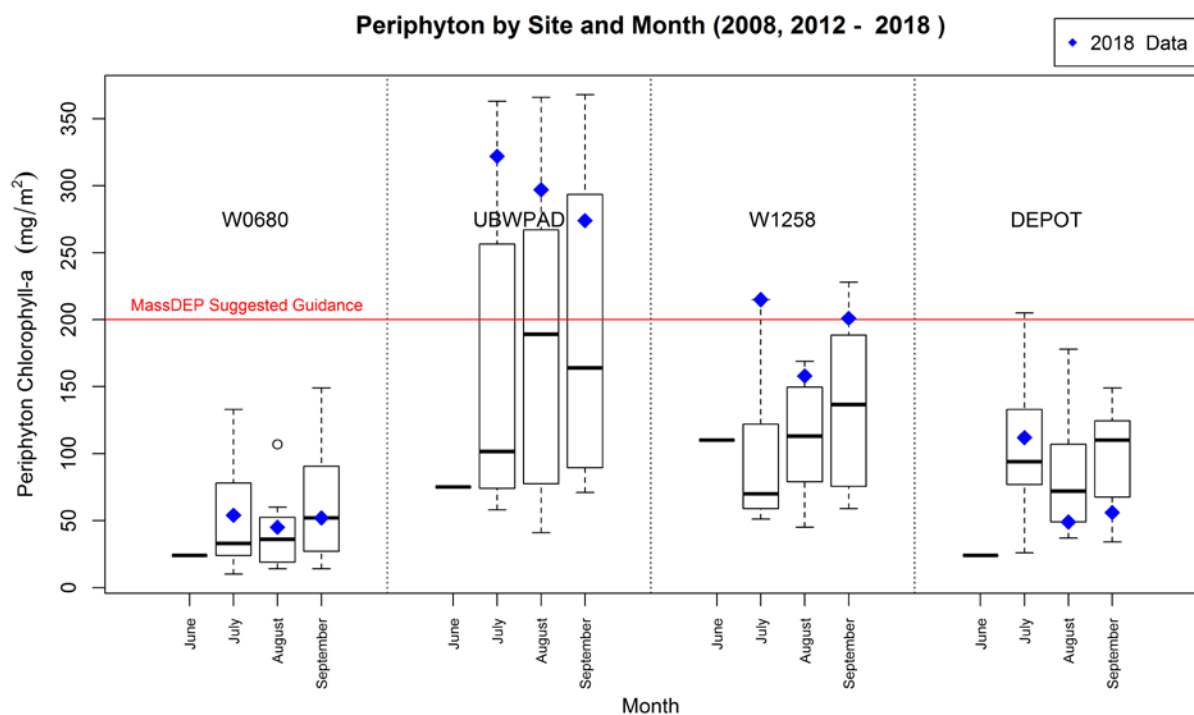


Figure 46: Periphyton chlorophyll-a concentrations by sampling site and month 2008 and 2012 - 2018

Starting in 2014, water column samples were collected at the time of periphyton sampling and analyzed for TP and chlorophyll-a, Table 24. Nutrient levels in the stream may influence periphyton growth, however similar in-stream TP concentrations can have very different corresponding periphyton chlorophyll-a concentrations, Figure 47, suggesting that other factors also influence algal growth. In this figure, data points representing the observed periphyton levels at the UBWPAD periphyton sampling location are highlighted. Points falling along the same horizontal line are characterized by the same periphyton chlorophyll-a levels, but are characterized by different water column TP concentrations. For example, periphyton chlorophyll-a levels greater than 350 mg/m² have been observed three times, twice in 2016 and once in 2017. However, the corresponding water column TP concentrations varied from 171 to 341 ppb.

Mean summertime (June – September) TN and TP concentrations (earlier Figures 20 and 27) provide information on the longer-term availability of nutrients during the periphyton growing season. Data are available for three of the periphyton monitoring sites, W0680, UBWPAD, and W1258. The highest average June - September TN and TP concentrations observed occurred in 2014, however the highest observed periphyton chlorophyll-a concentrations were observed in 2016 and 2018. Nutrient availability is only one of several environmental conditions that may impact periphyton growth.

Table 21: Available water column Chlorophyll-a and TP data collected during the week of periphyton sampling

Month	Site	Water Column Chlorophyll-a (ppb)					Water Column TP (ppb)				
		2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
June	W0680	3	--	--	--	--	47	--	--	--	--
	UBWPAD	1	--	--	--	--	171	--	--	--	--
	W1258	3	--	--	--	--	109	--	--	--	--
	Depot	1	--	--	--	--	107	--	--	--	--
July	W0680	2	1	4	4	3	39	51	75	60	71
	UBWPAD	1	1	4	1	3	121	167	341	212	270
	W1258	2	2	3	1	3	103	89	213	126	206
	Depot	3	1	4	2	3	85	240	165	89	128
Aug.	W0680	2	4	3	3	4	--	48	50	36	70
	UBWPAD	2	2	2	2	3	--	147	202	134	227
	W1258	2	2	3	6	4	--	134	171	143	110
	Depot	3	3	6	3	3	--	102	147	129	108
Sept.	W0680	1	2	2	1	3	20	16	44	28	43
	UBWPAD	2	1	1	1	4	280	164	171	183	231
	W1258	1	1	1	1	14	320	117	155	137	179
	Depot	3	5	3	2	3	320	71	137	118	102

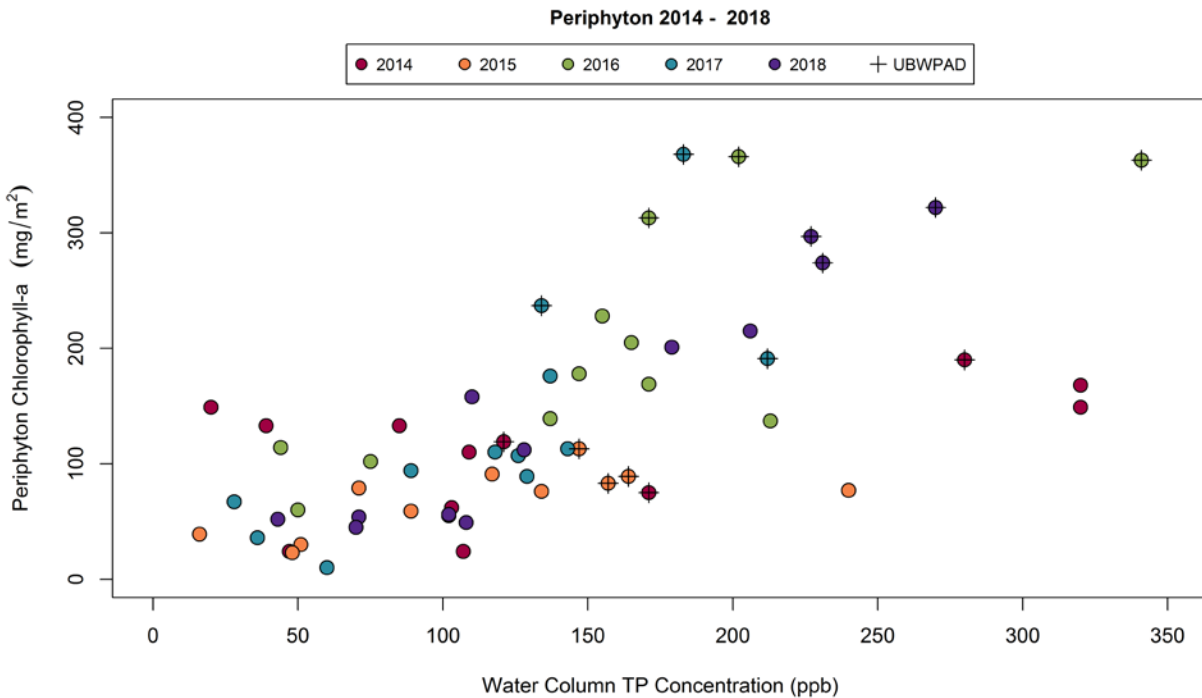


Figure 47: Measured periphyton chlorophyll-a concentrations in 2014 - 2018 plotted against water column TP concentration. Data for the UBWPAD periphyton monitoring location are noted.

7.0 Discussion

A combination of factors, including temperature, exposure to sunlight, streamflow, nutrient availability on the days preceding routine sampling, and along-stream transport dynamics likely contribute to the observed year-to-year differences in water column chlorophyll-a and periphyton levels.

In 2018, TP summer concentrations were average to low at all sampling sites, and TN concentrations continued to be on the low end of observed data. TP and TN loads, however, were higher at all sites than they have been since 2012, though they were still lower than before the UB plant upgrade. This of course is due to high water volumes in the Blackstone River in 2018. River flows were average to low in the spring but became increasingly high throughout the summer and fall, exceeding the upper quartile of historical data every month from August through November.

Complex river hydrodynamics make it difficult to fully understand the impacts of rainfall, other wastewater facilities, and nonpoint source wet weather contributions of nutrients to the river based on data from the current sampling scheme alone. A more comprehensive sampling scheme would need to be devised in order to better understand such influences, including temporal sampling during wet weather events, and targeted spatial sampling to identify contributions from additional sources. In addition, hydraulic modeling is necessary to understand the complexities of along stream transport dynamics, including influence of the dams on downstream delivery of nutrients. An extension of the

current HSPF model, facilitating its use through the most recent sampling season, would provide such insight.

8.0 Summary

Upper Blackstone has conducted water quality monitoring and periphyton sampling since 2012. This report presents the 2018 field data. In addition, trends in water quality and the potential impacts of flow and effluent concentrations on in-stream river water quality are examined.

The 2018 sampling season was preceded by a snowy winter and in general the year can be characterized by normal temperatures but higher than average precipitation and streamflow.

Upper Blackstone continues to refine its treatment process to minimize nutrient loads and daily variability, particularly in the summer months. The facility performed at about the same level in 2018, not quite meeting its seasonal total phosphorus concentration limit (0.2 vs 0.1 mg/L) but continuing to meet its total nitrogen limit (4.90 vs 5.0 mg/L) in the summer. Winter effluent concentrations met the permit concentrations.

Upper Blackstone flow contributions to the Blackstone River vary from year to year (33% to 65% since 2003). In summer of 2018 that contribution averaged 39% of the river flow at Millbury, one of the lower contributions on record, due to the high natural streamflows observed this year.

In-stream TP and TN levels in the river in 2018 show continued improvement, except at the two upstream sites in Rhode Island. In-stream TP concentrations were below the Massachusetts CALM guidance of 100 ppb 69% of the time, when looking at all sites and all sampling dates.

Average water column TP and TN concentrations in 2018 fell within or below the interquartile range of values observed since 2012 at all sampling sites. For TN, the values fell below 2012 – 2018 median levels at all sites.

TP and TN loads observed in the river were higher than average, due to higher streamflows in 2018.

Trends in water quality were evaluated on streamflow-weighted TP and TN data collected since 2012; Decreasing TP trends were noted at four sites (RMSD, W1242, W1779, and R116), and decreasing TN trends were noted at all sites *except for* W0767, UBWPAD2, and W0680.

Chlorophyll-a concentrations were below the CALM guidance of 16 µg/L 90% of the time in 2018. However, trend analysis of the data collected since 2012 suggests that overall chlorophyll-a levels are increasing slightly, especially at the mid-river sites (W1258, W1242, W0767, and W1779).

Average summer chlorophyll-a levels were elevated compared to other years at all sites except Sutton St. Bridge (W0767) and just below Rice City Pond (W1779)

Highest periphyton chlorophyll-a levels were observed in July at all sites. That month was the hottest and with the next to lowest streamflow in 2018, conditions that are favorable to productivity. Higher streamflows in August and September likely contributed to lower periphyton chlorophyll-a levels in the river in those months

MassDEP utilizes 200 mg/m² as guidance for “nuisance levels” of periphyton chlorophyll-a based on the literature (MassDEP, 2009; NEIWPCC, 2001). Data collected in 2012 through 2015 all fall below this target level, but Since 2016, periphyton samples collected at the sites downstream from the confluence exceed the MassDEP 200mg/ m² every year at least once. In 2018, periphyton chlorophyll-a levels were below the guidance level 58% of the time.

9.0 Future Work

Upper Blackstone plans to continue water quality monitoring in the Blackstone River in 2019 to track the impacts of reduced nutrient concentrations in Upper Blackstone plant effluent. Blackstone River data collected in 2018 will be added to the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) database, which is sponsored by the National Science Foundation (www.cuahsi.org). The 2018 data, in addition to the data from 2012 – 2017 already submitted, will be publicly available for download through the CUAHSI Hydrologic Information System (HIS) databases and servers (data.cuahsi.org). In addition, the 2018 data will be submitted to MassDEP to supplement the data already submitted.

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