Blackstone River Water Quality Monitoring Program

2019 Sampling Season Report

Prepared for

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by

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Front cover photo: Upper Blackstone staff Sharon Lawson and Timothy Loftus deploying a data logger at the Depot site in July 2019. Photo by MF Hatte.

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1.0 Introduction

In 2012, Upper Blackstone Clean Water (Upper Blackstone) initiated a voluntary water quality monitoring program to evaluate the impact of treatment plant upgrades and subsequent treatment process optimization. This report presents water quality data collected on behalf of Upper Blackstone along the mainstem of the Blackstone River between April and November 2019. It includes a brief overview of trends in total phosphorus, total nitrogen, and chlorophyll-a data observed since the start of the sampling program in 2012.

There were several changes in 2019 compared to previous years. Personnel-wise, this was the first year that PI MF Hatte planned the whole year's project after the departure of this project's initiator Dr. Paula Rees. The University of Massachusetts Field Coordinator and Environmental Lab Analyst Travis Drury left UMass just before sampling season started and was succeeded a month later by Cameron Richards. The same protocols were followed in the lab but it should be noted that a change in personnel may result in slight changes in the way analyses are performed and results presented. In addition, the UMass Dartmouth laboratory experienced problems with blank samples for the analysis of Nitrogen compounds, which resulted in some data being flagged for failing data quality objectives. This will be discussed further in the nutrient results section. One site, W0767, was moved from the stream bank to a bridge upstream. Finally, construction began in October at RMSD, the downstream-most site, which may have affected water quality results that month, and in November the site had to be moved slightly upstream of the historical site due to construction impacts preventing access to the regular site.

New this year are measurements of water temperature, dissolved oxygen, pH and conductivity. A summary of dissolved oxygen data collected with continuous data loggers is included in this report.

More detailed technical information regarding the sampling program is available in the Field Sampling Plan and the Quality Assurance Project Plan (QAPP) for this project (Appendix E and F, respectively). 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. Starting this year, the data is uploaded to EPA's Storet database instead of CUAHSI.

2.0 Background

The Blackstone River watershed encompasses an area of approximately 480 mi^2 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), 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). 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 mill dam built by Samuel Slater at the outlet of the river in 1793. Water-powered textile mills proliferated up and 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. 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 dams (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 initiate a watershed assessment study to improve its 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 supported additional water quality data collection in 2010 and 2011, and since 2012 has supported consistent annual 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.

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
13.1	**USGS gaging station 01112500**	39.8	Singing Dam
15.5	Thundermist Hydro Dam	41	Millbury Electric Dam
15.5	State Line, RI (RMSL)	42.7	Central Cemetery, Millbury, MA (W1258)
16.5	Blackstone Dam	43.9	McCracken Rd Dam
17.4	Branch River	44.4	Upper Blackstone WWTF
17.8	Tupperware Dam	44.6	Below confluence with UB effluent (UBWPAD2)
19.2	Mill River	45.2	New Millbury St bridge, Worcester, MA (W0680)
22	Uxbridge WWTF	46.4	Worcester CSO
24.2	West River	46.6	**Mill Brook/Middle River Confluence & USGS gaging station 01109730**
25.9	Mumford River		

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

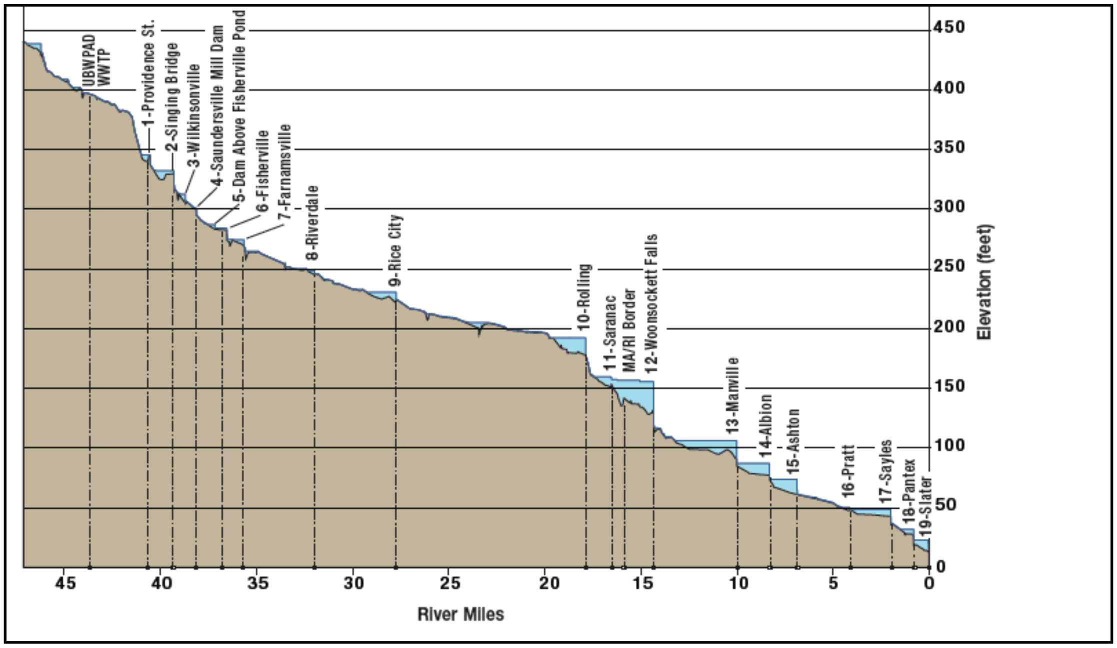


Figure 1: River elevation profile

3.0 Blackstone Water Quality Sampling Program

In 2019, the river monitoring program again included monthly water quality sampling for nutrients and chlorophyll-a from April through November. Three Rhode Island sites were co-sampled with the Narragansett Bay Commission (NBC). Periphyton sampling was not continued in 2019, as surveys from the previous years pointed to a stable condition and concluded that a yearly assessment was not expected to yield new information.

Sampling locations for routine and continuous dissolved oxygen 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 chemical 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 2019 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 (last amendment approved by MassDEP in 2019), available upon request.

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. Continuous data loggers were placed at four sites from July through October.

Table 2: Blackstone River 2019 sampling sites

Site ID#	Site Name	Lat	Lon	River Mile[2]	HSPF Reach[2]	Sampling Details[3]
RSMD[1]	Slater Mill Dam, Pawtucket, RI[7]	41.876909 41.879836	-71.38194 -71.38156	0.0	200	N
R116[1]	Rte 116 Bikepath Bridge, Pawtucket, RI	41.938	-71.434	6.3	228	N
RMSL[1]	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[6]	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	--	DO
W1258	Central Cemetery, Millbury, MA	42.194	-71.766	42.7	392	NDO
UBWPAD2[4]	Confluence Site, Millbury, MA	42.206	-71.781	44.6	402	NDO
W0680[5]	New Millbury St Bridge, Worcester, MA	42.228	-71.787	45.2	414	NDO

[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* (UMass and CDM Smith, August 2008) and the *Blackstone River HSPF Water Quality Model Calibration Report Addendum* (UMass and CDM Smith, October 2011).

[3] Sampling Types: N = 9 sites, nutrients & chlorophyll-a + handheld meters 1 event/4-weeks; DO = 4 sites, Continuous Data Loggers July - Oct.

[4] Site replaced original confluence site (UBWPAD) in 2013

[5] W0680 is located between the Worcester CSO discharge and UBWPAD2

[6] In 2019, This site was changed from the bank of the river to the middle of the bridge at those coordinates. The bank site, labeled W0767BANK, was sampled 3 times in 2019

[7] In October 2019, construction began at this site, and in November 2019, sampling took place upstream of the usual site, at the second set of coordinates

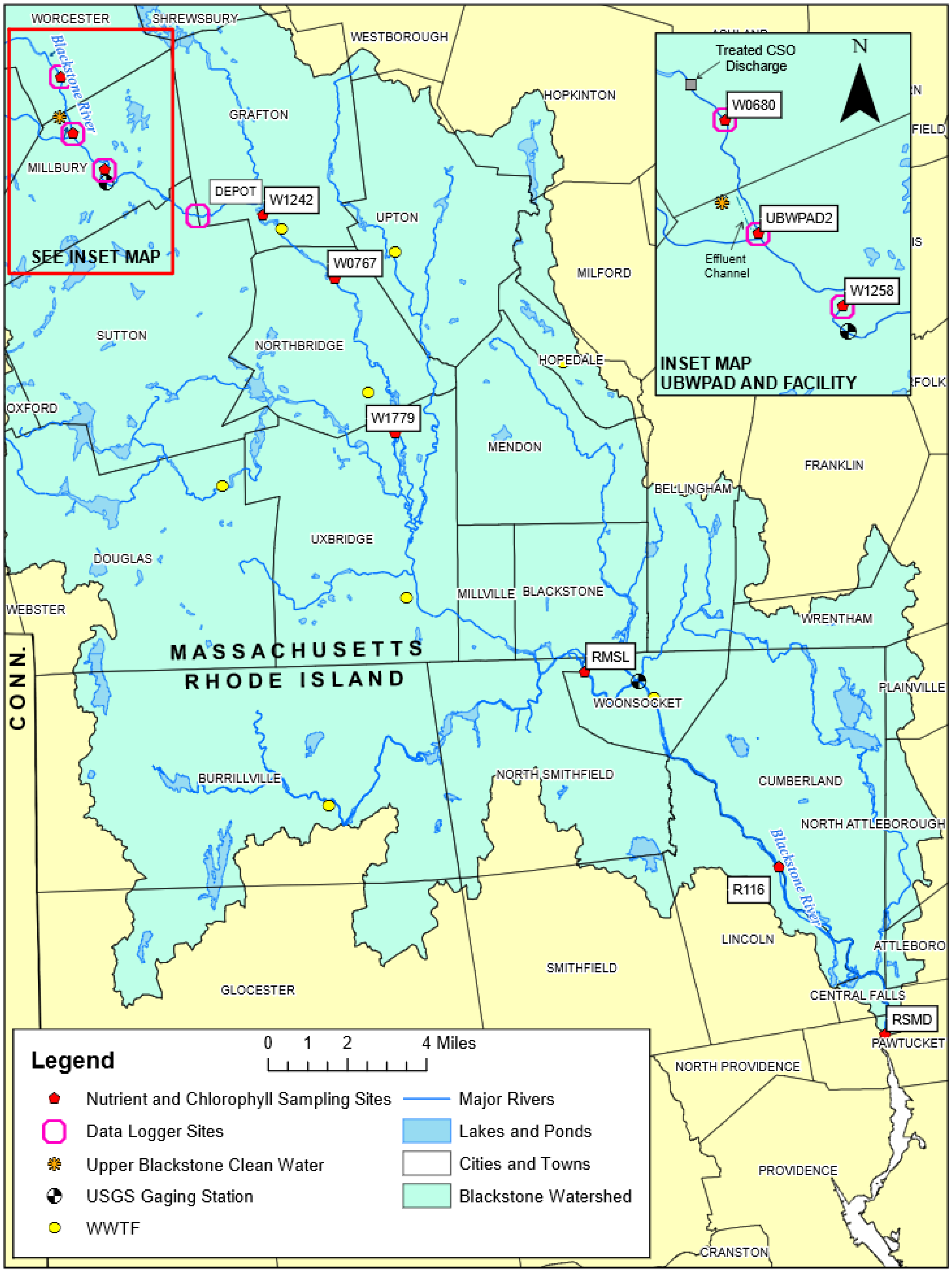


Figure 2: Blackstone River 2019 sampling sites and location of continuous data loggers

Notes about sampling site changes in 2019:

- The sampling location for site W0767, Sutton Street Bridge in Northbridge, MA was moved from the left bank just downstream of the bridge to a sampling location from the bridge on the downstream side at mid-channel to achieve a sample more representative of the bulk river flow. To evaluate the potential impact of this change, samples were collected from both locations in June, August, and October 2019. Relative percent difference was calculated for each pair of observation and were found to be acceptable (within 30%, the data quality objective we use for field duplicates) for all parameters discussed in this report (Table 3).
- Construction began at the Slater Mill Dam site in Pawtucket, RI (RMSD) in October 2019. Samples were still taken at the usual site in October, though the stream water was visibly more turbid than usual. In November the site was closed to the public, and samples were taken from the closest bridge upstream of the site (Exchange Street Bridge). No side-by-side samples could be taken, but a visual examination of the results, comparing the October and November results to results from previous months, did not indicate unusual or unexpected values for the parameters that are discussed in this report.

Table 3: Comparison of nutrient and chlorophyll-a results between historical and new sites at W0767

Date	Site ID	TP (ppb)	RPD	Chl-a (ppb)	RPD	TN (ppb)	RPD
6/19/2019	W0767	87.9	-26%	BRL	0%	2032	-6%
6/19/2019	W0767-BANK	114		BRL		2154	
8/15/2019	W0767	66.2	12%	5	0%	1985.01	7%
8/15/2019	W0767-BANK	58.7		5		1851.12	
10/9/2019	W0767	66	-4%	4.0	2%	2023.66	22%
10/9/2019	W0767-BANK	68.5		3.9		1618.94	

3.2 Sampling Dates and Data Collected

2019 sampling dates are summarized in Table 4.

Table 4: 2019 river sampling dates

Site ID#	4/23	5/21	6/19	7/17	8/15	9/11	10/9	11/6
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
W0767bank[1]			X		X		X	
W1242	X	X	X	X	X	X	X	X
W1258	X	X	X	X	X	X	X	X
UBWPAD2	X	X	X	X	X	X	X	X
W0680	X	X	X	X	X	X	X	X

Samples collected for nutrient analysis are analyzed for total ammonia nitrogen (dNH_4), dissolved nitrite-nitrate nitrogen (dNO_{23}), either total Kjeldahl nitrogen (TKN) or dissolved total nitrogen (dTN) depending on the analysis laboratory, particulate organic nitrogen (PON), total orthophosphate (TOP), total phosphorus (TP), total suspended solids (TSS), and chlorophyll-a (chl-a), **Table 5**. 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 5: 2019 river sampling program analytes and laboratories

Parameter	Upper Blackstone Lab	NBC Lab	UMass EAL	UMD Lab
Dissolved Ammonia (dNH_4)	--	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
Total Orthophosphate (TOP)	Apr – Nov All 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	--
Dissolved Oxygen (DO)	Apr-Nov All Sites & Continuous Jun-Oct 4 sites (meter)			
Water Temperature	Apr-Nov All Sites & Continuous Jun-Oct 4 sites (meter)			
pH	Apr-Nov All Sites (meter)			
Specific Conductance (SC)	Apr-Nov All Sites (meter)			

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 ~4,000 cfs[1] 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 cfs[2] 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.

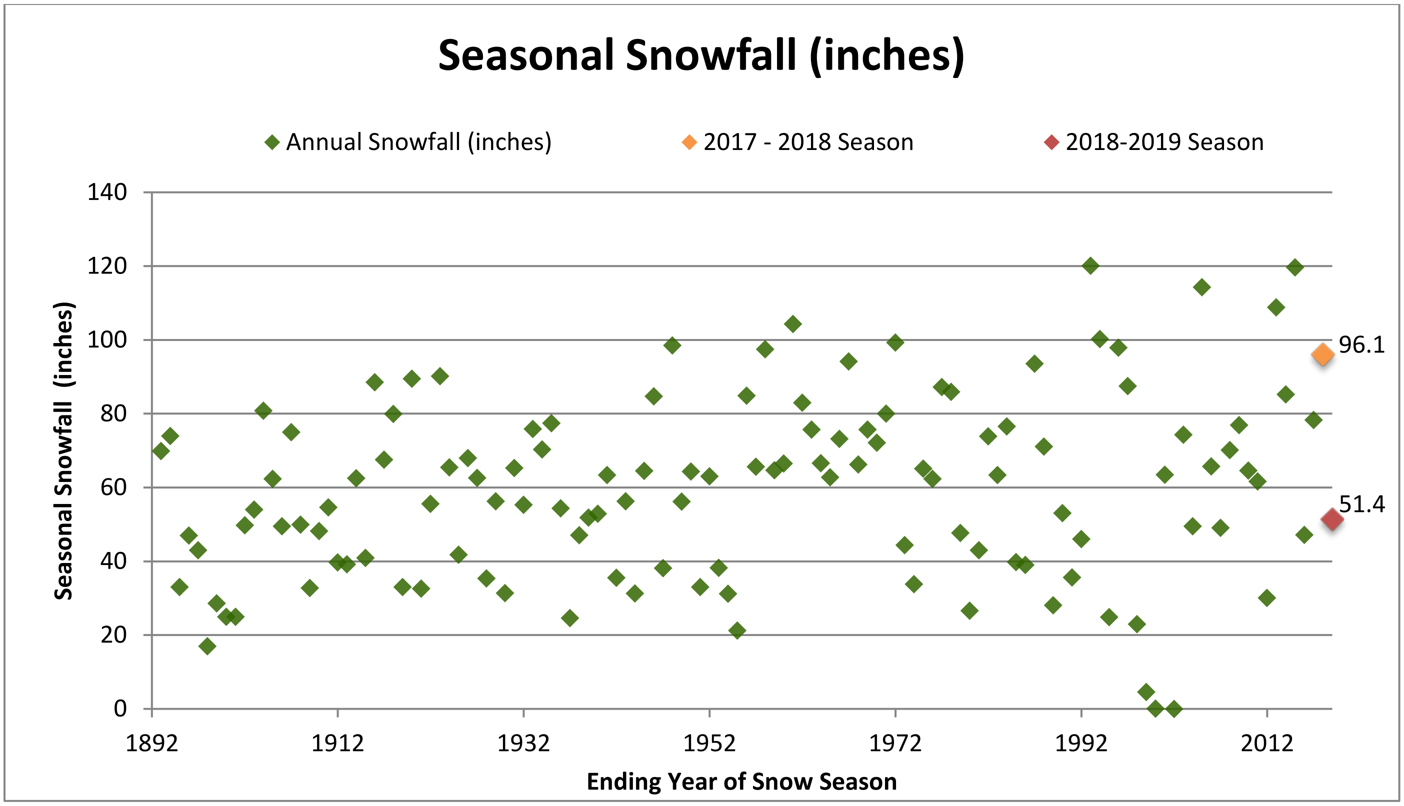
Data describing the 2019 environmental conditions are presented in this section. Precipitation and air temperature data are presented in Section 4.1, followed by a summary of the river streamflow conditions in Section 4.2. Section 4.3 provides a brief summary of the potential relative impacts of these 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). This 125-year record is summarized in **Figure 3** based on published monthly data. Snowfall accumulations from the winters of 2011 – 2012 through 2018 - 2019 are highlighted due to their potential influence on the subsequent sampling season results. The nine 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 6**. The 2019 sampling season was preceded by the third least snowy winter in the past nine years, with 51.4 inches of snowfall (ranked 79th since 1892).

[1] A flow of 4,000 cfs is exceeded ~1% of the time at the Woonsocket stream gaging station

[2] 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



(Note: year plotted is end of snow season)

Figure 3: Seasonal snowfall (inches) in Worcester from 1893 through 2019, inclusive

Table 6: Snowfall totals winters 2011-2012 to 2018-2019

	Snow (in)	Rank in 126 years of record (1 = snowiest)
Winter 2011 - 12	30.1	113th
Winter 2012 – 13	108.8	4th
Winter 2013 – 14	85.2	20th
Winter 2014 – 15	119.7	2nd
Winter 2015 – 16	47.2	86th
Winter 2016 - 17	78.3	27th
Winter 2017 - 18	96.1	11th
Winter 2018 - 19	51.4	79th

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 box plot, with the data for 2019 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." Temperatures in the winter (e.g., January-March), as well as April and June 2019 were close to average. May was colder than average, but the summer tended to be warmer than average, especially in July. While the monthly average temperature in October still reached the upper quartile of historical data, in November it dipped below the lower quartile, only to return near average historical value in December.

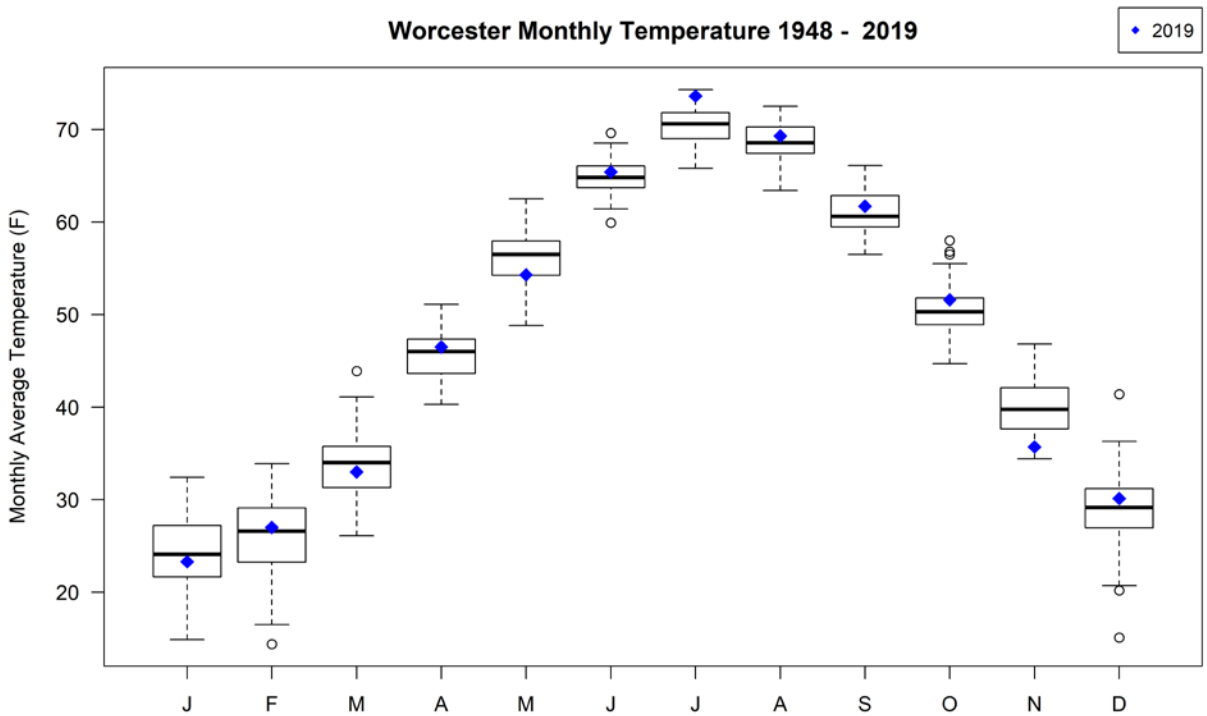
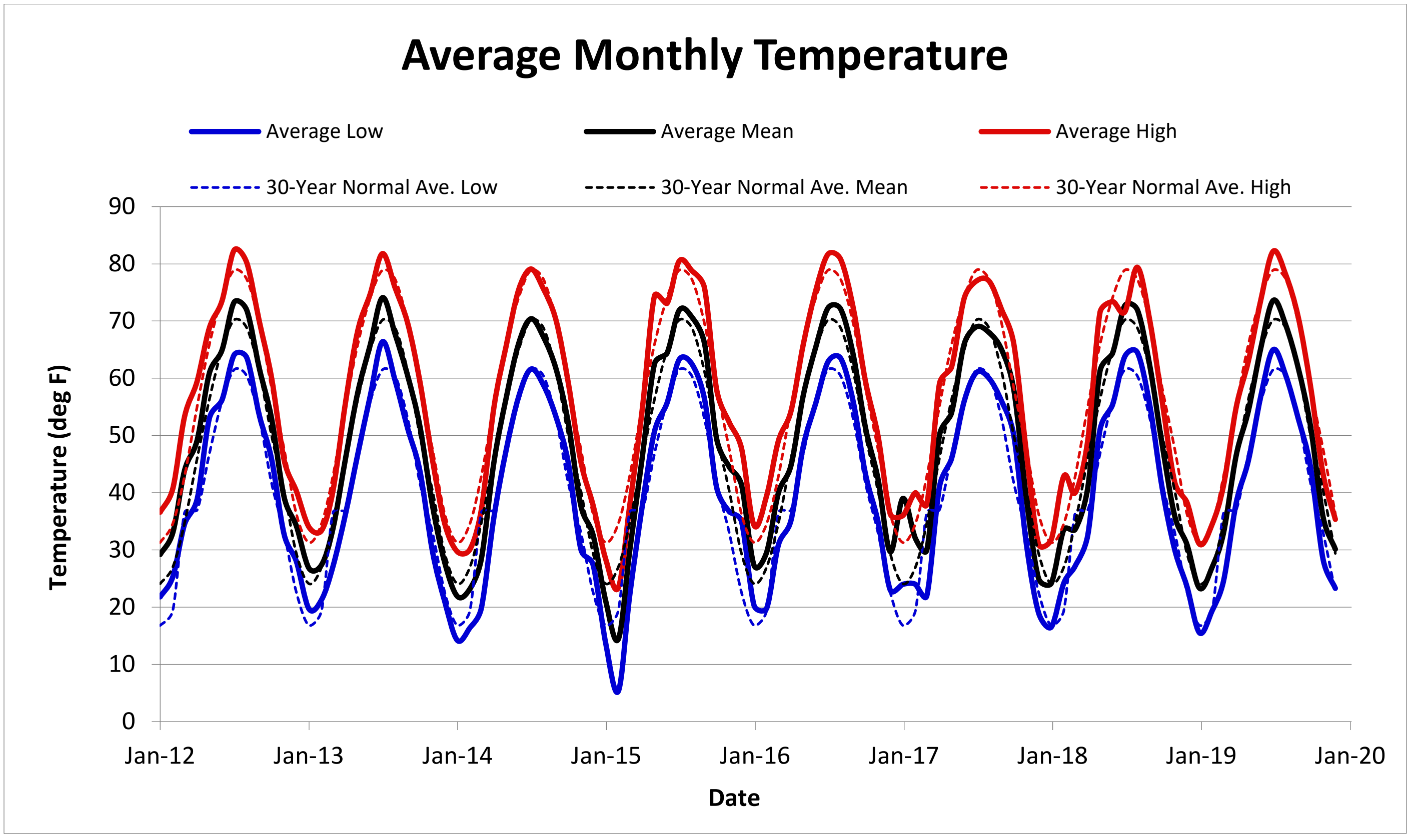


Figure 4: Worcester monthly air temperatures 1948 - 2019

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 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 2019 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.



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

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

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 2019, 54.7 inches, was somewhat higher than the average of the observed values since 1949 (47.9 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 2019 again shows higher precipitation amounts than average.

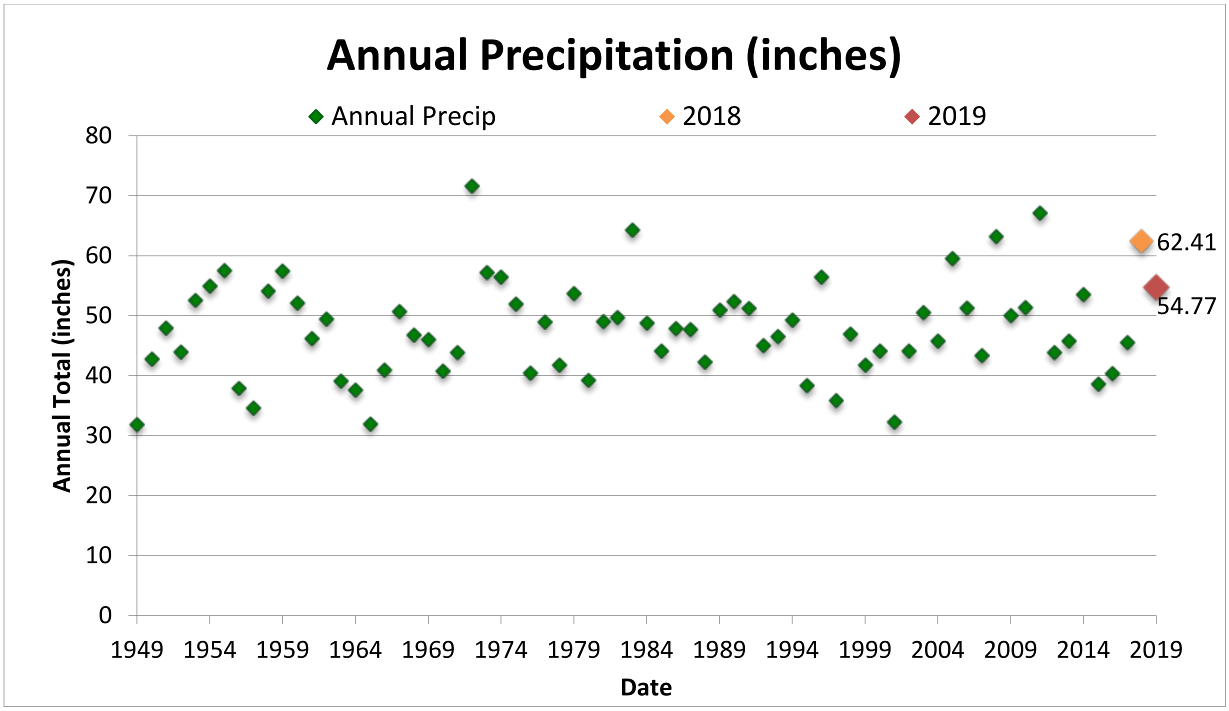
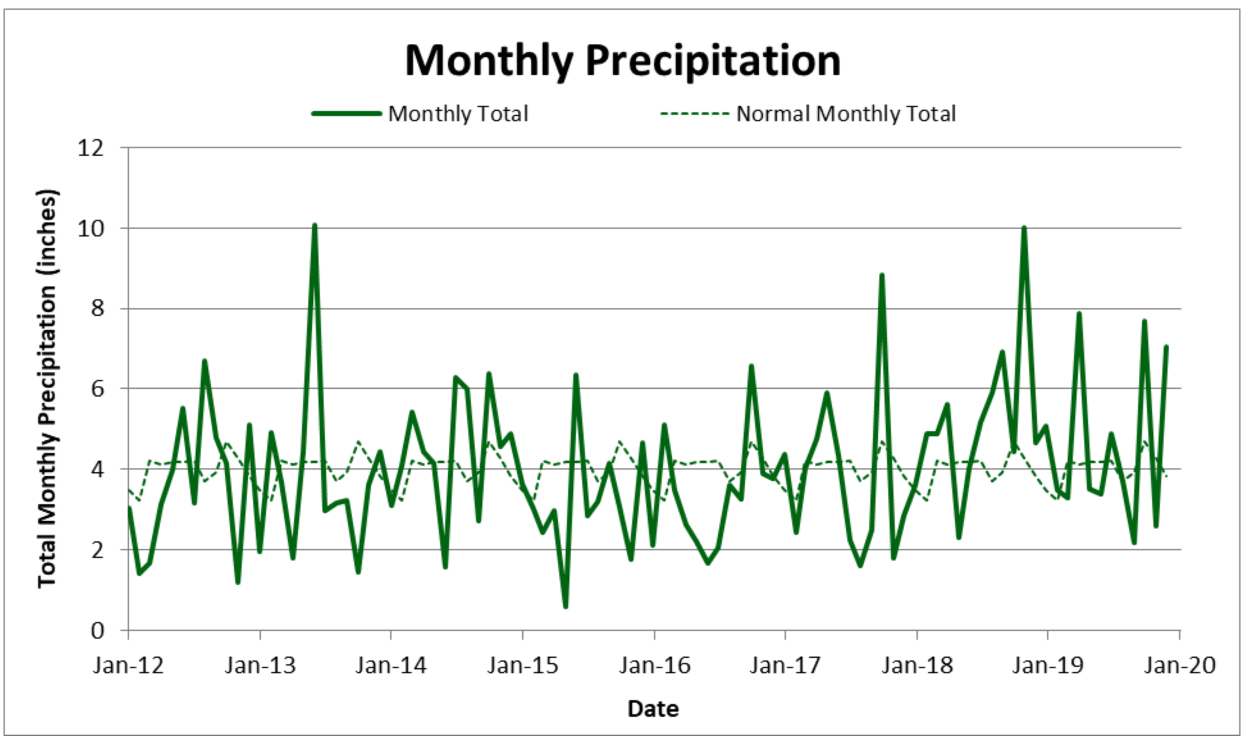


Figure 6: Annual precipitation (inches) in Worcester since 1949



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

Figure 7: Monthly precipitation totals 2012-2019 compared to normal monthly totals

Monthly precipitation totals since 1948 for Worcester are summarized using box plots on **Figure 8**. Data for 2019 are represented by blue diamonds. April, June, and October stand out as months when 2019 rainfall totals were higher than the historical median. Conversely, September and November 2019 experienced lower precipitation than historically. Monthly precipitation condition data for the 2019 sampling years compared to the NWS 30-year normal are provided in Appendix A.

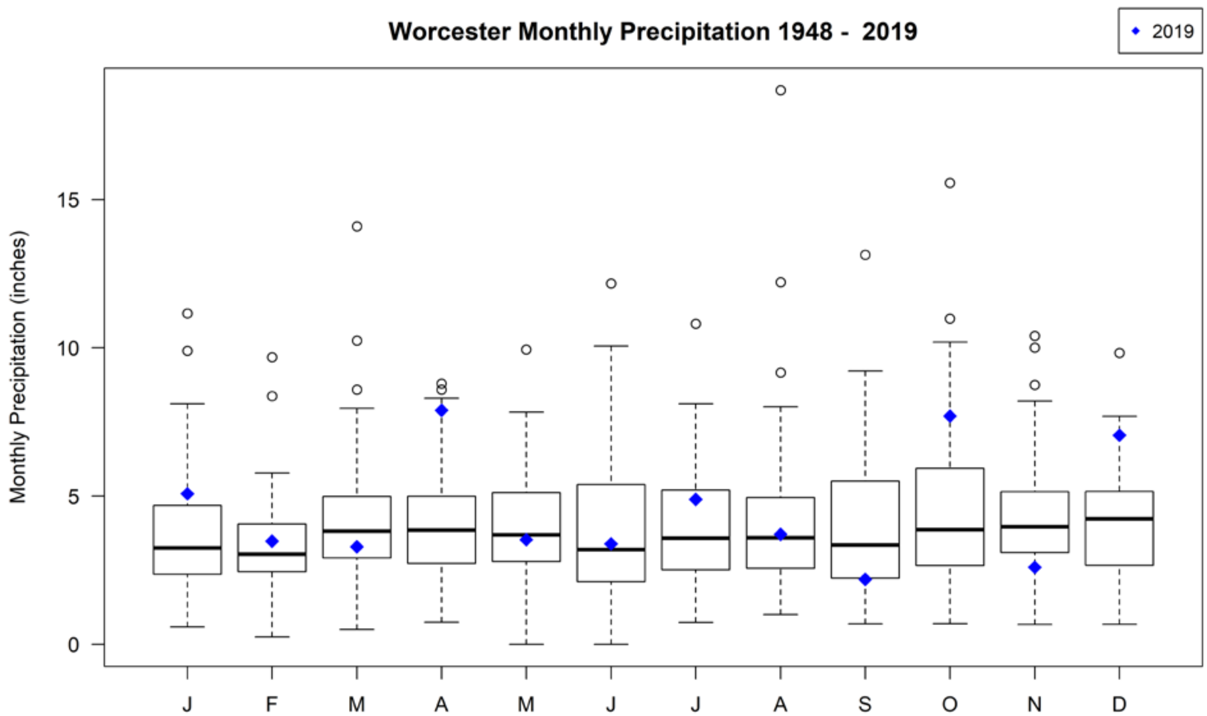


Figure 8: **Worcester monthly precipitation 1948 - 2019**

Daily precipitation data as measured at the Worcester Airport are plotted on **Figure 9** for 2019. 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 54.77 inches in 2019. Cumulative rainfall in the 2019 sampling season was higher than the historical cumulative until August, then lower than historically the rest of the year.

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 and chlorophyll-a. Sampling day and antecedent precipitation conditions are summarized in **Table 7** for all routine sampling dates in 2019. Most routine sampling in 2019 occurred on days with little to no precipitation, except on April 23rd. Significant rainfall (>0.5 inches) occurred during the week prior to sampling every month except August and September. 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.

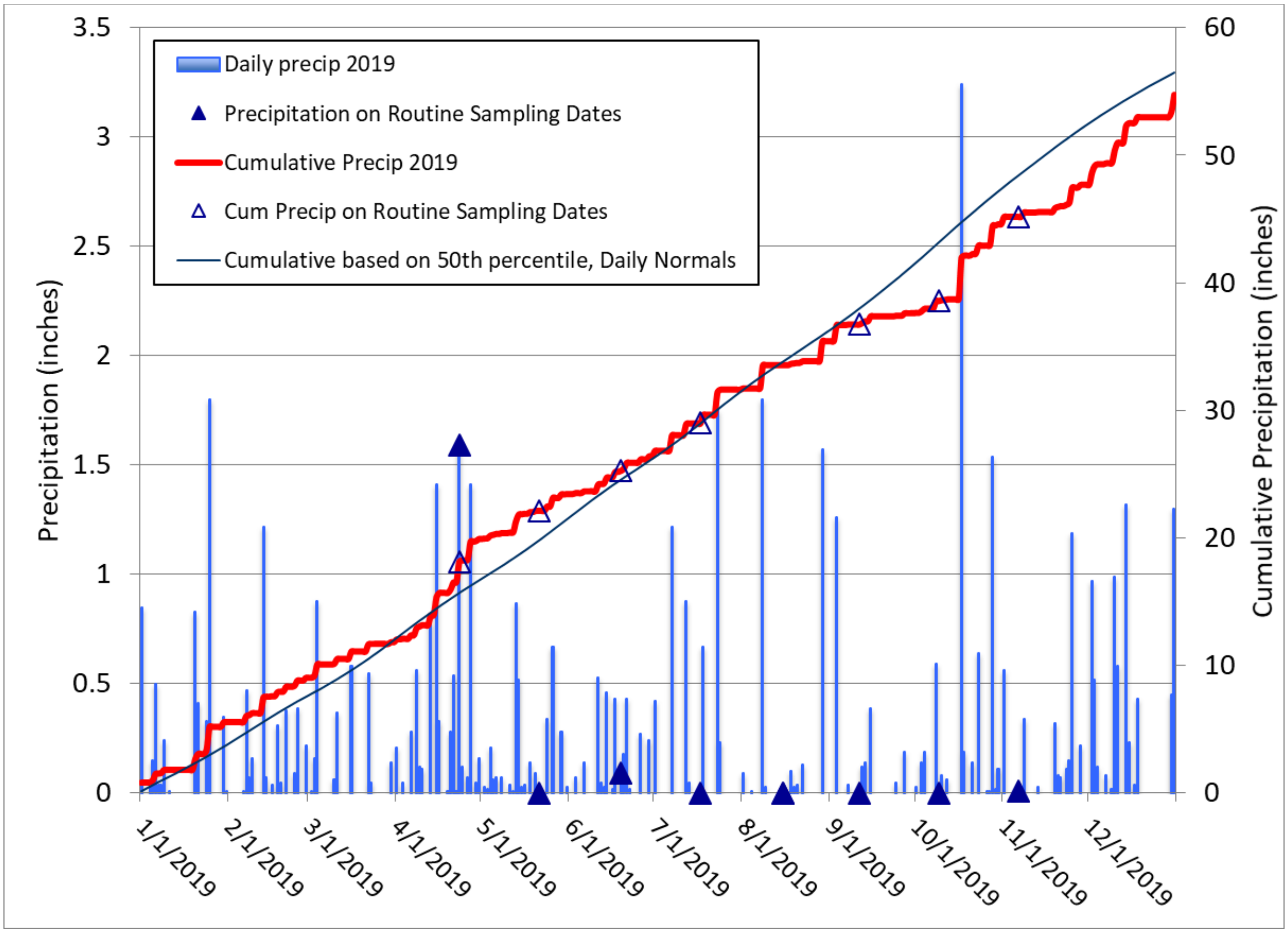


Figure 9: 2019 sampling season daily precipitation at Worcester Airport (KORH) compared against 50^{th} percentile daily normal precipitation

Table 7: Day-of and antecedent precipitation on routine sampling dates in 2019

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
23 April	1.59	0.01	0.83	1.17
21 May	0.00	0.09	0.23	0.82
19 June	0.09	0.00	0.45	0.99
17 July	0.00	0.00	0.00	0.93
15 August	0.00	0.00	0.00	0.03
11 September	0.00	0.00	0.00	0.04
9 October	0.00	0.59	0.59	0.92
6 November	0.01	0.00	0.00	0.67

4.2 Streamflow Conditions

Blackstone River Streamflow conditions during the 2019 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 2003 are summarized on **Figure 10** as a box plot, with the data for 2019 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 8**. Streamflows were above or at the median value until June, when they got lower or near the median. Flows were higher than historically at the Woonsocket gage in October and November.

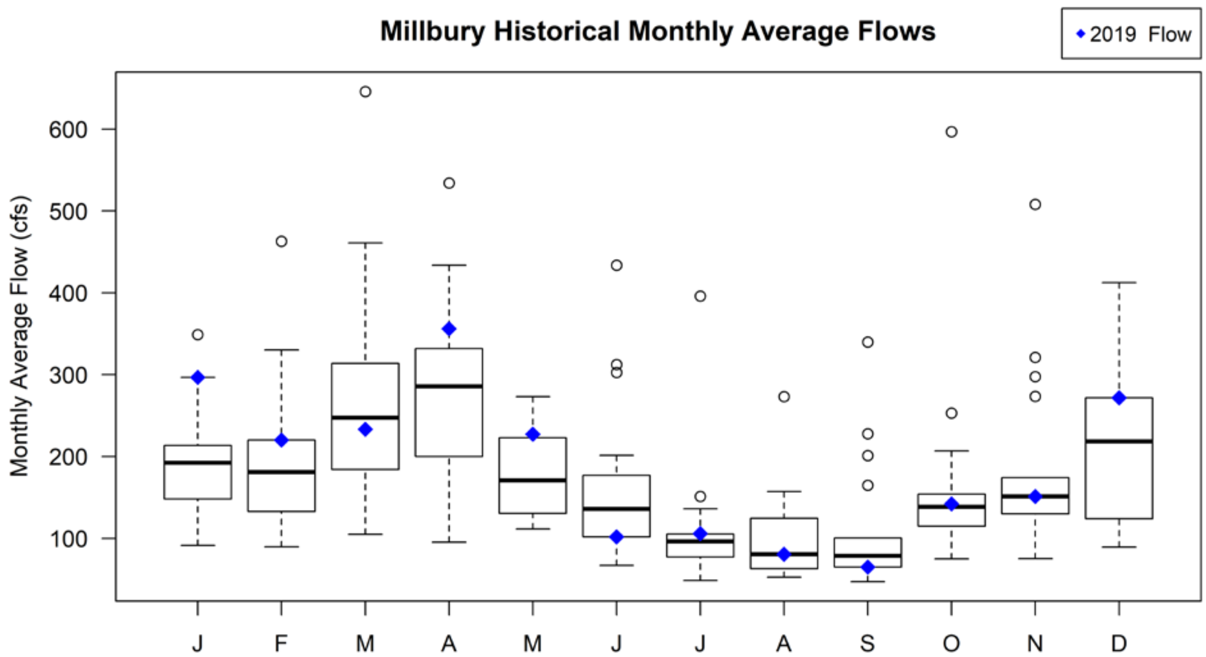


Figure 10: Millbury, MA, USGS gaging station 01109730 historical monthly average streamflows, 2003 - 2019

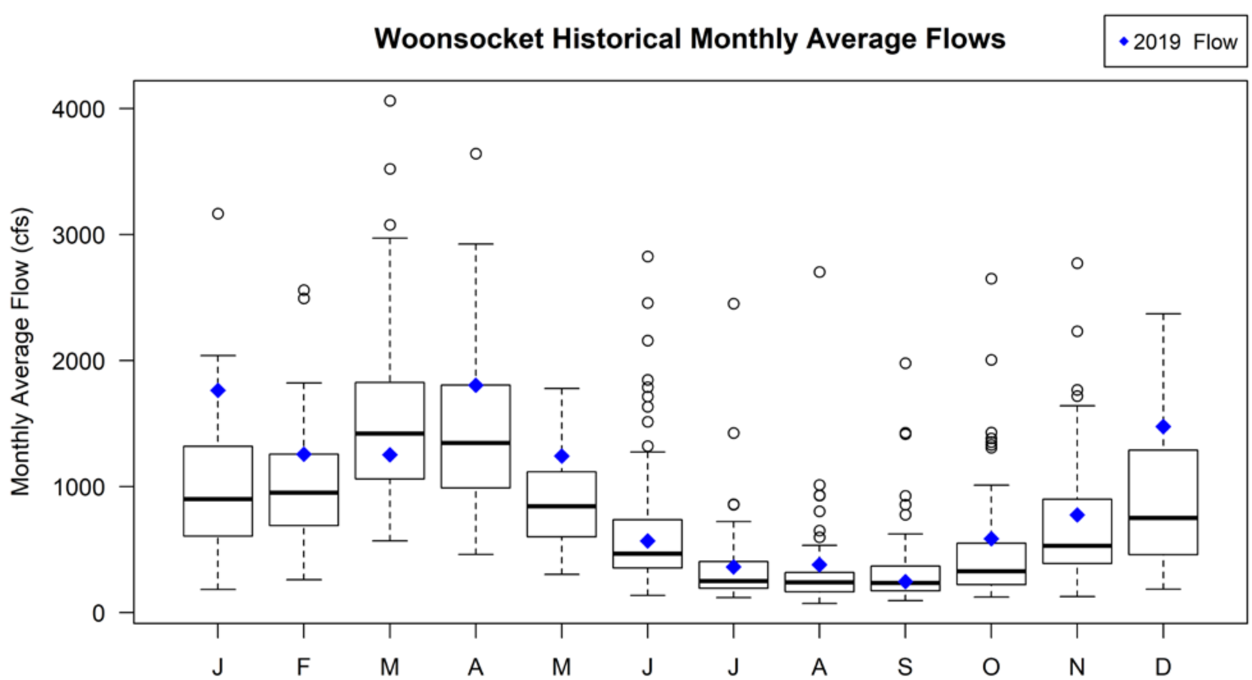
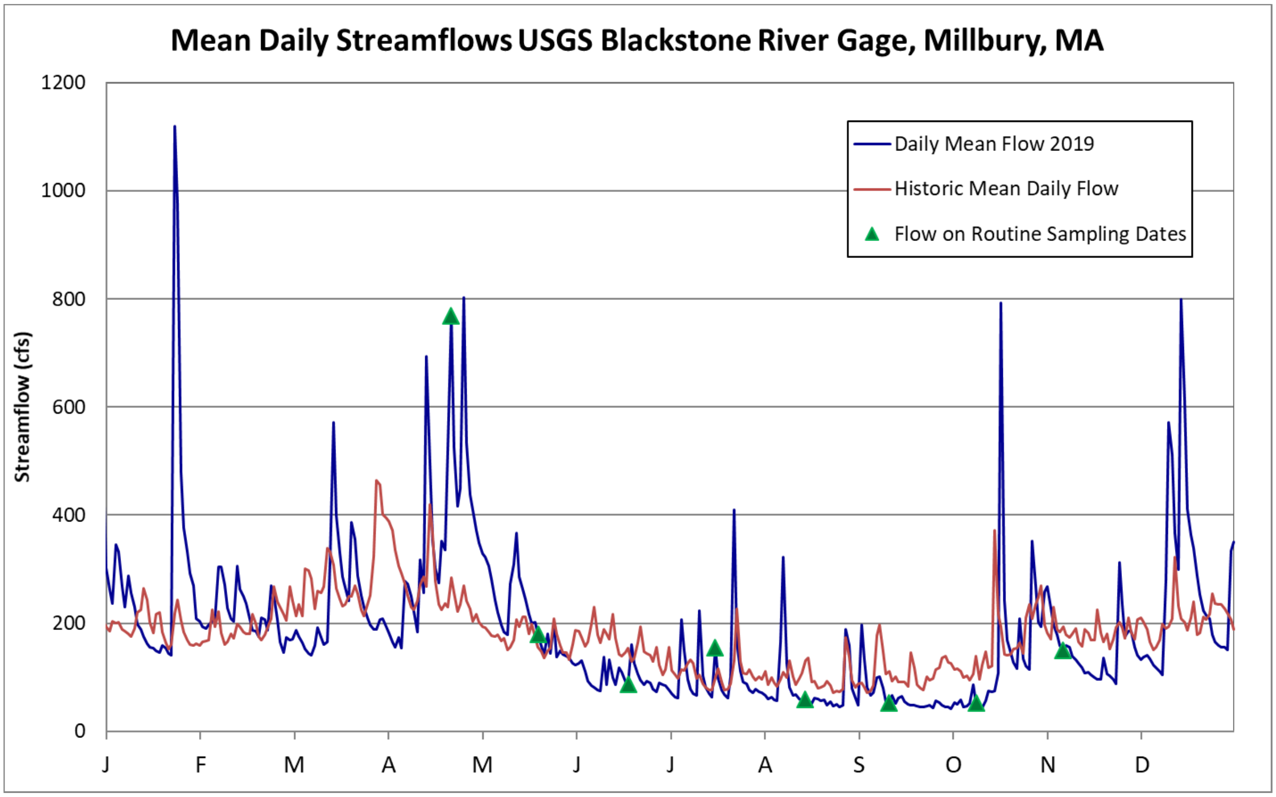


Figure 11: Woonsocket, RI, USGS gaging station historical monthly average streamflows, 1930 – 2019

Table 8: Mean monthly streamflows in 2019 compared to median, mean, minimum

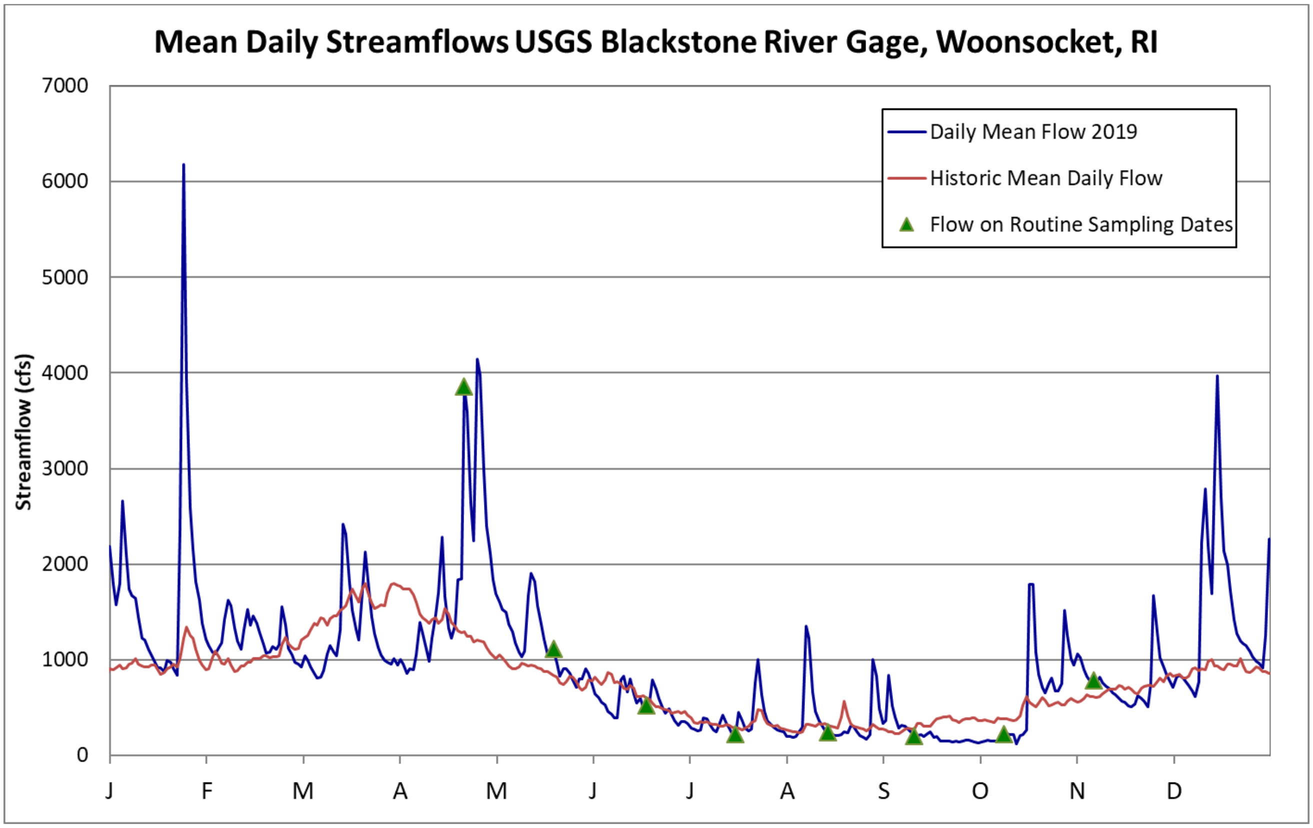
Millbury (cfs)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
2019 Monthly Q_{ave}	*356*	*227*	*102*	*106*	*81*	*65*	*142*	*151*
Median 2003 – 2019	*286*	*171*	*136*	*96*	*81*	*79*	*138*	*151*
Average 2003 – 2019	*282*	*175*	*163*	*112*	*101*	*109*	*166*	*182*
Minimum 2003 – 2019	*95*	*112*	*67*	*49*	*53*	*47*	*75*	*75*
Woonsocket (cfs)	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
2019 Monthly Q_{ave}	*1805*	*1243*	*568.6*	*362.5*	*380.5*	*245.1*	*586.3*	*774.9*
Median 1930 - 2019	*1346*	*843*	*467*	*251*	*240*	*234*	*326*	*529*
Average 1930 - 2019	*1435*	*877*	*649*	*342*	*309*	*329*	*475*	*696*
Minimum 1930 – 2019	*461*	*303*	*137*	*120*	*72*	*95*	*123*	*127*

Mean daily streamflows measured at Millbury and Woonsocket are compared to historic mean daily streamflows on **Figure 12** and **Figure 13** for the 2019 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. It has already been noted that monthly streamflows were high spring to early summer in the 2019 sampling season, then closer to the median the rest of the year, especially at the Millbury gage. In 2019 at the Millbury stream gage, daily streamflows were below average historical conditions except mid-April to mid-May and during short duration storms in August and the fall. At the Woonsocket gage, streamflow was more often above historical average then below. The exception is during the month of September when mean daily streamflow was below historical average.



(Notes: Historical Mean Daily streamflow data through 2019)

Figure 12: **2019 mean daily streamflows at USGS Millbury, MA stream gage**



(Notes: Historical Mean Daily streamflow data through 2019)

Figure 13: **2019 mean daily streamflows at USGS Woonsocket, RI stream gage**

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 2019

Sampling Date	Woonsocket, RI – USGS Station 01112500			Millbury, MA – USGS Station 01109730		
	2019 Mean Daily Q (cfs)	[a]Historical Mean Daily Q (cfs)	% of normal	2019 Mean Daily Q (cfs)	[a]Historical Mean Daily Q (cfs)	% of Normal
23 April	3860	1230	314%	769	205	375%
21 May	1110	736	151%	179	149	120%
19 June	527	582	91%	87	131	66%
17 July	226	285	79%	155	104	149%
15 August	240	307	78%	60	136	44%
11 September	205	335	61%	53	86	61%
9 October	219	520	42%	52	145	36%
6 November	782	577	136%	149	152	98%

[a] Historical Mean Daily Q (cfs) based on data through 2019

4.3 Environmental Conditions Summary

In 2019, spring temperatures were close to average, while summer temperatures were higher than average.

The spring was wet due to rainfall more than due to snowmelt, but summer precipitation was average and fall was dry compared to historical precipitation.

Consequently, streamflow was high in the spring and back to average in the summer and fall in the upper watershed, while it returned to higher than average in Rhode Island in November. 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 limits[3] 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 in accordance with the 2014 Administrative Order on Consent and a 2016 schedule modification. These steps include:

[3] 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.

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

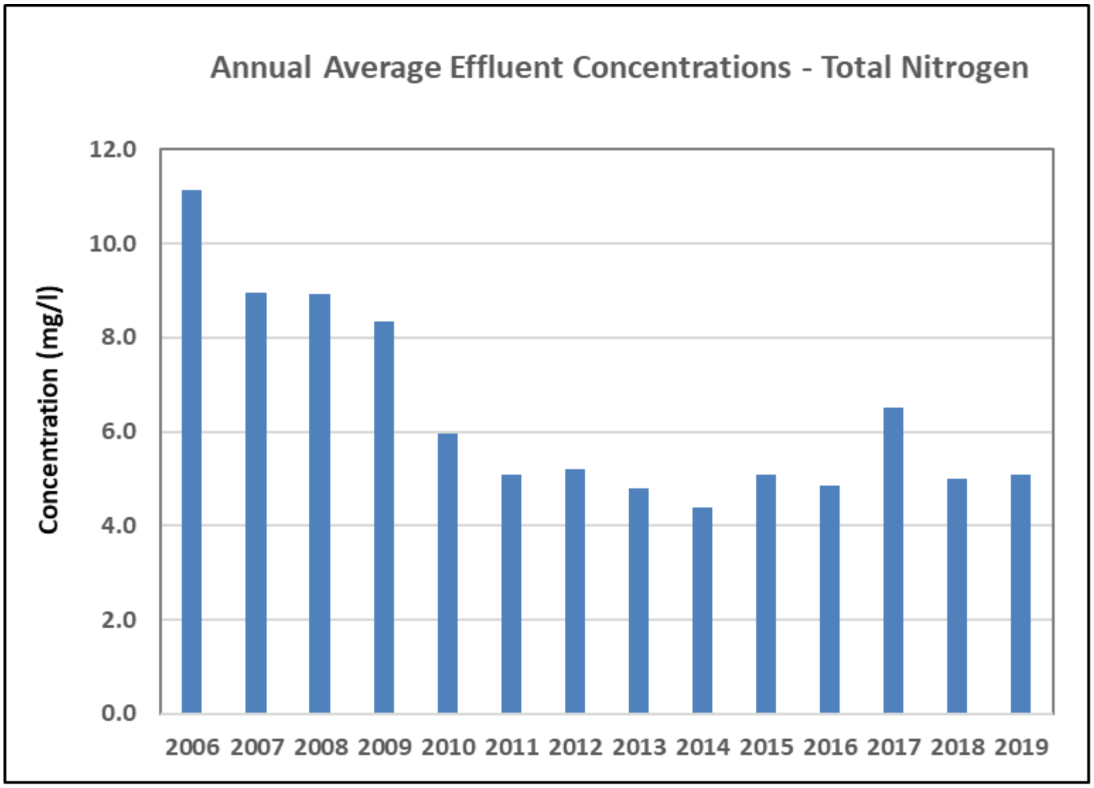
The facility is operated to remove nitrogen and phosphorus year-round, even though it has only a May – October seasonal nitrogen permit limit, and much less stringent wintertime limits for total phosphorus.

Figure 14 shows the actual effluent TN and TP annual 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**	**2019**
Total Phosphorus (mg/L)								
Apr – Oct (summer)	0.48	0.17	0.35	0.18	0.20	0.17	0.20	0.17
Nov – Mar (winter)	0.43	0.17	0.19	0.18	0.55	0.34	0.12	0.11
Total Nitrogen (mg/L)								
May – Oct (summer)	5.2	4.3	4.5	4.6	3.9	5.0	4.90	5.1
Nov – Apr (winter)	4.0	5.5	4.6	5.3	6.1	9.1	5.1	5.3

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



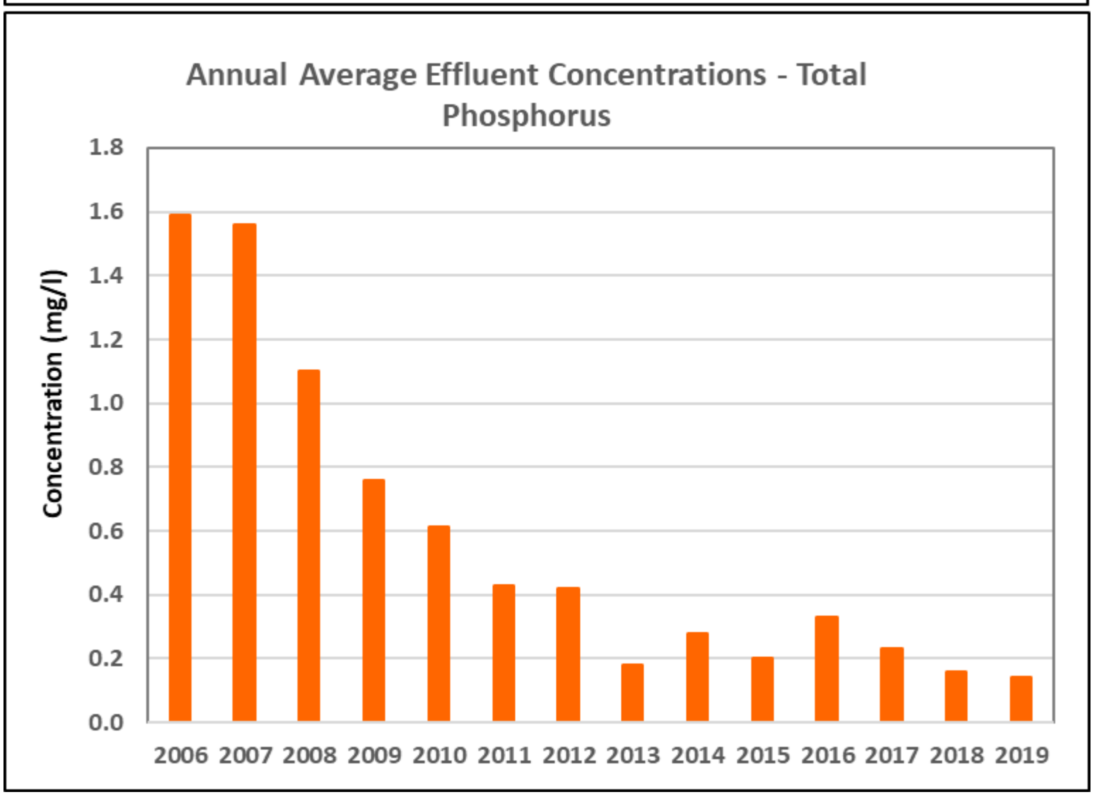


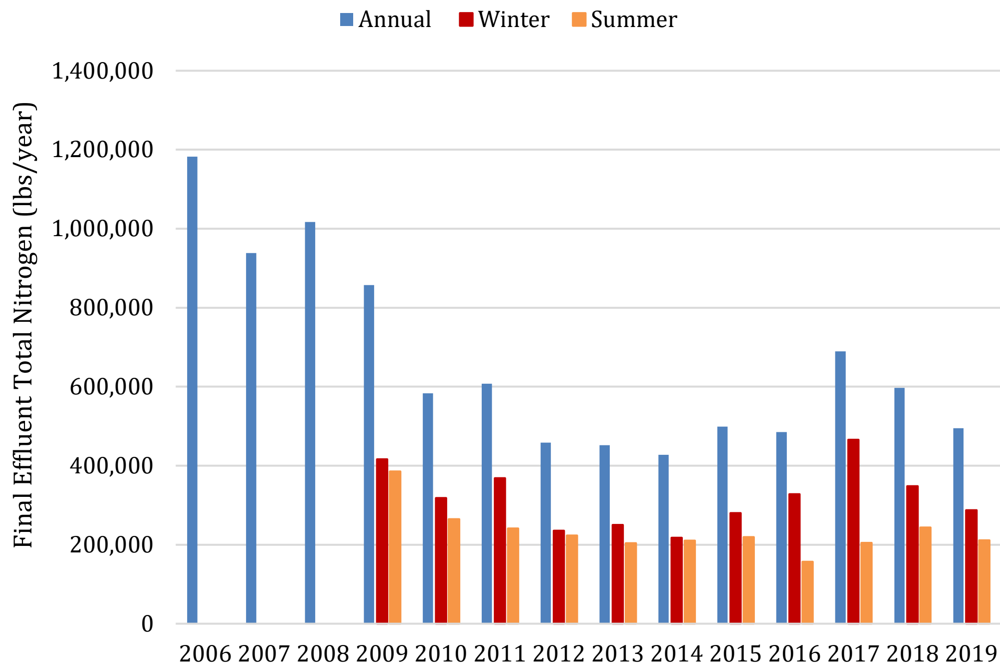
Figure 14: Annual average effluent total nitrogen and total phosphorus concentrations 2006 – 2019

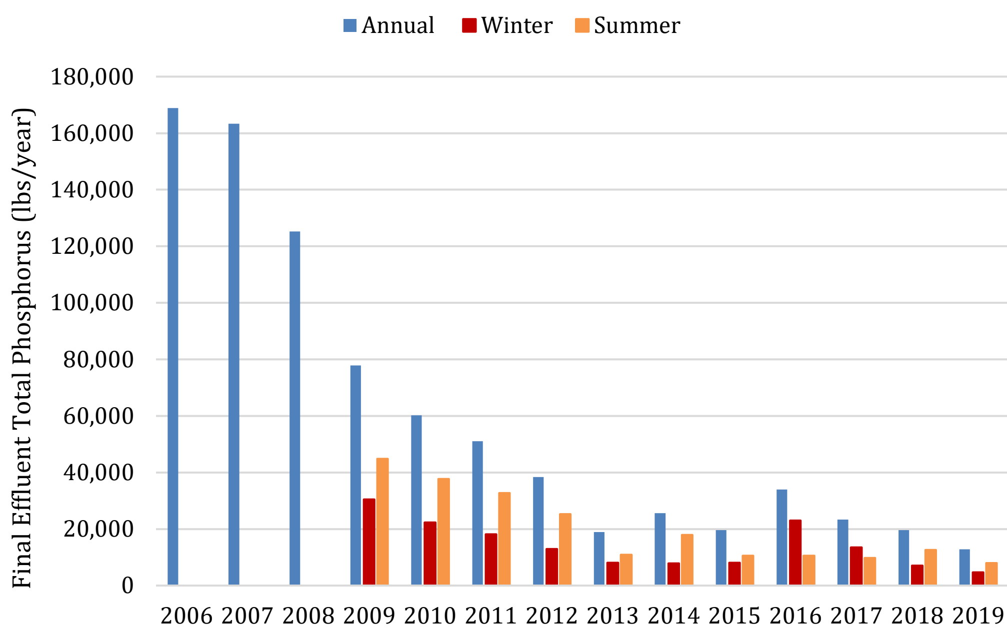
Yearly TP and TN effluent loads prior to plant upgrade (2006-2008) and since 2012 are shown in **Table 12**, along with percent reduction in loads in the effluent since 2006-2008

Table 12: 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%
2019	12.8×10^3	92%	495×10^3	53%

Figure 15 shows the effluent TN and TP annual total loads since 2006, and seasonal loads for summer and winter for 2010-2019.





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

Figure 15: Total annual, winter permit, and summer permit total nitrogen and total phosphorus loads to the Blackstone River 2006 – 2019

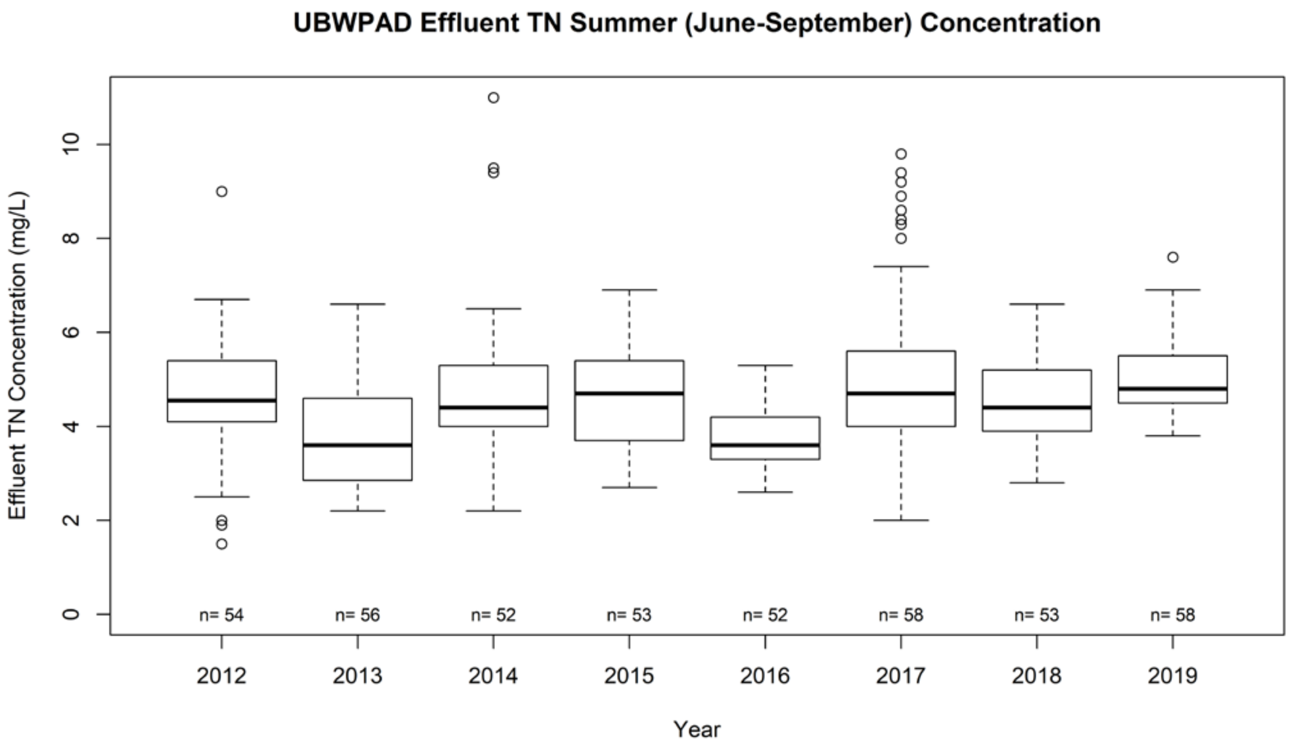
The highest biological activity in the river typically occurs during the warmest months of the year, from June through September. It is thus also useful to identify year-to-year differences in effluent nutrient characteristics for this summer growing period~~,~~ which may provide insight into river conditions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

Effluent nutrient and flow data during each year from 2006 - 2019 were used to calculate the daily average concentration and load from June through September, **Table 13**.

Table 13: Average of the daily effluent nutrient characteristics during the June - September growing season in 2006 to 2019, and Flow (Q) during this season from 2009 to 2019.

	Effluent Flow	Effluent TP		Effluent TN	
Year	**June – September Ave. Mean Daily Q (cf/s)**	**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	n/a	1.7	403	NA	NA
2007	n/a	2.1	424	8.3	1,687
2008	n/a	1.5	421	8.0	2,178
2009	54.9	0.9	238	7.8	2,089
2010	35.7	1.0	237	6.1	1,346
2011	53.6	0.4	151	4.2	1,411
2012	39.9	0.4	99	4.6	1,094
2013	48.3	0.1	45	3.8	1,065
2014	38.2	0.5	114	4.8	1,104
2015	43.2	0.2	44	4.5	1,167
2016	33.1	0.2	43	3.8	782
2017	38.3	0.2	36	4.4	1,729
2018	41.3	0.2	53	4.8	1,280
2019	38.0	0.2	43	5.1	1,066

A box plot of the daily data from June through September each year is shown on **Figure 16** for concentrations and **Figure 17.** for loads from 2012 – 2019. The box plots provide an indication of the day-to-day variability during the June – September growing period each year of the monitoring program.



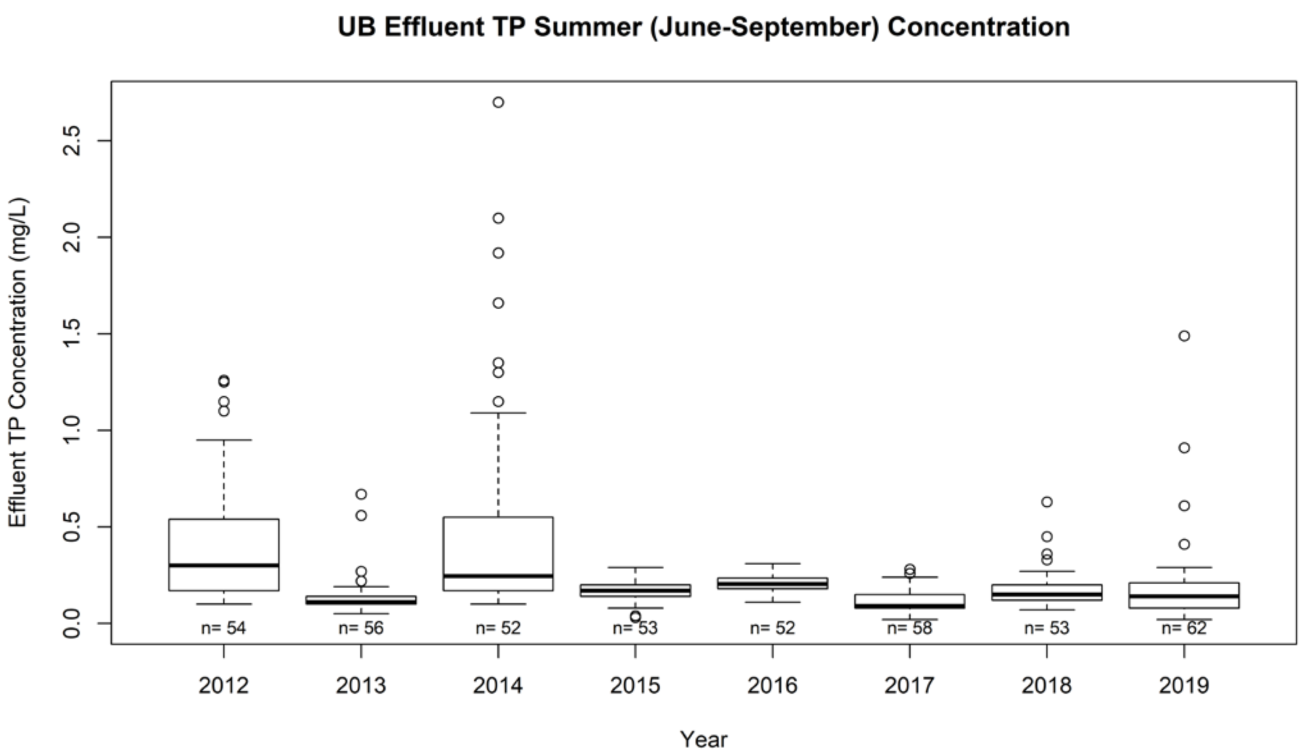
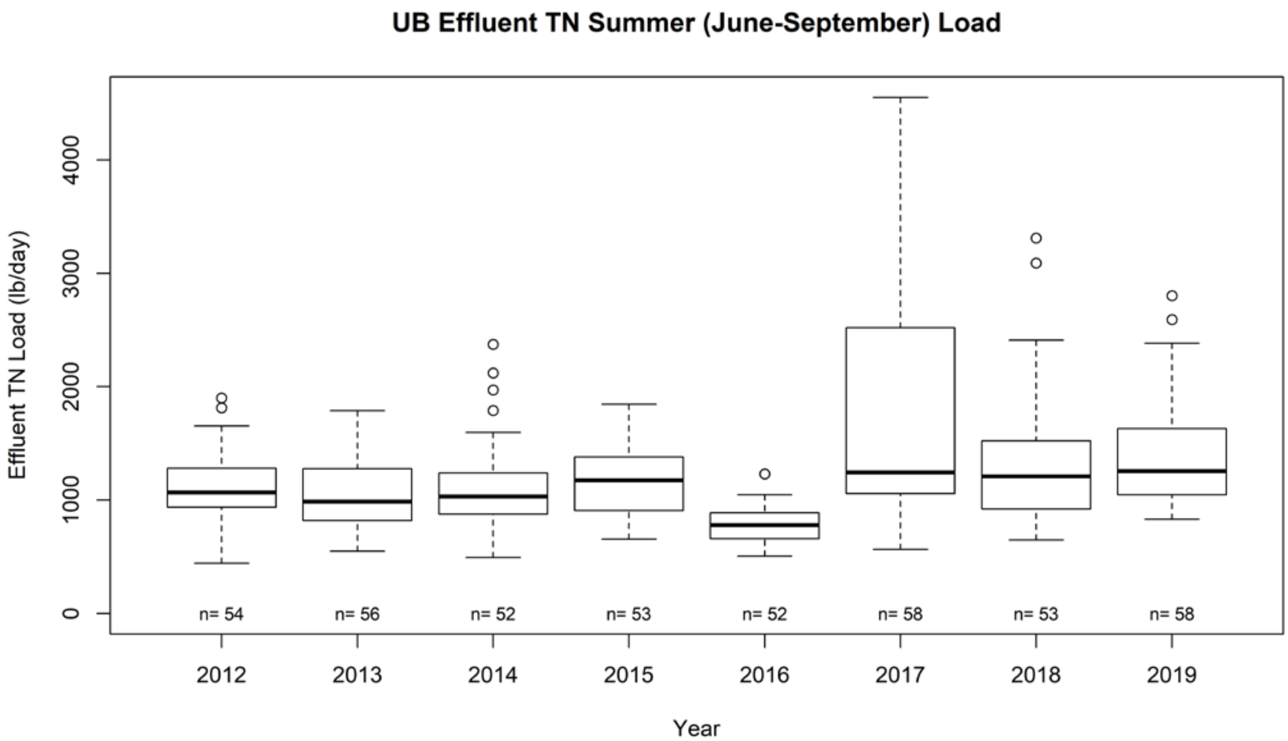


Figure 16: Upper Blackstone daily effluent TN and TP concentrations by year from June - September



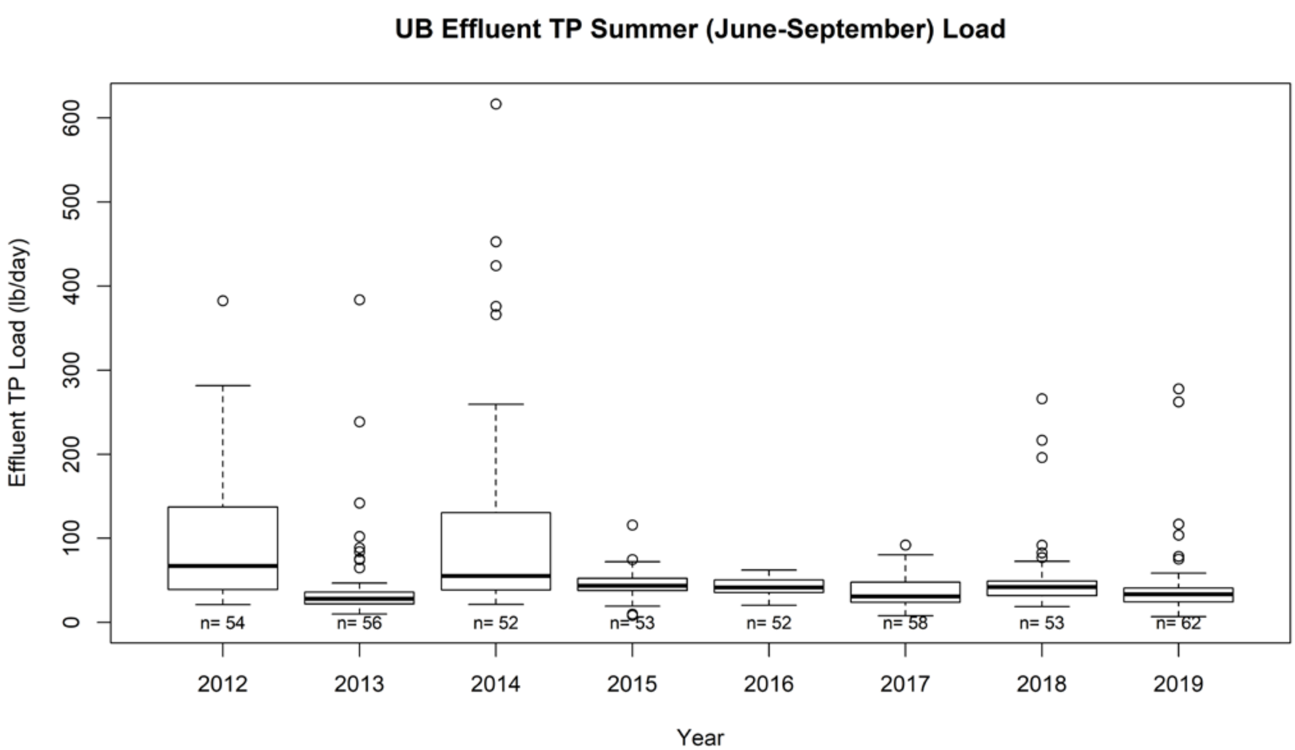


Figure 17: Upper Blackstone daily effluent TN and TP loads to the river by year from June - September

The interquartile range of daily TN effluent loads from June – September has been relatively constant since 2012. Daily growing season TN loads in 2019 were similar to data from 2015 – 2018, although levels were slightly higher than in 2018. TP effluent loads during the summer growing season showed little day-to-day variability, as indicated by a small interquartile range in 2013 and 2015-2019, but larger variability in 2012 and 2014, when Upper Blackstone refined its optimization process. Time series plots of effluent TP and TN characteristics, as well as effluent flow, are included in Appendix B.

Upper Blackstone's effluent discharge can account for a significant percentage of the flow in the Blackstone River. The average daily Upper Blackstone effluent flow contributions to summer flows (June through September) at Millbury on a yearly basis since 2009 vary between 33% and 64%. In 2019, Upper Blackstone flow contributed between 16% (minimum) and 73% (maximum) of the daily streamflow at Millbury, averaging 49% from June to September.

This contribution can be examined on a daily basis, and **Table 14** lists calculated estimates of the relative contribution of Upper Blackstone effluent flow to the streamflow measured at the Millbury gage on each of the 2019 sampling days. On most sampling days, this calculated value was above 30%, except in April (14%) and May and November (28% each).

Table 14: **Relative contributions by volume on sampling days 2019**

Sampling Date	Upper Blackstone % of Millbury streamflow
4/23/2019	14%
5/21/2019	28%
6/19/2019	45%
7/17/2019	32%
8/15/2019	57%
9/11/2019	67%
10/9/2019	63%
11/6/2019	28%

6.0 Sampling Season Data for 2019

Routine monitoring was conducted monthly from April to November for nutrients, chlorophyll-a, dissolved oxygen, temperature, conductivity, and pH at nine in-stream locations. Sampling and field measurements were conducted monthly, regardless of streamflow conditions. Continuous data loggers monitoring water temperature and dissolved oxygen were installed on July 9, 2019 at W0680, UBWPAD2, W1258, and Depot, and were removed on October 29, 2019.

In order to provide a more focused look at the impact of Upper Blackstone effluent quality 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).

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 field measurement results. In-stream data are reported as ppb in this report. To compare with effluent data from the previous sections, note that 1 mg/L = 1000 ppb = 1 µg/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. **Figure 18** shows calculated flows on each sampling day at each sampling site compared to mean historical flow at that site. **Figure 19** is zoomed in to the lower ratios in order to distinguish the sites. To obtain estimated sampling day flows for each site, a ratio of flows at Millbury, MA to Woonsockett, RI USGS gages on sampling days is calculated first, then compared to a spreadsheet containing flow ratios between gages and sites, as computed for the years 1997 to 2011 by the HSPF model (UMass and CDM Smith, October 2011). The ratio closest to the calculated ratio that is also within a similar hydrological period is chosen, and the computed ratios at each site are multiplied by the actual flow at the nearest gage on the sampling day. The mean historical flow is computed by taking the average from computed flows at those sites during the years 1997-2011 using the HPSF model (UMass and CDM Smith, October 2011).

Data points for each site are displayed against areas showing low, average, and high streamflow conditions. Low streamflow conditions were defined as 2019 estimated streamflow that are less than half of the average streamflow in a reach, high streamflow conditions were defined as 2019 estimated streamflow greater than 1.5 times the average streamflow in a reach, and all other streamflows were categorized as average. It is evident that in April, all sites experienced very high flows compared to average flows, while the rest of the season most sites experienced average flows. A few sites had low flows between June and November, mostly W0680, W1242, and W1779 and W0767 a few times.

Calculated mean streamflow at each sampling site is shown on **Figure 20**. The data for 2019 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 2019 sampling season saw the second highest streamflow conditions during sampling days since 2012, especially at the Rhode Island sites (the 3 most downstream sites).

In the subsequent discussion, TP and TN concentration data are similarly summarized based on streamflow condition for comparison against data from other time periods.

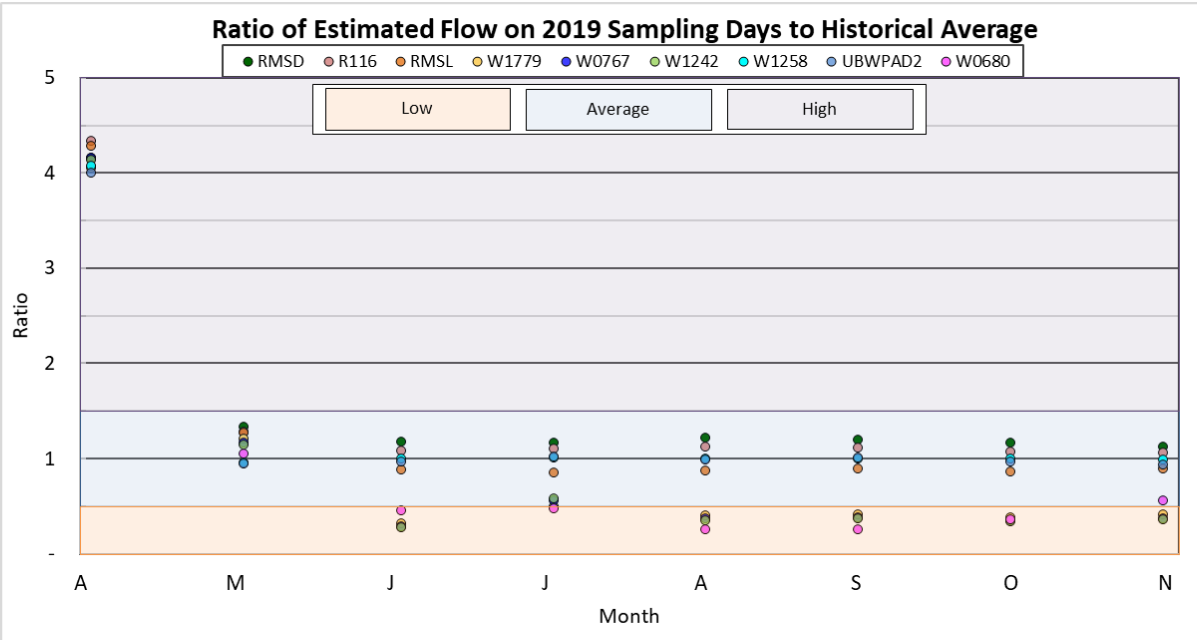


Figure 18: Ratio of estimated flow to historical average flow at each site for each sampling day in 2019

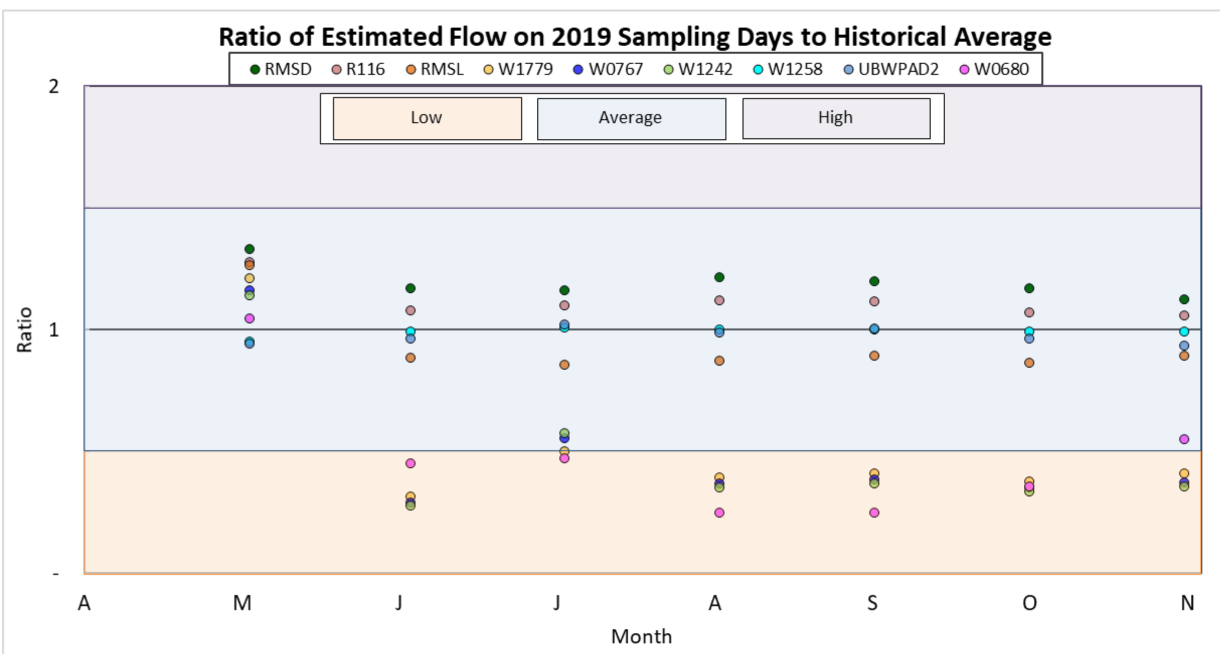
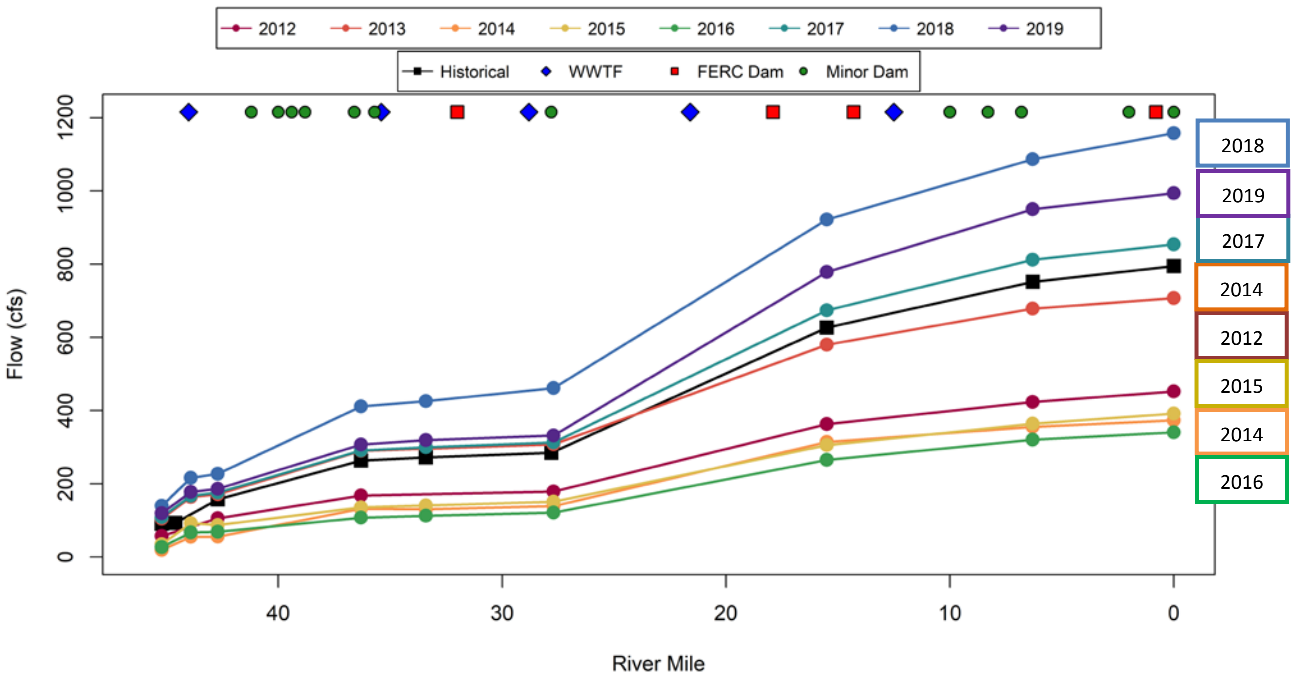


Figure 19: Detail of Figure 18 to distinguish sites in the Low ratio zone

Yearly Calculated Mean Flows on Sampling Days, 2012 - 2019



Note: Historical data covers years 1997-2011

Figure 20: **Comparison of average calculated streamflow conditions on sampling date by year**

6.2 Routine Monitoring Data

Sampling data results for TP, TN, chlorophyll-a, and field measurements are summarized in sections 6.2.1, 6.2.2, 6.2.3, and 6.2.5, respectively, using a consistent series of plots and analyses. Sufficient data are now available to conduct a robust trend analysis based on streamflow-weighted concentration data. Streamflow-weighted concentration trend analyses are presented for TP, TN, and chlorophyll-a in Section 6.2.4. 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 21** using box plots. Data for all sampling locations are grouped by year. While, in general, the same sample locations were surveyed 2012-2019, 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 (± 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 2019 were characterized by the smallest interquartile range and lowest median value compared to earlier sampling years. The two TP concentration data points identified as outliers in 2019 on **Figure 22** are for UBWPAD2 in June and July, and are lower than outliers in prior years. The monthly average streamflow was low in June at the Millbury stream gage, but in July it was slightly above the median.

The mean summer (June – September) TP concentration at each sampling location in the Blackstone River is shown on **Figure 23** for sampling data collected since 2012. Data are clustered by sampling site, plotted from the upstream W0680 site (left) to the downstream RMSD site (right). Each year is shown as a different color, with 2019 in brown. At most sampling locations, average TP concentrations in 2019 were the lowest observed in the past four years, except at W1258.

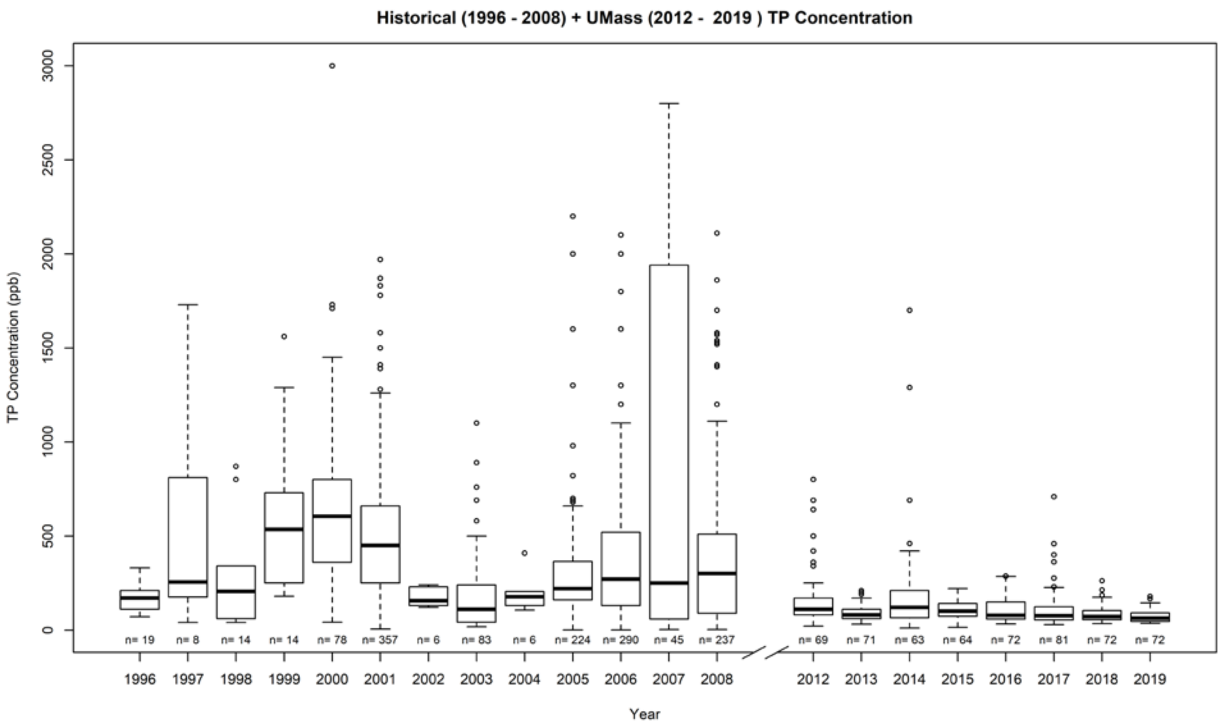
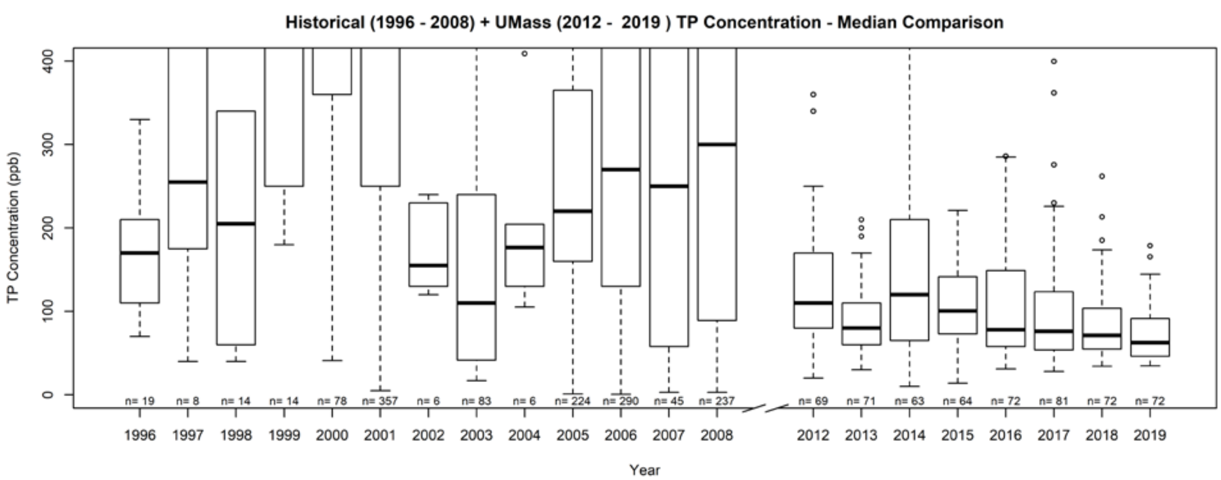


Figure 21: **TP concentrations observed in the river 1996 – 2008 and 2012 – 2019**



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

Figure 22: **TP concentrations observed in the river 1996 – 2008 and 2012 – 2019**

TP (ppb)	W0680	UBWPAD2	W1258	W1242	W0767	W1779	RMSL	R116	RMSD
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
2019	50.7	134.8	108.5	90.2	70.8	123.3	57.1	52.2	61.2

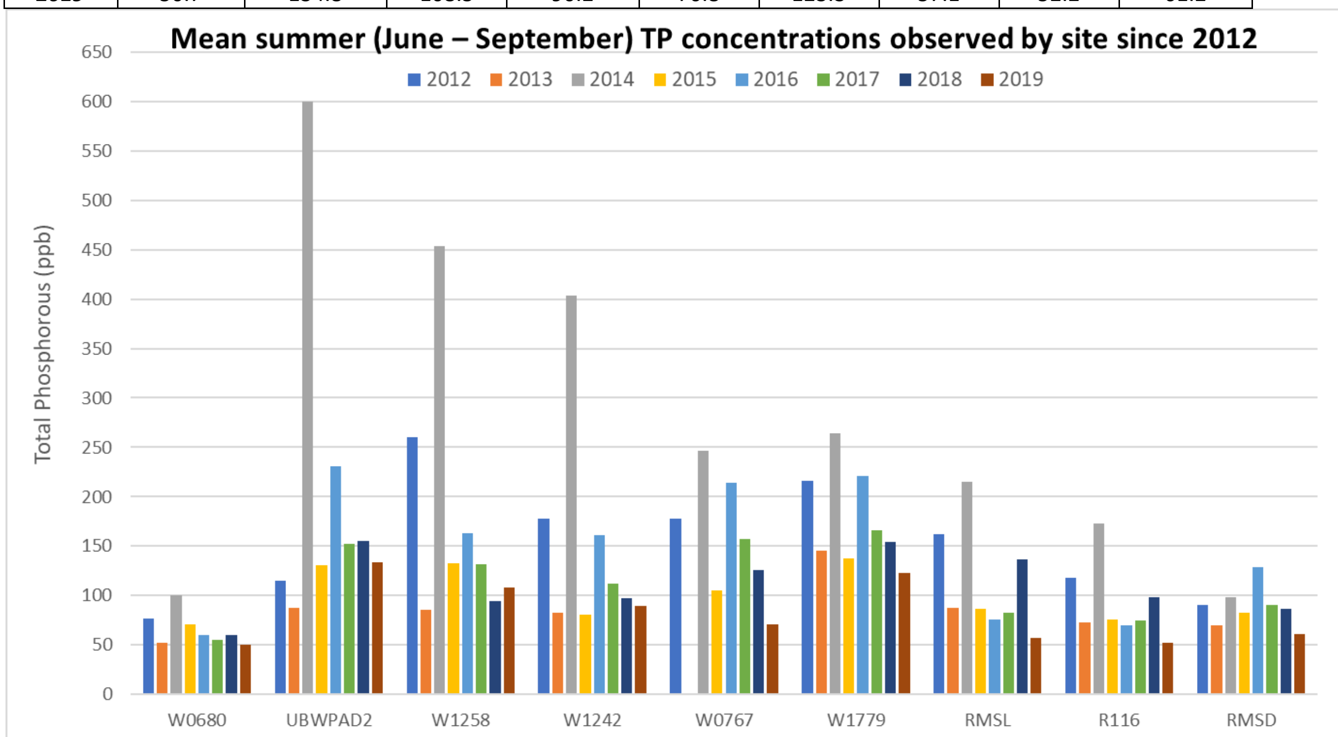


Figure 23: Mean summer (June – September) TP concentrations observed by site since 2012

The full range of TP concentrations observed at each site since 2012 is summarized in **Figure 24** with sites plotted from the upstream W0680 site (left) to downstream RMSD site (right) as before. Average concentrations in 2019 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 2019 fell on the median at the upstream-most site~~,~~ and were in the lower quartile range of values observed since 2012 at all the other sites.

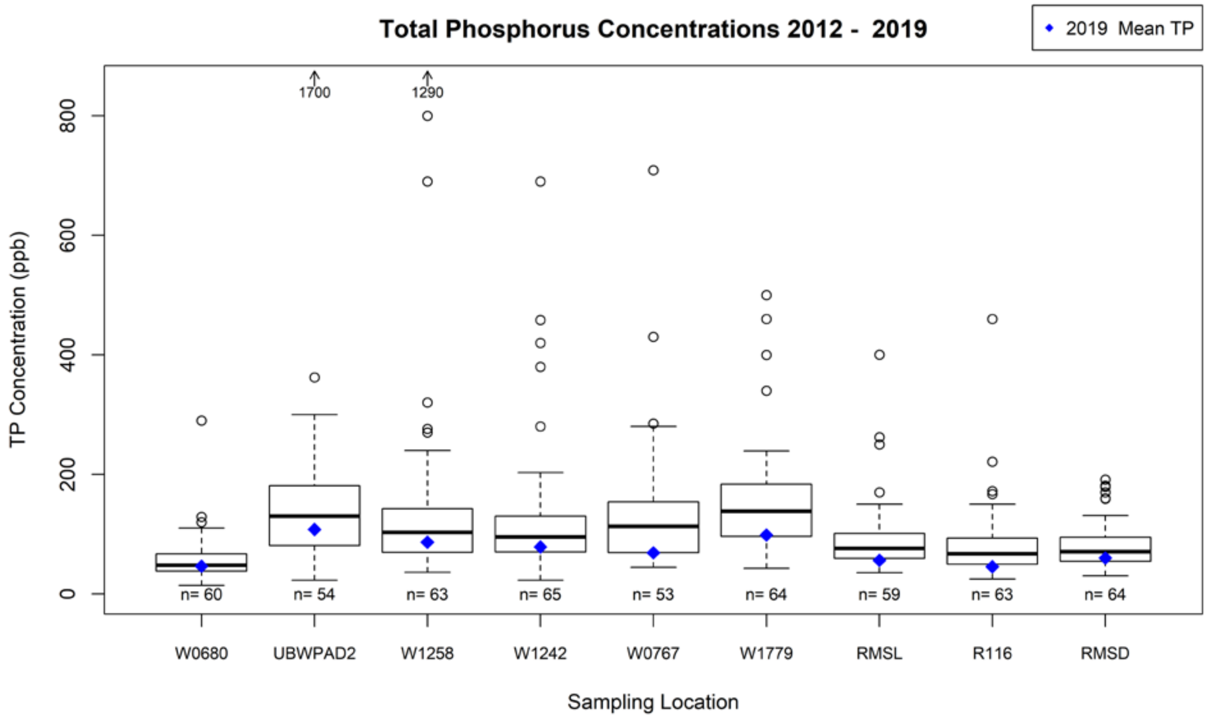
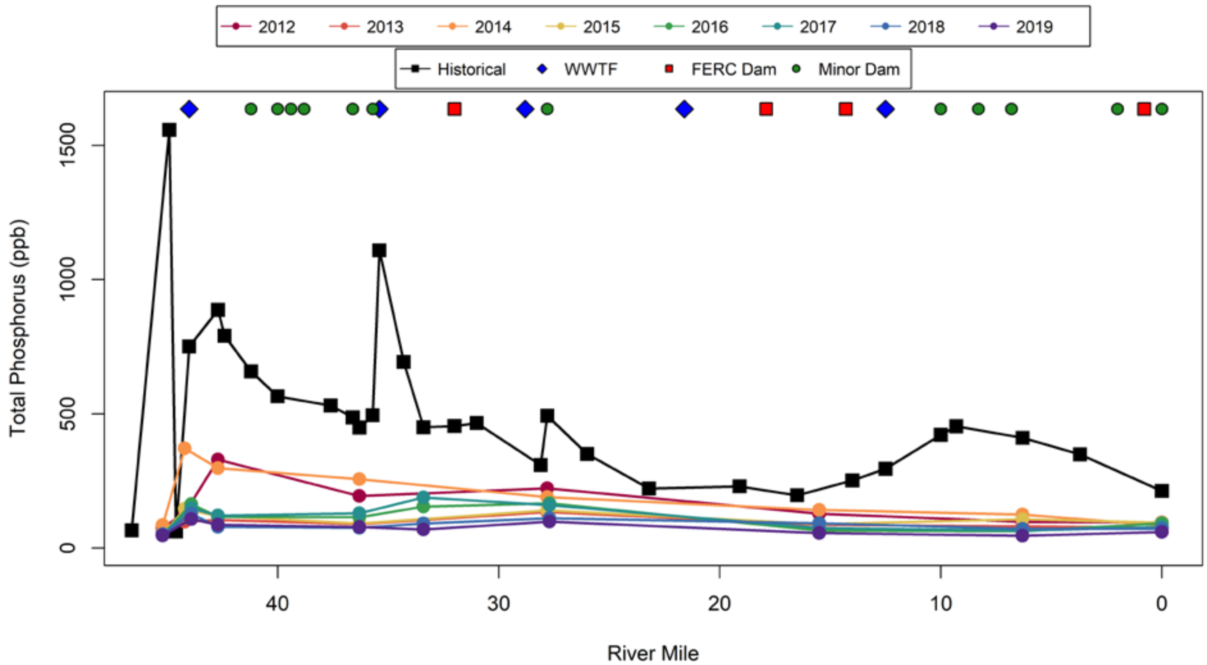


Figure 24: TP concentrations by site from 2012 - 2019

Average TP concentrations in 2012 – 2019 are compared to historical concentrations in **Figure 25**, plotted against river mile with upstream W0680 site on the left (river mile 50) and the downstream RMSD site on the right (river mile 0), analogous to the earlier plots where site name is indicated instead of river mile. The average low river TP concentrations at the three RI sites have been the lowest since 2017. For the MA sampling locations, 2019 mean concentrations were the lowest since 2012, and lower than all historical (1996 – 2008) levels as well. Upper Blackstone's efforts to reduce effluent TP translate into reductions in stream TP levels during dry and wet conditions.

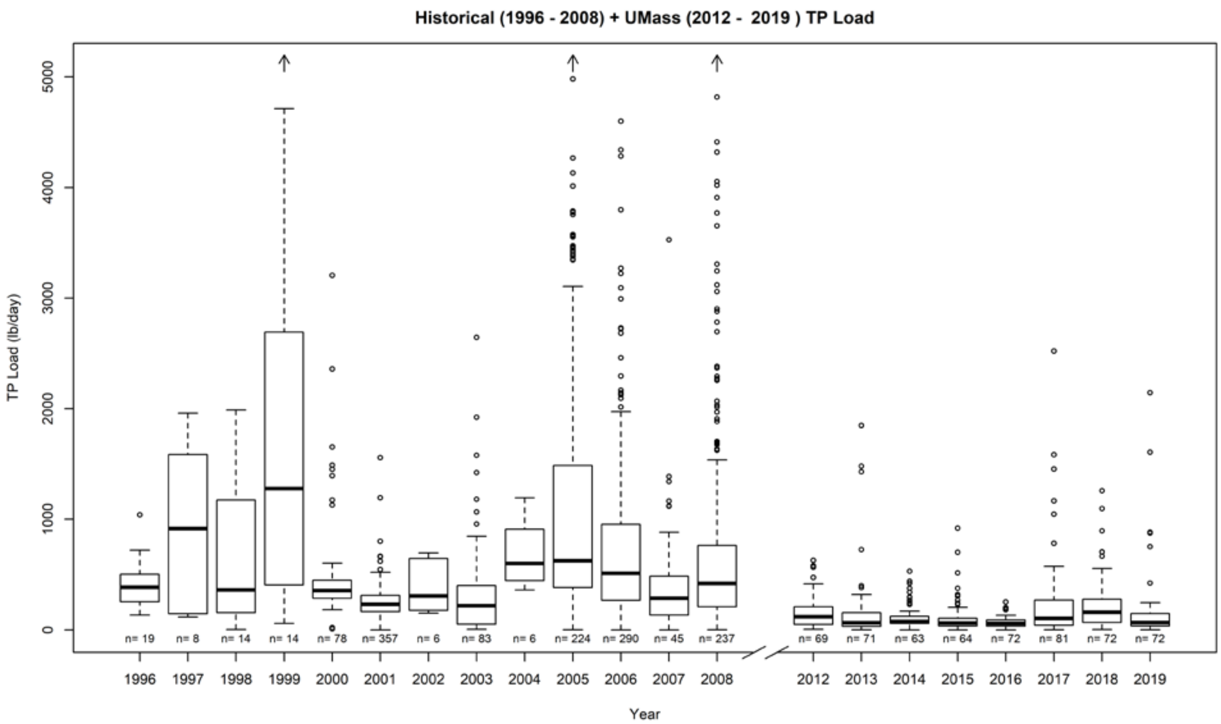
Yearly Mean TP concentration on Sampling Days, 2012 - 2019



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

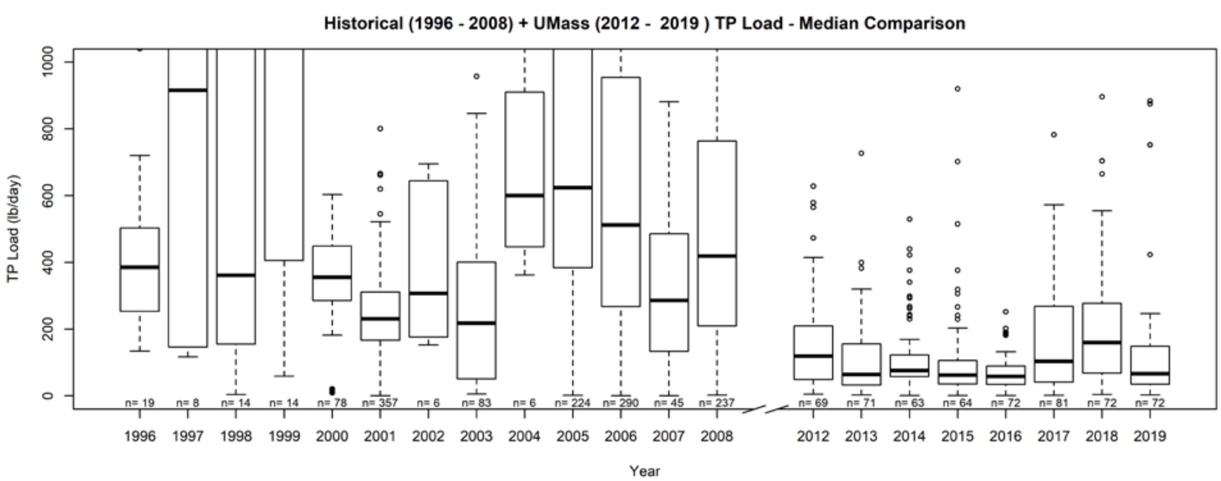
Figure 25: Along stream TP concentrations

Estimates of mass flux (or load) based on the observed concentrations and flow estimates provide information on the benefits of the plant upgrades for downstream receiving waters, such as Narragansett Bay. Estimates of TP loads since 1996 in the Blackstone River are summarized in **Figure 26** (shown zoomed in on **Figure 27**). 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. Calculated TP loads observed at each site since 2012 are summarized in **Figure 28**, and 2019 data show a median load that is near the lowest historically (2016 was a little bit lower), though the interquartile range is larger than in some earlier years. This is despite streamflows being the second highest since 2012.



(note, additional extreme outliers not shown, as indicated by arrows)

Figure 26: Summary of TP loads observed in the river 1996 – 2008 and 2012 – 2019



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

Figure 27: Summary of calculated TP loads based on streamflow estimates and reported concentrations for sampling days, 1996 – 2008 and 2012 – 2019

Along stream average TP loads, **Figure 28** and **Figure 29**, illustrate the impact of streamflow conditions on load estimates. As streamflow increases downstream, so do loads, and in 2019 it is clear that loads were highest in Rhode Island. Examined separately by site, it is also evident in **Figure 28** that 2019 TP loads were higher this year compared to the median between 2012 and 2019. However, **Figure 29** shows that 2019 (purple line) yearly mean TP loads were variable along the river: in the middle range at most sites, but higher than average at two of the Rhode Island sites.

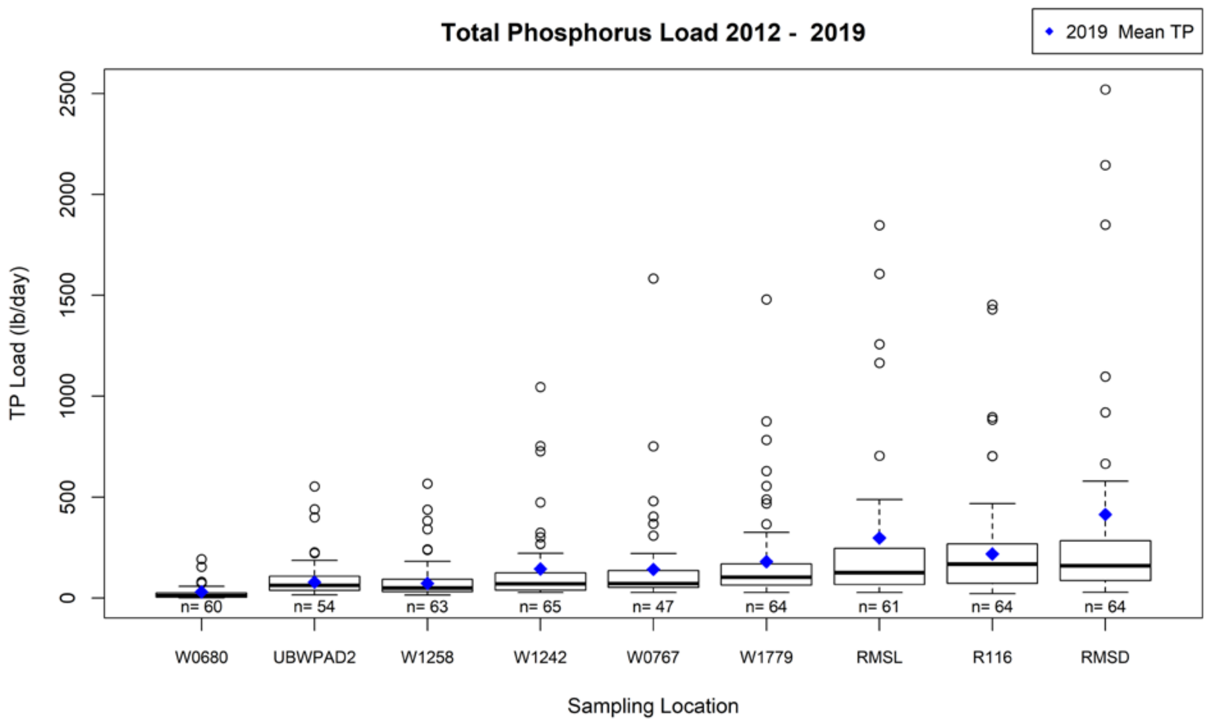


Figure 28: TP load data by site from 2012 - 2019

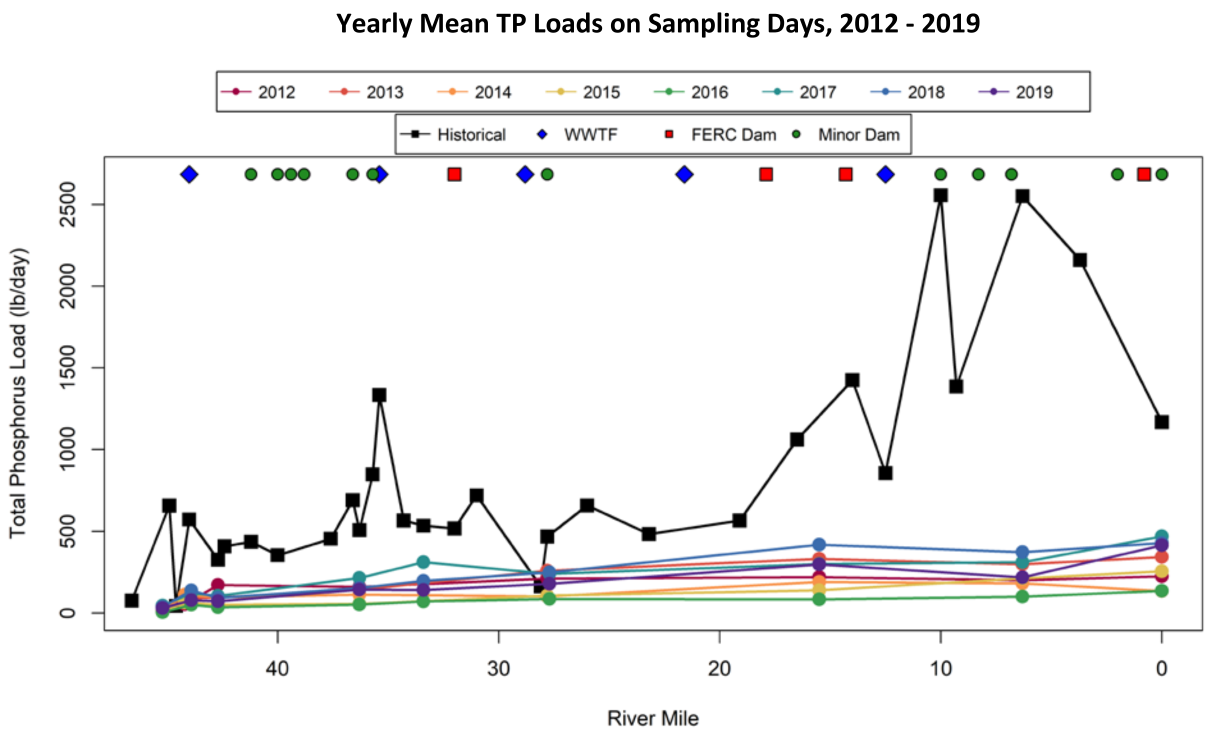


Figure 29: **Mean TP Loads on Sampling Dates**

Massachusetts uses a narrative nutrient criteria, which is interpreted in the Consolidated Assessment and Listing Methodology (CALM) manual using a weight of evidence approach that integrates nutrient concentrations, dissolved oxygen, periphyton, phytoplankton, benthic macroinvertebrates, and other indicators of aquatic health to evaluate whether a waterbody is impaired. One element of the weight of evidence approach is a TP threshold of 100 ppb; exceeding the TP threshold alone does not necessarily indicate impairment.

In 2019, TP concentrations in the Blackstone River were below the MassDEP 2018 CALM screening threshold of 100 ppb 80% of the time, **Figure 30**.

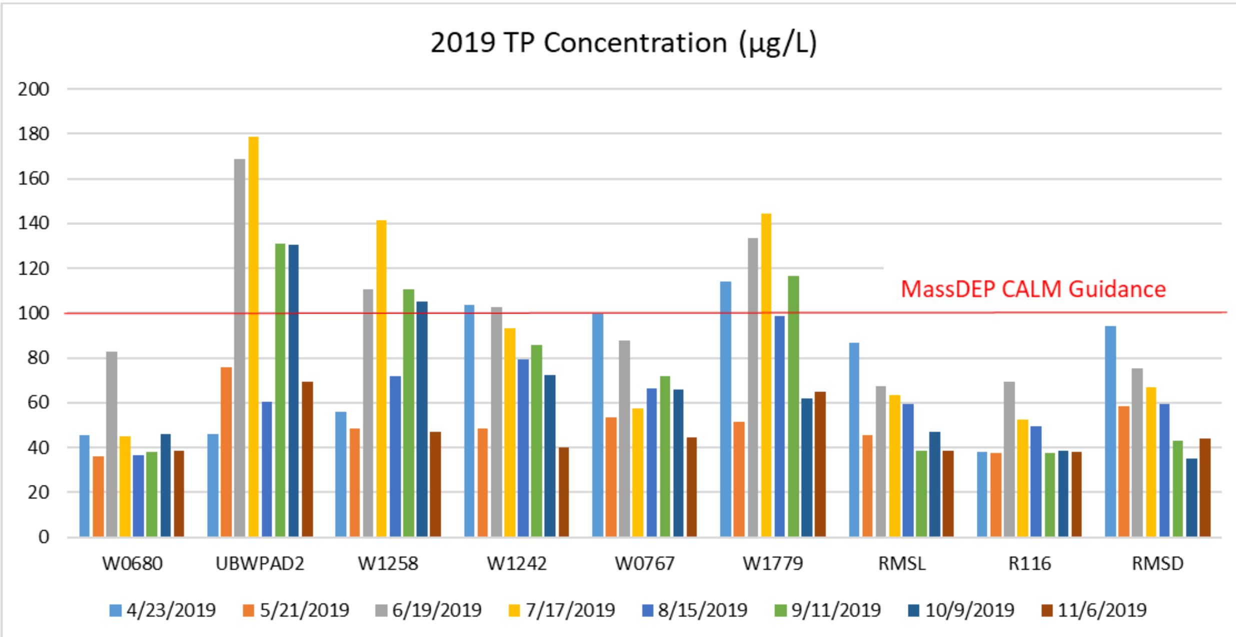
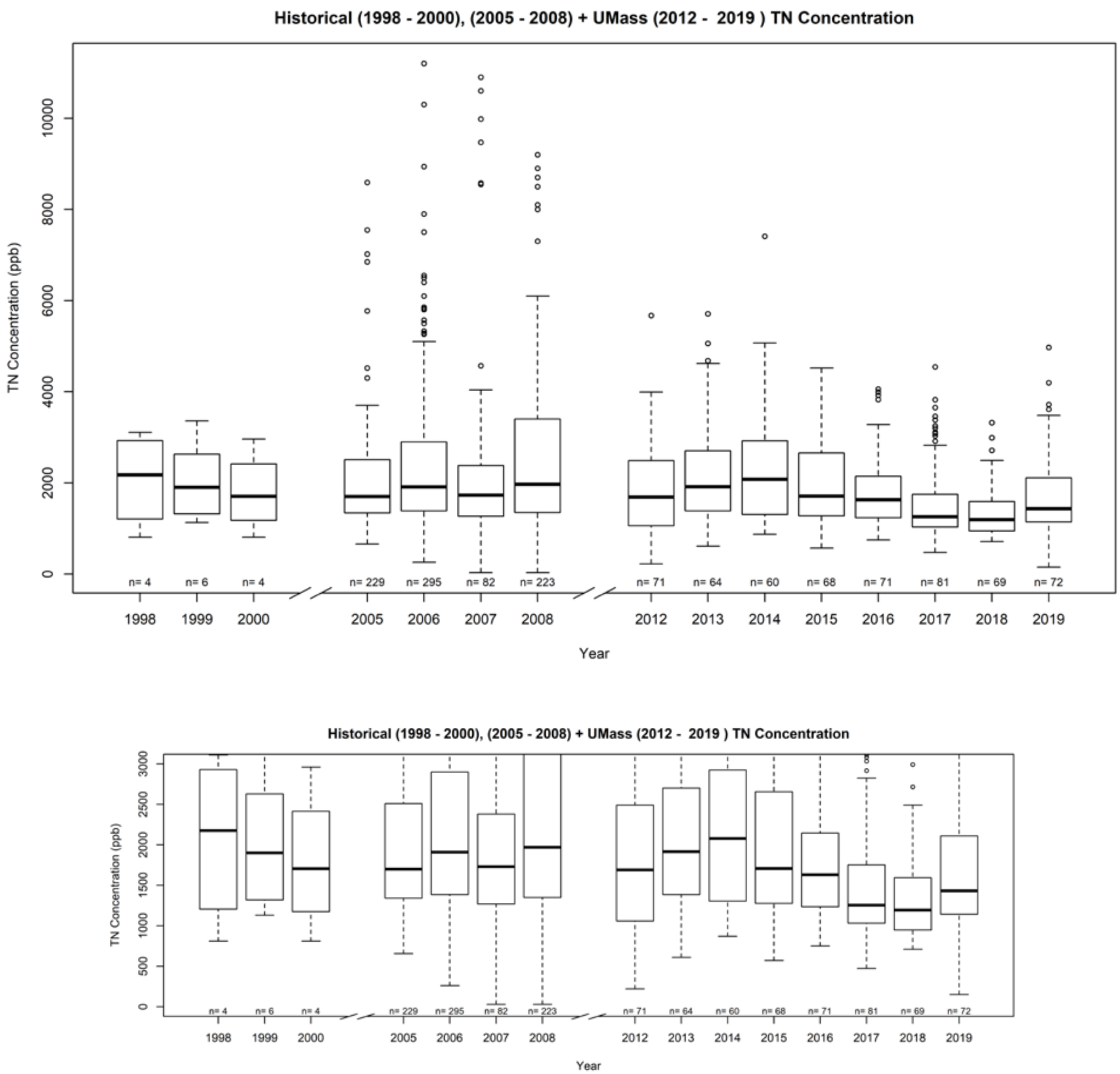


Figure 30: 2019 TP concentrations compared with MassDEP CALM guidance

6.2.2. Total Nitrogen

Available TN concentration data for the Blackstone River since 1996 are summarized in **Figure 31**.

In 2019, TN effluent concentrations were 55% lower during summer months compared to the average pre-upgrade concentration (2006-2009). The impact of the new limits and associated plant upgrades which came online in 2009 is evident. The TN concentration data points identified as outliers in 2019 all occurred at UBWPAD2 in the 4 summer months (June-September) during relatively low river flows with effluent contributing between 32% and 67% of the streamflow on those sampling days.



(lower figured zoomed in)

Figure 31: Summary of TN concentrations observed in the river, 1998 – 2000, 2005 – 2008, and 2012 – 2019

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, though in 2019 both increased. Trends in TN are discussed further below.

The mean summer (June – September) TN concentration at each sampling location in the Blackstone River is shown on **Figure 32** for sampling data collected since 2012. Data are clustered by sampling site, plotted from the upstream site W0680 (left) to the downstream site RMSD (right). Each year is shown as a different color, with 2019 in brown. 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 farther 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 2019 were higher than previous years except at two Rhode Island sites.

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
2019	977.3	4125.3	3175.8	2335.5	2453.5	1988.3	1220.3	1342.3	1226.0

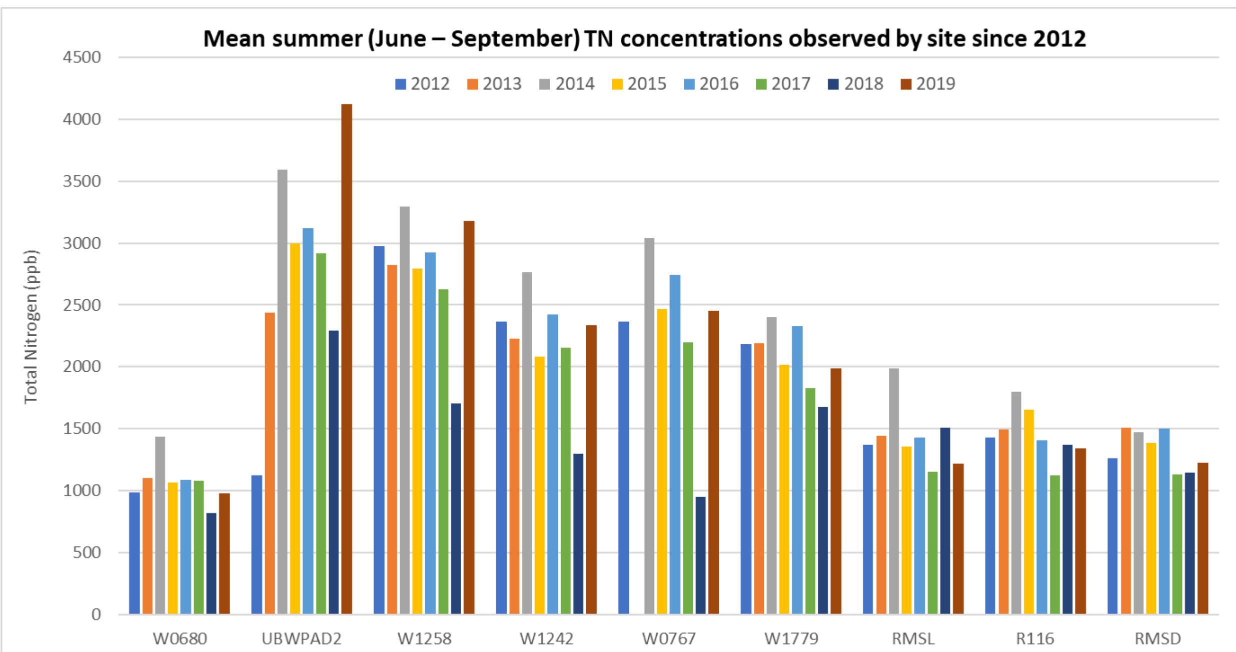


Figure 32: Mean summer (June – September) TN concentrations observed by site since 2012

The full range of TN concentrations observed at each site since 2012 is summarized in **Figure 33**, 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 2019 (depicted with blue diamonds) fell within the interquartile range of values observed since 2012 at all sampling sites. The average TN concentration for most locations fell at or below the lower quartile (exceptions are UBPWAD2, W1242, and W0767).

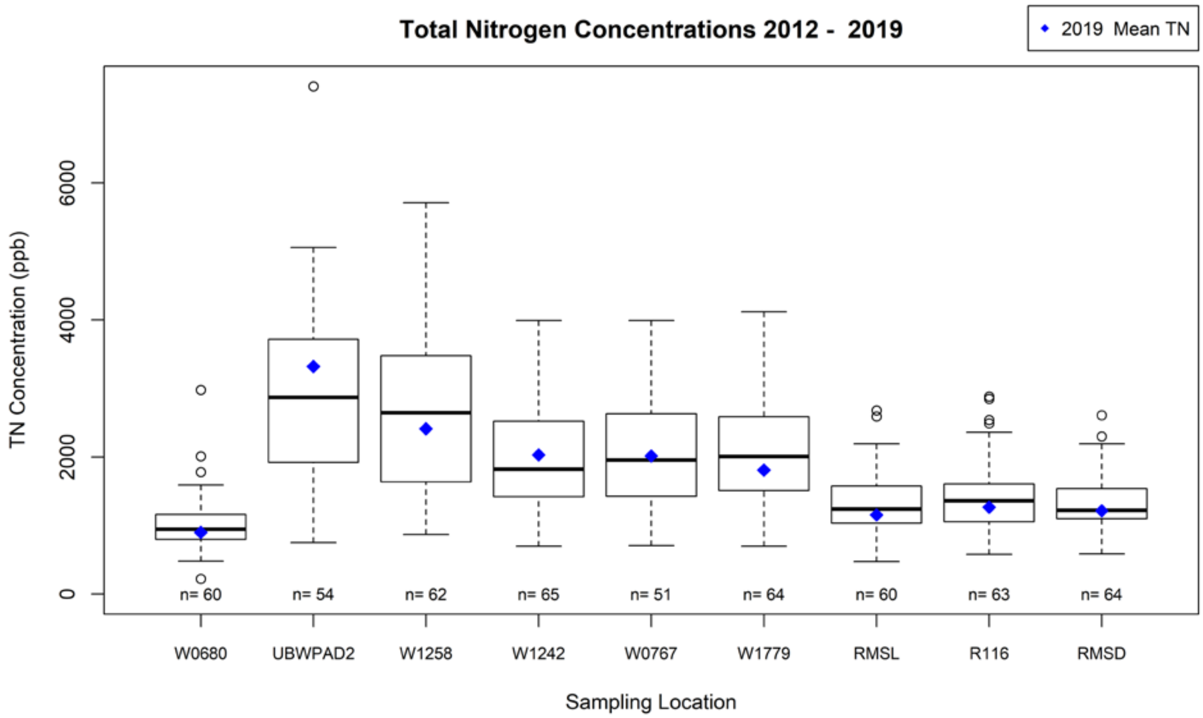


Figure 33: TN Concentrations by sampling location 2012 -2019

Average TN concentrations in 2012 – 2019 are compared to historical concentrations in **Figure 34**, plotted against river mile with headwater locations on the left (river mile 50) and the outlet on the right (river mile 0). The means echo the story shown by the medians, where the 2019 TN concentrations fall in the lower range of values seen since 2012 for all sites except at UBWPAD2.

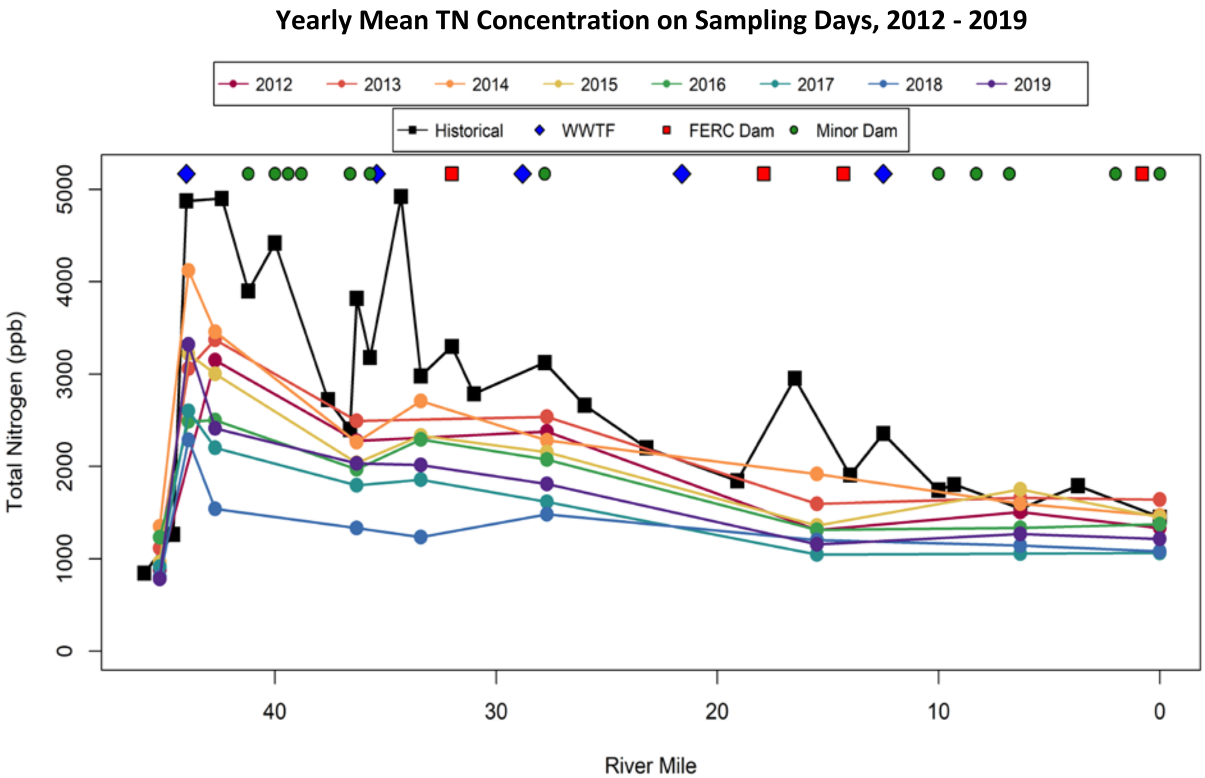


Figure 34: Along stream TN concentration, 2012 -2019

Estimates of TN loads since 2012 in the Blackstone River are summarized in **Figure 35**. Data for all sampling locations along the river are grouped by site. 2019 TN loads are lower than in 2018, which is to be expected considering that streamflow was lower this year.

TN load data statistics are shown in **Figure 36** and zoomed in **Figure 37**, and suggest a decrease in TN loads transported by the river since Upper Blackstone's upgrades were completed in 2009. The interquartile range of observed TN loads from 2012 through 2019 are smaller than from 1999 through 2008. In 2019, the median and interquartile range of the TN load decreased compared to 2018 and are comparable to 2017 levels.

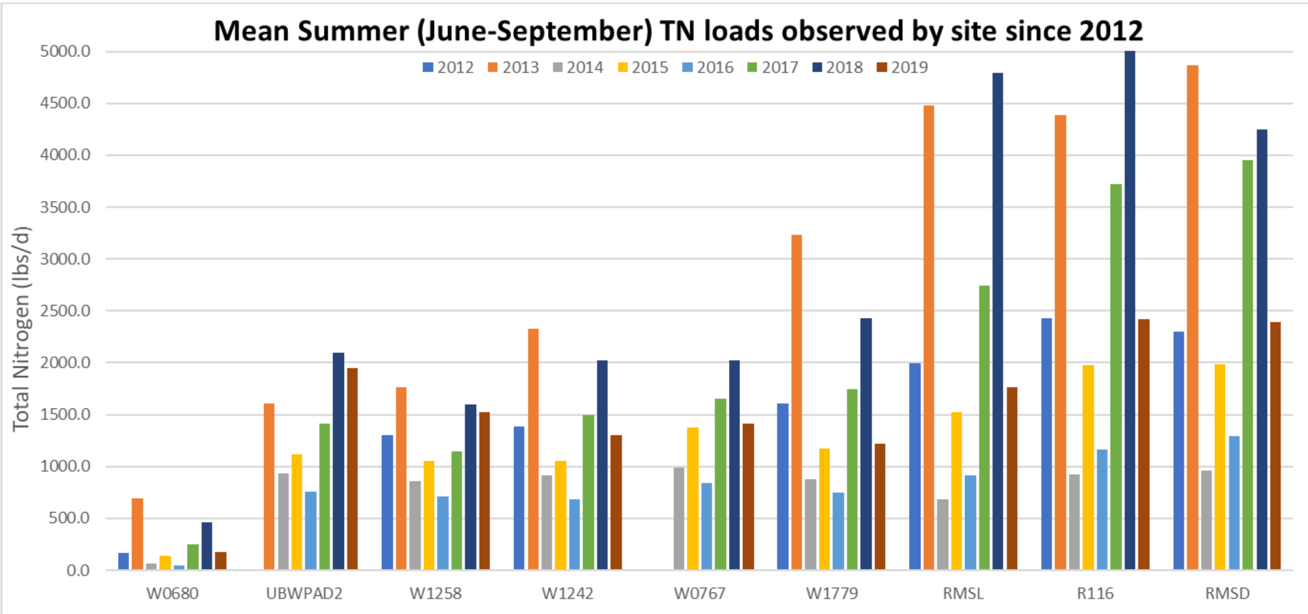


Figure 35: Mean Summer TN Loads for each site, 2012-2019

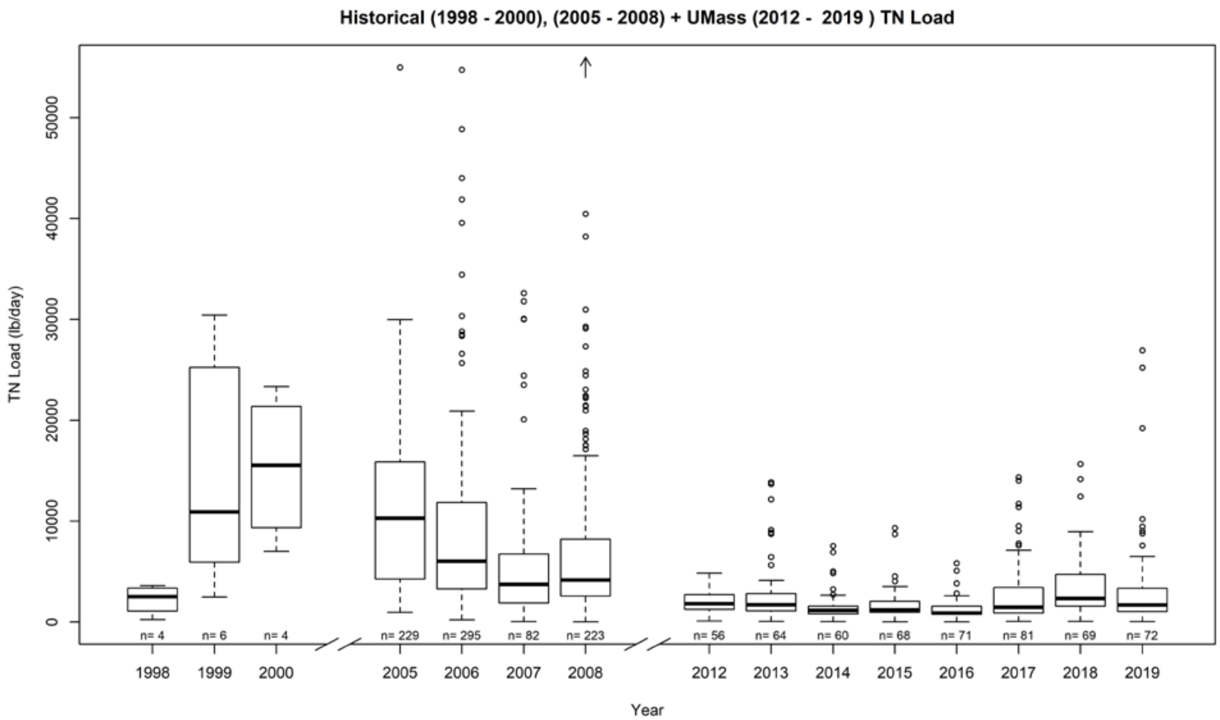


Figure 36: TN loads observed in the river 1998 – 2000, 2005 – 2008, and 2012 – 2019

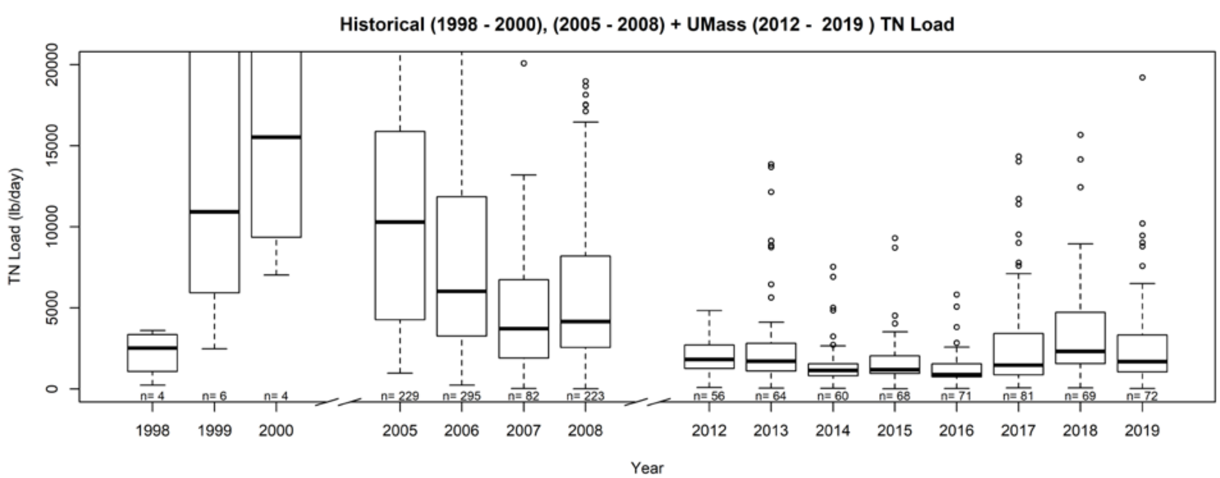


Figure 37: TN loads observed in the river 1998 – 2000, 2005 – 2008, and 2012 – 2019
(zoomed in)

Along stream average TN loads, as summarized by year and site on **Figure 38** and **Figure 39**, show 2019 loads to be on the higher end of the 2012-2019 spectrum, though clearly lower than that of historic data.

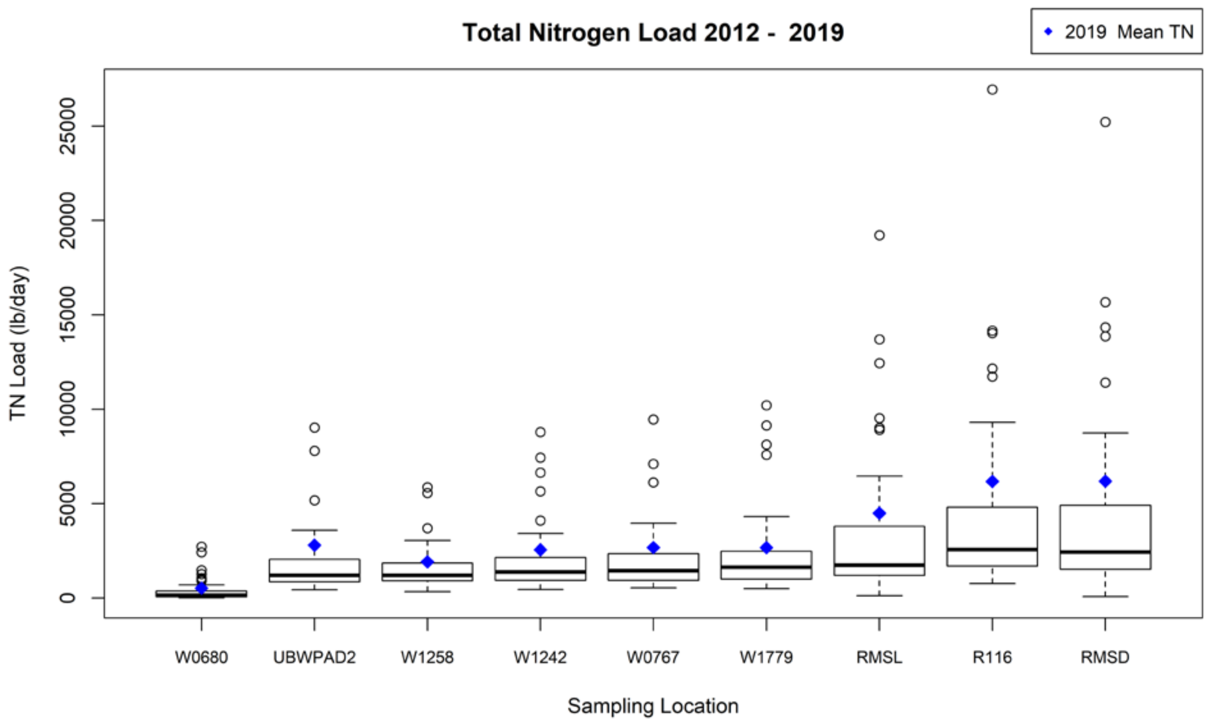


Figure 38: TN load data by sampling location 2012 - 2019

Yearly Mean TN Loads on Sampling Days, 2012 - 2019

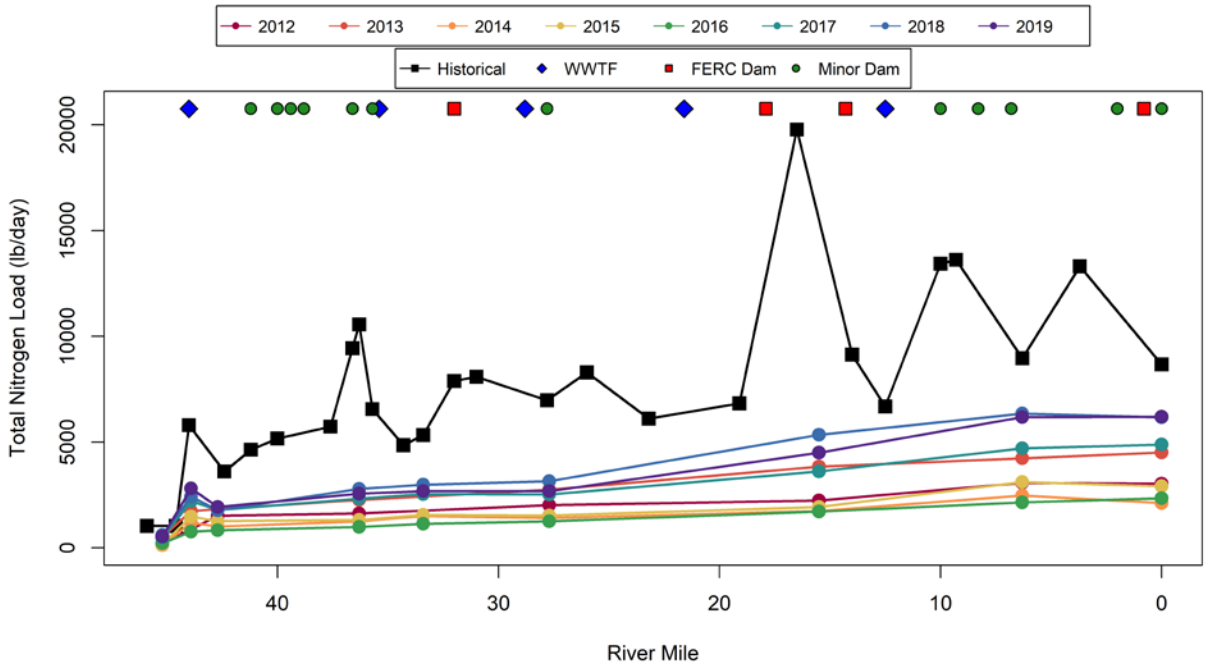


Figure 39: Along stream TN loads

6.2.3. Chlorophyll-a

Chlorophyll-a concentrations observed during the summer months (June – September) since 2012 are summarized by year in **Figure 40**. Overall, summertime chlorophyll-a levels in 2019 exhibited an interquartile range comparable to that observed in 2017. Interquartile range is tighter every other year as seen in this figure, but does not vary very much, except in 2014. The average spread in values and the median are comparable to those of some previous years (2015 and 2017), and lower than in 2018.

The same data are summarized by site in **Figure 41** for just the months of June – September, plotted from the headwaters (left) to the outlet (right). At individual sampling locations, mean summer concentrations in 2019 (blue diamonds) are at or lower than the median for all years except at the three most downstream sites, where the mean values are higher.

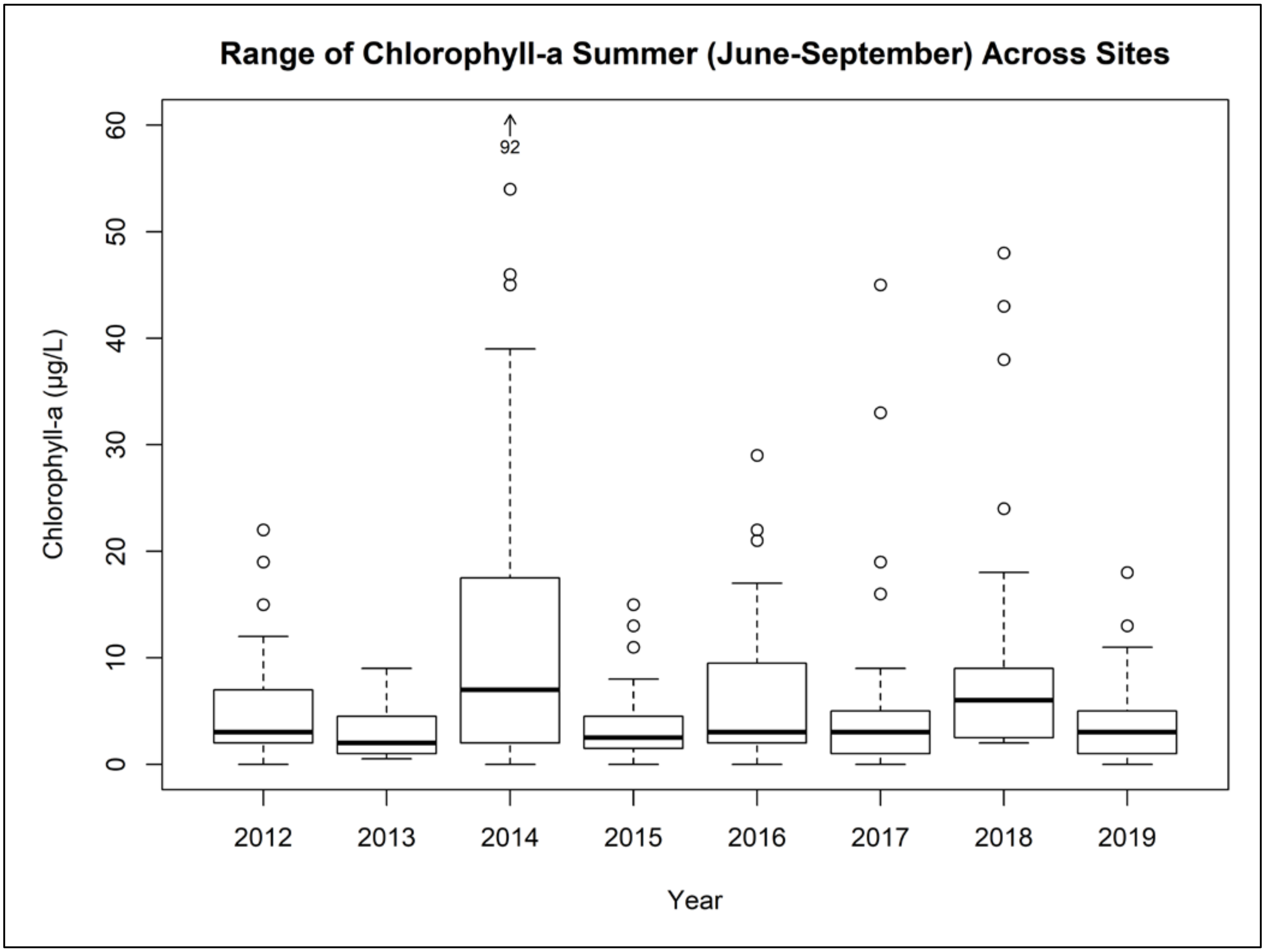


Figure 40: Chlorophyll-a concentrations observed during June, July, August, and September since 2012, summarized by year

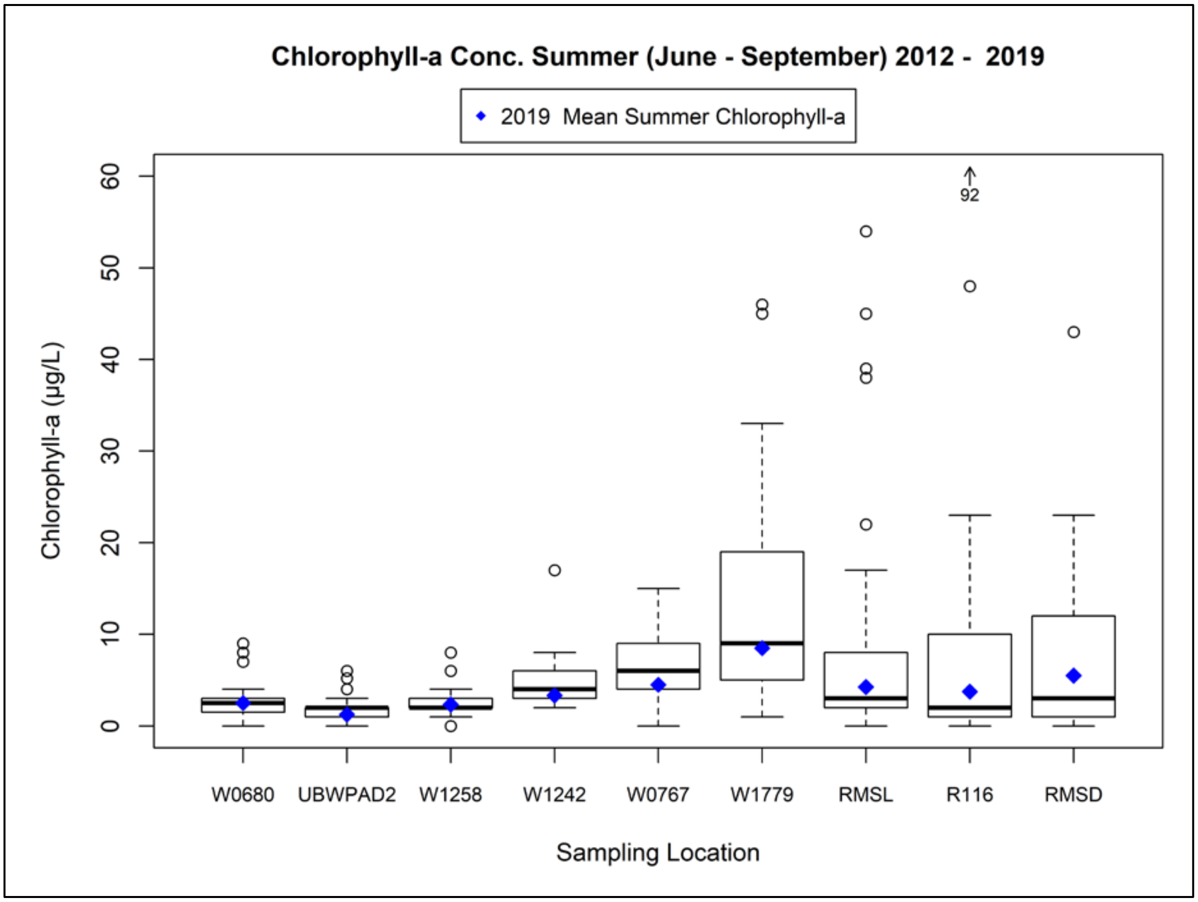


Figure 41: Chlorophyll-a concentrations observed during June, July, August, and September since 2012, summarized by sampling location

The mean summer (June – September) chlorophyll-a concentrations for each year and sampling location on the Blackstone River are also summarized on **Figure 42**. Data are clustered by sampling site, again plotted from the headwaters (left) to the outlet (right). In 2019, summertime chlorophyll-a levels were lower than historical data at all sites. The highest summer mean observed is at W1779, below Rice City Pond, but remained below the 16 µg/L MassDEP guidance value. This location has historically had high chlorophyll-a concentrations in recent years, with 3 out of the past 8 years having a mean chlorophyll-a concentration exceeding the MassDEP guidance value.

Chl-a (µg/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
2019	2.5	1.3	1.8	2.5	4.5	8.5	4.3	3.8	5.5

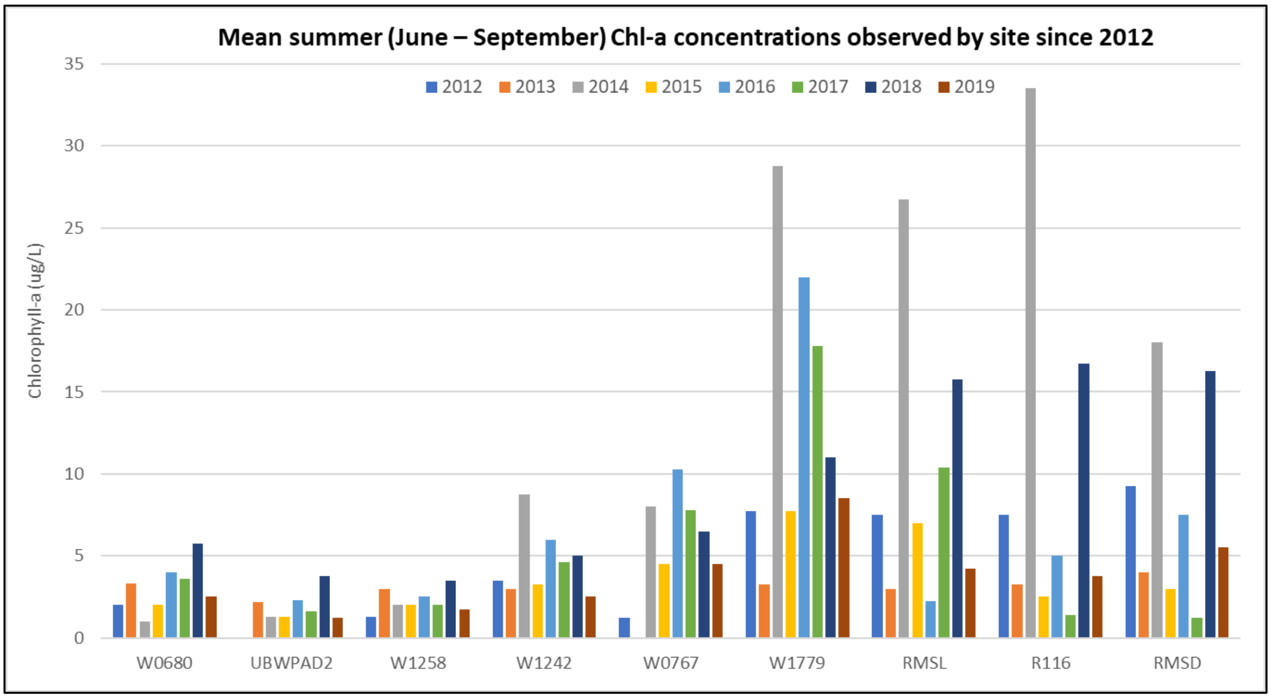


Figure 42: Mean summer (June – September) chlorophyll-a concentrations by site since 2012

The annual average chlorophyll-a concentration data for 2019, **Figure 43**, was below MassDEP screening guidelines at all locations.

In 2019, the maximum chlorophyll-a concentrations observed at each sampling location (**Figure 44**) remain in the lower to middle range of historical data, and the rise at the most downstream site is much less pronounced than in 2018. In 2019, chlorophyll-a concentrations in the Blackstone River were below the MassDEP 2016 CALM screening threshold of 16 µg/L most of the time, with only one sample at 18 mg/L the entire season (**Figure 45)**. This sample was taken at the most downstream site, RMSD, in July.

Yearly Mean Chlorophll-a Concentrations on Sampling Days, 2012 - 2019

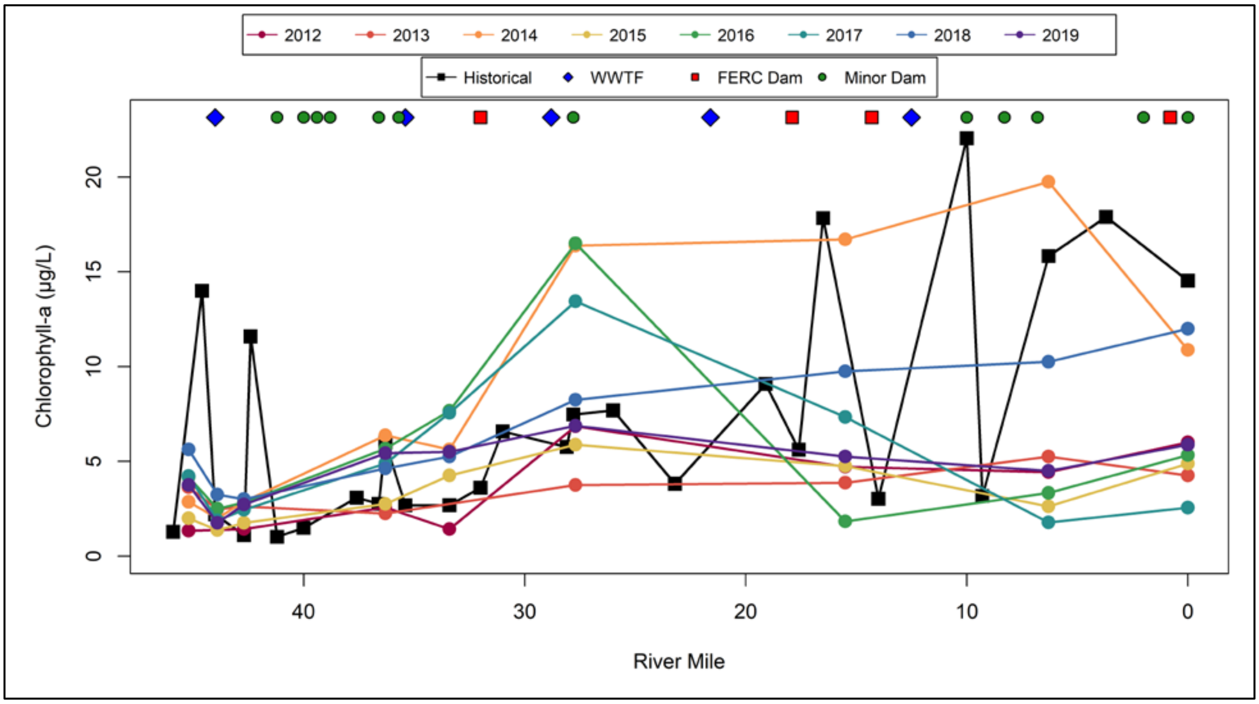


Figure 43: Along stream average chlorophyll-a levels

Yearly Maximum Chlorophyll-a Concentrations on Sampling Days, 2012 - 2019

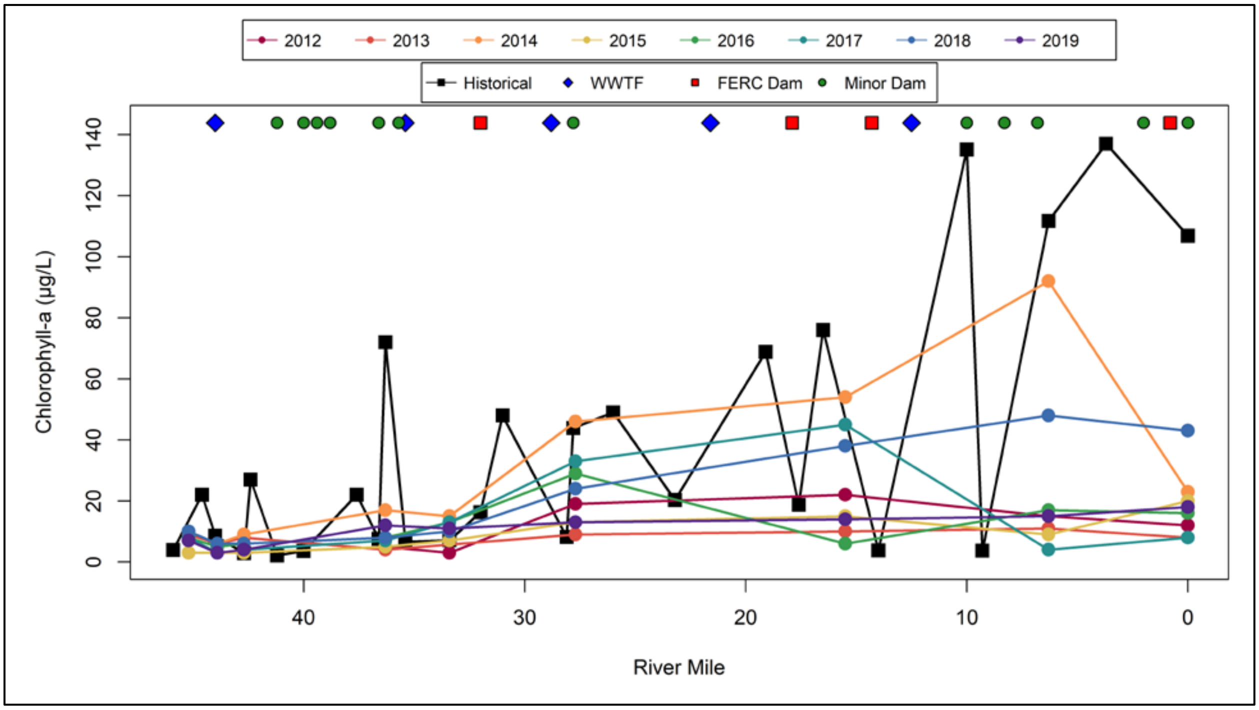


Figure 44: Along stream maximum chlorophyll-a levels

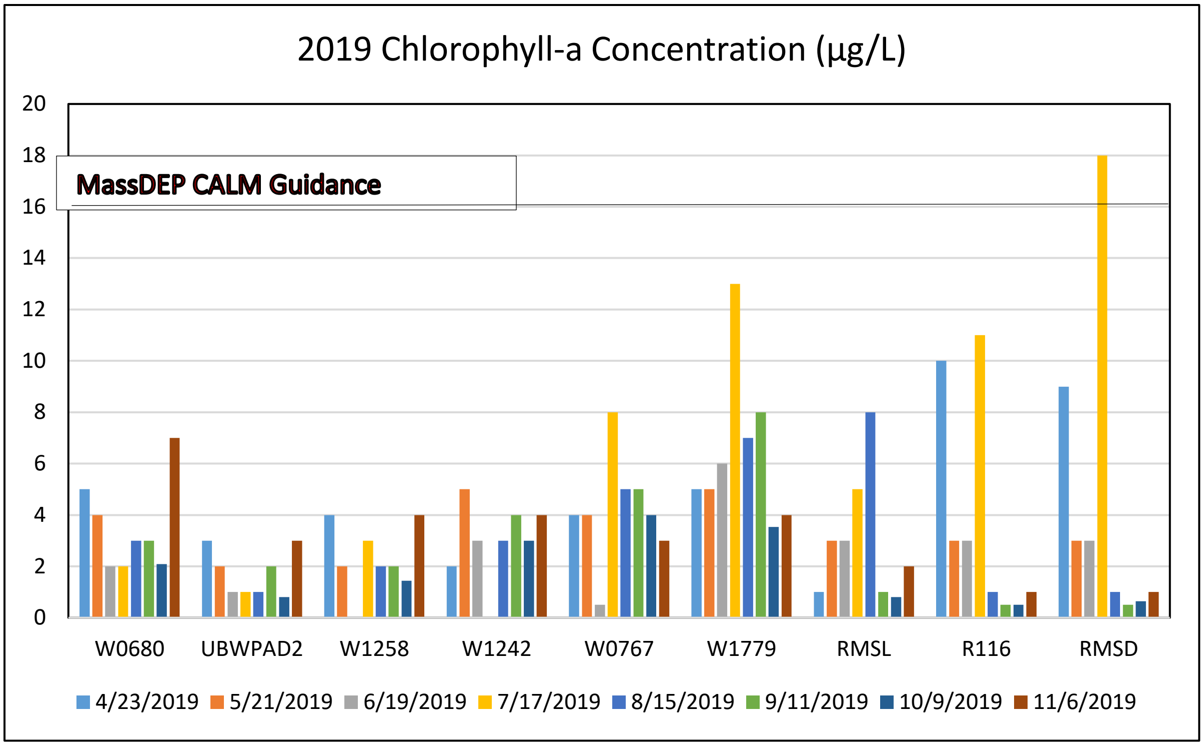


Figure 45: 2019 chlorophyll-a concentrations relative to MassDEP CALM guidance

6.2.4. 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 regression (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 15-17**. 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), State Line (RMSL), and Rice City Pond (W1779) sampling sites (99%

significance level); at the Bikepath Bridge (R116) and Central Cemetery (W1258) sampling sites (95% significance level); and at Sutton St. Bridge (W0767) and Route 122, Grafton (W1242) sampling sites (90% level).
When data are grouped by season, RMSD, R116, and RMSL exhibit a decreasing trend at the 99% significance level; W1779, W1242, and W1258 show a decreasing trend at the 95% significance level, and W0680 shows a decreasing trend at the 90% significance level (**Table 15**).

- Decreasing trends in TN streamflow-weighted concentration are observed at the 99% significance level at W1258 only; at the 95% significance level at R116, W1779, and W1242; and at the 90% significance level at RMSL.
When the data are grouped seasonally, a decreasing trend is observed at the 95% significance level at RMSD, RMSL, and W1779; and at the 90 % significance level at R116 and W0680 (**Table 16**).
- 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 W1258.
When grouped seasonally, site W1258 is the only site where a positive trend is detected, at the 95% significance level, and RMSD shows a decreasing trend while W0680 shows an increasing trend at the 90% level (**Table 17**).

Table 15: 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	>99%	Decreasing
R116	Flow-weighted TP	Month	>95%	Decreasing
RMSL	Flow-weighted TP	Month	>99%	Decreasing
W1779	Flow-weighted TP	Month	>99%	Decreasing
W0767	Flow-weighted TP	Month	>90%	Decreasing
W1242	Flow-weighted TP	Month	>90%	Decreasing
W1258	Flow-weighted TP	Month	>95%	Decreasing
UBWPAD2	Flow-weighted TP	Month		
W0680	Flow-weighted TP	Month		
All Sites	Flow-weighted TP	Site+Season	>99%	Decreasing
RMSD	Flow-weighted TP	Season	>99%	Decreasing
R116	Flow-weighted TP	Season	>99%	Decreasing
RMSL	Flow-weighted TP	Season	>99%	Decreasing
W1779	Flow-weighted TP	Season	>95%	
W0767	Flow-weighted TP	Season		
W1242	Flow-weighted TP	Season	>95%	Decreasing
W1258	Flow-weighted TP	Season	>95%	Decreasing
UBWPAD2	Flow-weighted TP	Season		
W0680	Flow-weighted TP	Season	>90%	Decreasing

Table 16: 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		
R116	Flow-weighted TN	Month	>95%	Decreasing
RMSL	Flow-weighted TN	Month	>90%	Decreasing
W1779	Flow-weighted TN	Month	>95%	Decreasing
W0767	Flow-weighted TN	Month		
W1242	Flow-weighted TN	Month	>95%	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	>90%	Decreasing
RMSL	Flow-weighted TN	Season	>95%	Decreasing
W1779	Flow-weighted TN	Season	>95%	Decreasing
W0767	Flow-weighted TN	Season		
W1242	Flow-weighted TN	Season		
W1258	Flow-weighted TN	Season		
UBWPAD2	Flow-weighted TN	Season		
W0680	Flow-weighted TN	Season	>90%	Decreasing

Table 17: 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		
W0767	Flow-weighted Chl-a	Month		
W1242	Flow-weighted Chl-a	Month	>95%	Increasing
W1258	Flow-weighted Chl-a	Month	>95%	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	>90%	Decreasing
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	>95%	Increasing
UBWPAD2	Flow-weighted Chl-a	Season		
W0680	Flow-weighted Chl-a	Season	>90%	Increasing

6.2.5. Field Water Quality Measurements

In 2019, UB purchased two hand-held Hach HQ 40 D multimeters equipped with two probes. Water temperature, dissolved oxygen, and pH were measured in situ at each site every sampling day. Measurements were taken directly in the river, or if the meter cables were not long enough to reach the stream (because sampling was done from a very high bridge), a sampling container on a rope was lowered into the river, and measurements were taken from the container back on the bridge. Measurements were taken ten times both in the river and the sampling container (bucket) to document whether taking measurements in the sampling container introduced a bias. These comparison measurements were taken on different days by different crews at different sites. The relative percent difference (RPD) was calculated for each parameter for each pair of measurements. RPD was low (3% or less) 84% of the time, and always under 10% except once for water temperature and once for pH. (See Appendix C.)

Water temperature at all sites throughout the sampling season can be seen in **Figure 46.** Temperature stays below 20°C April through June and again In October and November at most sites (notable exception for RMSL in June), and warmest temperatures are observed in July. Sampling begins around 8 AM in the upper loop (starting at W0767 and moving upstream) or 8:30 AM in the lower loop (starting at RMSD and moving upstream to W1779) and continues to about 12PM, but the difference in temperature between sites on a given day usually doesn't vary by more than 2°C. Notable exceptions were observed in October at UBWPAD2 when the temperature jumped from 14.4°C from W0680 to 19.5°C at UBWPAD2. Water temperatures were never observed above the Massachusetts Water Quality standard of 28.5°C (28.3°C in Rhode Island) for class B waters.

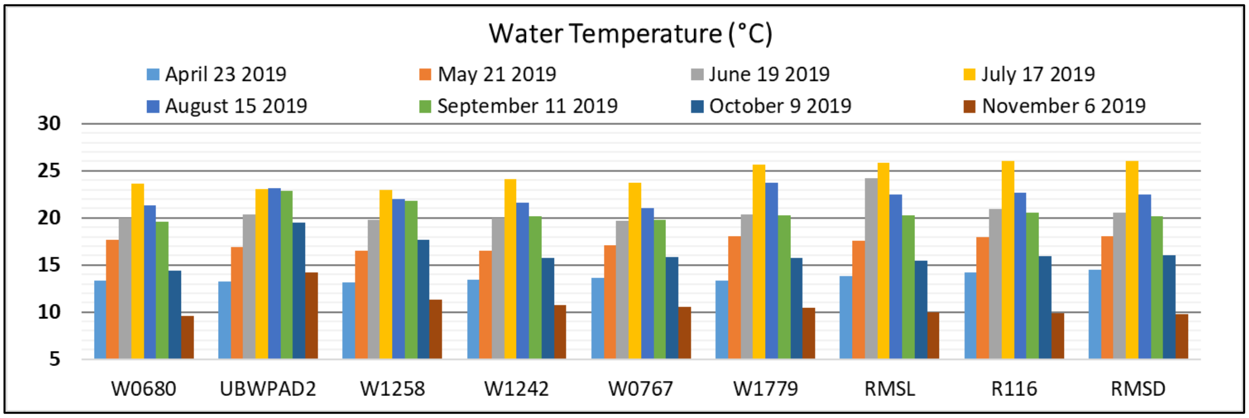


Figure 46: Water temperature at each site and each sampling event

pH at each site for each date can be seen in **Figure 47**. Data are missing for May at all sites and in September for the lower loop sites because of meter malfunctioning which resulted in censoring data at those times. Our field measurements show that pH remained within the Massachusetts Surface Water Quality Standards for class B waters (between 6.5 and 8.3) all sampling season.

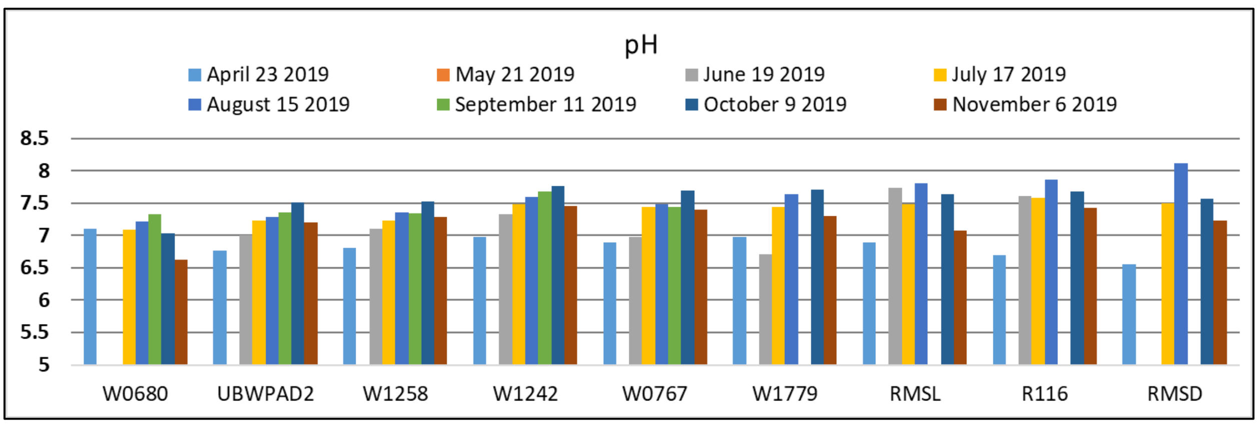


Figure 47: 2019 pH at each site

Dissolved oxygen was also measured between the hours of 8 AM and 12 PM, so it would not be expected to observe measurements falling below the Massachusetts Water Quality Standards (5mg/L for class B waters), and indeed no measurements fell below that standard at any site (**Figure 48**). Percent saturation exceeded 80% at each site each sampling day except at UBWPAD2 in July (77%) and W1258 in October (71%). It exceeded 90% saturation 77% of the time (**Figure 49**).

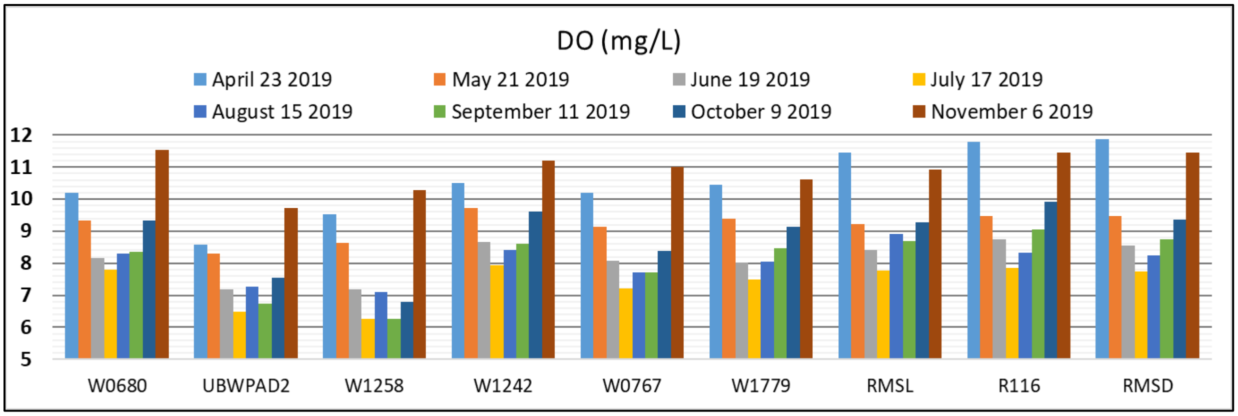


Figure 48: Dissolved Oxygen in mg/L at each site

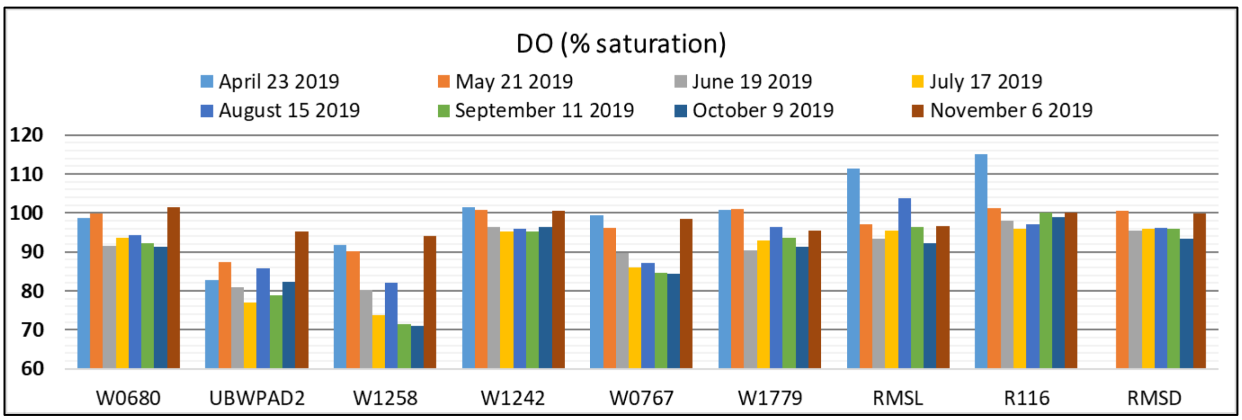


Figure 49: 2019 Dissolved Oxygen Percent Saturation at each site

Conductivity

Hand-held meters were used to measure conductivity (specific conductance), but not in the field because only one probe was available. Measurements were made in the UB lab, on the sample that is also analyzed for TSS. Results are shown in **Table 18** and **Figure 50.** Unsurprisingly, conductivity is highest every month at the site just downstream of the Upper Blackstone effluent confluence (UBWPAD2) and usually decreases progressively downstream. It is interesting to note that conductivity at the site upstream of the confluence has relatively high conductivity as well (700 µS/cm and up) starting in June and through October. The Blackstone River is an urban river system upstream of the Upper Blackstone effluent channel, receiving stormwater runoff from the City of Worcester and treated combined sewer overflow just upstream of W0680.

Table 18: 2019 Conductivity (µS/cm)

Site/Date	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
W0680	354	502	697	783	811	872	728	481
UBWPAD2	561	783	888	982	968	936	878	777
W1258	390	652	832	956	951	931	780	637
W1242	387	574	700	799	804	788	772	583
W0767	379	563	675	784	781	742	800	576
W1779	370	545	635	719	718	624	821	555
RMSL	262	325	390	473	453	440	576	335
R116	273	351	449	481	449	476	585	365
RMSD	292	357	418	505	441	459	556	366

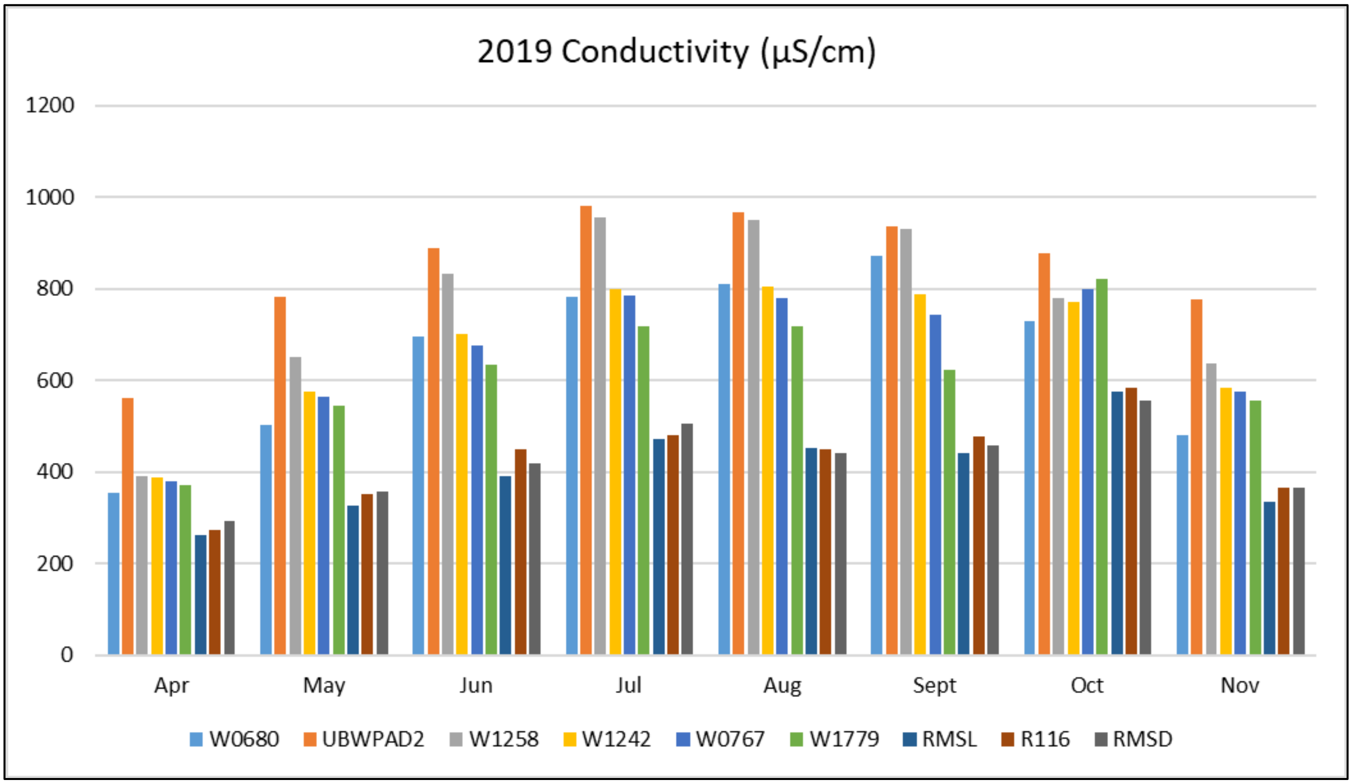


Figure 50: Conductivity at each site on sampling dates

6.2.6. Continuous Water Quality Monitoring

Data collected during the regular monthly sampling program provide important information on the Blackstone River's health. However, these data do not provide any information about water quality between sampling events. To help fill this gap, in 2019 Upper Blackstone purchased and installed four continuous temperature (T) and dissolved oxygen (DO) probes at four locations in the Blackstone River between July and October. These probes were installed at the same location as the periphyton sampling and the continuous T/DO metering that has been conducted in previous years (see **Figure 2**).

Massachusetts water quality standards require a minimum DO concentration of 5 mg/L in the Blackstone River. In addition, the CALM has a guidance value for diel (daily) DO variations, where a diel change in DO greater than 3 mg/L is a potential indicator of nutrient enrichment.

Continuous T and DO data collected during 2019 indicate that the river is supportive of aquatic life upstream of the Upper Blackstone discharge and at the downstream Depot sampling location, with DO concentrations above state standards and minimal diurnal variability. Water quality conditions at the UBWPAD2 and W1258 sites occasionally exceed the 5 mg/L water quality standard and the 3 mg/L diel variability guidance value; the 2019 data from these sites do not support the aquatic life use. Exceedances of water quality guidance and standards occurred most frequently during a very low flow period in September and October.

The full report on continuous water quality monitoring can be found in Appendix D.

6.2.7. Data Quality Objectives

All data collected during the 2019 monitoring program were evaluated against the Data Quality Objectives (DQOs) in the QAPP to determine whether the data quality was adequate for analysis.

Due to problems with measuring blank samples at the UMD lab, 100% of the TN data ended up flagged for failed quality control in 2019. To evaluate whether these data should be censored from the analysis, a statistical correlation analysis was performed to evaluate whether a statistically significant difference exists between the full dataset (with flagged values) and the censored dataset (with flagged values removed). Statistical correlation analysis was performed by separating the data into two distinct populations: the data passing the DQOs (uncensored) and the data failing the DQOs (censored). If the underlying statistics between these two populations are the same, then there will not be a statistically significant difference and the full dataset (including values failing the DQOs) is suitable for use in the analysis. **Figures 51 and 52** present a comparison of these two populations using a boxplot (**Figure 5**1) and an empirical cumulative distribution function (**Figure 52**) for dissolved ammonia (dNH_4), dissolved nitrate + nitrite (dNO_{23}), particulate organic nitrogen (PON), total dissolved nitrogen (TDN), and total nitrogen (TN). The boxplot shows the range of data in each data quality population for the nitrogen series, and the empirical cumulative distribution function the overall distribution of the underlying data. Note that all ammonia samples passed the DQOs, so there are no censored data in this dataset.

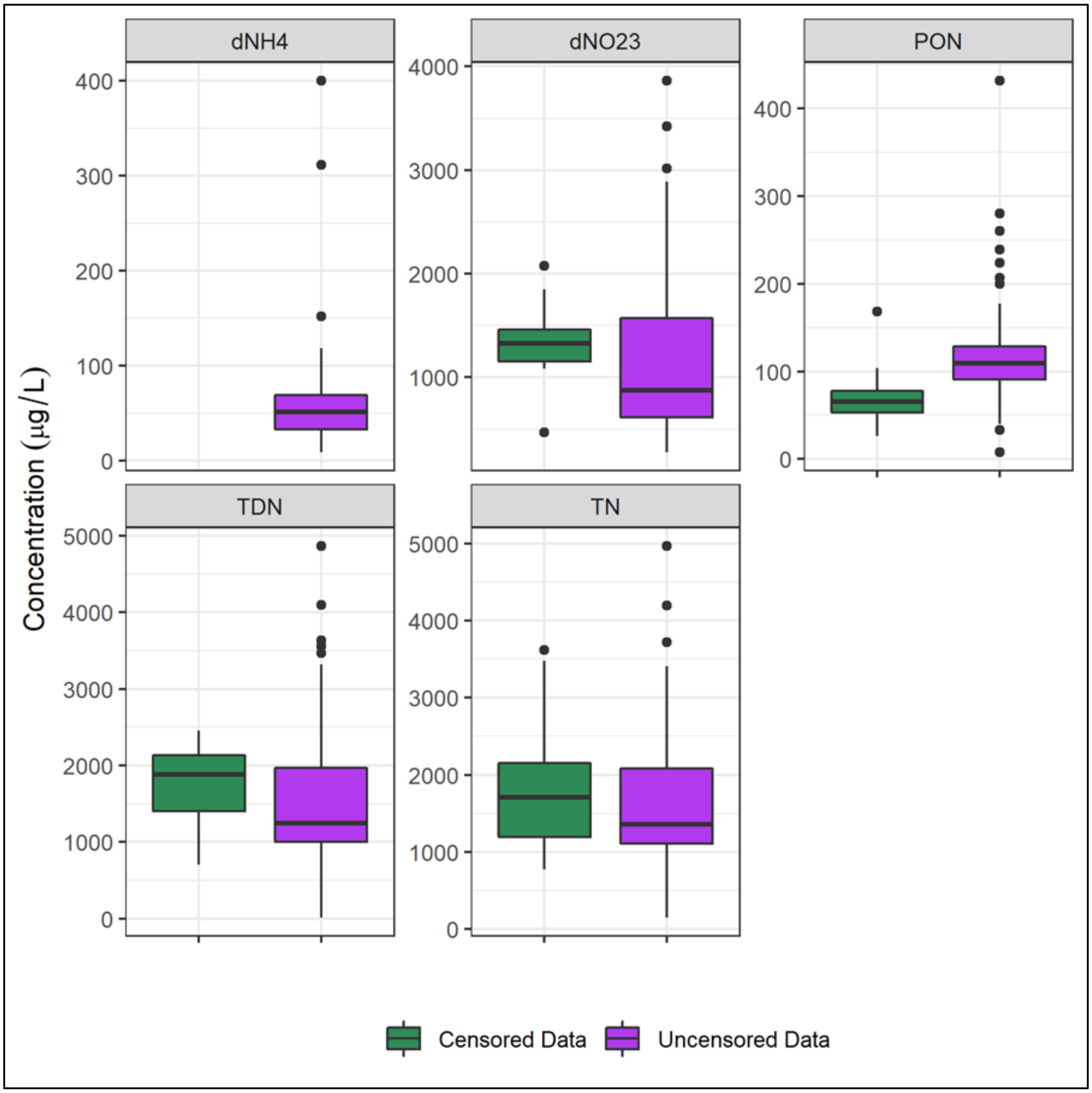


Figure 51: Comparison of censored and uncensored nitrogen data from the 2019 monitoring program

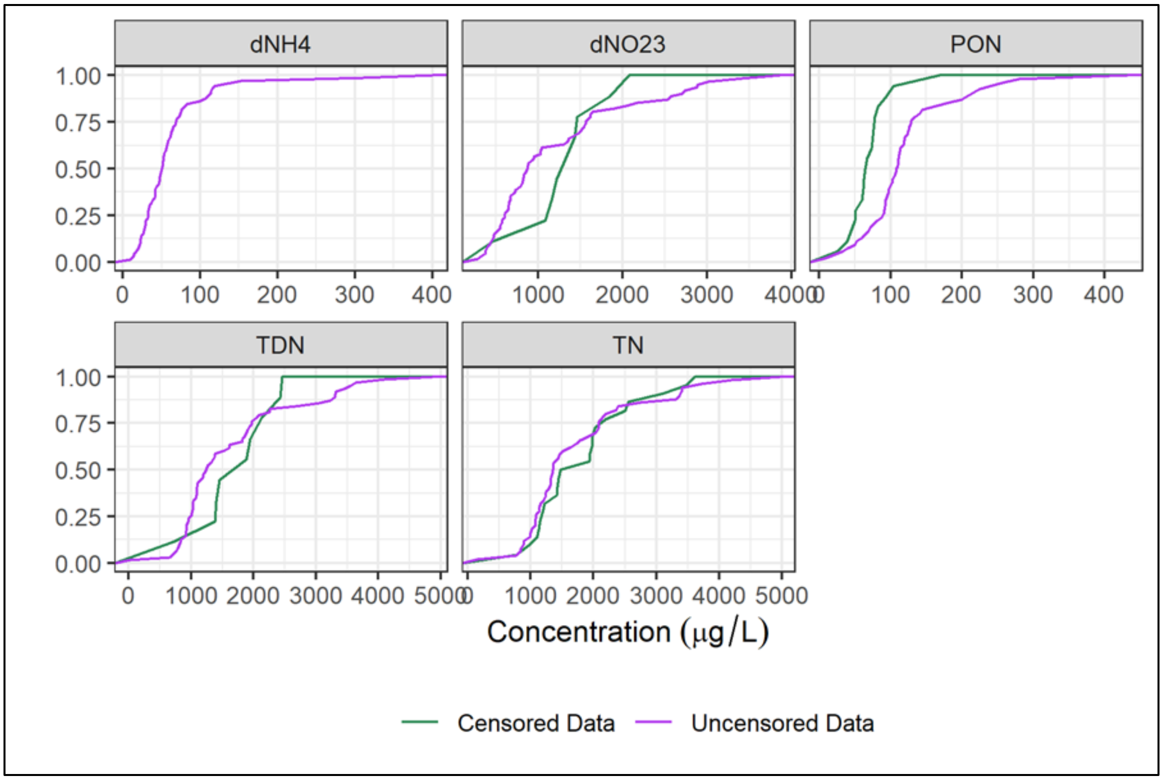


Figure 52: Comparison of censored and uncensored nitrogen data using an empirical cumulative distribution function

A two-sided Wilcox test was performed on these two datasets to evaluate statistical significance. The Wilcox test is a non-parametric test that evaluates whether the populations are derived from the same underlying statistical distribution. This test was used because the underlying statistical distribution of the data is not known. The results of the hypothesis tests are presented in **Table 19.** These results show the p-value for the alternative hypothesis; if p is less than or equal to 0.05 then the two populations are significantly different at the 95% confidence level.

Table 19: Wilcox test results for the 2019 nitrogen DQO assessment

Parameter	*p-value* (95% CI)
dNH4	n/a
dNO23	0.24
PON	**0.0002**
TDN	0.23
TN	0.38

This result indicates that there is no statistically significant difference between the censored and uncensored dataset for ammonia, nitrate + nitrite, total dissolved nitrogen, and total nitrogen. A statistically significant difference was found for particulate organic nitrogen. The DQO failures for particulate organic nitrogen are related to failed field duplicate and field split tests. This could be related to sample variability in the particulate fraction, where the samples are not homogenous in the particulate fraction. Since the concentrations and sample volumes are relatively low, it does not take that large of a difference to fail the 30% RPD criterion. Furthermore, the difference between the censored and uncensored total nitrogen data were not statistically significant. Therefore, all data were included in this analysis and discussion.

7.0 Summary and Discussion

The Upper Blackstone river water quality monitoring program was initiated in 2012 to monitor and assess the impact of WWTF upgrades. Since the 2008 upgrades were completed and brought online in 2009, Upper Blackstone has continued to refine its treatment process to minimize nutrients, particularly in the summer months. Compared to 2018, the WWTF performed at about the same level in 2019, the effluent TP load has been reduced by 92% and the effluent TN load has been reduced by 53% compared to the average pre-upgrade nutrient loads between 2006 and 2008.

Water quality monitoring data collected by Upper Blackstone in 2019 continued to show water quality improvements relative to conditions prior to the WWTF upgrade. Reduced nutrient loads from the WWTF's effluent correlate with reduced river nutrient and chlorophyll-a levels, increasingly meeting MassDEP river water quality guidelines for the Blackstone River. In 2019, river TP concentrations were average to low at all sampling sites, with 80 percent of the samples collected below the 100 ppb MassDEP guidance value. River TN concentrations were slightly higher than in the past few years, especially just below the UB effluent confluence with the Blackstone River, but are still lower than the pre-upgrade condition, contributing to observed water quality improvements in downstream marine waters such as Narragansett Bay. The 2019 river TP loads were in general average to lower, though TP loads increased at the Rhode Island sites. TN yearly loads were higher at all sites, but lower than in the past three years when averaged over summer months. The increase in river loads can be explained by high streamflows in the spring and fall, and low streamflows in the summer. However, when compared to before the Upper Blackstone plant upgrade, overall nutrient loads have been greatly reduced.

The 2019 sampling season was preceded by a lower than average snowy winter and in general the year can be characterized by normal temperatures though a warmer summer, and somewhat higher than average precipitation and streamflow until July. 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 nutrient and chlorophyll-a levels. Though river nutrient loads were higher than average in 2019, and despite summer temperatures being higher than average, chlorophyll-a measurements met MassDEP's guidance values nearly all of the time. Field measurements of water temperature, pH, and dissolved oxygen, in addition to conductivity measured in the laboratory, documented that the Blackstone River meets state water quality standards on the dates and times visited by this project's crews.

Continuous Dissolved Oxygen levels followed a consistent pattern in the stretch of the Blackstone River that was monitored in 2019. DO levels above the Upper Blackstone treated effluent discharge (W0680) indicate the river supports aquatic life uses based on guidance in MassDEP's 2018 CALM. At the middle two stations in the program aquatic life uses are not supported due to occasional drops in DO below 5 mg/L and DO diurnal variations that exceed 3 mg/L. But farther downstream aquatic life uses are again supported based on DO data. Exceedances of water quality guidance and standards occurred most frequently during a very low flow period in September and October.

Finally, one benefit of a long-term data collection efforts like Upper Blackstone's is that a more robust statistical analysis of data trends can be completed. Trends in water quality were evaluated on streamflow-weighted TP and TN data collected since 2012. Statistically significant, decreasing TP trends were noted at all sites except for W0680 and UBWPAD2, and decreasing TN trends were noted at all sites except for W0680, UBWPAD2, and W0767. The chlorophyll-a trend analysis suggests that overall chlorophyll-a levels are increasing slightly, especially at the upper mid-river sites (W1258 and W1242); however, the overall chlorophyll-a concentrations are generally low.

The Upper Blackstone water quality monitoring program has documented significant improvements relative to nutrient and chlorophyll-a concentrations in the Blackstone River since the WWTF upgrade was completed. Subsequent optimization efforts have resulted in continued reductions in nutrients and chlorophyll-a concentrations. These trends are promising, and water quality is expected to improve even more as Upper Blackstone continues its work to improve its effluent water quality in accordance with its NPDES permit and Administrative Order on Consent.

8.0 Future Work

Upper Blackstone plans to continue water quality monitoring in the Blackstone River in 2020 to track the impacts of reduced nutrient concentrations in Upper Blackstone plant effluent. Blackstone River data collected in 2019 will be added to EPA's WQX database. The 2019 data, in addition to the data from 2012 – 2018 was submitted to the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) database, which is sponsored by the National Science Foundation, and will be publicly available for download through the CUAHSI Hydrologic Information System (HIS) databases and servers (data.cuahsi.org). In addition, the 2019 data will be submitted to MassDEP to supplement the data already submitted.

In 2020 the monitoring of nutrients and river chemistry at the 9 sampling sites will be continued, as will measurement of continuous dissolved oxygen at 4 sampling sites.

9.0 References

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