Blackstone River Water Quality Monitoring Program

2020 Sampling Season Report

Prepared for

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by

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Front cover photo: UMass WRRC Research Fellow Cameron Richards collecting a sample at W1779 (Below Rice City Pond in Uxbridge, MA) in July 2020. 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 July and November 2020. 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.

2020 presented a special challenge due to the COVID-19 pandemic which caused the temporary closure of facilities as well as disallowed travel for staff. Sampling therefore started July 1 instead of late April as was customary in previous years. Sampling, sample handling, and laboratory analyses were unchanged from previous years, though chlorophyll filtering and aliquot splitting were done in a separate lab at the Upper Blackstone plant. Sampling sites remained at the same locations as in 2019. More detailed technical information regarding the sampling program is available in the 2020 Field Sampling Plan and the Quality Assurance Project Plan (QAPP) for this project. Water quality reports and fact sheets 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 (through 2019) and via EPA WQX starting with 2020 data.

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 River 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 (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 (UMass et al, 2015). A new approved QAPP covered sampling in 2017 – 2019 (UMass et al, 2017), and the latest QAPP covers sampling from 2020 through 2022. (UMass and CDM Smith, 2020). 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

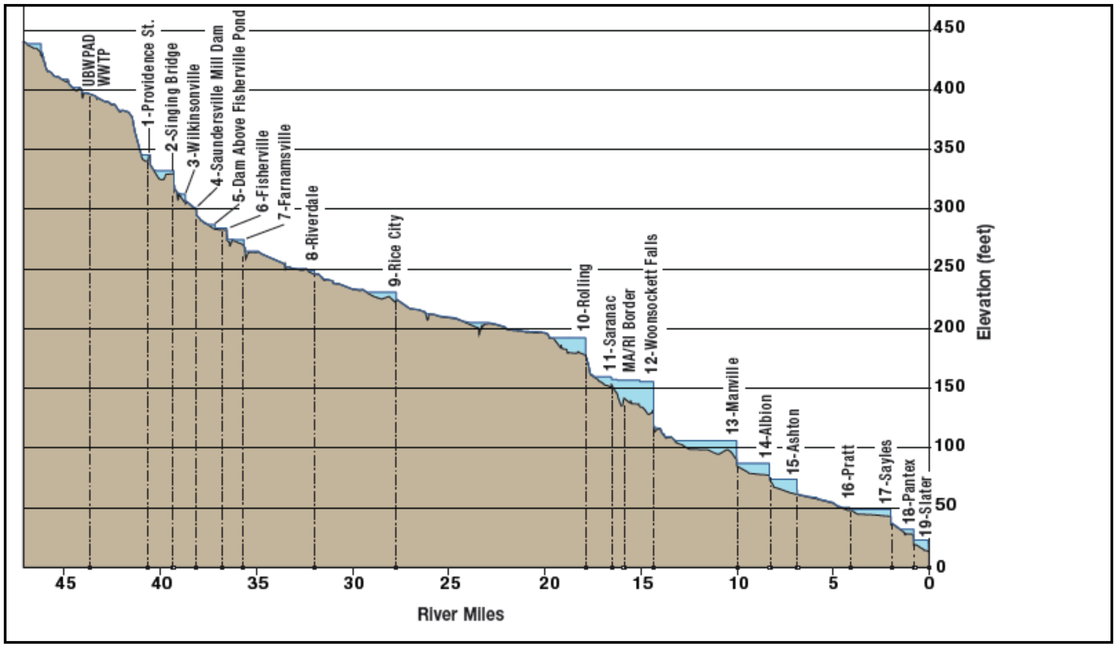

Figure 1: River elevation profile

3.0 Blackstone Water Quality Sampling Program

In 2020, the river monitoring program included monthly water quality sampling for nutrients, chlorophyll-a, and field parameters (dissolved oxygen, temperature, conductivity, and pH) from July through November. The three Rhode Island sites were co-sampled with the Narragansett Bay Commission (NBC).

Sampling locations for routine nutrient/chlorophyll-a monitoring 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 2020 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 2020), 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 were conducted from July through November 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 early November.

Table 2: Blackstone River 2020 sampling sites

Site ID#	Site Name	Lat.	Long.	River Mile[2]	HSPF Reach[2]	Sampling Details[3]
RSMD[1]	Slater Mill Dam, Pawtucket, RI	41.877	-71.382	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.
[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.

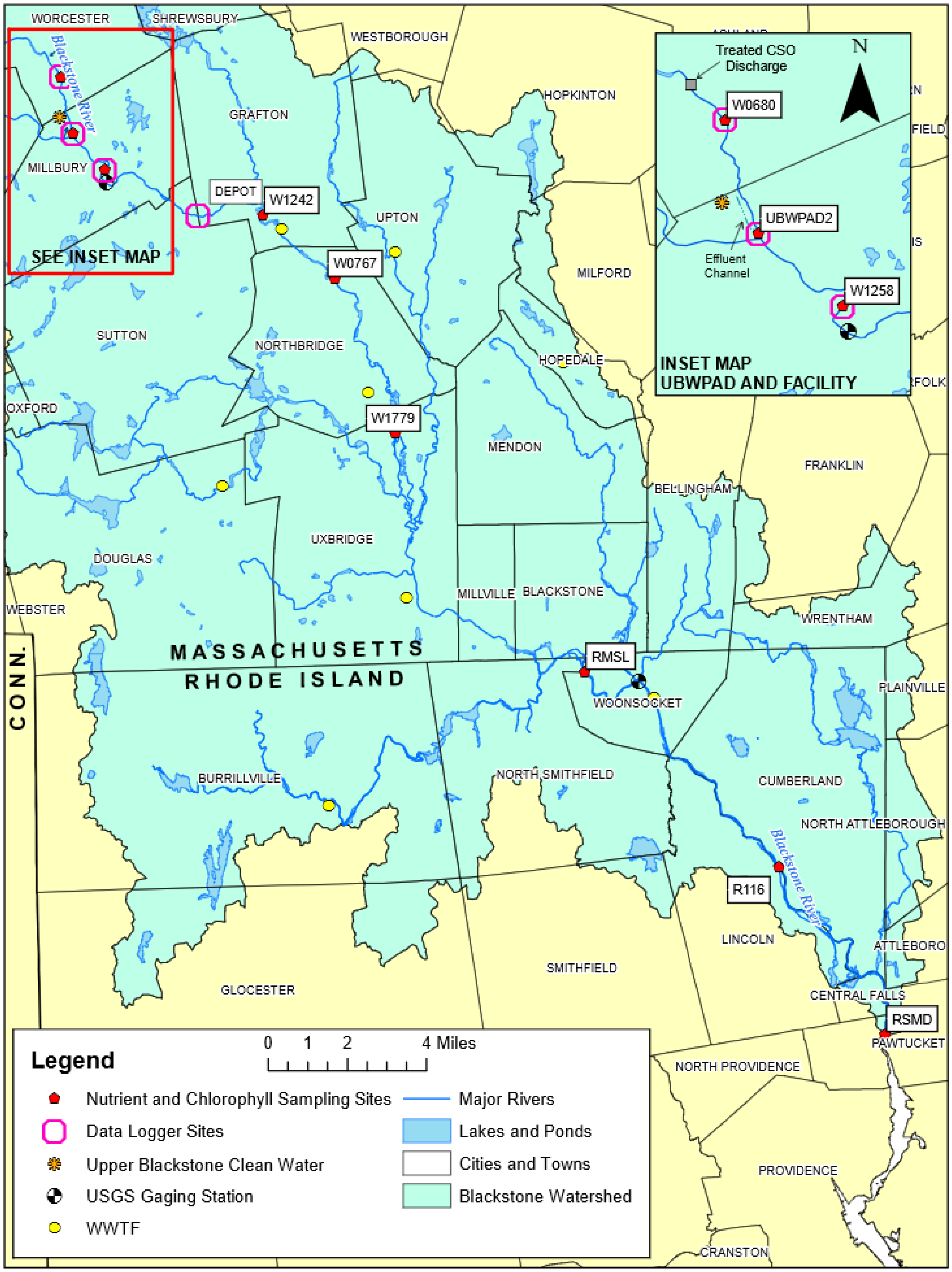

Figure 2: Blackstone River 2020 sampling sites and location of continuous data loggers

3.2 Sampling Dates and Data Collected

2020 sampling dates are summarized in **Table 3.** Note that the sampling program was truncated due to the COVID-19 pandemic.

Table 3: 2020 river sampling dates

Site ID#	7/1	7/29	8/26	9/23	10/21	11/18
RSMD		X	X	X	X	X
R116		X	X	X	X	X
RMSL		X	X	X	X	X
W1779	X	X	X	X	X	X
W0767		X	X	X	X	X
W1242		X	X	X	X	X
W1258	X	X	X	X	X	X
UBWPAD2	X	X	X	X	X	X
W0680		X	X	X	X	X

X: Data collection completed
Note that compared to other years, sampling dates are 2 weeks later in the month
Note that in the analyses, 7/1 was considered a "June" event

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 4**. 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: 2020 river sampling program analytes and laboratories

Parameter	Upper Blackstone Lab	NBC Lab	UMass EAL	UMD Lab
Dissolved Ammonia (dNH_4)	--	Jul – Nov 3 RI Sites	--	Jul – Nov All sites
Dissolved Nitrite/Nitrate (dNO_{23})	--	Jul – Nov 3 RI Sites	--	Jul – Nov All sites
Total Dissolved Nitrogen (TDN)	--	Jul – Nov 3 RI Sites	--	Jul – Nov All sites
Total Nitrogen (TN)	--	--	--	Calculated
Particulate Organic Nitrogen (PON)	--	--	--	Jul – Nov All sites
Total Orthophosphate (TOP)	Jul – Nov All sites	--	--	--
Total Phosphorus (TP)	--	--	Jul – Nov All sites	--
Total Suspended Solids (TSS)	Jul – Nov All sites	Jul – Nov 3 RI Sites	--	--
Chlorophyll-a (chl-a)	--	--	Jul – Nov All sites	--
Dissolved Oxygen (DO)	Jul 29 - Nov All Sites & Continuous Jul-Nov @ 4 sites			
Water Temperature	Jul 29 - Nov All Sites & Continuous Jul-Nov @ 4 sites			
pH	Jul 29 - Nov All Sites			
Specific Conductance (SC)	Jul -Nov All 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 ~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

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

tend to be higher. Shallower 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 could 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 2020 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 2018 - 2019 and 2019-2020 are highlighted due to their potential influence on the subsequent sampling season results. The ten sampling seasons in the current project 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 2020 sampling season was preceded by the second least snowy winter in the past ten years, with 44.9 inches of snowfall (ranked 91st since 1892).

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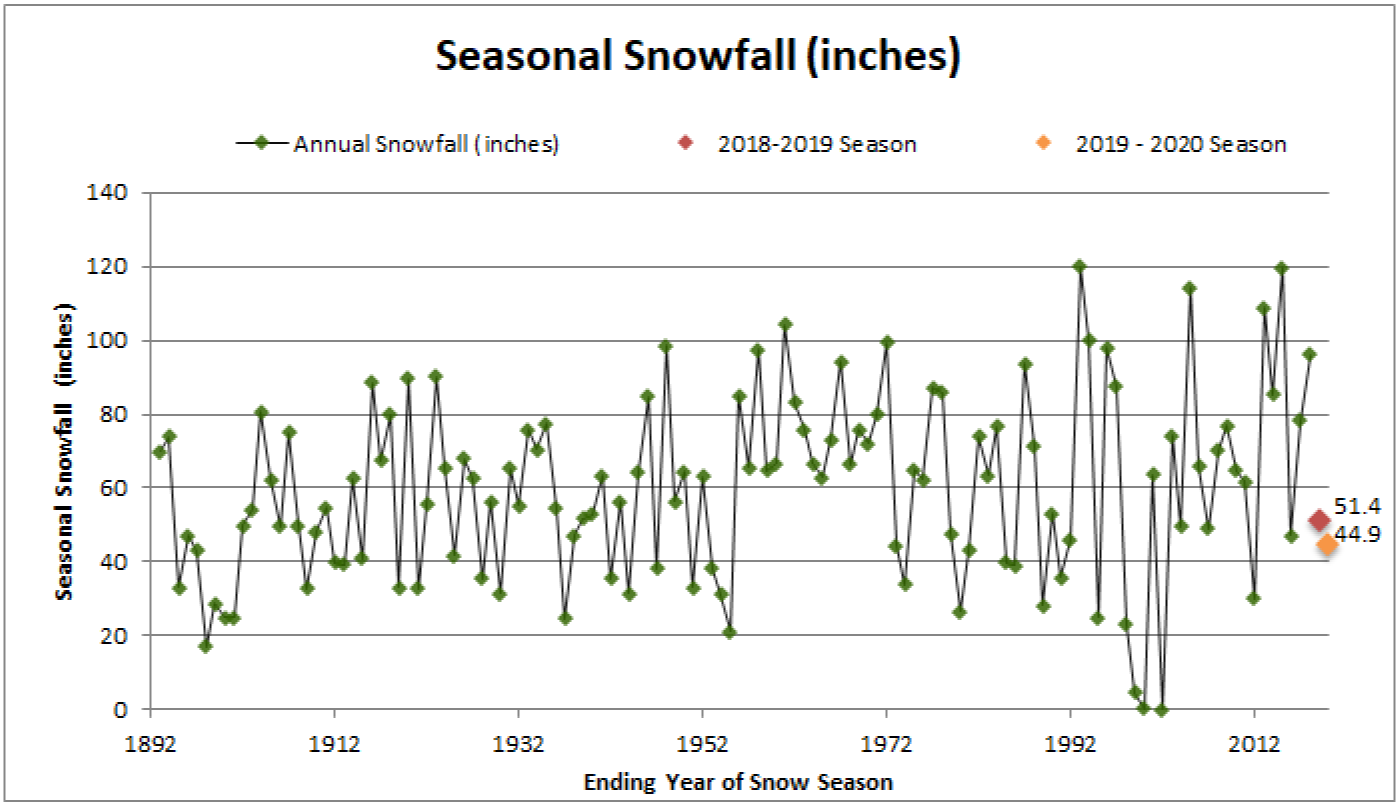
[2] 85 cfs is the lowest average discharge over a period of seven days that occurs on average once every 10 years (7Q10) at the Woonsocket stream gaging station



(Note: year plotted is end of snow season)

Figure 3: Seasonal snowfall (inches) in Worcester from 1893 through 2020, inclusive

Table 5: Snowfall totals winters 2011-2012 to 2019-2020

	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
Winter 2019 - 20	44.9	91st

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 2020 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 2020 were higher than historical median every month except April and May. April was the coldest compared to previous years, while May temperatures were near the historical median. Summer months (June, July, August) saw much higher temperatures to the historical record, all falling near the top of the statistical distribution. While September and October temperatures did not exceed historical values, they were still at the 75th percentile, while November temperatures reached far above the 75th percentile. Looking at the 2020 sampling season (July through November), air temperature was higher than the median each month.

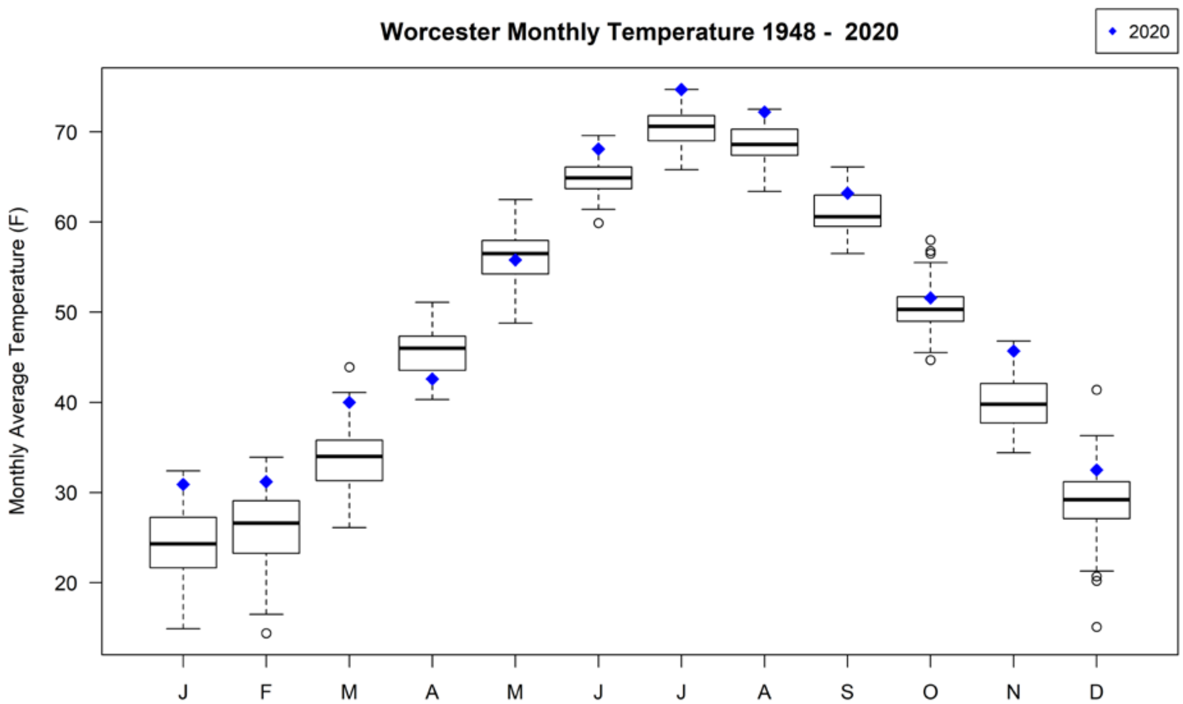
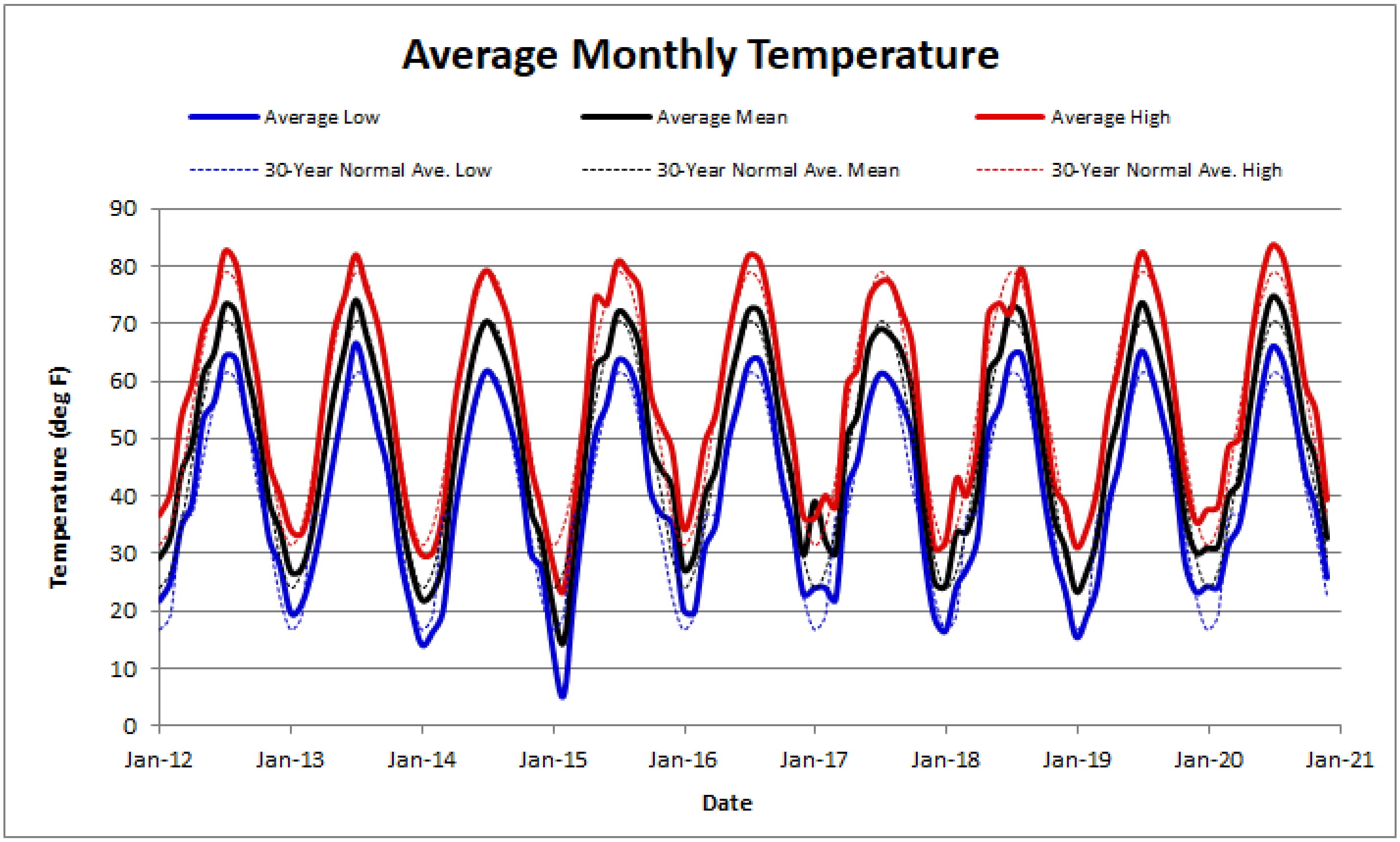


Figure 4: Worcester monthly air temperatures 1948 - 2020

Figure 5 presents three statistics to summarize monthly temperature conditions at the Worcester airport 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 2020 sampling season was noticeably 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 2019 and 2020 noted with the associated accumulation. The annual precipitation in 2020, 46.9 inches, was much lower than the previous two years, and one inch lower than the average of the observed values since 1949 (47.9 inches).

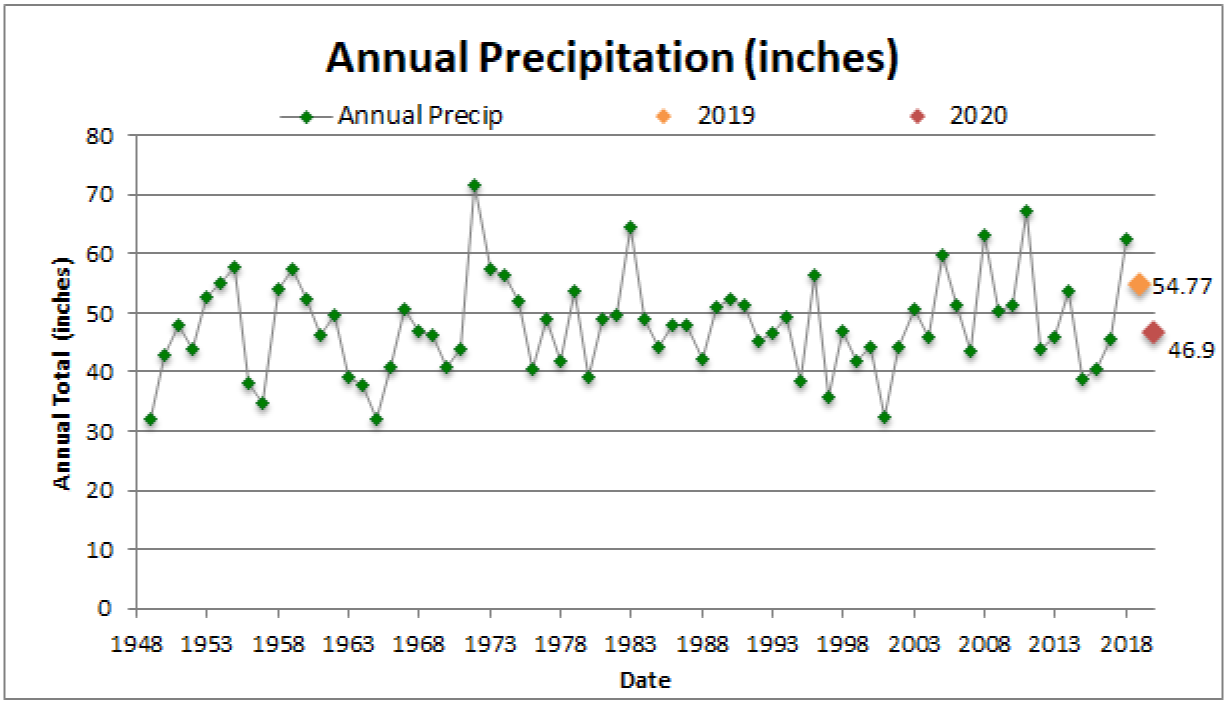
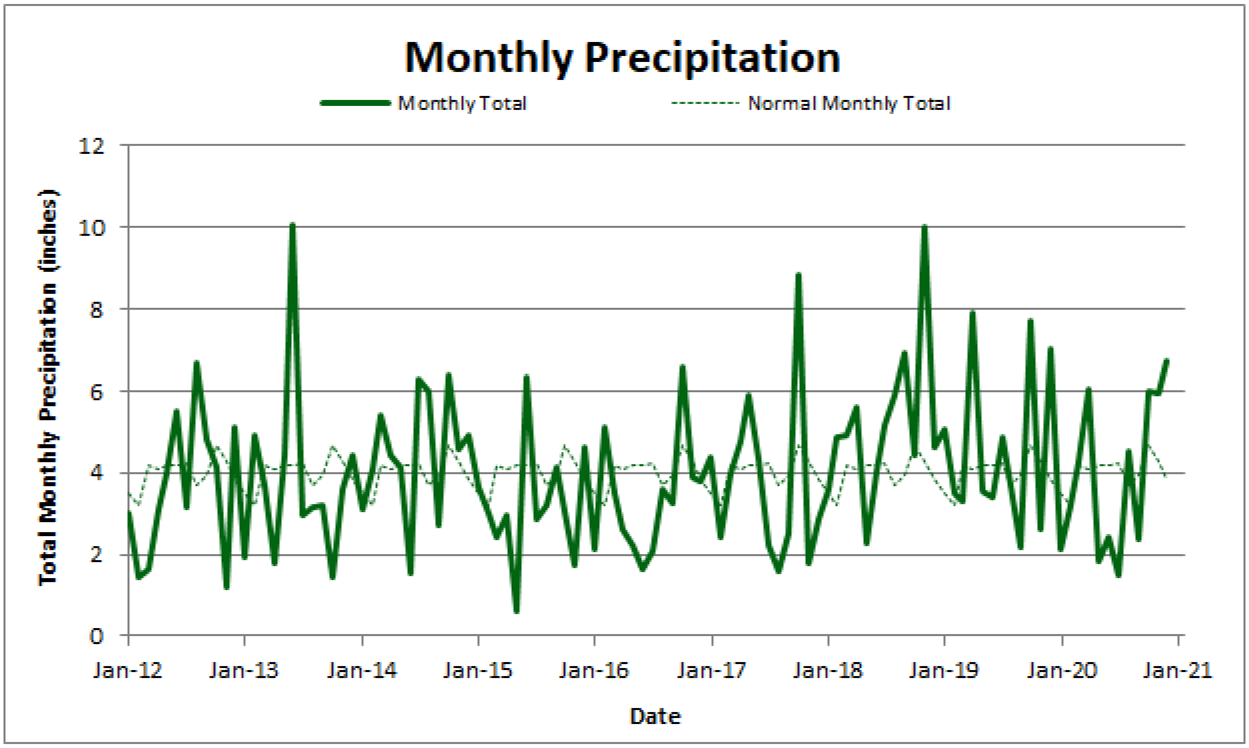


Figure 6: Annual precipitation (inches) in Worcester since 1949

Figure 7 summarizes monthly precipitation conditions based on Worcester Airport data 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 2020 generally shows lower precipitation amounts than average, except in early spring and late fall.



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 2012-2020 compared to normal monthly totals

Monthly precipitation totals since 1948 for Worcester are summarized using box plots on **Figure 8**. Data for 2020 are represented by blue diamonds. In 2020, April, August, October and November saw higher precipitation than historical trends, while May, June, July and September were much drier than historical trends. Monthly precipitation condition data for the 2020 sampling year compared to the NWS 30-year normal are provided in Appendix A.

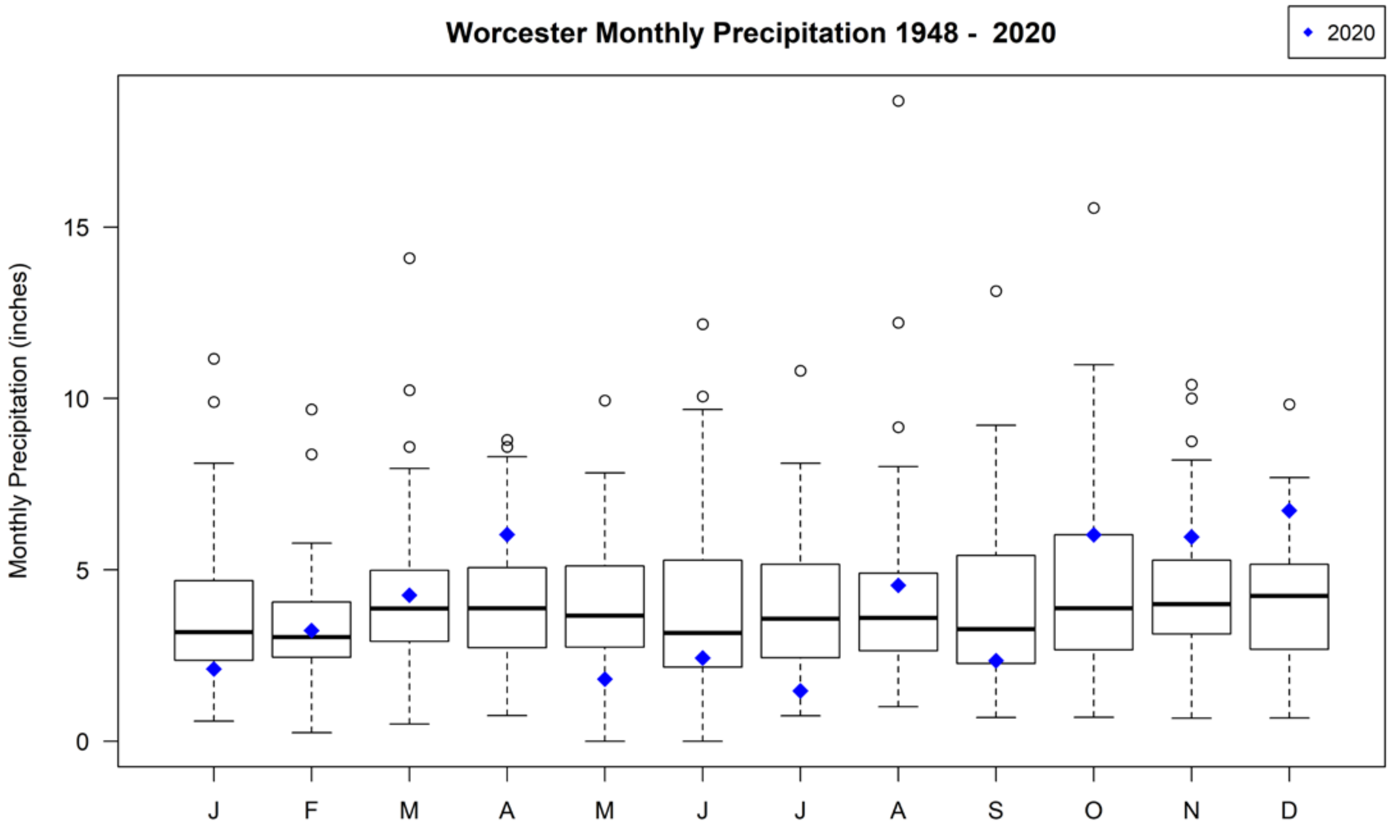


Figure 8: **Worcester monthly precipitation 1948 - 2020**

Daily precipitation data as measured at the Worcester Airport are plotted on **Figure 9** for 2020. The precipitation on sampling dates is highlighted with triangles. 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 46.9 inches in 2020. Cumulative rainfall in the 2020 sampling season was lower than the historical cumulative 50th percentile all 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 6** for all routine sampling dates in 2020. Most routine sampling in 2020 occurred on days with little to no precipitation, except on July 1st. Significant rainfall (>0.5 inches) occurred during the week prior to sampling every month except July 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.

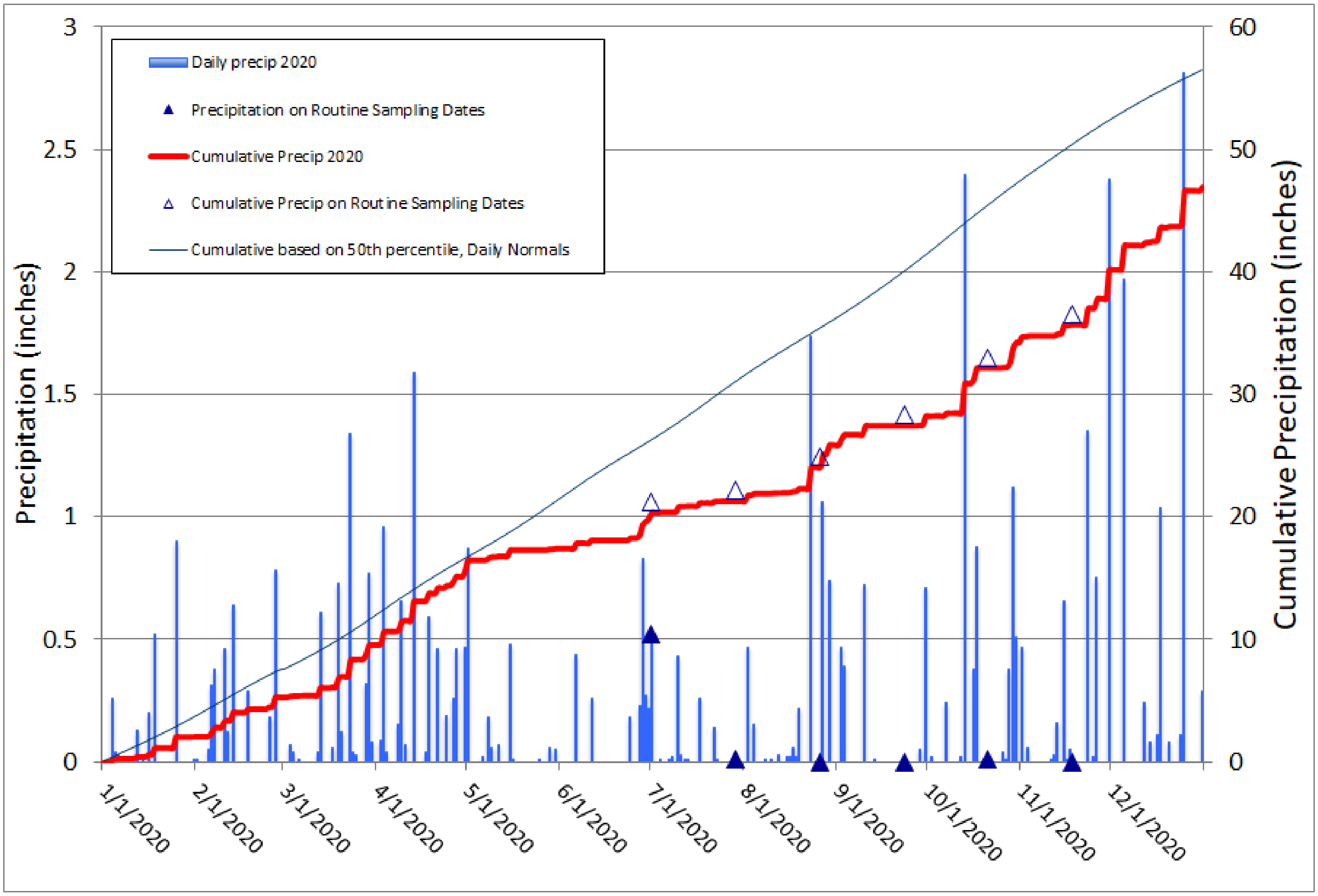


Figure 9: 2020 sampling season daily precipitation at Worcester Airport (KORH) compared against 50th percentile daily normal precipitation

Table 6: Day-of and antecedent precipitation on routine sampling dates in 2020

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
1 July	0.52*	0.22	1.32	1.73
29 July	0.01	0.00	0.00	0.15
26 August	0.00	0.00	1.74	1.96
23 September	0.00	0.00	0.00	0.00
21 October	0.01	0.00	0.00	1.26
18 November	0.00	0.05	0.72	0.92

*Occurred late in the day, after sampling concluded

4.2 Streamflow Conditions

Blackstone River Streamflow conditions during the 2020 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 (01109730), since 2003 are summarized on **Figure 10** as a box plot, with the monthly average data for 2020 depicted with blue diamonds. Data for the USGS gage at Woonsocket, RI (01112500), 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**. During the 2020 sampling season, streamflows at the Millbury gage were below the median value during the entire sampling season. Monthly average flows were below the 25% quartile in June, July and September, near or at the 25% percentile in August and October, and just below the median in November. At the Woonsocket gage, monthly average streamflows were also lower than in previous years, but closer to the median, except in August and September when they were below the 25% quartile.

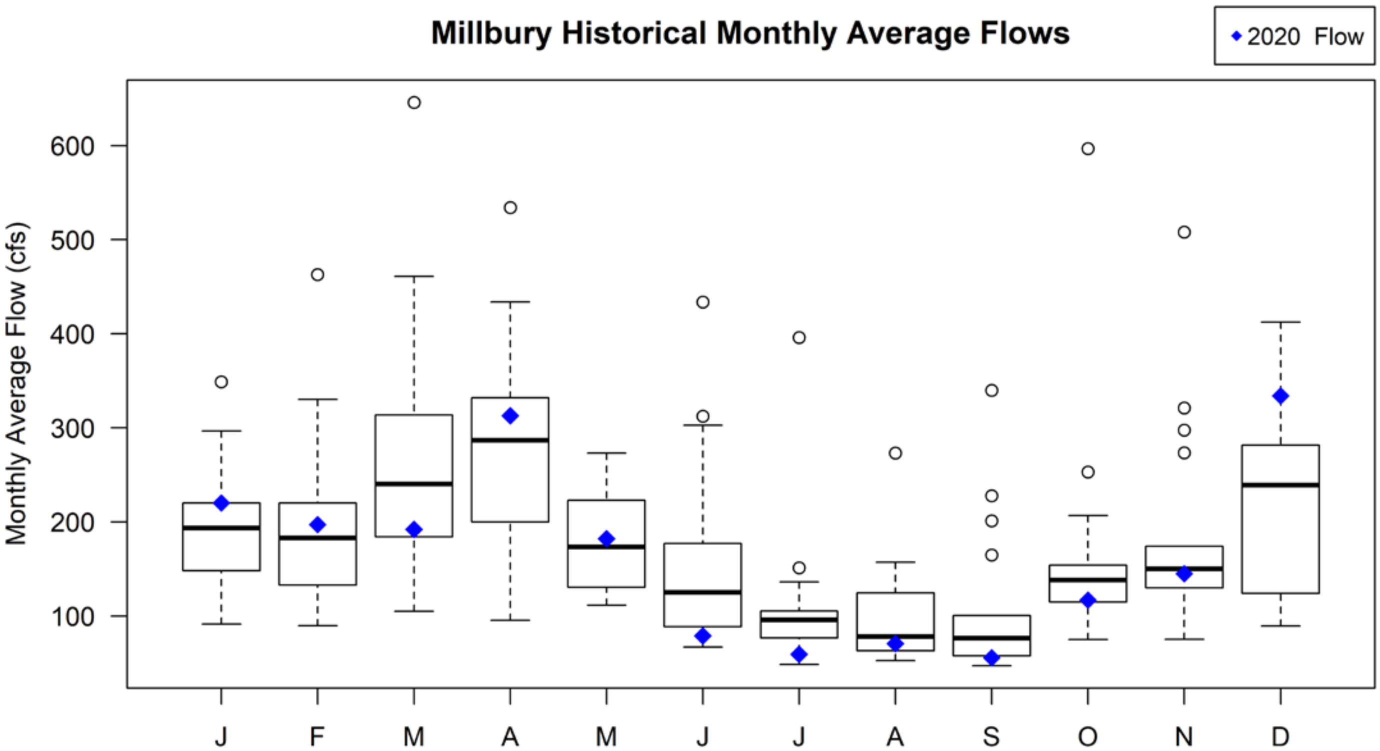


Figure 10: Millbury, MA, USGS gaging station 01109730 historical monthly average streamflows, 2003 - 2020

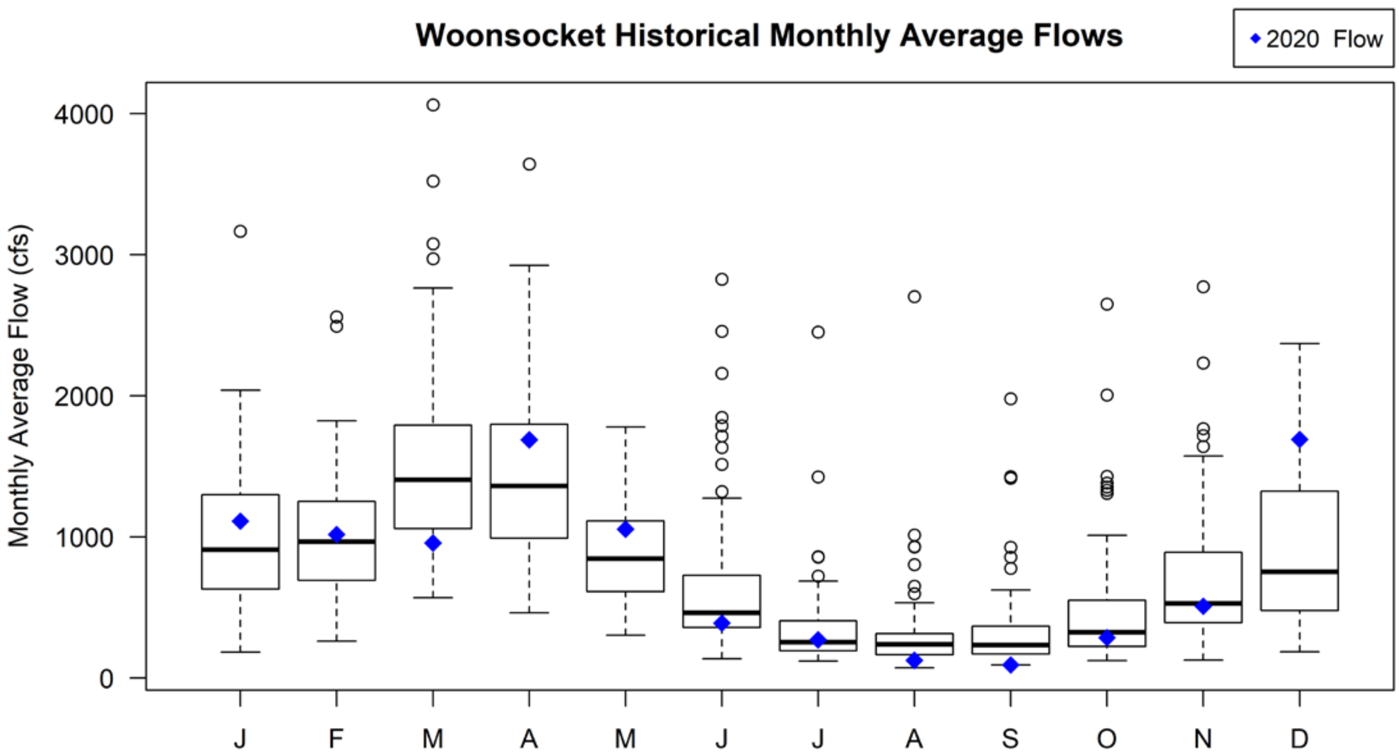
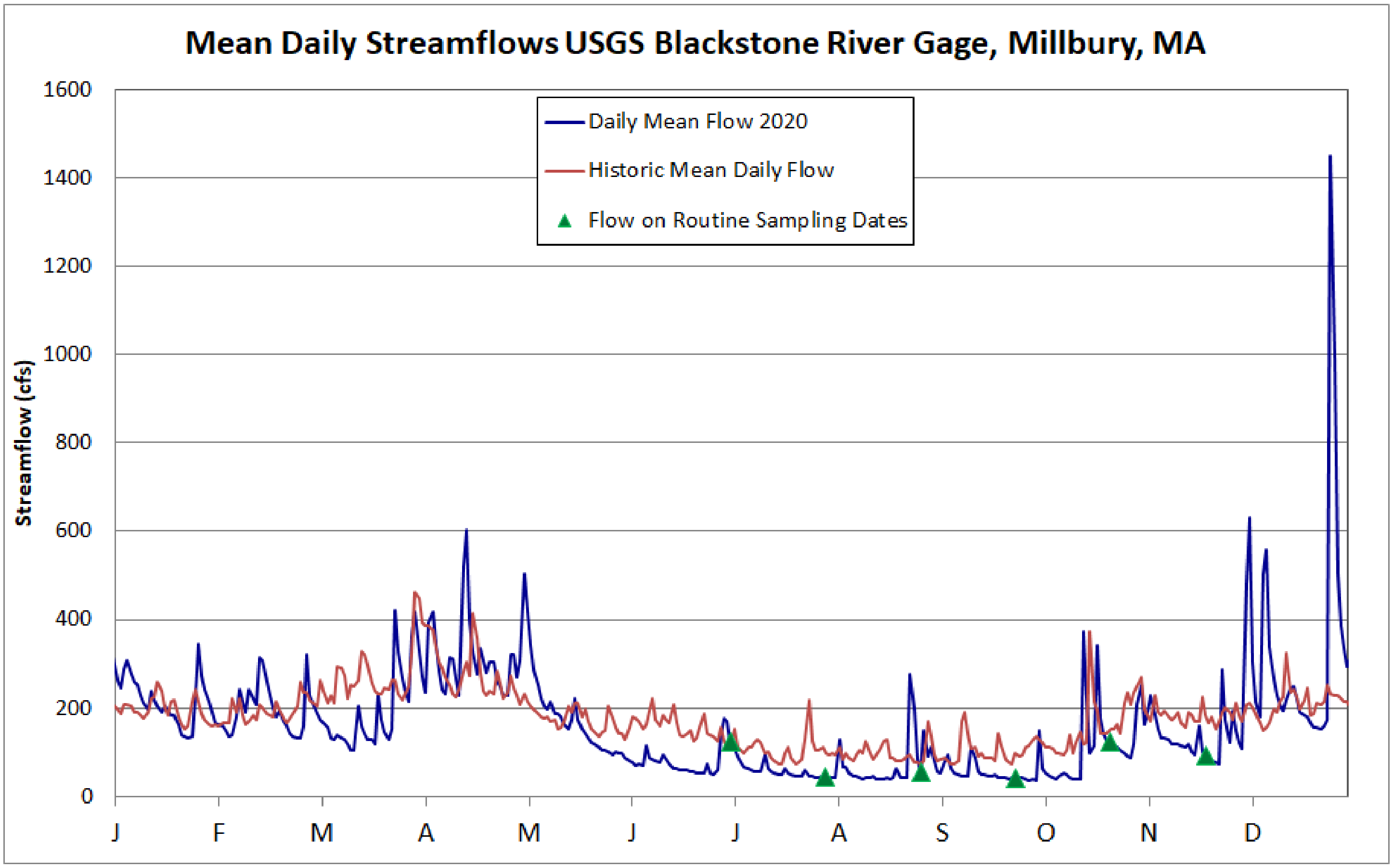


Figure 11: Woonsocket, RI, USGS gaging station historical monthly average streamflows, 1930 – 2020

Table 7: Mean monthly streamflows in 2020 compared to median, mean, minimum

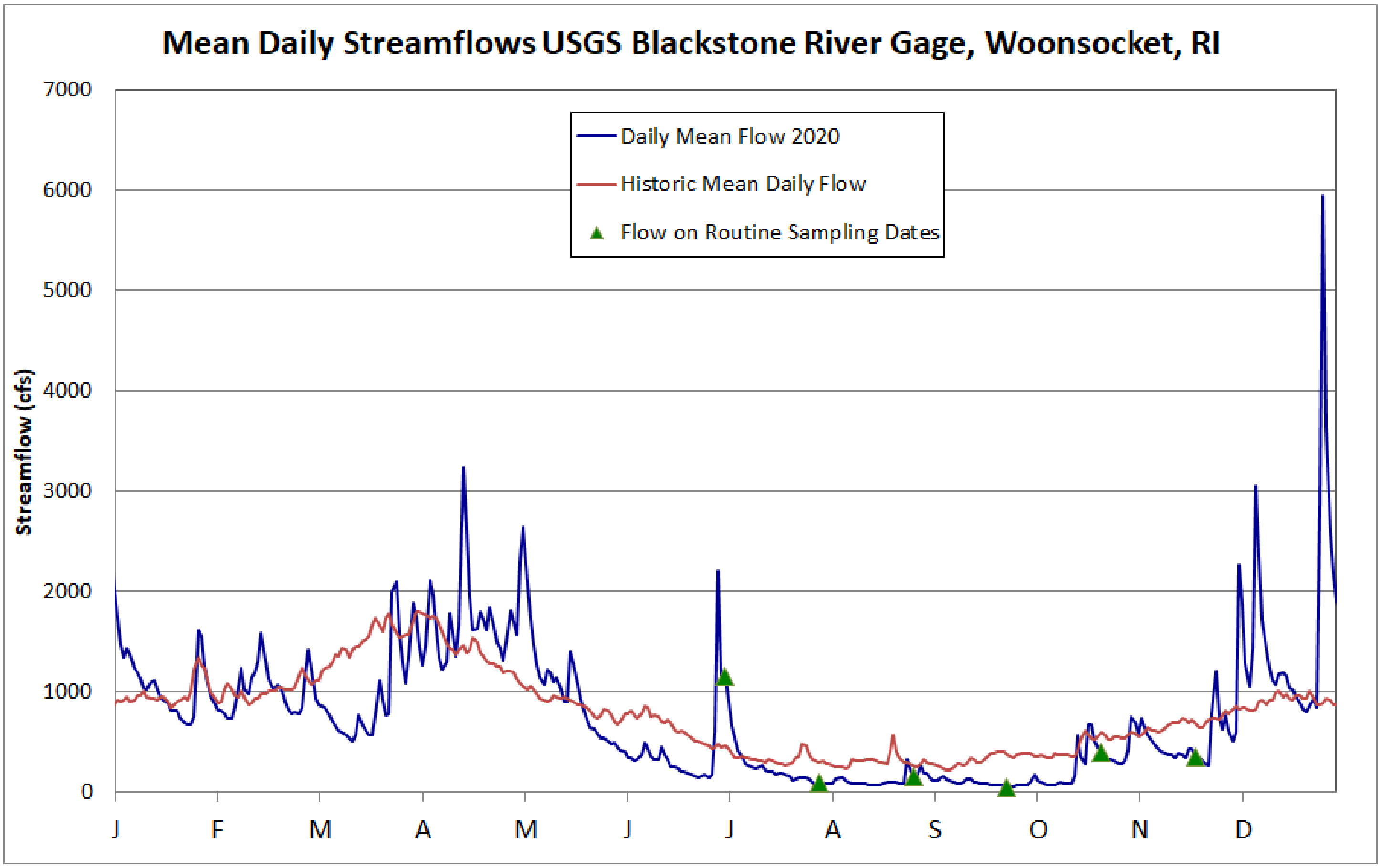
Millbury (cfs)	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
2020 Monthly Q_{ave}	*78.9*	*59.3*	*70.7*	*55.6*	*117*	*145*
Median 2003 – 2020	*125*	*96*	*78*	*76*	*138*	*150*
Average 2003 – 2020	*158*	*109*	*99*	*106*	*163*	*180*
Minimum 2003 – 2020	*67*	*49*	*53*	*47*	*75*	*75*
Woonsocket (cfs)	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
2020 Monthly Q_{ave}	*389*	*271*	*125*	*93*	*286*	*508*
Median 1930 - 2020	*462*	*253*	*239*	*233*	*324*	*528*
Average 1930 - 2020	*646*	*341*	*308*	*326*	*474*	*694*
Minimum 1930 – 2020	*137*	*120*	*72*	*93*	*123*	*127*

Mean daily streamflows measured at Millbury and Woonsocket are compared to historic mean daily streamflows on **Figure 12** and **Figure 13**, respectively**,** for the 2020 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 lower than historically most of the sampling season, especially at the Millbury gage. In the 2020 sampling season at the Millbury stream gage, daily streamflows were mostly below average historical conditions except early September and starting in November. At the Woonsocket gage, streamflow was also low during the 2020 sampling season, except late June-early July and in the fall.



(Notes: Historical Mean Daily streamflow data through 2019)

Figure 12: **2020 mean daily streamflows at USGS Millbury, MA stream gage**



(Notes: Historical Mean Daily streamflow data through 2019)

Figure 13: **2020 mean daily streamflows at USGS Woonsocket, RI stream gage**

Table 8 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 8** may differ from the monthly mean.

Table 8: Routine sampling day-of streamflow conditions 2020

Sampling Date	Woonsocket, RI – USGS Station 01112500			Millbury, MA – USGS Station 01109730		
	2020 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
1 July	1160	466	249%	122	103	118%
29 July	92.9	303	31%	43	58.5	74%
26 August	148	275	59%	56	67	84%
23 September	53.5	378	14%	41	59.4	69%
21 October	394	607	65%	122	105	116%
18 November	348	649	54%	92	108	85%

[a] Historical Mean Daily Q (cfs) based on data through 2020

4.3 Environmental Conditions Summary

- Snowfall in the 2019-2020 season was low and snowmelt did not impact the monitoring program.
- Temperatures during the 2020 sampling season were higher than average.
- 2020 summer precipitation was below average in July and September, but above average the rest of the sampling season.
- Consequently, streamflow in 2020 was for the most part lower than average the entire sampling season until November, with a few spikes each month.

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 9.** 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:

- 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;

[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.

- WWTF upgrade construction to implement successfully tested interim measures and to modernize facility SCADA and data collection systems;
- Design of phosphorus removal system to meet 2008 permit limits.

Table 9: 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 TP and TN annual daily concentrations since 2006, and **Table 10** summarizes TP and TN effluent concentrations by season, corresponding to the permit limits, since 2012.

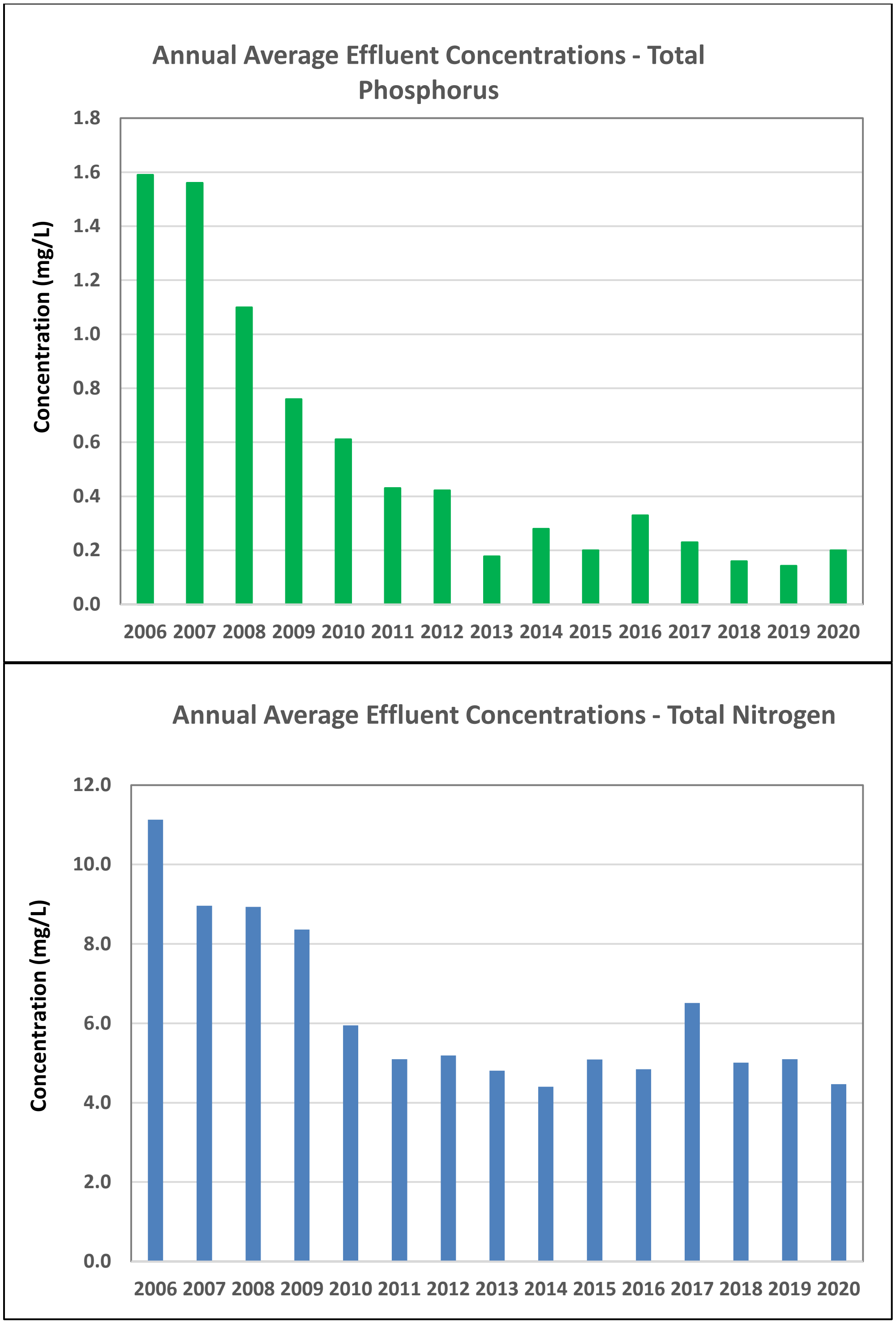


Figure 14: Annual average effluent total phosphorus and total nitrogen concentrations 2006 – 2020

Table 10: Upper Blackstone average permit season TP and TN effluent concentrations*

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Phosphorus (mg/L)									
Apr – Oct (summer)	0.48	0.17	0.35	0.18	0.20	0.17	0.20	0.17	0.24
Nov – Mar (winter)	0.43	0.17	0.19	0.18	0.55	0.34	0.12	0.11	0.13
Total Nitrogen (mg/L)									
May – Oct (summer)	5.2	4.3	4.5	4.6	3.9	5.0	4.9	5.1	4.4
Nov – Apr (winter)	4.0	5.5	4.6	5.3	6.1	9.1	5.1	5.3	4.6

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

Yearly TP and TN effluent loads prior to plant upgrade (2006-2008) and since 2012 are shown in **Table 11**., along with percent reduction in loads in the effluent since 2006-2008

Table 11: Annual TP and TN Effluent Loads and 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 x 10^3	--	1045 x 10^3	--
2012	38.3 x 10^3	75%	458 x 10^3	56%
2013	18.9 x 10^3	88%	452 x 10^3	57%
2014	25.6 x 10^3	83%	428 x 10^3	59%
2015	19.6 x 10^3	87%	499 x 10^3	52%
2016	33.9 x 10^3	78%	485 x 10^3	54%
2017	23.3 x 10^3	85%	690 x 10^3	34%
2018	19.6 x 10^3	87%	597 x 10^3	43%
2019	12.8 x 10^3	92%	495 x 10^3	53%
2020	15.4 x 10^3	90%	364 X 10^3	64%

Figure 15 shows the effluent TN and TP annual total loads since 2006, and seasonal loads for summer and winter for 2010-2020.

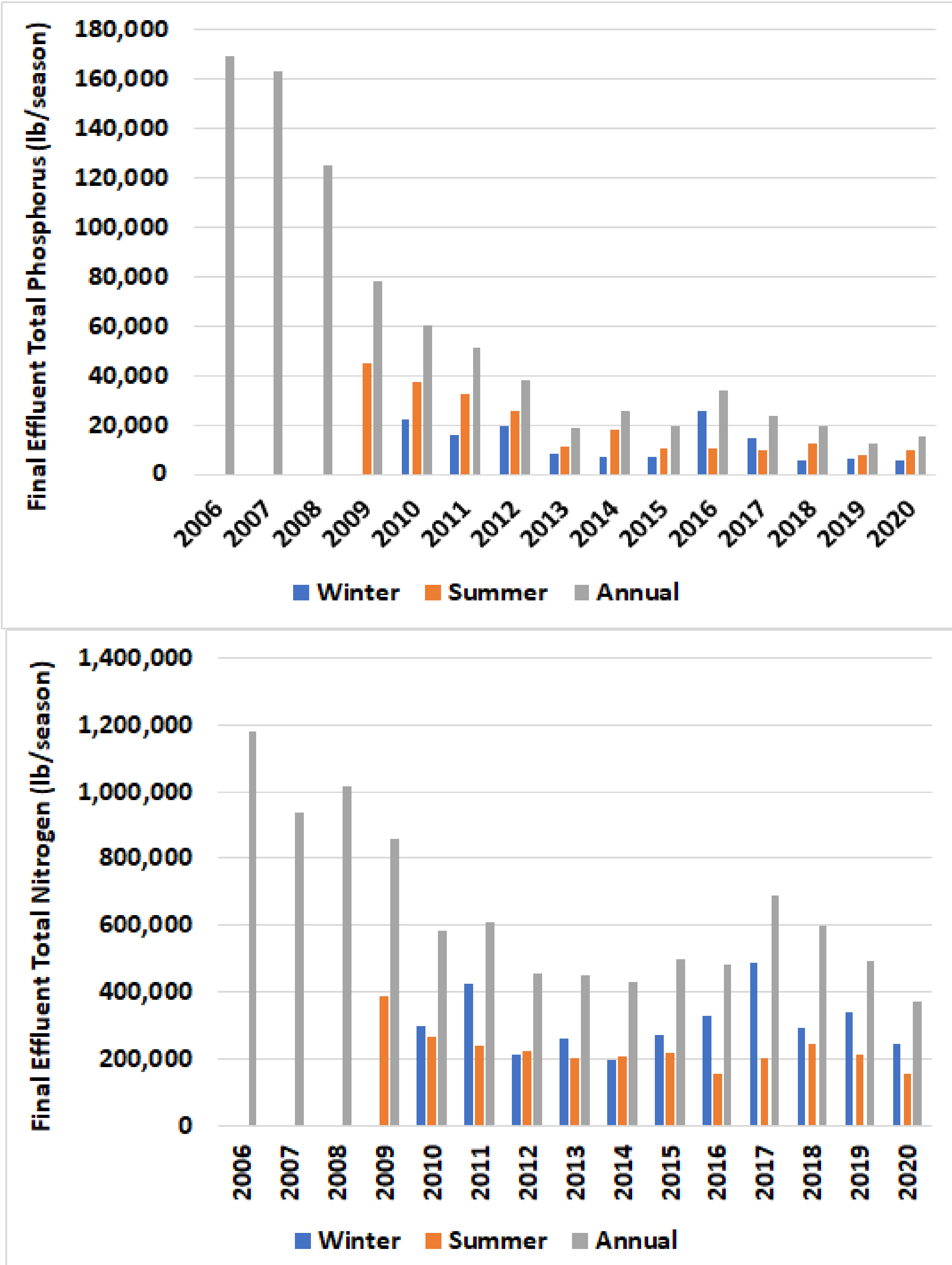


Figure 15: Total annual, winter permit, and summer permit total nitrogen and total phosphorus loads to the Blackstone River 2006 – 2020

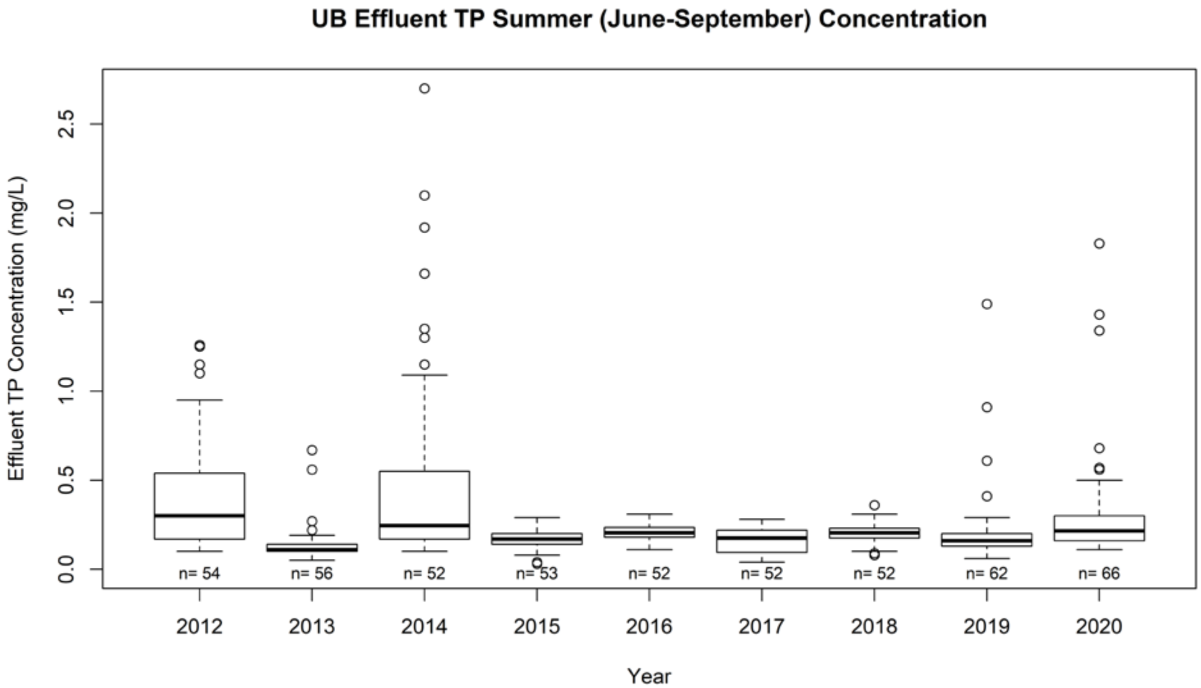
The highest biological activity in the river typically occurs during the warmest months of the year, from June through September. It is thus also useful to identify year-to-year differences in effluent nutrient characteristics for this summer growing period which may provide insight into river conditions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

Effluent nutrient and flow data during each year from 2006 - 2020 were used to calculate the daily average concentration and load from June through September, **Table 12**.

Table 12: 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 2020.

	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	0.89	238	7.8	2,089
2010	35.7	1.0	237	6.1	1,346
2011	53.6	0.45	151	4.2	1,411
2012	39.9	0.40	99	4.6	1,094
2013	48.3	0.14	45	3.8	1,065
2014	38.2	0.50	114	4.8	1,104
2015	43.2	0.17	44	4.5	1,167
2016	33.1	0.21	43	3.8	782
2017	38.3	0.17	36	4.4	1,729
2018	41.3	0.20	53	4.8	1,280
2019	38.0	0.21	43	5.1	1,066
2020	34.3	0.31	57.7	4.4	834

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 – 2020. The box plots provide an indication of the effluent variability during the June – September growing period each year of the monitoring program.



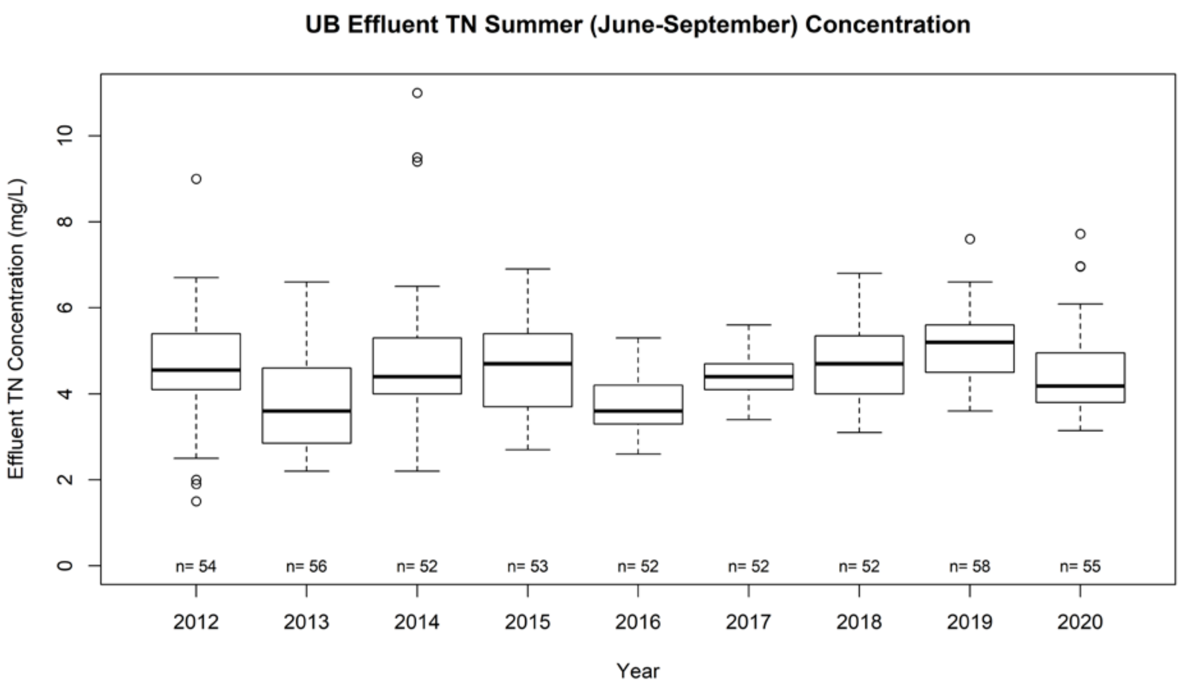
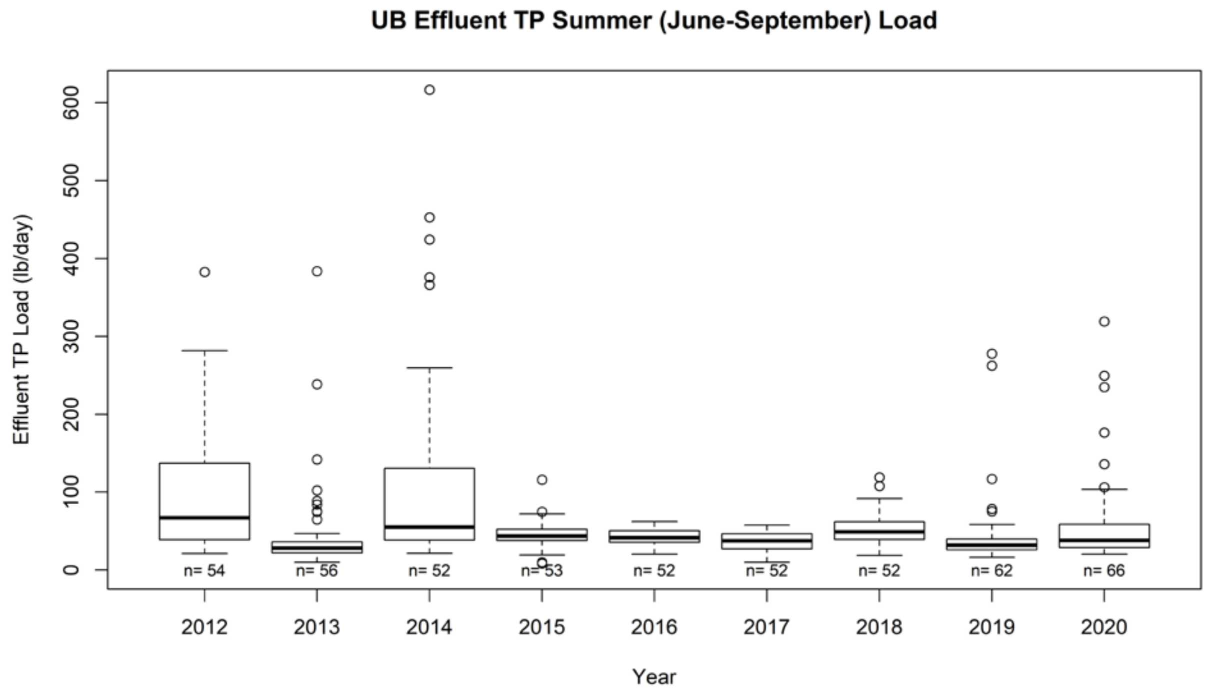


Figure 16: Upper Blackstone daily effluent TN and TP concentrations by year from June - September



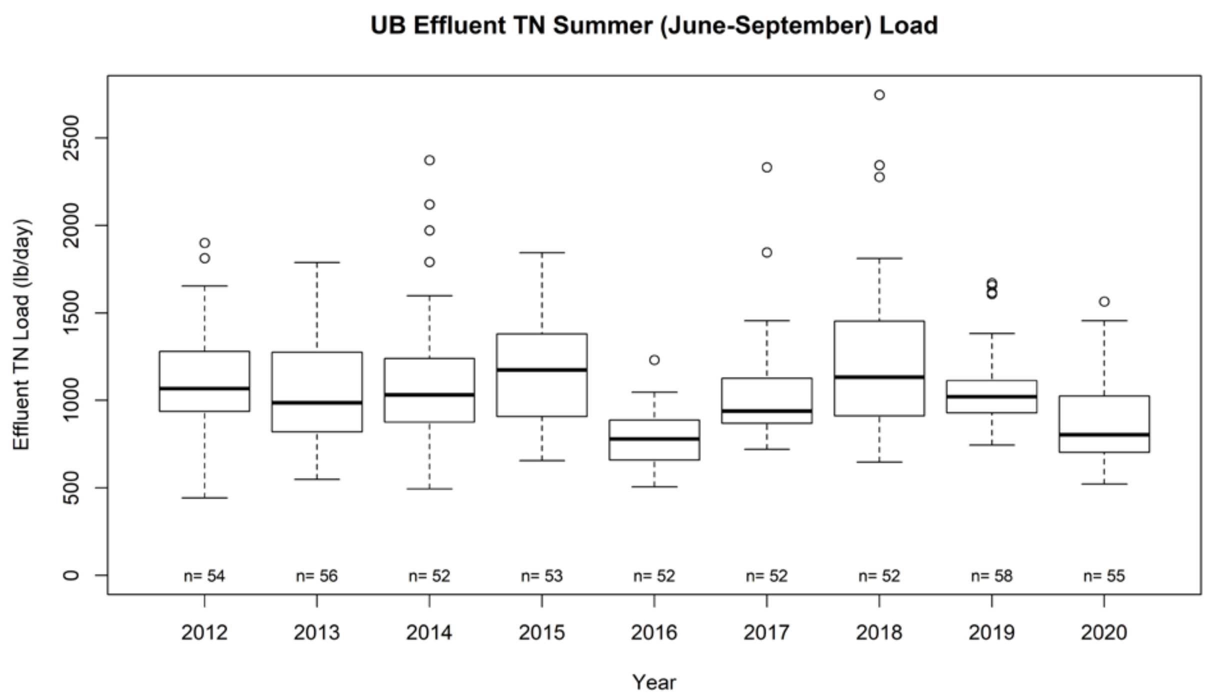


Figure 17: Upper Blackstone daily effluent TN and TP loads to the river by year from June - September

TP effluent concentrations and loads during the summer growing season have shown lower variability since 2015, as indicated by a small interquartile range in 2015-2020, but larger variability in 2012 and 2014, when Upper Blackstone refined its optimization process. In 2020, the median TP concentration and load were slightly larger and had more variability relative to historical concentrations in prior years. However, the effluent concentrations remained lower than pre-upgrade conditions.

Daily TN effluent concentration from June – September has been relatively constant since 2012, and was lower than historical, post-upgrade values in 2020. This pattern is also observed for daily growing season TN loads in 2020. 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. Since 2009, the average daily Upper Blackstone effluent flow contributions to summer flows (June through September) at Millbury has varied between 33% and 77%. In 2020, Upper Blackstone flow contributed between 19% (minimum) and 85% (maximum) of the daily streamflow at Millbury between July 1 and November 30, averaging 62% from July to September. As the 2020 summer was drier than typical conditions, the contribution of effluent to the river was higher than usual.

This contribution can be examined on a daily basis, and **Table 13** lists calculated estimates of the relative contribution of Upper Blackstone effluent flow to the streamflow measured at the Millbury gage on each of the 2020 sampling days. On most sampling days, this calculated value was above 30%, except in October (27%). The Upper Blackstone effluent was over 70% of the Millbury streamflow in late July and in September.

Table 13: **Relative contributions by volume on sampling days 2020**

Sampling Date	Upper Blackstone % of Millbury streamflow
7/1/2020	32%
7/29/2020	72%
8/26/2020	56%
9/23/2020	77%
10/21/2020	27%
11/19/2020	43%

6.0 Sampling Season Data for 2020

Routine monitoring (grab samples) was conducted monthly from July to November for nutrients, chlorophyll-a, dissolved oxygen, temperature, conductivity, and pH at nine in-stream locations. Sampling was conducted monthly, regardless of streamflow conditions. Continuous data loggers monitoring water temperature and dissolved oxygen were installed between July 7 and July 10, 2020 at W0680, UBWPAD2, W1258, and Depot, and were removed between November 5 and November 9, 2020. These locations were the same as the 2017 and 2019 continuous monitoring programs.

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.

Observed sampling day streamflow at Millbury, MA (USGS 01109730) and Woonsocket, RI (USGS 01112500) were used to estimate streamflow for load calculations at each sampling location. The streamflow at each location for each sampling date was estimated by comparing and extracting representative streamflow values from 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 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 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.

6.1.1. Total Phosphorus

Available TP concentration data for the Blackstone River since 1996 are summarized in **Figure 18** using box plots. Data for all sampling locations are grouped by year. While, in general, the same sample locations were surveyed 2012-2020, 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.”

River 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 2020 were very similar to those in the past four years, with a median slightly higher than in 2019 and with a larger interquartile spread. **Figure 19:** TP concentrations observed in the river 1996 – 2008 and 2012 – 2020 shows the same data with the Y-axis truncated at 400 ppb to help see details in the more recent years when concentrations are much lower than before 2012.

The mean summer (June – September) TP concentration at each sampling location in the Blackstone River is shown on **Figure 20** for sampling data collected since 2012. Data are grouped 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 2020 in purple. While the summer average TP concentration at the upstream-most site (W0680) was comparable to that of previous years, at the UBWPAD2 site (just below the effluent channel confluence) the TP concentration was higher than in the past few years. The concentration was also higher at Massachusetts sites downstream of UBWPAD2.

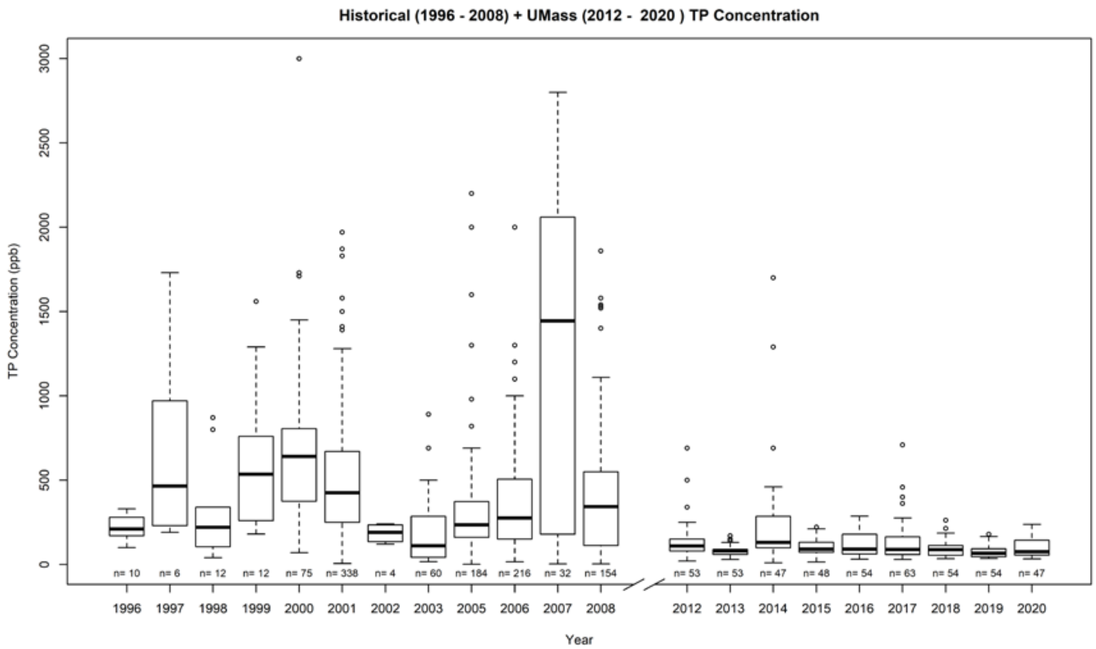
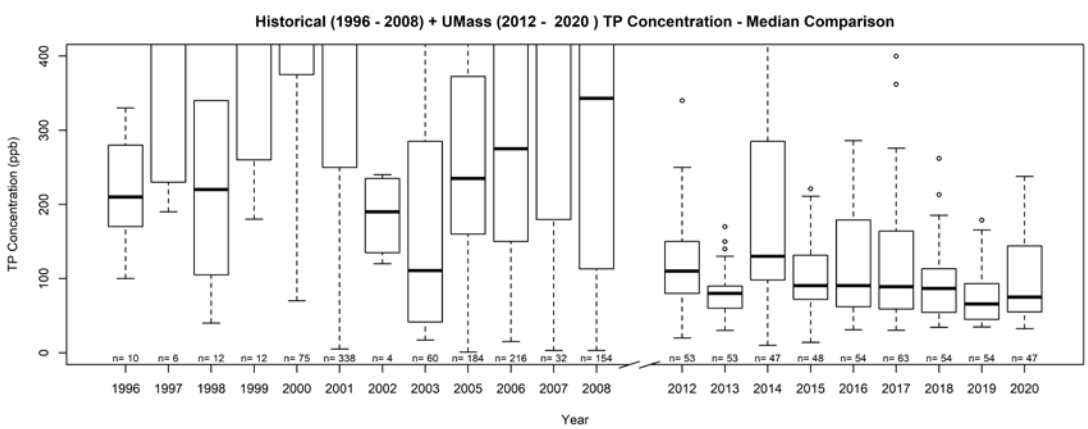


Figure 18: TP concentrations observed in the river 1996 – 2008 and 2012 – 2020



(Y-axis truncated at 400 ppb to highlight post-upgrade conditions)

Figure 19: **TP concentrations observed in the river 1996 – 2008 and 2012 – 2020**

TP (ppb)	W0680	UBWPAD2	W1258	W1242	W0767	W1779	RMSL	R116	RMSD
2012	77	143	157	157	157	220	185	140	87
2013	50	83	83	80	NA	137	77	70	60
2014	100	707	453	403	246	264	215	173	98
2015	71	130	115	81	106	137	86	76	82
2016	60	231	23	161	215	221	76	71	129
2017	55	152	131	112	157	166	83	74	91
2018	60	156	94	97	126	154	136	99	87
2019	50	134	108	90	70	123	57	52	61
2020	55.1	199.6[a]	137.3 [a]	156.3	132.0	174.4 [a]	62.0	85.0	50.7

[a] These means include June 1 data

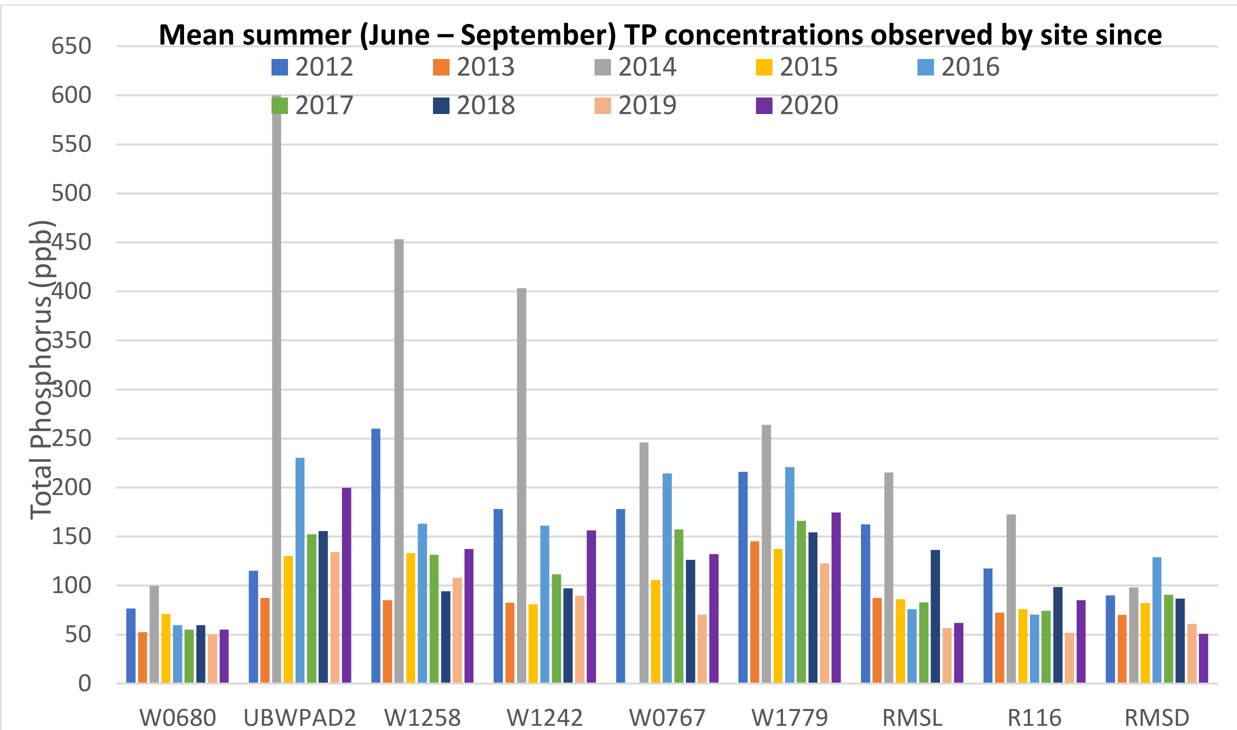


Figure 20: Mean summer (June – September) TP concentrations observed by site since 2012

The full range of TP concentrations observed at each site since 2012 is summarized in **Figure 21** with sites plotted from the upstream W0680 site (left) to downstream RMSD site (right) as before. The average concentrations in 2020 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 2020 were higher than the median at UBWPAD2 and W1242, and near the median or lower at the other sites. All the averages were within the 50% quartile.

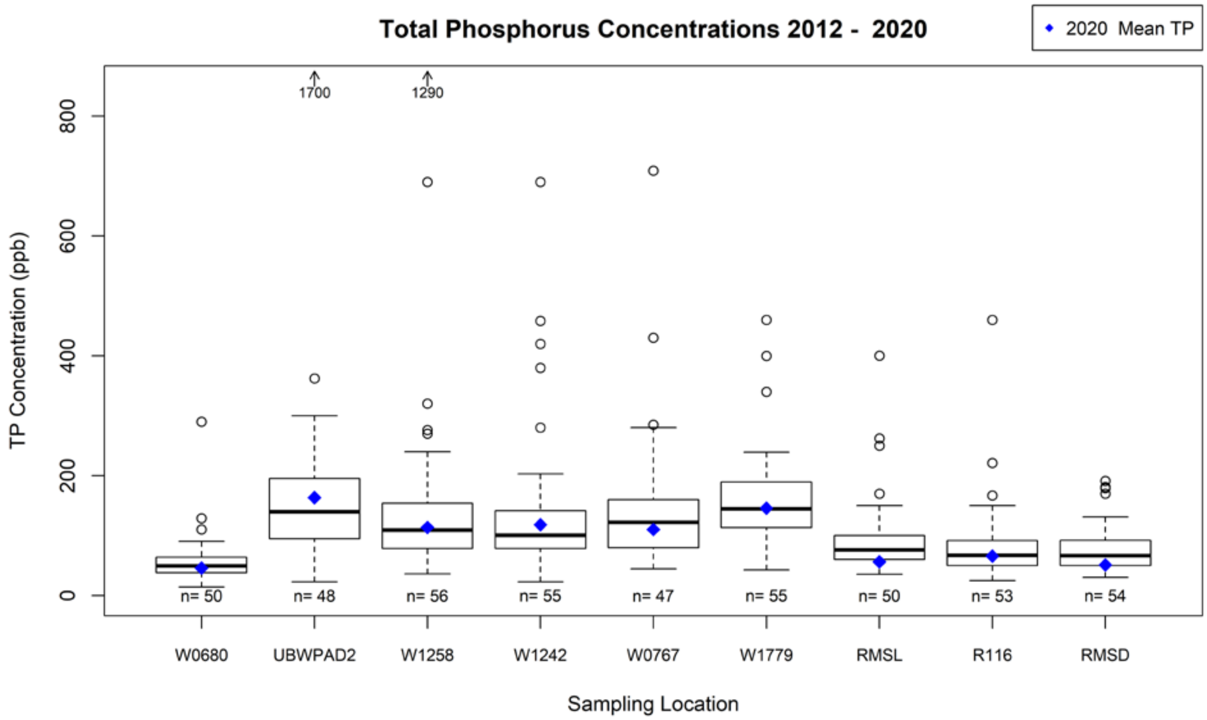
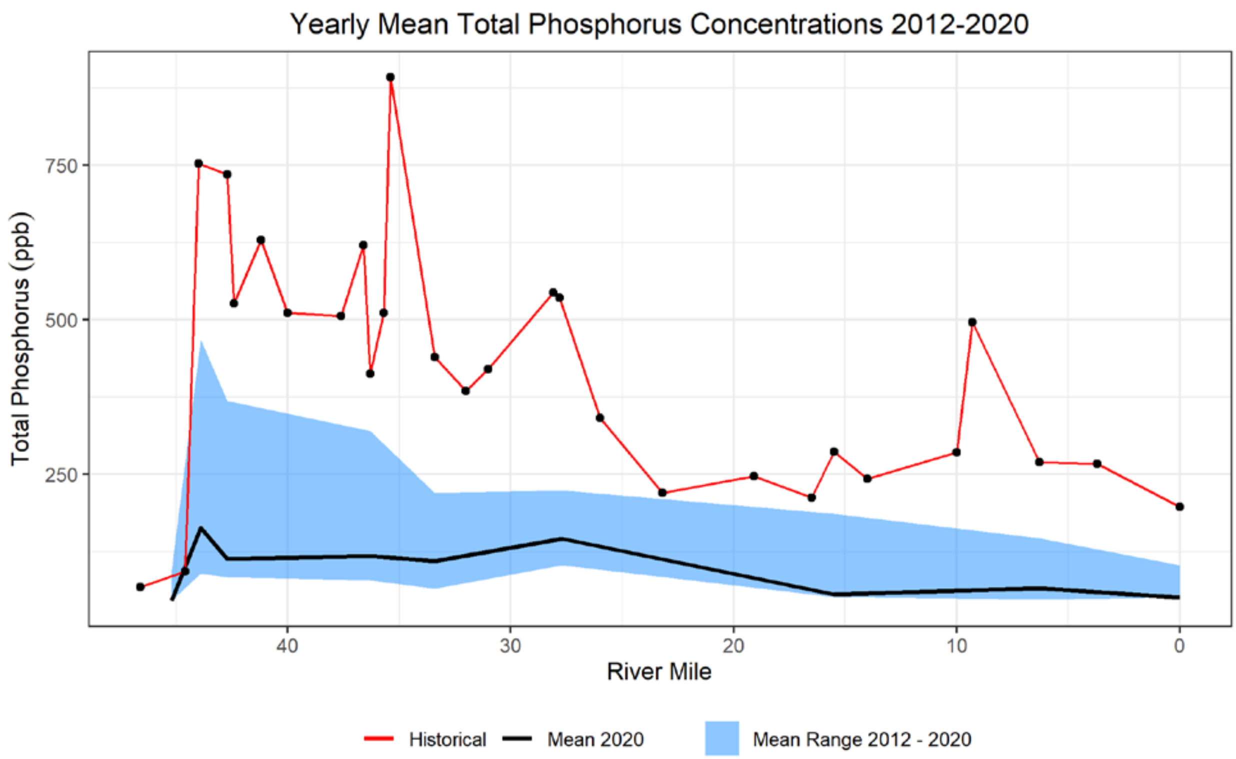


Figure 21: TP concentrations by site from 2012 - 2020

Average TP concentrations in 2012 – 2020 are compared to historical concentrations in **Figure 22**, 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. At the upstream site W0680, yearly mean TP concentration was the lowest since this study began. Yearly mean TP concentrations were low at all other sites, especially at the Rhode Island sites, a trend that has been observed since 2017. For the Massachusetts sampling locations, 2020 mean concentrations are in the lower range of concentrations measured 2012, and much lower than all historical (1996 – 2008) levels.

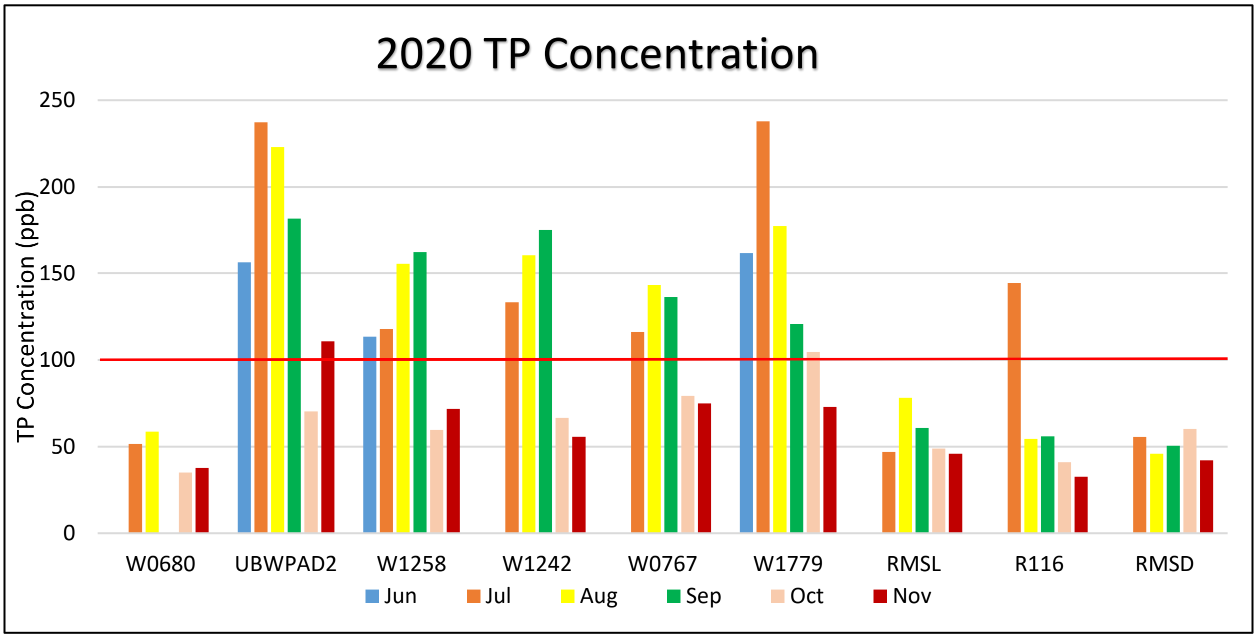


Note that historical data are means for sites with >8 data points

Figure 22: Along stream TP concentrations

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. Rhode Island does not specify a numeric criteria or threshold for phosphorus in flowing rivers; for this report the total phosphorus concentrations at the three Rhode Island monitoring locations (RMSL, R116, and RMSD) are compared against the MassDEP screening threshold.

In 2020, TP concentrations in the Blackstone River were below the MassDEP 2018 CALM screening threshold of 100 ppb 35% of the time June through September, **Figure 23**.

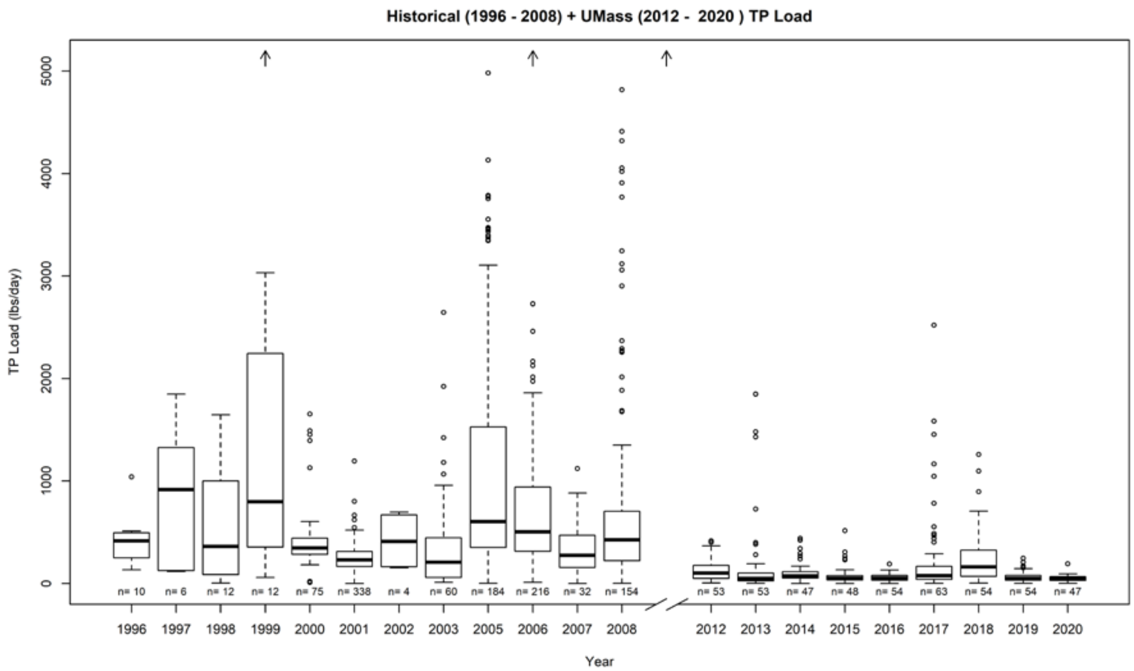


Note: W0680 September sample was not analyzed due to laboratory error

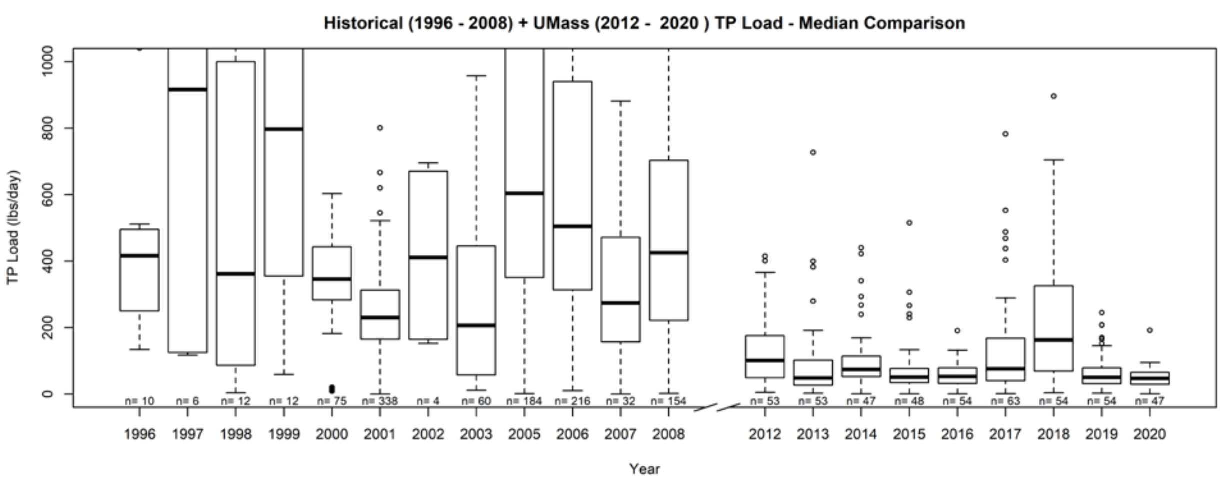
Figure 23: 2020 TP concentrations compared with MassDEP CALM guidance

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 load since 1996 in the Blackstone River are summarized in **Figure 24** (shown zoomed in on lower graph).

Data for all sampling locations along the river are grouped by year. There continues to be a 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; 2020 data show a median load that is the lowest historically (along with that of 2013), as well as the smallest interquartile range.



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



(Y-Axis truncated at 1000 lb/day to clarify differences in later years)

Figure 24: Summary of calculated TP loads based on streamflow estimates and reported concentrations for sampling days, 1996 – 2008 and 2012 – 2020

Along-stream average TP loads, **Figure 25** and **Figure 26**, illustrate the impact of streamflow conditions on load estimates. As streamflow increases downstream, typically so do loads, but in 2020 this was not observed. Loads appear very similar from below the effluent channel confluence to the mouth of the river in Pawtucket, RI. The largest load was seen at W1779, a site immediately downstream of a shallow impoundment (Rice City Pond), where total phosphorus concentrations were particularly high in July.

Examined separately by site, it is also evident in **Figure 25** that 2020 TP loads this year were comparable or lower than the 2012-2020 median. **Figure 26** illustrates how mean summer TP loads were in general lower in 2020, especially at the three Rhode Island sites. The low calculated loads are due in part to lower than normal streamflow during the 2020 monitoring period.

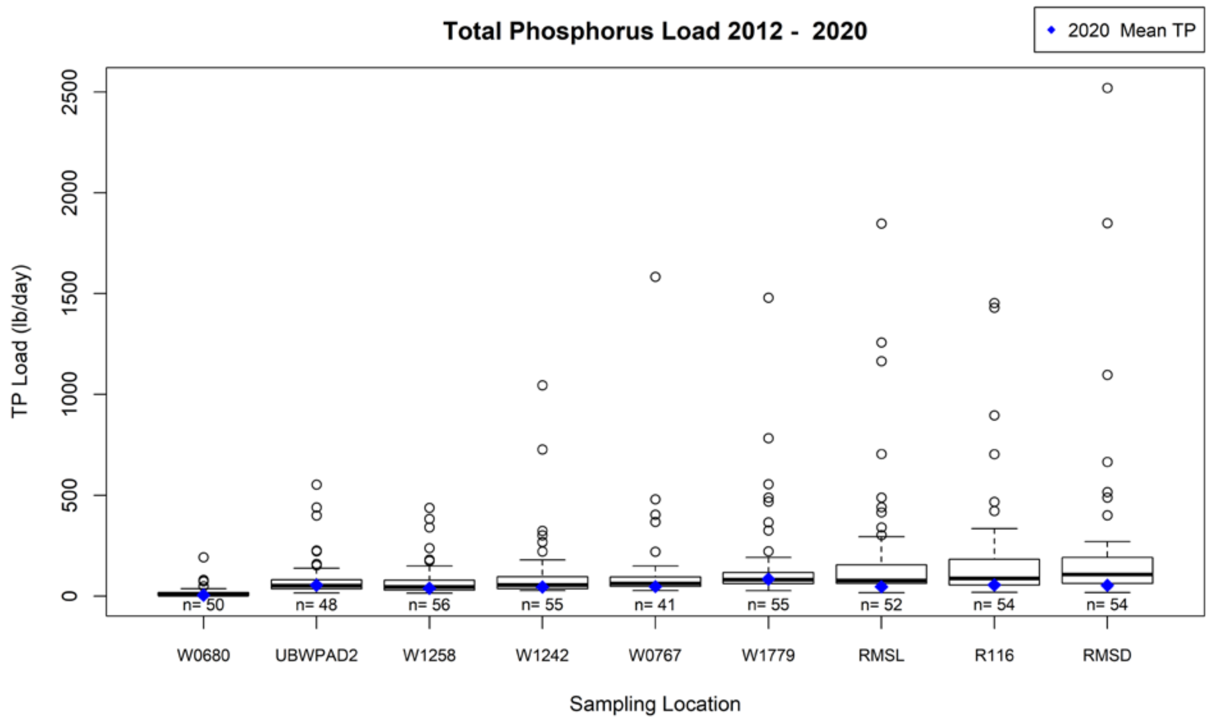


Figure 25: TP load data by site from 2012 - 2020 (Jun-Nov only)

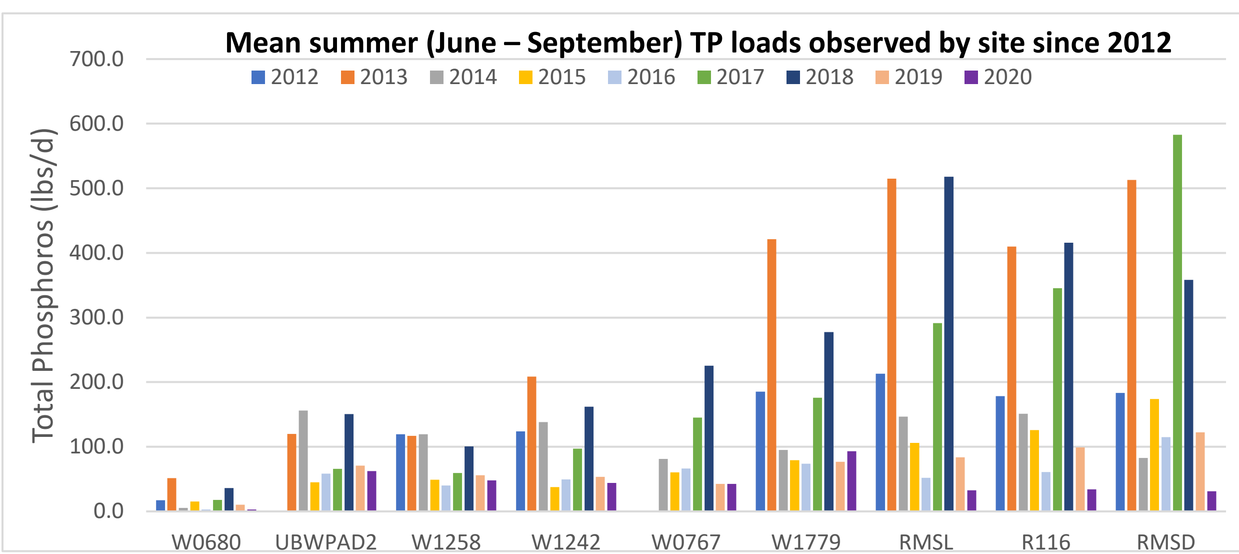


Figure 26: Mean summer TP loads 2012-2020

Figure 27 shows that 2020 (black line) estimated yearly mean TP loads were at their lowest level in nine years at all sites.

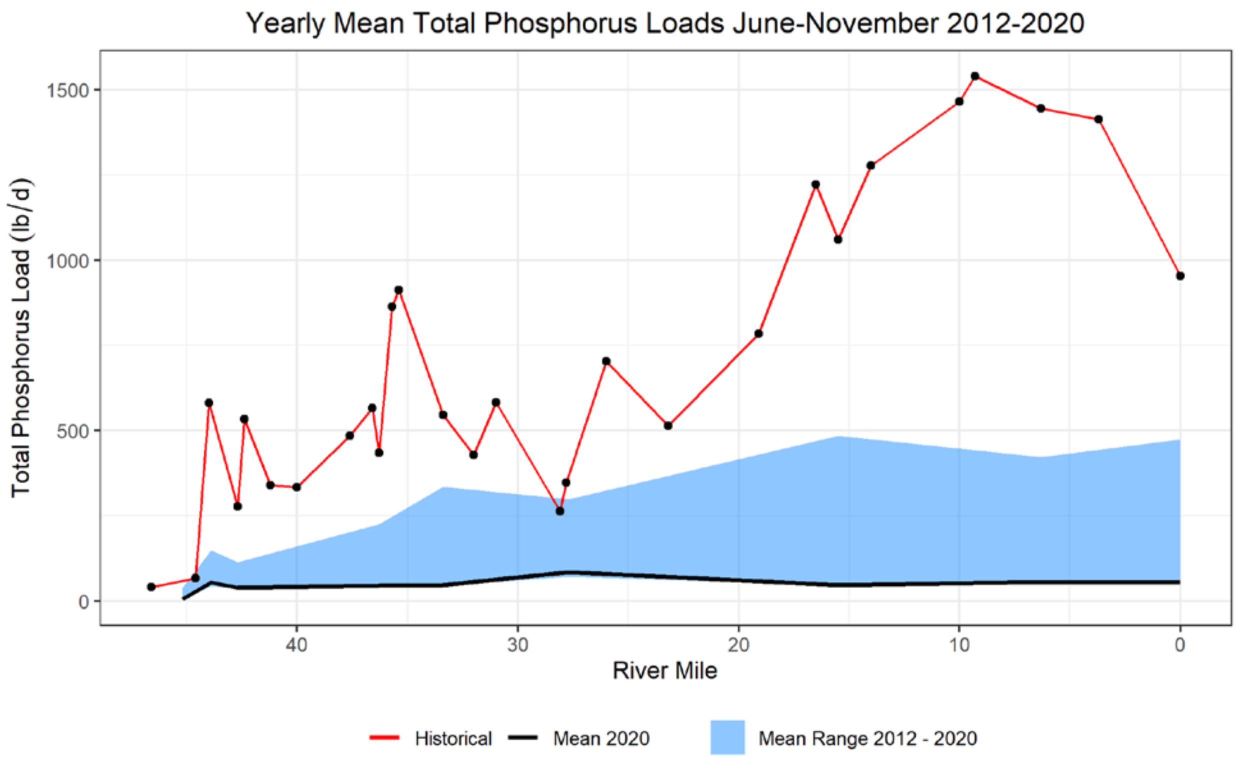


Figure 27: **Mean TP Loads on Sampling Dates**

6.1.2. Total Nitrogen

Available TN concentration data for the Blackstone River since 1998 are summarized in **Figure 28**.

In 2020, TN effluent concentrations were 90% lower during summer months compared to the average pre-upgrade concentration (2006-2008). 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 2020 all occurred in September at UBWPAD2 through W1779, during low river flow conditions.

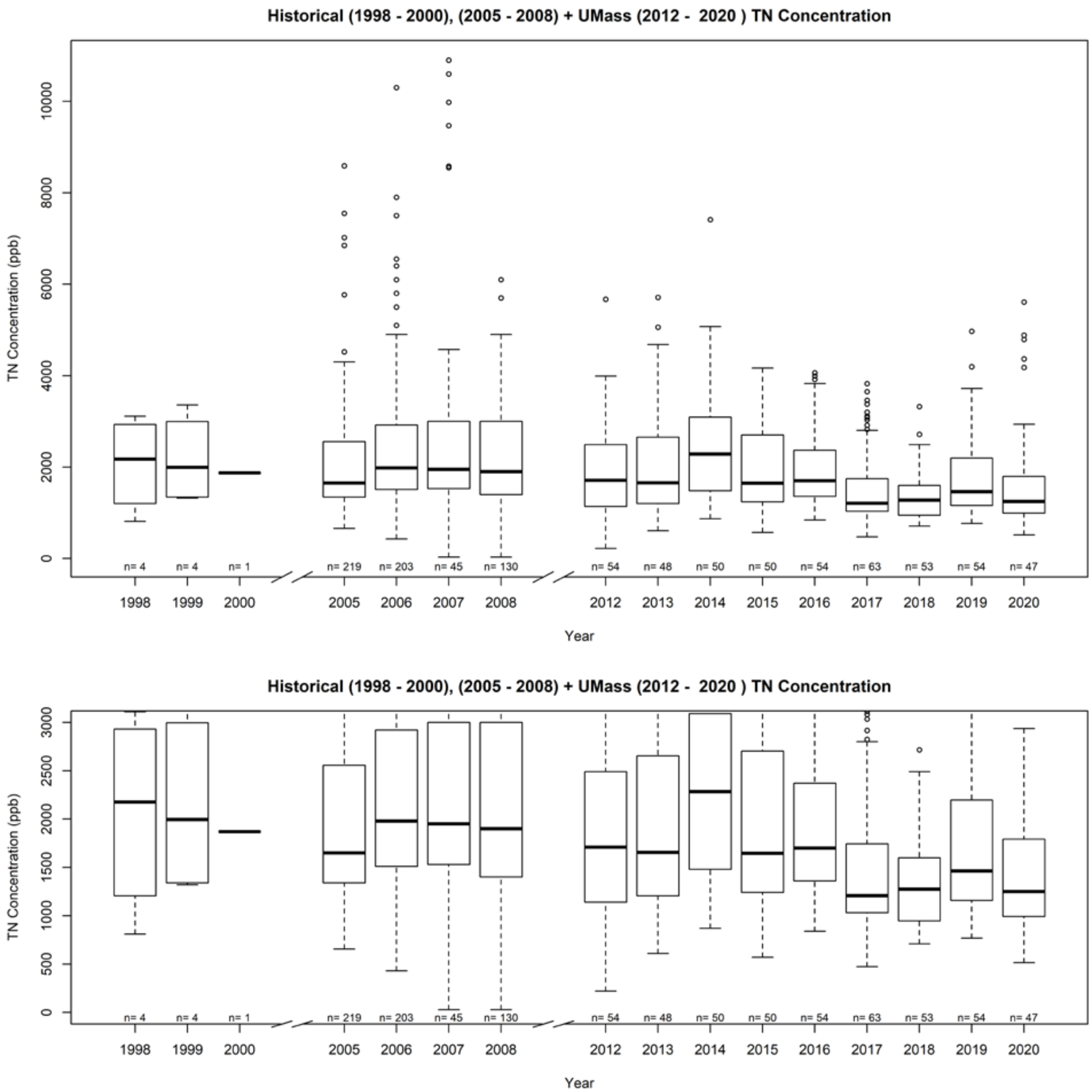


Figure 28: Summary of TN concentrations observed in the river, 1998 – 2000, 2005 – 2008, and 2012 – 2020 (Lower figure is cut off at 3000 ppb)

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 29** 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 2020 in lavender. 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 2020 were in general lower than last year except at the mid river sites W01242, W0767, W1779 and RMSL.

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
2020	914.7	2647.3	2786.8	2976	2703.7	2208	1345.3	1229	1142.7

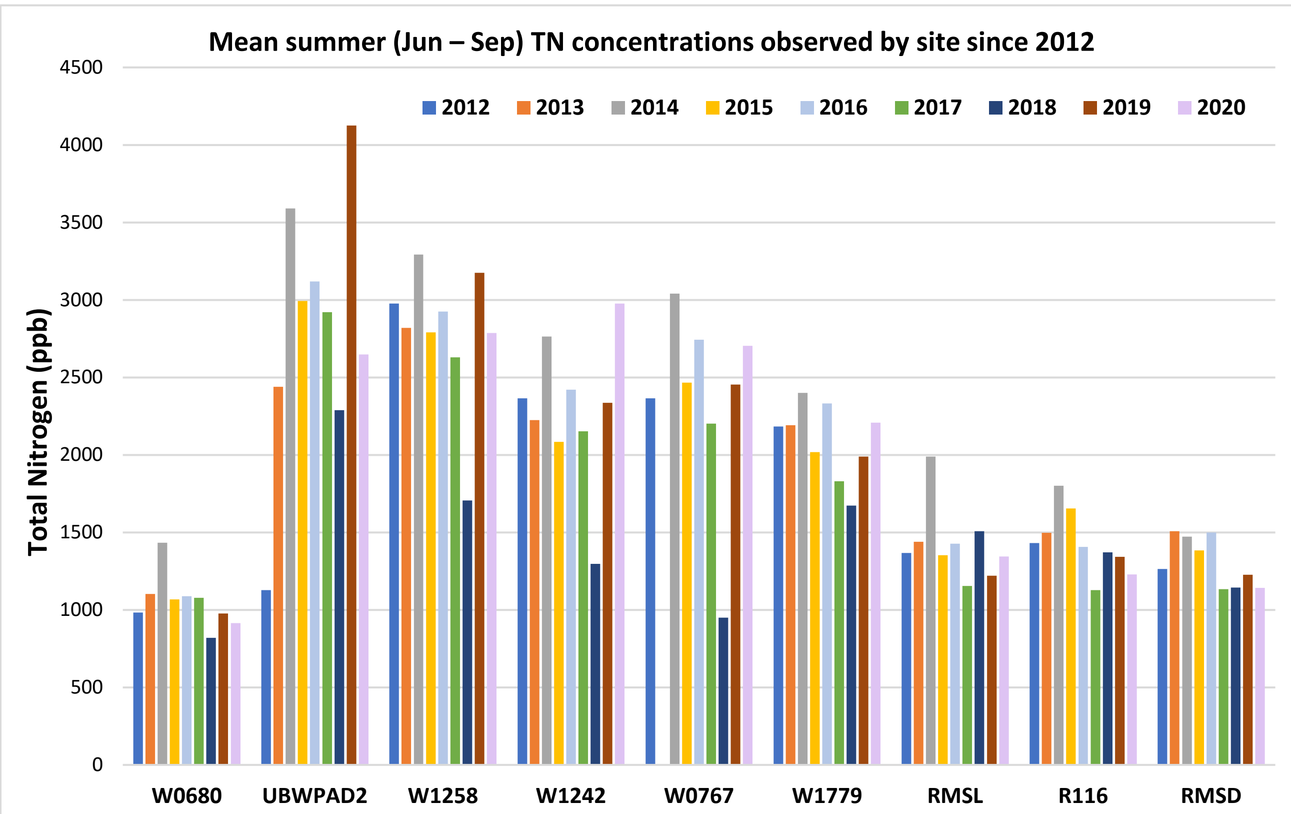


Figure 29: Mean summer (June – September) TN concentrations observed by site since 2012

The full range of TN concentrations observed at each site since 2012 is summarized in **Figure 30**, with sites plotted from the headwaters (left) to outlet (right) as above.

Data for both the original UBWPAD site (2012) and new site, UBWPAD2 (where data collection started in 2013 and continues) are included. Average TN concentrations in 2020 (depicted with blue diamonds) fell within the interquartile range of values observed since 2012 at all sampling sites, except at RMSL where the mean concentration was below the 25% quartile. Average TN concentration for most locations were at or below the nine-year median, with the exception of W1242, which was above the median value.

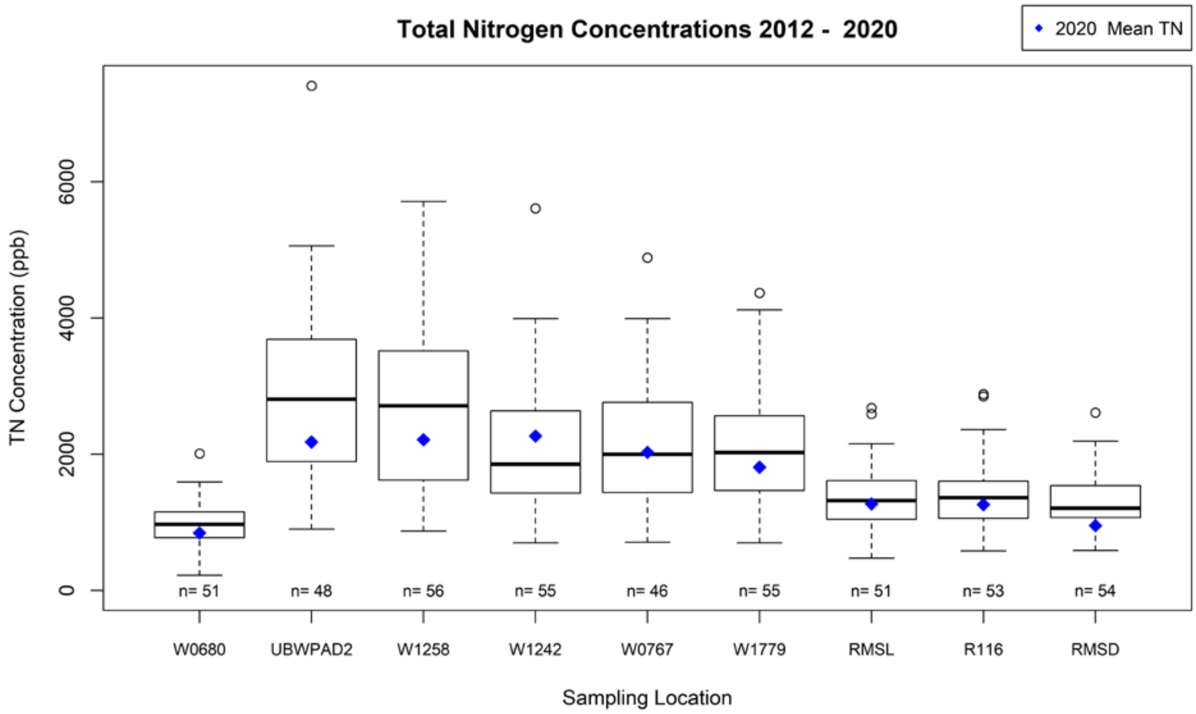


Figure 30: TN Concentrations by sampling location 2012 -2020

Average TN concentrations in 2012 – 2020 are compared to historical concentrations in **Figure 31**, plotted against river mile with headwater locations on the left (river mile 50) and the outlet on the right (river mile 0).

Unlike the mean TP concentrations, mean TN concentrations in 2020 were not the lowest observed since 2012 at all sites. The mid-river sites (W1242, W0767, and W1779) concentrations, averaged over the June through November period, are near the middle of the 9-year range, while the downstream sites fall in the lower third of the range.

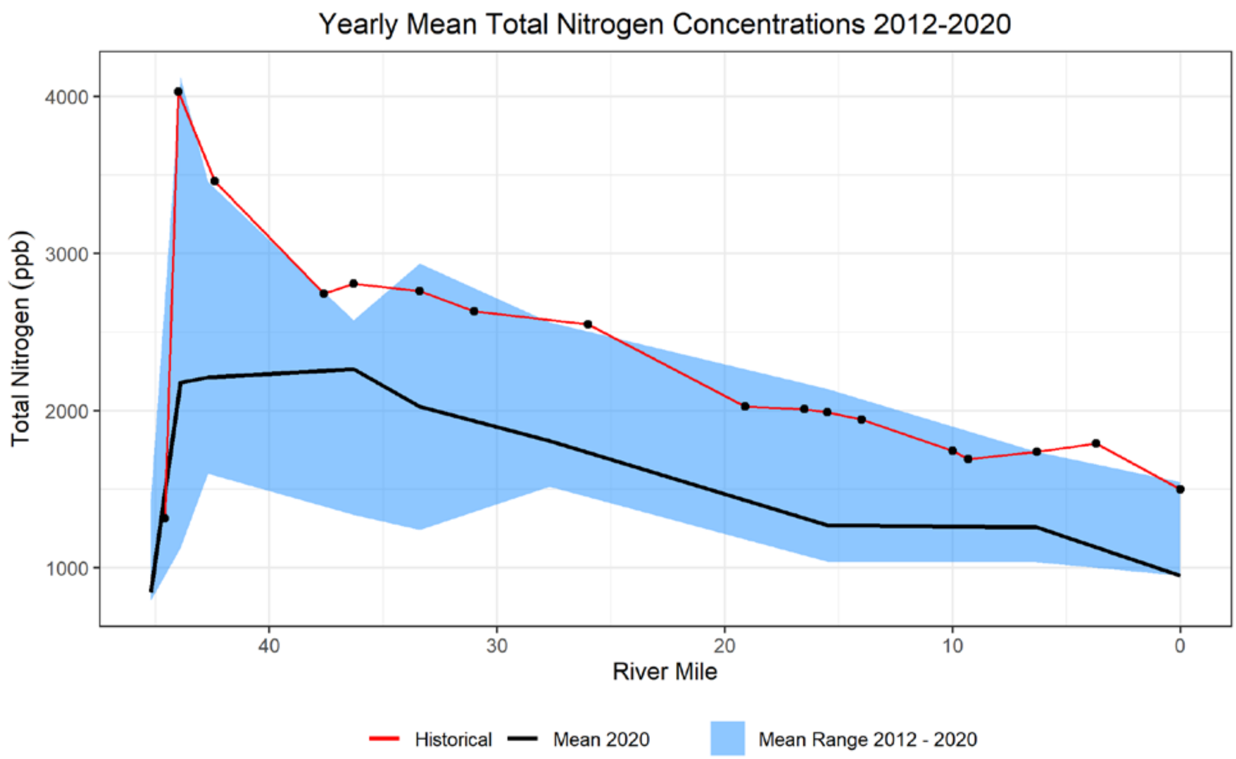


Figure 31: Along stream TN concentration, 2012 -2020

Estimates of TN loads since 2012 in the Blackstone River are summarized in **Figure 32**. Data for all sampling locations along the river are grouped by site. 2020 TN loads were the lowest in 9 years at all sites, except at W1258 when the estimated mean TN Load was even lower in 2016, another year that was particularly dry in the summer.

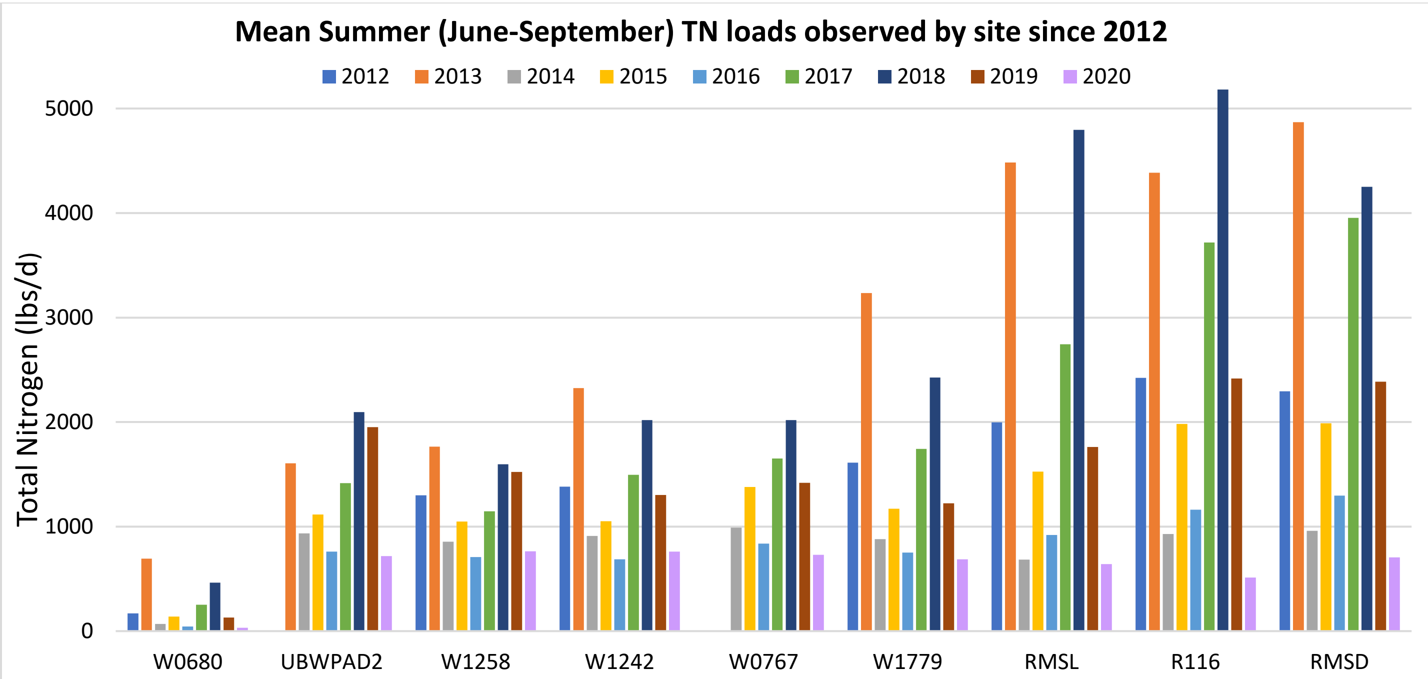


Figure 32: Mean Summer TN Loads for each site, 2012-2020

TN load data statistics are shown in **Figure 33** and zoomed in **Figure 34**, and suggest a decrease in estimated 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 2020 are smaller than from 1998 through 2008. In 2020, the median and interquartile range of the TN load are very low compared to previous years, certainly due to the low streamflow this year, combined with a lower TN concentration in the effluent.

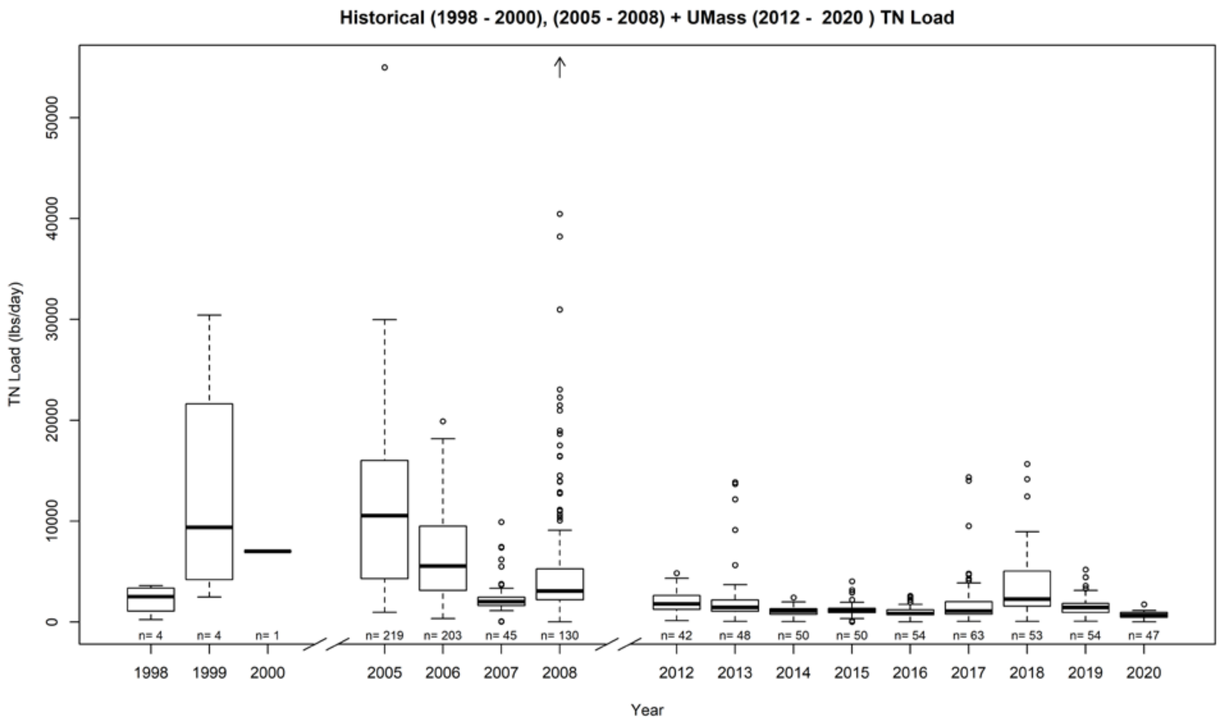


Figure 33: TN loads observed in the river 1998 – 2000, 2005 – 2008, and 2012 – 2020

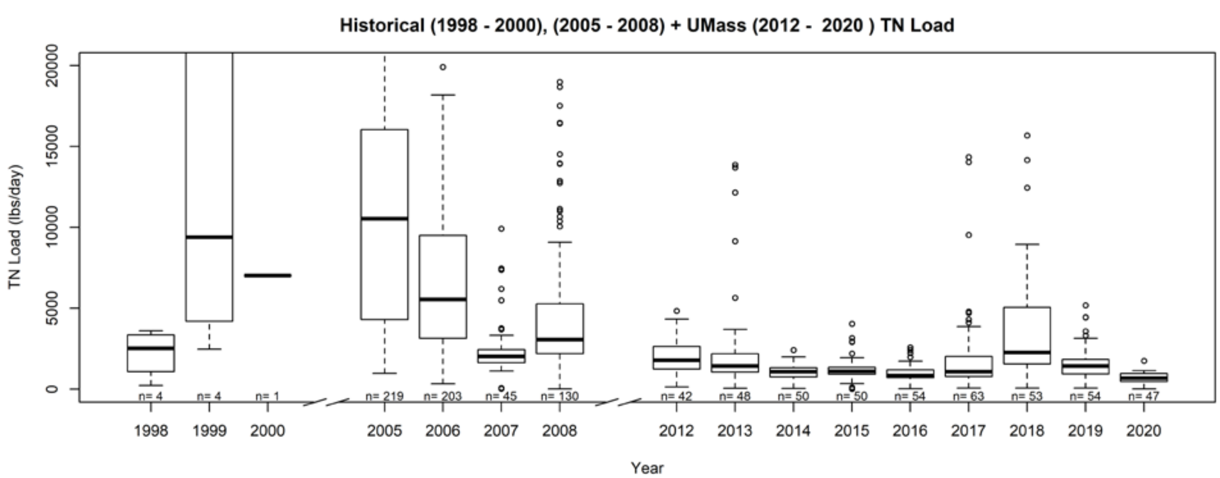


Figure 34: TN loads observed in the river 1998 – 2000, 2005 – 2008, and 2012 – 2020
(zoomed in)

Along stream average TN loads, as summarized by year and site on **Figure 35** and **Figure 36**, show 2020 estimated loads to be on the lower end of the range calculated for 2012-2020. This is particularly obvious on **Figure 36**, which shows 2020 to display the lowest loads in the nine-year period. Note that this is observed both when the entire data set is used and when only June-November data are plotted, though removing April and May clearly reduces the magnitude of TN loads throughout the years, likely due to the higher spring streamflow in the spring months that cause the loads to increase (Apr-Nov data rise up to 25,000 lb/day, while Jun-Nov data rise only to 14,000 lb/day).

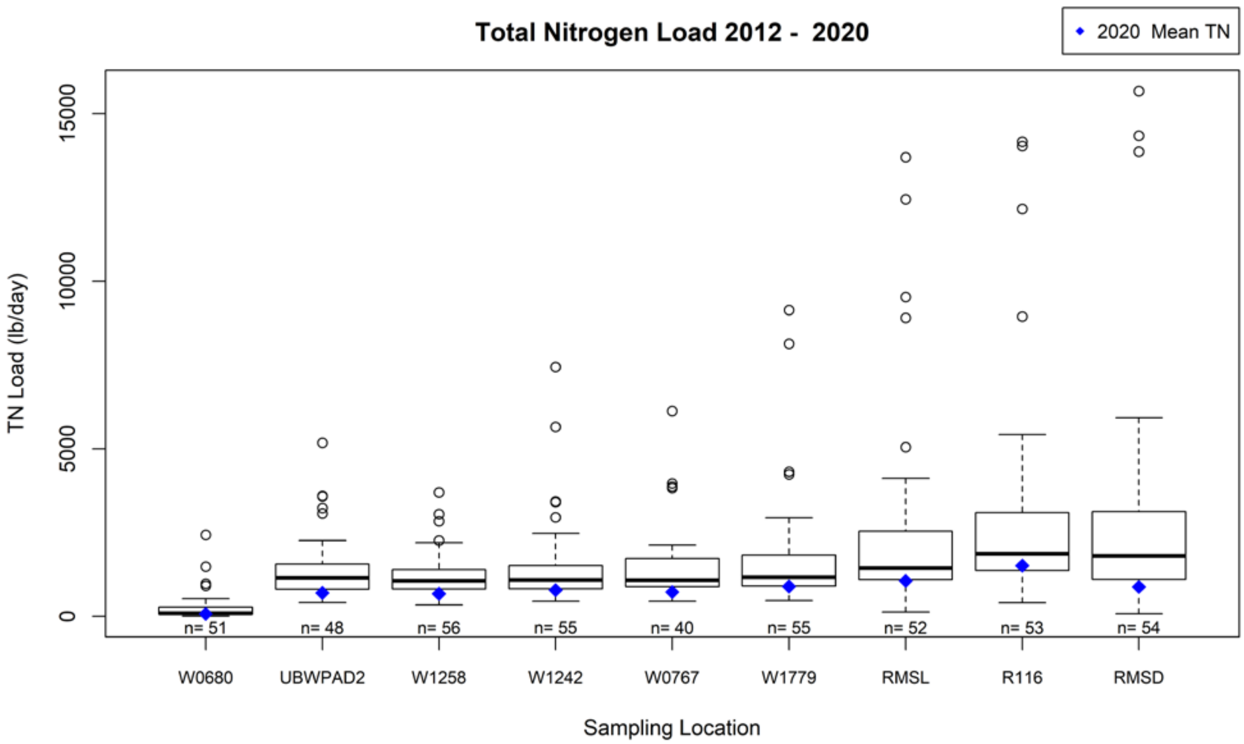


Figure 35: TN load data by sampling location 2012 - 2020

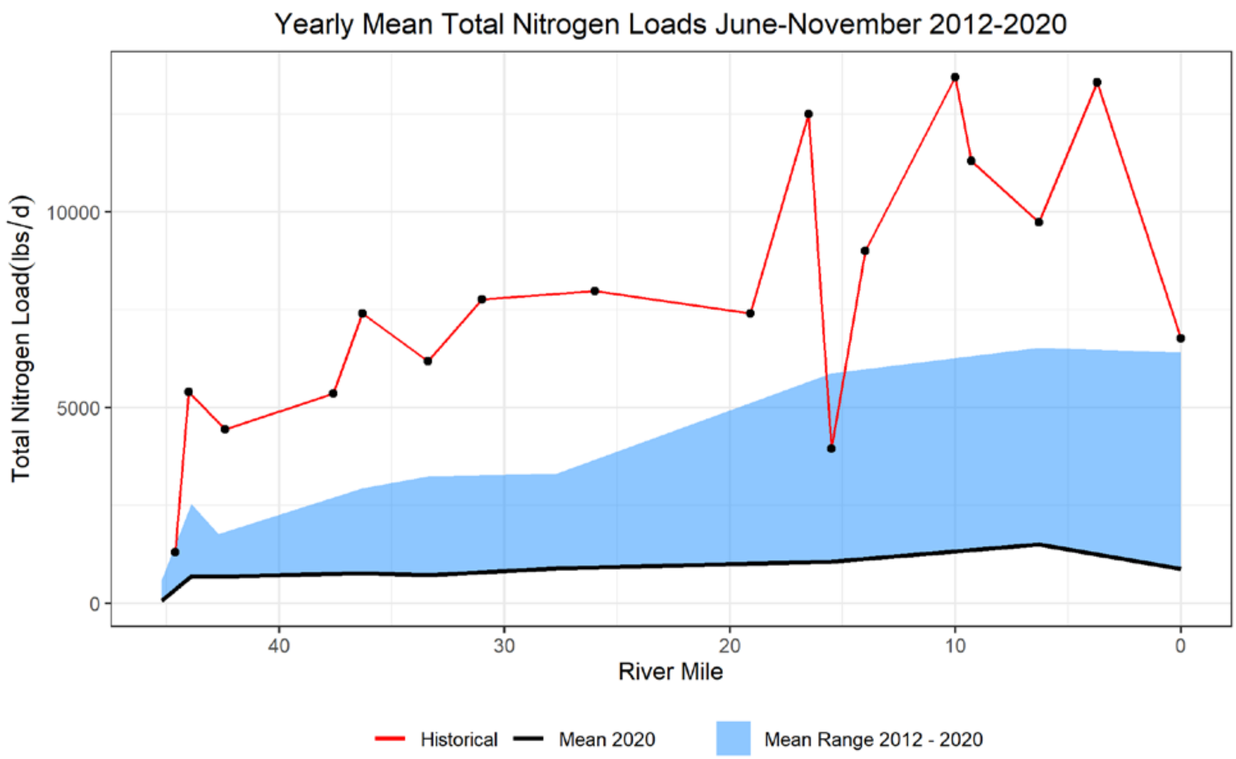


Figure 36: Along stream TN loads

6.1.3. Chlorophyll-a

Nutrients in the river from both point and nonpoint sources can contribute to increased algal growth, measured with chlorophyll-a. Massachusetts does not have a numeric criterion for chlorophyll-a, but has a guidance value in the CALM of 16 µg/L that is used as a screening level to indicate the potential for nutrient-related impairments to the aquatic life designated use. MassDEP typically considers a river to be at risk of impairment if the mean summer (May through September) chlorophyll-a concentration exceeds 16 µg/L. As with the total phosphorus screening level, MassDEP uses a combination of indicators to assess whether a river is impaired. Summer mean chlorophyll-a concentrations exceeding the 16 µg/L threshold are one indicator used in the weight of evidence approach to determine whether an aquatic life use impairment is warranted. Rhode Island does not have a comparable numeric criterion or guidance value but uses a narrative criterion that uses excess algal growth as one indicator of an exceedance of its narrative water quality criteria. Therefore, for the analysis presented in this report the MassDEP 16 µg/L screening value will be applied to data collected at the Rhode Island sites.

Chlorophyll-a concentrations observed during the summer months (June – September) since 2012 are summarized by year in **Figure 37**. Overall, summertime chlorophyll-a levels in 2020 exhibited an interquartile range comparable to the narrowest one (2015) in the study period. The 2020 chlorophyll-a concentrations were among the lowest in the study period.

The same data are summarized by site in **Figure 38** for just the months of June – September, plotted from the headwaters (left) to the outlet (right). At individual sampling locations, mean summer concentrations in 2020 (blue diamonds) are at or lower than the median for all years at six sites (the four upstream-most sites, RMSL and RMSD), while they are higher at the other three sites, particularly at W1779 and R116. W1779 (below Rice City Pond), is immediately downstream of a large shallow impoundment and has exhibited high chlorophyll concentrations on dry years when the pond level and streamflow is low, conditions that could favor algae growth. R116 is not immediately downstream of an impoundment, but there are dams on the river 0.5 mile, 1.9, and 3.1 miles upstream of the site that may be influencing phytoplankton dynamics at the R116 location.

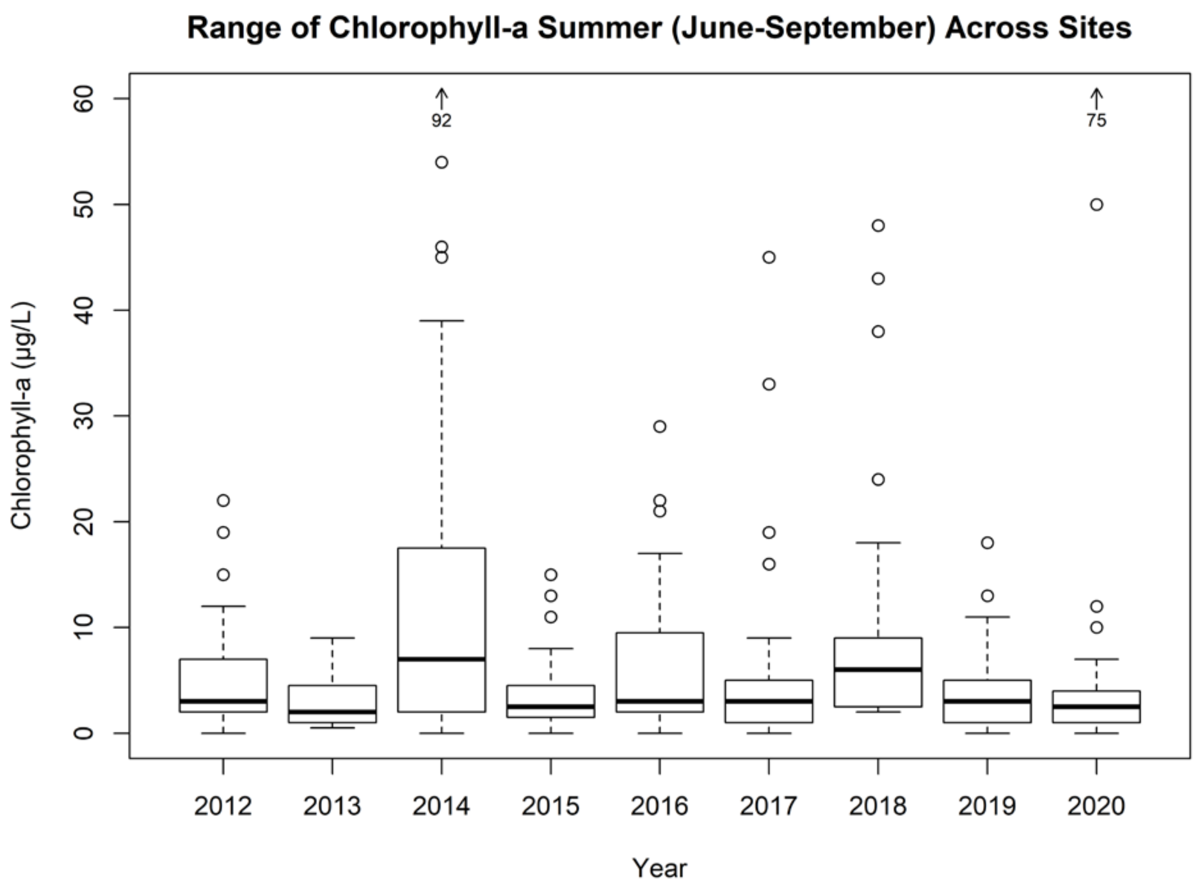


Figure 37: Chlorophyll-a concentrations observed during June, July, August, and September since 2012, summarized by year

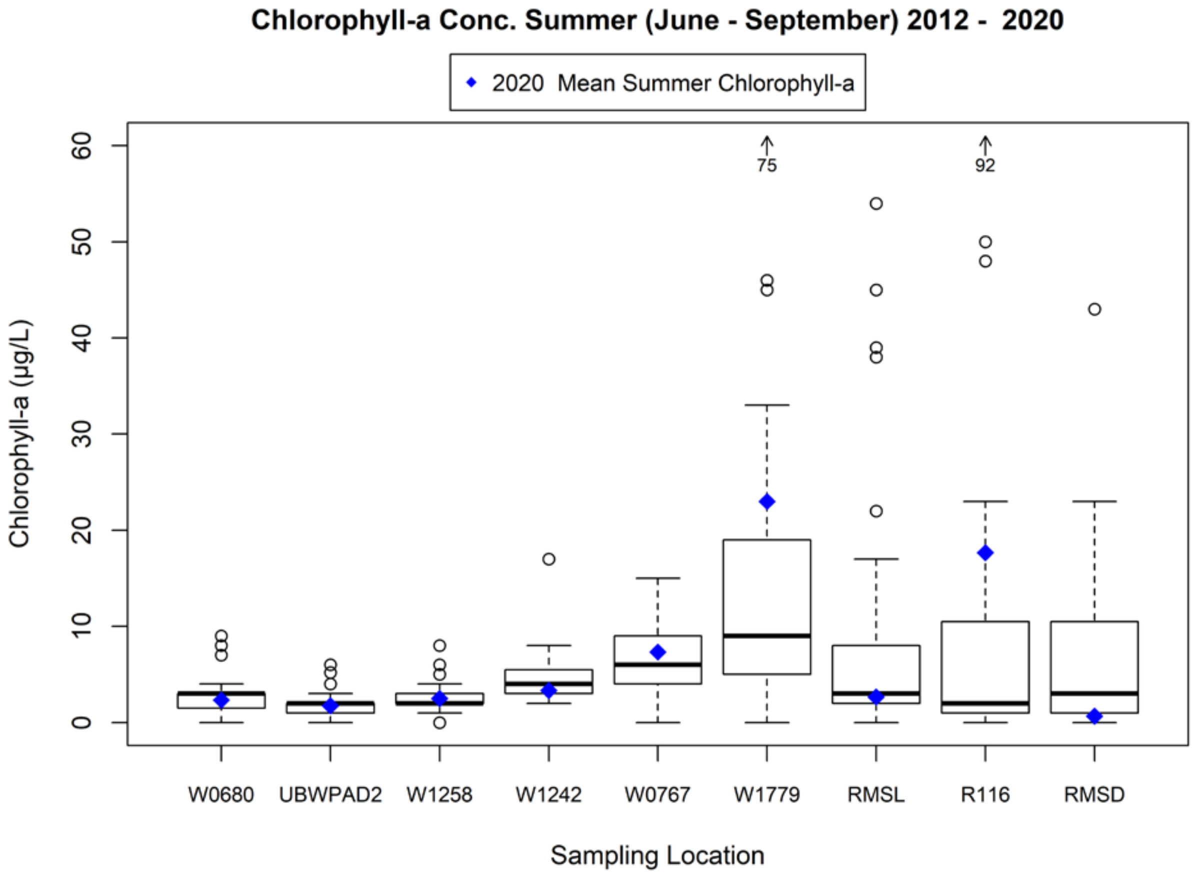


Figure 38: Chlorophyll-a concentrations observed during June, July, August, and September since 2012, summarized by sampling location

The mean summer (June – September) chlorophyll-a concentrations for each year and sampling location on the Blackstone River are also summarized on **Figure 39**. Data are clustered by sampling site, again plotted from the headwaters (left) to the outlet (right). In 2020, summertime chlorophyll-a levels were higher than historical data at most sites except at W0680, RMSL and RMSD. The highest summer means were observed at W1779 and R116, exceeding the 16 µg/L MassDEP guidance value.

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

Chl-a (ppb)	***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
2020	2.2	1.6	2.6	3.6	7.3	22.9	2.8	17.8	0.9

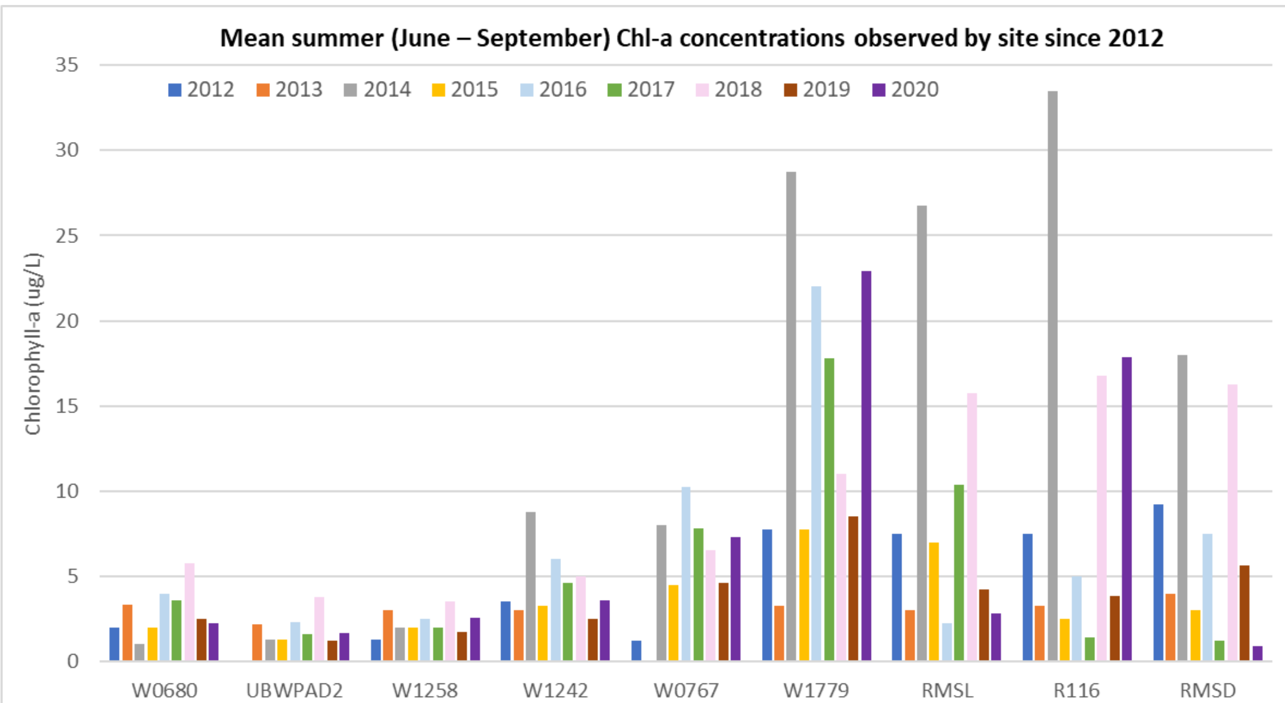
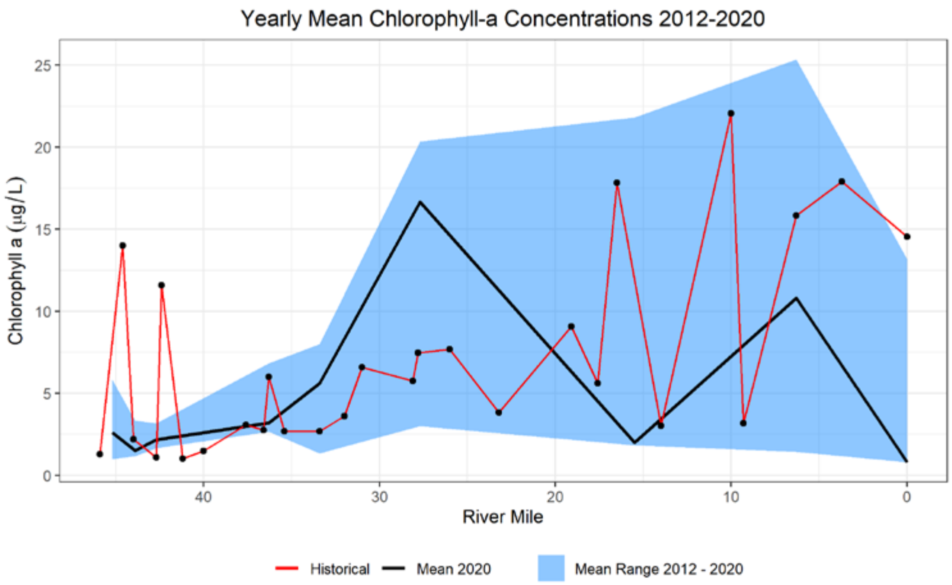


Figure 39: Mean summer (June – September) chlorophyll-a concentrations by site since 2012

The annual average chlorophyll-a concentration data for 2020, **Figure 40**, was below MassDEP screening guidelines at all locations except W1779.

Annual average chlorophyll-a concentration 2012-2020:
(RM= river mile)

Ave Chl-a *(ppb)*	***W0680*** *RM 45.2*	***UBWPAD2*** *RM 44.6*	***W1258*** *RM 42.7*	***W1242*** *RM 36.3*	***W0767*** *RM 33.4*	***W1779*** *RM 27.8*	***RMSL*** *RM 15.5*	***R116*** *RM 6.3*	***RMSD*** *RM 0*
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	4.6	8.5	4.3	3.9	5.6
2020	2.6	1.5	2.3	3.3	5.7	16.7	2.1	10.9	0.9



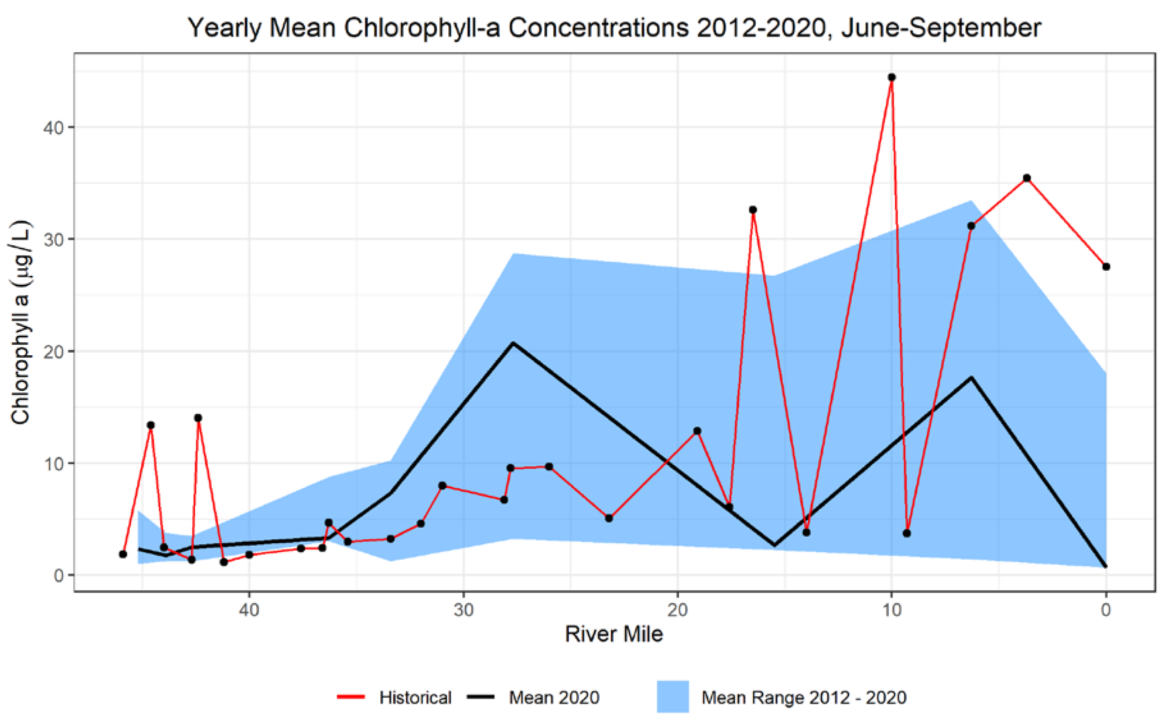


Figure 40: Along stream average chlorophyll-a levels

In 2020, chlorophyll-a concentrations in the Blackstone River were below the MassDEP 2016 CALM screening threshold of 16 µg/L 96% of the time(93% of the time in summer months), with two samples above on July 29 (W1779, 75 µg/L and R116, 50 µg/L) (**Figure 41**).

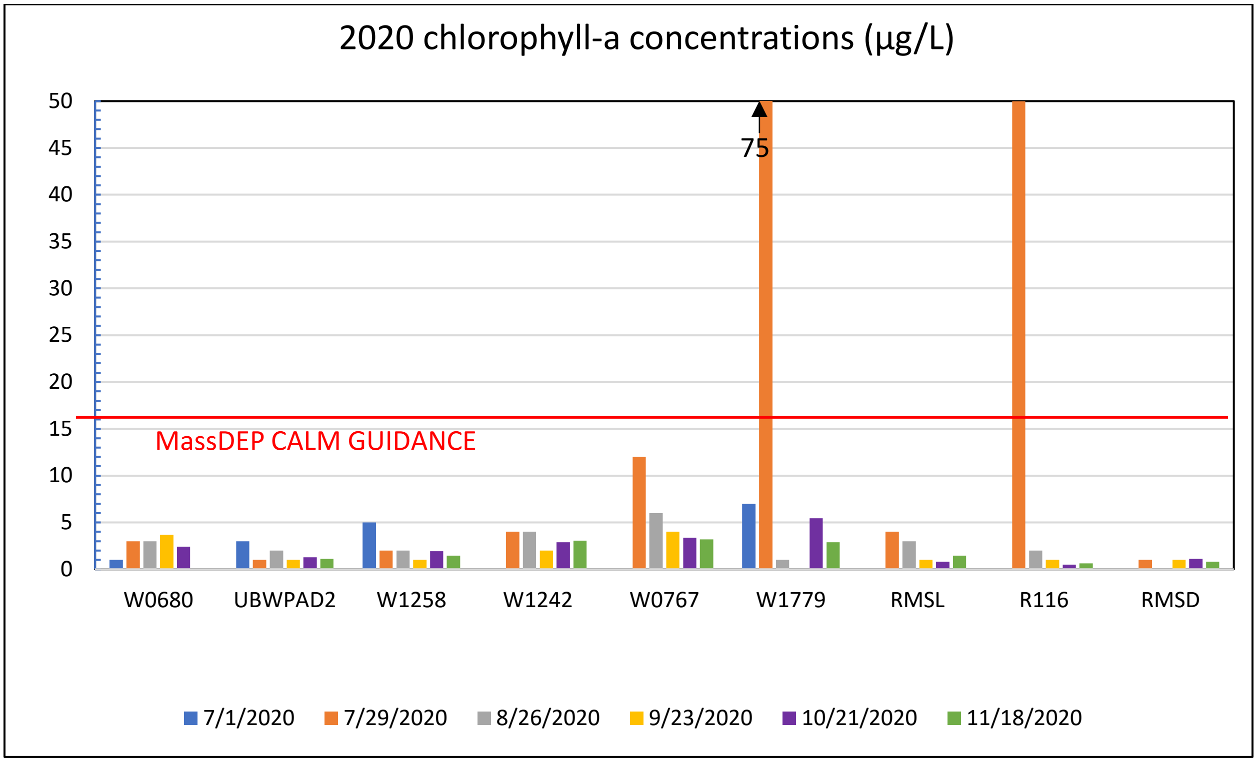


Figure 41: 2020 chlorophyll-a concentrations relative to MassDEP CALM guidance

6.1.4. 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 14-16. The Mann-Kendall analysis becomes more robust as more data become available. The analysis was completed on the full dataset and 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.
- Most sites also exhibit statistically significant decreasing trends in streamflow-weighted TP concentration. Only W0680 and UBWPAD2 do not show a statistically significant trend, either when grouped by month or season (**Table 14**).
- Significant decreasing trends in TN streamflow-weighted concentration are also observed at most sites, when considered together or individually at both the monthly or seasonal groupings. Here, W0767 and UBWPAD2 are the only sites that do not show any significant trends (**Table 15**).
- For chlorophyll-a, however, RMSD is the only site showing a decreasing trend. Most other sites show no significant trend, and W1258 and W0680 (upstream of the Upper Blackstone effluent channel) show an increasing trend, at the 95% and 99% significance level, respectively. When all sites are grouped together, an increasing trend is statistically significant at the 90% level when conducted monthly (**Table 16**).

Table 14: 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	>99%	Decreasing
RMSL	Flow-weighted TP	Month	>99%	Decreasing
W1779	Flow-weighted TP	Month	>99%	Decreasing
W0767	Flow-weighted TP	Month	>95%	Decreasing
W1242	Flow-weighted TP	Month	>95%	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%	Decreasing
W0767	Flow-weighted TP	Season	>90%	Decreasing
W1242	Flow-weighted TP	Season	>90%	Decreasing
W1258	Flow-weighted TP	Season	>90%	Decreasing
UBWPAD2	Flow-weighted TP	Season		
W0680	Flow-weighted TP	Season		

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

Table 16: Streamflow-weighted seasonal trend analysis results for chlorophyll-a

Site	Point	Block	Significance	Trend
All Sites	Flow-weighted Chl-a	Site+Month	>90%	Increasing
RMSD	Flow-weighted Chl-a	Month	>95%	Decreasing
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		
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		
RMSD	Flow-weighted Chl-a	Season	>99%	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		
UBWPAD2	Flow-weighted Chl-a	Season		
W0680	Flow-weighted Chl-a	Season	>90%	Increasing

6.1.5. Field Water Quality Measurements

Water temperature, dissolved oxygen, and pH were measured in situ at each site with hand-held Hach HQ 40 D multimeters starting July 29. 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.

Water temperature at all sites throughout the sampling season is shown in **Figure 42.** Temperature was below 20°C September through November at all sites (except at UBWPAD2 in September), and warmest temperatures were 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 is probably not caused by the time of measurement. Water temperatures were never observed above the Massachusetts Water Quality criterion of 28.5°C or the 28.3°C criterion in Rhode Island) for class B waters, except at RMSD on July 29 when it reached 29°C.

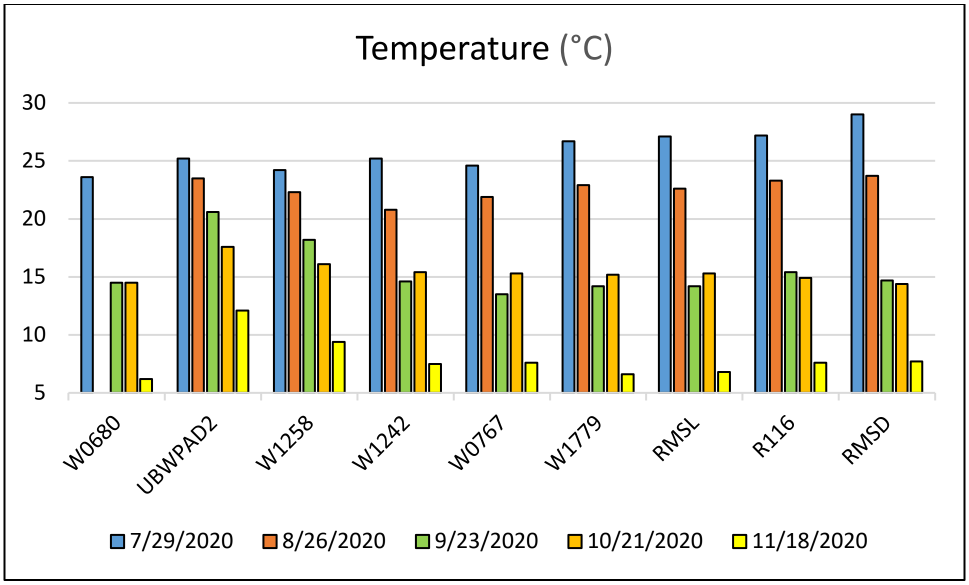


Figure 42: Water temperature at each site and each sampling event

pH at each site for each date can be seen in **Figure 43**. Field measurements show that pH was within the Massachusetts Surface Water Quality Standards for class B waters (between 6.5 and 8.3) and the Rhode Island criterion (between 6.5 and 9.0) on each sampling date throughout the sampling season.

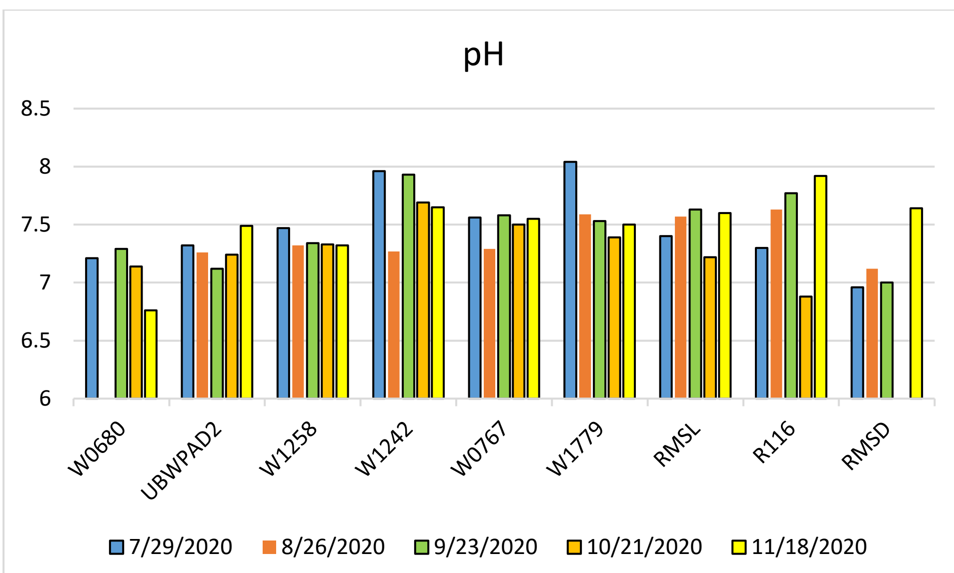


Figure 43: 2020 pH at each site

Dissolved oxygen was also measured between the hours of 8 AM and 12 PM. No measurements fell below the Massachusetts water quality criterion at any site (**Figure 44**). Percent saturation exceeded 75% at each site each sampling day except at W1258 July through September and at W0767 in July. It exceeded 90% saturation 66% of the time (**Figure 45**).

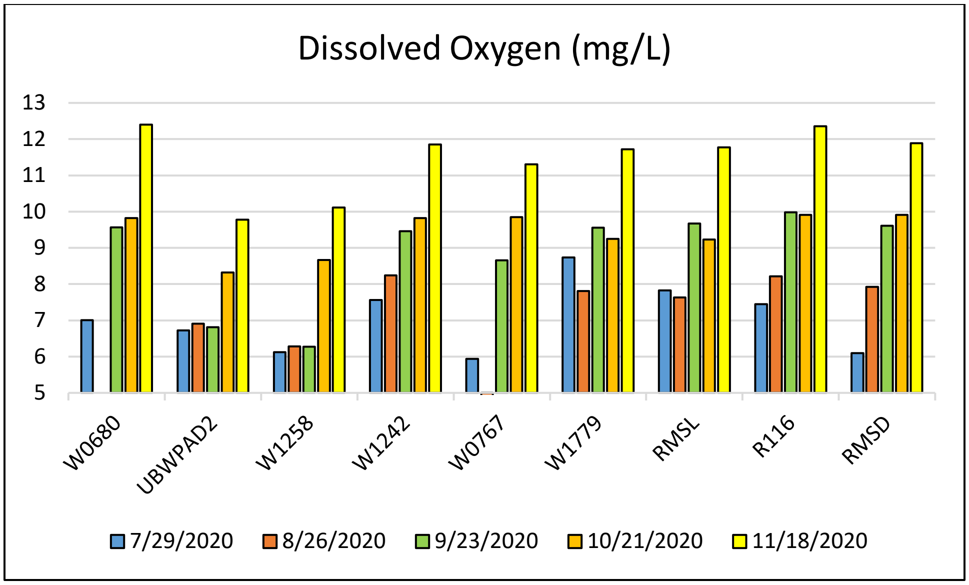


Figure 44: 2020 Dissolved Oxygen in mg/L at each site

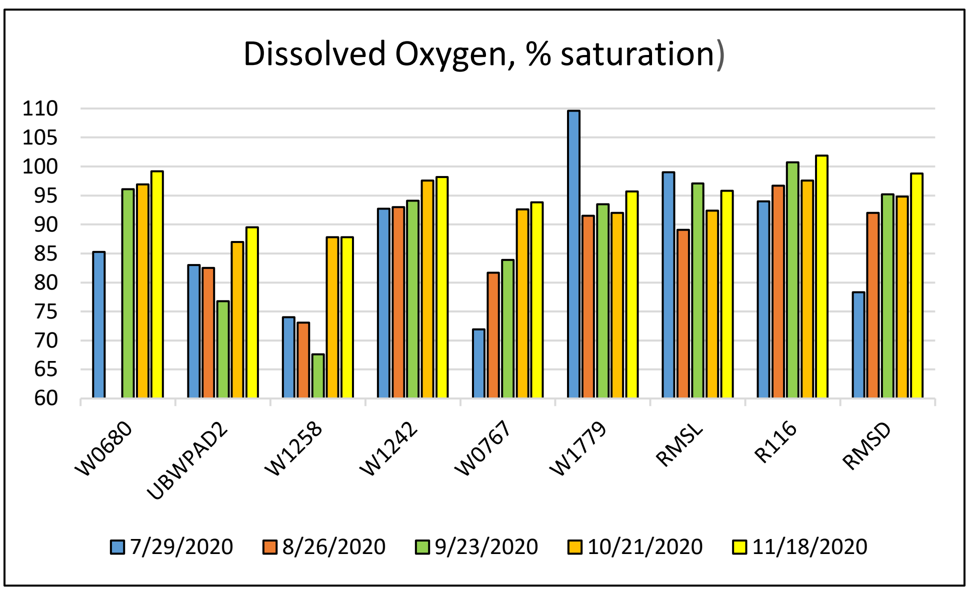


Figure 45: 2020 Dissolved Oxygen Percent Saturation at each site

Conductivity

Hand-held meters were used to measure conductivity (specific conductance) in the UB lab. Results are shown in **Table 17** and **Figure 46.** Conductivity is not highest every month at the site just downstream of the Upper Blackstone effluent confluence (UBWPAD2). In July and September, conductivity was higher at the upstream site W0680 and at the site just downstream at W1258. In October and November, however, the trend we observed last year resumed with highest conductivity at UBWPAD2 and decreased 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 and treated combined sewer overflow from the City of Worcester just upstream of W0680. Since the streamflow was below average for most of the sampling season, there may have been less dilution of urban pollution and effluent discharge than occurs in wetter years.

Table 17: 2020 Conductivity (µS/cm)

Site/Date	7/29/2020	8/26/2020	9/23/2020	10/21/2020	11/18/2020
W0680	976	641	991	554	528
UBWPAD2	941	842	978	749	757
W1258	951	796	994	669	686
W1242	909	692	930	609	625
W0767	876	668	903	597	615
W1779	846	604	877	564	586
RMSL	562	478	649	440	474
R116	577	673	621	426	507
RMSD	566	639	656	409	504

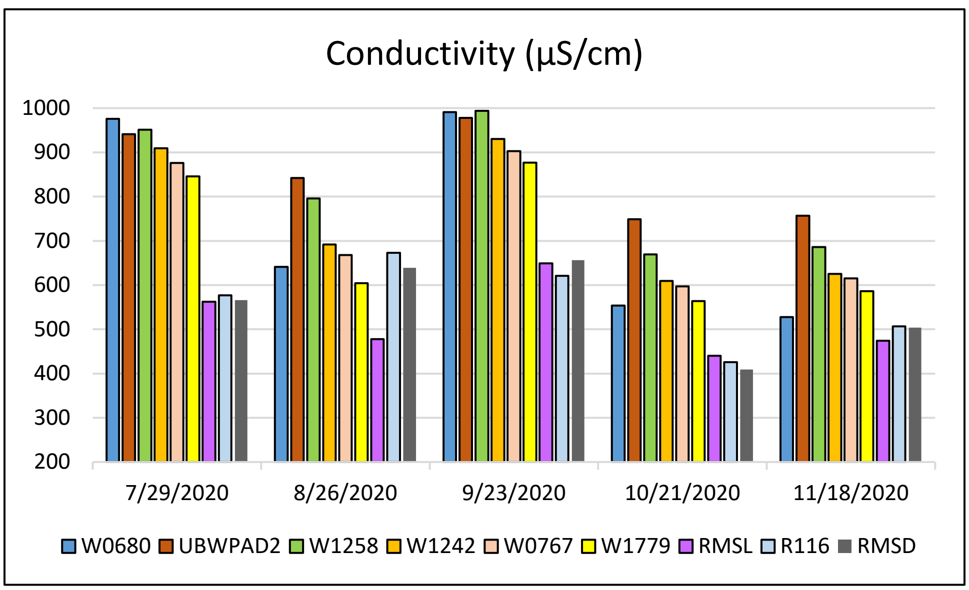


Figure 46: Conductivity at each site on sampling dates, 2020

6.1.6. 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.

Upper Blackstone and the Water Resources Research Center at the University of Massachusetts collaborated to deploy and manage four Onset HOBO U26-001 continuous meters with a temperature (T) and dissolved oxygen (DO) probe on the Blackstone River. The evaluation of continuous meter DO/T data is summarized below. A more detailed presentation of the data and analysis is contained in Appendix C.

The meters were deployed between July 7-10, 2020 and November 5-7, 2020 at stations W0680, UPWPAD2, W1258 and MID2 (Figure 2), all located in MassDEP Assessment Unit MA51-03 (MassDEP establishes segments, known as Assessment Units, for Clean Water Act reporting purposes). The meters recorded DO and T every 15 minutes until August 19th when they were reprogrammed to record readings every 10 minutes. Upper Blackstone staff used a calibrated hand-held T/DO probe to collect grab measurements every one-to-two weeks until September, and about monthly for the remainder of the deployment period. The measurements were collected next to and at the same depth as the continuous meter at each site, and were later used to review and correct the meter data. The continuous probes were cleaned during field vists between grab DO measurements. However, there were some field vists during which meter anchor wires were replaced or meters were repositioned without taking grab samples and without cleaning. The farthest upstream meter (W0680) was occasionally found overturned or out of the water during the 2020 program, likely due to high flow conditions, resulting in measurements not representative of river conditions. Therefore, much of those data at W0680 were invalidated.

Upper Blackstone encountered technical difficulties with data transfer from the meters due to issues with the meters' data shuttle between July 24th and August 25th but worked closely with Onset technical support to resolve the issues. While the Onset technical support staff were able to retrieve a subset of the data, most of the data during this period were corrupted and unretrievable.

Following the guidance in the 2020–2022 Quality Assurance Project Plan (QAPP) (Massachusetts Water Resources Research Center 2020), the procedures described in the USGS guidance document *Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting* (Wagner et al. 2006) were used to assess continuous T and DO data. Graphs showing the raw and corrected DO and T concentration values at each of the four sampling locations are presented in Appendix D.

The corrected T and DO data were compared to the Massachusetts Surface Water Quality Standard for Class B freshwater as well as the guidance described in the 2018 CALM (MassDEP, 2018):

- Minimum DO concentration greater than 5 mg/L (MA Class B Standard) when river flow is above the critical flow (7Q10)

- Maximum diel DO change less than 3 mg/L (CALM guidance value for the Aquatic Life Use)
- Maximum DO saturation of less than 125 percent (CALM guidance value for the Aquatic Life Use).

The occurrence of extremely low river flow conditions during the 2020 monitoring period affected which recorded data were compared against the standards and guidelines. Massachusetts water quality standards and guidelines apply to river flow conditions when river flow is greater than the 7Q10 flow. Precipitation during the months of May, June, July, and September was well below average, leading to low river flow conditions throughout the summer that were close to or below the calculated 7Q10 value (37.2 cfs).

The percent of time or number of days that the data were above the water quality criteria is provided in **Table 18** below. At the four monitoring locations the surface water quality was in compliance with the Massachusetts minimum DO standard of 5 mg/L more than 90 percent of the time. Furthermore, DO percent saturation data at all four locations always met the 125 percent guidance value.

Table 18: Summary of Continuous Corrected DO Data Against Massachusetts Surface Water Quality Standards and Guidance

Metric	W0680	UBWPAD2	W1258	MID2 (Depot)
Days of corrected data	48	89	97	84
Days where Diel ΔDO < 3.0 mg/L	47	77	51	82
% of days where Diel ΔDO < 3.0 mg/L	98%	87%	53%	98%
% of the time DO > 5.0 mg/L	97%	87%	84%	97%
% of the time DO > 5 mg/L and river flow is above 7Q10 flow	99%	92%	90%	98%
Days where % Saturation > 125%	0	0	0	0

DO at station W0680 was at levels that support Aquatic Life Use based on guidance in MassDEP's 2018 CALM. At the middle two stations, UBWPAD2 and W1258, DO was not consistently at levels that support Aquatic Life Use because of the DO diel variations that exceeded 3 mg/L frequently. DO at the most downstream station (Depot/MID2), was at levels that support Aquatic Life Use.

6.1.7. Data Quality Objectives

All data collected during the 2020 monitoring program were evaluated against the Data Quality Objectives (DQOs) in the QAPP to determine whether the data quality was adequate for analysis. See Appendix E for the 2020-2022 QAPP.

Several field or lab blanks from the UMD lab did not pass the DQO for TDN and PON, and therefore a subset of the TN data is flagged for failed quality control in 2020. One equipment blank sample failed quality control for TN. The data was not censored, however, even the one month when TN data was not five times larger than the largest blank value, because we performed a statistical correlation analysis in 2019 to evaluate whether a statistically significant difference exists between the full dataset (with flagged values) and the censored dataset (with flagged values removed). The result of this analysis indicated that there is no statistically significant difference between the censored and uncensored dataset. Therefore, all data were included in the analysis and discussion presented in this report (See Hatte et al., 2020).

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 nutrient loads to the river. The WWTF has maintained the significant improvement in the water quality of its effluent since the upgrades were brought online. In 2020, the effluent TP load has been reduced by 90% and the effluent TN load has been reduced by 64% compared to the average pre-upgrade nutrient loads between 2006 and 2008.

Water quality monitoring data collected by Upper Blackstone in 2020 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 Massachusetts and Rhode Island river water quality criteria and guidelines for the Blackstone River.

In 2020, river TP concentrations were somewhat higher than in the past, with only 55 percent of the samples collected below the 100 ppb MassDEP guidance value. River TN concentrations were lower than in the past few years at two-thirds of the sites, and are still lower than the pre-upgrade condition, which is desirable for downstream marine waters such as Narragansett Bay. The 2020 river TP loads were in general low, especially at the Rhode Island sites, compared to 2019. TN yearly loads were the lowest observed in the 9-year study. This decrease in river loads is mostly due to low streamflows this summer but could also be a result of lower TN concentrations in the Upper Blackstone effluent. We continue to see that overall nutrient loads have been greatly reduced compared to before the Upper Blackstone plant upgrade.

The 2020 sampling season was preceded by a lower than average snowy winter and was characterized by warmer temperatures and a very dry summer. Streamflow was lower than average until November. 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 lower than average in 2020, high temperatures and low streamflow compensated to create favorable conditions for algae growth, particularly in impoundments, which could explain why chlorophyll-a measurements were not comparatively lower than in recent years, and even exceeded MassDEP's guidance values at two sites in late July.

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 2020. 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.

Finally, with nine years of data, a 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 again for W0680 and UBWPAD2, and decreasing TN trends were noted at all sites except for UBWPAD2, and W0767. The chlorophyll-a trend analysis now suggests that chlorophyll-a levels are decreasing at the mouth of the river (RMSD), and only two sites show increasing trends (W0680 and W1258), while no significant trend is detected at the other sites. When grouped together by month, however, an increasing trend is significant at the 90% level.

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 2021 to track the impacts of reduced nutrient concentrations in Upper Blackstone plant effluent, and return to a sampling season starting in April. Blackstone River data collected in 2020 will be added to EPA's WQX database. The 2020 data will be submitted to MassDEP to supplement data submitted for the past eight years.

In 2021 the monitoring of nutrients and river chemistry at the 9 sampling sites will be continued, as will measurement of continuous dissolved oxygen at 4 river sites.

9.0 References

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Blackstone River Water Quality Monitoring Program

2020 Sampling Season Report

APPENDIX

Appendix A: Additional Tables

Table A1: Summary of 2020 precipitation in relation to NWS 30-year normal monthly data

	Monthly Precipitation (inches)					
	Worcester, MA (NWS station KORH)			Taunton, MA (NWS station KTAN)		
	2020	Normal Month Total[a]	% of normal	2020	Normal Month Total[a]	% of normal
Jan	2.11	3.49	60%	1.63	3.98	41%
Feb	3.23	3.23	100%	2.89	3.56	81%
Mar	4.26	4.21	101%	4.11	5.11	80%
Apr	6.03	4.11	147%	5.93	4.61	129%
May	1.81	4.19	43%	1.72	3.59	48%
Jun	2.43	4.19	58%	4.37	3.63	118%
Jul	1.47	4.23	35%	1.49	3.75	118%
Aug	4.55	3.71	123%	1.63	4.08	47%
Sep	2.35	3.93	60%	1.33	4.32	37%
Oct	6.02	4.68	129%	5.9	4.29	130%
Nov	5.96	4.28	61%	5.08	4.5	87%
Dec	6.73	3.82	185%	5.72	4.32	177%

Notes: [a] Based on data from 1981 – 2010, NWS Normal Monthly Data, available online: www.ncdc.noaa.gov/cdo-web/datasets#GHCND

Table A2: Summary of 2020 monthly flow conditions

	Monthly Mean Discharge (cfs)					
	Woonsocket, RI – USGS Station 01112500			Millbury, MA – USGS Station 01109730		
	2020	**Ave 1930 – 2020**	**% normal**	**2020**	**Ave 2003 – 2020[a]**	**% normal**
Jan	1111	980	113%	220	196	112%
Feb	1018	1014	100%	198	192	103%
Mar	957	1492	64%	192	267	72%
Apr	1688	1442	117%	313	284	110%
May	1055	883	119%	182	175	104%
Jun	389	646	60%	79	158	50%
Jul	271	341	79%	59	109	54%
Aug	125	308	41%	71	99	72%
Sep	93	326	29%	56	106	53%
Oct	299	474	63%	117	163	72%
Nov	507	694	73%	145	180	81%
Dec	1687	923	183%	334	217	154%

Note: [a] Long-term average in January – December based on data from 2002 – 2020.

Table A3: Summer monthly mean streamflows (cfs)

	Monthly Mean Streamflow (cfs) at Millbury, MA – USGS Station 01109730										
	2008	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
June	114	202	136	434	80	164	67	177	89	102	79
July	151	93	68	105	77	96	49	89	105	106	59
August	143	273	105	86	68	60	59	59	156	81	71
September	228	340	88	82	70	72	48	58	201	65	56

Appendix B: Additional Figures

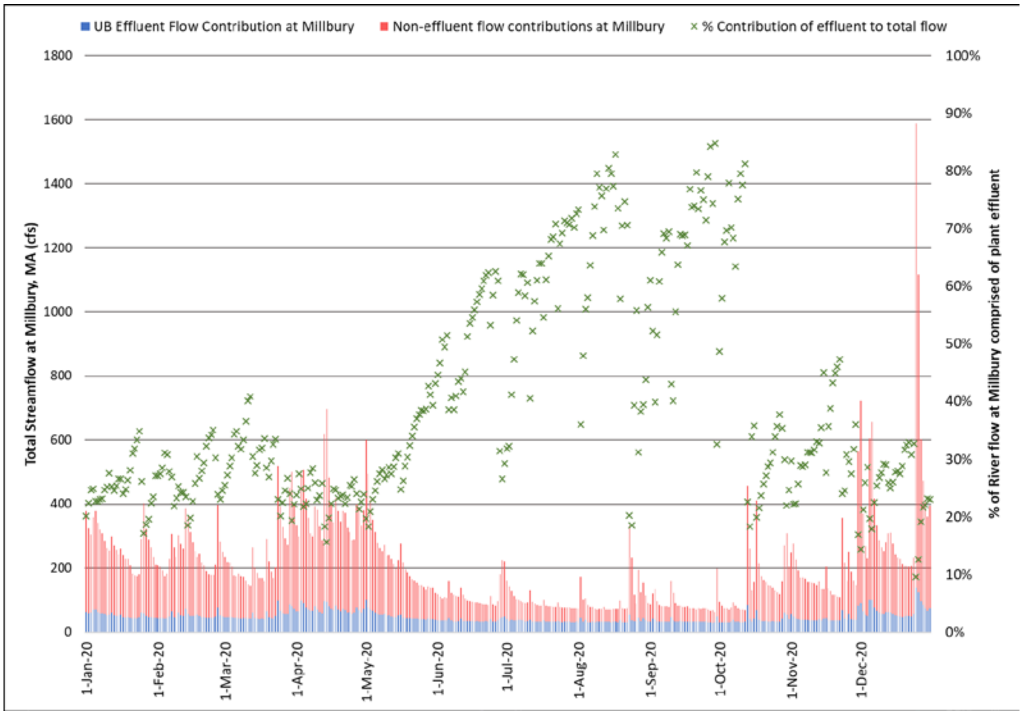
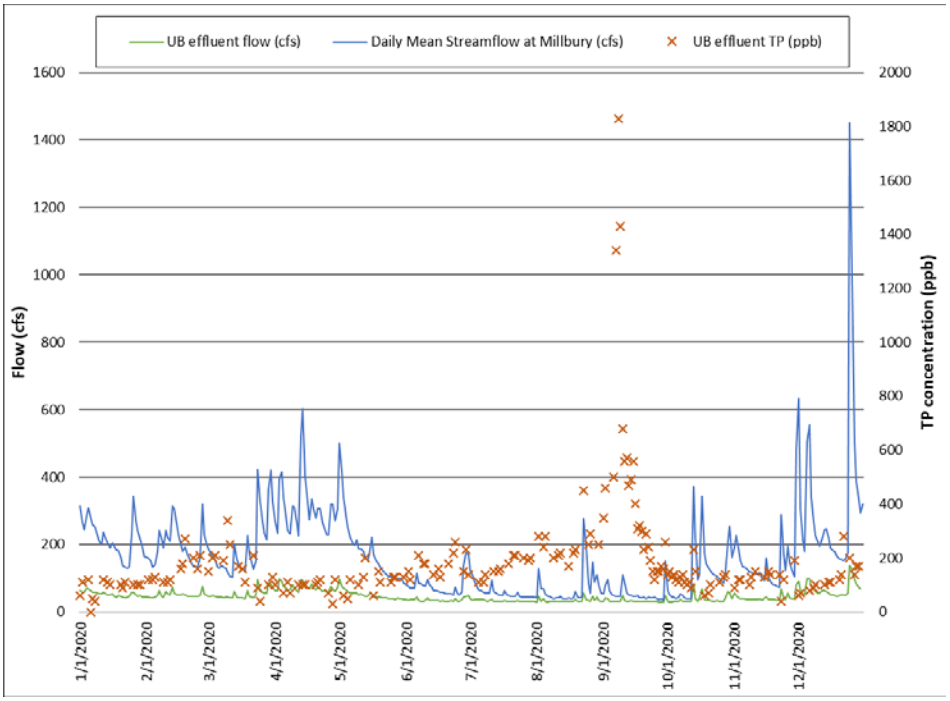


Figure B1: Effluent flow contributions at Millbury, 2020

Appendix B – Additional Figures



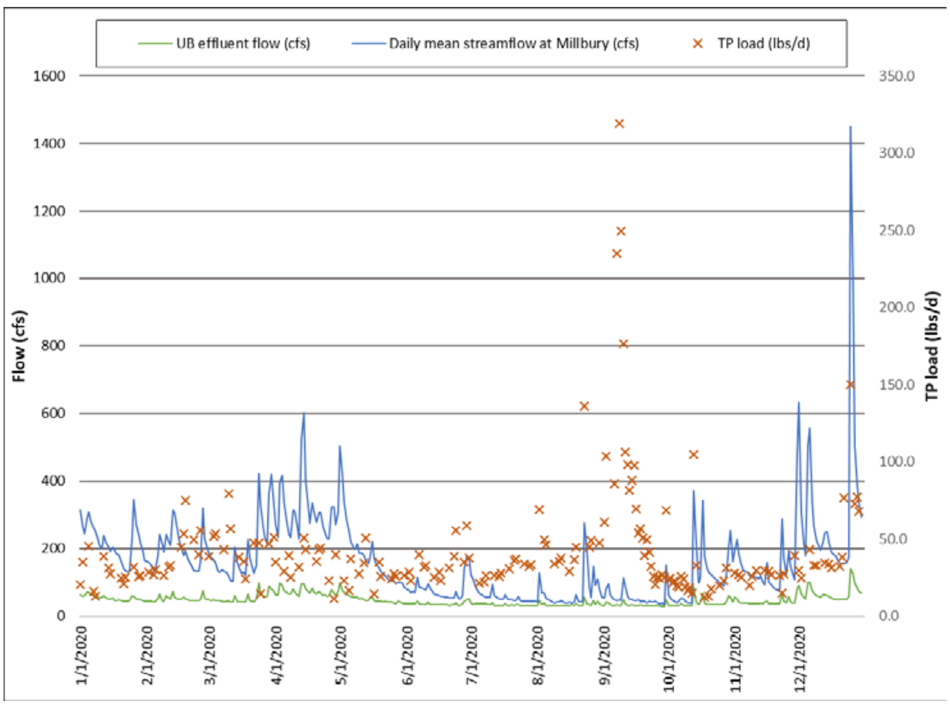
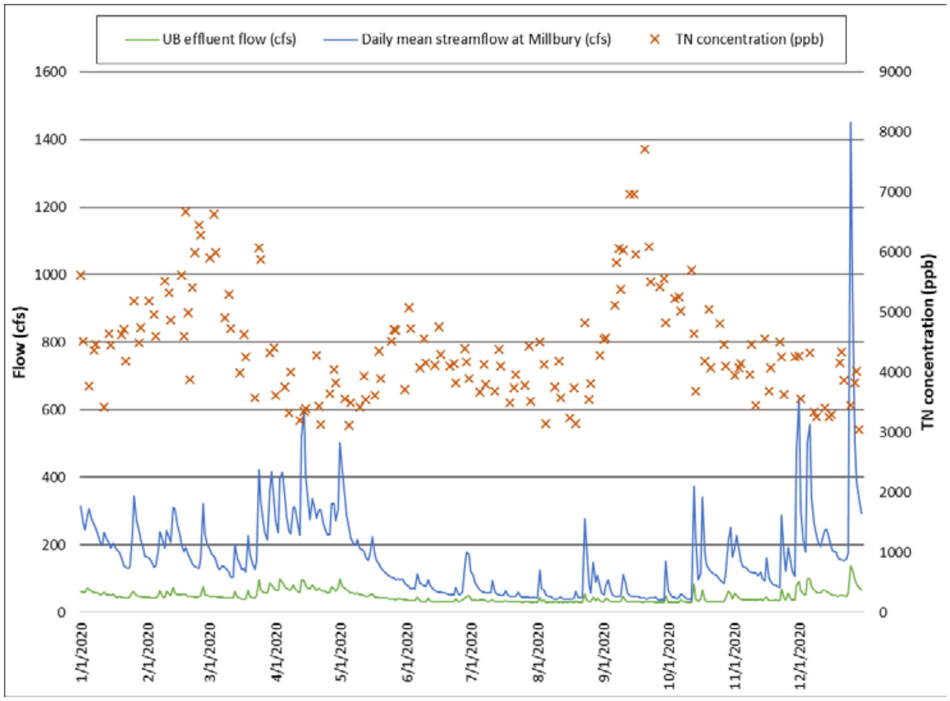


Figure B2: Effluent TP characteristics, 2020

Appendix B – Additional Figures



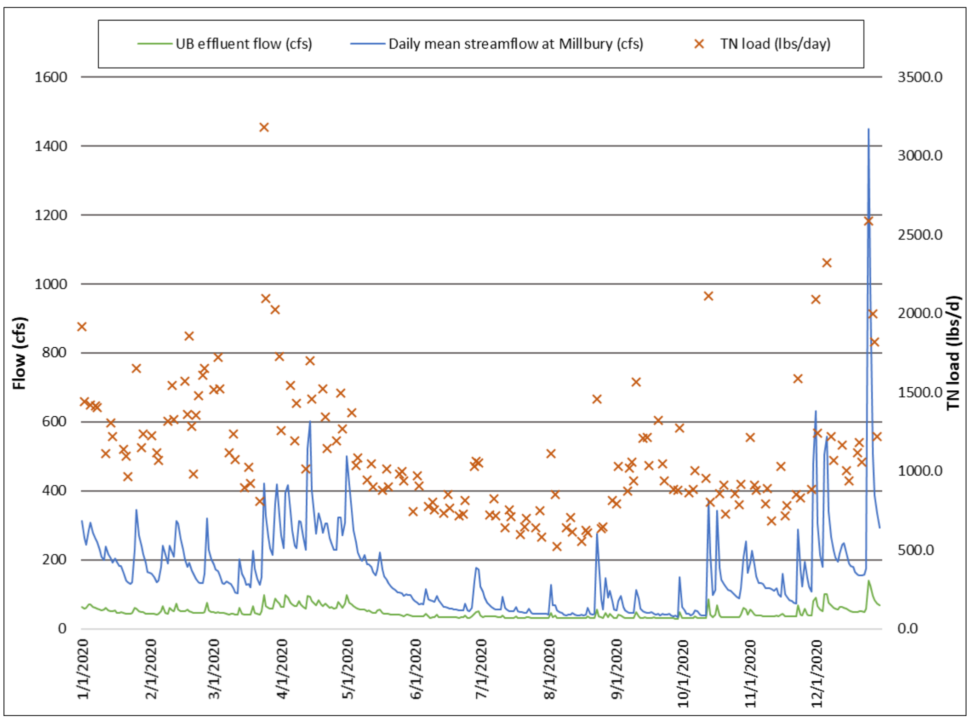


Figure B3: Effluent TN characteristics, 2020

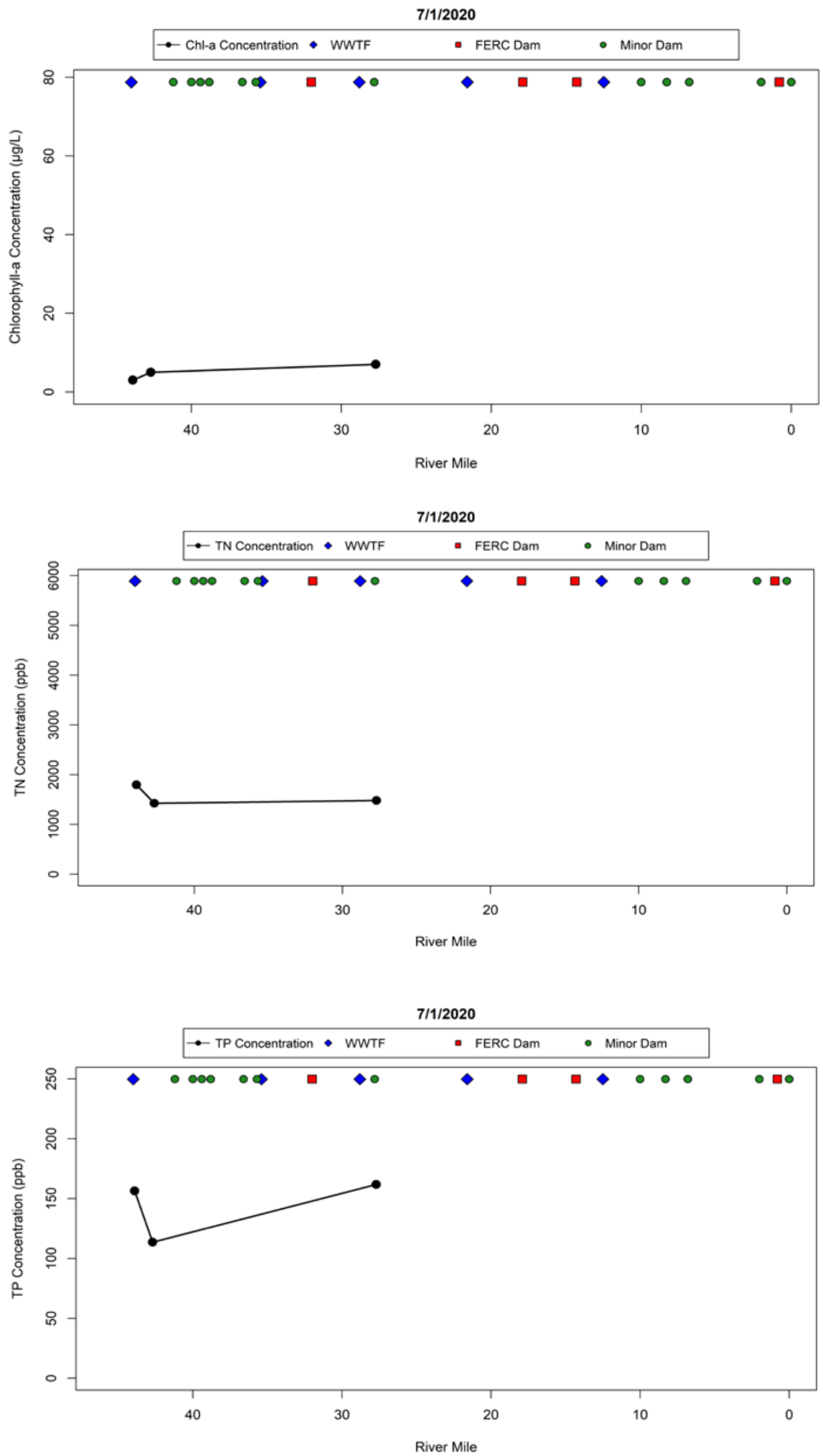


Figure B4: July 1 (treated as June) 2020 along stream concentration (Chl-a, TN, TP)

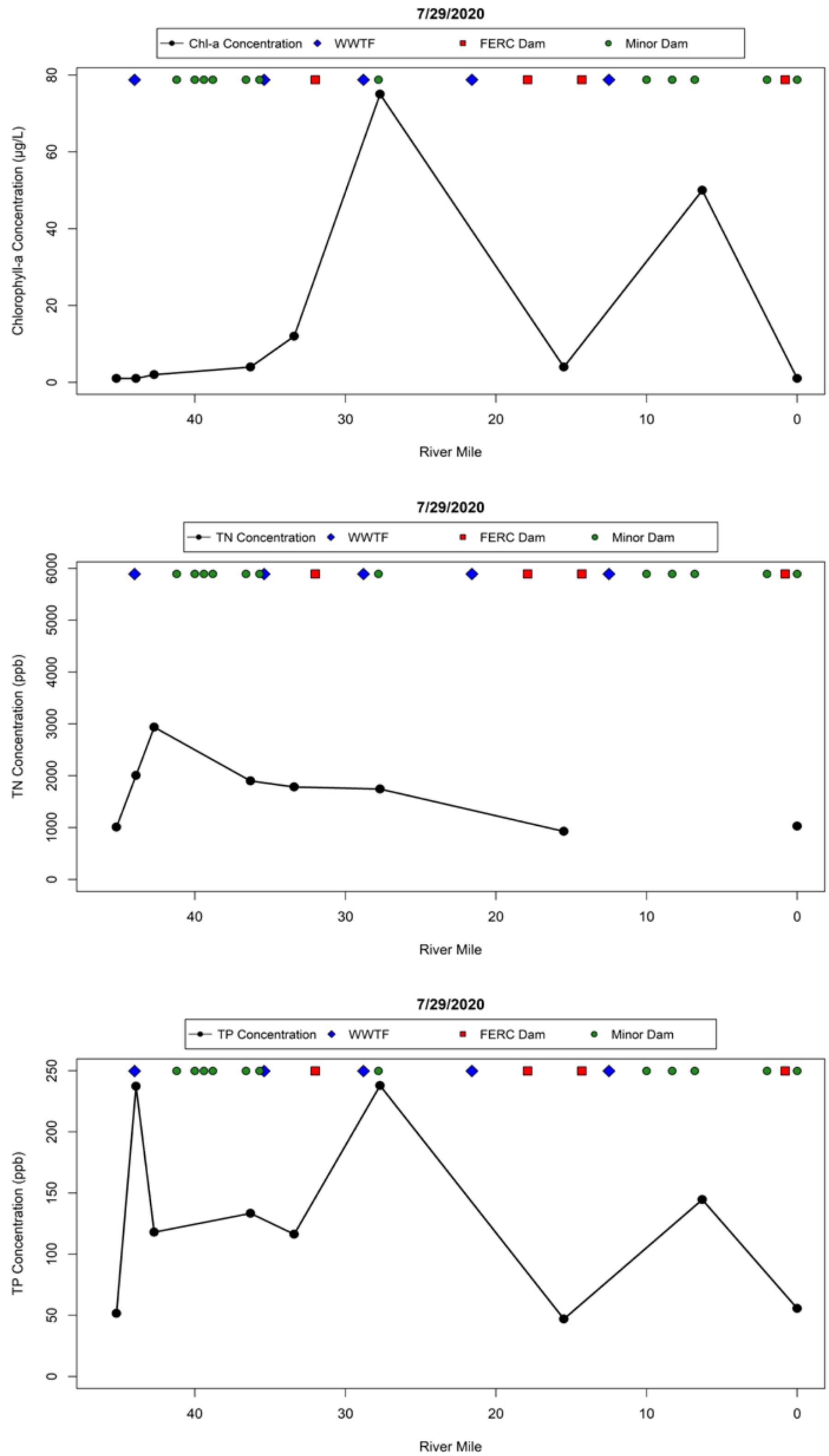


Figure B5: July 29 (treated as July) 2020 along stream concentration (Chl-a, TN, TP)

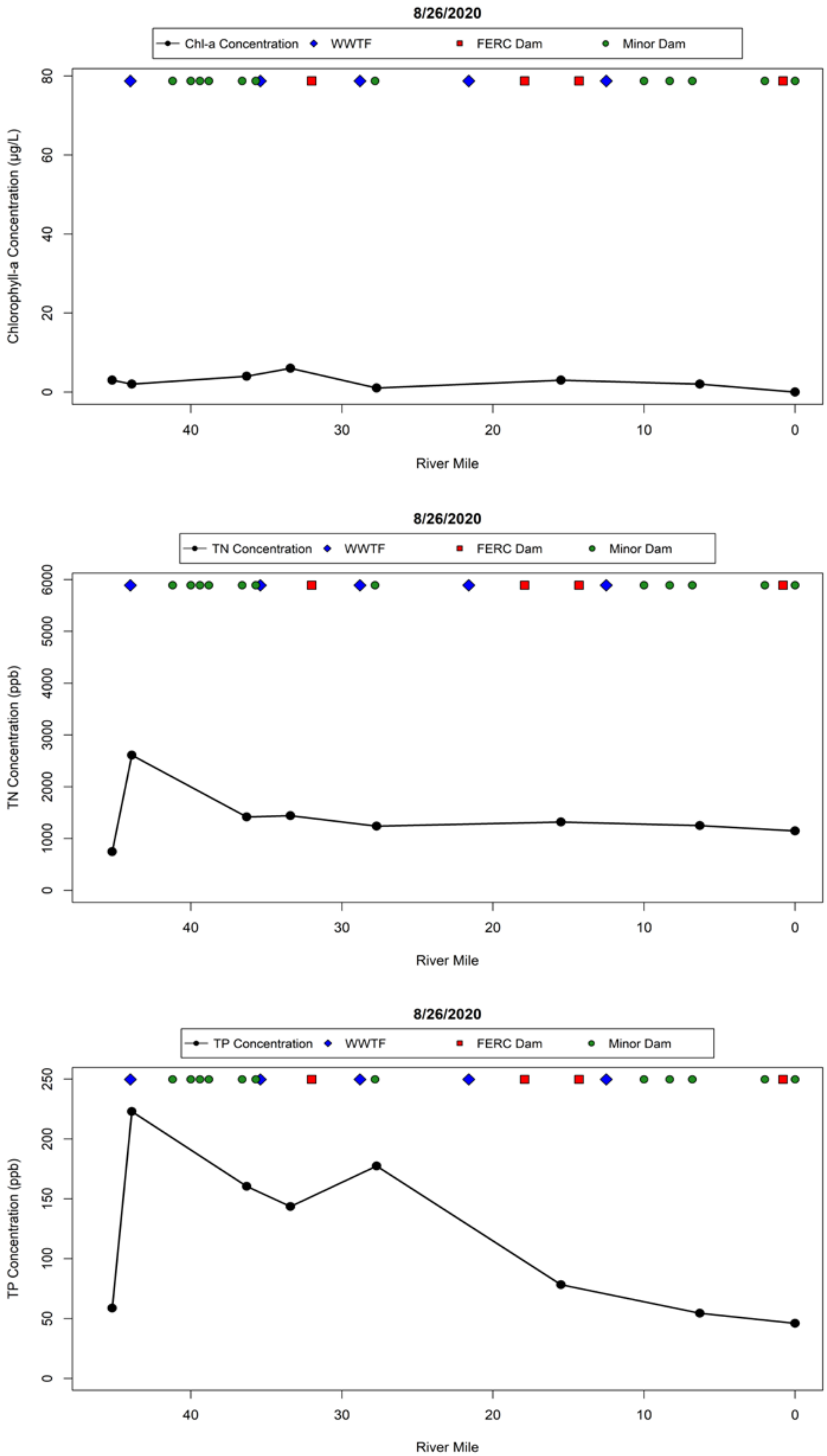


Figure B6: August 2020 along stream concentration (Chl-a, TN, TP)

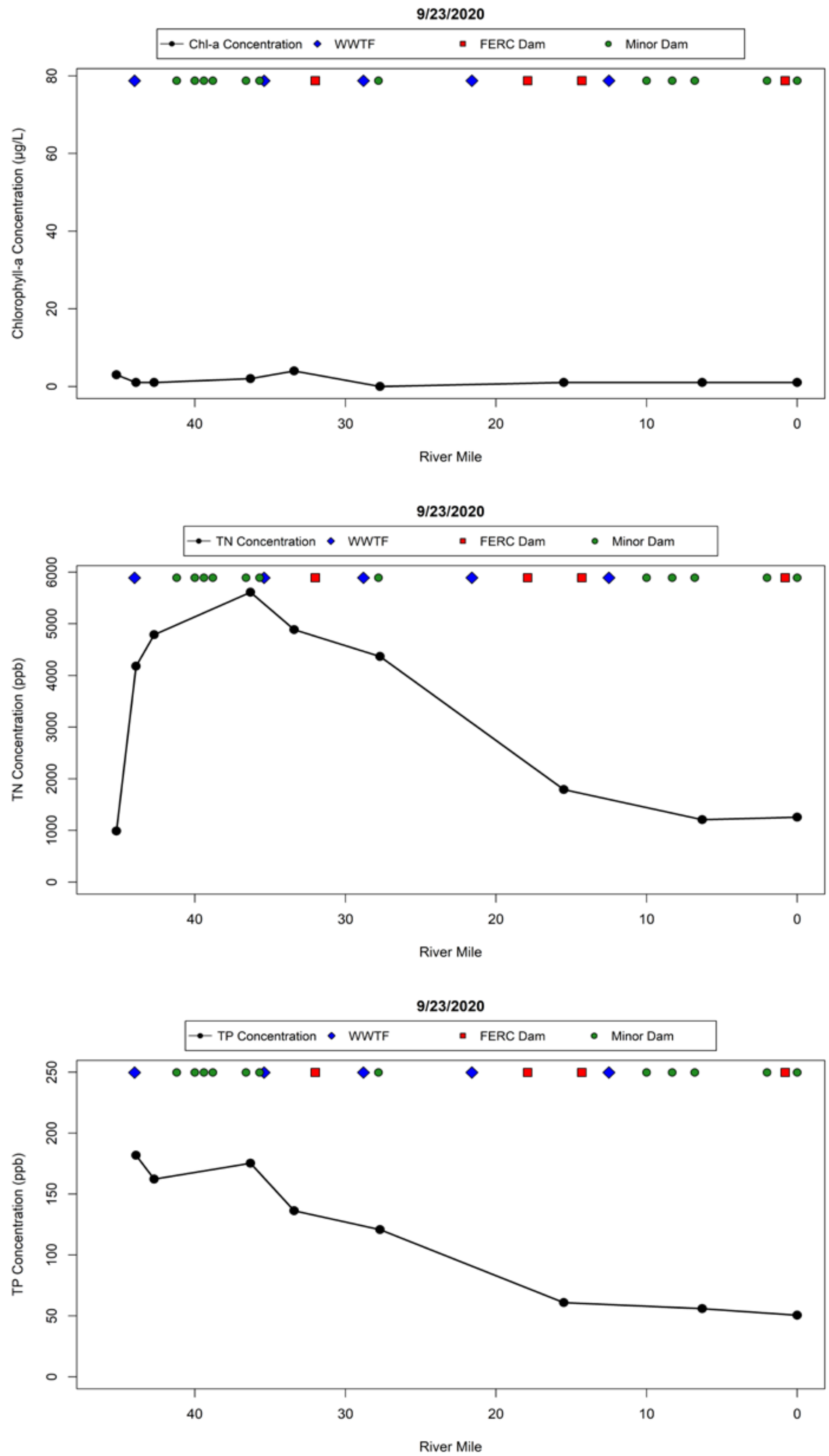
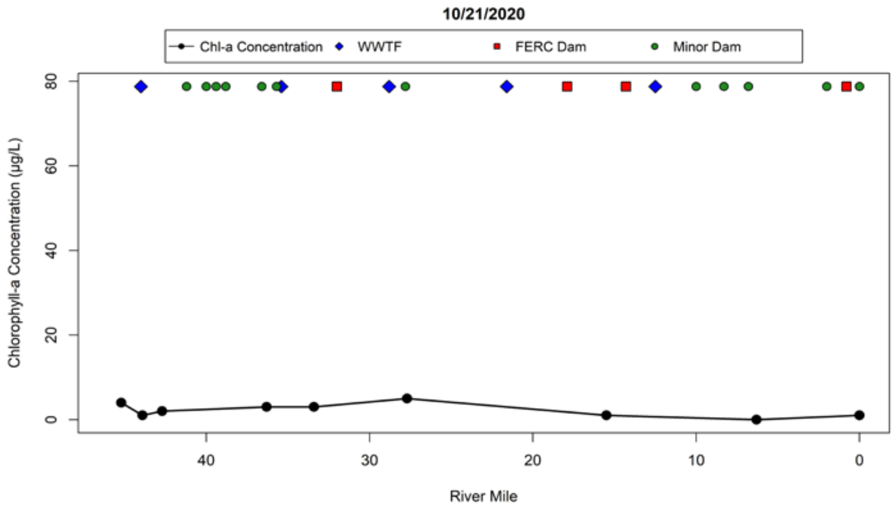
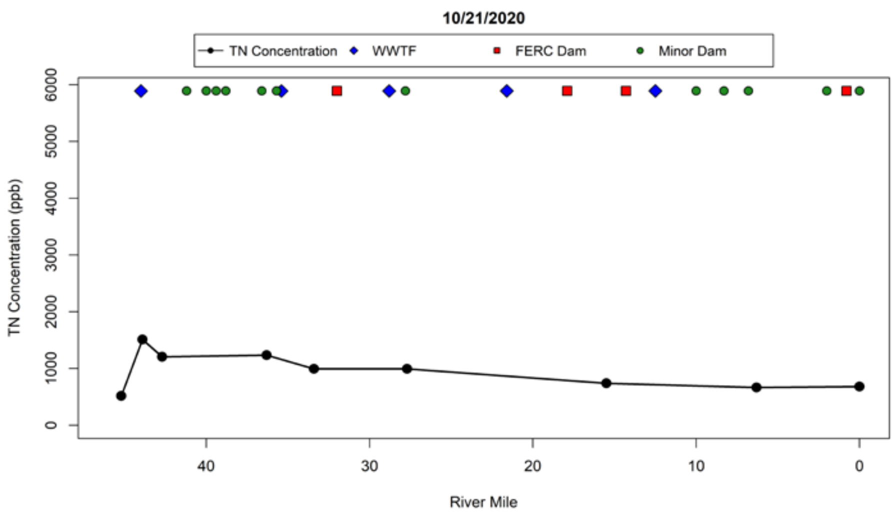


Figure B7: September 2020 along stream concentration (Chl-a, TN, TP)





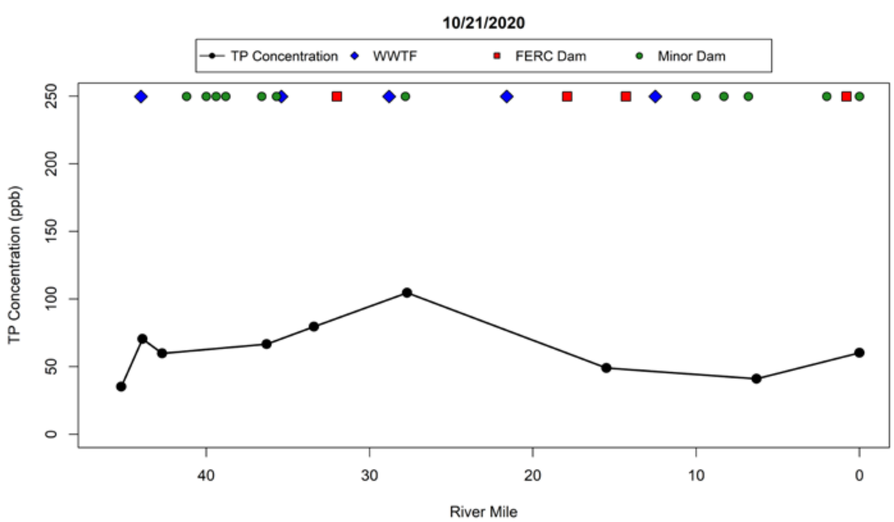


Figure B8: October 2020 along stream concentration (Chl-a, TN, TP)

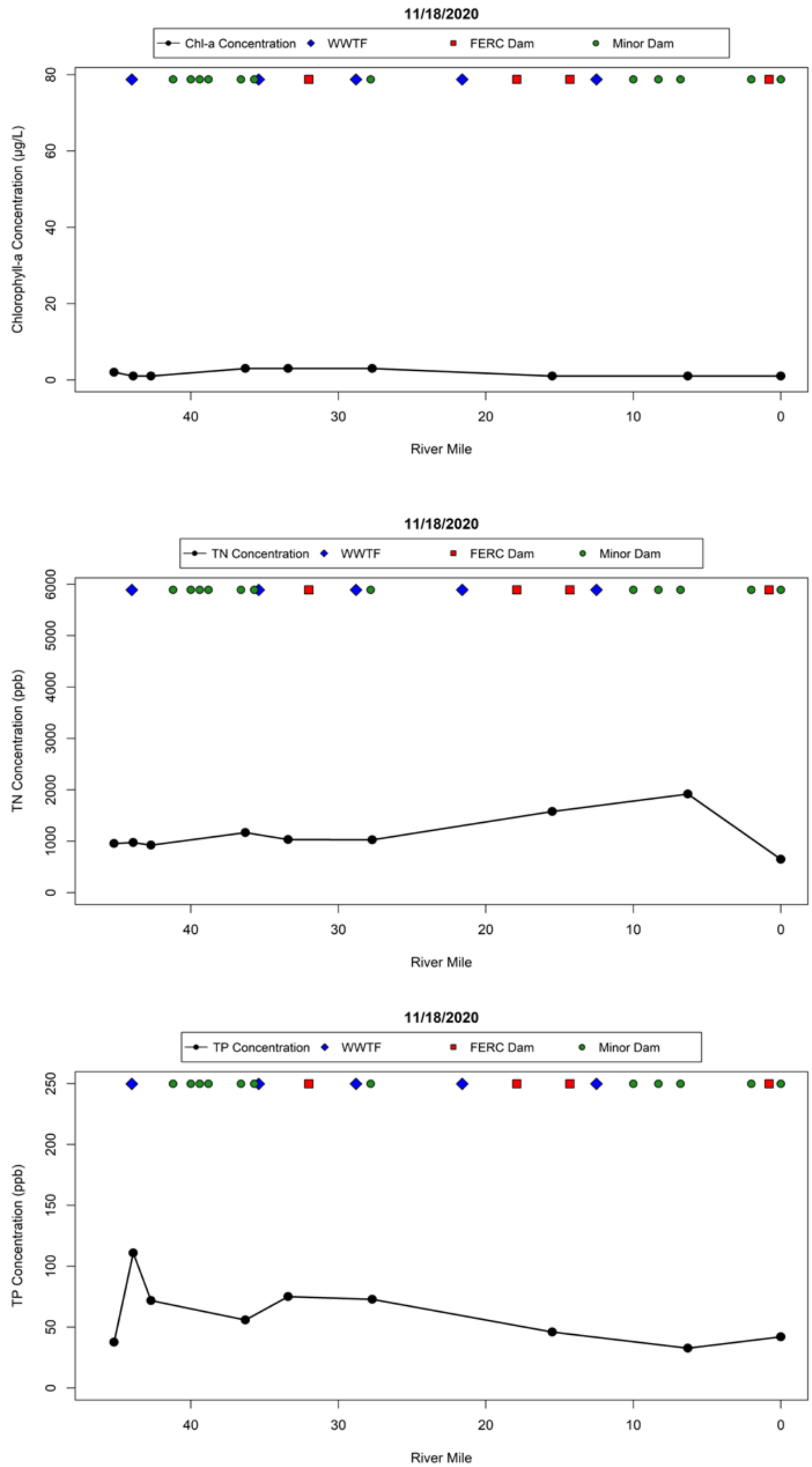
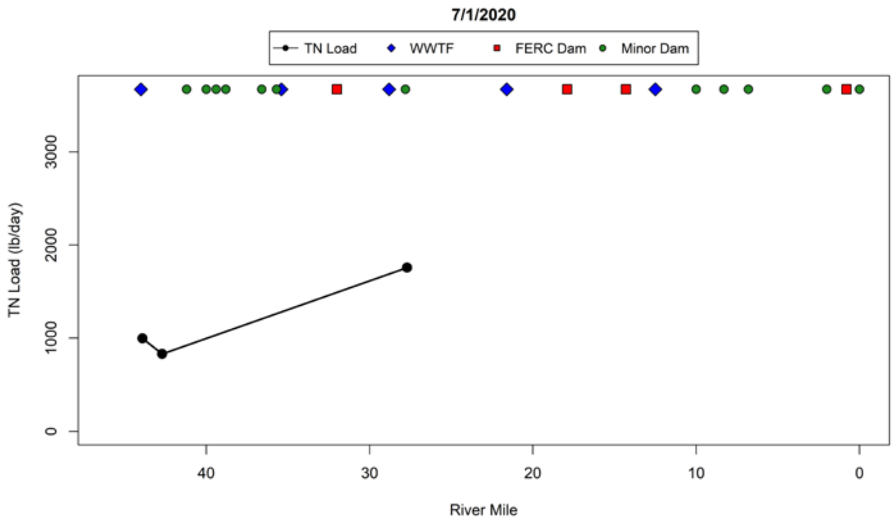


Figure B9: November 2020 along stream concentration (Chl-a, TN, TP)



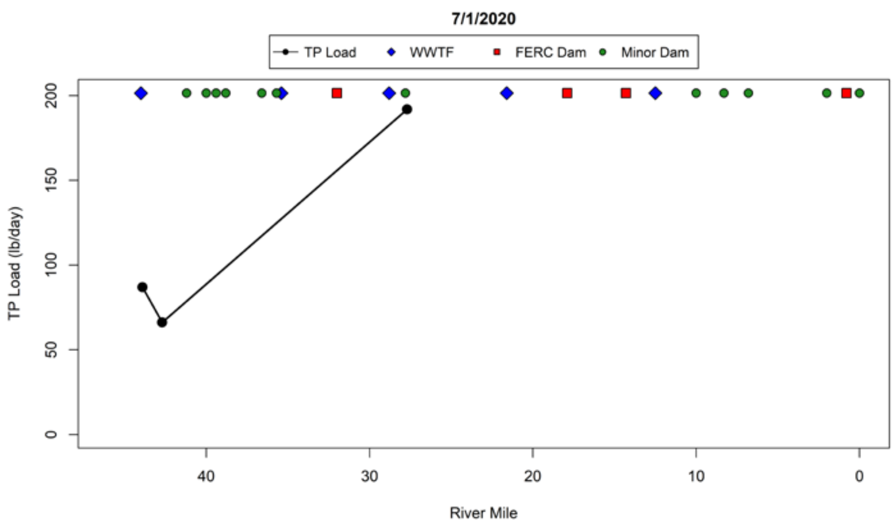
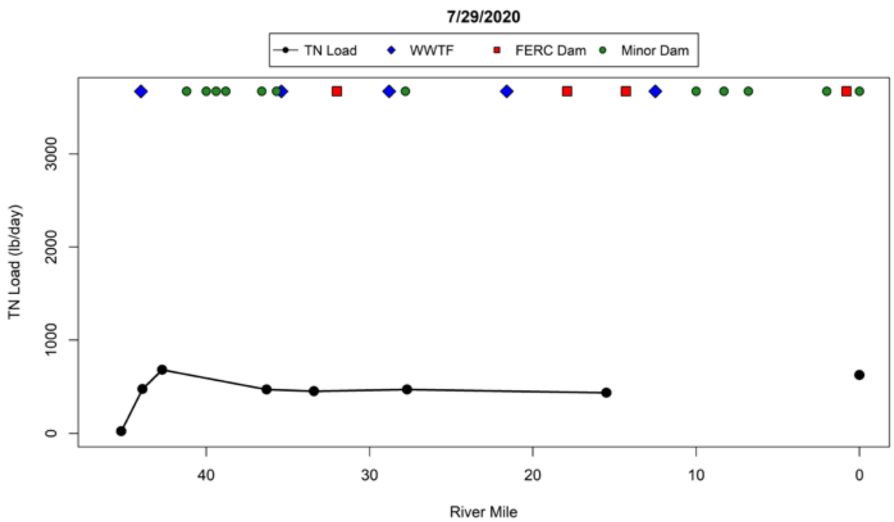


Figure B10: July 1 (treated as June) 2020 along stream load plots (TN, TP)



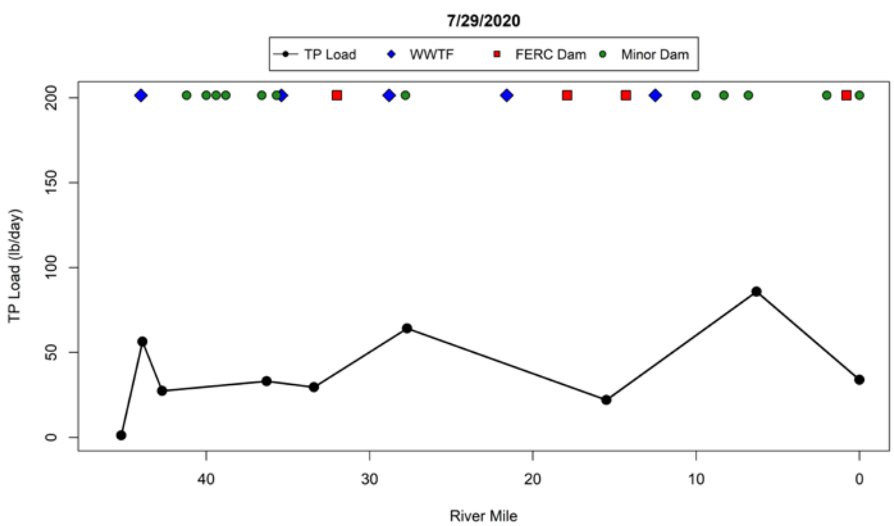


Figure B11: July 29 (treated as July) 2020 along stream load plots (TN, TP)

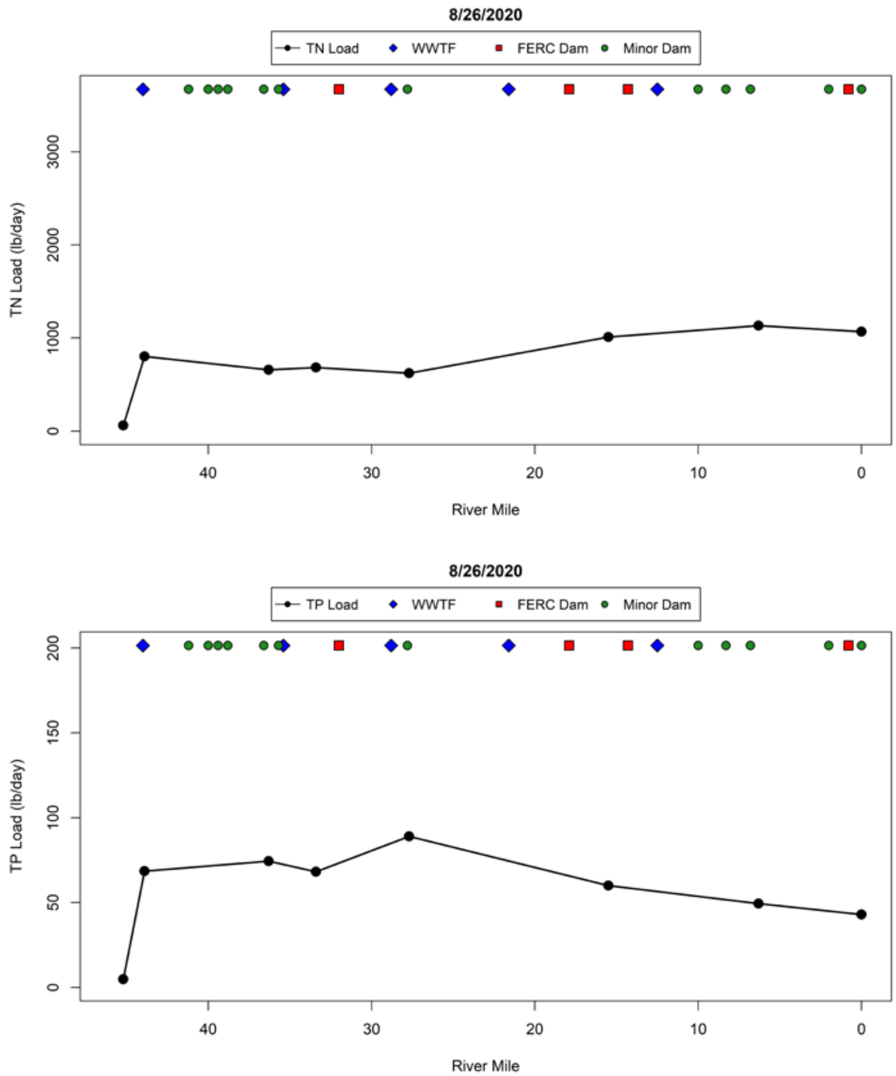
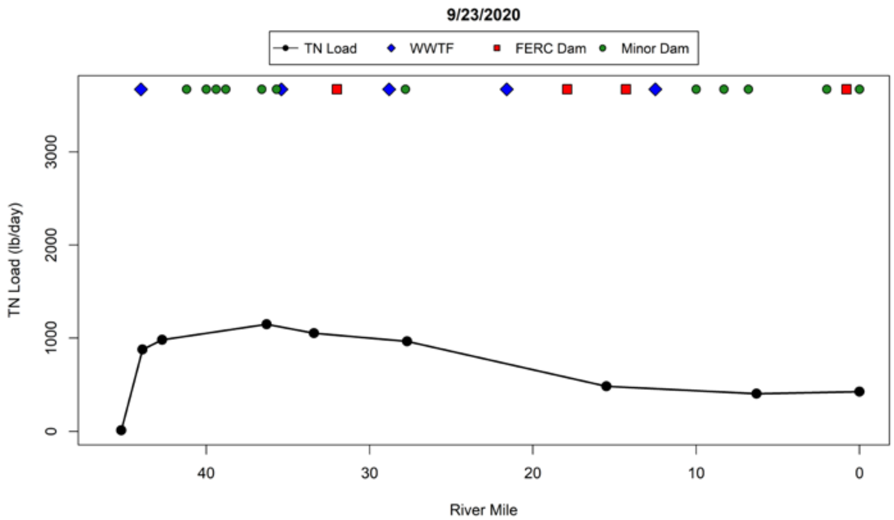


Figure B12: August 2020 along stream load plots (TN, TP)



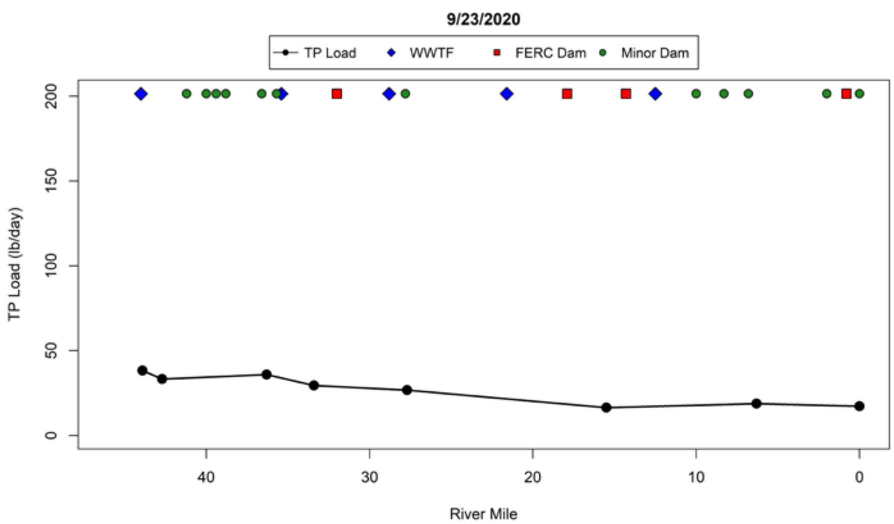
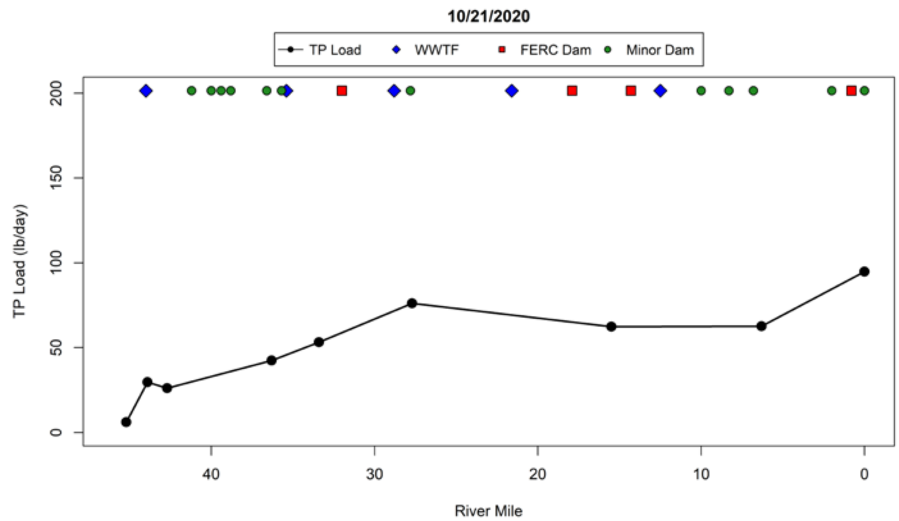


Figure B13: September 2020 along stream load plots (TN, TP)



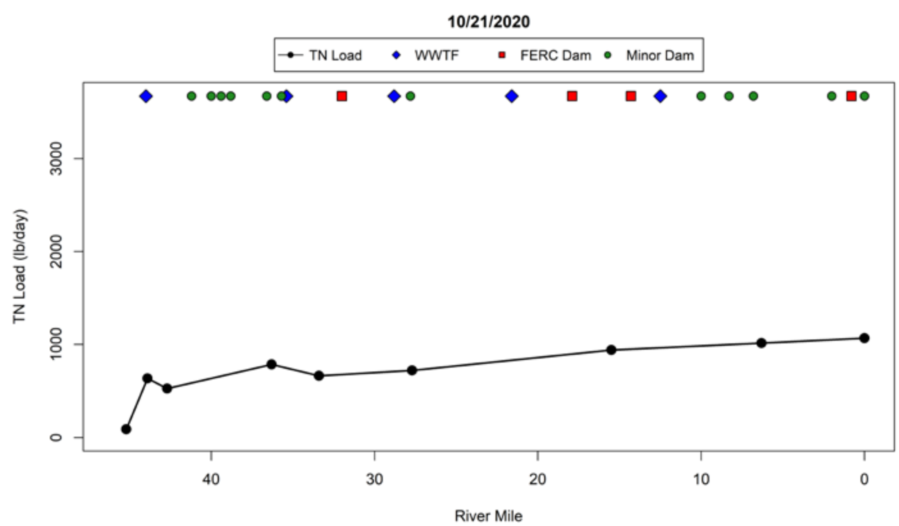


Figure B14: October 2020 along stream load plots (TN, TP)

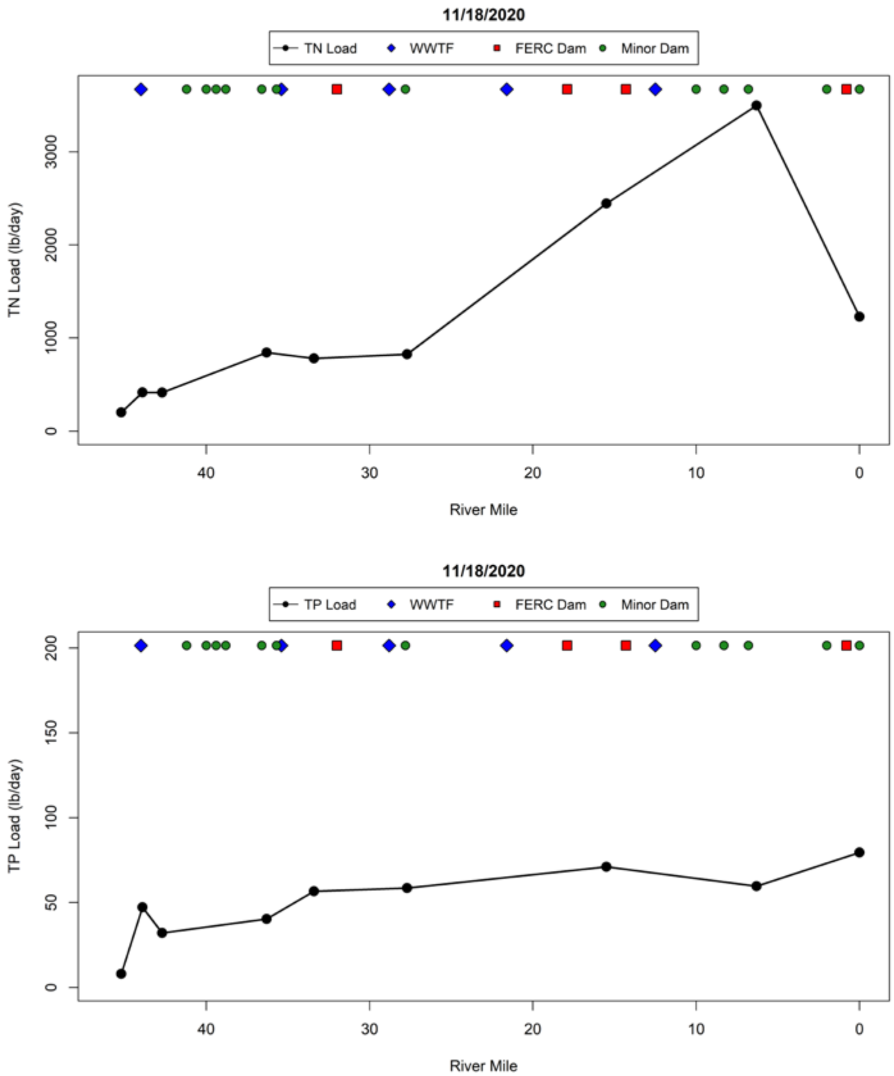


Figure B15: November 2020 along stream load plots (TN, TP)

Appendix C: In-Situ Temperature and Dissolved Oxygen Monitoring: Blackstone River, July – November 2020

In Situ Temperature and Dissolved Oxygen Monitoring: Blackstone River July – November 2020

May 26, 2021

CDM Smith

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In Situ Temperature and Dissolved Oxygen Monitoring: Blackstone River, July – November 2020

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In Situ Temperature and Dissolved Oxygen Monitoring: Blackstone River, July – November 2020

1.0 Introduction

Upper Blackstone Clean Water (Upper Blackstone) and the Water Resources Research Center at the University of Massachusetts (UMass) collaborated to deploy and manage four Onset HOBO U26-001 continuous meters with temperature (T) and dissolved oxygen (DO) probes on the Blackstone River for four months (July through October 2020). Continuous meters were calibrated and deployed by Upper Blackstone at four locations: one upstream and three downstream of the Upper Blackstone effluent discharge location (**Figure 1**). All four meters were deployed in MassDEP Assessment Unit MA51-03 (MassDEP establishes river segments, known as Assessment Units, for Clean Water Act reporting purposes).

CDM Smith reviewed the data from the 2020 continuous metering program, corrected the T and DO data at each site using United States Geological Survey (USGS) guidance (Wagner et al. 2006) based on periodic in situ measurements taken with a handheld probe, and compared the corrected data to Massachusetts' surface water quality criteria and guidance for dissolved oxygen. CDM Smith's data analysis is the subject of this report.

In 2020, Upper Blackstone encountered technical difficulties with data transfer from the meters due to issues with the meters' data shuttle between July 24th and August 25th, but worked closely with Onset technical support resolved the issues. While the Onset technical support staff were able to retrieve a subset of the data, most of the data during this period were corrupted and unretrievable. In addition, constraints on field visits due to COVID-19 reduced the planned frequency of instrument maintenance and grab measurements during the 2020 monitoring program.

This report is structured as follows:

- Section 2: Conditions During Sampling
- Section 3: Continuous Meter Locations and Recorded Data
- Section 4: Data Correction
- Section 5: Discussion – Data Analysis and Interpretation
- Section 6: Summary
- Section 7: References

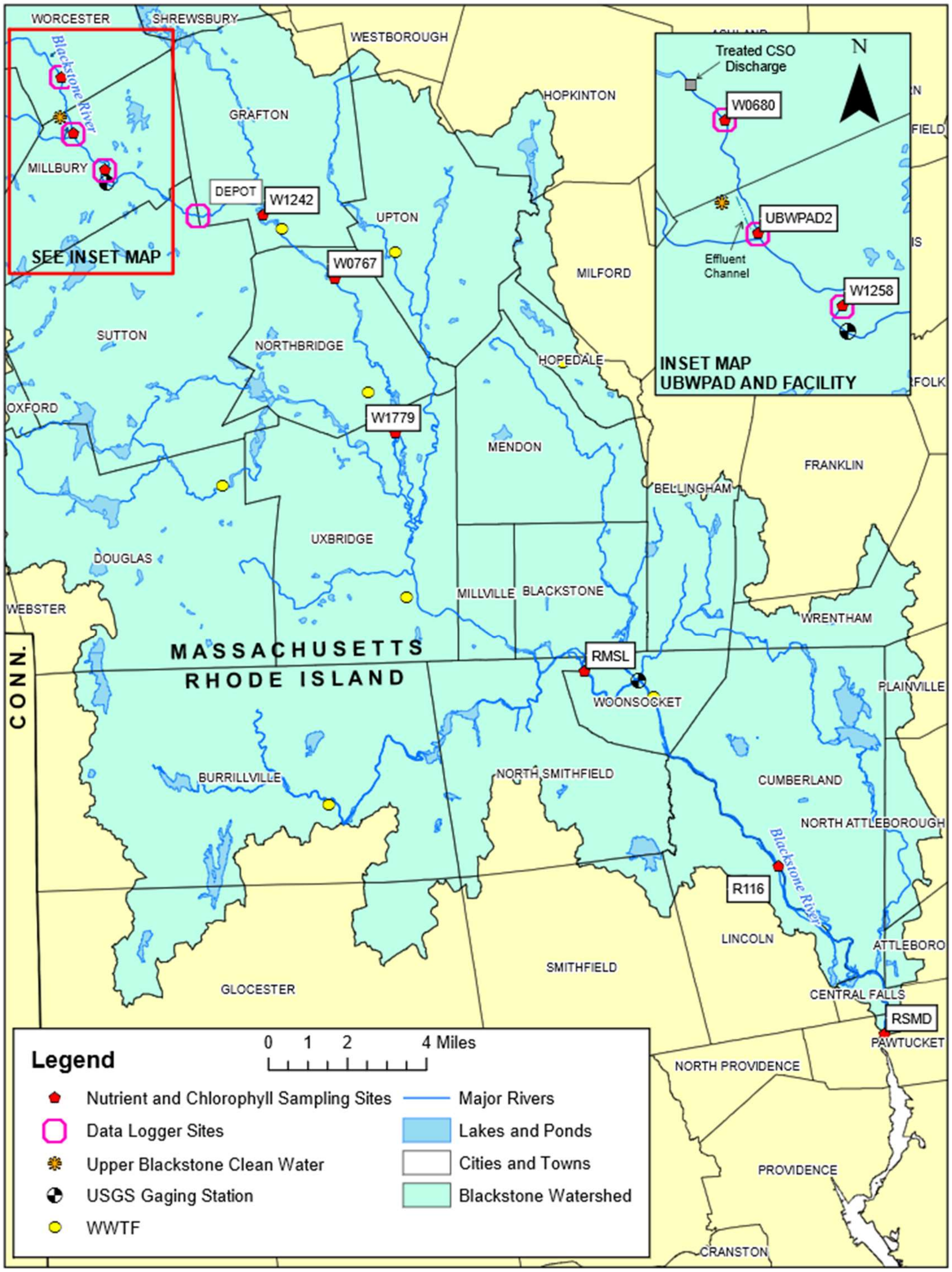

Figure 1: Upper Blackstone Sampling Locations: 2020 Continuous Dissolved Oxygen Meters Installed at W0680, UBWPAD2, W1258, and MID2 (Depot)

2.0 Conditions During Sampling

Environmental conditions during the monitoring program can impact the DO dynamics observed by the continuous data loggers. In general, 2020 precipitation was below average, and temperature was above average relative to historical trends based on data from the Worcester Regional Airport (KHOR), with drought conditions reported throughout the watershed. This resulted in low stream flow relative to historical averages, as was indicated at the USGS gage in Millbury, Massachusetts (USGS 01109730), which is about 2 miles downstream of the Upper Blackstone discharge.

To characterize the low stream flow periods observed during the 2020 monitoring program relative to the historical record, CDM Smith calculated the 7Q10 flow from the available stream flow record at the USGS Millbury gage. The 7Q10 flow is the seven-day average low flow that occurs at a 10-year recurrence interval and is used by the Massachusetts Department of Environmental Protection (MassDEP) to identify extreme low-flow conditions. MassDEP guidance in the Consolidated Assessment and Listing Methodology (CALM) manual interprets the Massachusetts Surface Water Quality Standards such that water quality criteria do not apply to stream flow below 7Q10 in receiving waters with wastewater discharges (like the Blackstone River). Therefore, comparing the statistically based 7Q10 flow to river flows observed in 2020 can be used to understand the relative severity of low-flow conditions during the monitoring period and to guide the interpretation of the data relative to the Massachusetts Surface Water Quality Standards.

CDM Smith calculated the 7Q10 flow for the full period of accepted data (2002 through 2020) using the United States Environmental Protection Agency's (EPA) DFLOW (EPA DFLOW 2006) software. This flow is calculated by fitting a Log-Pearson Type III distribution to the annual series of 7-day average low flows. The 7Q10 flow is the value of the Log-Pearson Type III fit at the 10-percent (%) non-exceedance probability (10-year recurrence interval). **Figure 2** shows the Log-Pearson fit to the annual 7-day average low-flow values. This value is identified on the fit Log-Pearson distribution as the green cross, marking a 7Q10 flow of 37.2 cubic feet per second (cfs).

Figure 3 shows the 70 occurrences when river flow was at or below the 7Q10 flow during the period when the continuous meters were deployed, and the occurrences (start time, end time, duration) are tabulated in **Table 1**. These occurrences ranged from 15 minutes to more than 14 hours and generally were centered on the low-flow periods of the day at the Millbury gage. Because the Millbury gage includes, and at low flow is dominated by, Upper Blackstone plant flows, the occurrences of flow below 7Q10 match the overnight low diurnal signal in the wastewater flows.

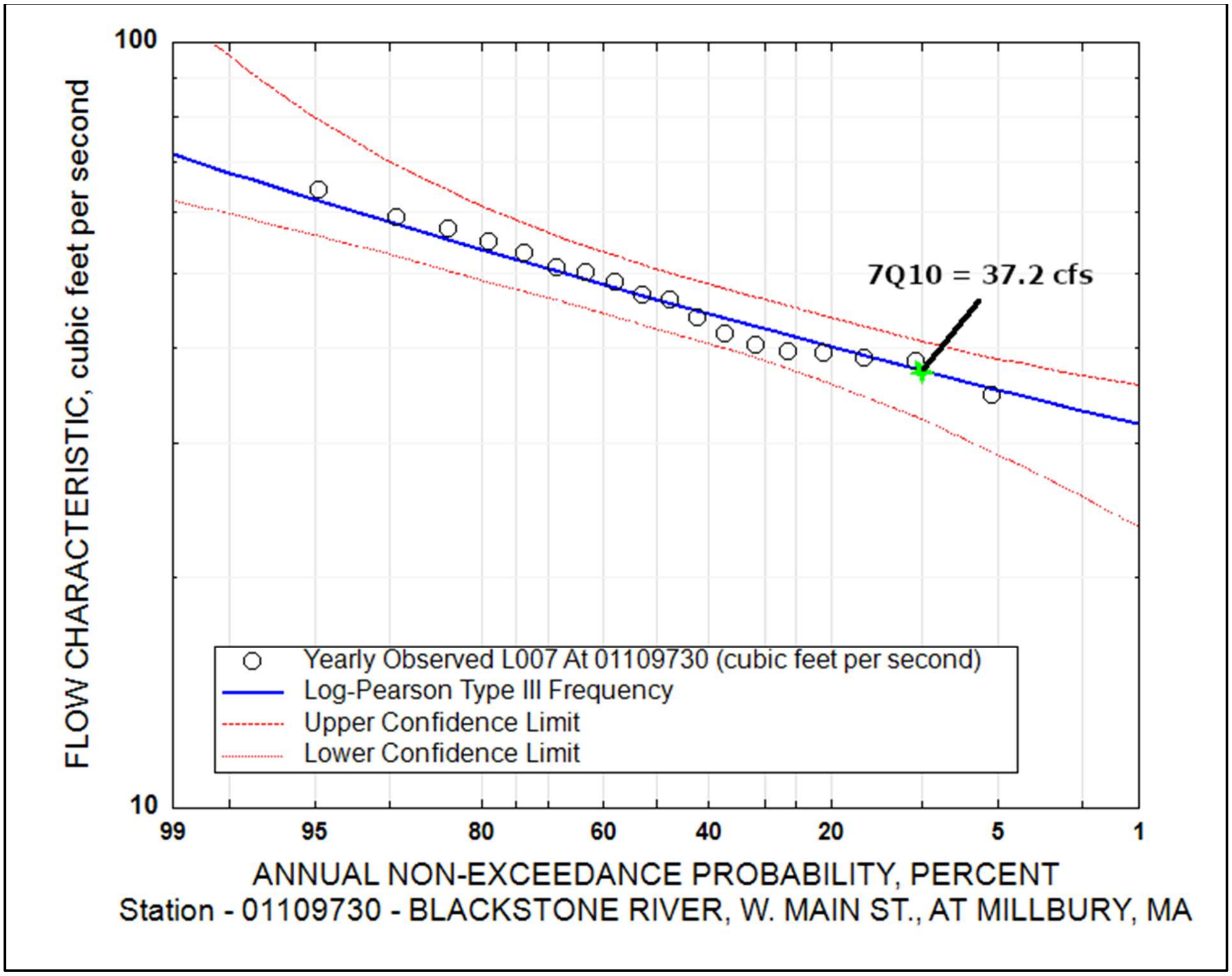

Figure 2: Log-Pearson fit to the Annual 7-day Average Low-Flow Values and the 7Q10 Flow at USGS Gage 01109730 at Millbury

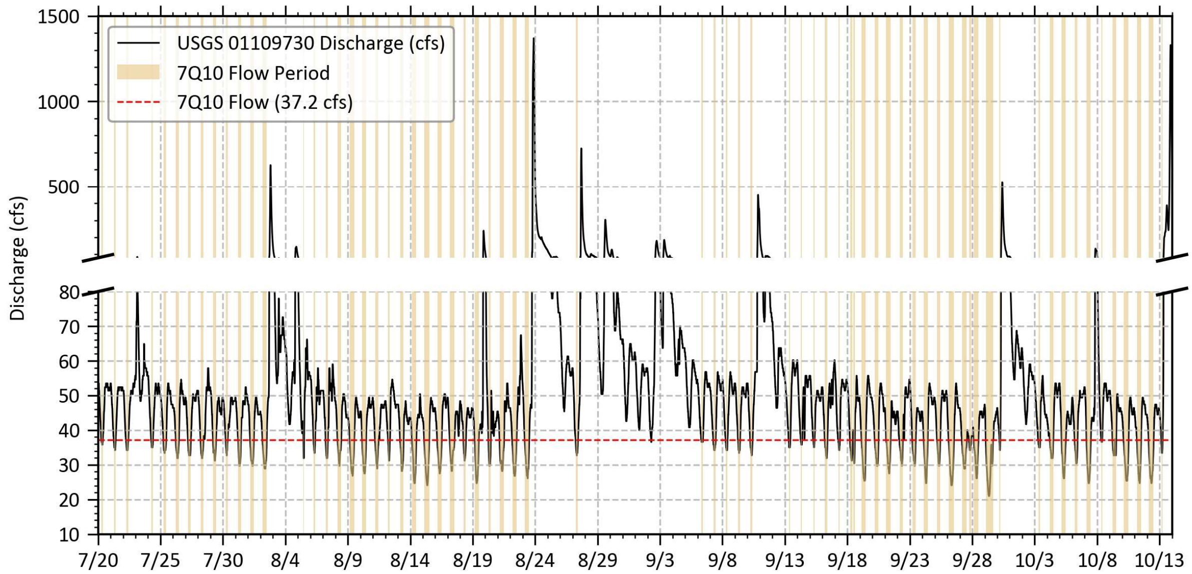

Figure 3: Flow at USGS Gage 01109730 during 2020 Monitoring Season with below 7Q10 Periods Marked in Tan Shading

Table 1: 7Q10 Flow Occurrences during the 2020 Monitoring Season

Start	End	Duration (hours)
7/20/2020 6:45	7/20/2020 9:00	2.25
7/21/2020 6:30	7/21/2020 9:45	3.25
7/22/2020 6:00	7/22/2020 10:00	4
7/24/2020 6:30	7/24/2020 9:30	3
7/25/2020 6:00	7/25/2020 10:45	4.75
7/26/2020 5:45	7/26/2020 11:15	5.5
7/27/2020 5:00	7/27/2020 10:15	5.25
7/28/2020 5:15	7/28/2020 10:15	5
7/29/2020 5:15	7/29/2020 10:30	5.25
7/30/2020 5:30	7/30/2020 9:00	3.5
7/31/2020 5:30	7/31/2020 10:30	5
8/1/2020 4:30	8/1/2020 11:15	6.75
8/2/2020 4:15	8/2/2020 12:00	7.75
8/5/2020 11:00	8/5/2020 11:45	0.75
8/6/2020 6:15	8/6/2020 9:00	2.75
8/7/2020 5:30	8/7/2020 9:30	4
8/8/2020 4:30	8/8/2020 11:15	6.75
8/9/2020 4:00	8/9/2020 12:15	8.25
8/10/2020 3:45	8/10/2020 11:00	7.25
8/11/2020 4:30	8/11/2020 10:45	6.25
8/12/2020 5:30	8/12/2020 8:45	3.25
8/13/2020 4:45	8/13/2020 11:00	6.25
8/14/2020 3:45	8/14/2020 11:30	7.75
8/15/2020 3:00	8/15/2020 12:15	9.25
8/16/2020 4:00	8/16/2020 12:15	8.25
8/17/2020 4:00	8/17/2020 12:45	8.75
8/18/2020 6:30	8/18/2020 10:45	4.25
8/19/2020 4:15	8/19/2020 11:30	7.25
8/20/2020 6:30	8/20/2020 10:30	4
8/21/2020 3:45	8/21/2020 12:00	8.25
8/22/2020 4:15	8/22/2020 12:00	7.75
8/23/2020 4:15	8/23/2020 12:15	8
8/27/2020 6:00	8/27/2020 10:00	4
9/2/2020 7:00	9/2/2020 7:30	0.5
9/6/2020 7:45	9/6/2020 10:15	2.5
9/7/2020 6:30	9/7/2020 10:45	4.25
9/8/2020 6:15	9/8/2020 9:30	3.25
9/9/2020 6:15	9/9/2020 9:45	3.5
9/10/2020 5:30	9/10/2020 9:45	4.25
9/13/2020 7:30	9/13/2020 10:15	2.75

Start	End	Duration (hours)
9/14/2020 6:45	9/14/2020 8:45	2
9/15/2020 7:00	9/15/2020 8:45	1.75
9/16/2020 5:00	9/16/2020 9:30	4.5
9/17/2020 6:45	9/17/2020 9:30	2.75
9/18/2020 5:15	9/18/2020 10:00	4.75
9/18/2020 12:00	9/18/2020 14:15	2.25
9/19/2020 3:30	9/19/2020 11:00	7.5
9/20/2020 5:00	9/20/2020 11:45	6.75
9/21/2020 2:45	9/21/2020 11:00	8.25
9/22/2020 4:15	9/22/2020 10:15	6
9/23/2020 5:00	9/23/2020 11:15	6.25
9/24/2020 3:00	9/24/2020 10:15	7.25
9/25/2020 4:45	9/25/2020 10:15	5.5
9/26/2020 2:45	9/26/2020 12:30	9.75
9/27/2020 4:15	9/27/2020 13:15	9
9/27/2020 18:00	9/27/2020 21:45	3.75
9/28/2020 3:15	9/28/2020 11:45	8.5
9/29/2020 2:15	9/29/2020 15:45	13.5
9/30/2020 4:15	9/30/2020 5:45	1.5
10/3/2020 7:15	10/3/2020 10:15	3
10/4/2020 5:15	10/4/2020 11:30	6.25
10/5/2020 4:00	10/5/2020 11:30	7.5
10/6/2020 5:00	10/6/2020 10:15	5.25
10/7/2020 3:45	10/7/2020 11:30	7.75
10/8/2020 8:30	10/8/2020 9:30	1
10/9/2020 5:45	10/9/2020 12:30	6.75
10/10/2020 3:00	10/10/2020 12:15	9.25
10/11/2020 4:45	10/11/2020 12:15	7.5
10/12/2020 3:15	10/12/2020 12:15	9
10/13/2020 3:30	10/13/2020 5:30	2

3.0 Continuous Meter Data

3.1 Summary of Field Procedures and Raw Data

Meter locations and deployment periods are described in **Table 2**. The meters recorded DO and T every 15 minutes until August 19th, when they were reprogrammed to record readings every 10 minutes. Upper Blackstone staff used a calibrated handheld T/DO probe to collect grab measurements every one-to-two weeks until September; for the remainder of the deployment period, grab measurements were collected approximately monthly. The measurements were collected next to and at the same depth as the continuous meter at each site. The continuous probes were cleaned during field vists between grab DO measurements. However, there were some field vists during which meter anchor wires were replaced or meters were repositioned without taking grab samples and without cleaning. **Figure 4** shows the housing for the probe and the cinder block used to anchor it in the river. The raw DO and temperature data, handheld T/DO measurements, and river flow at the USGS gage in Millbury (USGS 01109730) are presented in **Figure 5**.

The farthest upstream meter (W0680) occasionally was found overturned or out of the water during the 2020 program, likely because of the high-flow conditions, resulting in measurements not representative of river conditions. Therefore, much of those data at W0680 were invalidated (see **Table 2**).

Table 2: Blackstone River Continuous Meter Locations in 2020

Meter	Location	River Mile[1]	Sensor Depth at Time of Deployment (meter [m])	Total Depth at Time of Deployment (m)	Field Notes
W0680	New Millbury St. Bridge, Worcester, MA; Upstream of Upper Blackstone Effluent Channel Deployed July 10th Removed November 5th	45.2	0.15	0.38	–Data download failed 7/31, 8/1, 8/6, 8/12, 8/19, 8/25 –Found out of river 8/25 –Found pushed downstream and overturned 9/2 –Sand and mud found in housing 9/2 –Found upside down but still in flow 9/15 –Found on side but still in flow 10/1 –Found out of water on shore 10/16 –Found overturned 11/5, data record ends
UBWPAD2	Downstream of Upper Blackstone Effluent Channel, Millbury Deployed July 7th Removed November 5th	44.6	0.38	0.58	–Data download failed 7/31, 8/6, 8/12, 8/19, 8/25 –Found pushed downstream and upside-down 8/25
W1258	Central Cemetery, Millbury Deployed July 9th Removed November 9th	42.7	0.53	0.64	–Data download failed 7/31, 8/5, 8/19, 8/25 –Found overturned, but end of probe was submerged 11/9
MID2 (Depot)	Depot Street, Sutton, MA Deployed July 9th Removed November 9th	38.0	0.25	0.45	–Data download failed 7/31, 8/5, 8/11, 8/19 –Found on side but submerged, pointing upstream 9/9 –Slimy brown growth cleaned from housing 10/1

[1]Note: River Mile 0 is located at the Slater Mill Dam in Pawtucket, Rhode Island.

Figure 4: Dissolved Oxygen Meter Housing and Cinder Block Anchor

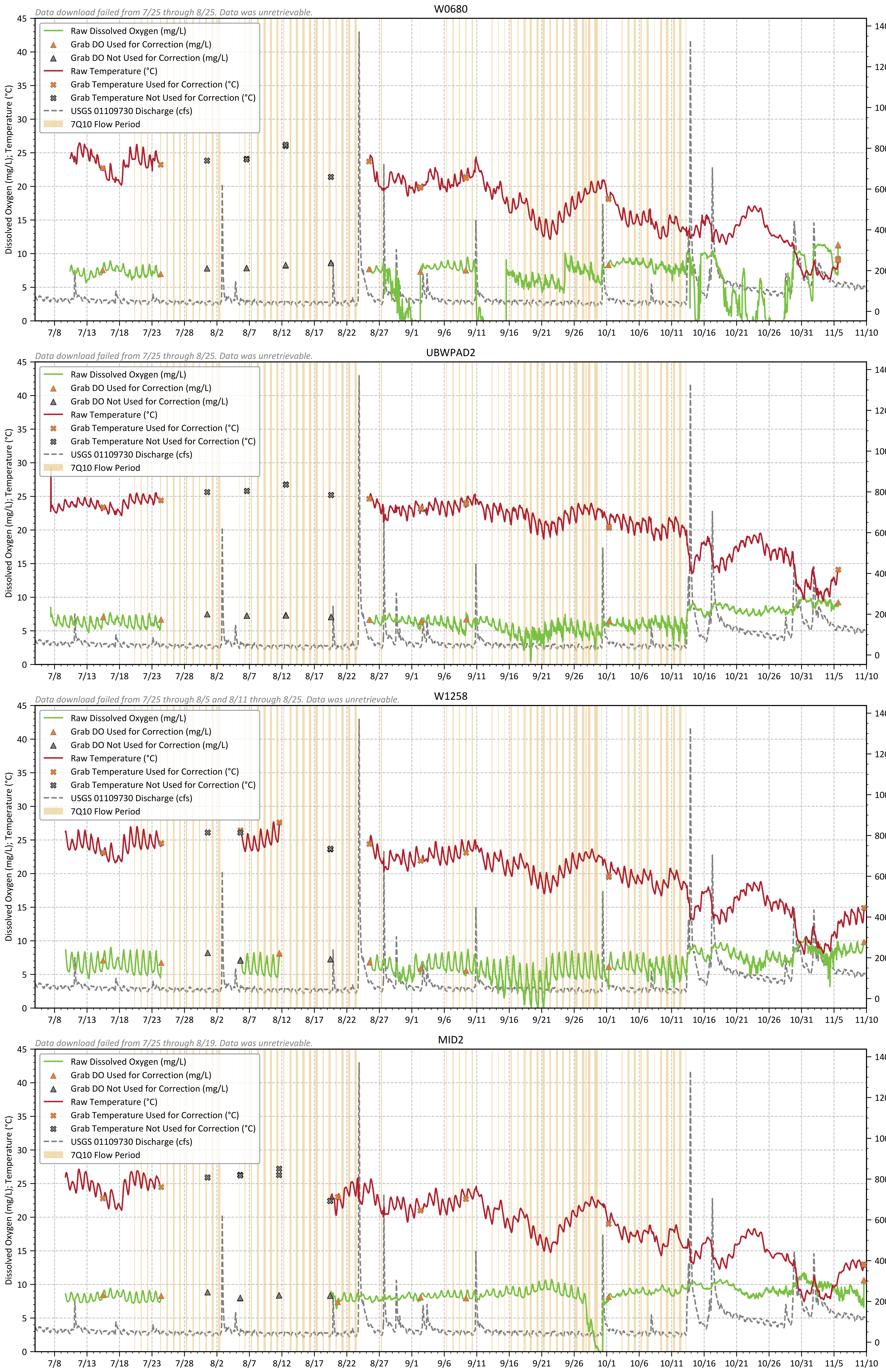

Figure 5: Raw Dissolved Oxygen and Temperature Data (2020 Monitoring)

3.2 Field Notes from Meter Deployment and Data Observations

The Upper Blackstone staff prepared detailed notes on site and meter conditions during deployment in July, throughout the sampling period, and when the meters were removed in November. Important observations are summarized in **Table 2**. Additional details from the notes, and the relevance to data interpretation, are provided below.

W0680 (Sonde ID 20634477)

On July 10, 2020, this meter was placed at a depth of 0.15 m in 0.38 m of water. Over the course of the deployment, the following incidents were noted:

1. On August 25th, the meter was found out of the river. The displacement was assumed to be from turbulent flows resulting from heavy rains on August 23rd. The meter was put back in place before taking handheld readings during the visit. This visit was during the period when the Onset shuttle was malfunctioning, and the data were not recovered.

2. On September 2nd, the probe was found displaced downstream and overturned with the housing packed with sand and mud. The displacement was assumed to be from turbulent flows resulting from heavy rains on August 27th. The data indicate that the meter may have malfunctioned from August 27th until it was repositioned on September 2nd. During this period the DO signal was erratic, often rising and dropping by 2–4 milligrams per liter (mg/L) over the course of 1–2 hours, which is uncharacteristic of this site based on data from previous years and not mirrored by the downstream meters. Consequently, the DO data from the sampling interval of August 25th to September 2nd were determined to be invalid.

3. On September 10th, the measured DO dropped from 8 mg/L to 0 mg/L in 4 hours and remained between 0 mg/L and 2 mg/L until the meter was found overturned and subsequently repositioned on the September 15th field visit, during which no side-by-side measurement was taken. None of the other meters exhibited this drop in DO, suggesting the displacement impacted the meter’s ability to capture representative DO measurements. Therefore, the DO data from the sampling interval of September 9th to September 15th were determined to be invalid. Because no side-by-side measurement was taken on September 15th, DO corrections made after that date were based on the side-by-side measurements taken on September 9th and October 1st.

4. On September 24th, the meter anchor wire and wire crimps were replaced. Since the previous visit on September 15th, the measured DO signal showed a downward trend. Before the wire and crimps were replaced on the 24th at 1:35 p.m., measured DO abruptly increased from 5.61 mg/L to 9.95 mg/L in a 10-minute recording interval. After the visit, the downward trend on DO restarted and continued until the 30th when flow measured in Millbury increased by 150 cfs due to rainfall, and the DO signal jumped from about 5 mg/L to 8 mg/L, remaining stable at those levels thereafter.

   The large jump in DO on the September 24th was not observed at any of the other downstream sites, and its coincidence with a field visit during which no cleaning was performed suggests the change in measured DO was not associated with fowling. However, no side-by-side measurements were made to validate the DO increase, so the validity of DO measurements taken since the last field visit on September 15th could not be determined. Additionally, the same downward trend that was noted from the 15th to the 24th persisted after the field visit until September 30th, when a significant flow in the river stabilized the DO signal. The source of this downward trend is unclear, but the period from September 15th to the 30th is suspicious, because repositioning a meter without cleaning its probe should not significantly change measured DO. Either the meter's position was impacting its ability to measure representative DO or the meter was measuring representative DO, but the presence of the field staff locally impacted DO conditions. Because it cannot be determined which was the case, the DO data between September 15th and September 30th were considered valid, and corrections made during this period were based on the side-by-side measurements taken on September 9th and October 1st.

5. Between October 13th and November 6th, measured DO dropped to zero on three occasions and exhibited an erratic signal with readings often fluctuating up to 8 mg/L over the course of 1–2 hours. Two field visits were conducted during this period, the first on October 16th, when the meter was found out of the water on shore, and the second on November 5th, when the meter was found displaced and overturned. The displacements were assumed to be from turbulent flows resulting from heavy rains on October 13th and 17th, respectively. The data during this period were considered invalid because the downstream meters did not exhibit the same unstable signal, and the meter's multiple displacements likely interfered with its ability to take representative DO measurements.

UBWPAD 2 (Sonde ID 20634480)

On August 25th, the meter was found displaced downstream and overturned. The displacement was assumed to be from turbulent flows resulting from heavy rains on August 23rd. The meter was put back in place before taking handheld readings during the visit. This visit was during the period when the Onset shuttle was malfunctioning and the data prior to August 25th were not recovered.

W1258 (Sonde ID 20634478)

1. On October 1st during a routine field visit to the W1258 site, no abnormal meter conditions were noted, with side-by-side handheld probe and meter readings matching very well, showing DO at a concentration of about 6.1 mg/L before and after the meter probe was cleaned. However, 10 minutes before the first side-by-side measurement, the in-situ meter measured DO of approximately 2.8 mg/L. This is similar to the September 24th field visit at W0680, during which DO measured about 4.3 mg/L in the 10-minute recording interval preceding a side-by-side measurement. Because it immediately preceded the first side-by-side measurement, the abrupt increase in DO likely was not from the meter being repositioned for the side-by-side measurement. However, it cannot be determined whether the W1258 meter's initial position impacted its ability to measure representative DO or whether the meter measured representative DO, but the activity of the field staff locally impacted DO conditions. Consequently, these data were considered valid and were corrected based on the side-by-side measurements taken on September 9th and October 1st.

2. On November 9th, the meter was found overturned, but the end of the probe was submerged. The measured DO preceding that field visit generally shows similar levels and trends to those measured at upstream and downstream meters, suggesting the meter's displacement did not appear to impact its ability to take representative readings because the final side-by-side comparison on November 9th was comparable. Notably, DO briefly dipped below 5 mg/L twice on November 4th for 10 minutes at 2:30 a.m. and for 50 minutes at 8:20 a.m. These sags did not occur at the other meters; thus, they appear to be due to an unknown local meter-specific event.

MID2 (Depot) (Sonde ID 20634479)

1. On September 27th, the DO signal declined over two days, from about 9 mg/L to 0 mg/L. The signal remained at 0 mg/L for about 21 hours until it increased to 8 mg/L over 3 hours on September 30th, immediately following a relatively high-flow event in the river; the upstream meters did not show a similar signal pattern. Grab measurements taken during field visits 20 days before (September 9th) and 1 day after (October 1st) the low DO event indicate the meter had excellent and good accuracies, respectively (see **Section 4.2** below). Additionally, no significant displacement was noted on the October 1st field visit, but field notes indicate a slimy brown growth accumulated on the probe housing, which was cleaned off. Because no significant abnormalities were noted in the field visit on October 1st, the data were not considered invalid, but suspicious. As discussed in Section 2.0 describing 2020 river flow, there were several extended occurrences of river flow below 7Q10 starting on September 26th. While it is unknown if this impacted the recorded DO levels, it does indicate that the 2021 field program should consider placement of the meters carefully, so they are in an actively flowing part of the river under low-flow conditions.

2. Side-by-side measurements taken with the calibrated field meter and the in-situ meter on November 9th differed by 2.47 mg/L, exceeding the maximum allowable limit for data correction; a field measurement taken at 2:10 p.m. measured 10.6 mg/L while the continuous meter measured 8.13 mg/L at the same time. During the two-point data correction procedure applied between grab measurement readings on October 1st and November 9th, corrective adjustments exceeded the USGS maximum allowable limit from October 27th at 4:20 p.m. through November 9th at 2:10 p.m.

4.0 Data Correction

Following the guidance in the 2020–2022 Quality Assurance Project Plan (QAPP) (Massachusetts Water Resources Research Center 2020), the procedures described in the USGS guidance document *Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting* (Wagner et al. 2006) were used to assess continuous T and DO data. In addition, the USGS procedures were used to correct the DO data for total drift, which combines fouling and sensor drift.

4.1 Procedure

The procedure used to correct the DO data collected in this study was performed in two steps:

- Deployment periods when the meter was malfunctioning physically were removed from the record; these are described in the preceding section.
- The USGS procedures were used to evaluate the remaining data for validity.

As presented in **Table 2** and discussed in the previous section, the meter at location W0680 was moved by high flows during several periods. During these periods, the meter reported spurious data that are not related to drift; in situ DO measurements taken during these periods of malfunction could not be used to correct the continuous data**.** These failure periods were flagged as invalid and removed from the DO data sets. The temperature data appear to be less affected during these periods (as the temperature records trended similarly across the stations) and were only flagged as invalid when the meter was found out of the water during a field visit.

The remaining valid data were corrected for drift when the deviation between the continuous monitoring data and the calibration points differed by +/- 0.3 mg/L or 5% (whichever was greater). Correction was done using a two-point linear algorithm, assuming that the rate of drift is constant between calibration sample points. The percentage error at each calibration point was calculated as follows:

$$\%C_d = 100\left(\frac{V_s - V_c}{V_c}\right)$$

where V_s is the value of the DO calibration measurement using the handheld probe, and V_c is the continuous meter reading at the same time. The percentage error was linearly interpolated between the two sampling points. **Figure 6** shows the dates when the field team conducted calibration measurements ("Grab Sample Visit") and the interpolated percent error between handheld and continuous meter DO measurements at MID2 to demonstrate how the correction was calculated. The data from the data loggers were adjusted ("corrected") such that the adjusted data set matches the calibration points.

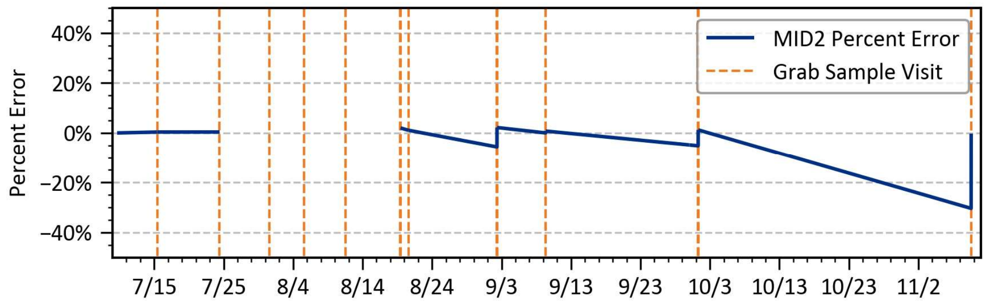

Figure 6: Percent Error at MID2 between the In Situ Meter and the Handheld Field Meter

Data accuracy was assessed using the classifications listed in **Table 3**. For DO, a classification is assigned based on the larger of the concentration or percentage differences (on an absolute value basis) comparing the raw and corrected data.

Table 3: Continuous Meter Accuracy Classifications for Dissolved Oxygen and Temperature[1]

Data Type	Measurement Type	Excellent	Good	Fair	Poor	Maximum Allowable Limits for Correction
DO	Conc. or % Diff.	≤ ±0.3 mg/L or ≤ ±5%	±0.3–0.5 mg/L or ±5–10 %	±0.5–0.8 mg/L or ±10–15%	±0.8–2 mg/L or ±15–20%	±2 mg/L or ±20%
Temperature	Degrees	≤ ±0.2°C	±0.2–0.5°C	±0.5–0.8°C	±0.8–2.0°C	>2.0°C

[1] Modified from Table 18 in Wagner et al. (2006).

For this assessment, drift was assumed to occur linearly between calibration points, which means that the accuracy assessment could be evaluated independently for each 15-minute or 10-minute reading throughout the period of record.

4.2 Data Accuracy Classification

Upper Blackstone calibrated each of the four meters prior to deployment and assessed calibration drift and fouling periodically. If the periodic grab measurements indicated that recalibration was necessary, the instrument would have been retrieved from the field and recalibrated in the Upper Blackstone lab. However, over the course of the metering period, all four meters maintained their calibration.

Between deployment and the July 31st field visit, calibration assessments consisted of (1) using the field instrument to collect side-by-side readings with the continuous meter, (2) removing the meter from the river and cleaning its probe, (3) collecting a bucket of water from the sampling site, (4) taking simultaneous readings from both the meter and a handheld probe in the bucket, and (5) replacing the in situ meter.

Beginning with the August 5th field visits, the field calibration assessments consisted of (1) using the field instrument to collect side-by-side readings with the continuous meter, (2) removing the meter from the river and cleaning its probe, and (3) replacing the continuous meter and taking a second side-by-side reading with the handheld field instrument. The QAPP was amended and approved by MassDEP to account for this change in field procedure.

Significantly different measurements from the meter and handheld instrument after cleaning indicate sensor drift, and the meter must then be recalibrated in the Upper Blackstone lab.

For each continuous meter, **Table 4** compares the synchronous field handheld and continuous meter DO readings taken in the river during field visits and provides the corresponding USGS accuracy classification.

If the difference exceeds 0.3 mg/L or 5% (the maximum allowable difference for a rating of excellent), then some sensor drift has occurred (based on USGS guidelines). The data in **Table 4** indicate that some DO sensor drift occurred at least once for each meter (indicated in blue bold text), but only the meters at UBWPAD2 and MID2 showed significant fouling (indicated by accuracy ratings of "poor" and "exceeds correction limits"), which were addressed by cleaning the probe tips. W0680 did have one "exceeds correction limits" rating on September 2nd, but that rating is associated with invalid data from meter displacement rather than sensor drift or fouling.

Table 4: Comparison of Dissolved Oxygen Field Data with Continuous Dissolved Oxygen Data

Site	Grab Reading Date	Continuous DO Meter Reading (mg/L)	Field Handheld DO Reading (mg/L)	Difference in DO Readings (mg/L)	Percent Difference in DO Readings (%)	USGS Accuracy Rating
W0680	7/15/20 9:45	7.39	7.56	0.17	-2.30	Excellent
	7/24/20 8:15	6.86	6.99	0.13	-1.90	Excellent
	8/25/20 10:03	7.68	7.69	0.01	-0.13	Excellent
	9/2/20 7:23	**0**	**7.33**	**7.34**	**> 20**	**Exceeds Correction Limits**
	9/2/20 7:43	7.54	7.36	-0.18	2.39	Excellent
	9/9/20 7:23	7.61	7.51	-0.1	1.31	Excellent
	9/9/20 7:33	7.64	7.55	-0.09	1.18	Excellent
	10/1/20 6:33	8.39	8.31	-0.08	0.95	Excellent
	10/1/20 6:43	8.49	8.34	-0.15	1.77	Excellent
	11/5/20 14:53	**10.75**	**11.23**	**0.48**	**-4.47**	**Good**
	11/5/20 15:03	11.43	11.34	-0.09	0.79	Excellent
UBWPAD2	7/15/20 11:30	6.99	7.04	0.05	-0.72	Excellent
	7/24/20 9:15	6.49	6.68	0.19	-2.93	Excellent
	8/25/20 10:44	6.65	6.65	0	0.00	Excellent
	9/2/20 9:24	6.18	6.35	0.17	-2.75	Excellent
	9/2/20 9:34	6.54	6.37	-0.17	2.60	Excellent
	9/9/20 9:04	**7.7**	**6.72**	**-0.98**	**12.73**	**Poor**
	9/9/20 9:14	6.81	6.69	-0.12	1.76	Excellent

Site	Grab Reading Date	Continuous DO Meter Reading (mg/L)	Field Handheld DO Reading (mg/L)	Difference in DO Readings (mg/L)	Percent Difference in DO Readings (%)	USGS Accuracy Rating
	10/1/20 8:14	6.23	6.44	0.21	-3.37	Excellent
	10/1/20 8:24	6.51	6.43	-0.08	1.23	Excellent
	11/5/20 15:34	9.35	9.25	-0.1	1.07	Excellent
	11/5/20 15:44	9.42	9.25	-0.17	1.80	Excellent
W1258	7/15/20 11:00	6.99	7.09	0.1	-1.43	Excellent
	7/24/20 10:30	**6.2**	**6.74**	**0.54**	**-8.71**	**Fair**
	8/5/20 15:15	7.33	7.23	-0.1	1.36	Excellent
	8/11/20 14:30	**7.76**	**8.1**	**0.34**	**-4.38**	**Good**
	8/11/20 14:45	8.2	8.2	0	0.00	Excellent
	8/25/20 11:20	6.65	6.78	0.13	-1.95	Excellent
	9/2/20 8:50	5.91	5.89	-0.02	0.34	Excellent
	9/2/20 9:00	5.94	5.92	-0.02	0.34	Excellent
	9/9/20 8:30	5.57	5.6	0.03	-0.54	Excellent
	9/9/20 8:40	5.63	5.56	-0.07	1.24	Excellent
	10/1/20 7:40	6.46	6.16	-0.3	4.64	Excellent
	10/1/20 7:50	6.1	6.12	0.02	-0.33	Excellent
	11/9/20 14:40	9.6	9.81	0.21	-2.19	Excellent
	11/9/20 14:50	9.71	9.83	0.12	-1.24	Excellent
MID2	7/15/20 10:30	8.46	8.43	-0.03	0.35	Excellent
	7/24/20 10:00	8.32	8.29	-0.03	0.36	Excellent
	8/19/20 11:00	8.55	8.38	-0.17	1.99	Excellent
	8/20/20 14:30	7.49	7.41	-0.08	1.07	Excellent
	9/2/20 8:10	**7.66**	**8.09**	**0.43**	**-5.61**	**Good**
	9/2/20 8:20	8.28	8.1	-0.18	2.17	Excellent
	9/9/20 8:00	7.95	7.95	0	0.00	Excellent
	9/9/20 8:10	8.04	7.98	-0.06	0.75	Excellent
	10/1/20 7:10	**7.76**	**8.16**	**0.4**	**-5.15**	**Good**
	10/1/20 7:20	8.25	8.15	-0.1	1.21	Excellent
	11/9/20 14:10	**8.13**	**10.6**	**2.47**	**< -20**	**Exceeds Correction Limits**
	11/9/20 14:20	10.63	10.66	0.03	-0.28	Excellent

Note: Measurements in blue bold text indicate that sensor drift/fouling occurred.

For each continuous meter, **Table 5** compares the synchronous continuous meter temperature and handheld readings taken in the river during field visits and provides the corresponding USGS accuracy classification. Based on these guidelines, if handheld instrument and continuous meter temperature readings differ by more than 0.2°C (the maximum allowable difference for a rating of excellent), some sensor drift has occurred. The data in **Table 5** show that each meter exhibited some minor drift at one point during the sampling program, but only the W1258 meter received a rating below "good" on August 5th.

Table 5: Comparison of Temperature Grab Data with Continuous Temperature Data

Site	Grab Reading Date	Continuous Temperature Meter Reading (°C)	Field Handheld Temperature Reading (°C)	Difference in Temperature Readings (°C)	Percent Difference in Temperature Readings (%)	USGS Accuracy Rating
W0680	**7/15/20 9:45**	**22.4**	**22.7**	**0.3**	**1.26**	**Good**
	7/24/20 8:15	23.2	23.2	0.1	0.26	Excellent
	8/25/20 10:03	23.8	23.7	-0.1	-0.51	Excellent
	9/2/20 7:23	**19.6**	**19.9**	**0.3**	**1.73**	**Good**
	9/2/20 7:43	19.7	19.8	0.1	0.51	Excellent
	9/9/20 7:23	21.2	21.4	0.2	0.76	Excellent
	9/9/20 7:33	21.3	21.2	-0.1	-0.26	Excellent
	10/1/20 6:33	18.1	18.2	0.2	0.92	Excellent
	10/1/20 6:43	18.1	18.1	0.0	0.22	Excellent
	11/5/20 14:53	**8.7**	**9.2**	**0.5**	**5.66**	**Good**
	11/5/20 15:03	9.2	9.0	-0.2	-1.94	Excellent
UBWPAD 2	7/15/20 11:30	23.3	23.4	0.1	0.29	Excellent
	7/24/20 9:15	24.3	24.4	0.1	0.32	Excellent
	8/25/20 10:44	**24.8**	**24.6**	**-0.2**	**-0.84**	**Good**
	9/2/20 9:24	22.9	23.1	0.2	0.78	Excellent
	9/2/20 9:34	23.0	23.2	0.2	0.77	Excellent
	9/9/20 9:04	23.8	23.9	0.1	0.37	Excellent
	9/9/20 9:14	23.8	24.0	0.2	0.68	Excellent
	10/1/20 8:14	20.1	20.3	0.2	0.80	Excellent
	10/1/20 8:24	**20.3**	**20.5**	**0.2**	**1.10**	**Good**
	11/5/20 15:34	14.0	14.1	0.1	0.99	Excellent
	11/5/20 15:44	14.2	14.1	-0.1	-0.43	Excellent
W1258	7/15/20 11:00	23.0	23.1	0.1	0.58	Excellent
	7/24/20 10:30	24.4	24.5	0.1	0.57	Excellent
	8/5/20 15:15	**25.9**	**26.4**	**0.5**	**2.13**	**Fair**
	8/11/20 14:30	**27.2**	**27.6**	**0.4**	**1.33**	**Good**
	8/11/20 14:45	**27.4**	**27.6**	**0.2**	**0.81**	**Good**
	8/25/20 11:20	24.6	24.4	-0.2	-0.72	Excellent

Site	Grab Reading Date	Continuous Temperature Meter Reading (°C)	Field Handheld Temperature Reading (°C)	Difference in Temperature Readings (°C)	Percent Difference in Temperature Readings (%)	USGS Accuracy Rating
	9/2/20 8:50	21.8	21.9	0.1	0.46	Excellent
	9/2/20 9:00	21.8	21.9	0.1	0.36	Excellent
	9/9/20 8:30	23.0	23.1	0.1	0.53	Excellent
	9/9/20 8:40	23.0	23.1	0.1	0.43	Excellent
	10/1/20 7:40	19.5	19.5	-0.1	-0.34	Excellent
	10/1/20 7:50	19.5	19.6	0.1	0.31	Excellent
	11/9/20 14:40	**14.6**	**14.9**	**0.3**	**1.78**	**Good**
	11/9/20 14:50	14.9	14.9	0.0	-0.15	Excellent
MID2	7/15/20 10:30	22.7	22.8	0.1	0.24	Excellent
	7/24/20 10:00	24.4	24.5	0.1	0.30	Excellent
	8/19/20 11:00	**22.8**	**22.5**	**-0.4**	**-1.61**	**Good**
	8/20/20 14:30	22.9	23.0	0.1	0.61	Excellent
	9/2/20 8:10	21.0	21.0	0.0	0.08	Excellent
	9/2/20 8:20	21.0	21.0	0.0	0.19	Excellent
	9/9/20 8:00	22.7	22.7	0.0	0.17	Excellent
	9/9/20 8:10	22.7	22.7	0.0	-0.17	Excellent
	10/1/20 7:10	19.0	19.0	0.0	0.12	Excellent
	10/1/20 7:20	19.0	19.0	0.0	-0.20	Excellent
	11/9/20 14:10	**12.7**	**13.0**	**0.3**	**2.18**	**Good**
	11/9/20 14:20	**13.3**	**12.9**	**-0.4**	**-3.29**	**Good**

Note: Measurements in bolded blue indicate that some sensor drift/fouling occurred.

4.3 Final Corrected Data

Figure 7 shows the raw DO concentration values (green), the corrected DO concentration values (blue), the side-by-side calibration sample points (x markers), the river flow (black), and the periods when river flow was below 7Q10 (tan bars) for each of the four sampling locations. The corrected DO data also are shown in **Figure 8** without the raw data and calibration sample points.

Figure 9 shows the raw temperature values (red), the corrected temperature values (blue), the side-by-side calibration sample points (x markers), and the river flow (black) for each of the four sampling locations. For each continuous meter, the corrected temperature data are also shown in **Figure 10** without the raw data and calibration sample points.

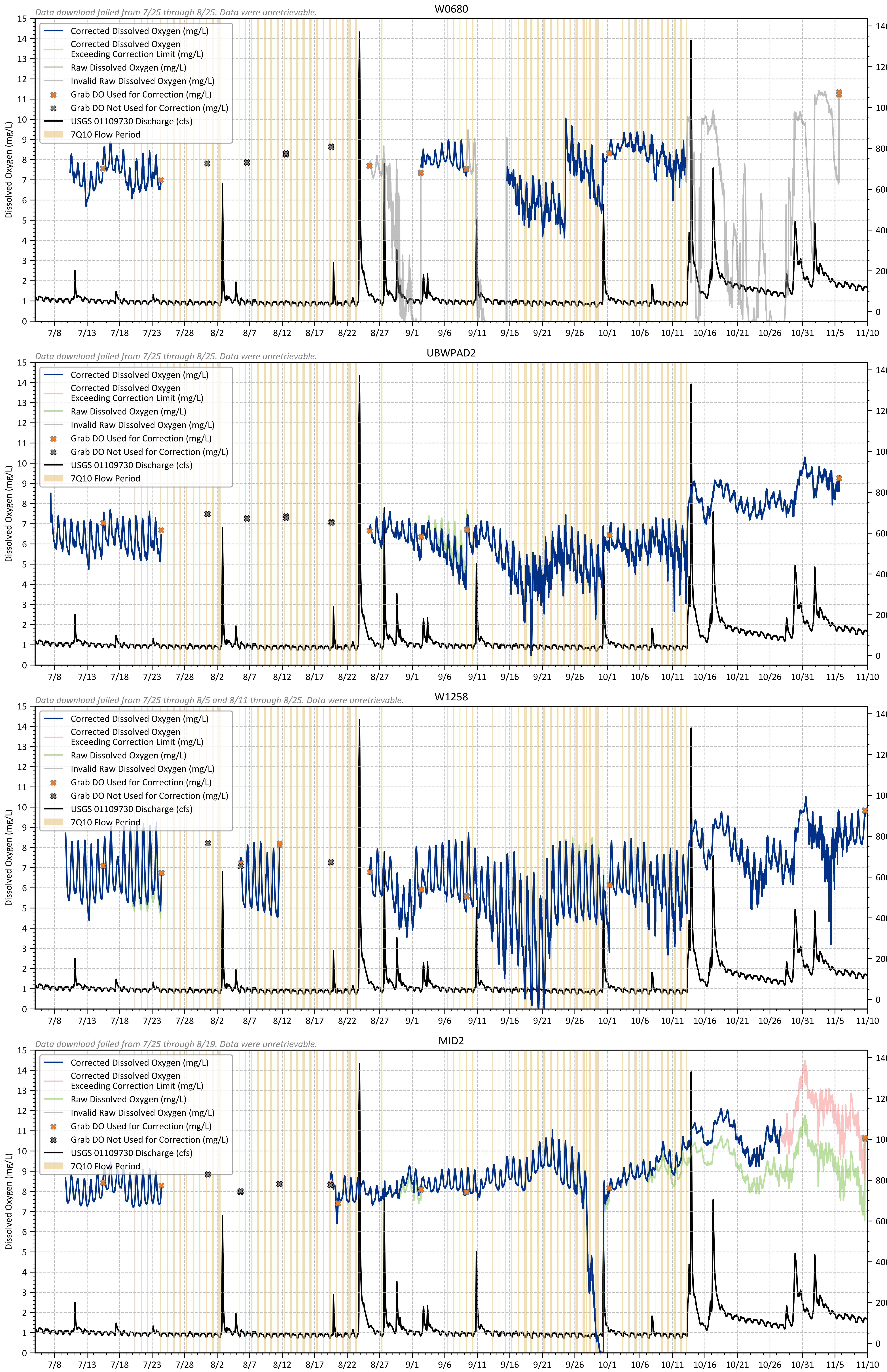

Figure 7: Raw, Invalid, Suspect, and Corrected Dissolved Oxygen Data (2020 Monitoring)

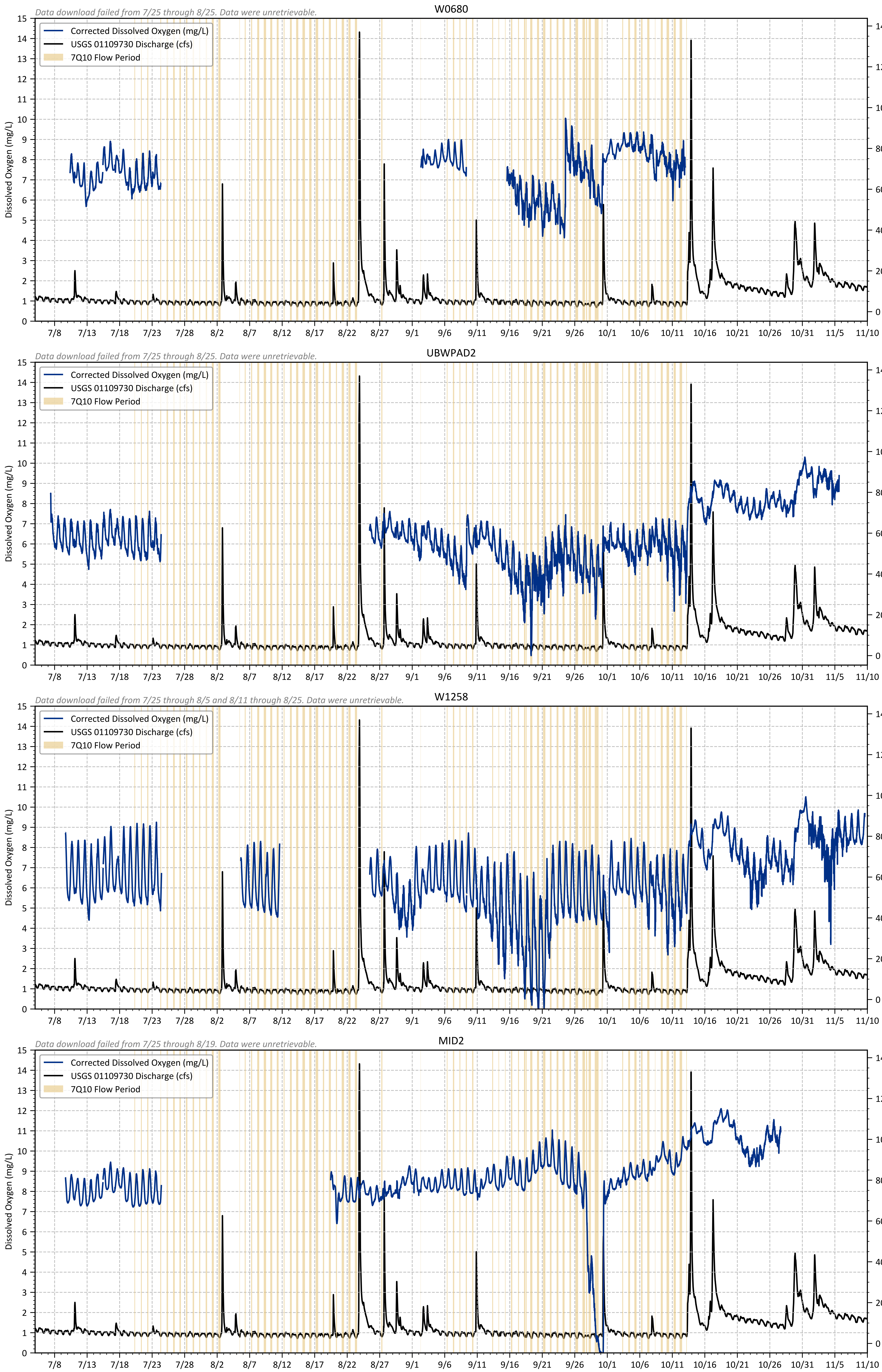

Figure 8: Corrected Dissolved Oxygen Data (2020 Monitoring)

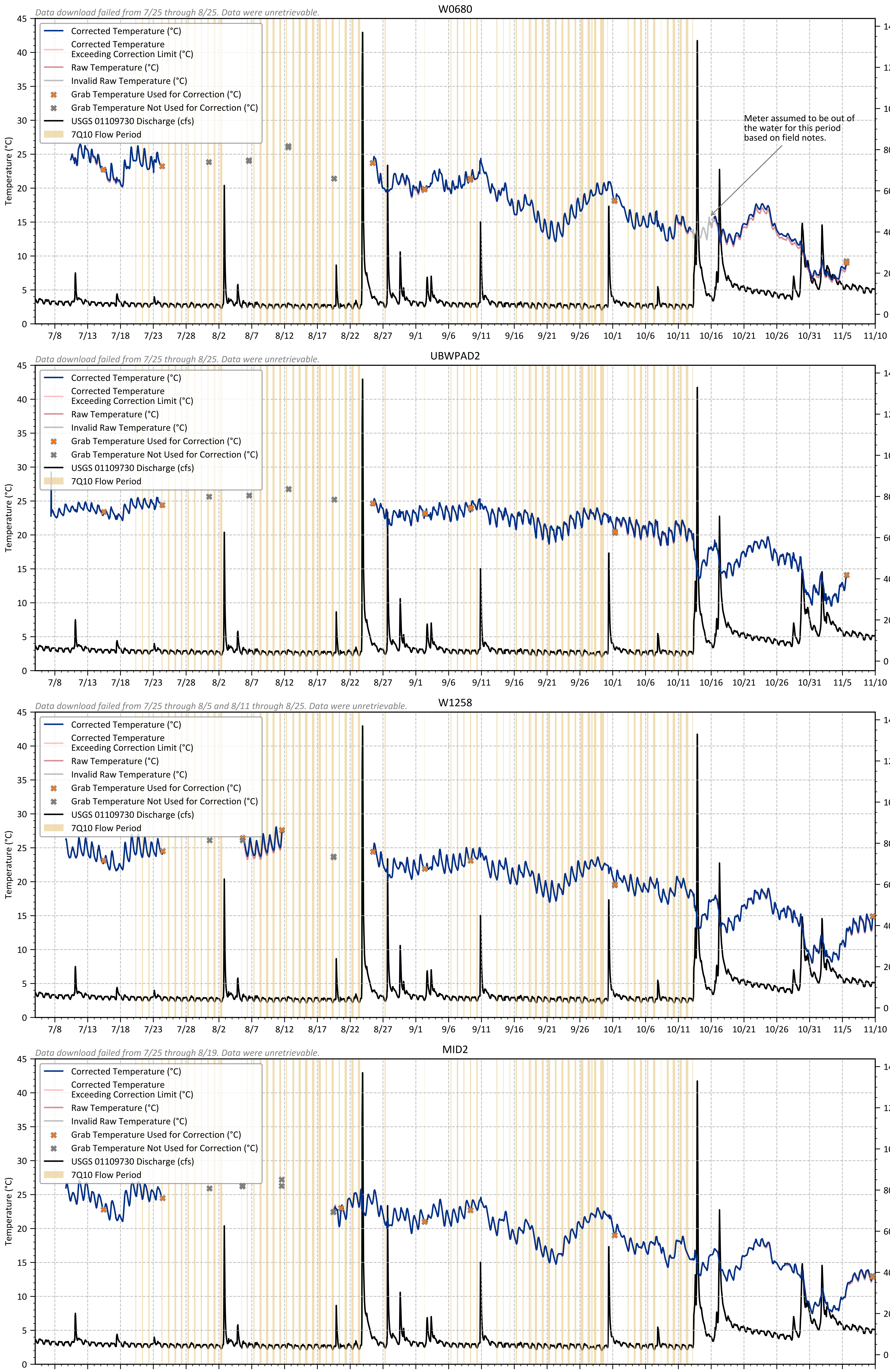

Figure 9: Raw, Invalid, and Corrected Temperature Data (2020 Monitoring)

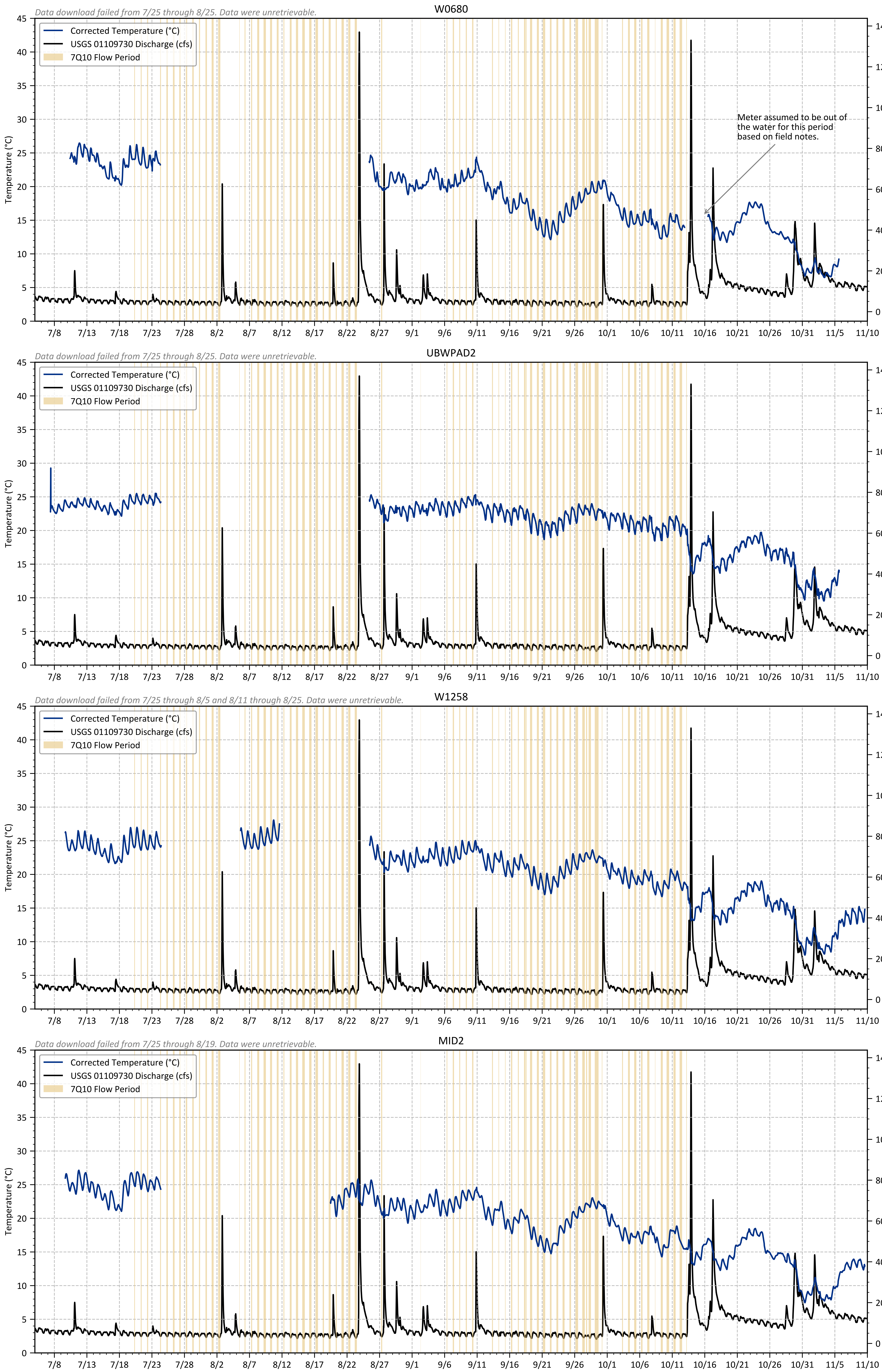

Figure 10: Corrected Temperature Data (2020 Monitoring)

5.0 Discussion – Data Analysis and Interpretation

The adjusted DO/T data values were compared to Massachusetts Surface Water Quality Criteria and guidance for DO. T data were used to calculate DO percent saturation. River flow conditions, which during the period of continuous meter deployment were very low, play a role in how the surface water quality criteria are applied and interpreted.

The corrected DO data were compared to the Massachusetts Surface Water Quality Standards for Class B freshwater as well as the guidance described in the 2018 CALM (MassDEP 2018), as follows:

- Minimum DO concentration greater than 5 mg/L (MA Class B Standard) when river flow is above the critical flow (7Q10)
- Maximum diel DO change less than 3 mg/L (CALM guidance value for the Aquatic Life Use)
- Maximum DO saturation of less than 125 percent (CALM guidance value for the Aquatic Life Use)

The percentage of time or number of days the data were above the water quality criteria is provided in **Table 6**. The table also lists the percentage of time DO was above 5 mg/L when the river flow was above 7Q10 flow, because 7Q10 flow is defined as the critical flow in the Massachusetts surface water quality standards. Data collected during the period when river flow was below this critical value are not considered to be violations of the water quality criteria. The percentages listed in **Table 6** were calculated using only the accepted data as the actual number of hours above 5 mg/L compared to the total number of hours. The days in which the diel change in DO was 3 mg/L was calculated as the number of days when the difference between the minimum and maximum measurement on that day exceeded 3 mg/L. The days when the diel change in DO concentration was within the 3-mg/L criterion were not modified due to the occurrence of 7Q10 flow, because there were no 24-hour periods (the period over which diel changes are evaluated) when the flow was below 7Q10.

Table 6: Summary of Continuous Corrected Dissolved Oxygen Data Against Massachusetts Surface Water Quality Standards and Guidance

Metric	W0680	UBWPAD2	W1258	MID2 (Depot)
Days of corrected data	48	89	97	84
Days where diel ΔDO < 3.0 mg/L	47	77	44	81
% of days where Diel ΔDO < 3.0 mg/L	98	87	53	98
% of the time DO > 5.0 mg/L	97[1]	87	84[2]	97[3]
% of the time DO > 5 mg/L and river flow is above 7Q10 flow	99[1]	92	90[2]	98[3]
Days where % Saturation > 125%	0	0	0	0

[1] Includes suspect period between 9/15/2020 and 10/1/2020 discussed in the text in Section 3.2

[2] Includes suspect period between 9/30/2020 and 10/1/2020 discussed in the text in Section 3.2

[3] Includes suspect period between 9/27/2020 and 9/30/2020 discussed in the text in Section 3.2

Data from each of the meters show that compliance with the Massachusetts minimum DO standard of 5 mg/L ranged from 92% to 99% when the river was above 7Q10 flow. The data from meters at UBWPAD2 and W1258 accounted for most of the corrected DO measurements below the 5-mg/L standard. The DO percent saturation data always met the 125 percent guidance value.

Readings at W0680 dropped below 5 mg/L 10 times, all between September 17th and 24th. The majority of the events were less than 2 hours, occurring at late night or early morning hours when the diel variation was at its lowest concentration.

Readings at UBWPAD2 dropped below 5 mg/L 91 times during the monitoring period: three times in July, 76 times in September, and 12 times in October. Most of these events were less than 2 hours in length and associated with the overnight portion of the diel variation during the autumn months. The longest continuous duration of sub-5 mg/L conditions at UBWPAD2, while the river was flowing higher than 7Q10, occurred for 14.2 hours starting on September 16th. This event was consistent with a low DO event also observed at the downstream meter W1258.

Readings at W1258 dropped below 5 mg/L 92 times: once in July, 17 times in August, 60 times in September, and 14 times from October through the end of the monitoring period. As with UBWPAD2, most of these events were associated with the overnight portion of the strong diel signal observed at this site (3–6 mg/L), 64 of them lasting less than 2 hours. The longest continuous duration of sub-5 mg/L at W1258, while the river was flowing higher than 7Q10, occurred for 14.8 hours starting on August 30th.

Table 7: Summary of Continuous Dissolved Oxygen Data Against Massachusetts Water Quality Standards and Guidance

Event Duration	Number of Sub-5 mg/L Events While Above 7Q10 Flow			
	W0680	UBWPAD2	W1258	MID2
<1 hour	5*	69	51	-
1–2 hours	2*	6	13	-
2–3 hours	2*	1	6	-
3–4 hours	1*	1	2	2***
4–5 hours	-	2	1	-
5–6 hours	-	-	5	-
6–7 hours	-	2	-	-
7–8 hours	-	1	2	-
8–9 hours	-	-	5	-
9–10 hours	-	2	5	-
10–11 hours	-	3	-	-
11–12 hours	-	1	-	-
12–13 hours	-	-	1**	1***
13–14 hours	-	2	-	-
14–15 hours	-	1	1	1***

* From the period of suspect data between 9/15/2020 and 10/1/2020 discussed in the text in Section 3.2
** From the period of suspect data between 9/30/2020 and 10/1/2020 discussed in the text in Section 3.2
*** From the period of suspect data between 9/27/2020 and 9/30/2020 discussed in the text in Section 3.2

Overall, a consistent pattern in DO was observed in the stretch of the Blackstone River that was monitored in 2020. DO levels above the Upper Blackstone-treated effluent discharge (at site W0680) were generally high with small diel variations. For about a week in mid-September, the overnight low reading dropped below 5 mg/L but not below 4 mg/L. With the exception of this week, DO at W0680 indicated that the river supports the Aquatic Life Use based on guidance in MassDEP's 2018 CALM. At the middle two stations in the program, UBWPAD2 and W1258, the Aquatic Life Use was not supported consistently because of the occasional drops in DO below 5 mg/L and DO diel variations that exceeded 3 mg/L frequently at UBWPAD2 and W1258. At the most downstream station (Depot/MID2), the Aquatic Life Use is again supported, based on DO data. More detailed observations by station follow:

- Oxygen levels at W0680, upstream of the Upper Blackstone discharge, indicated no DO impairment—DO levels stayed above 6 mg/L except during a one-week period between September 15th and September 24th. Diel variation in DO concentrations was typically between 1 mg/L and 1.5 mg/L. Trends relative to rainfall events were harder to discern because of the meter malfunctions and displacement that occurred after large runoff events.
- At UBWPAD2, just downstream from where the Upper Blackstone discharge enters the river, the river met DO criteria/guidance until early September with DO concentrations above 5 mg/L and diel swings typically up to about 2 mg/L. Precipitation during the months of May, June, July, and September were all well below average, leading to low-flow conditions throughout the summer, subject to transient increases after rainstorms largely in late August. During this dry period, there were several days with DO diels exceeding 3 mg/L, and 16 dates when the lowest DO of the day was less than 4 mg/L.
- At all four meters, there was a discernable pattern of DO diels decreasing immediately following an event and then re-establishing a dry weather pattern within about a week. This suggests that scour of periphyton after a runoff event periodically reduces the role algae play in DO dynamics in the river.
- Downstream at W1258, DO diel variation was larger than at UBWPAD2 (typically 3 mg/L to more than 4 mg/L). During the lowest DO conditions of the monitoring period (September 18th through September 21st), diel variation peaked at 6 to 6.5 mg/L. After that time, diel variations returned to the 3–4-mg/L range, which is typical for this site during late summer–early fall until large river flows on October 13th, after which variation remained between 1 mg/L and 3 mg/L.
- The farthest downstream meter (MID2) contrasted with the preceding stations by having uniformly good to excellent DO levels and minimal DO diel variations. DO levels indicated the Aquatic Life Use was not impaired at this station.

6.0 Summary

Upper Blackstone and the Water Resources Research Center at the University of Massachusetts collaborated to deploy and manage four Onset HOBO U26-001 continuous meters with a temperature (T) and dissolved oxygen (DO) probe on the Blackstone River during July through November 2020. CDM Smith reviewed the data from the 2020 continuous metering program, corrected the T and DO data based on periodic in situ measurements taken with a handheld probe at each site using USGS guidance (Wagner et al., 2006), and compared adjusted data values to Massachusetts Surface Water Quality Standards and guidance for dissolved oxygen.

Precipitation during the months of May, June, July, and September was well below average, leading to low river flow conditions throughout the summer, which were close to or below the calculated 7Q10 value (37.2 cfs). The occurrence of these low-flow conditions affected the comparison of DO values to Massachusetts Water Quality Standards and guidelines, which apply to river flow conditions when river flow is greater than the 7Q10 flow.

Data from each of the meters showed that compliance with the Massachusetts minimum DO standard of 5 mg/L ranged from 92% to 99% during periods when standards apply (river flow greater than 7Q10 value).

DO at station W0680 was at levels that support Aquatic Life Use based on guidance in MassDEP's 2018 CALM. At the middle two stations, UBWPAD2 and W1258, DO was not consistently at levels that support Aquatic Life Use because of the DO diel variations that exceeded 3 mg/L frequently. DO at the most downstream station (Depot/MID2), was at levels that support Aquatic Life Use.

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Appendix D: Blackstone River Water Quality Monitoring program Field 2020 Sampling Plan

BLACKSTONE RIVER WATER QUALITY MONITORING PROGRAM FIELD 2021 SAMPLING PLAN

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April 16, 2021

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Note that all forms, SOPs, and instructions can be found in the Blackstone River Assessment of Water Quality, Ecological Health, and Ecological Risk through Data Collection and Modeling Quality Assurance Project Plan 2020 – 2022

2021 Sampling Season
Scope of Work
Blackstone River, Massachusetts

1.0 Historical Overview

The Blackstone River Watershed Assessment Study began in 2003 with the goal of conducting a watershed management study of the Blackstone River Basin in Massachusetts and Rhode Island. Objectives included evaluation of trends in river quality as well as flow management opportunities with existing hydraulic structures so that water quality and aquatic habitat can be improved throughout the basin.

In 2004 through 2006, a monitoring program was conducted to collect water quality, streamflow, and sediment data sufficient for the calibration and validation of computer models to simulate pollutant loading, transport, and in-stream fate and distribution along the main stem and tributaries of the Blackstone River. From 2006 – 2012, a water quality model of the Blackstone River was developed, calibrated, and validated using Hydrological Simulation Program – Fortran (HSPF). This model was based on an existing water quantity model of the Blackstone River watershed, which was developed by the United States Geological Survey (USGS) (Barbaro and Zariello, 2006). The HSPF model currently represents conditions through 2011 and has been used to evaluate and model dynamic water quality conditions incorporating daily, monthly, seasonal and inter-annual variability. Both point source (e.g., waste water treatment plants) and non-point source (e.g., stormwater runoff) loads to the river are incorporated explicitly into the modeling analysis.

Upper Blackstone Clean Water (Upper Blackstone or UB) plant upgrades designed to meet the 2001 permit limits have been online since Fall 2009. In late 2009 and early 2010, slight adjustments to the system were made to optimize performance. As of August 2010, the Upper Blackstone Wastewater Treatment Facility 2001 permit upgrades were fully operational. A new monitoring program was initiated in Spring 2011 and expanded in 2012 to help assess response of the river to the reduced nutrient concentrations in the effluent. Water quality monitoring of the main stem river will continue in 2021, as described in this Scope of Work. Sampling in 2021 will continue the program initiated in 2012 and include routine (monthly) sampling for nutrients and chlorophyll-a, measurement of water temperature, dissolved oxygen, pH and conductivity, and deployment of four dissolved oxygen data loggers.

2.0 Objectives for 2021 Monitoring

The Blackstone River is formed by the confluence of the Middle River and Mill Brook in Worcester, Massachusetts. From there, the River flows approximately 48 miles south into Rhode Island where it becomes the Pawtucket River at the Main Street Dam in Pawtucket, Rhode Island. The main stem Blackstone River is joined by many small tributaries, as well as six major rivers: the Quinsigamond River, the Mumford River, the West River, the Mill River, the Peters River, and the Branch River. The watershed consists of over 1,300 acres of lakes and ponds; the largest is Lake Quinsigamond in Shrewsbury and Grafton.

The scope of the 2021 monitoring program is outlined in this document. The 2021 water quality monitoring program is designed to:

- Build upon work conducted by Upper Blackstone, Massachusetts Department of Environmental Protection (MassDEP), the U.S. Geological Survey (USGS) and others;
- Support future analysis, if needed, of river surface water flow and quality;
- Collect data to assess changes in riverine nutrient and chlorophyll-a concentrations and fluxes through comparison against historical data; and
- Collect data to describe riverine water temperature, dissolved oxygen, pH, and conductivity.

These objectives were used to select sampling locations as well as suitable sampling methods, analytes, measurement techniques, and analytical protocols with the appropriate quality assurance and quality control guidelines. This Scope of Work falls under the Blackstone River 2020 – 2022 Quality Assurance Project Plan (QAPP) and associated Standard Operating Procedures (SOPs), submitted to MassDEP in March, 2020. The 2020 – 2022 QAPP is a revision of the 2017 – 2019 QAPP last approved by MassDEP in December, 2019. The QAPP is designed to cover the range of sampling activities anticipated under the Blackstone River Watershed Assessment Study and serves as an umbrella document for specific Field Sampling Plans, such as this Scope of Work, that will be conducted as part of the study.

3.0 Nutrient Sampling

3.1 Nutrient Sampling Locations & Rationale

The number and location of sampling sites are described in this section. Nutrient sampling will be conducted at 9 main stem run-of-river locations deemed to be the most relevant for understanding potential impacts of the Upper Blackstone's wastewater effluent on downstream water quality. The main stem sampling locations included in the 2021 FSP have been selected in order to provide:

1. Data on changes in concentration and load along the river, particularly downstream of the confluence with the Upper Blackstone effluent and upstream of the confluences with the Mumford and West Rivers,
2. Information on nutrient loads crossing the MA/RI state line, and
3. Information to help understand the impact of the impoundments and nutrients on productivity within RI reaches.

Starting in April 2021, UMass, with the assistance of Upper Blackstone staff, will collect samples for nutrient and chlorophyll-a analysis and collect hand-held meter measurements monthly (e.g., roughly every 4 weeks) at nine locations, including three Rhode Island sites along the main stem of the Blackstone River that will be co-sampled with the Narragansett Bay Commission (NBC). Sampling will continue through November (see **Table 1**). Samples will be collected routinely each month for nutrients, including phosphorus, nitrogen, and chlorophyll-a, regardless of weather conditions, as described in Section 4.0. Information on sampling frequency, sampling program logistics, schedule, and sampling methods is provided in subsequent subsections.

Table 1: 2021 sampling dates

28 April
19 May
16 June
14 July
11 August
8 September
6 October
3 November

The sampling sites are provided in **Table 2** and are consistent with the sites sampled in 2019-2020. Detailed text descriptions, driving directions, and maps of the locations are provided in Appendix A. Figure 1 shows the location of the sampling sites relative to each other and the basin.

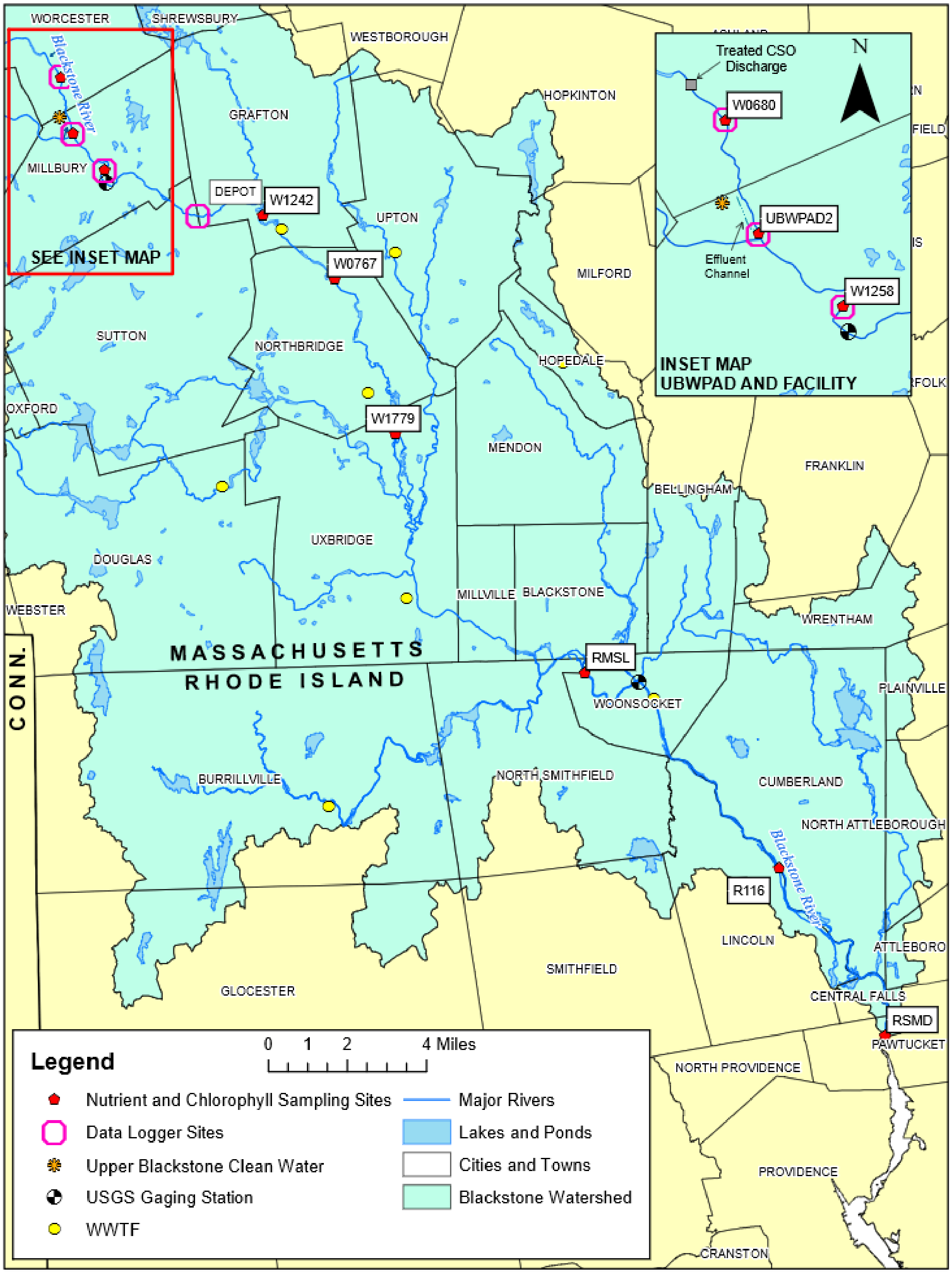
Table 2: 2021 Sampling Sites (all sites located on the main stem)

Site ID#	Site Name	Lat	Lon	River Mile[2]
RMSD[1,]	Slater Mill Dam, Pawtucket, RI	41.876909	-71.381940	0.0
R116[1]	Rte 116 Bikepath Bridge, Pawtucket, RI	41.938066	-71.433769	6.3
RMSL[1]	State Line, RI	42.009974	-71.529313	15.5
W1779	Below Rice City Pond Sluice Gates, Hartford St., Uxbridge, MA	42.097270	-71.62241	27.8
W0767	Sutton St. Bridge, Northbridge, MA	42.153922	-71.652521	33.4
W1242	Route 122A, Grafton, MA	42.177153	-71.687964	36.3
W1258	Central Cemetery, Millbury, MA	42.19373	-71.76603	42.7
UBWPAD2	New Confluence site, downstream of effluent canal	42.20702	-71.78154	44.6
W0680[3]	New Millbury St Bridge, Worcester, MA	42.22784	-71.78762	45.9

[1] Locations of co-sampling with NBC

[2] Corresponding river mile

[3] W0680 is located between the Worcester CSO discharge and UBWPAD2. The Worcester CSO enters the river downstream of the confluence of Mill Brook and the Middle River at approximately river mile 46.4.



Note: one or more data logger sites may be relocated in 2021

Figure 1: 2021 Blackstone River water quality monitoring locations

3.2 Nutrient Parameters, Methods, and Detection Limits

Aliquots prepared from the surface water grab samples will be analyzed at the Upper Blackstone laboratory, UMass Dartmouth (UMD) laboratory, or the UMass Environmental Analysis Laboratory (EAL), depending on the parameter. Samples collected from the sites co-sampled with NBC will also be analyzed at the NBC laboratory. Laboratory analysis methods and detection limits are summarized in **Table 3**.

Method Detection Limits (MDLs) are the lowest values at which a parameter can be measured using the reference method. The MDL is defined as the constituent concentration that, when processed through the complete method, produces a signal with 99 percent probability that it is different from the blank. Lab specific MDLs are developed for each particular analyte of interest and are established as targets for ensuring that the data quality obtained is adequate for interpreting the data; these MDLs are the minimum to be achieved by the laboratories.

The reporting limit (RL) is defined as the lowest level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions and can vary by sampling date. For this project, laboratories will be responsible for calculating the RL for each analysis batch, and will report out values below their RL as "non-detect."

In the database for the project, these data points will be flagged with the code "LT" (less than) and the detection limit value from Table 2 listed as the result. This value will be used in plotting; half of the MDL will be utilized for calculations. The analyses and responsible laboratories for the 2020 sampling season are as follows:

- Samples will be analyzed at Upper Blackstone for total suspended solids (TSS), conductivity (Specific Conductance or SC), and total orthophosphate (TOP).
- The NBC lab[1] will analyze samples collected at the three Rhode Island sites for dissolved nitrate/nitrite (dNO_{23}), dissolved ammonia (NH3) and ammonium (dNH_4), total dissolved nitrogen (TDN), dissolved orthophosphate (DOP), total nitrogen (TN), dissolved silicate and total suspended solids (TSS). These three sites are co-sampled by UMass and NBC. A single large volume bulk environmental sample is collected, and aliquots for analysis at each lab are then split from this volume.
- Samples will be sent to the UMD laboratory for analysis of total dissolved nitrogen (TDN), dissolved nitrite/nitrate nitrogen (dNO_{23}), and dissolved ammonium (dNH_4). These samples will be filtered in the field utilizing a 0.22-micron filter.
- UMD will also analyze samples for particulate organic nitrogen (PON) and calculate total nitrogen (TN) for each sampling location/date based on the results of these analyses, Table 3.
- Samples will be analyzed for chlorophyll-a (chl-a) and total phosphorus (TP) at EAL.

Table 3 provides a summary of the data calculated by each lab.

[1] SOPs and the QAPP for the NBC were not included under cover of the QAPP for this project, as these data are part of their sampling program and considered external to the UMass sampling program. Details of their analysis methods, however, are provided herein.

Table 3: 2021 Analyses, Laboratories, Methods, and Limits

Upper Blackstone Clean Water		
Parameter	Method	Minimum Detection Limit
TOP	Hach 8048	20 ppb[4]
TSS	USGS I-3765-85	2 ppm
Conductivity	STD Method 2510B	0.0 µS/cm
UMass EAL		
Parameter	Method	Minimum Detection Limit/Minimum Reporting Limit
TP	STD Method 20th ed., 4500P	2 ppb/8 ppb
Chl-a[1c]	STD Method 20th ed., 10200 H	1 ppb
UMass Dartmouth		
Parameter	Method	Minimum Detection Limit/Minimum Reporting Limit
dNH_4[1d]	STD Method 20th ed, 4500-NH3-F	1.4 ppb/2.8 ppb
dNO_{23}[1d]	STD Method 19th ed, 4500-NO3-F	3.5 ppb/7 ppb
TDN[1d]	STD Method 19^{h} ed, 4500-Norg	5.3 ppb/10.3 ppb
PON	EPA 440.0	10 ppb

[1] Filtration for dissolved nutrients varies by lab as detailed below.

[a] Starting in 2015, NBC moved to lab filtration for their dissolved constituents utilizing 0.45 micron filters.

[c] Filtered in the lab within 4-hours of sample collection with Whatman GF/F 47 mm, 0.70 micron filter.

[d] Field filtered utilizing Millipore (SLGP033RS), Millex-GP Syringe 0.22-micron filter units.

[3] Laboratories will be responsible for calculating the RL for each analysis batch, and will report out values below their RL as "BRL.". In the database for the project, these data points will be flagged with the code "LT" (less than) and the detection limit value listed as the result. This value will be use in plotting; half of the MDL will be utilized for calculations.

[4] The Upper Blackstone lab has worked to achieve the lowest detection limit possible with their existing equipment and methodologies, however the labs primary focus is analysis of WWTF effluent. It is acknowledged that these DLs are high for riverine analysis.

Table 4: Parameters Calculated Based on Lab Results

Lab	Parameter	Calculation[1]
NBC	Dissolved Inorganic Nitrogen	DIN = dNO_{23} + dNH4
	Dissolved Organic Nitrogen	dON = TDN - DIN
	Dissolved Kjeldahl Nitrogen	dTKN = TDN - dNO_{23}
UMD	Total Nitrogen	TN = TDN + PON

Note: [1] Half the detection limit will be utilized in the calculation when laboratories report results for constituent parameters below the reporting limit.

3.3 Sampling Collection Details

This section describes the procedures for collecting and analyzing samples. It identifies the sampling equipment, performance requirements, and decontamination procedures utilized. The procedures for identifying sampling or measurement system failures and for implementing corrective actions are also summarized.

General Sample Collection

The field program will be conducted based on the Standard Operating Procedures (SOPs) on file as part of the 2020-2022 Quality Assurance Project Plan (QAPP) prepared for the Blackstone River Watershed Assessment Study. The QAPP is designed to serve as an umbrella document for any field sampling conducted as part of the project. Utilizing standard procedures and sampling techniques helps ensure the collection of accurate, precise, and representative samples, as well as helping to ensure data comparability and usability.

The SOPs on file that will be utilized during this field monitoring program were submitted as part of the QAPP prepared for the project and are listed in **Table 5**.

Table 5: Summary of SOPs for Sample Collection of Nutrients and Field Measurements

Document Name	Title
SOP-FLD-001	Collection and Handling of Water Samples for Water Quality Analyses
SOP-FLD-009	Calibration and Maintenance of Measuring and Test Equipment
SOP-FLD-010	Field Sampling of Chlorophyll-a
SOP-FLD-013	Field Measurement of Temperature, Dissolved Oxygen, and pH
SOP-FLD-014	Data Logger Measurement of Temperature and Dissolved Oxygen

Samples collected during the 2021 sampling season will be surface water samples collected from locations believed to be generally representative of net water quality within the river. Routine monthly samples will be collected regardless of precipitation and antecedent conditions.
Field data sheets will be used to document daily site activities and sample collection. Any variations from established procedure will be documented on the project Field Change Request and submitted to the Project Manager for review and archival.
Prior to collecting samples, the sampling location will be visually inspected and a Rivers and Streams Field Sheet completed. Any sampling issues will be noted either on an Equipment Problem Report Sheet or a Field Change Request Form. At each sampling location, the collection date, time, and additional collection details will be noted on the Bulk Sample Collection Data Sheet for the sampling event. Sampling data sheets will be transferred to UMass and retained as part of the monitoring record. Project field sheets and checklists are provided in Appendix B. Any observation that is not appropriate to note on individual field sheets will be recorded in the sampling crew's Field Notes Log Book.

Sample collection and bulk storage bottles will be cleaned with non-phosphate containing detergent between each sampling event as per the project SOPs, summarized in **Table 6**. The bottles will be filled with DI water after washing and the conductivity tested after 24-hours. Bottles with conductivity results above 2 microsiemens/centimeter will be rejected. Bottles that pass will be emptied, allowed to air dry, then capped and stored for the next event. All aliquot bottles, with the exception of those received from

UMD, will be similarly washed, tested, and dried. At least two spare bottles will be available each sampling trip in case of mishap.

Table 6: Sampling Container Decontamination Procedures

Sample type	Container	Decontamination	Staff
Sampling container	4 L, plastic	Phosphate-free soap, DI rinse	UMass
Bulk sample container	4 L and 6 L, plastic	Phosphate-free soap, DI rinse	UMass
Chl-a	500 mL and 1 L, amber plastic	Phosphate-free soap and acid wash, DI rinse	UMass
TP	125 mL, amber plastic	Phosphate-free soap and acid wash, DI rinse	UMass
TOP	237 mL, plastic	New, DI rinse	UMass
TSS, SC	1 L, plastic	New, DI rinse	UMass
dNH_4, dNO_{23}, TDN	60 mL, plastic	Acid wash, DI rinse	UMD
PON	1 L, plastic	Acid wash, DI rinse	UMD

Nitrile gloves will be worn by all sampling personnel, and will be changed between sampling sites.

Bulk water samples for nutrient analysis will typically be collected from either a bridge, utilizing a Nalgene 4-L wide-mouth HDPE bottle attached to a rope and reel or a peristaltic pump, or from the stream bank directly using the bulk sampling bottle attached to a sampling pole. The sampling rope and reel are technically considered to be non-dedicated sampling apparatus, as they contact surface water samples from more than one monitoring location. However, because they come into contact with the outside of the bottle only, this will not cause cross-contamination. The associated sampling container, however, is also utilized at more than one location. To minimize potential cross-contamination, the sampling container will be rinsed three times with river water prior to collecting the final sample. The sampling container is filled twice after rinsing with river water. The first time, the water is poured from the sampling container to the chlorophyll sample bottle to rinse it three times, then to fill it. The second fill is transferred into a clean 4-L wide-mouth HDPE bottle (the bulk collection bottle), which will also be rinsed three times with the sample water previous to final sample collection. An equipment blank will be collected at one site from the sampling container at the start of the sampling season, mid-season, and at the end of the season.

To collect samples from the stream bank, the sample bottle will be attached to the sampling pole. At W1779, the sample bottle used is the 4-L bulk sample bottle. At W0680 and UBWPAD2, the sample bottle used is the 1-L brown Nalgene bottle. The sample bottle is uncapped and dipped upside down in the water, rinsed and emptied downstream three times. The sample bottle is then dipped upside down in the water until fully submerged. The bottle is then turned right-side up and held in place until no more air bubbles come out and brought back to the stream bank. This bottle is used to rinse three times the other bottle at the stream bank (whether the other bottle is a 1-L brown Nalgene bottle or a 4-L bulk sample bottle), and is refilled as many times necessary to fill the other sample bottle at the stream bank. It is then filled and capped.

At the RI sites, a 6-L Nalgene carboy bottle with spigot will be utilized as the collection bottle to enable collection of a bulk sample large enough to provide splits for both NBC and UMass. At these three locations, the sample will be collected utilizing NBC's peristaltic pump. This pump is designed to have minimal effect on water quality. Cross-contamination will be minimized by fully flushing the pump tubing prior to rinsing the collection bottles and caps three times with river water. Rinse water will be emptied away from the sampling location.

The bulk sample bottles will be labeled and put into a cooler packed with ice until they can be transferred to the lab for splitting into sub-sample bottles and preserved for subsequent laboratory analysis. Labels for the bulk sample bottles will be printed prior to the event (see Appendix C).

Chlorophyll-a Sample Collection

As per the chlorophyll-a SOP, samples for chl-a analysis are collected in amber containers, protected from sunlight, and filtered as soon as possible through a 47 mm diameter Whatman GF/F 0.7-micron pore size glass microfiber filter. Amber bottles will be put into a cooler packed with ice until they can be transferred to the Upper Blackstone lab where they will be filtered. Filtering will typically occur within four hours of sample collection.

Field Filtering for Dissolved Nutrients

NBC analyzes samples collected at their three Blackstone River sampling locations for dissolved nutrients. NBC filters samples in the field with a 45 µm filter. UMass began field filtration in 2015 per MassDEP guidance, both with a 45 µm filter and with a 22µm filter. UMass now filters only with 22 µm filter for analysis of dissolved nutrients at UMD as part of the project. **Table 7** provides an overview of the preparation of filtered samples.

Table 7: Summary of Sample Filtration

Parameter	Filter	Sites	Filtering location	Staff filtering
dNO_{23}	0.22 µm	All	Field	UMass (5 sites), Upper Blackstone (4 sites)
dNH_4	0.22 µm	All	Field	UMass (5 sites), Upper Blackstone (4 sites)
TDN	0.22 µm	All	Field	UMass (5 sites), Upper Blackstone (4 sites)
Chl-a[1]	0.7 µm	All	Upper Blackstone Lab	UMass

[1] Sample analyzed is filter residue, not the filtrate.

At all sites, aliquots for dissolved analysis will be field filtered with Millipore (SLGP033RS) 0.22-micron filter units attached to a Millex-GP syringe for analysis of the nitrogen series at UMD. A new syringe and filter unit will be utilized at each site. The syringe will be rinsed three times with water from the bulk collection bottle by removing the plunger, pouring into the barrel, and then replacing the plunger to shake and then dispose of the rinse water. After the final rinse, the Millipore filter unit will be attached, and the syringe filled with water from the bulk collection bottle. Next, 20 mL of sample will be filtered through the disposable 0.22-micron filter housing and discarded. Then, 20 mL of sample will be filtered into the sample bottle to rinse and discard. The remaining 20 mL water in the syringe will be filtered into the 60 mL sample bottle. After removing the plunger, the filter will be removed from the syringe and discarded, then a new 0.22-micron filter will be attached. The syringe will be refilled with sample water, 20 mL wasted through the filter, and the remaining 40 mL of sample in the syringe then utilized to fill the 60 mL bottle containing 20 mL of sample from the first 0.22-micron filter. It should be noted that aliquot bottles provided by UMD will not be washed at UMass.

Field Blanks

Field blanks will consist of water that is transferred from one bulk collection bottle that was filled with DI water from the EAL lab the day before sampling, to a "field blank" collection bottle at the sampling site. A field blank will be collected for all parameters at a frequency of at least ten percent, or one field blank per ten samples. Sampling crews will be given specific instructions as to the sampling location where field blanks should be processed, transferring the DI water from the lab bottle to the bulk sample bottle. Processing of the field blank to aliquots, including the field filtration step, will occur in the same manner as for regular grab samples. Field blanks will provide an indication of whether atmospheric conditions or field procedures have the potential to lead to sample contamination.

Equipment Blanks

To ensure that samples collected with the 4-L sampling container are not contaminated from water collected at previous sites, an equipment blank will be collected the first sampling day in 2021 at a randomly selected bridge site. Two one-gallon jugs of Upper Blackstone DI will be transported to the field and used to rinse the sampling container three times and fill the sampling container. A bulk sample bottle labeled 'Equipment Blank' will then be filled from the sampling container. Processing of the equipment blank to aliquots, including the field filtration step, will occur in the same manner as for regular grab samples. An equipment blank will be also run mid-season and at the end of the season at another bridge site.

Field Duplicates

Field duplicates will consist of a second bulk sample collected at approximately the same time. Field duplicates will be collected for all parameters at a frequency of at least ten percent, or one duplicate per ten samples. Processing of the field duplicates, including the field filtration step, will occur in the same manner as for regular grab samples. Field duplicates will provide an indication of the inherent variability of nutrients in the water column over short spatial and temporal differences

Field Splits

Field splits will consist of a second set of aliquots processed from the bulk collection bottle. Field splits will be collected for all parameters at a frequency of at least ten percent, or one split per ten samples. Field splits will provide an indication of the inherent variability within a sample, independent of replicates run by the laboratories. Enough water will be collected to allow splitting into all the aliquots at the UB lab. An extra 2-L bottle will be given to the crew collecting the field split in order to have enough sample water for 2 TSS/SC samples.

Performance Tests

A performance test (PT) will be provided to each laboratory per sampling event for dissolved phosphorus, dissolved orthophosphate, dissolved nitrite-nitrate, and dissolved ammonia, depending on the parameters analyzed for in their laboratory. The PT aliquots will be prepared each day before sampling by EAL staff from standards of a known concentration.

Sample Processing

The remainder, after field filtration, of the bulk samples will be transported back to the Upper Blackstone Alden building, where they will be split into smaller volume bottles for subsequent analysis. Labels for the aliquot splits will be printed prior to the event (see Appendix C). In general, when the coolers are brought inside for sample processing, the amber bottles for Chl-a analysis will be separated so that one crew member can begin filtering. The second crew member will begin to process the aliquots from the bulk samples.

All lab personnel will wear nitrile gloves, and will change gloves when switching to processing a new site. Working from downstream to upstream, the order in which sites were sampled, the bulk sample for each site will be found in the cooler and processed. Sets of bottles (a 1-L jug, a 243 mL squat bottle, etc.) will be set out for the given sampling location. Based on a sampling QAQC table provided to the sampling crew identifying sites where field splits are to be analyzed, additional bottles will be added to the site sets. Labels for the bulk and aliquot bottles will be compared; the sample collection time will be added to the aliquot bottle labels. After loosening the aliquot bottle caps, the bulk sample bottle will be fully mixed by inverting 10 times and the aliquot bottles rinsed three times. The bulk sample bottle will then again be fully mixed and the aliquot bottles filled with sample. Both the aliquot and bulk sample bottles will be re-capped as soon as possible and the bulk sample returned to its cooler. After completing the appropriate line on the chain of custody forms for the aliquots, the aliquots will be placed in separate coolers, one for each bottle type. If called for, bulk sample field blanks and duplicates will be processed after the bulk grab sample for the same site is processed.

At least one split duplicate (e.g., two aliquots taken from the same bulk sample bottle) and one field duplicate (a second bulk sample co-collected in the field) will be collected, processed, and analyzed for each parameter and sampling event to meet our QAQC objectives.

Table 8 summarizes the container, handling and preservation, and hold time for each analyte. At least two spare bottles for each aliquot type and blank labels will be available in case of mishap. Step-by-step directions utilized by the aliquot splitter have been developed and are available upon request.

Table 8: Sample Container Codes, Types, Volumes, Preparation, Special Handling, Preservation, Holding Times

Analysis	Cont. Code	Container	Handling & Preservation	Holding Time
TOP	A - Upper Blackstone	237 mL, plastic	Store ≤6°C	48 hours
TSS, SC	C - Upper Blackstone	1 L, plastic	Store <=6°C	7 days
Chl-a[1, 2]	D – EAL (filter retained only[1])	1 L, amber plastic	0.7-micron pore size glass microfiber filter, dry filter and freeze, store in dark, discard filtrate	21 days
TP	E - EAL	125 mL, amber plastic acid washed	Freeze	1 year
PON[1]	H – UMass Dartmouth	1 L, Plastic	Store 4±2°C. Transport to UMD (lab filtered by UMD; filter analyzed, filtrate discarded)	48 hours
dNH_4, dNO_{23}, TDN	I – UMass Dartmouth	60 mL, Plastic	0.22 µm filter[3]. Store filtrate 4±2°C. Transport to UMD.	48 hours

Notes:

[1] Sample analyzed is filter residue, not the filtrate

[2] Filtration occurs within 4 hours of sample collection.

[3] Filters are analyzed within 21 days according to the EAL QAPP

Preparation of Lab Blanks

The day prior to sampling, lab blanks will be prepared by filling aliquot bottles directly from the EAL source of DI water. The lab blank aliquot bottles will travel with the samplers from site-to-site and then be added to the appropriate cooler based on analyte type and lab at the end of the day. Lab blanks will provide an indication of whether DI source water, transportation steps, or laboratory analysis procedures have the potential to lead to sample contamination. In the event that positive blanks or duplicates are outside the acceptable precision range, additional blanks and/or duplicates will be added in subsequent sampling events to try and determine the source of contamination if it is not readily identifiable from existing data and documentation.

Sample Preservation

Once all aliquots are split, the 243 mL (TOP), 1 L (TSS/SC) for analysis at the Upper Blackstone will be moved from coolers to the walk-in refrigerator, unpreserved. Samples for delivery to UMD will be placed in a dedicated cooler with fresh ice and shipped via FedEx overnight. Samples for delivery to EAL will be moved from the Upper Blackstone freezer to a cooler, transported, and immediately placed in the EAL freezer. No acidification is necessary for sample preservation this season, except for RI samples on one summer sampling date, if pertinent.

Filtering for Chlorophyll-a

Following SOP protocols, water samples collected in amber bottles for chlorophyll-a analysis will be filtered in the Upper Blackstone lab through a 47 mm diameter Whatman GF/F 0.7-micron pore size glass microfiber filter as soon as possible but no later than within 4 hours. Prior to filtering, all filtering equipment and containers will be rinsed three times with deionized (DI) water and then once with sample water. The filtering process will be set up with vacuum flask, filter holder, glass fiber filter, and filling funnel. After placing the filter rough side up on the filter holder, an exact sample volume will be measured out using a graduated cylinder, filtered, and the volume filtered recorded. Each sample will be filtered until the filter is visibly green or greenish brown. This coloration indicates enough chlorophyll has been collected for the chlorophyll-a analysis. For the Blackstone River, 250 mL of water will be typically filtered during the growing season, but during early spring and late fall, when productivity in the river is less, larger volumes will likely be filtered. During July and August, peak seasons for growth, smaller volumes may be filtered. When the entire measured sample has been filtered, the filling funnel will be removed and the filter carefully transferred from the filter holder with forceps, folded in half (green side in), and placed in an air-drying box. When all samples have been filtered, the drying box will be plugged in and the sample filters completely air-dried for approximately 25 minutes. The filters will then be removed with forceps, placed in aluminum foil, and labeled with the site name, date, time of sampling, and volume of water filtered. Filters will be frozen as soon as possible for preservation prior to chlorophyll-a analysis.

Chain of Custody

Chain of custody will be maintained in accordance with standard procedures. Chains of custody will be pre-filled out with the expected samples and analyses, including a line for each aliquot. At the time bulk samples are split into aliquots for preservation and subsequent analysis, chain of custody forms will be checked against the aliquot bottles and the collection times will be added. One chain of custody form will be prepared for each lab (Upper Blackstone, EAL, UMD), plus one for the NBC lab to accompany the PT sample given to the NBC sampling crew. Copies of the chain of custody forms are provided in Appendix D. Once the chain of custody forms are checked and signed by UMass staff, they will be transferred to the respective laboratories for their staff to sign.

Sample ID Nomenclature

Sample IDs will follow a set nomenclature consisting in general of four parts: sampling site ID, sample type, filtration code, and date. Unique sampling site identifications for each site are listed in the first column of Table 1. Sample types include both the sample itself, designated as a grab sample, as well as the quality assurance quality control (QAQC) samples such as splits, duplicates, blanks, and performance evaluation samples, **Table 9**. Each sample ID will also include a filtration code, as indicated in Table 9. The last field will be the sample collection date as MMDDYY.

Table 9: Sample Type Codes

Code	Description
G	Grab sample
FS	Field split
FD	Field duplicate
LB	EAL DI water lab blank
FB	EAL DI water field blank
EB	UB DI water equipment blank
P	Performance evaluation sample
TC	Temperature Check bottle

Table 10: Filtration Codes

Code	Description
UF	Unfiltered
FF22	22-micron field filtered
NA	Not applicable (e.g., for lab blanks)
FR	Filter residue (e.g., analysis done on a filter, such as for PON)

4.0 Field Water Quality Measurements

In 2021, field water quality measurements (water temperature, dissolved oxygen [DO], and pH will be collected at all sites. Field parameters will be collected with a hand-held Hach HQ 40 D multimeter equipped with two probes. Temperature, DO, and pH will be measured in situ by each field crew.

Each meter will be calibrated by UB staff at the UB lab on the morning of each sampling day, prior to sampling. Both DO and pH probes will be attached to the meter. Calibration forms are found in Appendix E, along with measurement instructions from the meter manual.

At the sampling site, measurements will be taken with the meter before or at the same time as the collection of river samples. The probe comes with a 25-foot cable. If the river surface cannot be reached, measurements will be taken from a sampling container. Measurements will be taken from both the river and a sampling container a few times during the season to compare the two sets of measurements. If sampling container measurements are not acceptable, no further measurements will be made from those containers. At each site:

1. Rinse the probes with DI water, then lower the probes into the river where water chemistry samples are collected, just below the water surface.
2. Press the READ key. When the screen shows that the measurements have stabilized, record the readings for water temperature (%), DO saturation, DO concentration in mg/L, and pH on the field sheet.
3. Rinse the probes with DI water, and place the probes in their respective sleeves/flasks. Place the meter and probes in the travel bucket.

An SOP was created in 2019 and submitted as an addendum to the QAPP: SOP-FLD-013: Handheld Multimeter Field Measurements (see SOP-013 in Appendix F).

At the RI sites, the field parameters recorded by NBC should also be recorded on the field sheet.

Upon return to the UB lab, the pH probe will be placed in each of the buffers and readings recorded on the calibration form. The DO probe will be placed in the air-saturated water flask and the reading will be recorded on the calibration form. A photocopy of the calibration form for the sampling day will be given to the UMass team.

Conductivity will be measured with the Hach meter and a conductivity probe in the UB lab from the same samples used for TSS analysis. The lab SOP for conductivity measurement is included in Appendix F.

Upper Blackstone will install four continuous temperature and dissolved oxygen probes in the Blackstone River (see Figure 1 for locations). The data loggers will be installed in late spring or early summer, depending on river streamflow, and will be removed in late October or early November. SOPs governing the deployment of the data loggers are described in Appendix F.

5.0 Schedule

The nutrient sampling program will follow the sampling schedule NBC has in place for their Blackstone River sampling. Because NBC sometimes needs to adjust their schedule, sampling dates will be confirmed with NBC and the labs one-week prior to each planned event. Samples will be collected routinely for nutrients once every 4th Wednesday, regardless of weather conditions, starting in April, though there will be only three weeks between the April and the May sampling dates. See **Table 1** for sampling dates in 2021.

6.0 Quality Assurance

Prior to the first sampling event, sampling staff from UMass and Upper Blackstone will read through the Field Sampling Plan, sampling SOPs, and review field data sheets. UMass and Upper Blackstone sampling staff will then participate in a conference call or meeting which will act as a refresher on sampling protocols and will also enable staff to discuss any questions or concerns related to sampling. To ensure sampling procedures are followed and QAQC objectives are being met, Zachary Eichenwald will conduct a field audit during the first sampling event to observe sampling crews and document any deviations from the sampling SOPs. Field audit results will be made available to all sampling staff and any issues will be corrected.

Measurement performance criteria, including the precision, accuracy, completeness, comparability, and representativeness of the data will be used to assess the quality of all environmental measurements in relation to the objectives of this Scope of Work. The criteria for this project are presented in Appendix E. To meet these objectives, field duplicates, laboratory replicates, and blanks will be run. QAQC samples will at a minimum consist of 1 field duplicate (rate of 1:9) and one blank each sampling run (rate of 1:9).

Additional blanks and duplicates will be added if positive blanks or duplicates outside of the acceptable precision range are noted.

In addition, a limited number of Performance Test (PT) samples will be used as a double-blind evaluation on the respective laboratory's performances for the following parameters: total dissolved phosphorus (TDP), dissolved orthophosphate (DOP), dissolved nitrate/nitrite (dNO_{23}), and dissolved total ammonia (dNH_4). The PT samples will be purchased from an outside PT manufacturer, diluted to concentrations representative of riverine conditions, and will be provided with a known quantity of analyte. Typically, one set of PT samples will be incorporated within the batch of river samples and submitted blindly to the laboratories. The laboratory's analytical results will be compared to the known analyte concentrations provided based on the PT manufacturer and known dilutions.

To ensure proper temperature storage of samples on sampling day, a 500 mL bottle filled with tap water will be added to each cooler before setting out to sample. The temperature of the water in this bottle will be measured when the cooler arrives at the UB laboratory.

7.0 Team Organization and Contact Information

Key team members participating on the Blackstone River Watershed Assessment Study include the following:

- Upper Blackstone Clean Water (Upper Blackstone)
- University of Massachusetts at Amherst (UMass)
- University of Massachusetts at Dartmouth (UMD)
- CDM Smith
- Narragansett Bay Commission (NBC)

The following section provides a brief discussion of the team member roles and responsibilities. Table 10 provides contact information for these team members and others that will assist with the sample collection.

Program Management and Technical Oversight. Ms. Karla Sangrey, P.E., Upper Blackstone Director, shall serve as the primary point of contact for the UB on the river sampling. Ms. Kristina Masterson, P.E., CDM Smith, will serve as the primary point of contact for CDM Smith on the river sampling. They will provide program management guidance and technical oversight, including review of the proposed Scope of Work and data reporting.

Upper Blackstone Laboratory Coordinator. Mr. Timothy Loftus will be the primary contact for the UB laboratory. He will coordinate with UMass to ensure the UB can assist with sampling and analysis on sampling week, reserve the Upper Blackstone vehicle, and coordinate with the Upper Blackstone staff in terms of meeting times and duties. In addition, he will assist UMass to ensure the sample volumes and plans for filtering/preserving meet the UB needs.

EAL Laboratory Coordinator. Mr. Cameron Richards will be the primary contact for the EAL laboratory. He will ensure that all necessary supplies are available. He will also run Chl-a and TP samples sent to EAL.

NBC Laboratory Coordinator. Ms. Karen Cortes will be the primary contact for NBC. She will assist in coordinating sampling dates and co-sampling timing.

UMD Laboratory Coordinator. Ms. Sara Sampieri Horvet will be the primary contact for UMD. She will assist with coordinating aliquot bottle and filter delivery to UMass prior to each sampling event, and be the interface for data delivery and questions.

Principal Investigator. UMass will be responsible for field sampling and associated activities performed under this Scope of Work under the direction of Ms. Marie-Françoise Hatte, who will serve as principal investigator. Ms. Hatte will ensure that the work completed by the Project Team meets the prescribed scope of work; she will be the primary point of contact between UMass and the Upper Blackstone. Ms. Hatte will work closely with the Upper Blackstone, CDM Smith and NBC to make any necessary adjustments to the sampling plan and solicit feedback regarding the effort. Ms. Hatte and staff will also be responsible for coordinating the specific details of the data collection and review efforts, including:

- Oversight/assistance of the field program
- Oversight of identifying and resolving problems at the field team level
- Identifying, implementing, and documenting corrective action
- Oversight of documentation
- Data review and reporting.

Field Program Coordinator. Mr. Cameron Richards will serve as the Field Program Coordinator. He will be responsible for mobilizing, coordinating and managing sampling events, as well as, gathering and analyzing data in the field. Ms. Hatte will provide assistance where necessary.

Document and Data Custodian. Mr. Cameron Richards will serve as the document custodian, assisted by Ms. Hatte and a UMass Amherst undergraduate student. The Document Custodian will be responsible for maintaining project files and filing project documents, project correspondence, sample integrity data sheets, chain of custody forms, field report forms, field and equipment notebooks, generated data and other associated and pertinent project information. The Document Custodian will:

- Review documents for quality control when submitted, ensuring that data recording procedures have been carried out as per this SOP
- Maintain hardcopy and electronic records, converted paper files to an electronic database as needed
- Maintain and backup the master database for the project
- Assist in data analysis and visualization
- Assist in the interface between the monitoring and modeling portions of the project
- Be responsible for transferring data to Project PI
- Complete the required QAQC calculations based on duplicate and blank sample data returned from the labs
- Perform data review, verification, and validation, as described in Section 4

QAQC Officer. Ms. Hatte will serve as the QAQC Officer. She will review the QAQC data and suggest modifications to the sampling plan to address any concerns.

External QAQC Officer. Zachary Eichenwald of CDM Smith will serve as external QAQC Officer. He will conduct a field sampling audit on April 28, 2021.

Table 11: Team Contact Information

Name/Organization	Role	Contact
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8.0 References

ASTM Method D3370-82. *Standard practice for sampling water*.

Barbaro, J.R. and Zariello, P.J. (2006). *A Precipitation-Runoff Model for the Blackstone River Basin, Massachusetts and Rhode Island*. U.S. Geological Survey Scientific Investigations Report 2006-5213.

Hatte, MF (2020). Blackstone River Assessment of Water Quality, Ecological Health, and Ecological Risk through Data Collection and Modeling Quality Assurance Project Plan 2020-2022.

U.S. EPA, 40 CFR 136, Guidelines Establishing Test Procedures for the Analysis of Pollutants. Title 40 Part 136 of the Code of Federal Regulations.

U.S. Geological Survey (USGS). 2012. Office of Water Quality Technical Memorandum 2013.01, "Guidance on Methods for Determining the Concentration of Total Nitrogen in Whole-Water Samples", November 30, 2012.

APPENDIX

A: Site Directions and Maps

B: Field Sheets and Check Lists

C: Labels

D: Chains of Custody

E: Calibration Forms and Meter Manual

F: Field SOPs

Appendix E: Blackstone River Water Quality Monitoring Quality Assurance Project Plan 2020-2022

Blackstone River

Assessment of Water Quality, Ecological Health, and Ecological Risk through Data Collection and Modeling

Quality Assurance Project Plan

2020 – 2022

Version 3 (Amendment 2)

Prepared for:

Upper Blackstone Clean Water

Prepared by:

The University of Massachusetts Amherst

CDM Smith

April 16, 2021

QUALITY ASSURANCE PROJECT PLAN

for

Blackstone River Watershed Assessment Study

PREPARED BY: Massachusetts Water Resources Research Center
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APPROVED BY:

Upper Blackstone Engineer-Director/Treasurer:

____ Date:___________________

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Appendix E **Field Collection Forms**

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Appendix G **Lab QAPPs and Standard Operating Procedures for Laboratory Analyses**

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3 - Upper Blackstone Laboratory SOPs

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Acronyms and Abbreviations

%R	Percent Recovery
µg/L	Micrograms per Liter (0.000001 L)
AOC	Administrative Order on Consent
ASTM	American Society of Testing and Materials
BRL	Below Reporting Limit
Chl-a	Chlorophyll-a
CMR	Code of Massachusetts Regulations
COC	Chain of Custody
DO	Dissolved Oxygen
dNO23	Dissolved Nitrite-Nitrate Nitrogen
DQO	Data Quality Objective
EPA	United States Environmental Protection Agency
EAL	Environmental Analysis Laboratory
FSP	Field Sampling Plan
HSPF	Hydrologic Simulation Program – Fortran
L	Liter
LCS	Laboratory Control Sample
LCSD	Laboratory Control Sample Duplicate
MassDEP	Massachusetts Department of Environmental Protection
MassDPH	Massachusetts Department of Public Health
MaWRRC	Massachusetts Water Resources Research Center
MDL	Method Detection Limits

mL	Milliliter (0.001 L)
NBC	Narragansett Bay Commission
NCEI	National Centers for Environmental Information
NO23	Total Nitrite-Nitrate
NPDES	National Pollutant Discharge Elimination System
NWS	National Weather Service
PE	Performance Evaluation
P.E.	Professional Engineer
PON	Particulate Organic Nitrogen
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RIDEM	Rhode Island Department of Environmental Management
RL	Reporting limit
RPD	Relative Percent Difference
SC	Specific Conductance (also called Conductivity)
SOP	Standard Operating Procedures
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
TDN	Total Dissolved Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TOP	Total Orthophosphate
TSS	Total Suspended Solids
UB	Upper Blackstone Clean Water

UMD	UMass Dartmouth
Upper Blackstone	Upper Blackstone Clean Water
UMass	University of Massachusetts Amherst
USGS	United States Geological Survey
WPP	Watershed Planning Program (at MassDEP)
WWTF	Wastewater Treatment Facility

3. QAPP Distribution List

The following individuals shall receive copies of the approved QAPP and any subsequent revisions:

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4. Project / Task Organization

4.1 Study Authority

The Blackstone River Watershed Assessment Study was initiated by Upper Blackstone Clean Water (Upper Blackstone) in 2003, and over the years has included data collection and analysis as well as numerical modeling of Blackstone River flow and water quality.

Wastewater treatment plant upgrades at Upper Blackstone designed to meet the 2001 NPDES permit limits were completed in fall 2009. Since that time, Upper Blackstone has continued a river monitoring program to collect data to assess the response of the river to reduced nutrient concentrations in the Upper Blackstone wastewater treatment plant effluent.

This Quality Assurance Project Plan (QAPP) was developed to cover routine river monitoring conducted by Upper Blackstone from 2020 – 2022. This document is based on the United States Environmental Protection Agency's (EPA) *QA/R-5: EPA Requirements for Quality Assurance Project Plans* (March 2001), the Massachusetts Inland Volunteer Monitoring General Quality Assurance Project Plan (December 2008), and the 2017 - 2019 QAPP approved by the Massachusetts Department of Environmental Protection (MassDEP). This submittal is comprised of the following four components:

- QAPP: Provides a summary of the project scope and objectives, defines the project quality objectives, methods for water quality measurements and provides an overview of the field, analytical, and quality assurance/ quality control (QA/QC) activities;
- 2020 Field Sampling Plan (FSP): Describes the specific sampling criteria, locations, and frequency for water quality measurements and other river monitoring activities conducted in 2020;
- Standard Operating Procedure (SOP) Compendium: Compilation of SOPs detailing the specific sampling and laboratory procedures; and
- Associated laboratory QAPPs and SOPs.

FSPs for each year will be provided when available.

The QAPP is designed to cover the range of sampling activities anticipated under the Blackstone River Watershed Assessment Study and serves as an umbrella document for sampling season specific FSPs. Sampling locations, the number of samples per sampling location, and parameters analyzed will be specified in each annual FSP. Amendments will be made to this QAPP as necessary to encompass new sampling activities or the measurement of additional environmental parameters.

Copies of this QAPP are provided to the Massachusetts Department of Environmental Protection (MassDEP) for review, comment, and acceptance so that data collected by Upper Blackstone may be submitted to the MassDEP Watershed Planning Program (WPP) for use in decision making regarding surface water quality assessments required by Sections 305(b) and 303(d) of the Clean Water Act.

4.2 Team Organization

Key team members participating on the Blackstone River Watershed Assessment Study include the following:

- Upper Blackstone Clean Water (Upper Blackstone)
- University of Massachusetts Amherst (UMass)
- CDM Smith
- UMass Dartmouth Coastal Systems Program Lab (UMD)

A project organizational chart is shown in Figure 1.

The following section provides a general discussion of the team member roles and responsibilities.

Upper Blackstone Engineer-Director/Treasurer. Ms. Karla Sangrey, P.E., Upper Blackstone Engineer-Director/Treasurer, shall serve as the primary point of contact for Upper Blackstone on the Blackstone River Watershed Assessment Study. In her role, Ms. Sangrey will provide direction regarding the scope and focus of the program including sampling locations and the proposed parameters to be measured. She, with the assistance of UMass and CDM Smith, will present annual field sampling program plans to the Upper Blackstone Board of Directors for approval.

Monitoring Program Coordinator. All field sampling and associated activities performed under this QAPP, and the preparation of associated yearly Field Sampling Plans, will be completed by the UMass Massachusetts Water Resources Research Center under the direction of Marie-Françoise Hatte, who will serve as the Monitoring Program Coordinator. Ms. Hatte will ensure that the work completed by the Project Team meets the prescribed scope of work; she will be the primary point of contact between UMass, CDM Smith, and Upper Blackstone. Ms. Hatte will also be responsible for coordinating the specific details of the data collection and review efforts, including:

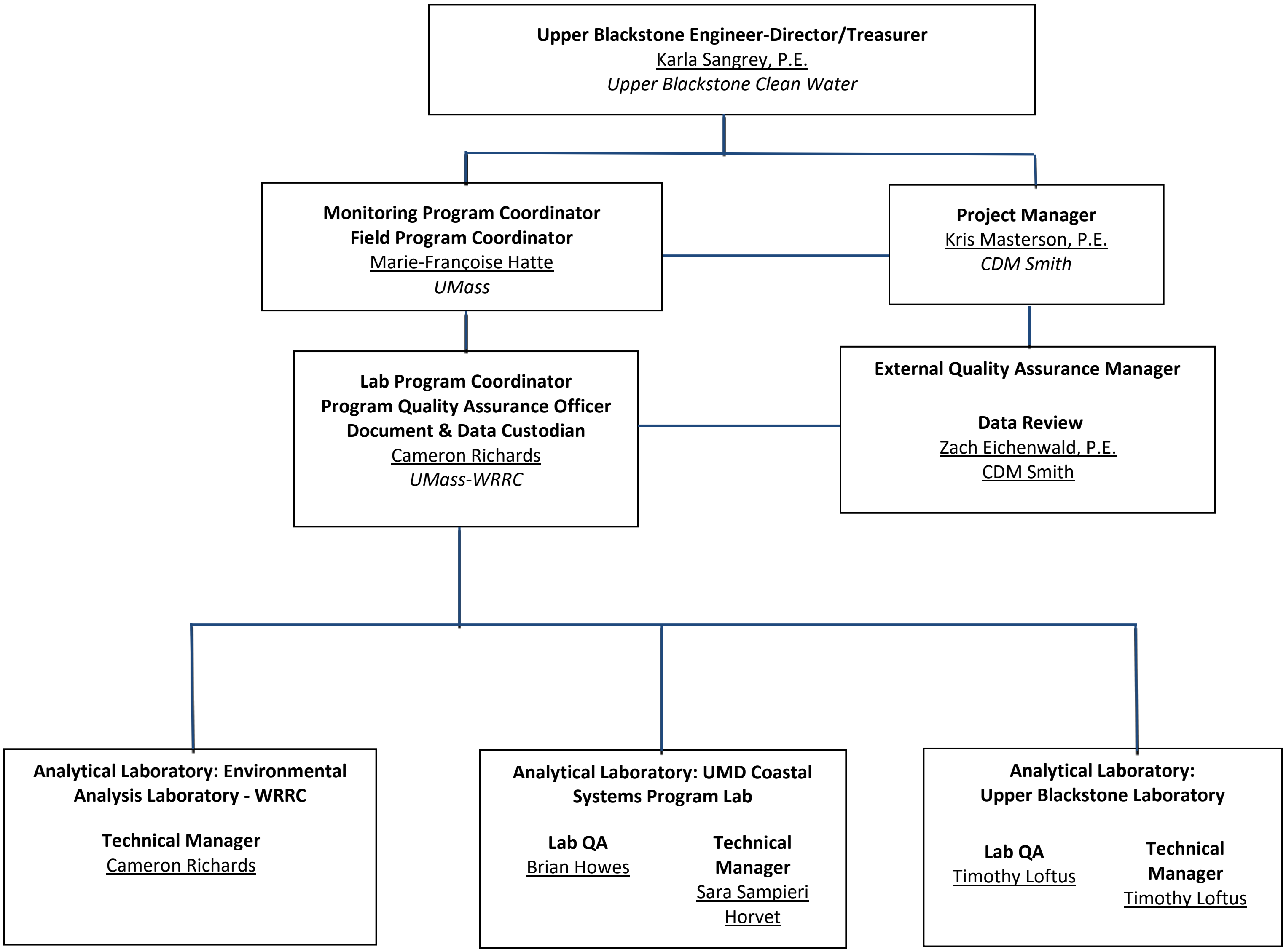

Figure 1: Project Organizational Chart

- Overseeing preparation for sampling events, including bottle and sampling equipment preparation, organization of field crews, and notification of the laboratories;
- Identifying and resolving problems at the field team level;
- Identifying, implementing, and documenting corrective action; and
- Oversight of data review and reporting.

Project Management and Technical Oversight. CDM Smith will provide project management guidance and technical oversight for the Blackstone River Watershed Study. Ms. Kristina Masterson will serve in a project management/coordination role to provide technical guidance for the field program, including technical review of the collected data, review of annual program reports, and assistance with public outreach.

Field Program Coordinator. The Field Program Coordinator will be responsible for mobilizing, coordinating and managing sampling events, as well as gathering and analyzing collected data. Marie-Françoise Hatte, or a designated UMass staff member or student, will serve as the Field Program Coordinator. CDM Smith will provide field program coordination assistance as necessary.

The Field Program Coordinator will be responsible for tracking weather conditions to determine when sampling events dependent on weather conditions will be conducted, however the Monitoring Program Coordinator will make the final go or no-go decisions in collaboration with the lab technical managers, CDM Smith, and Upper Blackstone.

The Field Program Coordinator will also oversee equipment function checks and calibration as detailed in the annual Field Sampling Plan and associated Standard Operating Procedures. He/she will be responsible for ensuring the completion of all appropriate Calibration Sheets, Field Sheets (FS), and/or notebooks documenting completion of these duties. They will also be responsible for transferring raw data, calibration, equipment check and other FS's to the Document and Data Custodian.

The Field Program Coordinator will be assisted in these duties by trained staff and/or student project personnel.

Field Samplers: Collection of samples will be performed by two teams: The Upper Loop or Northern team will consist of the Program Quality Assurance Officer assisted by a trained UMass undergraduate student (or the Field Program Coordinator), and the Lower Loop or Southern team will consist of two Upper Blackstone laboratory staff.

Lab Program Coordinator. The Lab Program Coordinator will be responsible for interface between labs, the Field Program Coordinator, the Monitoring Program Coordinator, the Program Quality Assurance Officer, and the External Quality Assurance Managers. As such, they will complete the required Quality Assurance/Quality Control calculations based on duplicate and blank sample data returned from the labs. In addition, they will coordinate external review of these data and all sampling procedures. Specifically, the Lab Program Coordinator will:

- Organize Field Quality Control Check data into a separate database so that lab performance on duplicates, blanks, and Performance Evaluation (PE) samples may be evaluated;
- Organize Field Analytical Quality Control Check data either into a separate database or integrate with existing field database so that quality can be assessed;
- Perform data review, verification, and validation, as described in Section 4;
- Calculate measurement performance criteria, as described in Section 1.4.2;
- Submit results of internal quality control checks to the Monitoring Program Coordinator, who will review and submit to appropriate delegates for further review;
- Lead data review, analysis and visualization; and
- Assist with project reporting.

Cameron Richards will be the Lab Program Coordinator but may be assisted by trained student project personnel.

Program Quality Assurance Officer. The Program Quality Assurance Officer will also serve as the Document and Data Custodian. WRRC staff member Cameron Richards will serve in these roles. As such, he will be responsible for ensuring the QA/QC objectives of the project, as outlined in this QAPP, are met. In addition, he will be responsible for maintaining project files and filing project documents, project correspondence, sample integrity data sheets, chain of custody forms, field report forms, field and equipment notebooks, generated data and other associated and pertinent project information. In summary, the Program Quality Assurance Officer will:

- Review documents for quality control when submitted, ensuring that data recording procedures have been carried out as per this QAPP;
- Ensure that hardcopy data entries (calibration dates, field checks, etc.) are converted to an electronic database;
- Maintain and backup the master database for the project;
- Review the adherence of the monitoring and laboratory analysis portions of the project to the stated quality objectives;
- Coordinate and respond to the review of External Quality Assurance Managers; and
- Assist in project reporting of these items.

External Quality Assurance Manager. The External Quality Assurance Manager will provide an independent review of the project both in terms of technical procedures and data quality. CDM Smith's Zach Eichenwald will serve in this capacity as both the Technical and Data reviewer. The Quality Assurance Manager will be responsible for assessing the effectiveness of the field sampling program implementation and associated quality assurance and control activities. The purpose of this assessment is to ensure that the QAPP is implemented as prescribed and that appropriate responses are in place to address any non-conformances and deviations from the QAPP. Specific duties of the Quality Assurance Manager include:

- Conduct Field Audits, as described in Section 20.2;
- Review Laboratory Audits, as described in Section 20.3;
- Ensure that proper corrective actions are taken (Section 20.4);
- Review data validation and usability procedures and documentation, conducted by Program Quality Assurance Officer; and
- Review measurement performance criteria results, produced by Program Quality Assurance Officer, Section 7.2.

The External Quality Assurance Manager, in terms of both technical and data review, will be an independent reviewer.

Analytical Laboratories. The Upper Blackstone Lab, the Environmental Analysis Laboratory (EAL) at UMass Amherst, and the UMass Dartmouth Coastal Systems Program Lab will provide analytical support of water samples collected during this investigation. If additional labs are needed, the QAPP will be amended as necessary. The contacts at the Upper Blackstone Lab, EAL, and UMD labs are Timothy Loftus, Cameron Richards, and Sara Sampieri Horvet, respectively. Each analytical laboratory has identified both a Lab Quality Assurance Officer and a Lab Technical Manager for the project. Their duties will be as described in Section 19. The Program Quality Assurance Officer is responsible for assuring that the Quality Assurance Plans for their respective laboratories is adhered to and that the quality assurance and quality control criteria stipulated in this QAPP is achieved and documented for all analyzed samples. Laboratory technical staff is responsible for sample analysis and identification of corrective action. None of the labs used in this project are state-certified by MassDEP.

5. Problem Identification / Background

5.1 Problem Definition and Background

5.1.1 Study Background

The study was initiated in 2003 with the objective of developing key planning documents necessary for monitoring and modeling in the Upper Blackstone watershed. During this period, the study team developed a framework for evaluating the relative impacts of the following:

- Phosphorus and nitrogen in the effluent from the Upper Blackstone wastewater treatment plant,
- Phosphorus, nitrogen, and bacteria from other point sources and diffuse sources in the Upper Blackstone basin, and

- The likely in-stream effect of various mitigation/abatement plans for these pollutant sources.

From 2004 – 2006, monitoring was conducted as specified in the 2005 Upper Blackstone FSP. In addition to the development and implementation of a watershed-monitoring plan for the Blackstone River, a computer simulation model was refined to enhance understanding of the causal mechanisms and fate of nutrients in the Blackstone River Basin. The modeling effort built on earlier work conducted by the U.S Geological Survey (USGS), and included simulation of river flows and water quality using the Hydrologic Simulation Program - Fortran (HSPF).

During the period between 2007 and 2010, the model calibration was refined per recommendations suggested by the Technical Advisory Committee (TAC). In particular, the calibration and validation incorporated data collected by USGS and MassDEP in 2007 and 2008.

Since 2011, the river has been monitored annually for nutrients and associated indicator parameters such as chlorophyll-a and dissolved oxygen. In 2011, data on dissolved nutrients and chlorophyll-a were collected monthly at 14 mainstem locations from May through November. Mid-month, additional samples were collected at 11 mainstem locations only for chlorophyll-a analysis. In 2012, the focus shifted to total nitrogen and phosphorus, subspecies, and chlorophyll-a, with the sampling sites and sampling schedule remaining the same. Periphyton sampling was incorporated into the monitoring program, occurring at 8 sites in August and September. In 2013, the number of monthly monitoring locations was reduced to 9 and the additional mid-month chlorophyll-a sampling was dropped. Three sites were sampled for periphyton in June, July, August, and September. In 2017 and 2019 continuous temperature and dissolved oxygen data loggers were deployed at four locations during the growing season.

This QAPP was developed to cover the 2020 Sampling Season Scope of Work as well as sampling anticipated in 2021 and 2022. In 2020, monthly routine sampling for nitrogen, phosphorus, and chlorophyll-a as well as hand-held meter measurements (dissolved oxygen, temperature, pH, and conductivity) will continue from April through November at 9 locations. In addition, the continuous temperature and dissolved oxygen data loggers will be deployed from approximately June through October (conditions permitting).

Table 1 summarizes the various phases of the project since it began in 2003. A QAPP was submitted to MassDEP in 2004 outlining sampling and analysis procedures for river samples collected in 2004-2006. A revised QAPP addressing comments provided by MassDEP was submitted in August 2005 (UMass and CDM Smith, 2005). The QAPP covering the period 2014 – 2016 was submitted in April 2015 and subsequently revised based on comments and approved in June 2015. The QAPP covering the 2017-2019 period was revised several times during that period.

Table 1: Summary of Blackstone River Monitoring and Modeling Study

Dates	Phase	Activities
2003 – 2004	I	Project framework development
2004 - 2006	II	▪ HSPF water quality model development, calibration, and validation ▪ **Water quality monitoring 2005** - Parameters o Bacteria (fecal coliform, *E. coli*, enterococci) o Total nutrients (phosphorus[1], orthophosphate[2], nitrogen, nitrate/nitrite, ammonia, total suspended solids, chlorophyll-a) o Total and dissolved heavy metals (cadmium, copper, lead, zinc) o Biochemical oxygen demand (BOD) - Dry weather event o Upper watershed (above confluence with the Quinsigamond River) - 5 upper watershed tributaries - 4 mainstem locations in upper watershed - 1 point source o 5 mainstem locations in Massachusetts o 1 tributary (Quinsigamond River) - Three wet weather events o Same locations as dry weather, plus an addition of 1 point source - Continuous in situ monitoring for physical data at 9 locations, including 5 headwater tributaries and 5 mainstem locations ▪ **Water quality monitoring 2006** - Same parameters as in 2005 - Dry weather event o Upper watershed (above confluence with Quinsigamond River) - 6 upper watershed tributaries - 4 mainstem locations in upper watershed - 1 point source o Massachusetts mainstem (confluence with Quinsigamond River to state line) - 5 mainstem locations - 4 point sources - 3 tributaries o Rhode Island - 3 tributaries - 3 mainstem locations - Two wet weather events o Upper watershed (above confluence with Quinsigamond River) - 3 mainstem locations - 2 point sources - 1 tributary o Massachusetts mainstem (confluence with Quinsigamond River to state line) - 5 mainstem locations - 3 tributaries o Rhode Island - 3 tributaries - 2 mainstem locations - Continuous in situ monitoring for physical data at 9 locations o 1 upper watershed tributary o 2 mainstem locations in the upper watershed above confluence with the Quinsigamond River

		o Quinsigamond River outlet o 4 mainstem locations in Massachusetts between the confluence with Quinsigamond River and the state line o 1 mainstem Rhode Island location
2007 - 2010	III	▪ Data analysis ▪ Work with Technical Advisory Committee (TAC) ▪ Refinement of HSPF model calibration ▪ Incorporation of data collected by USGS and MassDEP in 2007 and 2008
2011	IV	▪ Water quality monitoring - April – November monthly dissolved nutrient and chlorophyll-a data at 14 mainstem locations - "Off" bi-weekly sampling at 11 mainstem locations for chlorophyll-a
2012	V	▪ Water quality monitoring - April – November monthly total nutrient and chlorophyll-a data at 14 mainstem locations - "Off" bi-weekly sampling at 11 mainstem locations for chlorophyll-a - Periphyton sampling in August and September at 8 sites - Collection of in-situ continuous physical data (pH, conductivity, turbidity, and dissolved oxygen) the week of periphyton sampling at 4 locations
2013	VI	▪ Water quality monitoring - April – November monthly total nutrient and chlorophyll-a data at 9 mainstem locations - Periphyton sampling in June, July, August and September at 3 sites - Collection of in situ continuous physical data (pH, conductivity, turbidity, and dissolved oxygen) the week of periphyton sampling at 2 locations
2014	VII	▪ Water quality monitoring - April – November monthly nutrient and chlorophyll-a data at 9 mainstem locations - Periphyton sampling in June, July, August and September at 4 sites - Collection of in-situ continuous physical data (pH, conductivity, turbidity, and dissolved oxygen) the week of periphyton sampling at 2 locations - Macroinvertebrate sampling 5 locations
2015	VIII	▪ Water quality monitoring - April – November monthly nutrient and chlorophyll-a data at 9 mainstem locations - Periphyton sampling in July, August and September at 4 sites - Macroinvertebrate sampling at 5 locations - In situ physical data collected at each site on the day of sampling (pH, conductivity, turbidity, and dissolved oxygen).
2016	IX	▪ Water quality monitoring - April – November monthly nutrient and chlorophyll-a data at 9 mainstem locations - Periphyton sampling in July, August and September at 4 sites
2017	X	▪ Water quality monitoring - April – November monthly nutrient and chlorophyll-a data at 9 mainstem locations - Periphyton sampling in July, August and September at 4 sites - Continuous water temperature and dissolved oxygen monitoring at 4 sites from June through November
2018	XI	▪ Water quality monitoring - April – November monthly nutrient and chlorophyll-a data at 9 mainstem locations

		- Periphyton sampling in July, August and September at 4 sites
2019	XII	▪ Water quality monitoring - April – November monthly nutrient and chlorophyll-a data at 9 mainstem locations - Point data collected at each site on the day of monthly sampling (water temperature, pH, conductivity, and dissolved oxygen) - Continuous data for water temperature and dissolved oxygen at 4 mainstem locations July through October

1 Dry weather events and first wet weather event did not include; both total and dissolved phosphorus were added starting with the 2nd wet weather event. 2 Both total and dissolved orthophosphate was analyzed for during wet weather events

5.1.2 Description of Existing Conditions

The Blackstone River originates at the confluence of the Middle River and Mill Brook in Worcester, Massachusetts. It flows southeast for 48 miles into Rhode Island where it discharges into the Seekonk River. The Seekonk River discharges into the Providence River, which flows into Narragansett Bay. The mainstem of the Blackstone River is joined by six major tributaries: Quinsigamond River, Mumford River, West River, Mill River, Peters River, and Branch River, as well as many smaller tributaries. The Blackstone River watershed, shown on Figure 2, has an area of approximately 480 square miles. The watershed consists of over 1,300 acres of lakes and ponds including the largest, Lake Quinsigamond. Several reservoirs in the northwest portion of the basin are used for the City of Worcester water supply. Several 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) and the National Centers for Environmental Information (NCEI), also shown on Figure 2.

The Blackstone River Valley of Massachusetts and Rhode Island is the "Birthplace of the American Industrial Revolution." A farming and milling area in colonial days, the Blackstone River Valley was transformed into one of the 19th century's great industrial areas. With a 430-foot drop in elevation from Worcester, MA, to Providence, RI, the river was an excellent place to locate mills in the days before steam or electricity turned machinery. Water powered textile mills proliferated up and down the river. During the transformation from farm to factory economy, the river became polluted and its course was altered by intense industrial activity and settlement along it. The many dams, canals and other human interventions resulted in a river very different from its original free-flowing state. Nineteen of the dams are still in place today, and the presence of these dams influences the flow and quality of the river. In its natural, free flowing condition, water took approximately 5 days to travel from Worcester to Providence during periods of low river flow. Now, because of the impoundments, it could take almost a month for water to travel this same distance during low river flow conditions.

There are nine wastewater treatment facilities (WWTFs) that discharge into the Blackstone River watershed. The largest facility, in terms of average effluent flow volume, is the Upper Blackstone WWTF, which is located near the headwaters of the Blackstone River. The Woonsocket WWTF is the second largest plant in the watershed and is located in Rhode Island. Other WWTFs that discharge to the river include: Grafton, Northbridge, Burrillville, Uxbridge, Hopedale, Douglas, and Upton. In order to meet National Pollutant Discharge Elimination System (NPDES) permits, which are jointly issued by EPA and MassDEP, most WWTFs that discharge to the Blackstone River have incorporated advanced treatment upgrades.

In fall 2009, Upper Blackstone completed upgrades to its wastewater treatment facilities to meet more stringent discharge limits set by EPA and MassDEP in 2001. The 2001 permit established a seasonal (April through October) total phosphorus (TP) limit of 0.75 mg/L. Recognizing that nitrogen removal could be required in the future to control algal problems in Narragansett Bay, Upper Blackstone concurrently upgraded the plant to achieve total nitrogen treatment to 8-10 mg/L, consistent with limits then being imposed on other dischargers.

Upper Blackstone's current NPDES permit was issued in August 2008, with two modifications occurring in April 2009 and July 2010. The permit's nutrient limits became fully effective in May 2014 with an Administrative Order on Consent (AOC) that established interim limits for total phosphorus and total nitrogen as well as a schedule for compliance. The interim limits in the AOC required a total nitrogen level of 5.0 mg/L and a total phosphorus level of 0.1 mg/L for all 'dry' weather flows in each of the summer months by the end of October 2019. In addition, the AOC requires Upper Blackstone to examine options for achieving permit limits during 'wet' weather flows. A number of innovative measures to improve plant performance in the near-term have been piloted since 2014.

Reductions in the total phosphorus and nitrogen loads leaving the Upper Blackstone facility have been reflected in lower river total phosphorus and nitrogen concentrations and loads (Hatte et al., 2019). While exact values vary slightly from year-to-year, phosphorus has been reduced by 80 - 90% compared to previous levels. Nitrogen has been reduced by 57 - 61%.

MassDEP and the Rhode Island Department of Environmental Management (RIDEM) each maintain a list of impaired waters for sections of the river under their jurisdiction (MassDEP, 2019; RIDEM, 2018). The mainstem of the Blackstone River is considered impaired in Massachusetts due to total phosphorus and, in some sections, nutrient/eutrophication biological indicators and will require development of a TMDL, although no timeline for development has been set (Massachusetts Division of Watershed Management Watershed Planning Program, 2015). The Rhode Island mainstem is considered impaired due to total phosphorus. The timeline for completion of a TMDL in RI has been set for 2024, however in their 2014 303d list, RI DEM notes that the need for a TMDL will be determined post WWTF upgrades (RI DEM, 2015). While it is not clear why the two states have addressed TMDL development plans in slightly different ways (e.g., no TMDL schedule for nutrients in MA; TMDL scheduled for TP in RI, but with a qualifier that the need will be reassessed), both states appear to be acknowledging the disconnect between the 303(d) list publication date, ongoing WWTF upgrades, and the timeframe over which data utilized for the assessment is collected. For example, the data collection surveys upon which the 2014 MA assessments are based were conducted prior to the Upper Blackstone upgrades, and as such may not reflect current river conditions. The most recent water quality surveys by MassDEP on the Massachusetts portions of the Blackstone River were conducted in 2008 (MassDEP, 2008).

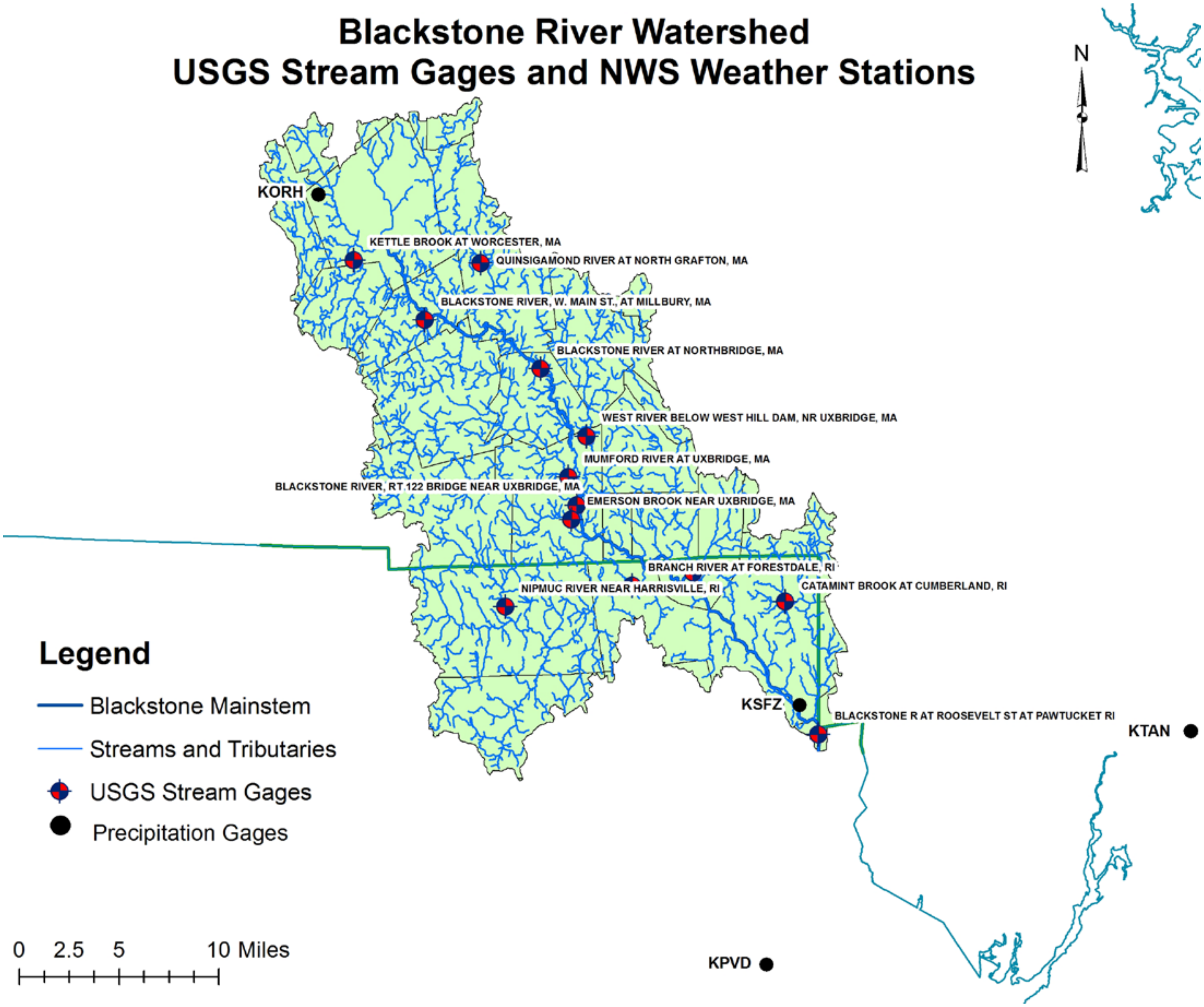

Figure 2 : Blackstone River watershed, USGS streamflow and NCDC precipitation gages

6. Project Purpose/Task Description

6.1 Study Purpose

Specific objectives for the 2020 - 2022 monitoring programs are to:

- Build upon earlier work conducted by Upper Blackstone, MassDEP, USGS and others;
- Support future analysis, if needed, of river water streamflow and water quality;
- Collect data to assess changes in riverine water column nutrient and chlorophyll-a concentrations and nutrient loads as well as some physical and chemical parameters through comparison against historical data; and
- Collect continuous dissolved oxygen data in the vicinity of the Upper Blackstone facility discharge to the river, in order to document the river's status with regard to its stated uses.

These objectives were used to select sampling locations as well as suitable sampling methods, analytes, measurement techniques, and analytical protocols with the appropriate quality assurance and quality control guidelines.

As necessary, additional field monitoring programs in the watershed may be specified in accordance with the procedural and quality-assurance guidelines in this QAPP. If necessary, this QAPP may be amended (following its approval) to include procedural and quality-assurance guidelines for additional water quality constituents or indicators, such as biological indicators, sediment toxicity, etc. Any amendments will be presented for review and approval to the QAPP reviewers listed at the beginning of this document.

6.2 Task Description

The overall goal of the field sampling program is to provide an accurate and representative picture of the current water quality conditions, relative to historical data for similar flow conditions, at specific sampling stations in the Blackstone River watershed. The environmental data collected under this task may be used as input to extend the water quality and hydrologic/hydraulic model of the Blackstone River that was developed, calibrated, and validated earlier in the study. The data may also help inform the development of future 303(d) impaired waters lists and TMDLs.

6.2.1 Study Area

The study area covered by this QAPP and the associated FSP is defined as the roughly 480 square mile watershed area upstream of Slater Mill Dam, located on the Blackstone River near Main Street in Pawtucket, RI. Data collection efforts are focused along the 48-mile mainstem of the river, extending from Slater Mill Dam to Worcester, upstream of the Upper Blackstone effluent channel.

The mainstem Blackstone River is joined by many small tributaries, as well as six major rivers: the Quinsigamond River, the Mumford River, the West River, the Mill River, the Peters River, and the Branch

River. The watershed consists of over 1,300 acres of lakes and ponds; the largest is Lake Quinsigamond in Shrewsbury and Grafton. Monitoring of these water bodies is beyond the scope of this study.

6.2.2 Field Sampling Program

This QAPP is designed to be an overarching document while yearly FSPs will provide the salient details for each sampling season. This QAPP is designed to cover the range of sampling activities anticipated under the Study. However, amendments to this QAPP will be made as necessary to include additional parameters and/or methodologies.

Individual FSPs will be developed for each year of the monitoring program. The FSPs are intended to provide the specifics with respect to the sampling location and frequency, sampling program logistics, schedule, sampling methods, field designation, and health and safety requirements. The sampling locations for 2020 are shown in Figure 3 and **.** In general, the monitoring programs include the following elements:

- Routine in-stream water quality sampling and subsequent analysis for nutrients (detailed below),
- Routine hand-held meter data collection,
- Continuous water quality collection with data loggers, and
- Download of basic hydrologic data (e.g., precipitation and streamflow data) from USGS and NCEI data sources.

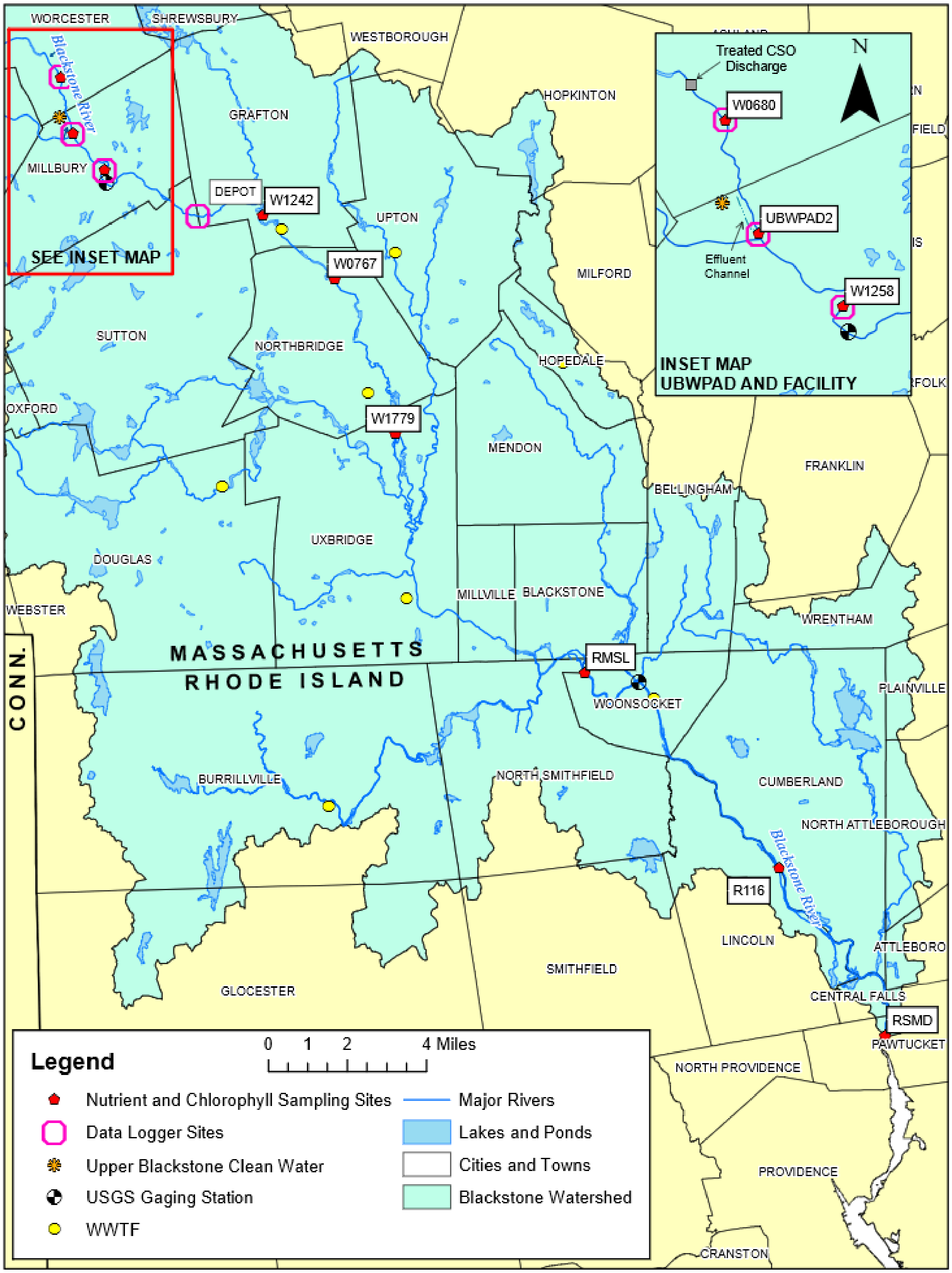

Figure 3: Current Field Sampling Sites

Table 2: 2020 Sampling Sites (all sites located on the main stem)

Site ID#	Site Name	Lat	Lon	River Mile[2]
RMSD-h[1] RMSD-n[1]	Slater Mill Dam, historical site Slater Mill Dam, new site Pawtucket, RI	41.876909[5] 41.879836[6]	-71.381940[5] -71.381556[6]	0.0
R116[1]	Rte 116 Bikepath Bridge, Pawtucket, RI	41.938066	-71.433769	6.3
RMSL[1]	State Line, RI	42.009974	-71.529313	15.5
W1779	Below Rice City Pond Sluice Gates, Hartford St., Uxbridge, MA	42.097270	-71.62241	27.8
W0767	Sutton St. Bridge, Northbridge, MA	42.153922	-71.652521	33.4
W1242	Route 122A, Grafton, MA	42.177153	-71.687964	36.3
DEPOT[4]	Depot St., Sutton, MA	42.177	-71.720	38.0
W1258[4]	Central Cemetery, Millbury, MA	42.19373	-71.76603	42.7
UBWPAD2[4]	New Confluence site, downstream of effluent canal	42.20702	-71.78154	44.6
W0680[3, 4]	New Millbury St Bridge, Worcester, MA	42.22784	-71.78762	45.9

[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] W0680 is located between the Worcester CSO discharge and UBWPAD2. The Worcester CSO enters the river downstream of the confluence of Mill Brook and the Middle River at approximately river mile 46.4

[4] Location of data logger deployments

[5] Historical RMSD site, will be sampled periodically in 2020 to determine whether the proposed new site is comparable to the historical site

[6] Proposed new site for RMSD starting in 2020

7. Quality Objectives and Criteria

Environmental data and streamflow measurements to be collected by the study team in support of the Blackstone River Watershed Assessment Study will meet the quality objectives outlined in this section. The specific quality assurance objectives and the measurement performance criteria serve as the basis for the annual FSP (Appendix H). This section provides overall guidelines as to the minimum requirements for quality control, whereas the FSP presents detailed information on locations, methods, and frequencies for environmental measurements and sample collection.

7.1 Data Quality Objectives

Data Quality Objectives (DQOs) are qualitative and quantitative statements that specify the characteristics of data required to support defensible decisions relating to specific environmental problems. DQOs are based on the end uses of the data to be collected; as such, different data uses may require different type and level of data quality. The data collection and analysis procedures will therefore be designed to meet the most stringent DQOs.

The following overriding DQOs have been developed for the Blackstone River Watershed Assessment Study:

- Collect water quality data to determine the likelihood that waterbodies in the Blackstone River Watershed meet state water quality standards;
- Collect water column data sufficient for identifying changes in water quality over time;
- Collect data to support assessment of the biological health of the river;
- Collect water quality data necessary to estimate the net daily and seasonal flux of pollutants along select reaches of the river; and
- Collect water quality data sufficient for the calibration and validation of computer models[1] to simulate pollutant loading, transport, and in-stream fate and distribution.

These objectives are used to select sampling locations, as specified in the annual Field Sampling Plan, as well as suitable parameters, sampling methods, measurement techniques, and analytical protocols with the appropriate quality assurance and quality control guidelines.

State Water Quality Standards

Both Massachusetts and Rhode Island categorize waters according to their use class. Each class is associated with a series of designated uses; the ability of a water body to support these uses is assessed based on its ability to meet the applicable water quality standards. In Massachusetts, these uses include fish consumption, aquatic life support, drinking water, shellfishing, primary contact recreation (swimming), and secondary contact recreation (boating). In Rhode Island, these uses include freshwater and seawater uses for fish and wildlife habitat, drinking water (freshwater only), primary and secondary contact recreation, and shellfishing (freshwater only).

Table 3 provides a summary of water quality guidelines as well as available data on background concentrations for constituents included in the monitoring program. It should be noted that neither Massachusetts nor Rhode Island have published numerical nutrient criteria, so the values listed in Table 3 are subject to change. These guidelines will be used to assess the likely compliance/non-compliance status of the waterways in the Blackstone River Watershed per the second DQO. All waterways in the watershed are classified Class A, the most stringent class designated for human consumption and shellfish harvesting, or Class B and Class SB, designated for primary and secondary contact recreational

[1] The HSPF Water Quality Model is calibrated to model total phosphorus (TP), orthophosphate, total nitrogen (TN), total ammonia, total inorganic nitrogen, nitrate-nitrate, chlorophyll-a, (chl-a) and dissolved oxygen. To enable validation of the model if it is extended beyond 2011, collection of additional data for these parameters is necessary. It is typically assumed that routine monitoring will capture the impacts of both dry and wet weather. For further information on the HSPF Water Quality Model, please see the Blackstone River HSPF Water Quality Model Calibration Report (UMass and CDM Smith, 2008), the Blackstone River HSPF Water Quality Model Calibration Report Addendum (UMass and CDM Smith, 2011), and the Blackstone River HSPF Model Validation Report (UMass and CDM Smith, 2011). All are available upon request.

activities in freshwater and saltwater, respectively. All classes include supporting fish and wildlife habitat.

Table 3: Water Quality Guidelines and Nutrient Background Concentrations

Metric	Acceptable Range	Rational for Metric	Source
Seasonal Mean Chlorophyll-a	< 10 µg/L	Target applied in Lower Charles TMDL	US-EPA (2007)
Peak Chlorophyll-a	< 18.9 µg/L	Target applied in Lower Charles TMDL	US-EPA (2007)
Chlorophyll-a Concentrations	< 3 µg/L	N.H. river guidance – "Excellent" conditions	NHDES
	3 – 7 µg/L	N.H. river guidance – "Good" conditions	NHDES
	7 – 15 µg/L	N.H. river guidance – "Less than desirable" conditions	NHDES
	> 15 µg/L	N.H. river guidance – "Nuisance" conditions	NHDES
	< 4.9 µg/L	New England Interstate Water Pollution Control Commission	NEIWPCC (2001)
Total Phosphorus	< 25.0 µg/L	EPA-within lakes or reservoir	US-EPA (1986)
	< 50.0 µg/L	EPA-entering lakes or reservoirs	US-EPA (1986)
	< 100.0 µg/L	EPA-in streams or other flowing waters not discharging directly to lakes or impoundments	US-EPA (1986)
	< 23.75 µg/L	EPA Ecoregion XIV, Subregion 59, 25th percentile guidance, all seasons	US-EPA (2000)
	< 25.0 µg/L	EPA Ecoregion XIV, Subregion 59, 25th percentile guidance, TP summer	US-EPA (2000)
	< 50.0 µg/L	EPA Ecoregion XIV, Subregion 59, 50th percentile guidance, TP summer	US-EPA (2000)
	< 28.0 µg/L	USGS 25th percentile guidance for Ecoregion XIV	Zimmerman & Campo (2007
	< 30.0 µg/L	USGS 25th percentile guidance for MA nutrient Ecoregion "High", which includes Blackstone	Zimmerman & Campo (2007
	< 20.0 µg/L	New England Interstate Water Pollution Control Commission median of four seasonal 25th percentiles, Northeastern Coastal Zone	NEIPCC (2003)
Total Nitrogen	440.0 µg/L	Eutrophication threshold utilized by OARS	OARS (2014)
	< 610.0 µg/L	EPA Ecoregion XIV, Subregion 59, 25th percentile guidance, TN calculated all seasons	US-EPA (2000)
	< 570.0 µg/L	EPA Ecoregion XIV, Subregion 59, 25th percentile guidance, TN reported all seasons	US-EPA (2000)
	< 440.0 µg/L	EPA Ecoregion XIV, Subregion 59, 25th percentile guidance, TN summer	US-EPA (2000)

	< 740.0 µg/L	EPA Ecoregion XIV, Subregion 59, 50th percentile guidance, TN summer	US-EPA (2000)
	< 583.0 µg/L	USGS 25th percentile guidance for Ecoregion XIV	Zimmerman & Campo (2007
	< 642.0 µg/L	USGS 25th percentile guidance for MA nutrient Ecoregion "High", which includes Blackstone	Zimmerman & Campo (2007
	< 560.0 µg/L	New England Interstate Water Pollution Control Commission median of four seasonal 25th percentiles, Northeastern Coastal Zone	NEIPCC (2003)
Conductivity	150-1500 µmhos/cm	EPA summary of studies of stream supporting good mixed fisheries	EPA
Dissolved Oxygen	≥5.0 mg/L ≥6.0 mg/L	Class A: ≥6.0 mg/L unless background conditions are lower Class B: ≥5.0 mg/L unless background conditions are lower	MassDEP Massachusetts Surface Water Quality Standards 314 CMR 4.00 (2013)
pH	6.5 – 8.3	MassDEP Surface Water Quality Standards	Massachusetts Surface Water Quality Standards 314 CMR 4.00 (2013)
Temperature	<20°C <26.7°C <26.7°C <28.3°C	Class A: < 83°F (28.3°C) and Δ1.5°F (0.8°C) for warm water fisheries, <68°F (20°C) cold water fisheries Class SB: <85°F (29.4°C) nor a maximum daily mean of 80°F (26.7°C) and Δ1.5°F (0.8°C) between July through September and Δ4.0°F (2.2°C) between October through June	Massachusetts Surface Water Quality Standards 314 CMR 4.00 (2013)

7.2 Measurement Performance Criteria

Measurement performance criteria, including the precision, accuracy, completeness, comparability, and representativeness of the data, will be used to assess the quality of all environmental measurements in relation to the DQOs. In order to meet the quality assurance objectives, the data must be (1) of known quantitatively measured precision and accuracy; (2) representative of the actual site in terms of physical and chemical conditions; (3) complete to the extent that necessary conclusions may be reached; and (4) comparable to previous and subsequent data collected under this program. Both field and laboratory quality objectives are addressed in each section. The percent frequency for each QC parameter can be found in **Table 4**.

Table 4: Quality Control Percent Frequency

QC Parameter	Frequency	Sample Parameters
Field Blank	10% each collection	TP, chl-a, dNH_4, dNOx, dTN, TSS, TOP, SC
Lab Blank	10% each collection	TP, chl-a, dNH_4, dNOx, dTN, TSS, TOC, SC
Field Duplicate	10% each collection	TP, chl-a, dNH_4, dNOx, dTN, TSS, TOC, SC
Field Split	10% each collection	TP, chl-a, dNH_4, dNOx, dTN, TSS, TOC, SC
Performance Test	10% each collection	TP, TOP, dNOx, $dNH_{4,}$ pH
Equipment Blank	10% first collection and an additional collection mid-season	TP, chl-a, dNH_4, dNOx, dTN, TSS, TOC, SC
Calibration (accuracy for hand-held meters)	Before and after each collection Before and after sampling season	DO, pH Temp
Meter comparison (precision for hand-held meters)	After each collection	DO, pH, Temp

7.2.1 Precision

The precision of a measurement is the degree to which two or more measurements are in agreement. Precision is quantitative and is most often expressed in terms of Relative Percent Difference (RPD). RPD is calculated for each pair of duplicates as indicated below:

$$RPD = \frac{(S - D) \times 100}{(S + D)/2}$$

where:

S = First sample value (original or matrix spike value)
D = Second sample value (duplicate or matrix spike duplicate value)

Field Precision Objectives

Field precision for measurements taken in the field with hand-held meters will be assessed by measuring a sample of river water at the laboratory with both instruments concurrently, at the end of each sampling day (once every 9 measurement, or 10%). Quality assurance precision objectives for field measurements are listed in Table 5.

For Data Logger measurements, DO and temperature precision will be assessed as follows: During the sampling season (at least biweekly), measurements of water temperature and dissolved oxygen will be taken with a hand-held meter next to the data logger at each site. The data will be downloaded from the logger, and results compared between data logger and hand-held meter. The difference between the hand-held meter and the data logger indicates the cumulative impact of fouling and meter calibration drift and will be used to evaluate meter precision.

Table 5: Quality Assurance Precision and Accuracy Objectives for Field Measurements

Parameter	Precision (RPD)	Accuracy
Water Temperature	≤ 5%	± 5% or 0.3 ˚C
Dissolved Oxygen	≤ 5%	± 5% or 0.3 mg/L
pH	± 0.2	± 0.2

For collected samples, field precision is assessed by analysis of duplicate and split samples. The results of the duplicate and split analyses are used to assess the degree of precision in the field samples. Duplicate samples will be bulk samples collected from the stream in two different bottles, collected at the same time and side-by-side at the sampling location. Split samples will be aliquots split from the same bulk sample bottle and submitted to the laboratory for analysis. Note that field split samples are distinct from lab replicate samples. Field precision for samples analyzed in the laboratories will be assessed at the rate of ten percent, or one duplicate for every 10 samples collected. The RPD will be calculated per the above equation.

Quality assurance precision objectives for field measurements are listed in Table 6.

Table 6: Quality Assurance Precision and Accuracy Objectives for Laboratory Analytical Analyses

Parameter[1]	Field Precision (RPD)[2]	Lab Precision (RPD)[2]	Accuracy (%R)[3]	Field Blank Cleanliness[4]
Water Column				
Total Phosphorus	≤ 30%	≤ 20%	80-120%	< RL
Total Orthophosphate	≤ 30%	≤ 20%	80-120%	< RL
Chlorophyll-a[5]	≤ 30%	≤ 20%	80-120%	< RL
Dissolved Ammonia-N	≤ 30%	≤ 20%	80-120%	< RL
Dissolved Nitrate/Nitrite	≤ 30%	≤ 20%	80-120%	< RL
Total Dissolved Nitrogen	≤ 30%	≤ 20%	80-120%	< RL
Particulate Organic Nitrogen	≤ 30%	≤ 20%	80-120%	< RL
Total Nitrogen[6]	≤ 30%	≤ 20%	80-120%	< RL
Total Suspended Solids	≤ 30%	≤ 20%	80-120%	< RL
Specific Conductance	≤ 30%	≤ 20%	80-120%	< RL

[1] Please refer to Section 10 for further discussion on the analyzed water column parameters and methods utilized for each laboratory;

[2]RPD= Relative Percent Difference

[3]%R= Percent Recovery

[4] RL= Reporting Limit

[5] Precision for chlorophyll shall be ± 2.0 if less than 15 µg/L or 30% RPD if more than 15 µg/L

[6] UMD does not directly measure total nitrogen, but rather calculates it as the sum of TDN and PON

Laboratory Precision Objectives. Precision in the laboratory is determined by the comparison of laboratory-generated replicate samples, where replicates result from an original aliquot sample that has been split for identical purposes. The precision is evaluated by determining the RPD of duplicate (replicate) analyses, as provided in the equation above. Specific laboratory precision requirements are discussed in the applicable analytical SOP and/or laboratory Quality Assurance Plan. Precision goals for each water quality parameter are provided in Table 6. Laboratories will be requested to provide their internal QA/QC data, including lab replicate results. In general, however, release of the data will indicate that the laboratory precision objectives have been met, as certified by the lab quality assurance officer.

7.2.2 Accuracy

Accuracy is defined as the extent of agreement between an observed value (*i.e.* sample result) and the accepted, or true, value of the parameter being measured. Accuracy is quantitative and is usually expressed as the percent recovery (%R) of a sample result as indicated below:

$$\%R = \frac{(A - B) \times 100}{C}$$

where: A = Analyte concentration determined experimentally with known quantity of reference material added

B = Background determined by separate analysis of sample or, in the field, a blank

C = True value of reference or standard added

Field Accuracy Objectives. Accuracy of water quality sample collection activities will be assessed using field blanks and by adherence to all sample handling, preservation, and holding times. Field blanks consisting of distilled, deionized water will be submitted to the analytical laboratories at a rate of ten percent, or one blank per ten samples collected. Field blank cleanliness requirements are provided in Table 6.

An equipment blank is intended to assess the contamination caused by sampling and processing equipment. Equipment blanks will be collected and analyzed under two circumstances: (1) when a cleaning procedure is followed for the first time; and (2) initial equipment blanks will also be run any time new procedures or equipment are used. These pre-sampling equipment blank checks will be conducted in a controlled field or laboratory setting.

Suitable deionized water will be collected and stored in a suitable and appropriately labeled (e.g., “Source Solution Blank” or “Blank”) bottle. An aliquot will be taken from the source solution blank water and adequately preserved as per the analyte. If the Blank Water is purchased, the date and lot number of the blank water will also be recorded and the same lot will be used for the entire procedure.

For equipment blanks, the source solution will then be taken through each phase of the sampling process for the analyte (as needed), saving sequential sample blanks. Initially only the first stage equipment blank will be submitted for analysis. If the data for all of the analytes come back from the laboratory at acceptable levels, then the equipment blank is acceptable and no further work is required. The sequential samples will then be discarded. If all or some of the data come back higher than acceptable levels, the previously collected sequential blanks will be submitted to the laboratory for analysis. The data from these sequential samples will be used to identify the source of contamination detected in the equipment blank, and remedial measures will be taken to eliminate it. The process will then be repeated. These steps should be evaluated in either field or laboratory conditions, depending on where sample processing will occur for the environmental samples.

Testing of equipment will be carried out for each type of sampler (split method and analyte) once per sampling season. Specific procedures for each sampler type are provided below.

To evaluate grab samples, source water will be poured into the sample bottle at the sampling site, then transported, preserved, and split in the same manner as regular river samples.

Quality assurance accuracy objectives for field measurements are listed in Table 6.

Field accuracy for measurements performed in the field with hand-held meters will be assessed by calibrating probes first thing in the morning on sampling days, and checking the probes against calibration samples or buffers upon return to the lab that day. For pH, a Quality Control sample manufactured at UMass EAL will also be used to assess accuracy. Data quality objectives for field measurements are listed in Table 5.

For Data Logger measurements, DO and temperature accuracy will be established with calibration of the data loggers prior to deployment. In addition, the data loggers will be pulled out of their housing (at least biweekly) and cleaned. To evaluate meter calibration drift, water temperature and dissolved oxygen will be measured with the hand-held meter next to the data logger before and after pulling the data logger out of the water for cleaning. If the RPD between the data logger data and the hand-held meter data are not within the greater of +/- 0.5 mg/L or 5% for DO or the greater of +/- 0.2°C or 5% for water temperature, the data logger will be retrieved from the site and re-calibrated.

Laboratory Accuracy Objectives. Laboratory accuracy is assessed through the use of known standards, such as Laboratory Control Samples (LCS), and matrix and analytical spikes. Accuracy within the laboratory is expressed in terms of percent recovery (%R). Specific laboratory accuracy requirements are discussed in the applicable analytical Standard Operating Procedure and/or laboratory Quality Assurance Plan. Accuracy goals with acceptance limits for applicable analytical methods are provided in Table 6.

In addition, a limited number of PE samples (one per sampling event) will be used as a double-blind evaluation on the respective laboratory's performances for the following parameters: total phosphorus (TP), total orthophosphate (TOP), dissolved nitrate/nitrite (NO_{23}), and dissolved total ammonia (dNH_4). The PE samples will be purchased from an outside PE manufacturer and will be provided with a known quantity of analyte.

One set of PE samples will be incorporated within the batch of river samples and submitted blindly to the laboratories during each sampling event. The laboratory's analytical results will be compared to the known analyte concentrations provided by the PE manufacturer.

7.2.3 Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained for that measurement under normal conditions. Events that may result in a reduction in measurement completeness include sample breakage during shipment, inaccessibility to proposed sampling location, and sampling equipment errors.

Field Completeness Objectives
Field completeness is a measure of how many valid results were obtained from field measurements. The Field Sampling Plan (Appendix H) specifies the number of field and laboratory measurements to be made during the program. The completeness criterion for all in situ measurements (including continuous dissolved oxygen, temperature) and analytical analyses is 90 percent (i.e., 90 percent of the planned samples must be collected and accepted for analysis) during sampling events.

The completeness criteria may also be violated if a group of samples is missing from one sampling region, such as one sampling reach or all source characterization samples, even if the missing samples total less than 10 percent of the samples collected during the event.

Resampling may be required if the completeness criteria are not met for a specific field activity. In the event of a catastrophic failure (one site or loss of all samples for an analyte), it will be resampled if feasible. Best professional judgment will be used in utilizing resampled data due to likely differences in environmental conditions.

Laboratory Completeness Objectives
Laboratory completeness is a measure of the amount of valid measurements obtained from all the samples submitted by the Project Team for each sampling activity. The laboratory completeness criterion is 95 percent. Note that the number of sampling events may be reduced due to unforeseen conditions, including pandemics.

7.2.4 Representativeness

Representativeness expresses the degree to which data accurately and precisely typify a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. One of the primary objectives of this field sampling program is to obtain water quality data that is representative of conditions in the Study Area.

Measures to Ensure Representativeness of Field Data
Representativeness is dependent upon the proper design of the field sampling program. These performance criteria will be met by ensuring that the sampling protocols listed in the FSP are followed. Additionally, the FSP will be developed considering the DQOs established herein and the appropriateness of sampling locations, sampling protocols, and water quality constituents. The sampling network designed and specified in the FSP will provide data representative of the designated study area for the expressed purposes of the water quality and flow monitoring activities.

Measures to Ensure Representativeness of Laboratory Data
Representativeness in the laboratory is ensured by the use of proper analytical procedures, following "good laboratory practices," meeting sample holding times, and analyzing and assessing field duplicates. Upper Blackstone and EAL have Quality Assurance Plans and follow written SOPs for each analytical analysis.

7.2.5 Comparability

Comparability is an expression of the confidence with which one data set can be compared with another. Data collected in one segment of the watershed may be compared to data from another area to allow for the relative comparison of water quality parameters between stations.

Measures to Ensure Comparability of Field Data

Comparability of data is assured by a properly designed field sampling program and is satisfied by following proper sampling protocols as outlined in the FSP. For this program, data comparability is assured by the use of identical sampling, measurement, analytical and data reporting methodologies in accordance with documented procedures.

Measures to Ensure Comparability of Laboratory Data

Comparable analytical data results from employing identical sampling and analytical methods as documented in this QAPP. Comparability of analytical data will be assessed under the supervision of the Project Manager.

8. Training Requirements and Certification

This investigation includes only standard field sampling techniques, field analyses, laboratory analyses, and data evaluation techniques. Specialized training is therefore not required. The UMass Field Program Coordinator is experienced in the standard protocols for surface water sampling using the equipment discussed in this QAPP and associated Field Sampling Plan; however, members of the sampling teams for individual sampling events may require additional training.

Individual certifications relevant to implementation of this plan will thus be conducted as outlined in the SOPs. In general, this will require that members of the project team have read the SOPs and any associated equipment manuals or procedures produced specifically for this project and have demonstrated the ability to follow the outlined procedures.

In addition to training staff in water sampling procedures, a tour of the sampling sites will be completed, if possible, for any new staff. A coordination meeting or conference call will be conducted prior to the commencement of each field sampling event to brief members of the sampling team on any updates to the sampling procedures. A run-through of sampling procedures, QC procedures, and sample-splitting procedures will be part of each training session.

All laboratory personnel are trained in accordance with the procedures outlined in their respective Quality Assurance Project Plans. The QAPPs for the EAL laboratory at UMass and the Upper Blackstone Laboratory have been submitted along with this QAPP under separate cover.

9. Documents and Records

This section of the QAPP describes how project data and information will be documented and tracked from its generation in the field to its final use and storage. This will ensure data integrity and defensibility.

9.1 QAPP Distribution and Version Control

The Project Manager will be responsible for distributing copies of the approved QAPP and any subsequent revisions to individuals on the Distribution List. In addition, UMass will maintain on file a complete copy of the original document and all revisions of the QAPP, including addenda and amendments.

Document control procedures will be used to identify the most current version of the QAPP. Each revision will be differentiated with a new revision number and date. The following document control information is included in the top right-hand corner of each page in this QAPP:

- Title of the document (abbreviated)
- Revision number and document status (i.e., draft, interim, final)
- Date of original or current revision

A Project Personnel Sign-Off Sheet will be used to document that all members of the Project Team have read the QAPP and will perform the tasks as described. UMass will maintain the Sign-Off Sheet. The following information will be required:

- Project personnel name, title, contact number, and signature
- Date QAPP was reviewed
- QAPP acceptable as written (Yes/No)

9.2 Data Reporting and Retention

Proper documentation of field and laboratory activities is essential for the attainment of the Data Quality Objectives outlined for this study. Data reporting is the detailed description of the data deliverables used to completely document the analysis, quality control measures, and calculations.

Data acquired in the field will be reported after reduction and evaluation by the responsible technical staff. Data from laboratory analyses will be reported after the data are reviewed, assessed for quality assurance, and the data usability is assessed based on guidance provided in subsequent sections of this QAPP. Preliminary data will not be released as a part of this Study. All data will be evaluated prior to distribution.

9.2.1 Project Documentation and Records

UMass will maintain a Final Evidence File, which will be the central repository for all documents that constitute evidence relevant to sampling and analysis activities as described in this QAPP and associated

Field Sampling Plan. Table 7 presents a summary of sample collection records, field analysis records, laboratory records, and data assessment records that will be contained in the file.

UMass will have the responsibility of implementing and maintaining a document control system. All members of the Project Team will be responsible for project documents in their possession while working on a particular task.

Electronic copies of all project files and deliverables, such as electronic databases, will be routinely backed-up and archived. The Technical Memorandum, or annual report, to be prepared at the conclusion of the field sampling program will be submitted to Upper Blackstone electronically as text in Microsoft Word. All data, reports, and materials obtained and/or created under this task will be turned over to Upper Blackstone at the completion of the project.

9.2.2 Field Analysis Data Package Deliverables and Reporting Formats

The Field Analysis Data Package Deliverables will include the list of items provided in Table 7 under "*Sample Collection and Field Analysis Records.*" Field crews will be instructed to document all activities associated with site visits and sampling efforts, including unusual and anomalous conditions, which will be used during data interpretation and analyses.

All field documentation will be recorded on standardized data collection forms developed specifically for the Blackstone River Watershed Assessment Study, or in field logbooks.

Field Data Collection Forms

Field data collection forms will be used to document equipment calibration, sample collection activities, field changes to procedures, and habitat and site conditions. Additionally, forms will be completed to document staff training in relevant sampling and monitoring procedures. Copies of the Field Data Collection Forms are included in this document as Appendix E.

The field data collection forms are grouped into the following categories:

- Staff Training and Field Program Coordination (Appendix A)
- Equipment Calibration/Inspection (Appendix B)
- Field Collection Forms (Appendix E)
- Chain of Custody Documents (Appendix F)

Field Logbooks

Field logbooks will be used to document all investigation and data collection activities performed at the site that are not covered by the aforementioned standard forms. The logbooks will be permanently bound and paginated prior to the initial entry for the purpose of identifying missing pages after completion. Logbooks will be maintained by members of the Project Team, in accordance with SOP-DOC-001, "Field Logbook Content and Control."

Table 7: Project Documents and Records

Sample Collection and Field Analysis Records
Field and/or lab logbooks
Field data collection and analysis forms
Chain-of-custody (COC) records
Corrective action reports
Field QC checks and QC sample records
QAPP and Field Sampling Plan
Laboratory Records
COC Records
Data summary reports
Corrective action reports
QC checks and QC sample results
Data Assessment Records
Field sampling audit checklists and reports
Field analytical audit checklists and reports
Fixed laboratory audit checklists and reports
Data validation reports
Corrective action reports
Progress reports
Final reports

9.2.3 Laboratory Data Reporting Package and Reporting Formats

Final laboratory data reports will be issued to the Monitoring Program Coordinator within one to two months of the sample receipt, depending on the constituent. Electronic data deliverables will also be provided whenever possible.

The Laboratory Analysis Data Package Deliverables will be provided in a format similar to that required by EPA's Contract Laboratory Protocol. This includes, but is not limited to the following, as appropriate for the respective analyses:

- Chain-of-custody forms (signed)
- Sample Receipt Log-in and Checklist Forms
- Analytical Results (including time, date, and appropriate qualifiers)
- Method Blank Results and Raw Data
- Sample Matrix Spike/Matrix Spike Duplicate Results and Raw Data (per request)
- Laboratory Control Sample Results and Raw Data (per request)
- Laboratory Duplicate Results and Raw Data (per request)

10. Sampling Process Design

The FSPs will provide specifics as to the type and number of samples required, the exact sampling locations and frequencies, and sampling methods. All field sampling programs developed for the project will be designed to meet the Data Quality Objectives discussed in Section 7, "Quality Objectives and Criteria."

The following section provides a general overview of sampling network design and rationale for the design developed for the Blackstone River watershed.

10.1 Study Area Definition

For the purposes of this Blackstone River Watershed Assessment Study, the Study Area has been defined as the entire Blackstone River watershed in both Massachusetts and Rhode Island upstream of Slater Mill Dam on Main Street in Pawtucket, Rhode Island, as shown in Figure 1-3. The Study Area consists of the Blackstone River and its tributaries in addition to lakes and reservoirs in the watershed.

The focus of the Blackstone River Watershed Assessment Study is to evaluate the overall health of the Blackstone River and to understand the river response to upgrades and nutrient optimization at the Upper Blackstone WWTF. To achieve this goal, we have selected monitoring locations at key mainstem monitoring locations upstream and downstream of the WWTF effluent channel. The six Massachusetts monitoring locations (W0680, UBWPAD2, W1258, W1242, W0767, and W1779) are located in a section of the Blackstone River with few major tributary inputs, so the addition of tributary sampling would not significantly change the understanding of water quality dynamics along this section of river.

The FSPs will provide detail regarding the specific study area definitions for each phase of the sampling program.

10.2 Field Monitoring Activities

Field monitoring activities anticipated under Upper Blackstone FSPs include:

- Routine in-stream water quality sampling and subsequent laboratory analysis for a select set of parameters
- Measurement of a select set of parameters with hand-held meters
- Continuous monitoring for temperature and dissolved oxygen during the months of June through October.

The water quality parameters selected for analysis in this study were chosen based on the DQOs described in Section 7. The focus of the 2020 - 2022 QAPP is on nutrients and associated indicators of river biological health such as dissolved oxygen.

Table 8 provides a summary of the field and analytical analyses included as part of the Blackstone River Watershed Assessment Study. All water columns samples will consist of discrete samples - no composite or flow-weighted sampling is planned.

Water temperature, dissolved oxygen, and pH will be measured in the field at each sampling site with a hand-held meter. Measurements will be recorded on the field data sheet.

Table 8: Anticipated Field and Analytical Analyses

Field Measurements
Water Temperature Dissolved Oxygen pH
Analytical Measurements
Nutrients and Impacts Total Phosphorus (TP) Total Orthophosphate (TOP) Dissolved Nitrate/Nitrite (dNO_{23}) Dissolved Ammonia-N (dNH_4) Total and Total Dissolved Nitrogen (TN, TDN) Particulate Organic Nitrogen (PON) Total Suspended Solids (TSS) Specific Conductance (SC) Chlorophyll-a

In addition, four data loggers will be deployed in June to continuously measure water temperature and dissolved oxygen at four monitoring sites. The data loggers will be removed in late October.

Nutrient sampling will be confined to mainstem run-of-river locations, including some located a short distance downstream from major impoundments. Samples will be collected routinely each month for nutrients, including phosphorus, nitrogen, and chlorophyll-a, regardless of weather conditions. Monthly sampling will typically occur April through November. Three Rhode Island sites along the mainstem of the Blackstone River will be co-sampled with the Narragansett Bay Commission (NBC) following the handling procedures outlined per this QAPP, with field splits sent to both the NBC and Upper Blackstone laboratories for analysis.

Samples will be analyzed at either the Upper Blackstone laboratory, the UMass Dartmouth Coastal Systems Program Analysis Laboratory or the UMass Environmental Analysis Laboratory depending on parameter. At *all locations*:

- Samples retained at UB will be analyzed for total suspended solids (TSS), total orthophosphate (TOP), and specific conductance (SC);
- Samples sent to EAL will be analyzed for chlorophyll-a (chl-a) and total phosphorus (TP);
- Samples sent to UMD will be analyzed for dissolved total ammonia nitrogen (dNH_4), dissolved nitrite/nitrate nitrogen (dNO_{23}), particulate organic nitrogen (PON), and total dissolved nitrogen (TDN), while total nitrogen (TN) will be calculated, Table 9.

Specific details regarding the sampling schedule, the number and type of samples required, and the sampling locations and frequencies will be discussed further in the respective annual Field Sampling Plans developed for this project.

Table 9: Parameters calculated based on lab results

Lab	Parameter	Calculation[1]
UMD	Total Nitrogen	TN = TDN + PON

1: Half the detection limit will be utilized in the calculation when laboratories report results for constituent parameters below the reporting limit.

10.3 Adequate Conditions for Sampling

Water column measurements and samples for nutrients, field parameters, and chlorophyll-a will be collected on a set day each month selected to coincide with monitoring conducted by NBC. Sampling will occur regardless of environmental conditions. Sampling will typically occur on a Wednesday, but some changes to the schedule may occur due to state holidays.

11. Sampling Methods

This section describes the procedures for collecting samples and identifies the specific sampling equipment and performance requirements, sample preservation requirements, and decontamination procedures. Also addressed are the procedures for identifying sampling or measurement system failures and for implementing corrective actions.

11.1 Sample Collection, Preparation, and Decontamination Procedures

Table 10 provides a summary of the specific SOPs that may be used during the field monitoring program; copies of these SOPs are provided in the appendices. The use of SOPs will ensure the collection of accurate, precise, and representative samples, as well as helping to ensure data comparability and usability. It is anticipated that personnel will have project specific recommendations for update of the SOPs. These recommendations will be incorporated as appropriate into the current SOPs and made part of the project record.

The field program will not require the use of any new or innovative procedures or sampling techniques. Study area-specific sample collection and preparation procedures will be provided in the annual Field Sampling Plans; these documents will reference the SOPs as appropriate.

Table 10: Summary of SOPs for Sample and Measurement Collection

Document Name	**Title**
SOP-DOC-001	Field Notebooks – Contents and Control
Step-by-Step Field Sampling Instructions	Field Sampling Protocol
SOP-FLD-013	Collecting Field Parameters Using a Hand-held Multiparameter Probe
SOP-FLD-014	Field Measurement of Water Temperature and Dissolved Oxygen with Hobo Data Logger

11.1.1 Manual Sampling

Samples will be collected manually. This is an acceptable method for the analytes covered under this QAPP because contact with air will not impair integrity of the samples.

Manual bulk sample containers as well as aliquot bottles will be prepared as specified by the analytical laboratory for each analyte. Bulk sample bottles that are reused for each event will be washed with non-phosphate detergent, and then filled with DI water for storage between sampling events. The conductivity of the DI water in the bottle will be checked prior to use to ensure no leaching from the bottle has occurred. Standard procedure will be to dispose of the DI storage water after testing for conductivity the week of sampling, and then to pre-rinse the bulk sample bottles three times with stream water prior to collecting the sample. Aliquot bottles will be prepared and tested the same way, regardless of whether they are re-used or discarded after a single use.

Typically one bulk sample will be collected and aliquots for the individual laboratory analyses will be prepared from this bulk sample. After collection, all samples will be cooled to 4 $\pm$2°C, or as otherwise directed by the analytical lab, and secured for storage and transport as soon as possible. Samples for chlorophyll-a analysis will be collected separately in a dark bottle to prevent light penetration. One field split and one field duplicate will be collected during each routine sampling event and analyzed for the same parameters as the regular samples at those sites. Splits will consist of separate aliquots taken from the same sample bottle and sent to the lab as an individual aliquot (field split). Duplicates will consist of bulk samples collected side by side (field duplicates) and processed as individual aliquots. Each laboratory will be expected to also run laboratory duplicates (from a single aliquot bottle).

Samples will be collected directly from the river, by using a pole from shore, or by sampling container or pump from a bridge When samples are to be collected directly from shallow streams or rivers (wading), the sampling location will be approached from downstream. The water sample will be collected upstream and perpendicular to the sampler's position to avoid contamination. The sample will be collected by grasping the bottle at its base, submerging it in the water with the mouth pointing upstream (so that any contamination from the sampler's hand or the outside of the bottle is washed away from the bottle), and allowing the bottle to fill. Ideally the bottle cap will be removed after the bottle is submerged in the water, and the mouth of the bottle will be kept under the surface as it is filling. While filling, the inside of the bottle cap and bottle inlet will be kept free from contamination; the bottle cap will not be set down nor the inside surface touched. The cap will be loosely tightened while the bottle is underwater and then removed from the stream. If necessary, a small portion of the sample will be discarded to ensure sufficient airspace at the top of the bottle (approximately one inch). If samples are collected using a pole from the bank, the sample bottle is securely affixed to the pole and is submerged in the river. Finally, samples are collected from bridges using a a sampling container. The sampling container is a Nalgene 4-L wide-mouth HDPE bottle attached to a rope and reel. It is used every collection at W0767, W1242 and W1258. The sampling container is washed and rinsed in the lab in the same manner as bulk bottles, and rinsed three times with river water at the sampling site before collecting a sample. See the Field Sampling Plan in Appendix H for a detailed description of sampling steps. At the three sites co-sampled with NBC staff, the Upper Blackstone samples will be filled using a peristaltic pump fitted with clean tubing provided by NBC. The field sampling sheet will indicate the sampling methodology used at each site.

11.1.2 Filtration

Table 11 provides an overview of the preparation of filtered samples. Samples at all sites will be field filtered with Millipore (SLGP033RS) 0.22-micron filter units attached to a Millex-GP syringe for analysis of the nitrogen series at UMD. A new syringe and filter unit will be utilized at each site. Each syringe will be rinsed with sample water then filled with a filter attached. The filter will be primed by wasting 20 mL of sample through the filter. The sample bottle will be rinsed with the next 20 mL through the syringe, then the remaining 20 mL will be added to the bottle as a filtered sample. The filter will be removed from the syringe and replaced with a clean filter. The syringe will again be filled with sample water, then 20 mL wasted to prime the filter, and the remaining 40mL added to the sample bottle. Once per collection, a field blank sample is filtered on site in the same manner as regular river samples.

Samples for chlorophyll-a analysis will be filtered as soon as possible, generally within 4 hours, through a 47 mm diameter Whatman GF/F 0.7 µm pore size glass microfiber filter in the lab. Filtering for chlorophyll-a will be conducted at the Upper Blackstone lab rather than in the field in order to more carefully control environmental conditions, such as exposure to sunlight, during filtering than could be in the field.

Table 11: ***Summary of Sample Filtration***

Parameter	Filter	Sites	Filtering location	Staff filtering
dNO_{23}	0.22 µm	All	Field	UMass (5 sites), UB (4 sites)
dNH_4	0.22 µm	All	Field	UMass (5 sites), UB (4 sites)
TDN	0.22 µm	All	Field	UMass (5 sites), UB (4 sites)
Chl-a[1]	0.7 µm	All	UB Lab	UMass

1 Sample analyzed is filter residue, not the filtrate.

11.1.3 Stream Mixing Conditions

To avoid potential incomplete mixing, all sampling locations will be selected such that they are hydraulically uniform, sufficiently distant from point sources and tributary confluences, and downstream of sufficient ripples to be well mixed.

11.1.4 Decontamination Procedures

All materials used during the collection of water quality samples will be decontaminated (washed with non-phosphate detergent) between samples and after use according to the appropriate SOP and as summarized in Table 12. The bottles will be filled with DI water after washing and the conductivity tested after 24-hours. Bottles with conductivity results above 2 microsiemens will be rejected. Bottles that pass will be emptied, allowed to air dry, then capped and stored for the next event. All aliquot bottles, with the exception of those received from UMD, will be similarly washed, tested, and dried. At least two spare bottles will be available each sampling trip in case of mishap.

Table 12: ***Sampling Container Decontamination Procedures***

Sample type	Container	Decontamination	Staff
Sampling bucket	4 L, plastic	Phosphate-free soap	UMass
Bulk sample container	4 L and 6 L, plastic	Phosphate-free soap	UMass
Chl-a	500 mL, amber plastic	Phosphate-free soap	UMass
TP	125 mL, amber plastic	Phosphate-free soap and acid wash	UMass
TOP	237 mL, plastic	New, DI rinse	UMass
TSS, SC	1 L, plastic	New, DI rinse	UMass
dNH_4, dNO_{23}, TDN	60 mL, plastic	Acid wash	UMD
PON	1 L, plastic	Acid wash	UMD

11.2 Sampling SOP Modifications

The SOPs provided in the Compendium to this QAPP have been adopted from the standard operating procedures used by various members of the Project Team, the USGS, state environmental protection agencies, and various sources.

11.3 Sampling/Measurement System Failure Response and Corrective Action

This section describes the sample and measurement system failure response and corrective action procedures that will be undertaken during field and laboratory activities.

11.3.1 Field Corrective Actions

Variation from established procedure requirements may be necessary due to unique circumstances encountered on individual projects. Corrective action in the field may be required when a modification is made to the sampling network (i.e., due to changes in the frequency or number of samples taken or changes in sampling locations), or when sampling procedures or field analytical methods require modifications due to unexpected conditions.

Any member of the Project Team may identify a problem requiring corrective action; the field staff in consultation with the Monitoring Program Coordinator will then recommend the correction action to the Project Manager. The Project Manager will approve the corrective measure, which will be implemented by the members of the Project Team. The Project Manager will inform Upper Blackstone and the Monitoring Program Coordinator of the problem and corrective action.

The Project Manager may authorize field staff to initiate variations as necessary. If practical, the request for variation shall be reviewed by the Project Manager prior to implementation, as discussed above. If prior review is not possible, the variation may be implemented immediately at the direction of the Monitoring Program Coordinator, provided that the Project Manager is notified of the variation within 24 hours of implementation, and the Field Change Request is forwarded to the Project Manager and QA Manager for review within two working days of implementation. If the variation is unacceptable to either reviewer, the activity shall be re-performed or action shall be taken as indicated in the "Comments" section of the Field Change Request.

All variations from established procedures shall be documented on the Field Change Request forms and reviewed by the Project Manager and the Monitoring Program Coordinator. All sampling or measurement system failures and resulting corrective actions will also be accurately documented in the field logbooks. All completed Field Change Requests shall be maintained in the project records. A Field Change Request form can be found in Appendix E.

11.3.4 Laboratory Corrective Actions

Corrective action in the laboratory may occur prior to, during, or after initial analyses. A number of conditions, such as broken sample containers, multiple phases, low/high pH readings, and potentially high concentration samples may be identified during sample log-in or just prior to analysis. The bench chemist will identify the need for corrective action. The Lab Manager or Technical Manager, in consultation with the laboratory staff, will approve the required corrective action for implementation by the laboratory staff.

All corrective actions shall be performed prior to the release of the data from the laboratory. The corrective action will be documented in both the laboratory's corrective action file and the narrative data report sent from to the Project Manager. If the corrective action does not rectify the situation, the laboratory will contact the Project Manager.

12. Sample Handling and Custody

This section of the QAPP describes the procedures by which sample custody will be maintained by all members of the Project Team and by the analytical laboratories. Also described are the sample handling and transport procedures that will be employed throughout the project.

12.1 Sample Labeling

Sample labels will be attached to individual sample aliquots for each investigation or quality control sample. The Monitoring Program Coordinator or a designated Task Leader will be responsible for ensuring that all lab processing labels are affixed to the aliquot bottles prior to event mobilization. Alternatively, labels may be affixed when processing samples. These may facilitate filling in additional information, such as the sample collection time and sampler name, which may be difficult if labels are wet. The decision on when to affix laboratory processing labels will be dictated by the number of aliquots and samples collected, the experience of the Field Team, and the need to minimize the potential for mislabeling.

Large volume sample bottles will be used to collect water (unless otherwise noted for select analytes) either directly from the river, with a sampling pole, a bucket, or via a pump and tubing. These bottles will thus also need to be labeled. The Monitoring Program Coordinator or designated staff will be responsible for printing these labels. Field staff will be responsible for affixing the labels when samples are collected (by hand) or set up in preparation for event sampling.

Each label will contain the following information:

- Sampling site ID - Sites co-located with former MassDEP sampling locations will utilize the MassDEP site ID; because sampling sites may change from year to year, the list of sampling site IDs is not provided in the QAPP, but in the annual FSP
- Additional fields will be appended to the sample site ID to identify the type of sample:
  - G = Grab sample
  - FS = Field split
  - FD = Field duplicate
  - LB = EAL lab blank
  - FB = EAL field blank
  - B9 = Blank, SMAST 60 mL pre-filled, left unopened
  - B10 = Blank, SMAST 1 L pre-filled, left unopened
  - B11 = Blank, 60 mL bottle left unopened, returned empty to UMD
  - EB = Equipment blank
- P = Performance evaluation sample
- Sampling date and time
- Aliquot labels will also include:

- The lab running the analyses
- The parameters to be analyzed and associated method and detection limit
- Preservation information
- Filtration information, and
- Bottle type.

Additional detail regarding the sample labeling system is provided in the FSP, including example labels.

12.2 Chain-of-Custody Procedures

Each sample must be properly documented to ensure the timely analysis of all parameters requested and to track the progress of the samples in the laboratory. To this end, chain-of-custody forms will be completed for all samples collected. Copies of the chain of custody forms are included in Appendix F. The forms will be filled out by the respective sampling teams at the end of each sampling round or as sample processing occurs, if the forms cannot be protected from inclement weather. When transferring sample custody, the individuals relinquishing and receiving the samples will sign, date, and note the time on the record.

The forms document the transfer of sample custody from the sampler to another person, to the permanent or mobile laboratory, or to/from a secure storage area. Representatives from both the Project Team and the laboratories will retain a copy of the forms. The chain-of-custody forms will be kept until all data has been received from the laboratories.

Specific laboratory custody procedures are described in Upper Blackstone's, UMD’s, and EAL's Quality Assurance Plans, including:

- Chain-of-custody procedures for assuming control of field samples,
- Detailed sample log-in procedures,
- Detailed internal sample tracking procedures,
- Procedures for internal transfer of sample custody,
- Specifications for sample storage,
- Disposal procedures for samples, extracts, and digestables, and
- Procedures for custody of analytical data and final data storage.

12.3 Sample Handling and Packaging

All grab samples will be collected in clean, bulk sample bottles prepared by UMass in accordance with the applicable SOPs (and briefly described above). This includes acid washing for TP sampling bottles. Water samples will be placed as soon as possible in coolers with sufficient ice to meet holding requirements. To ensure proper temperature storage of samples on sampling day, a 500 mL bottle filled with tap water will be added to each cooler before setting out to sample. The temperature of the water in this bottle will be measured when the cooler arrives at the UB laboratory.

At the UB laboratory, aliquots for individual analyses will be processed as soon as possible from the main sample. All aliquots will be preserved in accordance with specified analytical guidelines.

Table 13 summarizes the required sample volumes, collection containers, holding times, and preservatives for each water quality parameter. The column denoted "Group" identifies the aliquot bottle from which water for each analysis will be drawn. Additional information is provided in the respective laboratory and field SOPs for each analyte. Lab SOP requirements take precedence over those listed in either this QAPP or the field SOPs.

The split samples will be placed in separate coolers from the main samples that are being processed. A chain-of-custody form for the samples will be placed in a waterproof, plastic bag and affixed to the inside cover of the cooler. The logistics of delivering samples to the labs is described in detail in the Field Sampling Plan.

Table 13*: Summary of Analyte Collection Container, Holding Time, and Preservative*

Analysis	Lab	Container	Handling & Preservation	Holding Time
TOP	UB	237 mL, plastic	Store at ≤6°C	48 hours
TSS	UB	1 L, plastic	Store at ≤6°C	7 days
SC	UB	1 L, plastic	Store at ≤6°C	28 days
Chl-a[1]	EAL	1 L, plastic	0.7 µm pore size glass microfiber filter, dry filter and freeze, store in dark, discard filtrate	21 days[2] (hold time up to 3 months acceptable)
TP	EAL	125 mL, plastic acid washed	TP: freeze	1 year
PON	UMD	1 L, Plastic	Store 4±2°C. Transport to UMD (lab filtered by UMD; filter analyzed, filtrate discarded)	48 hours
dNH_4, dNO_{23}, TDN	UMD	60 mL, Plastic	0.22 µm filter. Store filtrate 4±2°C. Transport to UMD	48 hours

1 Sample analyzed is filter residue, not the filtrate

2 Filters are analyzed within 21 days according to the EAL QAPP, however historical method development testing within EAL showed that samples could reliably be held up to 3 months (personal communication with Paul Godfrey, prior WRRC Director and EAL Lab Manager)

13. Analytical Methods

Analytical methods are written instructions that describe how to prepare a sample for analysis, prepare and calibrate test equipment, perform the test, and calculate results. This section of the QAPP identifies the analytical field and laboratory measurements that will be made in support of the Blackstone River Watershed Assessment Study. Detailed information on field measurement techniques is provided in the Field Sampling Plan and referenced Standard Operating Procedures (SOPs); all laboratory methods are documented in the applicable SOPs (see SOP Compendium).

13.1 Laboratory Analytical Methods

Upper Blackstone, UMD and EAL will provide effective and timely analyses of the environmental samples collected under the Blackstone River Watershed Assessment Study. The required turnaround time for laboratory reports to be provided to the Project Team is one to two months. Whenever possible, Electronic Data Deliverables shall be provided.

Table 14 presents a summary of the analytical methods, method detection limits and respective analyzing laboratory for each water quality parameter of interest.

Method Detection Limits (MDLs) are the lowest values at which a parameter can be measured using the reference method. The MDL is defined as the constituent concentration that, when processed through the complete method, produces a signal with 99 percent probability that it is different from the blank.

MDLs are developed for each particular analyte of interest and are established as targets for ensuring that the data quality obtained is adequate for interpreting the data; these MDLs are the minimum to be achieved by the laboratories. The reporting limit (RL) is defined as the lowest level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. For this project, laboratories will be responsible for calculating the RL for each analysis batch, and will report out values below their RL as “BRL.” In the database for the project, these data points will be flagged with the code “LT” (less than) and the detection limit value from Table 14 listed as the result. This value will be used in plotting; half of the MDL will be utilized for calculations.

Table 14: Summary of Analytical Methods, Laboratory Responsibilities, and Detection Limits

Upper Blackstone Clean Water		
Parameter	Method	Minimum Detection Limit
TOP	Hach 8048	20 ppb[4]
TSS	USGS I-3765-85	2 ppm
Conductivity	STD Method 2510B	0.0 µS/cm
UMass EAL		
Parameter	Method	Minimum Detection Limit
TP	STD Method 20th ed., 4500P	2 ppb
Chl-a[1c]	STD Method 20th ed., 10200 H	1 ppb
UMass Dartmouth		
Parameter	Method	Minimum Detection Limit/Minimum Reporting Limit
dNH_4[1d]	STD Method 20th ed, 4500-NH3-F	1.4 ppb/2.8 ppb
dNO_{23}[1d]	STD Method 19th ed, 4500-NO3-F	3.5 ppb/7 ppb
TDN[1d]	STD Method 19h ed, 4500-Norg	5.3 ppb/10.3 ppb
PON	EPA 440.0	10 ppb

1 Filtration for dissolved nutrients varies by lab as detailed below.

a Starting in 2015, NBC moved to lab filtration for their dissolved constituents utilizing 0.45 micron filters.

c Filtered in the lab within 4-hours of sample collection with Whatman GF/F 47 mm, 0.70 micron filter.

d Field filtered utilizing Millipore (SLGP033RS), Millex-GP Syringe 0.22-micron filter units.

3 Laboratories will be responsible for calculating the RL for each analysis batch, and will report out values below their RL as "BRL.". In the database for the project, these data points will be flagged with the code "LT" (less than) and the detection limit value listed as the result. This value will be use in plotting; half of the MDL will be utilized for calculations.

4 The Upper Blackstone lab has worked to achieve the lowest detection limit possible with their existing equipment and methodologies, however the labs primary focus is analysis of WWTF effluent. It is acknowledged that these DLs are high for riverine analysis.

Analytical methods will be performed in accordance with the applicable laboratory SOP (Table 15). The laboratory SOPs have been identified as SOP-EAL for the Environmental Analysis Lab at UMass, SOP-UMD for the UMass Dartmouth Lab, SOP-UB for the Upper Blackstone Laboratory. All equipment requirements are specified in the respective SOPs. No nonstandard laboratory analyses will be required as part of this study.

Failures in the laboratory analytical system will be addressed in accordance with Section 11.3.4, "Laboratory Corrective Actions." This section also specifies the individuals responsible for corrective action and how the effectiveness of the corrective action will be determined and documented.

Table 15: Analytical Laboratory Standard Operating Procedures (SOPs)

SOP Number	Parameter	Title
EAL Lab		
SOP-EAL-001	NA	Sample Preparation, Filtering, and Digestion
SOP-EAL-002	Chlorophyll-a	Determination of Chlorophyll-a
SOP-EAL-003	Phosphorus	Total Phosphorus Determination
UMD Lab		
SOP-UMD-001	Ammonia	Laboratory SOP: Ammonium
SOP-UMD-002	Nitrate+Nitrite	Laboratory SOP: Nitrate+Nitrite
SOP-UMD-003	Total Nitrogen/Total Dissolved Nitrogen	Laboratory SOP: Total Nitrogen/Total Dissolved Nitrogen
SOP-UMD-004	Particulate Organic Nitrogen	Laboratory SOP: Particulate Organic Carbon and Nitrogen Analysis
Upper Blackstone Lab		
SOP-UB-004	Orthophosphate	Determination Orthophosphate Hach 8048
SOP-UB-007	Total Suspended Solids	Total Suspended Solids Dried at 103 – 105°C, SM 2540 D
SOP-UB-008	Specific Conductance	Measuring conductivity in the lab with Hach 40 D Multimeter with CDC401 probe

13.2 Field Parameter Measurement Methods

Field parameters (temperature, dissolved oxygen concentration, dissolved oxygen percent saturation, and pH) will be collected at each site using a hand-held multiparameter sonde. The instrument specifications, analytical methodologies, detection limits, instrument range, and instrument precision are listed in Table 16. Measurements will be collected using a Hach HQ40D portable multiparameter probe with probes measuring pH, dissolved oxygen, and temperature.

Table 16: Field Analytical Method Instrument Specifications

Parameter	Method	Minimum Detection Limit	Range	Precision
Dissolved oxygen concentration	ASTM D888-09	0.1 mg/L	0.1 – 20.0 mg/L	+/- 0.1 mg/L, 0 to 8 mg/L, +/- 0.2 mg/L, > 8 mg/L
Temperature	SM 2550 B	0°C	0 – 50°C	+/- 0.3°C
pH	SM 4500-H+B	2 units	2 – 14 SU	+/- 0.02 units

13.3 In Situ Meter Measurement Methods

Continuous temperature and dissolved oxygen are collected at four locations. The instrument specifications, analytical methodologies, detection limits, instrument range, and instrument precision are listed in Table 17. Measurements will be collected using an Onset HOBO U26-001 Dissolved Oxygen Data Logger with probes measuring dissolved oxygen and temperature.

Table 17: In Situ Meter Analytical Method Instrument Specifications

Parameter	Method	Minimum Detection Limit	Range	Precision
Dissolved oxygen concentration	ASTM D888-05	0 mg/L	0 – 30.0 mg/L	+/- 0.2 mg/L, 0 to 8 mg/L, +/- 0.5 mg/L, 8 to 20 mg/L
Temperature	SM 2550	-5°C	-5 – 40°C	+/- 0.2°C

14. Quality Control

Quality Control (QC) is the system of technical activities that measures the performance of a process. Internal QC checks will be performed for sampling, field, and laboratory analysis to verify compliance with project investigation requirements in accordance with the Data Quality Objectives and Measurement Performance Criteria established in Section 7, "Quality Objectives and Criteria."

This following section describes the general QC procedures that have been established for the Blackstone River Watershed Assessment Study; specific information as to the location and types of quality control checks is provided in the Field Sampling Plan.

14.1 Field Sampling Quality Control Checks

The desired field precision, accuracy, and field blank cleanliness for each parameter based on the quality objectives set forth in this QAPP is provided in Table 5 and Table 6. Precision and accuracy will be calculated in accordance with the procedures established in Section 7, "Quality Criteria and Objectives." Outlier data points will be considered on an individual basis and may be qualified depending on both upstream and downstream data measurements and on concentrations measured at different times, as applicable.

Sampling quality control will be assessed based on the use of field duplicates and field blanks that will be prepared in the field and transported to the subcontractor laboratories in accordance with standard procedures. The respective laboratories will analyze the QC samples in accordance with the analytical methods at the method-required frequency.

Nutrient QAQC samples will consist of at least 1 field duplicate, 1 field split, 1 aliquot bottle blank, and 1 bulk sample bottle blank each sampling run, as described in more detail below. Additional blanks and duplicates will be added if positive blanks or duplicates outside of the acceptable precision range are noted.

14.2 Field Measurements Quality Control Checks

For hand-held meter field measured parameters, DO and pH accuracy will be established with calibration of the meters performed each sampling day before setting out to the sampling locations. In addition, measurements will be taken in buffers and air-saturated water with each meter at the lab at the end of the sampling day. Additionally, the meter probes will be checked for pH accuracy by measuring a QC sample provided by EAL.

Temperature accuracy will be established by comparing the measurements taken with the meters in an ice bath and at room temperature with an NIST-certified thermometer at the start and end of the sampling season.

Precision will be measured by comparing temperature, DO, and pH measurements side by side with both meters in the laboratory in a beaker filled with tap water or leftover river samples.

For Data Logger measurements, DO and temperature accuracy will be established with calibration of the data loggers prior to deployment. During the sampling season (at least biweekly), measurements of water temperature and dissolved oxygen will be taken with a hand-held meter next to the data logger at each site. The data will be downloaded from the logger, and results compared between data logger and hand-held meter. The difference between the hand-held meter and the data logger indicates the cumulative impact of fouling and meter calibration drift and will be used to evaluate meter precision. Note that the data loggers take readings every 15 minutes, so the readings between logger and hand-held meter may not be taken at the exact same time.

In addition, the data loggers will be pulled out of their housing (at least biweekly) and cleaned. To evaluate meter calibration drift, water temperature and dissolved oxygen will be measured with the hand-held meter next to the data logger before and after pulling the data logger out of the water for cleaning. If the RPD between the data logger data and the hand-held meter data are not within the greater of +/- 0.3 mg/L or 5% for DO or the greater of +/- 0.2°C or 5% for water temperature, the data logger will be retrieved from the site and re-calibrated. At the end of the season, when the data loggers are pulled out of the water until the following year, the loggers' DO and temperature are checked against the hand-held meter using river water in a bucket.

14.2.1 Field Duplicates

Field duplicates are co-located samples collected simultaneously at given sample locations/times. The duplicates will be carried through all phases of the sampling and analytical procedures in an identical manner to provide overall precision information for each sampling event; these samples will be submitted blindly to the laboratory. Duplicates for manual samples will be collected for all parameters analyzed in the field at a frequency of at least ten percent, or one duplicate per 10 samples.

14.2.2 Field Splits

Field splits are duplicates for laboratory analysis split from the same original bulk sample volume into separate aliquot containers. The splits will be carried through all phases of the sample processing and analytical procedures in an identical manner to provide overall precision information for each sampling event. Splits will be collected for all parameters analyzed in the field at a frequency of ten percent, or one duplicate per 10 samples.

14.2.3 Field Blanks

Field blanks will consist of laboratory grade water from multiple labs. See Section 12.1 for a list of the blank designations associated with water from each lab. The blanks will be preserved as appropriate, will accompany the samples during transport to the laboratory, and will be analyzed as appropriate. Samples will be submitted blindly to the laboratory at a rate of at least ten percent, or one blank per 10 samples. Two types of blanks will be processed each sampling period. The first type, the Lab Blank, will consist of aliquot bottles filled directly from the laboratory water source for each parameter. These blanks will provide information on both the quality of the laboratory water as well as an indication of the potential for sample contamination due to leaching from the bottles or during laboratory processing. The second type, or Field Blank, will be prepared during the sample processing stage of the field-monitoring program. Prior to sampling, one of the bulk sampling bottles will be filled with laboratory water. This bulk sample blank will travel with the field crew during sampling and will be transferred to another bulk bottle in the field, then split into separate aliquot containers for laboratory analysis back in the laboratory at Upper Blackstone. These blanks will provide information on the potential for sample contamination due to leaching from the bulk sampling bottles as well as during collection and processing of the aliquots.

14.2.4 Field Analytical Quality Control Checks

Quality control checks on all instruments used to conduct field measurements will be conducted on a pre-determined basis; specific procedures will be discussed further in Sections 15.1 and 15.2.

14.3 Laboratory Quality Control Check

Upper Blackstone, EAL and UMD will use the procedures outlined in their respective Quality Assurance (QA) Plans to ensure the reliability and validity of analytical results. Copies of these Plans have been submitted along with this QAPP under separate cover.

Compliance with the QA Plans is coordinated and monitored by the respective laboratory's QA Officer. QC samples prepared by the laboratories may include the following, as specified in the respective Plans:

- Laboratory duplicates and blanks
- Matrix spikes and matrix spike duplicates (MS/MSDs)
- Laboratory Control Standard and Laboratory Control Standard Duplicates (LCS/LCSDs)

Additional information regarding laboratory QC procedures is provided in the specific analytical SOPs (see SOP Compendium). Specific criteria for the evaluation of laboratory precision and accuracy are provided in Section 7, "Quality Objectives and Criteria," and Table 6. Any samples analyzed in nonconformance with the QC criteria will be reanalyzed in the respective laboratory if sufficient sample volume is available and the sample is still within acceptable hold time limits.

We will also purchase Performance Evaluation samples and send these to the labs blind. Performance Evaluation Tests (PETs) will be run for chlorophyll-a, TOP, TP, dNH_4, and dNO_{23}. Concentrations of the PETs will be diluted to reflect the range of concentrations expected in the river based on historical data, with a different value each month. We will utilize the results for these samples to better understand laboratory accuracy as well as differences in the inter-laboratory results.

15. Instrument/Equipment Testing, Inspection, and Maintenance

This section of the QAPP describes the procedures and documentation activities that will be performed during the field sampling program to ensure that all equipment is in working order.

15.1 Field Instruments and Equipment

The inspection, testing, calibration, and maintenance of all field equipment and instruments will be performed in accordance with the applicable SOPs as noted in Section 2.4.1.

In all cases, specific preventative maintenance procedures as defined by the respective manufacturers will be followed. Additionally, field notes from previous sampling events will be reviewed by the respective field crew and the Field Program Coordinator**,** or designated substitutes, to ensure that any previous equipment problems have been identified, and that all necessary repairs have been made.

The Field Program Coordinator, or a designated substitute, will be responsible for testing, inspection, and maintenance of all equipment prior to mobilization. The designated Project Team member will then be responsible for completing the Equipment Inspection, Testing, and Maintenance Sheets during mobilization. An example is provided in the Field Sampling Plan.

15.2 Laboratory Instruments

Each laboratory will perform routine preventative maintenance in accordance with their respective Quality Assurance Plans and with manufacturer's specifications to minimize the occurrence of instrument failure and other system malfunctions. Each laboratory will maintain factory-trained repair staff with in-house spare parts or will maintain service contracts with applicable vendors.

Records of preventative maintenance, equipment repairs and replacement, and documentation of maintenance procedures will be maintained by the designed laboratory Quality Assurance Officer, and subject to auditing by the Project Team.

16. Instrument/Equipment Calibration and Frequency

This section describes the calibration procedures that will be followed for all equipment used to conduct field and laboratory analyses to maintain reliable and accurate measurement results. All calibrations will be performed in accordance with manufacturer's recommendations.

16.1 Field Instruments and Equipment

In-situ collection of chlorophyll-a, nitrogen, and phosphate data is beyond the current scope of this study. Any further water column data collection for these parameters will be accompanied by an amendment to the QAPP. Field equipment will consist of sampling apparatus and meters.

Two Hach HQ 40 D handheld meters will be used to collect DO and pH measurements in the field. They will be calibrated the morning of each sampling day by the UB staff at the UB facility. Calibration will be documented in Upper Blackstone's calibration logbook.

In June, Onset HOBO Dissolved Oxygen (U26-001) data loggers will be deployed at four sites (W0680, UWPAD2, W1258 and Depot). They will be calibrated before deployment, and recalibrated during the monitoring season as needed.

The Field Program Coordinator, or designated others, will be responsible for ensuring that all equipment has met the required calibration standards prior to event mobilization. In the event that an internally calibrated field instrument fails to meet calibration/check-out procedures, it will be returned to the manufacturer for service.

16.2 Laboratory Instruments/Equipment

Calibration procedures and frequencies of all laboratory equipment will be performed in accordance with the respective laboratory's Quality Assurance Plans, manufacturer's specifications, analytical SOPs, and written procedures approved by laboratory management. Records of calibration method and frequency will be filed and maintained by the designated laboratory Quality Assurance Officers; these may be subject to auditing by the Project Team.

17. Inspection and Acceptance of Supplies and Consumables

All supplies to be used during the field sampling program will be inspected prior to acceptance to ensure that they are in satisfactory condition and free of defects or contamination in accordance with the methods specified in Table 18.

Table 18: Summary of Supplies and Inspection Requirements

Critical Supplies and Consumables	**Inspection Requirements and Acceptance Criteria**
Sample bottles	Visually inspected upon receipt for cracks, breakage, cleanliness, and preservation solution (as needed)
Chemicals and reagents	Visually inspected for proper labeling, expiration dates, and approximate grade
Sampling equipment	Visually inspected for obvious defects, damage, and contamination

The Monitoring Program Coordinator, or her designee, will be responsible for ensuring the acceptability of all material to be used during field activities prior to event mobilization and for implementing corrective action, if necessary. Designated personnel from Upper Blackstone and EAL will be responsible for the inspection and acceptance of all material relating to laboratory analysis.

18. Data Acquisition

All environmental measurements performed under this activity will be taken directly by the Project Team and subcontracted laboratories. Flow measurements at all stream locations other than USGS streamflow gaging sites will be estimated indirectly based on hydrologic hydraulic model data in combination with observed flow conditions at the USGS Woonsocket and Millbury stream gauging locations.

Water quality data collected by other studies and volunteer monitoring groups may be reviewed and used to evaluate general background conditions and historical trends. Since the sampling procedures and protocol for these data may have differed from the procedures specified in this QAPP, care will be given in interpreting and drawing conclusions from the data.

19. Data Management

This section describes the data management procedures that will be followed in the collection, review, and reduction of all environmental data collected as a part of the Blackstone River Watershed Assessment Study field sampling program.

19.1 Data Recording, Handling, and Tracking

This section details the computerized and manual data recording, handling, and tracking procedures that will be used during the sampling program.

19.1.1 Data Recording and Tracking

Field Data. Field environmental measurements collected by the Project Team during sampling events will be recorded in field logbooks and field data collection forms in accordance with guidance provided in Section 9, “Documents and Records.” Upon completion of the sampling event, the data collected will be transposed to a project-specific electronic database, the format of which is discussed in section 19.1.2. The transfer of data from paper (*i.e.* logbooks or collection forms) to electronic format will be performed by the Data and Document Custodian; a second individual will then spot check the entries.

Copies of all field data will be maintained by UMass in a “Final Evidence” File in accordance with the document retention and control guidelines discussed in Section 9.2.

Laboratory Data. Laboratory results will be reported in accordance with the guidance provided in Section 9.2, “Data Reporting and Retention.” All information related to sample analysis will be documented in controlled laboratory logbooks, instrument printouts, or other approved forms in accordance with the laboratory’s Quality Assurance Plan. Analytical laboratory records will be reviewed by the respective laboratory Quality Assurance Officer, and subject to auditing by the Project Team.

Prior to releasing the final data, each laboratory will employ a tiered review process. Each analyst will be responsible for reviewing the analytical and quality control that he/she has generated; the analyst will verify that:

- The appropriate methodology has been used,
- Instrumentation and equipment was functioning properly,
- QC analyses were performed at the proper frequency and the analyses met the acceptance criteria,
- Samples were analyzed within the required holding times,
- All analytes were determined within the calibration range,
- Matrix interference problems were confirmed,
- Method specific analytical requirements were met, and
- Calculations, dilution factors, and detection limits were verified.

The raw data will then be released to the respective area supervisor who will also review the data for attainment of quality control criteria as required in the applicable standard method and for overall reasonableness. The area supervisor will be responsible for generating the data summary report, which will be reviewed by the laboratory Quality Assurance Officer. This review will verify that the report format and content meet the client specifications, that the data were reported correctly, and that analytical and quality control problems were addressed and documented in the file and summary report (if appropriate). Upon acceptance of the preliminary reports by the QA Officer, the final reports will be generated and signed by the Laboratory Project Manager.

Following the receipt of the data reports by the Project Manager or her designee, all results will be transposed or uploaded to the electronic database developed for the project by a member of the

Project Team. Data transcription will be spot checked by a second member of the Team. The final database will include all the data provided by the laboratories, as well as laboratory-provided data flags, including:

- Concentrations below the required detection limits,
- Estimated concentration due to poor relative percent difference,
- Estimated concentration due to poor spike recovery or other outlying QC data, and
- Concentration of chemical also found in laboratory blank.

19.1.2 Data Handling

All data gathered or generated as part of the Field Sampling Plan will be entered into a project-specific database, developed using Microsoft Excel. Data will be organized according to the unique sampling station locations (*i.e.,* Station ID) provided in the Field Sampling Plan. Each site will be referenced based on its latitude and longitude. The database will include at a minimum:

- Station ID,
- Station longitude and latitude, and
- Along stream river mile.

The above information will remain constant between sampling events and thus will be maintained in a separate datasheet. For each collected sample, the following information at a minimum will be included:

- Station ID,
- Sampling Date (MM-DD-YYYY),
- QC sample type, if applicable,
- Parameter ID,
- Analytical results (i.e. constituent concentration),
- Units,
- Reporting limits,
- Data Qualifier (Table 18), and
- Brief field or laboratory notes (as applicable).

Additional information contained in the field and laboratory data sheets may also be converted into a separate electronic file as deemed necessary. These data include:

- Sample collection time,

- Analysis date and time,
- Stream stage at time of sample, and
- Sample method (i.e. manual in-stream or manual from bridge)

Field and laboratory analytical data will be flagged based on the results of the data evaluation described in Section 22. Table 19 presents a summary of the data qualifiers or "flags" that will be used throughout the database. For ease of data presentation for annual reports, the data may be coded through highlights and appropriate notes provided to indicate the qualifiers. Data input to the master project database, however, will be coded with the data qualifiers.

Table 19: Summary of Data Qualifiers

Flag	Description
LT	The material was analyzed for, but was not detected above the level of the associated value. The associated value is either the sample quantification limit or the sample detection limit
R	The data are rejected
NC	No code; no other codes apply
PB	Positive blank; the blank in question has a value above the MDL/RL
BD	% relative difference for field duplicate is more the +/- 20% out of bounds
EPT	% relative difference for performance test is more than +/- 20% out of bounds
BS	% relative difference for field split is more the +/- 20% out of bounds
NA	No data available
LO	Flagged by lab's internal QAQC data as possible outlier
Calc-adj	Calculated value is based on a data value changed due to a PB

Data may be rejected for a variety of reasons, including positive detections in associated blanks, discrepancies between the total and dissolved fraction of an analyte, precision and accuracy outside of the acceptable project limits, or failure of performance evaluation tests. Typically all data for an associated parameter on a given date will be flagged due to these conditions. In some instances, such as due to internal laboratory QAQC data, only samples analyzed after a problem is detected may be flagged. Data validation and usability are discussed in Section 22.

An entry in the database will be made for each parameter that was scheduled to be collected. The analytical results of parameters for which no data are available will be recorded as "NA" and will be flagged as noted in Table 20, which presents a summary of additional data descriptors which will be used to record missing results.

Table 20: Additional Data Descriptors

Flag	Description
V	Validated by laboratory
IV	Invalidated by laboratory (exceeded holding limit, not preserved correctly, etc.)
ML	Sample mishandled by laboratory (sample dropped)
MF	Sample mishandled in field (i.e. bottle dropped or broken)
NR	Not recorded

Data collected by other studies and volunteer monitoring groups may also be added to the database as the information becomes available to the project team. The data will be flagged as being collected during a separate field program. The data will be reported and cited, as necessary, to support evaluations and conclusions made during the Blackstone River Watershed Assessment Study.

All electronic data files will be stored and maintained in accordance with the procedures detailed in Section 9, "Documents and Records."

20. Assessment and Response Actions

This section of the QAPP addresses the activities required for assessing the effectiveness of the field sampling program implementation and associated quality assurance and control activities. The purpose of the assessment is to ensure that the QAPP is implemented as prescribed and that appropriate responses are in place to address any non-conformances and deviations from the QAPP.

20.1 Assessments and Response Actions

Performance and system audits of both laboratory and field activities will be conducted to verify that sampling and analysis are performed in accordance with the procedures established in this QAPP and corresponding Field Sampling Plan. Field and laboratory performance audits are performed as an independent evaluation, through a review of internal quality control checks and procedures, of the data being generated. System audits are conducted as an onsite review and evaluation of facilities, instrumentation, quality control practices, data validation, and documentation practices.

20.2 Field Audits

Internal system and performance audits of field activities (sampling and measurement) will be conducted by the Quality Assurance Manager for the project. The scope of these audits may include, but is not limited to:

- Review of field sampling and measurement records,
- Review of field instrument operating records,
- Observation of sample collection, handling, and packaging procedures,
- Maintenance of QA procedures, and
- Chain-of-custody procedures.

Field audits typically occur at the onset of field operations to verify that all established procedures are implemented. The Technical Reviewer will handle audits of this nature. The Data Review audits will involve review of field measurement records, instrumentation calibration records, and sample documentation and will be handled by the Data Reviewer. These audits will occur throughout the project.

20.3 Laboratory Audits

Internal system and performance audits will be conducted by the respective laboratories in accordance with their specified Quality Assurance Plans. The type and frequency of these audits is dictated in their Plans.

Additionally, external laboratory audits may be conducted by the Project Team if problems with the data are observed, such as errors in a laboratory's internal sample tracking.

20.4 Audit Reporting and Corrective Action

Audit reports will be generated by the responsible party (*i.e.* QA Manager) at the completion of each assessment. The audit report will identify proficiencies, deficiencies, and opportunities for improvement, as applicable.

Corrective action includes the process of identifying, recommending, approving, and implementing measures to counter unacceptable procedures or practices that result in data quality beyond the required quality control performance standards. Such actions may occur during field activities, laboratory analyses, data evaluation, and data assessment.

For noncompliance problems, a formal corrective action program will be determined and implemented at the time the problem is identified. Any nonconformance with the established quality control procedures in the QAPP and Field Sampling Plan will be identified and corrected in accordance with the QAPP. The Project Manager, or an approved substitute, will issue a Nonconformance Report for each condition. All corrective actions will be further documented in the QA section of the project deliverables.

20.4.1 Field Corrective Action

Corrective actions in the field will be implemented on a case-by-case basis. Minor response actions taken in the field to immediately correct a problem will be discussed with the respective Field Program Coordinator and documented in the field logbook. The corrective action will be verbally relayed to the Project Manager and a Field Change Form will be filled out. Major corrective actions taken in the field will require approval by the Field Program Coordinator and Project Manager prior to implementation. Such actions may include revising procedures in the field, resampling, or retesting. A Field Change Form will also be filled out.

20.4.2 Laboratory Corrective Action

Corrective action undertaken by the laboratories will be completed in accordance with the procedures outlined in each lab's Quality Assurance Plan. All corrective actions will be reported to the Project Manager and will be documented in the respective data reports for each sampling round. The laboratories will also be required to take and document corrective actions for problems identified by the Project Team.

21. Reports

During the active phases of the sampling project, UMass will submit quarterly status reports to CDM Smith and Upper Blackstone identifying the activities performed, planned activities, and updated schedules. Any issues that are encountered in between the regular reporting will be addressed through personal communication, emails, or memos as appropriate. UMass and CDM Smith will be in communication during the sampling season on a weekly to monthly basis. The Project Team will also develop annual reports to summarize the sampling events and environmental data obtained during the sampling program.

Copies of the quality assurance reports will be provided to the Upper Blackstone Technical Manager and the Lab QA Manager when data or measurement quality problems are encountered. As previously noted, all corrective actions and nonconformance problems will be documented in the field logbooks and Nonconformance Reports. These will be further detailed in the task deliverable. The project data will be submitted to MassDEP and to EPA's WQX, and annual data reports will be shared with MassDEP along with the submitted data.

22. Data Review, Verification, and Validation

This section of the QAPP addresses the data review, verification, and validation procedures and criteria to be performed by the Project Team. These procedures and criteria will identify and qualify data that do not meet the established measurement performance criteria.

One hundred percent of the data collected as part of this program will be evaluated to determine its precision, accuracy, representativeness, completeness, and comparability to field QC samples.

If extreme data problems are identified during the evaluation process, EPA and MassDEP will be notified to determine if 10 percent of the data packages should be validated in order to assure that no global data problems exist. Additional information on the evaluation methods for water quality samples analyzed in the laboratory is provided in Section 23.

22.1 Laboratory Data

Table 21 and Table 22 provide a summary of the criteria that will be used during the evaluation process to accept, reject, or qualify the data, as per the data qualifiers listed in Table 15. This table will be updated as necessary and the QAPP amended to reflect updated analysis methods.

Table 21: Data Evaluation and Validation Criteria (Part I)

PARAMETER (METHODS)	TECHNICAL HOLDING TIME	LAB CALIBRATION		BLANKS	LAB PRECISION
		INITIAL	CONTINUING		
INORGANIC PARAMETERS	Method specific (2)	Calibration curves will be evaluated for applicable methods as per laboratory specific SOPs. Data not meeting internal laboratory controls will not be reported.		< MRL If criteria not met, data for that parameter/data are coded "PB" and 5 x Rule applied (3). Data calculated from results flagged with a "PB" are flagged "Calc-adj" to indicate the calculated value is based on a data value changed due to a "PB"	As per Section 1.4.2 %RPD ≤ 20% Internal lab check

FOOTNOTES

(1) All criteria are for surface water samples unless otherwise noted.

(2) See Table 13 for holding times

(3) 5 x Rule: The highest detected concentration in a blank sample is multiplied by 5. This establishes an action level. All positive sample results for the analyte detected in the blank that are below this action level are qualified as BRL (below reporting limit). If PB, data that are ≥ 5 x PB will be flagged. Data that are ≤ 5x PB will be flagged and censored

Table 22: Data Evaluation and Validation Criteria (Part II)

PARAMETER (METHODS)	LABORATORY PERFORMANCE EVALUATION CRITERIA	LABORATORY DUPLICATES	LAB MATRIX SPIKES & MATRIX SPIKE DUPLICATES (MS/MSD)	FIELD DUPLICATES and SPLITS
INORGANIC PARAMETERS	%R 80 – 120% If laboratory fails this criterion for a blind performance test, data for that parameter/date are coded "EPT"	%RPD ≤ 20% Internal lab check – Any data reported by labs as questionable due to their internal review flagged "LO"	%R 80 – 120% Internal lab check - Any data reported by labs as questionable due to their internal review flagged "LO"	%RPD ≤ 30% If criteria not met, data for that parameter/date are coded but reported: "BS" – field split out of bounds; "BD" – field duplicate out of bounds

22.2 Data Loggers

The continuous meter data will be corrected for sensor drift following the USGS procedures in TM 1-D3 (Wagner *et al.*, 2006) at the end of the sampling program. These procedures describe when data correction is required and the maximum allowable deviation from the calibration before the data should be censored. Table 23 presents the thresholds for which data correction is required. Correction is required if the deviation between the Data Logger and hand-held meter collected from the side-by-side measurements in the river differs by the greater of the absolute temperature/concentration or percent difference. If the deviation is less than the threshold in Table 23 then the data are used without correction.

Table 23: Data Logger Correction Criteria

PARAMETER	CRITERIA – CORRECTION REQUIRED
TEMPERATURE	+/- 0.2°C or 5% (greater of)
DISSOLVED OXYGEN	+/- 0.3 mg/L or 5% (greater of)

Correction should be completed using a two-point linear algorithm, assuming that the rate of drift is constant between calibration sample points. The percentage error at each calibration point is calculated as:

$$\%C_d = 100\left(\frac{V_s - V_c}{V_c}\right)$$

where V_s is the value of the DO calibration measurement using the hand-held probe and V_c is the continuous meter reading at the same time. The percentage error should be linearly interpolated between the two sampling points, and the continuous data adjusted by the linearly interpolated percentage error. The final result is an adjusted dataset that matches the calibration points.

The data quality of the corrected dataset should be flagged based on the following criteria (Table 24).

Table 24: Continuous Meter Data Quality Flags

DATA TYPE	MEASUREMENT TYPE	EXCELLENT	GOOD	FAIR	POOR	NOT VALID
DISSOLVED OXYGEN	Conc. or % Diff.	≤ ± 0.3 mg/l or ≤ ± 5%	± 0.3-0.5 mg/l or ± 5-10 %	± 0.5-0.8 mg/l or ± 10-15%	± 0.8-2 mg/l or ± 15-20%	> 2 mg/l or > 20%
TEMPERATURE		≤ ± 0.2°C	± 0.2 – 0.5°C	± 0.5 – 0.8°C	± 0.8 – 2.0°C	> 2.0°C

Data that exceed the maximum allowable limits (flagged as "not valid") will be censored. Both the raw dataset and the corrected dataset will be maintained and submitted to MassDEP.

23. Verification and Validation Methods

One hundred percent of the data and field QC samples will be evaluated for precision, accuracy, representativeness, completeness, comparability, and sensitivity in accordance with the "Region I, EPA-New England Data Validation Functional Guidelines for Evaluating Environmental Analyses." The evaluation process will include a review of the following, as appropriate:

- Sample holding times,
- Sample preservation methods,
- Method preparation blanks,
- Laboratory duplicates,
- Matrix Spikes (MS) and/or Matrix Spike Duplicates (MSD)[2],
- Laboratory Control Samples (LCS) and/or Laboratory Control Sample Duplicates (LCSD)[3],
- Sampling and analytical procedures,
- Data usability,
- Method detection limits and reporting limits,
- Field blanks,
- Field duplicates,
- Field splits, and

[2] These data reviewed internally by labs prior to release of data

- Performance Evaluation (PE) sample results (limited).

During data evaluation, analytical data will be qualified as specified in Table 20 through Table 24. A data evaluation summary report will be generated at the completion of the evaluation effort to document the data precision, accuracy, completeness, representativeness, and comparability; an assessment of the overall data usability will also be presented. Included in an appendix to this report will be the specific sample delivery group (SDG) evaluation reports presented in tabular format; an example table is provided as Table 25.

The need for corrective action may be identified during either data evaluation or data assessment. Potential types of corrective action may include resampling by the field team (if possible) or reanalysis of samples by the subcontracted laboratory. These actions are dependent upon the ability to mobilize the field team and whether or not the data is necessary to meet the specified Data Quality Objectives.

If a Project Team assessor identifies a needed corrective action, the Project Manager will be responsible for approving the implementation of the response action. Problems that may be attributed to laboratory quality assurance issues will be brought to the attention of the laboratory's Quality Assurance Officer, who will determine what, if any, action is required. The laboratory QA Officer will be responsible for implementing and reporting the corrective action.

Table 25: Example Data Evaluation Table for Water Quality Measurements

		Precision	**Accuracy**	**Representativeness**		
Sample ID	**Collection Date/Time**	**Field Dup. Analyses %RPD**	**Perf. Eval. Test %R**	**Holding Times**	**Pres.**	**Blanks**
R116G	10/17/14 9:15 AM	9% **Acceptable**	89% **Acceptable**	Acceptable	Acceptable	Acceptable

24. Reconciliation with User Requirements

One hundred percent of the analytical data from the subcontracted laboratories will be evaluated. The Project Team will determine which data are usable for their intended purposes, as defined by the Data Quality Objectives established in Section 7.1. This review will consist of the following steps:

- Review Data Quality Objectives and sampling design,
- Conduct preliminary data review,
- Identify data limitations, and
- Draw conclusions from the data.

The measured environmental and streamflow data will be compared to the applicable water quality standards for Massachusetts and Rhode Island, as appropriate. The findings of the data reconciliation will be presented in a data report to be developed annually at the conclusion of the sampling program.

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