Water Quality in Bloody Brook and Searles Pond

Searles Pond/Bloody Brook Corridor Resilience Planning

Prepared by the Merrimack River Watershed Council

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MRWC
MERRIMACK RIVER WATERSHED COUNCIL

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1. INTRODUCTION

1.1. BACKGROUND AND RATIONALE

This water quality monitoring effort is part of the larger Searles Pond and Bloody Brook Resilience Planning effort where the cities of Methuen, Lawrence, Groundwork Lawrence, the Merrimack River Watershed Council and Pare Corp worked together to understand and provide solutions to flooding issues experienced by environmental justice communities along the Jackson Street Corridor in Methuen and Lawrence. The project was funded by a Municipal Vulnerability Preparedness (MVP) Action Grant. The MVP grant program provides support for cities and towns in Massachusetts to plan and prepare for climate change, assess climate vulnerabilities and implement projects to improve climate resiliency.[1]

Searles Pond is part of an 8.7-acre conservation parcel owned by the City of Methuen and the City is interested in understanding how the area could be better managed to provide nature-based solutions to relieving downstream drainage system capacity constraints. The pond is at the upstream end of Bloody Brook which runs in the front and backyards of residential and business properties in Methuen before it goes underground in Lawrence. Localized flooding of Bloody Brook creating property damage and forcing road closures - including at the busy Jackson St./Swan Street intersection near the Lawrence line - are regularly occurring 2-3 times each year during flash rainstorms, according to Methuen Department of Public Works.

During the summer months, sections of Searles Pond have high levels of algae and invasive plant growth, which impacts aquatic habitats and local water quality. During routine investigations for MS4 permitting requirements, the EPA has found high bacteria levels from Bloody Brook.[1] They did not conclude the source was from outfalls, suggesting nonpoint source pollution as a potential issue. Additionally, in previous studies, Groundwork Lawrence identified multiple locations in Bloody Brook with *E. coli.* concentrations well above the safe limit for recreational use (235 cfu/100 mL), as well as at a site in the Spicket River which is downstream of the confluence with Bloody Brook (at Nina Scarito Park).[2,3] Bloody Brook is within an urban watershed, where likely a large portion of the bacteria and other pollution in the Brook is linked to nonpoint sources, and delivered to the Brook by runoff after rain events. Flooding events may expose residents and business owners to flooded storm water, and potential contaminants it carries, but nature-based solutions to flooding may also improve water quality issues.

With climate change forecasts predicting more frequent and intense precipitation storms in Northern Massachusetts, the rate and extent of flooding disruptions will increase. According to climate projections, annual precipitation in the Merrimack Basin in Massachusetts is expected to increase by between 1.87" and 2.5" by 2030 and between 3.98" and 4.37" by 2090 over a baseline annual amount of 44"[4]. The frequency of heavy precipitation events of over 1" is also projected to increase from 7 days per year to 8-11 days per year by 2090.[5] Data collected by the National Oceanographic and Atmospheric Administration show that four out of the five wettest

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[1] Learn more about the MVP program by visiting www.mass.gov/municipal-vulnerability-preparedness-mvp-program

years on record occurred within the past 25 years.[6] An increase in precipitation due to climate change will lead to a larger contribution of runoff, and therefore will not only exacerbate the existing flooding issue, but also the contribution of nonpoint source pollution to the Brook.

Naturally-functioning stream ecosystems and flood plains contribute to important processes like nutrient uptake, flood mitigation, regulating microclimates and air humidity, and buffering extreme air temperatures[7]. When a wetland is largely covered by impervious surfaces like roads, buildings and parking lots, it is unable to carry out these functions. Restoring a watershed's natural functions can increase climate resilience for the surrounding community but also benefit the ecosystem within the stream. While urban streams have fewer ecosystem services than streams in forested areas, they still provide habitat for aquatic organisms and support terrestrial species. The same nature-based solutions that would mitigate flooding and improve water quality, will also improve habitat conditions for fish, birds, mammals and other species that are a part of even urban watersheds.

This water quality monitoring effort aims to better understand the current water quality of Searles Pond and Bloody Brook, how they support a functioning aquatic ecosystem, the potential risk they may pose to human health during flooding events, other issues they may have and how that may change in the future with climate change. By collecting data on bacteria concentrations and chemical and physical parameters during both wet and dry weather conditions, water quality data can be studied to better understand potential pollution sources. For example, high levels of pathogens during wet weather conditions points towards contamination from stormwater runoff, while high levels of pathogens during dry weather conditions may be coming from sewer discharges or contaminated sources. It can also be used to determine the quality of habitat available in the system and areas that need improvement. This information can be used to design best management practices and nature-based solutions that provide multiple benefits to the stream and the surrounding community. The findings of this study will:

1. Inform the Cities of Methuen and Lawrence and community members where human health risks may occur due to exposure to pathogens in storm water flooding from Bloody Brook.
2. Present baseline information about water quality in the Brook to pinpoint opportunities for multi-benefit nature-based solutions to flooding, water quality issues and habitat improvements
3. Through the comparison of dry weather and wet weather sampling, suggest where further investigation is needed to identify pathogen sources unrelated to storm water such as septic system malfunctions, illicit sewer connections, or other potential sanitary sewer contamination.

1.2. STUDY AREA

The Bloody Brook watershed is a 1.2 square mile urban watershed located in Methuen and Lawrence. The Brook itself, Searles Pond - an impoundment along the Brook - and the surrounding area, have undergone significant changes in the past 135 years. **Figure 1** through **Figure 3** show historical US Geological Survey (USGS) Topo maps of the watershed. Originally, the Brook was meandering, flowing from northwest to southeast where it flowed into the Spicket River (**Figure 1**). By 1944, the Brook was dammed creating Searles Pond, and the path of the Brook was straightened, running along Jackson Street until it was shifted east into a wetland, and then moved underground just downstream of the wetland (**Figure 2**). Today, much of the watershed is covered by impervious surfaces (**Figure 3**). The Brook runs through a series of swales and culverts 1.3 miles from the Searles Pond dam outlet to the Spicket River. Along its path it crosses under Jackson Street by the Jehovah's Witness Church (at the corner of East & Jackson), the wetland area that existed in 1944 was developed on, and is now Bicknell Avenue where the Brook passes through residents' front yard and finally, it enters a culvert at the Swan St. intersection near CVS, where it stays underground until its confluence with the Spicket River (**Figure 3**). This area where the Brook goes underground is a particular problem area for flooding.[2] Water quality was assessed from the two sources of water that flow into Searles Pond, just downstream of the pond, and along the Brook to the outfall at the Spicket River, to capture the varying conditions from a less developed area upstream to a largely impervious area downstream.

[2] A photo tour and further information about the characteristics of the Brook are available through the project's website: Merrimack.org/bloodybrook

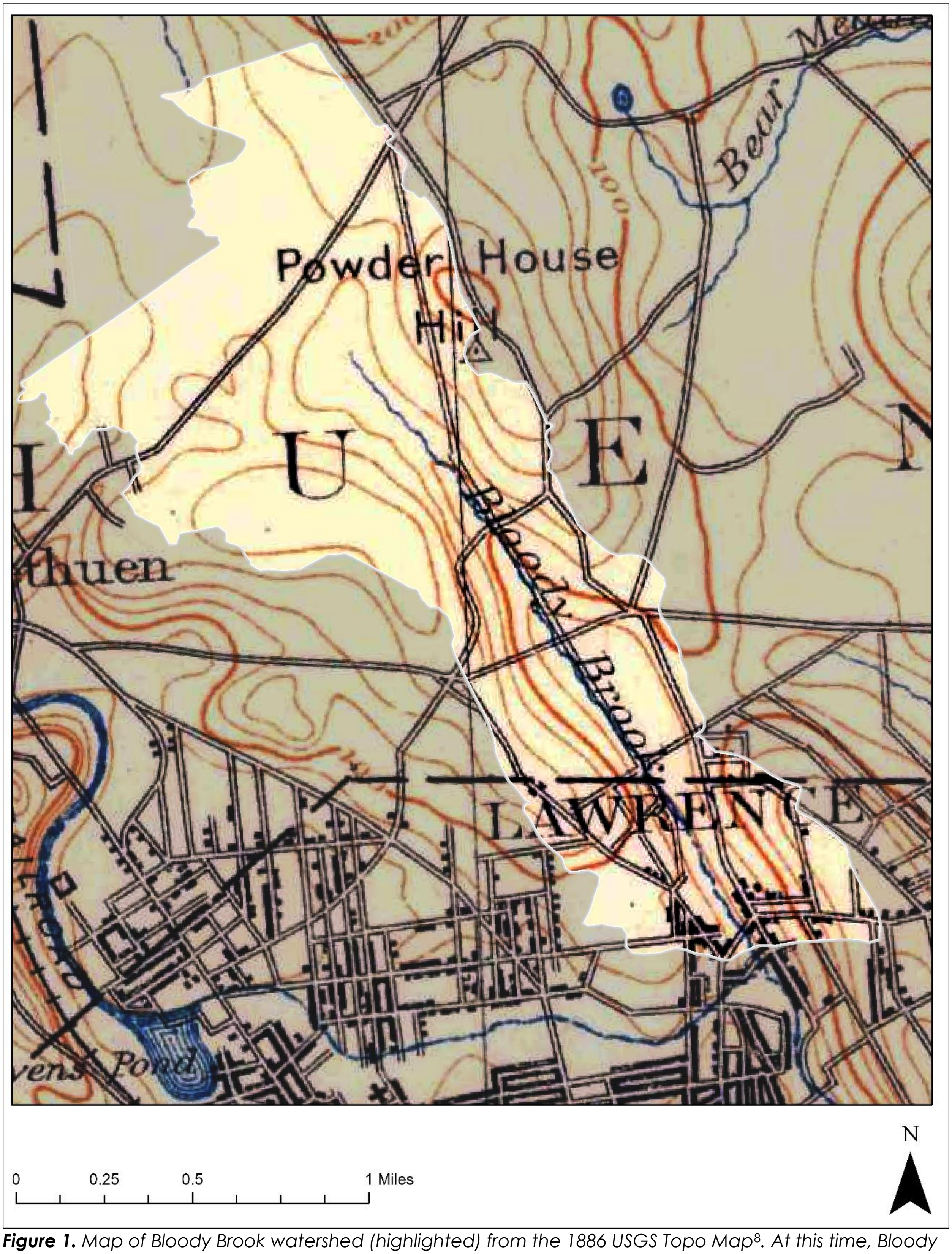

Figure 1. *Map of Bloody Brook watershed (highlighted) from the 1886 USGS Topo Map[8]. At this time, Bloody Brook was fully above ground and its path was not yet manipulated.*

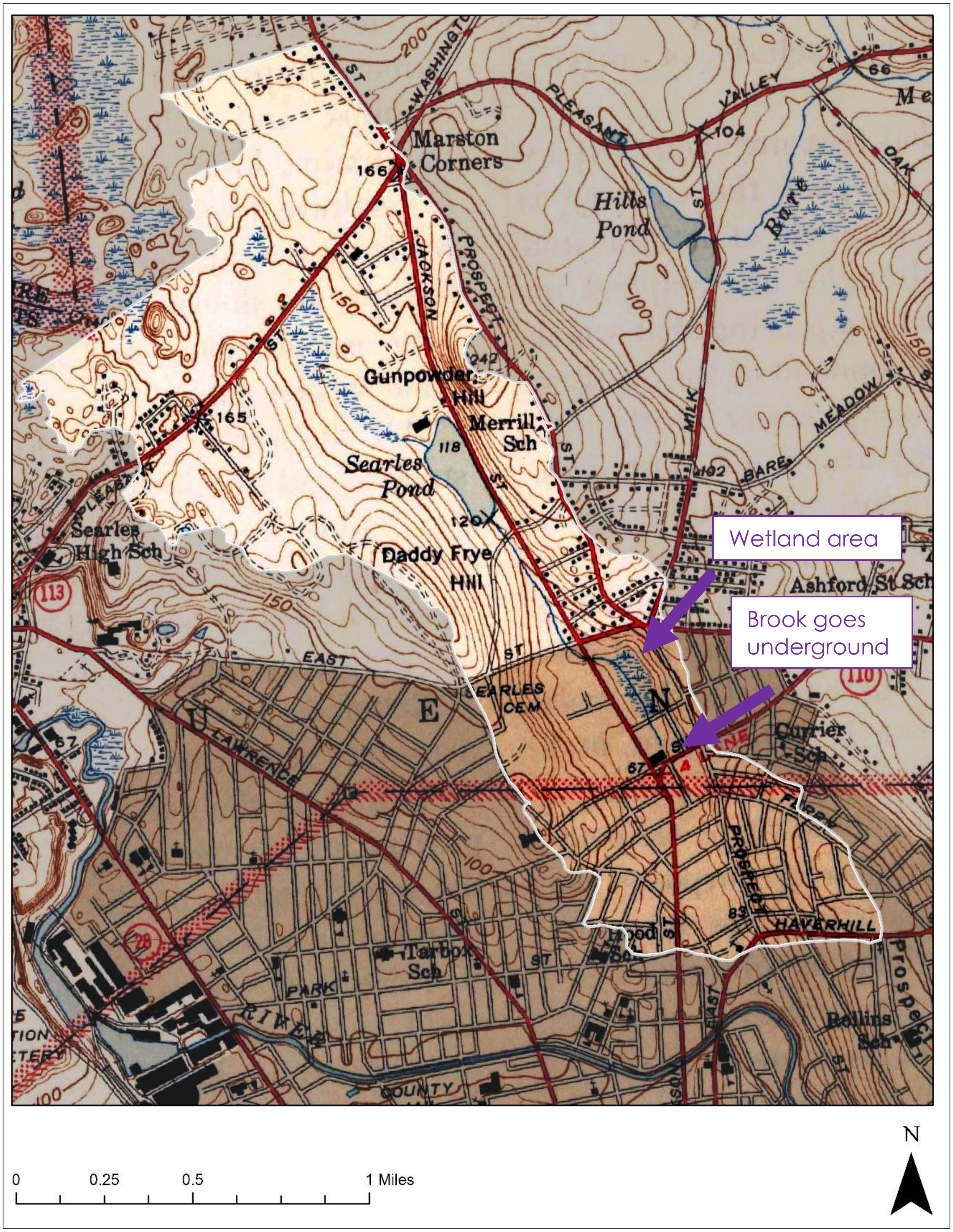

Figure 2. *Map of Bloody Brook watershed (highlighted) from the 1944 USGS Topo Map[8] pointing out important changes to the Brook.*

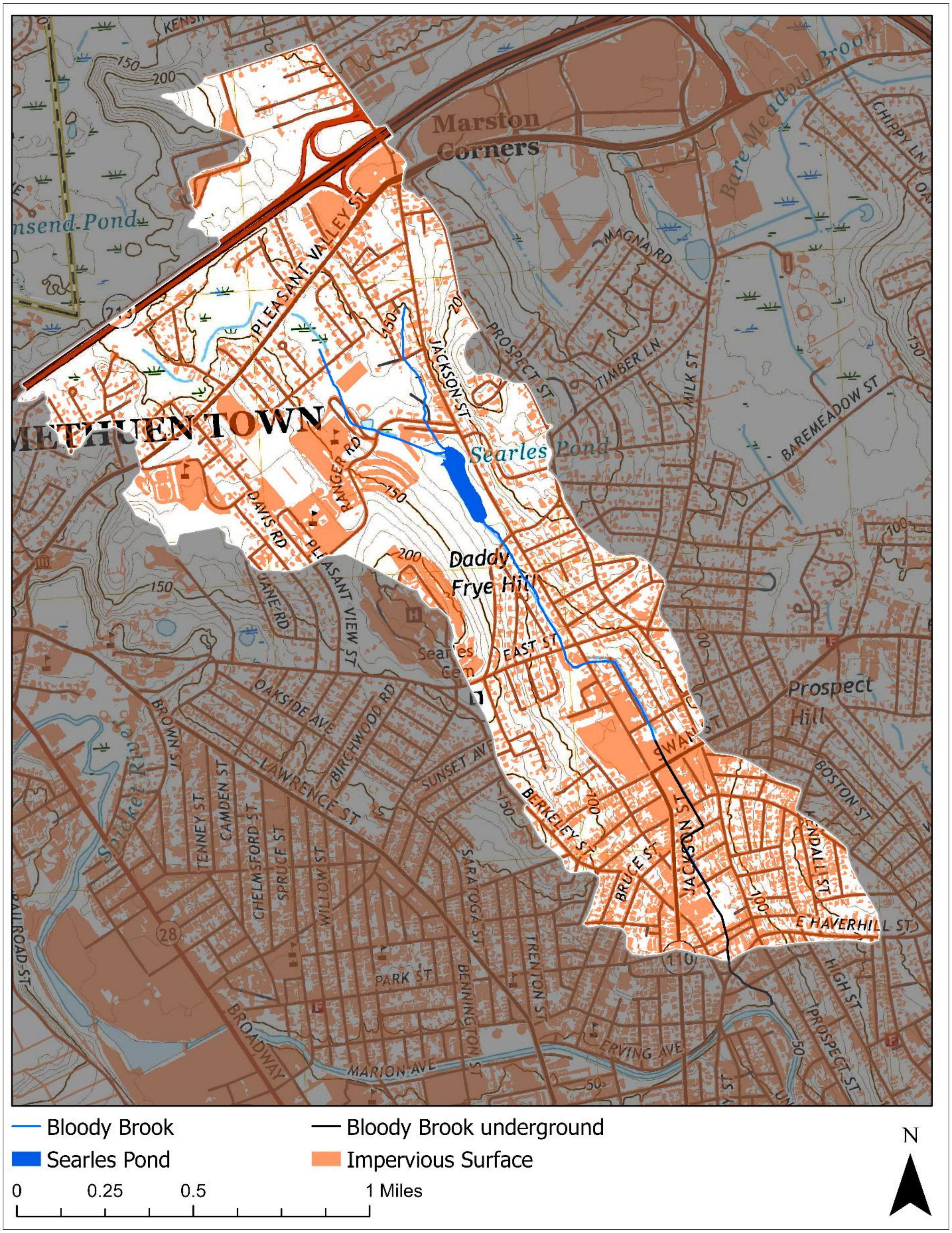

Figure 3. *Map of Bloody Brook watershed (highlighted) from the 2021 USGS Topo Map[8] and impervious surface[9].*

2. SAMPLING APPROACH

Volunteer community scientists and Merrimack River Watershed Council (MRWC) staff conducted water quality monitoring to document conditions in Bloody Brook during dry weather conditions (defined as <0.1 inches of cumulative rain in the 3 days prior to the sampling day) and wet weather conditions (defined as >/= 0.1 inches of cumulative rain in the 3 days prior to the sampling day). Samples were collected bi-weekly from November 18, 2021 to May 26, 2022 at six sites along Bloody Brook (Figure 4, Table 1). Sampling locations were selected based on previous sampling locations and areas upstream and within known flooding areas.

All samples and data were collected according to an approved Quality Assurance Project Plan (QAPP), included in Appendix A. Water quality monitoring volunteers followed the Bloody Brook Sampling Manual, included as Appendix B. During each sampling trip, samplers used a multi-parameter probe to measure pH (using a Hach Pro + meter) temperature, conductivity, total dissolved solids, dissolved oxygen, and salinity (Using a YSI 556 multiparameter meter) just below surface water.

At all stations, volunteers collected water samples in sterile bottles with sodium thiosulfate preservative which were analyzed for *E. coli* by an Environmental Protection Agency (EPA) approved commercial laboratory, or by the Merrimack River Watershed Council in their EPA and Department of Environmental Protection (DEP) approved laboratory (Appendix C). Samples were analyzed using Standard Operating Procedures, provided in Appendix A.

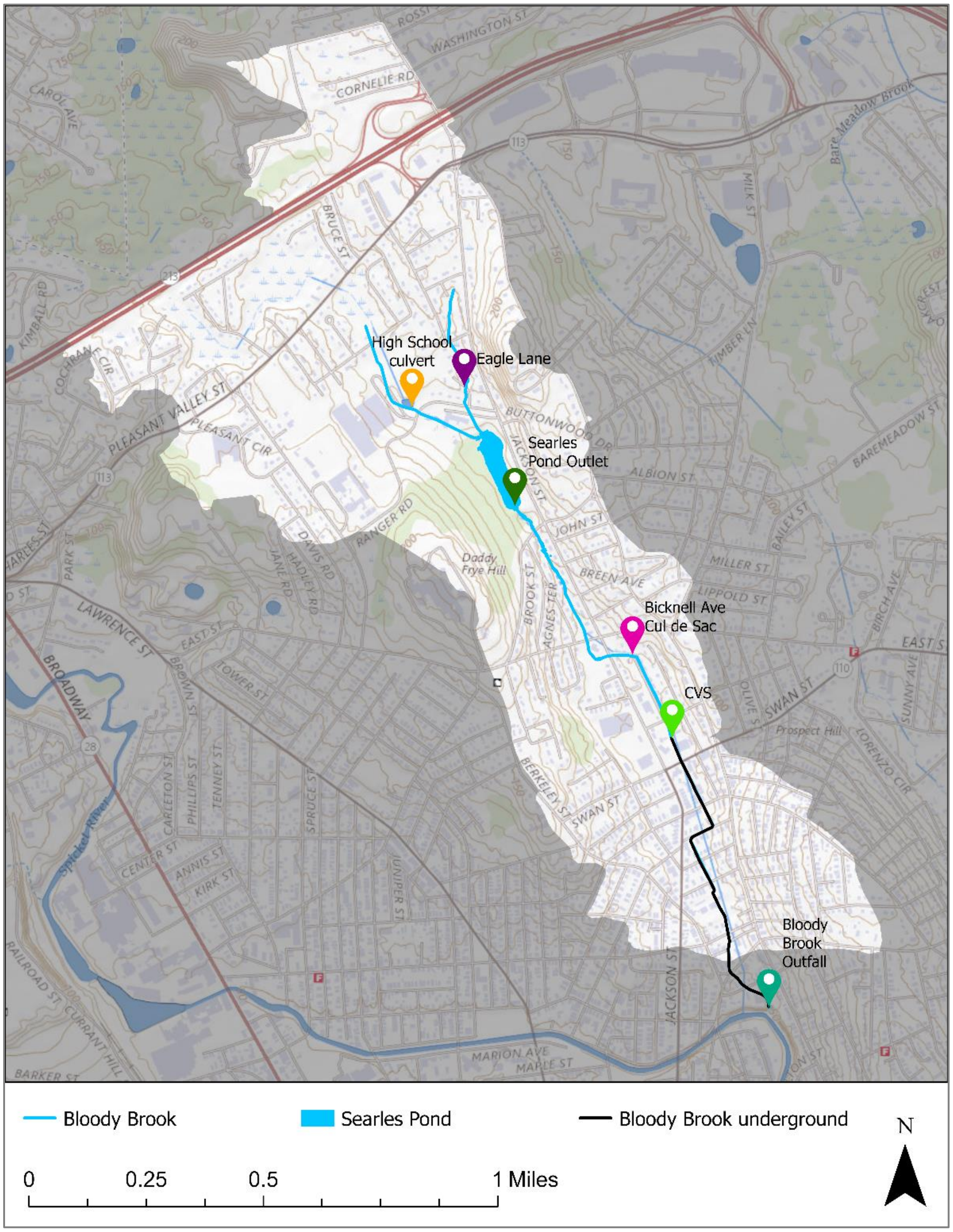

Figure 4. *Map of Study Area and Sampling Sites*

Site ID	Site Name	River Mile	Latitude/Longitude
HSC	High School Culvert	6.13	42.733347 / -71.169387
EL	Eagle Lane	5.68	42.733747 / -71.167444
SP	Searles Pond Outlet	3.08	42.730398 / -71.165186
BCDS	Bicknell Ave Cul de Sac	1.03	42.725990 / -71.160007
CVS	CVS	0.68	42.723437 / -71.158426
BBO	Bloody Brook Outfall	0	42.715112 / -71.154204

Table 1. *Sampling Sites*

3. ENVIRONMENTAL CONDITIONS

The samples were collected biweekly from November 18, 2021 to May 26, 2022. **Table 2** and **Figure 5** show the dry and wet weather sampling days relative to environmental conditions (streamflow[10] and rainfall[11]). Because weather and streamflow have a large impact on water quality, it is important to consider the environmental conditions when samples were collected in order to analyze water quality data. Runoff, which can occur from both snowmelt and rainfall can carry pollutants and natural material to the river affecting water quality. Particularly at the start of a storm, water quality will be most impacted by runoff. After continuous rainfall or snowmelt, pollutants or other natural material may be diluted in the river. Because sampling occurred over the winter and spring, both precipitation and streamflow conditions are important. Precipitation, in the form of snow, may not lead to runoff right away and may not impact water quality. However, snowmelt due to high temperatures with or without precipitation may lead to runoff and impact water quality. Because of the interconnection between precipitation, temperature and runoff, both streamflow and precipitation can help explain the conditions in the Brook.

During the study period, there were six sampling days during dry weather conditions and eight sampling days during wet weather conditions (**Table 2**). Comparison between average streamflow and actual streamflow during the study period shows that during the study period, spring high flows occurred earlier than average (during February and March rather than during March and April) (**Figure 5**). The sampling day on February 3rd, 2022 occurred after the largest sampling day rainfall (0.55 inches), five times larger than the next largest sampling day rainfall which occurred on the December 16th, 2021 sampling day (0.11 inches) (**Table 2**).

Sampling Days	Streamflow (cfs)	Sampling Day Precip (in)	3 Day cumulative precip (in)	Weather category
11/18/2021	213	0.02	0.09	Dry weather
12/2/2021	68.3	0.09	0.09	Dry weather
12/16/2021	116	0.11	0.2	Wet weather
1/6/2022	124	0	0.21	Wet weather
1/20/2022	186	0.06	1.36	Wet weather
2/3/2022	92	0.55	0.55	Wet weather
2/17/2022	179	0	0.38	Wet weather
3/3/2022	162	0.03	0.11	Wet weather
3/17/2022	123	0.01	0.01	Dry weather
4/5/2022	69.1	0	0.05	Dry weather
4/14/2022	92.9	0.05	0.18	Wet weather
4/28/2022	76.8	0	0.54	Wet weather
5/12/2022	31.1	0	0	Dry weather
5/26/2022	20.3	0	0	Dry weather

Table 2. *Environmental Conditions of Sampling Days*

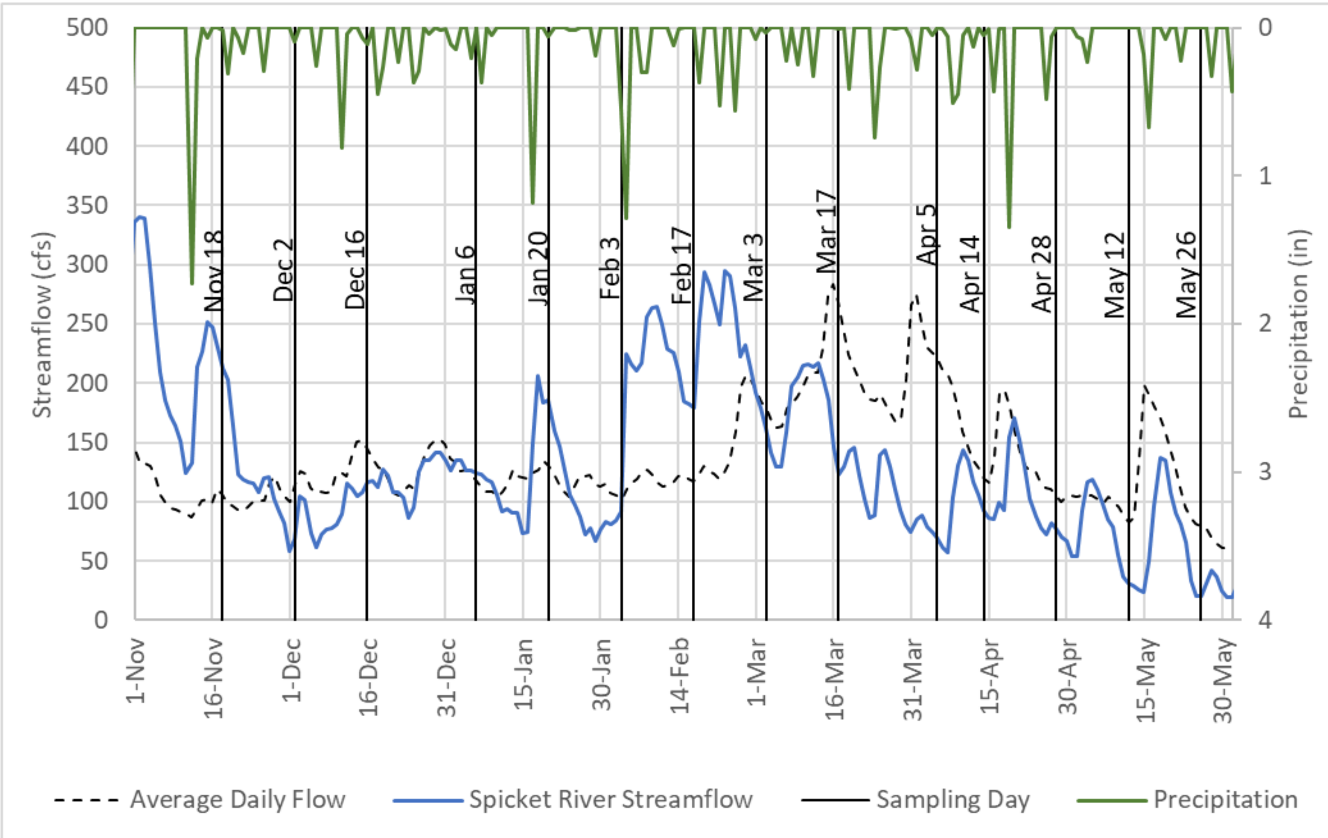

Figure 5. *Sampling days, relative to actual and daily average streamflow in the Spicket River near Methuen (USGS Gauge station: 01100561[10]) and rainfall at the Lawrence Municipal Airport[11]. Average daily streamflow calculated for available record: 10/1/2005 – 6/8/2022.*

5. CHEMICAL/PHYSICAL PARAMETERS

This section provides an overview of the chemical and physical parameters that were measured by volunteers and MRWC staff using hand-held multi parameter probes, as well as the conditions found in Bloody Brook.

5.1. PH

What is pH?

- pH is a measurement of how basic or acidic water is, or more specifically, the concentration of hydrogen ions in water; pH has no units
- pH ranges from 0 (most acidic) to 14 (most basic), with 7 being neutral
- pH is based on a logarithmic scale, so a pH of 5 is 10 times more acidic than a pH of 6 and a pH of 9 is 10 times more basic than a pH of 8.

Why is it important?

- Water that is too basic or too acidic can impact aquatic plants and wildlife, causing stress and reducing their overall growth, reproduction, and survival rates, and can lead to a reduction in biodiversity[12,13]

What changes pH values?

- The background pH in waterbodies is influenced by the types of rocks and soils present in a watershed. For example, streams in areas that have soils with high levels of carbonate often have slightly basic pH.[13]
- Human activities, such as mining runoff, industrial pollution, and the burning of fossil fuels, can cause a decrease in pH, making waters more acidic.[12]
- Industrial pollution dumped directly into the river can also affect the pH.
- The pH of seawater typically has a range between 7.5 and 8.5, freshwater between 6 and 8, and natural precipitation around 5.6. However, due to the acidification of atmospheric water from coal fired power plants in the Midwest, rainwater in New England has a pH between 4.5 and 4.7.[12]

What are important values for environmental or human health?

- The US EPA suggests a pH range of 6.5 to 9 to support aquatic organisms.[13]

What were the conditions in Bloody Brook?

During the study period, only one site on one sampling day had a pH outside the range that supports aquatic organisms, indicating that all sites maintain a pH value that is not harmful to aquatic species or humans (**Figure 6**). However, this study did not capture the summer low flow period, which should be further investigated. In comparison with data collected on the Spicket River in 2013,[3] Bloody Brook has a slightly lower pH (meaning more acidic) with a range of 6.17 – 7.63 compared to 6.58 - 8.80 in the Spicket River (**Table 3**). However, data from the Spicket River were collected from June – November, the opposite time of year from this study.

Site	Max	Median	Min
High School culvert	7.55	7.13	6.17
Eagle Lane	7.55	7.12	6.84
Searles Pond Outlet	7.54	7.22	6.90
Bicknell Ave Cul de Sac	7.51	7.35	7.05
CVS	7.63	7.37	7.14
Bloody Brook Outfall	7.62	7.40	7.01

Table 3. *Maximum, median and minimum pH by monitoring site.*

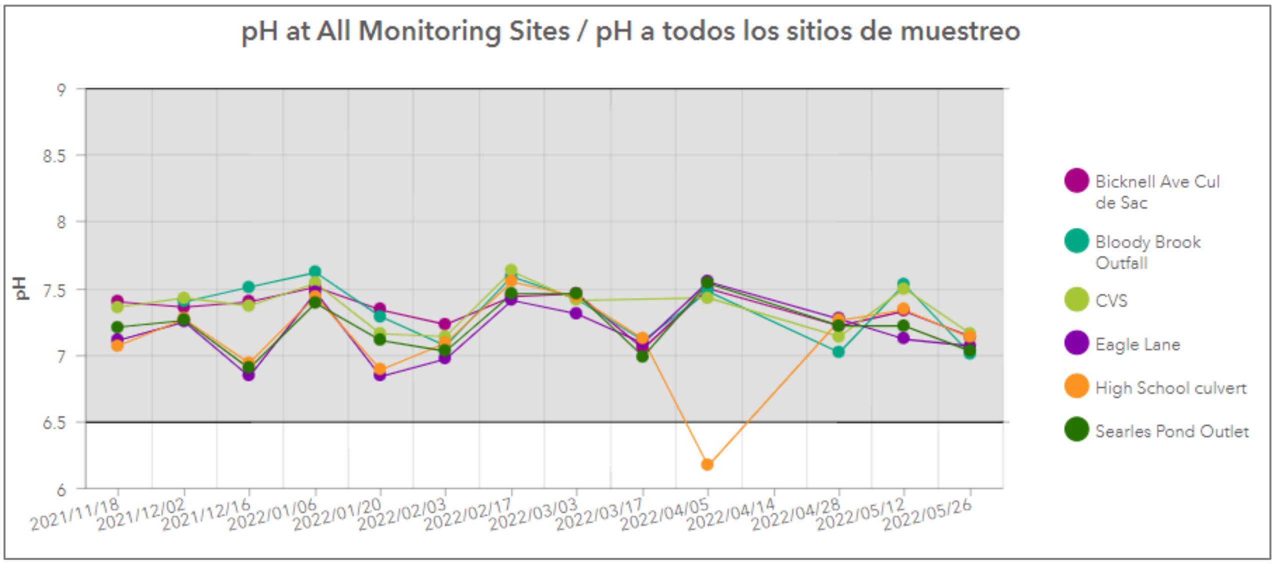

Figure 6. *pH measured at each monitoring site and day.*

5.2. TEMPERATURE

What is temperature?

- Temperature is a measurement of thermal energy, measured in degrees Celsius (˚C) or degrees Fahrenheit (˚F)

Why is it important?

- Aquatic plants and wildlife species have a preferred temperature range[14]
- Water bodies with higher temperatures contains less dissolved oxygen, which is important for aquatic organisms[14,15]
- Water bodies with high temperatures may also result in higher levels of toxicity from heavy metals[15]

What changes temperature?

- Temperatures naturally fluctuate with the seasons
- Human actions, such as building dams, running thermoelectric power plants, and cutting down riparian forests, can increase the temperature of rivers and water bodies[15]
- Increasing impervious surface area can also increase stream temperatures because runoff may flow over hot blacktop before reaching the stream

What are important values for environmental or human health?

- The Massachusetts Surface Water Quality Standard for temperature for Class B warm water fisheries waters is < 28.3ºC (83ºF).
- The standard for Class B cold water fisheries is < 20ºC (68ºF).[16]

What were the conditions in Bloody Brook?

During the study period, all sites could support cold water fisheries as temperatures were below 20 ˚C (**Figure 7**, **Table 4**). However, the study period did not include the warm, low-flow summer months, and therefore it is unlikely that temperatures would support cold water fisheries year-round. Additional monitoring would need to be done to determine if Bloody Brook could support warm water fisheries year-round or if the summer conditions would be too warm. Based on data collected in the Spicket River in June-November 2013[3], the Spicket River could support warm water fisheries as the temperatures stayed just below 25 ˚C. Due to the low flows in Bloody Brook and the urban watershed, it is likely the temperatures in the Brook exceed those in the Spicket River in the summer months.

Site	Max	Median	Min
High School culvert	15.6	5.44	1.32
Eagle Lane	13.17	6.02	1.23
Searles Pond Outlet	19.67	6.44	1.4
Bicknell Ave Cul de Sac	16.04	6.75	1.15
CVS	16.33	7.19	1.39
Bloody Brook Outfall	16.25	7.31	2.17

Table 4. *Maximum, Median and Minimum temperature (˚C) by monitoring site).*

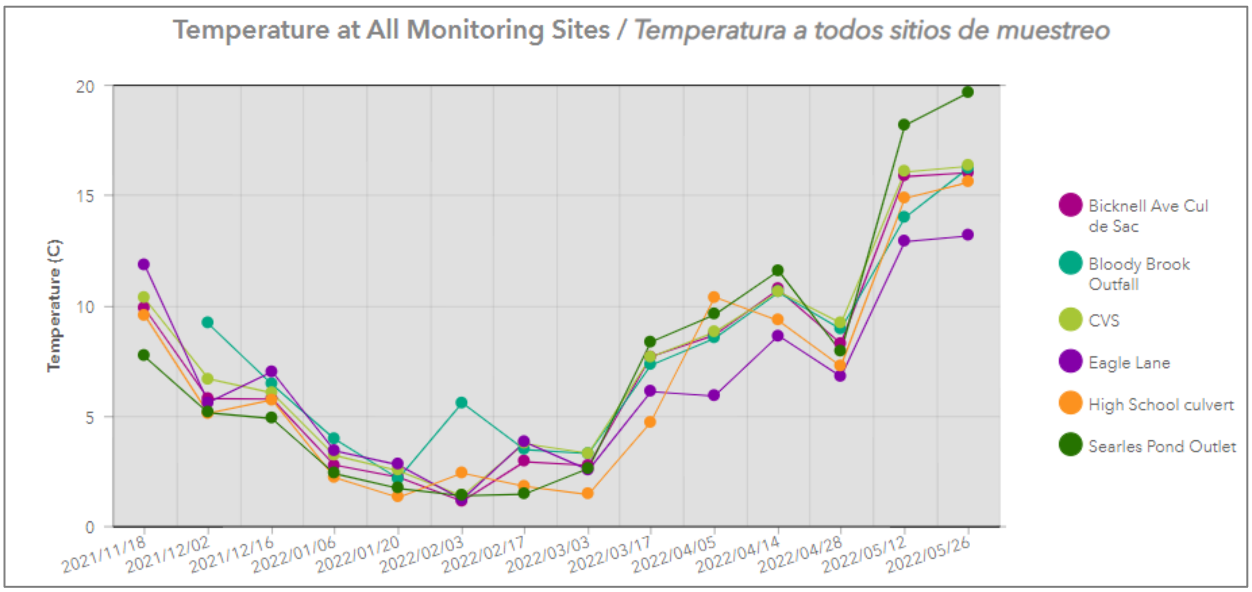

Figure 7. *Temperature measured at each monitoring site and day.*

5.3. DISSOLVED OXYGEN

What is dissolved oxygen?

- Dissolved oxygen (DO) is the amount of oxygen in the form of O_2 in water, measured in mg/L or as a percentage. The oxygen in water comes from both the atmosphere and from plants during photosynthesis.

Why is it important?

- Dissolved oxygen provides oxygen for all aquatic life. Too little oxygen causes organisms physiological stress and/or death.

What changes dissolved oxygen?

- Waste water from sewage treatment plants, storm water runoff, and failing septic systems, among others, contain organic materials that are decomposed by microorganisms, using oxygen in the process.
- Excessive nutrients arising from these sources (phosphate for freshwater, nitrogen for saltwater) increase algal growth. The decomposition of the algae can also lead to such low levels of oxygen that fish are either killed or they leave the area.
- Warmer water can hold less dissolved oxygen than colder water

What are important values for environmental or human health?

- The State of Massachusetts standards for Class B waters are ≥5.0 mg/L.[16] Fish are stressed when dissolved oxygen is less than 5mg/l, and most fish cannot survive for prolonged periods at levels below 3mg/L.

What were the conditions in Bloody Brook?

All sites and monitoring days except one showed dissolved oxygen levels supportive of aquatic life (above 5 mg/L). Searles Pond outlet on the last sampling day had DO levels below this threshold. This is a suggestion that levels likely do not support aquatic life during the summer months at all sites. This site and sampling day also had the highest water temperature, which is well correlated with DO. Additionally, this site is at the outlet of Searles Pond, a slow moving/stagnant water pond which is expected to have lower DO content as the water is not aerated in the pond the same way it is when moving through faster flowing sections of the Brook. A study of the Spicket River from June-November 2013[3] shows that most monitoring sites in the Spicket River contained DO levels too low to support aquatic life. It is likely that Bloody Brook would have similar results if monitoring was conducted during summer months.

Site	Max	Median	Min
High School culvert	14.3	12.3	6.9
Eagle Lane	14.6	12.4	7.8
Searles Pond Outlet	14.7	12.6	4.2
Bicknell Ave Cul de Sac	15.8	12.9	8.7
CVS	15.3	12.8	8.7
Bloody Brook Outfall	16.5	13.0	9.2

Table 5. *Maximum, median and minimum dissolved oxygen (mg/L) by monitoring site*

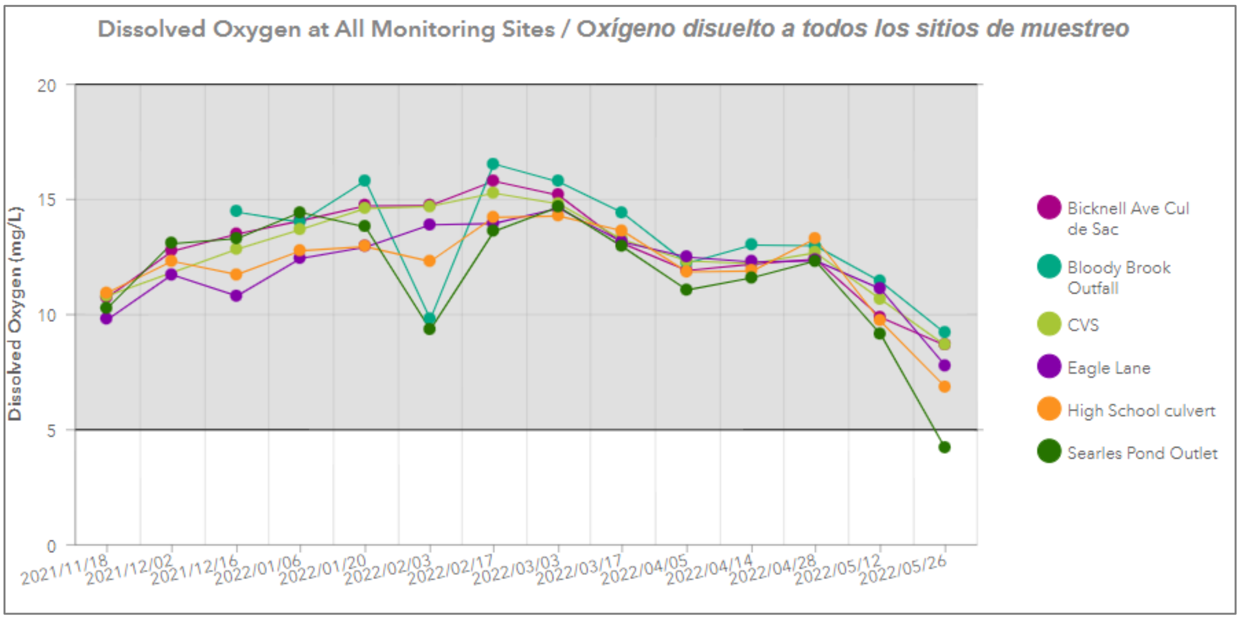

Figure 8. *Dissolved Oxygen (mg/L) measured at each monitoring site and day*

5.4. SALINITY

What is salinity?

- Salinity is the amount of dissolved salts in water, measured in parts per thousand (ppt)
- Salinity is closely linked with conductivity and total dissolved solids

Why is it important?

- Salinity levels impact the types of aquatic species that live in different parts of a water body[17]

What changes salinity?

- Increases in salinity are most commonly caused by saltwater mixing with a freshwater body (like during high tides in an estuary), and salinity can decrease through dilution when a large volume of freshwater is added to a water body (such as during heavy rainfall or snowmelt)
- Salinity can also increase in terminal river basins and lakes as freshwater evaporates and leaves behind natural salts, which can build up over time
- In smaller streams and tributaries like Bloody Brook, salinity can increase due to runoff from road salts used in the winter

What are important values for environmental or human health?

- Freshwater habitats typically have a salinity value of less than 0.5 ppt[17,18]
- Brackish water habitats (a mix of freshwater and ocean water) typically have a salinity value between 0.5 and 17 ppt[17,18]
- Ocean water typically has a salinity value around 30 to 35 ppt[17,18]

What were the conditions in Bloody Brook?

During the winter months (January and February) salinity levels in Bloody Brook were well over the level expected in a freshwater habitat. This is likely due to road salts and runoff during these months. These levels are problematic for freshwater species. Even outside of the winter months, salinity levels are still within the lower end of brackish habitats and above the level that freshwater species likely could tolerate. This may be due to other pollutants and the large amount of direct runoff that occurs in an urban watershed, where runoff does not infiltrate into the ground but runs directly off pavement into storm drains and then into the Brook. Because the Brook is small and has relatively low flows, even small amounts of salts contributing to the Brook can increase the concentration of salts.

Site	Max	Median	Min
High School culvert	0.76	0.445	0.28
Eagle Lane	2.17	0.450	0.28
Searles Pond Outlet	1.04	0.550	0.22
Bicknell Ave Cul de Sac	1.67	0.685	0.42
CVS	1.56	0.670	0.43
Bloody Brook Outfall	1.58	0.740	0.54

Table 6. *Maximum, median and minimum salinity (ppt) by monitoring site*

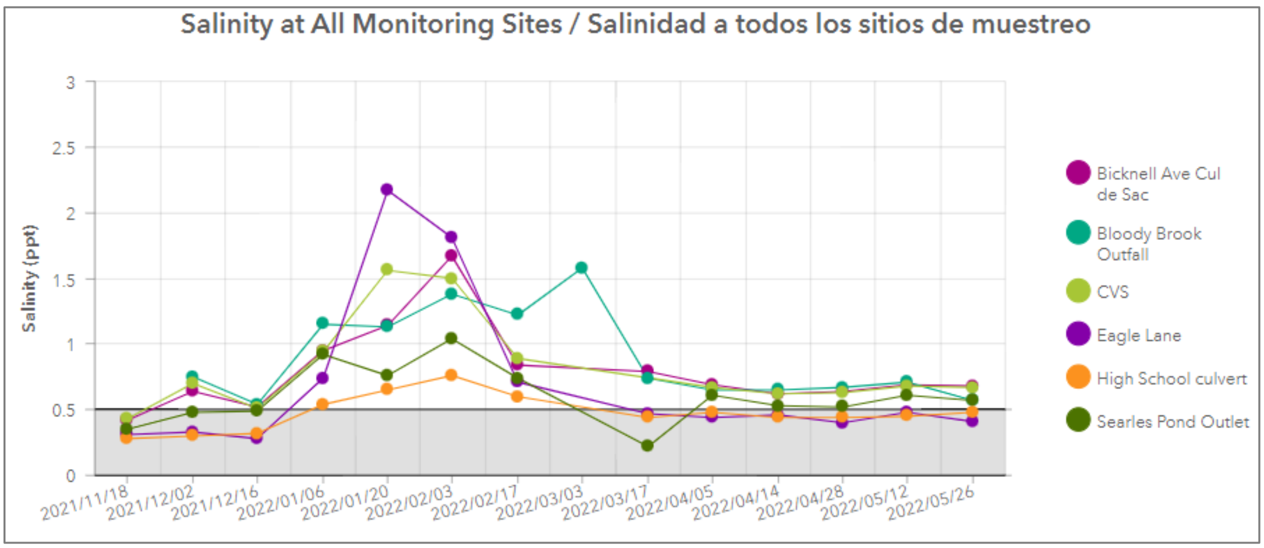

Figure 9. *Salinity (ppt) measured at each monitoring site and day*

5.5. SPECIFIC CONDUCTIVITY

What is specific conductivity?

- Specific conductivity is a measure of water's ability to conduct electricity, measured in micro-Siemens per centimeter (µS/cm) at 25˚C
- Conductivity is dependent on the amount of positive and negative ions in the water, usually due to the presence of dissolved salts
- Conductivity is closely linked to salinity and total dissolved solids

Why is it important?

- Rivers and streams usually have a relatively consistent conductivity value that is unique to that water body, and any significant change in conductivity measurements may indicate pollutants entering the river[18]
- Background levels of conductivity are dependent on the surrounding geology, with clay soils increasing conductivity and granite bedrock reducing it[18]

What changes conductivity?

- Agricultural runoff and sewage leaks may increase conductivity, while oil spills or other organic compounds may decrease conductivity[18]

What are important values for environmental or human health?

- Freshwater rivers in the US typically range between 50 and 1,500 µS/cm, with levels for supporting good mixed fisheries between 150 and 500 µS/cm[19]
- Industrial wastewater can measure 10,000 µS/cm or more[18,19], while seawater can measure 55,000 µS/cm or more[18]

What were the conditions in Bloody Brook?

Similar to salinity, conductivity levels were above the typical expected values for freshwater rivers during the winter months at all sites except High School Culvert, one of the most upstream sites. All but one measurement across the study were above the levels that support good mixed fisheries. When compared to the Spicket River data collected in June – November, 2013[3], conductivity in Bloody Brook is much higher (levels in the Spicket typically stayed below 500 µS/cm). However, these data from the Spicket River do not reflect winter months when road salts contribute to elevated conductivity. In this same study, elevated levels were observed at the Nina Scarito site, which is near where the Bloody Brook flows into the Spicket River. Bloody Brook could be a source of elevated conductivity to the Spicket River.

Site	Max	Median	Min
High School culvert	1521	902	567
Eagle Lane	4512	922	571
Searles Pond Outlet	2062	1152	448
Bicknell Ave Cul de Sac	3245	1375	858
CVS	3034	1343	872
Bloody Brook Outfall	3150	1501	1088

Table 7. *Maximum, median and minimum specific conductivity (µS/cm) by monitoring site*

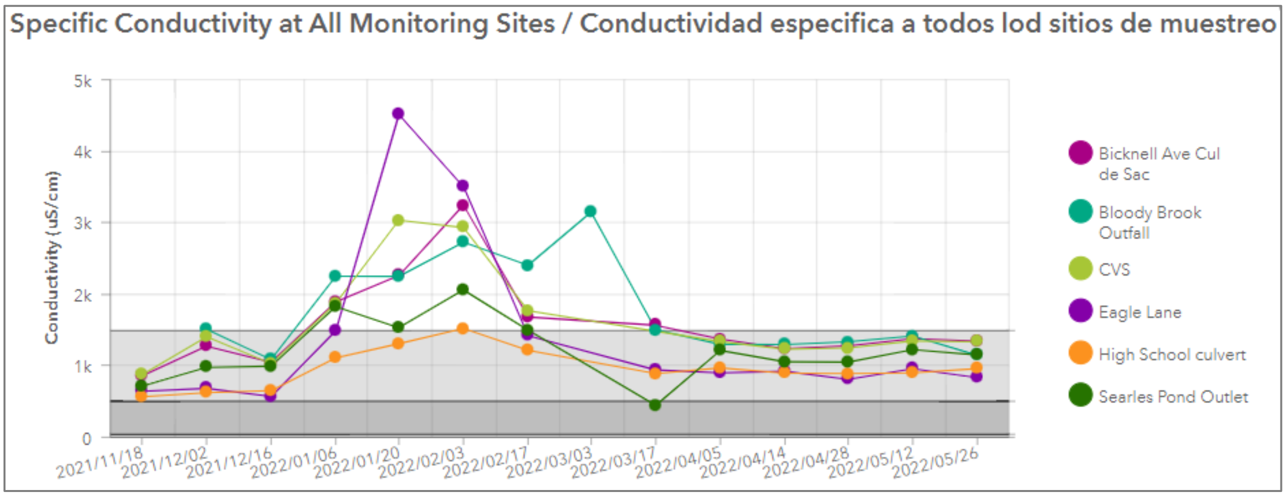

Figure 10. *Specific Conductivity (µS/cm) measured at each monitoring site and day*

5.6. TOTAL DISSOLVED SOLIDS

What are total dissolved solids (TDS)?

- TDS are the amount of all ions in water that are less than 2 microns (0.0002 cm) in length, measured in milligrams per liter of water (mg/L)
- TDS includes positive and negative ions, dissolved salts, and dissolved organic matter

Why is it important?

- If TDS levels are too high or too low, it could impact an organism's ability to move up and down in the water column, as well as limit the growth and lifespan of aquatic species[20,21]

What changes total dissolved solids?

- Heavy rains and large amounts of industrial and/or agricultural runoff from the watershed can temporarily increase total dissolved solids[18]
- However, high levels of total dissolved solids in freshwater during a dry period can be a sign of point source pollution[18]

What are important values for environmental or human health?

- There is no EPA recommendation for TDS limits for aquatic species, but TDS measurements over 1g/L in freshwater could impact fish reproduction[22]
- TDS values over 0.5 g/L require secondary treatment before being used as drinking water for humans[20]

What were the conditions in Bloody Brook?

Similar to salinity and conductivity, total dissolved solids were above the limit that may impact fish reproduction at all sites except High School culvert during the winter months. This is likely due to the application of road salts. Unlike conductivity and salinity, total dissolved solid concentrations decreased to below that threshold outside of the winter months. When compared with data collected in the Spicket River in June-Nov 2013[3], Bloody Brook data were much higher. Almost all Spicket River data points were below 1 g/L, with the exception of some spikes, notably at the Nina Scarito site near the Bloody Brook outfall. As with conductivity and salinity, because Bloody Brook is a small water body, small contributions from its urban watershed runoff can elevate the concentration of total dissolved solids. Bloody Brook may contribute elevated levels of TDS to the Spicket River.

Site	Max	Median	Min
High School culvert	0.989	0.586	0.369
Eagle Lane	3.245	0.599	0.371
Searles Pond Outlet	1.34	0.749	0.292
Bicknell Ave Cul de Sac	2.111	0.894	0.558
CVS	1.973	0.873	0.567
Bloody Brook Outfall	2.42	0.970	0.707

Table 8. *Maximum, median and minimum total dissolved solids (g/L) by monitoring site*

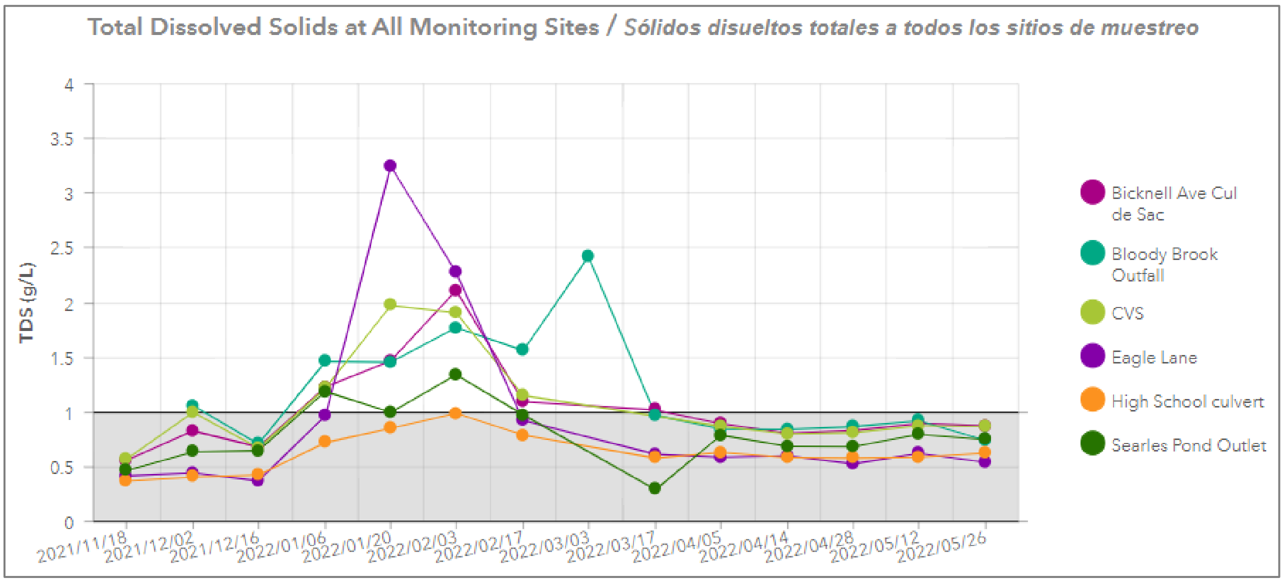

Figure 11. *Total dissolved solids (g/L) measured at each monitoring site and day*

6. BACTERIA CONDITIONS

This section provides an overview of why monitoring bacteria is important and a detailed spatial and temporal analysis of the bacteria conditions found in Bloody Brook.

What are pathogens and fecal indicator bacteria?

- Pathogens are disease-causing microorganisms, which can be bacteria (single-celled organisms), viruses, fungi, and protozoa
- A common bacteria used in water quality monitoring is *Escherichia coli* (*E. coli*) which is found in the gut and feces of warm-blooded animals.
- While *E. coli* itself is not particularly dangerous to humans, it often indicates the presence of more harmful pathogens such as norovirus and *Cryptosporidium*, which can make people sick. It is a fecal indicator bacteria.
- The source of fecal contamination is very important. Fecal contamination from human sources (e.g., sewage from an illicit connection) is likely to contain more pathogens that will have a greater impact on human health than fecal contamination from non-human sources (e.g., birds, wildlife, and farm animals).[23]
- *E. coli* is a good indicator of health impacts for humans in freshwater samples.[24]

Why are they important?

- When humans come in contact with pathogens, they can cause illnesses ranging from gastrointestinal discomfort to infections, and even death, with the very young, the very old, and those with weakened immune systems at greatest risk [25,26]
- A wide variety of pathogens can cause illness in humans and animals, but *E. coli* is commonly found, relatively easy to monitor, and has shown a correlation with cases of gastrointestinal illness among swimmers in waterbodies contaminated with human-sourced fecal matter.[27]

What changes bacteria concentrations?

- The concentration of bacteria measured at a specific site on a given day is influenced by many factors such as concentration from nearby sources, dilution, streamflow, dispersion, sedimentation, temperature, exposure to sunlight and decay/die off.
- Sources of bacteria could come from point sources or non-point sources. Point sources include a leaking or broken sewage pipe or a poorly maintain septic system. Non point sources may include animal waste, or manure applied to farms or gardens which is carried to the water body by runoff from rain or melting snow.
- Soil in vegetated areas will often filter and process out *E. coli* from non-point sources before it reaches the water body. However, in urban areas where soil is covered by impervious surfaces such as roads, buildings and parking lots, the water and contaminants flow directly into the storm drains and then water body, without being filtered by soil and vegetation.

What are important values for environmental or human health?

- The US EPA's 1986 Ambient Water Quality Criteria for Bacteria sets a standard for safe bacteria levels for designated beach areas (or "safe for recreational use" in this report): a maximum value of 235 MPN/100 mL for *E. coli* in freshwater samples.[28] While Bloody Brook is too small for recreational use, this threshold can still act as a reference to concentrations found in Bloody Brook.

6.1. SPATIAL ANALYSIS OF *E. COLI* IN BLOODY BROOK

By comparing *E. coli* concentrations across sampling sites, conclusions can be drawn about potential point sources of bacteria to a given site. For example, if one site consistently has high concentrations, but a site upstream of it does not, there is likely a bacteria source between the sites. Land use, known stormwater outfalls, septic systems and other information can be investigated to better understand the potential source.

This study found high/unsafe levels of *E. coli* concentrations (>235 MPN/100mL) at each site during at least two sampling days (**Figure 12**). Just over half of samples collected in this study were above this limit (43. 52%). The site with the fewest unsafe samples was Searles Pond Outlet (2, 14%), followed by High School culvert (3, 21%) (**Figure 12**). The site with the most unsafe samples was Eagle Lane (11, 79%), followed by Bloody Brook outfall (10, 77%) (**Figure 12**). In an urban watershed it is expected to see higher concentrations of pollutants accumulate in the downstream sections of the watershed and the part of the watershed that has more impervious surface, as in the downstream sections of the Bloody Brook watershed. Such high concentrations of *E. coli* at the upstream site of Eagle Lane were unexpected.

Regardless of the high concentrations from Eagle Lane, Searles Pond appears to attenuate *E. coli*, likely by dilution, decay/die off or a combination of the two. The only two samples from Searles Pond Outlet that were above the safe limit were collected on December 16th and February 3rd, the two days with the highest precipitation occurring on the sampling day (0.11 and 0.55 inches, respectively).

The highest single sample concentrations found during this study were from the Bicknell Ave Cul de Sac and CVS sites (>2419.6 MPN/100 mL, the maximum detection limit for the analysis method), and both samples were collected on February 3rd, the day with the highest precipitation occurring on a sampling day (0.55 inches). These sites as well as the Bloody Brook outfall site had consistently high concentrations of bacteria (**Figure 13**). In 2014, high concentrations of *E. coli were found* in the Spicket River just downstream of the confluence with Bloody Brook (at Nina Scarito Park, >1,000 MPN/100 mL, the highest level detectable by the analysis method)[3]. In 2014, Groundwork Lawrence collected samples in Bloody Brook on October 24 and November 21, 2014.[29] On both days, significantly high concentrations (above 5,000 MPN/100 mL) were found at the Bloody Brook outfall (**Table 9**). These are higher than concentrations seen at this site during this study. On the October 24th sampling day, significantly high concentrations were also found at a site near Bicknell Ave Cul de Sac, but when sampling occurred upstream of that site the following month, concentrations were low (**Table 9**). A significant amount of rain - 3.24 inches - fell the day prior to October 24th, 2014 and no rain fell within three days prior to November 21st, 2014. Because of these weather variations and because Bicknell Ave Cul de Sac, CVS and Bloody Brook outfall are downstream sites in the more urban section of the watershed, it is not as evident as with Eagle Lane that there may be a point source of bacteria upstream of these sites.

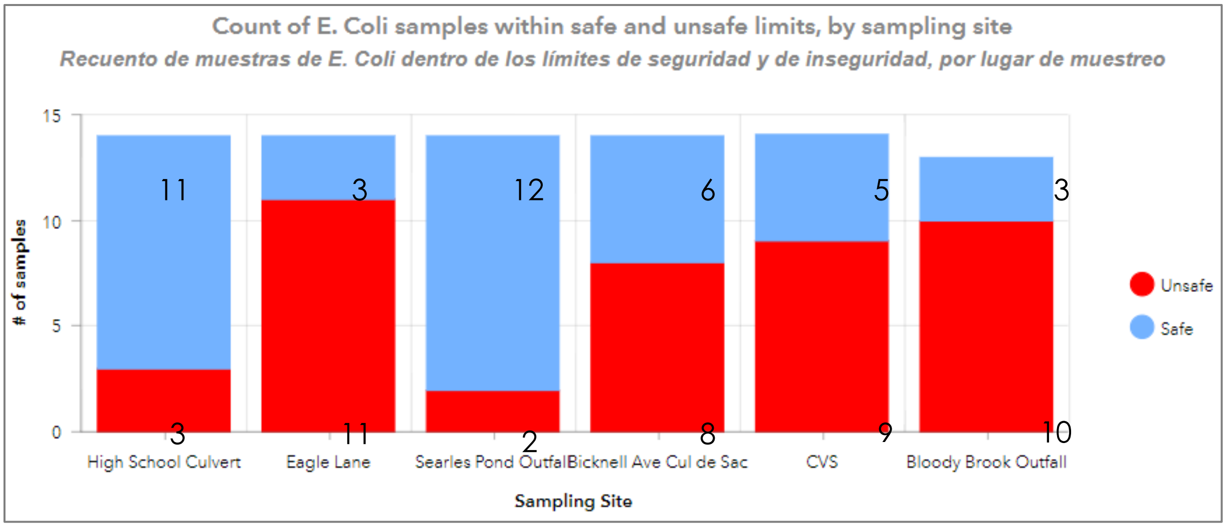

Figure 12. *Count of E. coli samples that fall below (safe) and above (unsafe)the threshold for recreational use (235 MPN/100mL). Sites are listed from upstream (left) to downstream (right).*

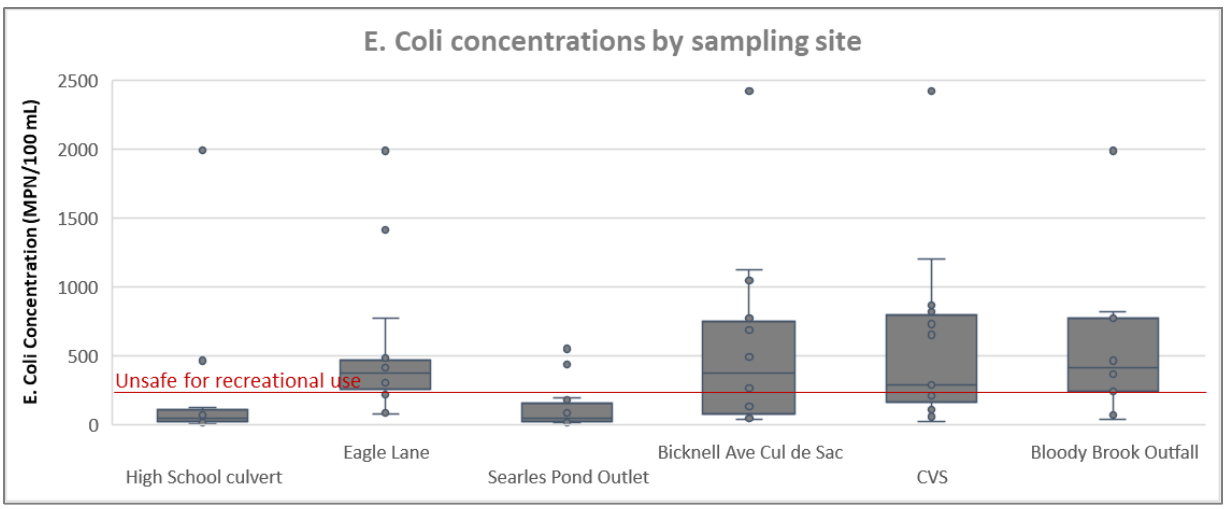

Figure 13. *Box and whisker plots of E. coli concentration (MPN/100 mL) by sampling site. Red line indicates the threshold for recreational use (235 MPN/100mL). Sites are listed from upstream (left) to downstream (right).*

Date	Site Name (from source study)	Lat	Long	Closest Site in this study	E. coli (MPN/ 100 mL)
10/24/2014	Bloody Brook Methuen[29]	42.72604	-71.1602	Bicknell Ave Cul de Sac	>5,794[1]
10/24/2014	Bloody Brook Lawrence[29]	42.71518	-71.1552	Bloody Brook Outfall	>5,794[1]
11/21/2014	Stream 1[29]	42.73417	-71.16754	Eagle Lane	134
11/21/2014	Stream 2[29]	42.73352	-71.16971	High School culvert	75
11/21/2014	Searles Pond[29]	42.73053	-71.16529	Searles Pond Outlet	146
11/21/2014	Bloody Brook Lawrence[29]	42.71518	-71.1552	Bloody Brook Outfall	5,475

Table 9. *E. coli concentrations from a previous investigation in Bloody Brook.*

[1] 5,794 MPN/100 mL was the highest detectable limit by the analysis method.

After multiple high concentration samples were collected from Eagle Lane during dry weather, further investigation was conducted upstream to identify a potential point source of *E. coli* on March 17th and April 14th, 2022. While high concentrations were found upstream, no point source was identified because the most upstream portion of the Brook (Hemlock Ct) was sampled and concentrations were still high (**Table 10**). Due to the consistently high concentrations at this site regardless of environmental conditions, it is assumed something other than non-point source pollution is contributing to the high concentrations at this site. Further investigation is warranted and an analysis for pharmaceuticals or other tracers that would indicate human vs animal-sourced *E. coli* would be beneficial.

Site Name	Lat	Long	*E. coli* Concentration (MPN/100mL)
March 17th, 2022			
Hemlock Ct	42.73724	-71.1684	410.6
Dearborn Rd	42.7356	-71.1681	579.4
Eagle Lane	42.73417	-71.1675	435.2
Searles Pond Outlet	42.73053	-71.1653	19.5
Bicknell Ave Cul de Sac	42.72604	-71.1602	58.1
CVS	42.72349	-71.1584	54.6
Bloody Brook Outfall	42.71518	-71.1552	34.1
April 14th, 2022			
Hemlock Ct	42.73724	-71.1684	1046.2
Dearborn Rd	42.7356	-71.1681	1046.2
Eagle Lane	42.73417	-71.1675	298.7
Searles Pond Outlet	42.73053	-71.1653	27.2
Bicknell Ave Cul de Sac	42.72604	-71.1602	36.8
CVS	42.72349	-71.1584	23.5
Bloody Brook Outfall	42.71518	-71.1552	65.7

Table 10. *E. coli concentrations for sites up and downstream of Eagle Lane on March 17th and April 14th, 2022. Two sites were added upstream of Eagle Lane on these dates Hemlock Ct and Dearborn Rd.*

6.2. TEMPORAL ANALYSIS OF *E. COLI* IN BLOODY BROOK

By comparing across sampling days, trends can be investigated relative to environmental conditions occurring within that day. These can suggest or rule out non-point sources of pollution, which are typically correlated with streamflow and precipitation.

When assessing results by sampling day, some correlations appear between environmental conditions and high concentrations. **Figure 14** shows all *E. coli* concentrations from each sampling site and day as well as some environmental conditions for that day. **Figure 15** shows box and whisker plots of *E. coli* concentrations by sampling day. Both figures include red text describing some observations of correlations between *E. coli* concentrations and environmental conditions. Correlations were observed visually by comparing data and were not analyzed for statistical significance.

Four days with notably high concentrations at multiple sites (Dec 16th, Feb 3rd, Feb 17th, April 28th, 2022) occurred on the days with high sampling-day precipitation, and/or high 3-day cumulative precipitation, and/or occurred when streamflow was rising indicating runoff was contributing to the stream. The highest concentrations of *E. coli* sourced from nonpoint sources will typically occur at the beginning of a storm, when the first flush of rain carries the highest concentration of bacteria to the river. As the storm continues, often the concentrations will be less high and will continue to decrease as flows decrease and the bacteria moves downstream. Storms that occur after a long period without precipitation will also result in higher concentrations of *E. coli* because *E. coli* sources will have been accumulating on the ground surface in between storms. We can assume that both the Feb 3rd and Feb 17th, 2022 samples were collected toward the start of the runoff because the streamflow in the river was rising, from a low point in the streamflow (**Figure 5**). The April 28th, 2022 samples were collected just after the peak streamflow, where *E. coli* concentrations may still have been high.

While the Jan 6th, 2022 sampling day occurred after the largest 3-day cumulative precipitation, concentrations were not as high as in the three previously noted sampling days – only slightly above the threshold for safe levels for recreation (excluding Eagle Lane). This may be because this sampling day was following multiple days of rain, and the peak streamflow had already occurred (**Figure 5**). Potentially the system had been already been flushed with higher concentrations occurring in the days prior to the sampling day which may have been more comparable to concentrations found on Dec 16th, Feb 3rd and Feb 17th, 2022.

Other notable days with high concentrations at multiple sites are May 12th and May 26th, 2022. By May, the water temperature had reached the highest levels since the study began (above 15ºC), which may have contributed to increased bacteria growth.

While Bloody Brook Outfall has consistently high concentrations, the days where concentrations were low are well correlated with low flow days with minimal precipitation (March 3rd – April 14th). Data collected in this study suggests that contributions of bacteria at this site are likely linked to nonpoint sources and the urban nature of the watershed. Apart from Eagle Lane, each site has only one or two sampling days that cannot be explained by environmental conditions. Because there is no obvious persistent trend at these sites as there is with Eagle Lane, it is not expected that point sources were a dominant source of bacteria to these sites during this study, but point source(s) still could be contributing. Further sampling, particularly with analysis for pharmaceuticals or other tracers that can identify human-sourced bacteria would be beneficial to confirm this.

While these correlations with environmental conditions may explain some high concentrations found during this study, this is still a small dataset, including only six months of the year and missing the warm low-flow months, intense thunderstorms during summer months and large precipitation events that occur in the fall. Additional data should be collected to capture these time periods and further confirm potential correlations with environmental conditions and sources.

	E. Coli Concentration (MPN/100 mL)						Environmental Conditions		
Sampling Day	High School culvert	Eagle Lane	Searles Pond Outlet	Bicknell Ave Cul de Sac	CVS	Bloody Brook Outfall	Sampling Day Precip (in)	Cumulative Precip (in)	Water Temperature (°C)
11/18/2021	67	236	86	46	205		0.02	0.09	9.9
12/2/2021	1990	326	84	74	249	411	0.09	0.09	6.3
12/16/2021	50	1414	435	1046	1203	816	0.11	0.2	6.0
1/6/2022	18	770	38	127	105	461	0	0.21	3.0
1/20/2022	121	1986	194	261	291	366	0.06	1.36	2.1
2/3/2022	27	411	548	2420[1]	2420[1]	770	0.55	0.55	2.2
2/17/2022	10	82	179	488	866	1986	0	0.38	2.9
3/3/2022	16	479	56	75	144	238	0.03	0.11	2.7
3/17/2022	4	435	20	58	55	34	0.01	0.01	7.0
4/5/2022	21	73	10	687	285	111	0	0.05	8.7
4/14/2022	479	299	27	37	24	66	0.05	0.18	10.3
4/28/2022	43	326	25	1120	727	488	0	0.54	8.1
5/12/2022	40	214	16	517	649	816	0	0	15.3
5/26/2022	461	411	13	770	816	270	0	0	16.2

High sampling day precipitation

Highest cumulative precipitation, past peak streamflow

Highest sampling day precipitation, rising streamflow

High 3-day cumulative precipitation, rising streamflow

High 3-day cumulative precipitation, near peak streamflow

Warm sampling days

Figure 14. *Grid of E. coli concentrations (MPN/100 mL) and environmental conditions. For E. coli concentrations, darker red means a higher concentration, darker blue means a lower concentration. For environmental conditions, darker green means a higher value.*

[1]2,420 MPN/100 mL was the highest level of detection for the analysis method.

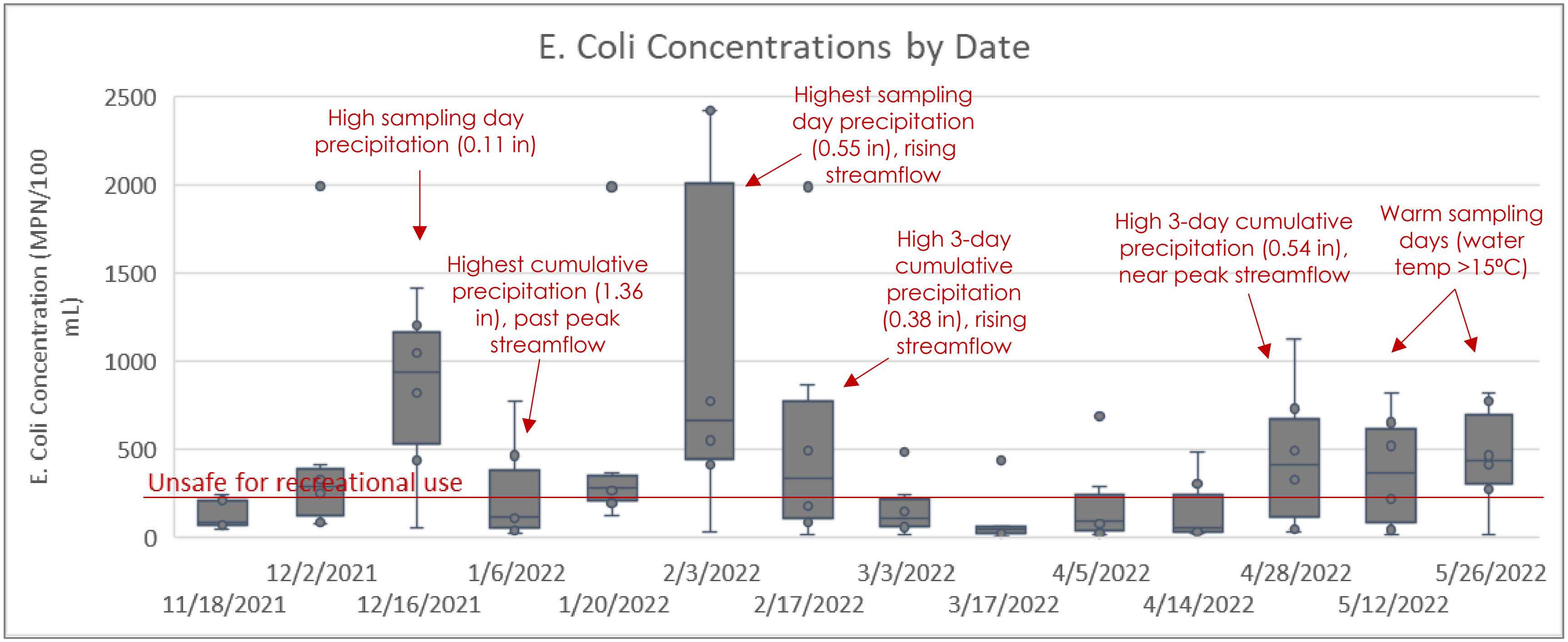

Figure 15. *Box and whisker plots of E. coli concentrations (MPN/100 mL) by sampling day. Red text provides some information about environmental conditions for days with high concentrations.*

7. WILDLIFE SIGHTINGS

Throughout the study, volunteers and MRWC staff observed various forms of wildlife around the sampling sites across the Bloody Brook watershed (**Table 11**). Farthest downstream at the Bloody Brook Outfall, near Dr. Nina Scarito Park, there were reports of multiple types of birds. A great blue heron (*Ardea herodias*) was reported at Bloody Brook Outfall, as well as at the opposite end of the watershed, at the High School Culvert site. Apart from the herons, four red tailed hawks (*Buteo jamaicensis*), cardinals, mallards, ducks and a catbird are other birds that were seen or heard nearby to the sampling sites.

A muskrat (Ondatra zibethicus) was seen at the Bicknell Avenue site and other typical urban wildlife such as racoons, or evidence of them, had been seen near Eagle Lane. Smaller aquatic species and insects that might provide food for these larger species were seen as well, including a fish, frogs and water striders.

While wildlife was not the focus of this study, it is noteworthy to mention the breadth and quantity seen given the urban nature of the watershed. Improving the natural functions of the Brook and watershed will have multiple benefits including flooding and improving water quality as previously discussed, and evidence of wildlife within the watershed provides additional motivation for protection of the natural areas that exist around Searles Pond, and improvement downstream.

Date	**Site**	**Animal**
11/18/21	HSC	Fish, great blue heron
12/2/21	HSC	Ducks
12/2/21	BCDS	Muskrat
2/3/22	EL	Unknown
3/3/22	BBO	4 red tailed hawks, 1 cardinal
3/17/22	EL	Racoon
4/5/22	EL	Racoon
4/5/22	BCDS	Water striders
4/28/22	BBO	Great Blue Heron
5/12/22	SP	Frogs, Catbird
5/12/22	HSC	Frogs
5/26/22	HSC	Mallards

Table 11. *Wildlife sightings by MRWC staff and volunteers while water sampling.*

8. POTENTIAL SOLUTIONS AND CONCLUSION

The goal of this study was to provide baseline water quality conditions in Bloody Brook, to better understand the potential risks that residents and business owners may be exposed to during flooding events in Bloody Brook, and to pinpoint locations to prioritize for nature-based solutions to water quality issues and stream habitat improvements. This was part of a larger effort to investigate flood mitigation along the Jackson Street Corridor particularly using nature-based solutions where possible.

High bacteria concentrations are prevalent in Bloody Brook, even during a study period excluding the warm low-flow summer months, thunderstorms, and large fall rainstorms when bacteria concentrations are expected to be highest. Bloody Brook experiences high bacteria concentrations as a result of potential point source pollution, particularly upstream of the Eagle Lane sampling site, and nonpoint source pollution, exacerbated by the urban watershed with significant impervious surfaces. This is particularly true in the downstream portion of the watershed, from Bicknell Ave to the outfall to the Spicket River.

Further investigation should be done to better understand contributions of *E. coli* to the Eagle Lane site, potentially including analysis for pharmaceuticals or other tracers to indicate whether bacteria are sources from human waste (such as from a poorly maintained septic, leaking sewer or other illicit sewer connection) or from animal waste.

This study revealed that there are impairments in water quality which may limit the Brook's ability to support aquatic ecosystems in some sections such as low DO and high temperatures in the late spring, and high salinity, conductivity and total dissolved solids in the winter. Despite this, wildlife has been spotted throughout the watershed, both in and out of the water, suggesting there is good potential to improve habitat conditions and increase populations of beneficial species. Measures should be taken to improve riparian habitat and water quality in Bloody Brook for wildlife and people alike.

The watershed would greatly benefit from nature-based solutions including green infrastructure and stormwater best management practices. In particular, the downstream portion of the watershed near the Lawrence-Methuen line where impervious surface is greatest would benefit from these solutions. Additionally, protecting the upstream portion of the watershed would further ensure that conditions do not worsen in this section, and Searles Pond and the surrounding wetland/forest area can continue to attenuate pollution sources entering from upstream of it. These same solutions would provide flood mitigation and would help remove excess salinity, conductivity and total dissolved solids. In addition to installing green infrastructure, education and outreach around rain gardens, rain barrels, and each land owner's contribution to the improvement or impairment of water quality would benefit the Brook and watershed as a whole.

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10. APPENDICIES

10.1. APPENDIX A: QUALITY ASSURED PROJECT PLAN

10.2. APPENDIX B: WATER QUALITY MONITORING MANUAL

10.3. APPENDIX C: QAPP ADDENDUM WITH APPROVED LABORATORY STANDARD OPERATING PROCEDURES