MERRIMACK RIVER WATERSHED COUNCIL

2021 WATER QUALITY REPORT

March 2022

Photo credit: Winslow Townson

EXECUTIVE SUMMARY

The Merrimack River Watershed Council's volunteer water quality monitoring program collects water quality data at 13 sites along the main stem of the Merrimack River, from Manchester, NH to Newburyport and Salisbury, MA. Data on pH, salinity, total dissolved solids, conductivity, and temperature were collected once or twice a month between January and December 2021. For all monitoring sites, the conditions for pH, salinity, total dissolved solids, conductivity, and temperature were within recommended limits for human use and/or are supportive of aquatic ecosystems.

In addition to the physical and chemical parameters, grab samples were collected and analyzed for fecal indicator bacteria a) once or twice a month and b) following several combined sewer overflow events (CSOs). The presence and concentration of *E. coli* and *Enterococcus* (two types of fecal indicator bacteria) show whether and to what extent a water body has been contaminated with fecal matter. The presence of fecal contamination in local water bodies (from stormwater runoff, illicit sewer connections and CSOs) presents a serious threat to both human and ecological communities. Although conditions in the Merrimack are safe most of the time, occurrences of high bacteria levels suggest that recreational activities, such as swimming or boating, may be unsafe at certain times.

Rainfall records show that 2021 was a relatively wet year, with the monthly total rainfall in July being the highest on record for that month, by almost two inches. This also led to near-record streamflow in July, as well as the greatest amount of CSO volume for the year since 2013: 822 million gallons.

During our regular monitoring program, 29 out of 140 *E. coli* samples (21%) were considered unsafe for recreational use, while for *Enterococcus*, 14 samples out of 73 samples (19%) were considered unsafe for recreational use. Most of the unsafe samples occurred during wet weather events for *Enterococcus*, but the opposite for *E. coli*. This could indicate another contamination source aside from CSOs at some sites. However, further investigation is needed to determine issues at specific locations.

During CSO event monitoring, 38 out of 75 *E. coli* samples (51%) were considered unsafe for recreational use, while for *Enterococcus*, 36 samples out of 64 samples (56%) were considered unsafe for recreational use. Of the unsafe samples, 100% occurred during wet weather events. This shows a strong relationship between wet weather events and unsafe bacteria concentrations.

MRWC is using this data to work towards solutions that will improve the bacteria conditions in the watershed, including working with the Boston University School of Public Health to model water quality conditions in the river and better understand the health risks associated with CSO events, helping municipalities develop watershed-based plans and implement green infrastructure projects to capture stormwater runoff and reduce nonpoint source pollution, and advocating to ensure upcoming federal money reaches our communities to improve combined sewer systems.

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HOW TO USE THIS REPORT

This report is written to provide information in a scientific format, but that is approachable for the general audience. Depending on your purpose for viewing the report, you may read the report from start to finish, or visit each of the standalone sections to find only the information you are looking for. Below is a guide to each section.

Introduction

This section provides information about how we run our program and why, including explanations on where bacteria in the Merrimack come from, and how we work to understand them with our sampling program.

Environmental Conditions

This section explains the conditions within the watershed during 2021 that provide context for our sampling. This includes how much rain fell and streamflow patterns in the river in 2021 and how that compares to other years, as well as how much CSO volume contributed to the river and where. By understanding the context within which we collected data, we can draw better conclusions about our findings.

2021 Monitoring Program Results

This section provides and explains all of the data we collected in 2021 for all sites along the Merrimack River. Each physical/chemical parameter (pH, specific conductivity, salinity, total dissolved solids, and temperature) is described in a two-page summary. Bacteria conditions for the entire Merrimack are described in an eight-page summary.

Regional Profiles

If you only want to learn about bacteria conditions in the area where you live, skip to this section. Here we interpret bacteria results in five regions by grouping our sampling sites and analyzing results according to where those sites are located relative to known potential contributions of bacteria to the river, such as large urban areas and CSO outfalls.

INTRODUCTION

Who is MRWC

The Merrimack River Watershed Council (MRWC) was founded in 1976 to address the issue of pollution in the Merrimack River. At the time, the river turned green, or red, or orange, depending on the color dye that was used in the mills that day. While the dyes are gone, the river still faces significant threats. Current issues that directly impact water quality in the Merrimack are related to increased human activities across the watershed and aging sewer infrastructure, which can alter physical, chemical, and bacteria conditions in the Merrimack River.

Collecting Data to Improve Decision Making

MRWC collects water quality data at sites along the main stem of the Merrimack River, from Manchester, NH to Newburyport and Salisbury, MA (Figure 1). We collect data on pH, salinity, total dissolved solids, conductivity, temperature, and concentrations of two types fecal indicator bacteria. **While there are many types of bacteria, we sample for Escherichia coli (*E. coli)* and *Enterococcus* which tell us if the river has been contaminated with fecal matter and to what extent.** We care about fecal contamination specifically because it presents a serious threat to both human and ecological communities and can make people sick. High fecal indicator bacteria levels indicate that recreational activities, such as swimming or boating, may be unsafe. **Throughout this report we will use "bacteria" for brevity, but are referring to the fecal indicator bacteria of *E. coli* and *Enterococcus.***

What about drinking water?

The Merrimack River is the second-largest surface-based drinking water source in New England, with more than 600,000 people getting their drinking water from the river. However, drinking water is heavily treated and it is unlikely that water coming out of the tap from city supplied water will be contaminated with bacteria. A study by the US Geological Survey did not find contaminants at reportable levels in treated drinking water, despite finding some in source water on the Merrimack. This suggests that water treatment methods are working correctly to eliminate contaminants from CSOs in drinking water.[30]

While we know there are periods when bacteria concentrations in the river are higher than the level considered safe for recreation, we also recognize that concentrations are below this level much of the time as well. There is still a major gap in understanding when, where, and for how long the river is unsafe to use after CSOs, rain events, or when snow is melting. The river monitoring program at MRWC aims to fill that gap in understanding. By collecting data consistently, we can better understand how changing environmental conditions and increasing human impacts affect the water quality of the Merrimack River. We use our data to inform residents about the conditions of the Merrimack; advocate for the right solutions to improve conditions; inform the development of regulations; remediate pollution hot spots; support litigation against polluters; and promote pollution reduction projects.

What is a CSO combined sewer overflow (CSO)?

A combined sewer system collects rainwater and wastewater into one pipe. Under normal conditions, it transports all of this water to a sewage treatment plant before discharging into a water body, keeping our rivers clean. Sometimes, during heavy rainfall and snowmelt, the volume of the combined storm and wastewater can exceed the capacity of the system and it discharges directly to nearby water bodies. ***Learn more at merrimack.org/cso***

Understanding Sources of Bacteria

Bacteria in the Merrimack typically comes from three sources: nonpoint sources (like stormwater runoff), CSOs, and illicit sewer connections. By collecting water quality data over time and at different sites, we can see trends in bacteria concentrations that may help us to understand the source. While this sounds relatively simple, the process of identifying the source of contamination is complex. Bacteria concentrations vary greatly, and any given location in the river might receive bacteria from more than one source. Bacteria also flow downstream with the current (which can move fast some days and slower others), and rainfall is a driver for both nonpoint sources and CSOs, making them hard to differentiate. The methods we use to quantify bacteria only count living bacteria. Water temperature, exposure to light, salinity and other environmental conditions can affect how quickly bacteria die off. All of these conditions are changing all the time, making for a lot of factors when comparing the results of one day of sampling to another.

In order to see trends in the data and determine the source(s) of bacteria, a large dataset is required. To build this dataset, MRWC collects samples at the same locations every two weeks, year-round, and will continue to monitor for many years into the future. Already, we can see trends in the data as outlined in this report, and we are working with communities to resolve known and suspected sources of fecal contamination. For example, we know CSOs happen because of rain events. Sites that have high bacteria concentrations during both wet and dry weather conditions are likely impacted by an illicit sewer connection, which contributes bacteria to the river whether or not it is raining. In 2020, we found that our sample site in Methuen falls within this category. The EPA recently investigated the area, found the source of pollution, and has been working with the City of Methuen to fix this issue. This demonstrates how impactful data collection can be.

BACTERIA SOURCES IN THE MERRIMACK RIVER

NONPOINT SOURCES:

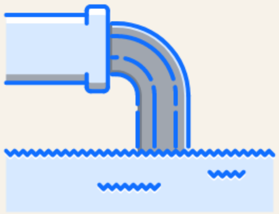
When rain runs over the land into rivers, it picks up and carries bacteria and other pollution. This might be animal waste from wildlife, your dog, or manure spread on agricultural fields. Wildlife that live in/on the Merrimack contribute fecal matter directly into the river.

In natural environments, rain falls on vegetated areas and seeps into the soil. As the water flows to the river, some pollutants and bacteria can be filtered out of the water by natural processes.

In urban areas, rainwater and snowmelt runs over parking lots and other impervious surfaces, where this natural filtration process doesn't happen.

POINT SOURCES:

Combined Sewer Overflows



Combined Sewer overflows (CSOs) occur when the combined sewer system that collects rainwater runoff, domestic sewage, and industrial wastewater into one pipe overflows.

Under normal conditions, these systems transport all the water to a sewage treatment plant. When the system works, it is best for the environment and our water bodies because it treats both stormwater and wastewater.

During heavy rainfall and snowmelt, the volume of combined storm and wastewater can exceed the capacity of the system. When this occurs, untreated stormwater and wastewater discharge directly into the Merrimack River.

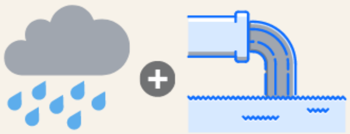
Illicit sewer connections

Illicit sewer connections are when older septic system or sewer pipes are leaking or directly flowing into the river.

HOW DO WE TRY TO UNDERSTAND SOURCES OF BACTERIAL CONTAMINATION IN OUR RIVER?

OBSERVATION IN MONITORING DATA	LIKELY SOURCE OF BACTERIA

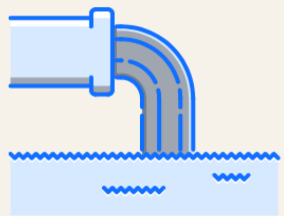
Time



Space

High bacteria levels after a known CSO event at sites downstream of a CSO outfall are likely caused by that that outfall. However, since nonpoint source pollution also occurs when it rains, we can't know whether high levels of fecal indicator bacteria are caused 100% by nonpoint pollution or a CSO outfall.

CSO



Time

Space

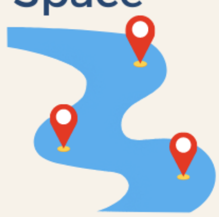
High bacteria levels during all weather events at the same site consistently, are likely caused by an illicit sewer connection.

Illicit connection

Time

and

Space



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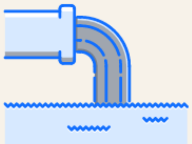

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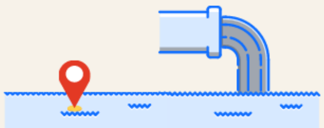
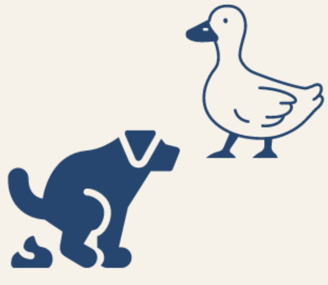


High bacteria levels during or after rainstorms (without a CSO) anywhere in the river or high levels after a CSO at sites upstream of a CSO outfall, are likely caused by nonpoint source pollution.

Nonpoint source



Monitoring Approach: Volunteer Powered

MRWC's water quality monitoring program relies on community science. All data are collected by community members who are trained by MRWC staff scientists to gather quality-controlled data in a standardized and reliable way. Each volunteer signs up for a six-month commitment, taking samples monthly at their assigned site (once monthly November-March due to ice conditions in the river and twice monthly in the remaining months). Each volunteer receives a 1.5-hour training along with a testing kit. Volunteers are responsible for calibrating, using, cleaning, and storing their kit.

MRWC volunteers currently collect water quality data at 13 sites on the main stem of the Merrimack River: 11 sites in MA and 2 sites in NH (See Figure 1 and Table 1). These locations were selected based on a variety of criteria, including their location upstream or downstream of cities (and known CSOs), proximity to popular recreation areas (for activities such as swimming, kayaking, motor boating, and fishing), and the safety of our volunteers when accessing the river.

Within these 13 sites, there are freshwater monitoring locations, which are not influenced by ocean water, and brackish (estuarine) monitoring locations, which experience changing salinity and streamflow due to the tides. Freshwater monitoring locations begin at West Newbury, MA and continue upstream to Manchester, NH, while the brackish monitoring sites begin at the mouth of the river and continue up to Deer Island in Amesbury, MA.

However, tidal influence can be seen as far upstream as the Essex Dam in Lawrence, as the downstream tides can increase water volume upstream, creating a tide-like state. Beginning in July 2021, we modified our program to collect water samples within two hours before low tide to ensure that we are monitoring what contaminants are coming downstream, rather than what is coming in from the ocean.

In 2021, MRWC added 2 new monitoring sites in NH to characterize water quality conditions up and downstream of known CSOs in Manchester, the largest CSO contributor in the Merrimack at this time. MRWC also added a site in Lowell at Hunts Falls Bridge to align with the USGS streamflow gauge located nearby. The monitoring site in Dracut, MA was relocated a few hundred feet downstream (from Heav'nly Donuts to the gravel pit) to an access point that is safer for volunteers to access.

13 monitoring locations

36 volunteers and back-up volunteers

Samples collected every 1 to 2 times per month and during CSO events

312 samples analyzed in 2021

Table 1. Key aspects of MRWC water quality monitoring sites

Site	Site Abbreviation	Site Type	Collection Location	GPS Coordinates
Manchester - Merrimack Foot Bridge	MMFB	Freshwater	Bridge	42.979072, -71.469388
Manchester - USGS Gauge	MUG	Freshwater	Shore	42.948027, -71.463148
Lowell - Pawtucket Blvd	LPB	Freshwater	Shore	42.6411911, -71.3460007
Lowell - Hunts Falls Bridge	LHFB	Freshwater	Bridge	42.64649, -71.29923
Dracut – Heav'nly Donuts	DHD	Freshwater	Shore	42.6585413, -71.2625371
Dracut - Gravel Pit	DGP	Freshwater	Shore	42.66614, -71.2417
Lawrence - Bashara Boathouse	LBB	Freshwater	Dock/Shore	42.6922158, -71.1773753
Methuen - Riverview Blvd	MRB	Freshwater	Shore	42.7273583, -71.1290352
Haverhill - Lincoln Ave Bridge	HLAB	Freshwater	Bridge	42.7642673, -71.0345758
West Newbury - Ferry Park	WNFP	Freshwater	Shore	42.8101931, -70.9963550
Amesbury - Deer Island	ADI	Brackish	Shore	42.8348062, -70.9068175
Newburyport - Road Bridge	NBRB	Brackish	Bridge	42.815705, -70.872899
Newburyport - Plum Island	NPIL	Brackish	Dock/Shore	42.816798, -70.820559
Salisbury Beach State Reservation	SBSR	Brackish	Shore	42.8218847, -70.8212684

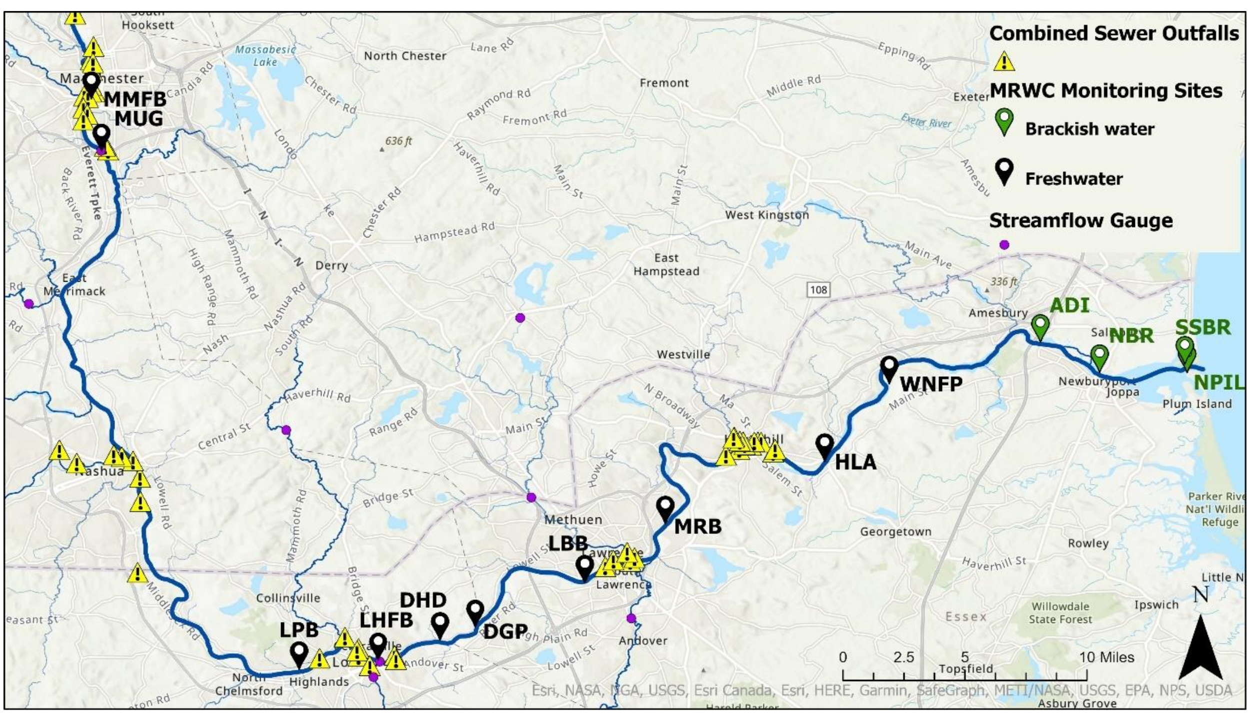


Figure 1. Map of the MRWC water quality monitoring sites.

Field Methods

Water quality data and water samples are collected twice monthly at each site. The river sample is collected either from a bridge, using a rope and bucket, or from the riverbank, obtaining the sample an arm's length into the river. Five physical and chemical water quality measurements are recorded on site using a handheld Pocket Pro+ Multi 2 Tester: 1) pH, 2) conductivity, 3) total dissolved solids (TDS), 4) salinity, and 5) temperature. Prior to testing, the meters are calibrated to ensure accuracy.

At each site, three readings for the physical and chemical properties are collected to ensure precision of the measurements. At brackish sites, volunteers are trained to properly dilute samples and adjust measurement calculations accordingly since the salinity at the most downstream sites can exceed the maximum reading level of the meters. The volunteers then record the measurements on datasheets provided by MRWC, along with observations about the ambient conditions and any nearby activity that may impact the sample.

After collecting the physical and chemical parameters, a grab sample is collected in a sterile sample bottle with a sodium thiosulfate preservative. Once collected, the samples are stored on ice and transported to the MRWC office, where they are then transported to an EPA-approved laboratory for analysis. After large CSO events that occur early in the week (see below for more information on this), volunteers may also be asked to collect daily grab samples for up to four days at all sites to track bacteria levels after CSO events

After sampling, the datasheets and the bacteria data from the laboratory are reviewed by MRWC staff for reasonableness and completeness before being entered into the MRWC water quality database. The results in that database form the foundation for this report.

Quality Assurance Project Plan

Our field and lab methods follow our Quality Assurance Project Plan (QAPP) which was approved by the EPA and MassDEP. Within our QAPP, we use approved standard operating procedures for sample collection, parameter measurements, and sample analysis.

Prior to July 2021, most samples were analyzed at Nashoba Analytical Laboratory. Starting in July 2021, MRWC began a partnership with the EPA Region 1 Laboratory, which now analyzes most samples collected in our program. During CSO events, other labs are occasionally used depending on lab availability. Across all labs, samples can only be analyzed during weekdays, limiting CSO monitoring to only events that occur early in the week so that samples can be collected and analyzed for 3-4 days following the event.

Nashoba Analytical Laboratory and the EPA Region 1 laboratory both report their results as most probable number per 100 milliliters (MPN/100 mL). However, other labs can report their results as colony forming units per 100 milliliters (CFU/100 mL). These two units are considered interchangeable and only indicate the lab procedure used to determine the results.

ENVIRONMENTAL CONDITIONS

Many conditions within the natural and human-made environment contribute to the water quality of the Merrimack River. These conditions influence changes in water quality parameters over time and space, and should always be taken into account when interpreting water quality data.

Rainfall

Rainfall has a large impact on river flows and water quality conditions. In vegetated places in the Merrimack River Watershed, rain falls on the ground and either absorbs into the soil or runs off directly into the river, carrying sediments, nutrients, and bacteria with it. In urban areas, there is very little soil to absorb the rain, so it often flows over paved surfaces into stormwater infrastructure. In most towns and cities, this untreated stormwater runs directly into the river, carrying with it everything that it picks up along the way. However, five regions along the Merrimack have combined sewer systems, which operate differently. In these systems, both stormwater and sewage flow to the wastewater treatment plant and are treated before being discharged into the river. If it rains enough or there is enough snowmelt to overwhelm the system, a CSO occurs, causing a mix of stormwater and sewage to flow directly into the river untreated.

Rainfall is measured daily at various rainfall gauges across the region. These gauges are maintained by the National Oceanic and Atmospheric Administration. For this analysis, we selected 5 stations along the Merrimack River in Concord and Manchester, NH and Lawrence, Haverhill, and Newburyport, MA, and compared the annual and monthly values for 2021 to the 10-year average (2011-2020) as well as the long-term average (1953-2020)[1].

Total Rainfall

Rainfall records from 2021 showed that it was a relatively wet year, with total rainfall being 17% higher than the 10-year average rainfall and 16% higher than the long-term average rainfall. In the three downstream locations in Lawrence, Haverhill, and Newburyport, MA, the total rainfall was between 19% and 28% higher than the 10-year average, indicating that the lower watershed received significantly more rain than normal. The upper watershed also experienced more rainfall than normal, with Concord, NH receiving 3% more rainfall and Manchester, NH receiving 10% more rainfall than the 10-year average (Table 2).

Table 2. Rainfall data from 5 stations in the Merrimack.

Rainfall Station Name	Elevation (m)	Total Rainfall in 2021 (in)	10-year average rainfall (in)	% Difference	Long-term average rainfall (in)	% Difference
CONCORD ASOS, NH	103.1	44.0	42.9	+3%	39.1	+13%
MASSABESIC LAKE, NH	77.1	45.3	41.3	+10%	39.4	+15%
LAWRENCE, MA	15.2	53.5	41.6	+28%	43.4	+23%
HAVERHILL, MA	6.1	53.7	45.2	+19%	45.8	+17%
NEWBURYPORT, MA	16.8	52.4	41.9	+25%	46.3	+13%
Average		**49.8**	**42.6**	**+17%**	**42.8**	**+16%**

Monthly Rainfall

When comparing the monthly rainfall amounts in Lawrence, the 2021 monthly values show a very high peak in July and a moderate peak in October, both of which are much greater than the 10-year and long-term averages for the sites. The monthly total rainfall in July was the highest on record by almost two inches. The monthly total for July 2021 (12.9 inches) is comparable to the precipitation in May 2006 (13.9 inches), which was during the memorable Mother's Day Floods (Figure 2).

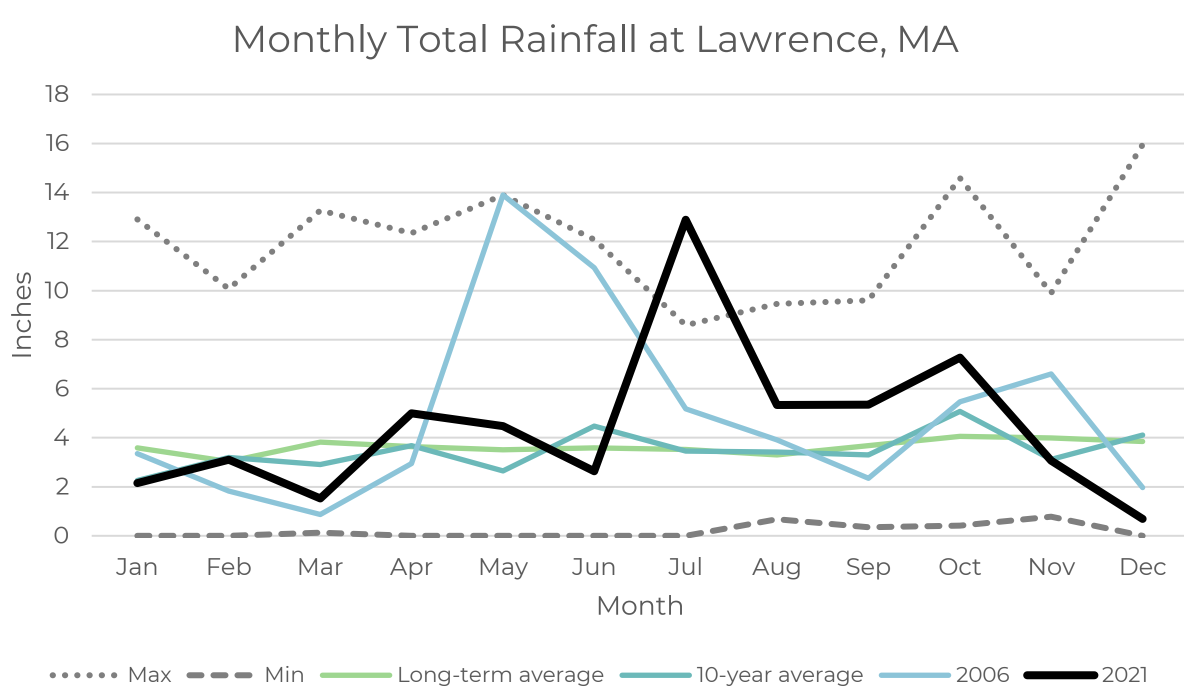


Figure 2. Average monthly rainfall at the Lawrence rainfall station

CSO Events Driven by Rainfall

Heavy rainfall causes CSO events in the Merrimack River. Rainfall intensity is the amount of rain that falls in a set time period, usually measured in inches per hour. Combined sewer systems vary in how they respond to rainfall. In Haverhill, rainfall intensity is a good predictor of whether a CSO event will occur or not (Figure 3, top). In Lowell, total rainfall is a better predictor (Figure 3, bottom). Once a larger dataset is available, further analysis of these patterns could lead to predictions of whether a CSO will occur and where it will occur given rain conditions.

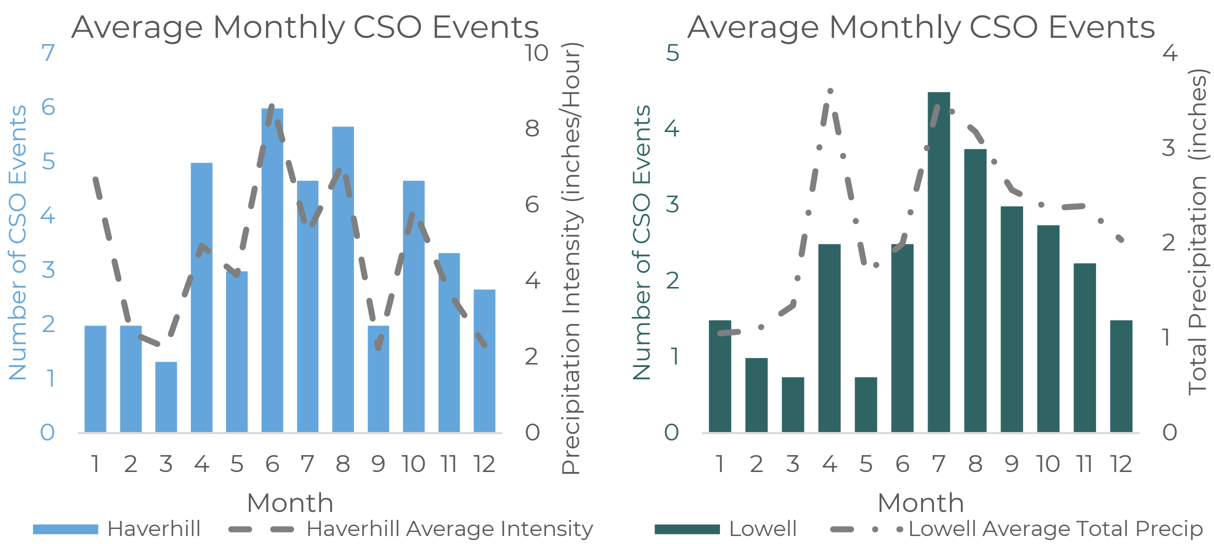


Figure 3. Average monthly CSO events and rainfall intensity at Haverhill (top, averaged over 2018-2020 because 2021 data were not available during the preparation of this report) and average monthly CSO events and total rainfall at Lowell (bottom, averaged over 2018-2021).

Streamflow

Streamflow, or the amount of water moving through the river at a certain location, is closely linked to snow melt and rainfall. Once rainfall and snowmelt carry bacteria from the source to the river, streamflow determines how quickly it will move downstream. There are two gauges in the Merrimack that measure streamflow, one in Manchester, NH and one in Lowell, MA. For this report, we analyzed the streamflow in Lowell, MA because it has a longer period of record.

In 2021, the peak streamflow in July is approaching the historical maximum average for that month, and reflects the unprecedented amount of rainfall that fell in July 2021 (Figure 4). Lower than average flows in January through June reflect a low snowpack year, resulting in lower flows in the spring. Likely, streamflow in July 2021 did not reach the peak seen in 2006 because the river started with relatively low flows before the July rain started. During the Mother's Day Floods in May 2006, the Merrimack was likely full with both snowmelt and runoff from rainfall, resulting in the historic flood conditions.

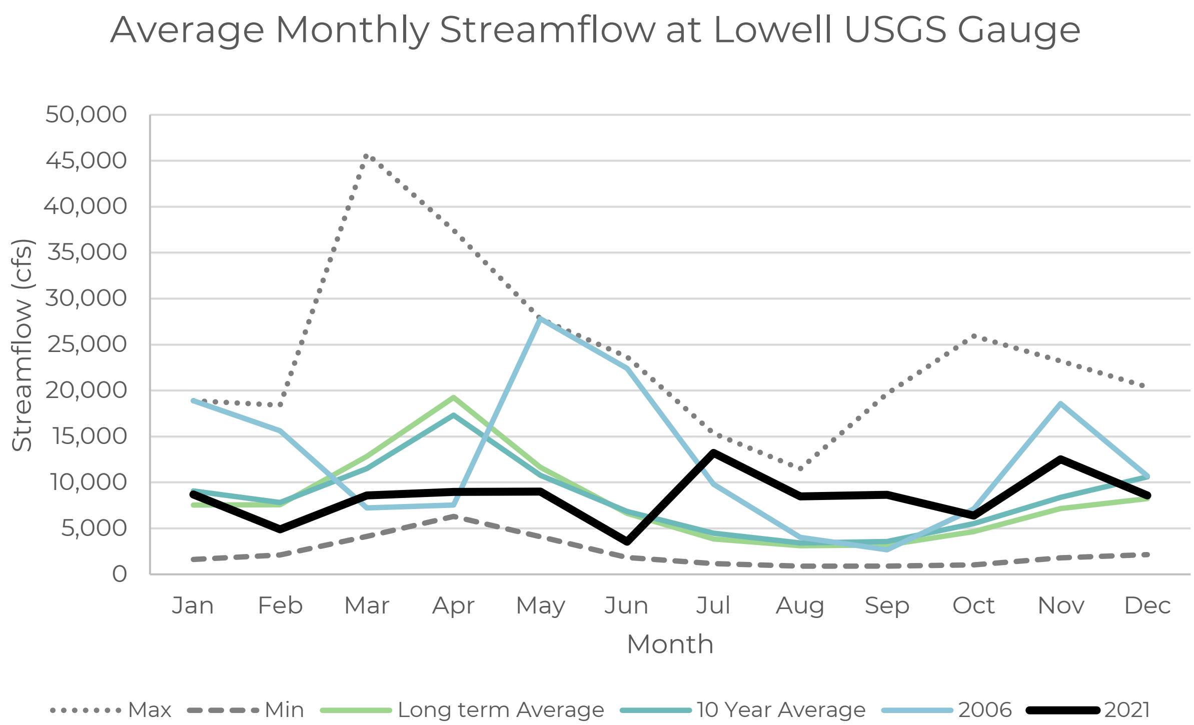


Figure 4. Average monthly streamflow at the USGS Gauge in Lowell, for different time periods.

Combined Sewer Overflows

CSO volumes can fluctuate annually depending on the rainfall and any changes made to combined sewer systems. CSO discharge volume also varies from event to event due to factors like rainfall intensity, rainfall duration, and soil saturation. There are five areas with combined sewer systems on the mainstem of the Merrimack River: Manchester and Nashua in NH, and Lowell, Greater Lawrence Sanitary District (GLSD), and Haverhill in MA.

Based on CSO volume data reported by wastewater treatment facilities in each of the five areas from 2013 to 2021, the year 2021 saw the largest annual volume of CSOs into the Merrimack with a total of 822 million gallons (Figure 5, Table 3)[2–5]. The largest contributor in 2021 was Lowell with 447 million gallons, nearly double their previous maximum in 2018 (Table 3). On average, Manchester and Lowell each contribute approximately 220 million gallons per year, each making up approximately 40% of the total CSO volume (Figure 5, Table 3). Nashua contributes the lowest annual average with 20 million gallons (Figure 5, Table 3).

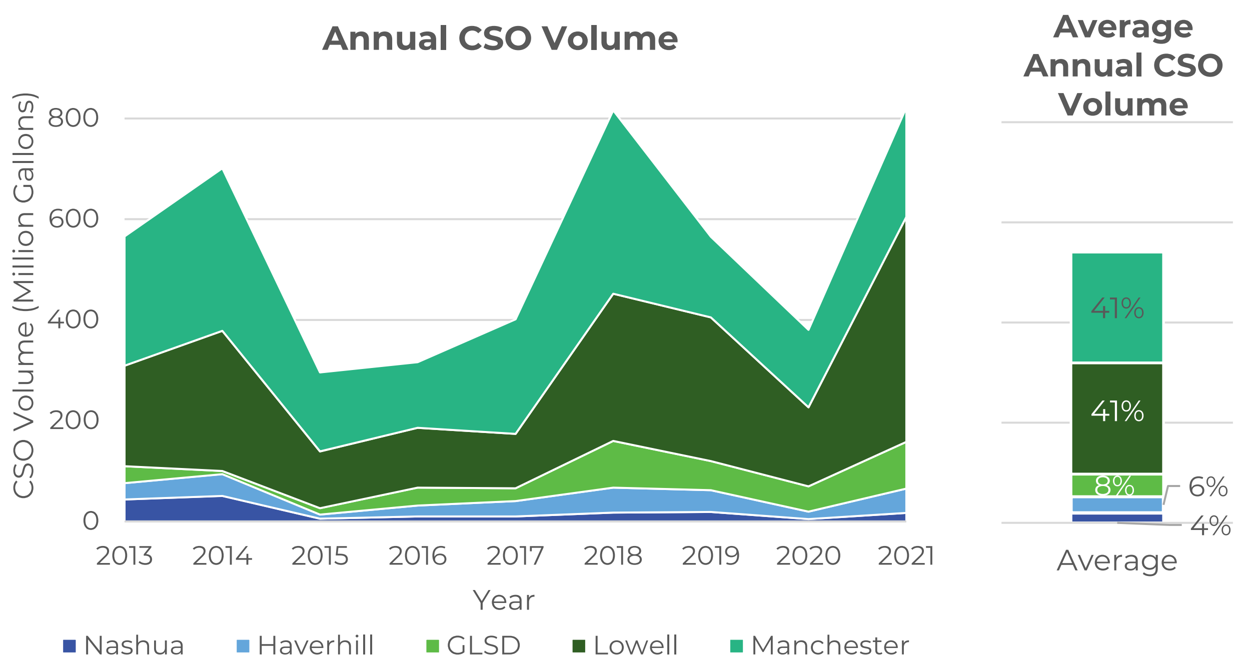


Figure 5. Average Annual CSO volume from the five combined systems on the Merrimack.

In terms of the number of CSO events in each year, Haverhill is the largest contributor historically, contributing 42% of the total CSO events each year (44 events on average, Figure 6). Haverhill typically has frequent but small volume events compared to Lowell or GLSD, which have less frequent but larger events. In 2021, we estimated that Haverhill contributed the same number of CSO events as in 2018 (the year with the closest annual volume to 2021), as individual event data were not available at the time this report was prepared (Figure 6). Manchester is not included in the CSO event analysis because they did not report individual events in 2021. At the time this report was prepared, Manchester only reported total annual volumes once per year. While 2021 saw the greatest volume in CSOs, 2018 still holds the maximum for number of CSO events, assuming Haverhill did not produce more events in 2021 than in 2018 (Figure 6).

CSO data can be accessed two ways. You can be alerted about CSOs when they are occurring via email. Currently, you must sign up for notifications from each waste water treatment facility individually. You may also download reports about all CSO events in a month, quarter or year, depending on the facility. Individual CSO event data from 2018-2021 used in this report are available in the appendix. Annual data from 2013 - 2017 were sourced from publicly posted annual reports and Freedom of Information Act requests, and are available by request.
Find out how to access data from waste water facilities at our website: merrimack.org/cso

Table 3. Annual CSO volume by year and combined sewer system.

			Total Annual CSO Volume (million gal)			
Year	**Haverhill**	**GLSD**	**Lowell**	**Nashua**	**Manchester**	**Total**
2013	32	34	200	44	257	**566**
2014	43	6	278	51	322	**701**
2015	8	13	113	6	157	**296**
2016	21	36	118	10	131	**316**
2017	31	26	108	10	227	**401**
2018	50	93	292	18	364	**816**
2019	44	58	285	19	160	**565**
2020	15	50	157	5	154	**380**
2021	48	93	447	17	217	**822**
Average	**32**	**45**	**222**	**20**	**221**	**540**
Percent	**6%**	**8%**	**41%**	**4%**	**41%**	

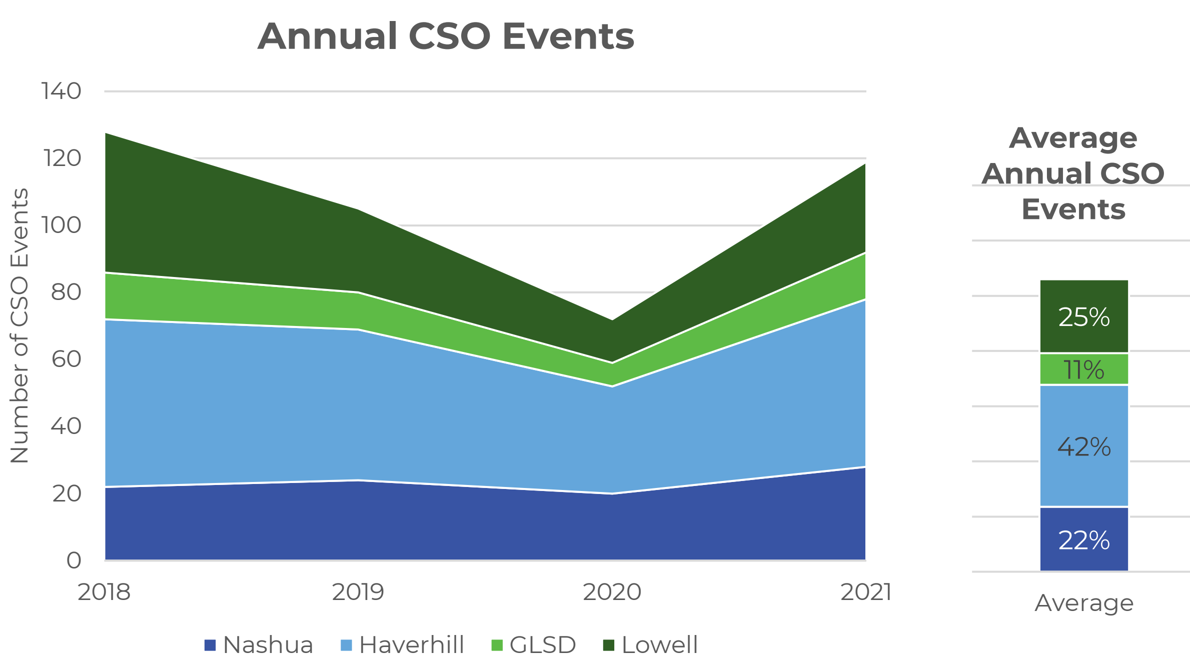


Figure 6. Average annual number of CSO events from four combined systems on the Merrimack. For 2021, the individual CSO event data for Haverhill were not available at the time this report was prepared. Manchester did not report on individual CSO events in 2021, they only released total annual volumes once per year, and therefore were not included.

Monthly trends in CSO volumes are a result of a variety of factors: how much it rains (total precipitation), how hard it rains (intensity) and how long it rains (duration). No single factor fully explains the monthly trends of CSO volumes. We see the highest cumulative volumes in CSO discharges in the spring (April), when long lasting heavy spring storms occur and summer to early fall (July to September) when short, but heavy thunderstorms occur (Figure 7). July 2021 saw the highest volume of CSO discharges of all years within the short record, even without Manchester or Haverhill included (197 million gallons, Figure 7). Climate change may shift these monthly trends. While precipitation in January, February, and March is historically made up of snow, warmer temperatures may cause increased rainfall and snowmelt events (and thus CSO events and volumes) in the winter months. In addition, more intense storms like those seen in July 2021 are predicted to become more common[6,7].

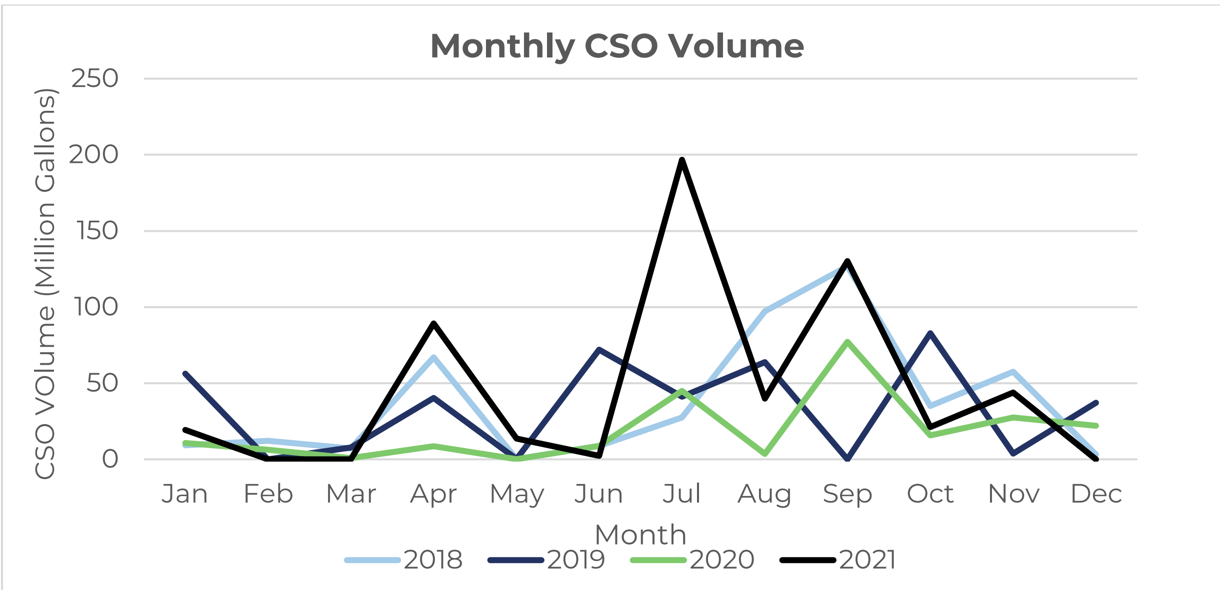


Figure 7. Monthly CSO volume for 2018-2021 from Nashua, Lowell, GLSD and Haverhill combined sewer systems on the Merrimack. For 2021, Haverhill's volume is missing as the data were not available at the time this report was written. Manchester did not report on individual CSO events in 2021, they only released total annual volumes once per year, and therefore were not included.

2021 MONITORING PROGRAM RESULTS

The next section reviews the different parameters MRWC measures as part of our water quality monitoring program. It includes information and context about each parameter as well as a review of the conditions in the Merrimack River in 2021.

Data Dashboards

Want to see all the data we collected this year on the Merrimack? Or see results at a specific monitoring site? Check out our new interactive dashboards! Go to **merrimack.org/science/water-quality-monitoring-program**

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[8,9]
- Water with pH that is too high or too low can also corrode water pipes and make it harder to treat drinking water[8]

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.[8]
- Human activities, such as mining runoff, industrial pollution, and the burning of fossil fuels, can cause a decrease in pH, making waters more acidic[8–10]
- 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.[8–10]

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[9]
- Between 6.5 and 8.5 is often considered ideal for drinking water for people[11]

What were the conditions in the Merrimack River in 2021?

For all monitoring sites, the median pH conditions in the Merrimack River are within the EPA's water quality criteria of between 6.5 and 9 (Table 4). There were two samples where the average pH measured was lower than 6.5 (meaning these samples were more acidic than typical water values). Both occurred at Salisbury - Beach State Reservation and were measured to be 6.47 (April 19, 2021) and 5.8 (May 21, 2021) (Figure 8). These appear to be short-lived events as the monthly averages are within the suggested limits and are unlikely to cause any impacts to aquatic species. MRWC will keep an eye on this site to see if additional acidic readings occur and could investigate a potential cause if it occurs more frequently.

Table 4 Minimum, maximum and median pH measurements from all monitoring activities 2021.

Site	Water Type	River Mile	Min pH	Max pH	Median pH
Manchester - Merrimack Foot Bridge	Freshwater	70.55	6.70	7.76	7.01
Manchester - USGS Gauge	Freshwater	67.86	6.90	7.23	7.05
Lowell - Pawtucket Blvd	Freshwater	47.75	6.77	8.27	7.02
Lowell - Hunts Falls Bridge	Freshwater	43.00	6.89	7.22	6.99
Dracut - Heav'nly Donuts	Freshwater	36.36	6.97	7.96	7.29
Dracut - Gravel Pit	Freshwater	34.00	6.71	7.78	7.36
Lawrence - Bashara Boathouse	Freshwater	29.02	6.80	8.04	7.15
Methuen - Riverview Blvd	Freshwater	26.20	6.80	8.76	7.12
Haverhill - Lincoln Ave Bridge	Freshwater	16.24	6.62	7.55	7.16
West Newbury - Ferry Park	Freshwater	12.43	6.61	8.08	7.13
Amesbury - Deer Island	Brackish	5.67	7.01	7.78	7.38
Newburyport - Road Bridge	Brackish	3.47	6.61	7.82	7.15
Newburyport - Plum Island	Brackish	0.74	6.72	8.04	7.41
Salisbury - Beach State Reservation	Brackish	0.72	5.80	8.05	7.23

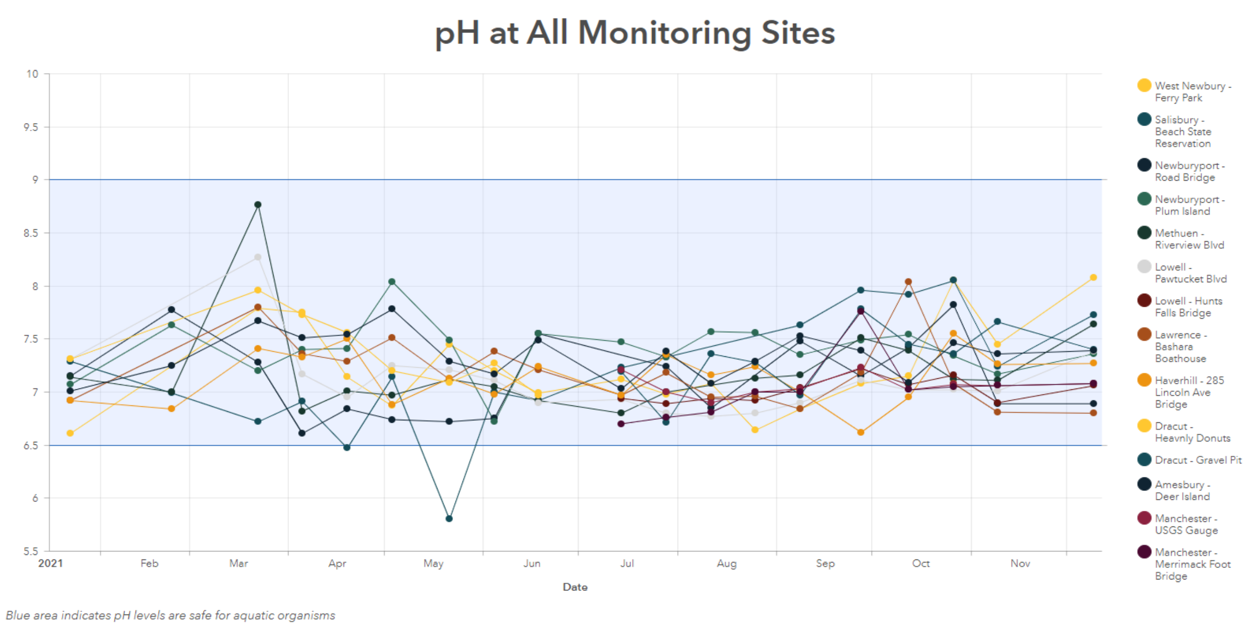


Figure 8. pH measurements from all monitoring activities in 2021. Use the online dashboard to see site-specific results: merrimack.org/science/water-quality-monitoring-program

Specific Conductivity

What is specific conductivity?

- Specific conductivity (often referred to as conductivity for short) 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[12]
- Background levels of conductivity are dependent on the surrounding geology, with clay soils increasing conductivity and granite bedrock reducing it[12]

What changes conductivity?

- Agricultural runoff and sewage leaks may increase conductivity, while oil spills or other organic compounds may decrease conductivity[12]

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[13]
- Industrial wastewater can measure 10,000 µS/cm or more[12,13], while seawater can measure 55,000 µS/cm or more[12]

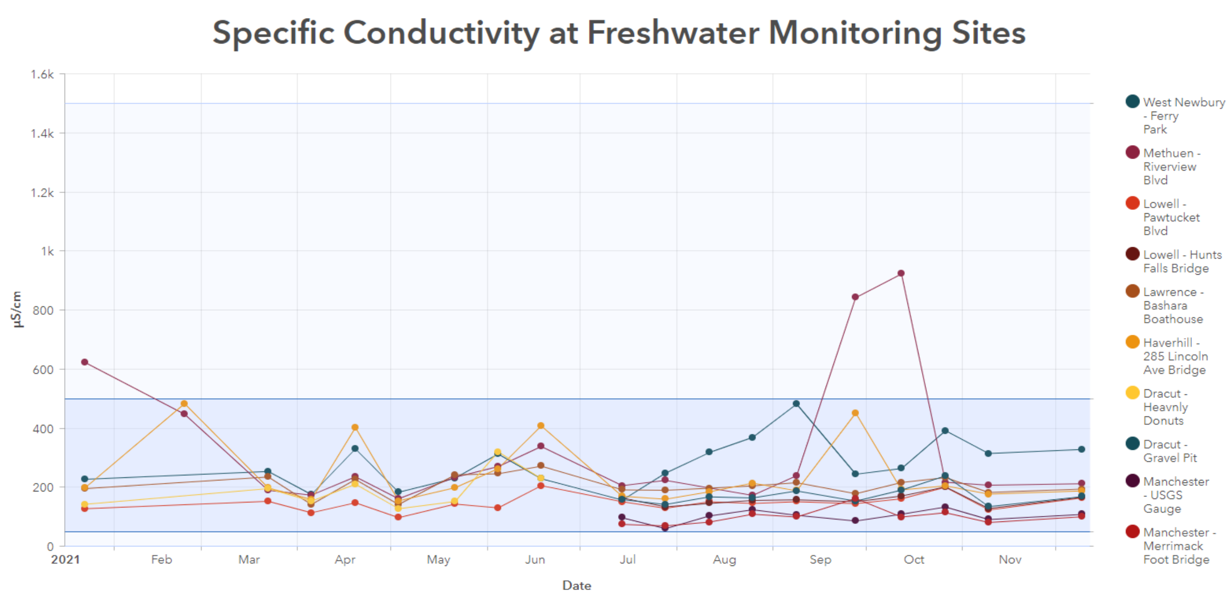
What were the conditions in the Merrimack River in 2021?

The average conductivity of freshwater sites in the Merrimack River are within the suggested range for supporting good mixed fisheries (Table 5, Figure 9). There were a few samples above 500 µS/cm at the Methuen Riverview Blvd site, but they were still within the typical range for freshwater streams and rivers. As much of the watershed contains granite bedrock and granitic soils, it is expected that the background conductivity levels will be relatively low, which is shown in the results. However, more years of conductivity data will be needed to determine a range of conductivity that is considered normal background levels for the Merrimack. Once this is known, future samples can be compared against that range to see if there are any strong deviations from what is considered normal for the Merrimack.

The brackish sites had samples up to 50,550 µS/cm. However, all samples above 10,000 µS/cm had salinities greater than 1 ppt, which indicates that the increased conductivity was likely due to the presence of seawater and not industrial pollutants.

Table 5. Minimum, maximum and median specific conductivity from all monitoring activities in 2021.

Site	Water Type	River Mile	Min Cond (µS/cm)	Max Cond (µS/cm)	Median Cond (µS/cm)
Manchester - Merrimack Foot Bridge	Freshwater	70.55	69.00	161.60	98.90
Manchester - USGS Gauge	Freshwater	67.86	59.20	132.70	103.65
Lowell - Pawtucket Blvd	Freshwater	47.75	96.80	204.70	145.95
Lowell - Hunts Falls Bridge	Freshwater	43.00	127.50	200.60	155.90
Dracut - Heav'nly Donuts	Freshwater	36.36	127.20	319.70	174.00
Dracut - Gravel Pit	Freshwater	34.00	134.20	238.30	165.25
Lawrence - Bashara Boathouse	Freshwater	29.02	141.10	271.30	200.25
Methuen - Riverview Blvd	Freshwater	26.20	160.40	922.00	228.15
Haverhill - 285 Lincoln Ave Bridge	Freshwater	16.24	153.10	482.70	197.40
West Newbury - Ferry Park	Freshwater	12.43	156.10	481.30	258.00
Amesbury - Deer Island	Brackish	5.67	54.30	14,043.30	240.30
Newburyport - Road Bridge	Brackish	3.47	164.20	39,183.30	2,480.00
Newburyport - Plum Island	Brackish	0.74	1,015.00	37,116.70	17,883.30
Salisbury - Beach State Reservation	Brackish	0.72	391.00	50,550.00	16,390.00



The darker blue area indicates specific conductivity levels support mixed, freshwater fisheries. The light blue area indicates typical range for freshwater streams and rivers.

Figure 9. Conductivity measurements from all monitoring activities in 2021. Use the online dashboard to see site-specific results: merrimack.org/science/water-quality-monitoring-program

Salinity

What is salinity?

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

Why is it important?

- Measuring salinity can help determine how far the tides flow up the Merrimack River
- Salinity levels impact the types of aquatic species that live in different parts of the river[14]

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 to the Merrimack, 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[12,14]
- Brackish water habitats (a mix of freshwater and ocean water) typically have a salinity value between 0.5 and 17 ppt[12,14]
- Ocean water typically has a salinity value around 30 to 35 ppt[12,14]

What were the conditions in the Merrimack River in 2021?

All freshwater monitoring sites have an average salinity of 0.15 ppt or less, with the highest single recording of 0.5 ppt at Methuen - Riverview Blvd. This is within the normal range for freshwater sources. The brackish sites have slightly higher average values, with the highest reading of 15.5 ppt at the most downstream site Salisbury - Beach State Reservation. It should be noted that water quality testing is usually scheduled within two hours of low tide so high tide conditions, which would increase salinity at some sites, are not represented in these data.

Table 6. Minimum, maximum and median salinity from all monitoring activities in 2021.

Site	Water Type	River Mile	Min Salinity (ppt)	Max Salinity (ppt)	Median Salinity (ppt)
Manchester - Merrimack Foot Bridge	Freshwater	70.55	0.10	0.30	0.10
Manchester - USGS Gauge	Freshwater	67.86	0.10	0.10	0.10
Lowell - Pawtucket Blvd	Freshwater	47.75	0.10	0.10	0.10
Lowell - Hunts Falls Bridge	Freshwater	43.00	0.10	0.10	0.10
Dracut - Heav'nly Donuts	Freshwater	36.36	0.10	0.20	0.10
Dracut - Gravel Pit	Freshwater	34.00	0.10	0.10	0.10
Lawrence - Bashara Boathouse	Freshwater	29.02	0.10	0.10	0.10
Methuen - Riverview Blvd	Freshwater	26.20	0.10	0.50	0.10
Haverhill - 285 Lincoln Ave Bridge	Freshwater	16.24	0.10	0.30	0.10
West Newbury - Ferry Park	Freshwater	12.43	0.10	0.30	0.10
Amesbury - Deer Island	Brackish	5.67	0.10	7.00	0.10
Newburyport - Road Bridge	Brackish	3.47	0.20	10.00	1.80
Newburyport - Plum Island	Brackish	0.74	0.50	7.60	2.80
Salisbury - Beach State Reservation	Brackish	0.72	0.20	15.50	3.80

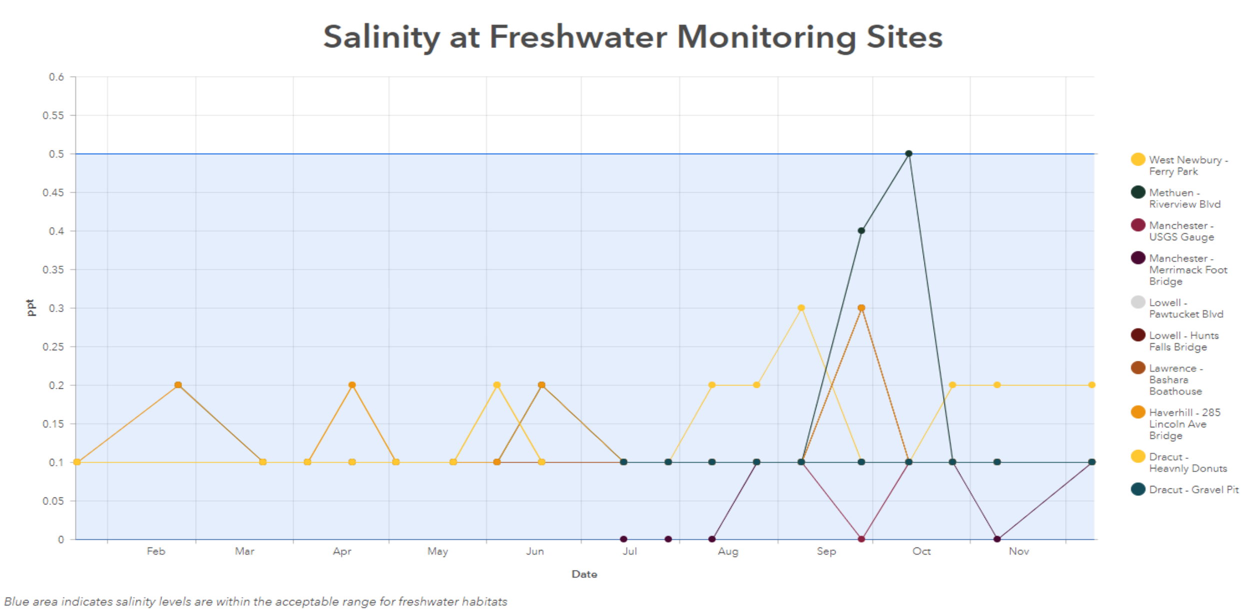


Figure 10. Salinity measurements from all monitoring activities in 2021. Use the online dashboard to see site-specific results: merrimack.org/science/water-quality-monitoring-program

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[15,16]

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[12]
- However, high levels of total dissolved solids in freshwater during a dry period can be a sign of point source pollution[12]

What are important values for environmental or human health?

- There is no EPA recommendation for TDS limits for aquatic species, but TDS measurements over 1,000 mg/L in freshwater could impact fish reproduction[17]
- TDS values over 500 mg/L require secondary treatment before being used as drinking water for humans[15]

What were the conditions in the Merrimack River in 2021?

All freshwater sites in the Merrimack are well below the 1,000 mg/L threshold, indicating the levels of TDS do not threaten freshwater aquatic species. Measurements at brackish sites are much higher, as would be expected with the introduction of ocean water. However, any aquatic species living in this zone are tolerant of changes in TDS and these elevated levels are not of ecological concern.

Table 7. Minimum, maximum and median total dissolved solids from all monitoring activities in 2021.

Site	Water Type	River Mile	Min TDS (mg/L)	Max TDS (mg/L)	Median TDS (mg/L)
Manchester - Merrimack Foot Bridge	Freshwater	70.55	48.90	122.00	70.10
Manchester - USGS Gauge	Freshwater	67.86	60.50	94.20	76.50
Lowell - Pawtucket Blvd	Freshwater	47.75	8.40	145.30	105.00
Lowell - Hunts Falls Bridge	Freshwater	43.00	90.60	142.70	115.00
Dracut - Heav'nly Donuts	Freshwater	36.36	89.90	235.00	126.80
Dracut - Gravel Pit	Freshwater	34.00	95.80	169.70	119.30
Lawrence - Bashara Boathouse	Freshwater	29.02	100.80	237.30	146.00
Methuen - Riverview Blvd	Freshwater	26.20	121.00	652.70	168.15
Haverhill - 285 Lincoln Ave Bridge	Freshwater	16.24	93.30	340.70	146.00
West Newbury - Ferry Park	Freshwater	12.43	114.00	370.70	185.50
Amesbury - Deer Island	Brackish	5.67	38.60	5,836.70	171.00
Newburyport - Road Bridge	Brackish	3.47	207.30	31,050.00	1,750.00
Newburyport - Plum Island	Brackish	0.74	316.80	28,633.30	13,050.00
Salisbury - Beach State Reservation	Brackish	0.72	2.80	35,716.70	13,023.35

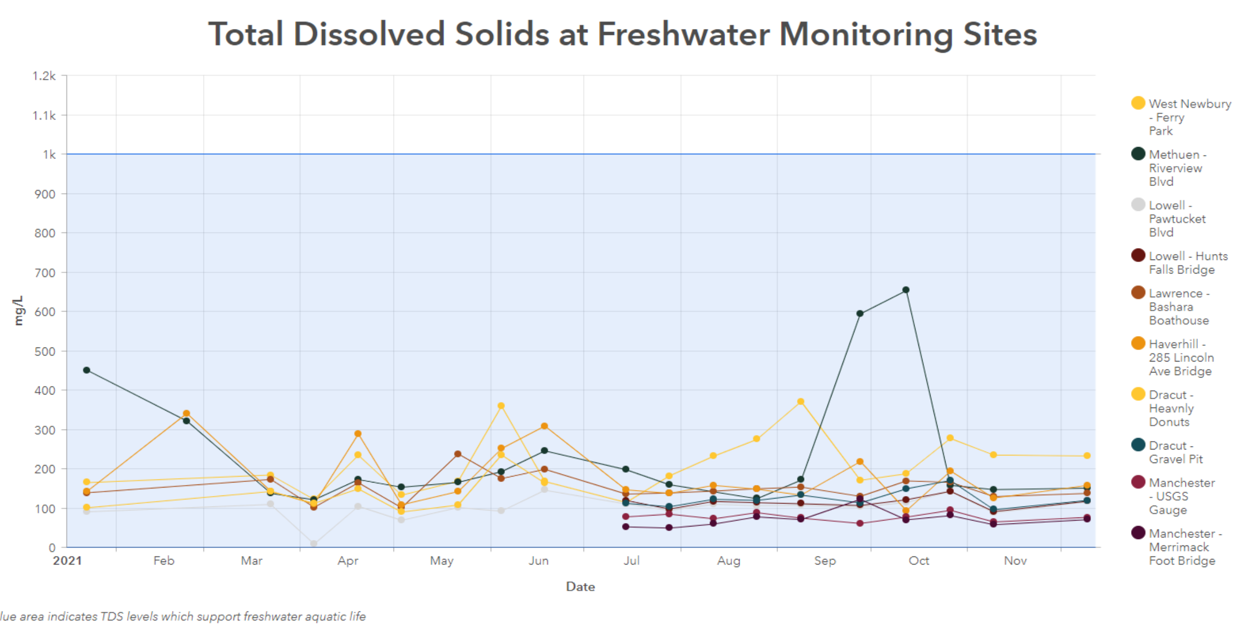


Figure 11. Total dissolved solids measurements from all monitoring activities in 2021. Use the online dashboard to see site-specific results: merrimack.org/science/water-quality-monitoring-program

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[18]
- Water bodies with higher temperatures contains less dissolved oxygen, which is important for aquatic organisms[18,19]
- Water bodies with high temperatures may also result in higher levels of toxicity from heavy metals[19]

What changes temperature?

- Temperatures naturally fluctuate with the seasons and can be influenced by tides containing ocean water
- Human actions, such as building dams, running thermoelectric power plants, and cutting down riparian forests, can increase the temperature of rivers and water bodies[19]

What are important values for environmental or human health?

- Cold water fish species, such as brook trout and salmon, cannot tolerate long-periods of water that is 20˚C (68˚F) or higher[20,21]
- Warm water fish species, such as Atlantic Sturgeon and American Eel, can tolerate temperatures up to 25˚C (77˚F), and sometimes higher[22,23]

What were the conditions in the Merrimack River in 2021?

Comparing all monitoring sites, the surface temperatures are quite similar (Table 8). The brackish sites may have a slightly warmer temperature in the winter months due to the influence of ocean water coming in with the tides, which is often warmer than the freshwater during these months. During the spring, fall, and winter, the Merrimack River is cool enough to be able to support cold water fisheries (Figure 12). However, during the warm summer months of June through September the average temperatures rise above 20˚C, meaning that any cold-water fish species in the main stem of the Merrimack will need to find cold water tributaries for refuge areas. While the mainstem of the Merrimack is not considered cold-water fishery habitat, it does serve as an important corridor for fish moving between tributaries. It should also be noted that the samples were taken near the surface of the water, which tends to be warmer due to heating from the sun. The water further down in the water column is likely much cooler and able to support important fish species, even in the warmer summer months.

Table 8. Minimum, maximum, and median temperature from all monitoring activities in 2021.

Site	Water Type	River Mile	Min Temp (˚C)	Max Temp (˚C)	Median Temp (˚C)
Manchester - Merrimack Foot Bridge	Freshwater	70.55	4.73	23.83	20.05
Manchester - USGS Gauge	Freshwater	67.86	4.23	23.83	20.00
Lowell - Pawtucket Blvd	Freshwater	47.75	2.57	23.67	19.10
Lowell - Hunts Falls Bridge	Freshwater	43.00	2.37	23.60	18.85
Dracut - Heav'nly Donuts	Freshwater	36.36	6.10	21.63	14.13
Dracut - Gravel Pit	Freshwater	34.00	3.80	24.13	19.65
Lawrence - Bashara Boathouse	Freshwater	29.02	2.47	23.87	17.30
Methuen - Riverview Blvd	Freshwater	26.20	4.37	25.50	20.73
Haverhill - 285 Lincoln Ave Bridge	Freshwater	16.24	5.83	26.20	20.23
West Newbury - Ferry Park	Freshwater	12.43	2.00	24.20	18.53
Amesbury - Deer Island	Brackish	5.67	4.00	23.43	17.54
Newburyport - Road Bridge	Brackish	3.47	3.27	25.47	15.89
Newburyport - Plum Island	Brackish	0.74	4.43	22.23	16.97
Salisbury - Beach State Reservation	Brackish	0.72	5.30	21.57	15.07

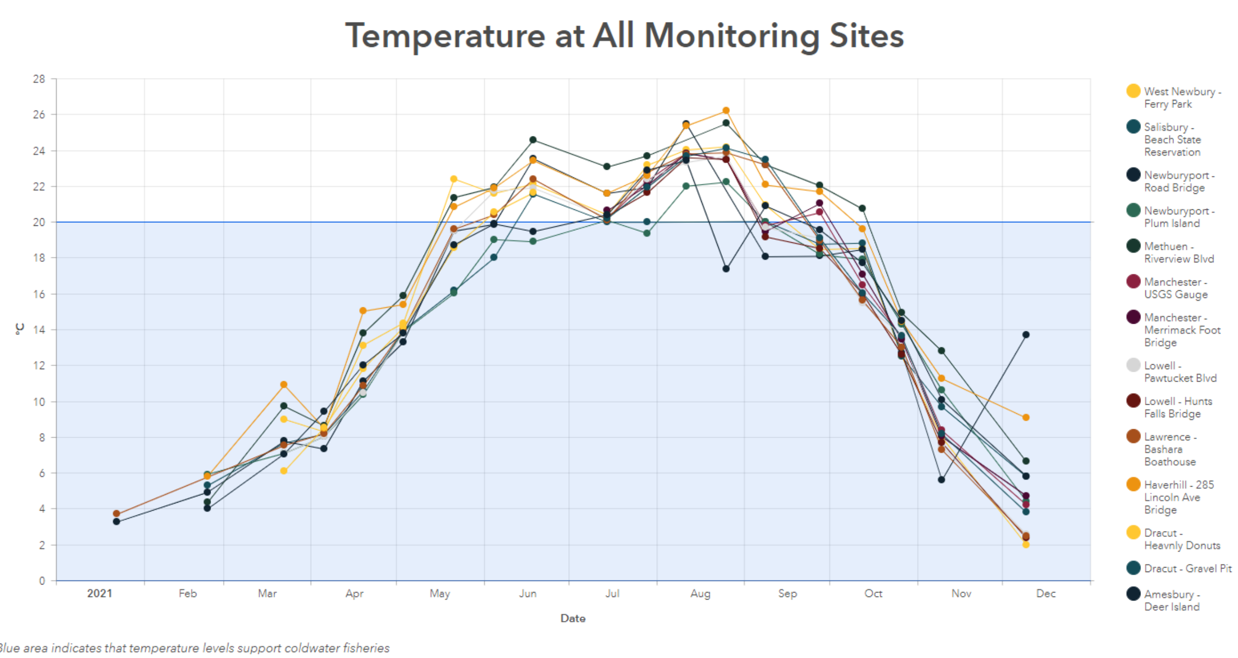


Figure 12. Temperature measurements from all monitoring activities in 2021. Use the online dashboard to see site-specific results: merrimack.org/science/water-quality-monitoring-program

Bacteria – *Escherichia coli* (*E. coli*) and *Enterococcus*

What are pathogens and fecal indicator bacteria?

- Pathogens are disease-causing microorganisms, which can be bacteria (single-celled organisms), viruses, fungi, and protozoa
- Two common bacteria used in water quality monitoring are *Escherichia coli* (*E. coli*) and *Enterococcus*, which are found in the gut and feces of warm-blooded animals.
- While *E. coli* and *Enterococcus* themselves are not particularly dangerous to humans, they often indicate the presence of more harmful pathogens such as norovirus and *Cryptosporidium*, which can make people sick.
- The source of fecal contamination is very important. Fecal contamination from human sources (e.g., sewage from an illicit connection or CSO event) 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).[24]
- *E. coli* is a good indicator of health impacts for humans in freshwater samples, while *Enterococcus* can be used as an indicator in freshwater and marine samples.[25]

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 [26,27]
- A wide variety of pathogens can cause illness in humans and animals, but *E. coli* and *Enterococcus* are commonly found, relatively easy to monitor, and have shown a correlation with cases of gastrointestinal illness among swimmers in waterbodies contaminated with human-sourced fecal matter.[28]

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, decay/die off, and tides. *Learn more on our website: merrimack.org/cso.*

What are important values for environmental or human health?

- NH and MA have their own state standards for water and environmental quality, and they do not align completely in numerical value or in theoretical approach, making them difficult to compare. Therefore, in this report, the monitoring results have been compared to a national standard: the US EPA's 1986 Ambient Water Quality Criteria for Bacteria.
- 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 CFUs/100 ml for *E. coli* in freshwater samples and 61 CFUs/100 ml for *Enterococcus* in freshwater and brackish samples.[29]

What were the conditions in the Merrimack River in 2021?

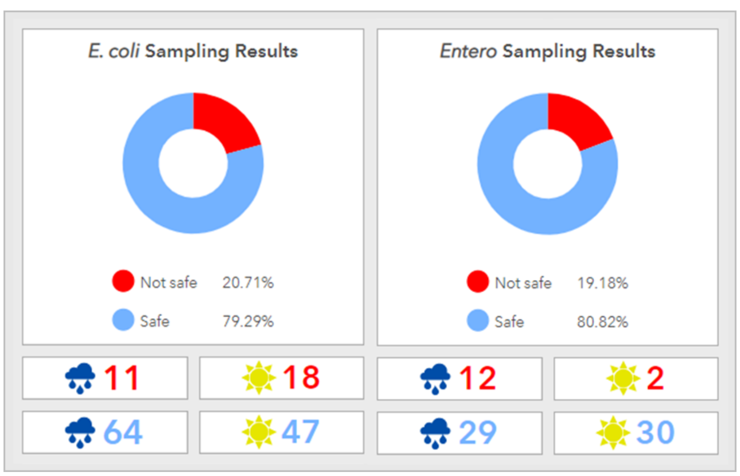
In 2021, MRWC collected data on *E. coli* at all sites and *Enterococcus* at the brackish sites. Beginning in July 2021, MRWC also began testing all samples for *Enterococcus* as well. However, since there is not a full year of data for *Enterococcus*, this report focuses on results for *E. coli* at freshwater monitoring sites and *Enterococcus* for brackish monitoring. All available *Enterococcus* data can be viewed on the MRWC Bacteria Monitoring Dashboard.

MRWC has two types of bacteria monitoring in our program: our regular monitoring program (where samples are collected once monthly November-March and twice monthly in the remaining months) and CSO event monitoring. Each bacterial monitoring sample was also classified according to precipitation conditions at the nearest NOAA rainfall gauge: it is considered wet weather conditions if it rained at least 0.1 inches within 72 hours of the sampling day, and dry weather conditions if it rained less than 0.1 inches. Our analysis of conditions has separated these types of monitoring to showcase the results of each monitoring effort as well as different environmental conditions.

Regular Monitoring Program

Results from our regular monitoring program include all regularly scheduled sampling days. It may happen that some of these days did follow rain or CSO events and are still included in this dataset. The purpose of this data set is to provide an unbiased view of the river's conditions, so sampling days are not selected based on weather, but are prescheduled at the beginning of the year.

During our regular monitoring program, 29 out of 140 *E. coli* samples (21%) were considered unsafe for recreational use, while for *Enterococcus*, 14 samples out of 73 samples (19%) were considered unsafe for recreational use (Figure 13). Most of the unsafe samples occurred during wet weather events for *Enterococcus*, but the opposite for *E. coli*. This could indicate another contamination source aside from CSOs at some sites. However, further investigation is needed to determine issues at specific locations.

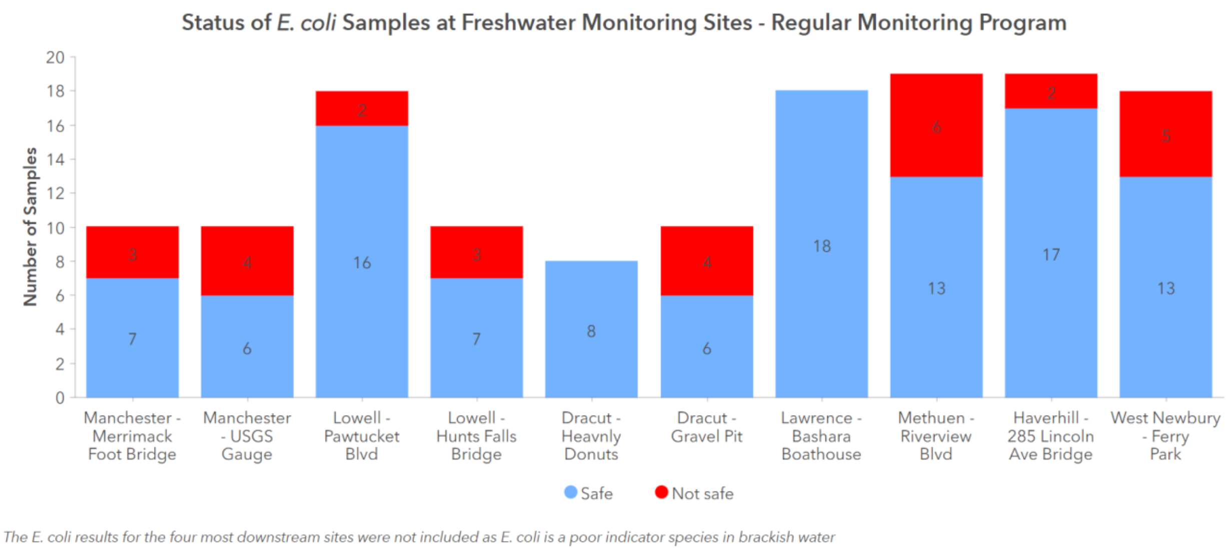


The circle graphs indicate safe (blue) and unsafe (red) samples at each site, relative to the EPA limit for recreational use. The number below the circle charts show the percentage and count of samples that are safe and unsafe, and whether they occurred during wet or dry weather conditions.

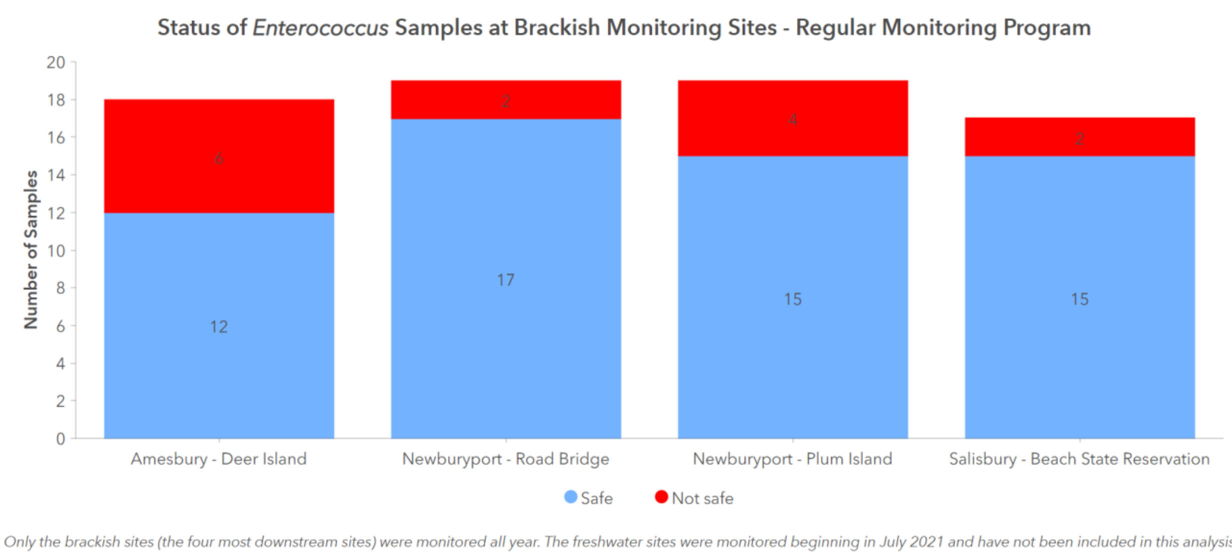
Figure 13. Summary of E. coli concentrations for all freshwater sites and Enterococcus concentrations for all brackish water sites for regular monitoring program samples in 2021.

2021 MONITORING PROGRAM RESULTS

Looking at these results by monitoring site, the data show that most samples are considered safe throughout the Merrimack but there are unsafe samples at each site (Figure 14). It is worth noting that Lawrence Bashara Boathouse had no unsafe samples during regular monitoring activities, while Methuen, West Newbury, and Amesbury Deer Island all had the highest number of unsafe samples and are located downstream of Lawrence. Further site-specific analyses on potential reasons are provided in the regional profiles section.



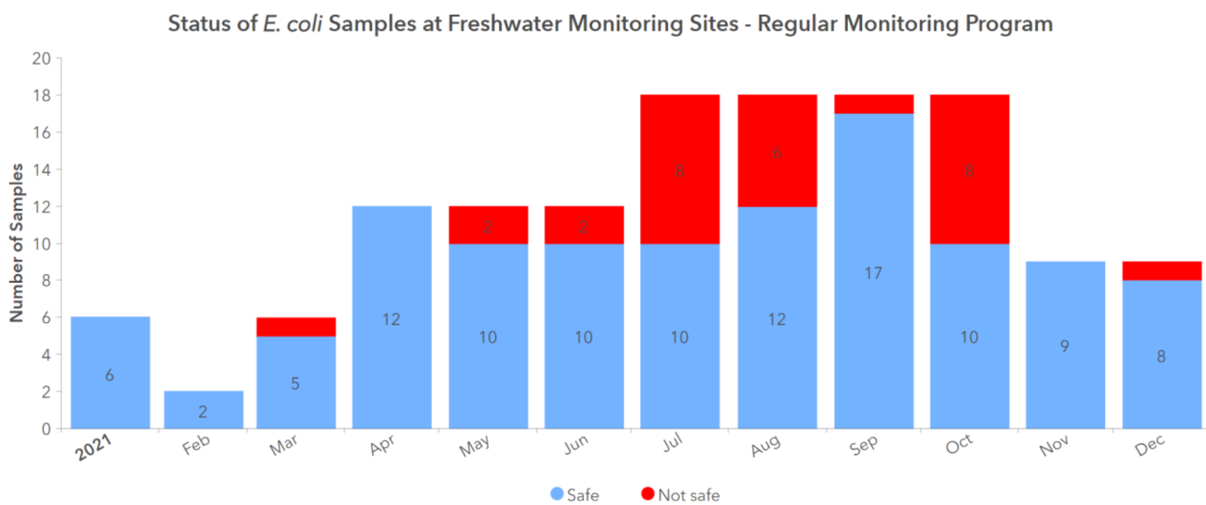
(a)



(b)

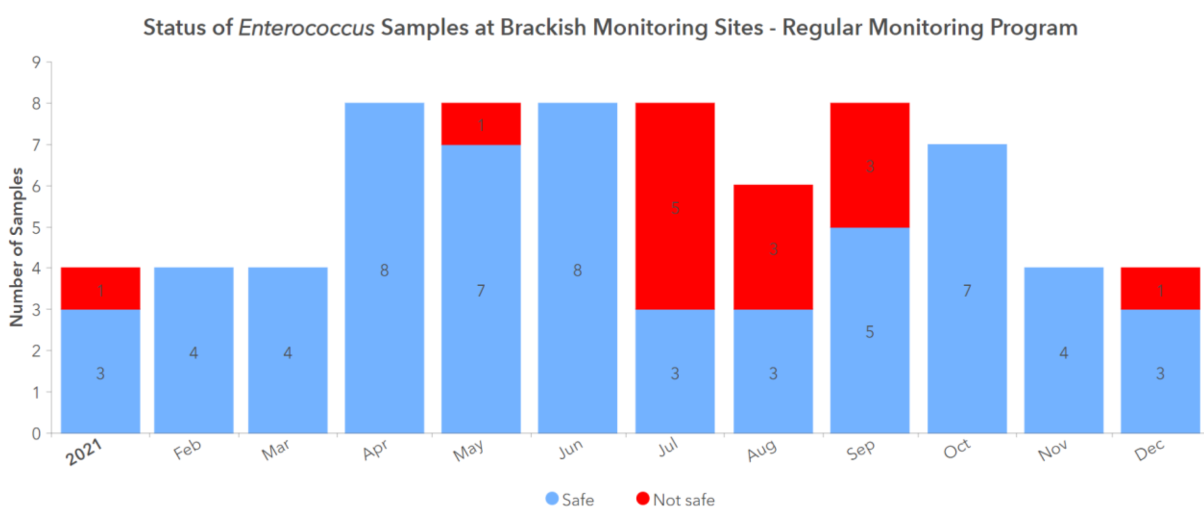
Figure 14. Number of safe and not safe samples by monitoring site for E. coli at freshwater monitoring sites (a) and Enterococcus at brackish water monitoring sites (b) in 2021. These data are for regular monitoring program samples.

Looking at these results by month, most samples were within the safe limit during spring, fall and winter (Figure 15). However, during the summer months of July through October, there were more unsafe samples than other months. This is important to note since these are the months where many recreational activities take place, increasing the exposure risk to humans. This is the period of time with frequent large rain events (such as summer thunderstorms) and CSO events. As such, these higher numbers could be due to the fact that some of our regularly scheduled monitoring days occurred during wet weather and CSO events.



The E. coli results for the four most downstream sites were not included as E. coli is a poor indicator species in brackish water

(a)



Only the brackish sites (the four most downstream sites) were monitored all year. The freshwater sites were monitored beginning in July 2021 and have not been included in this analysis

(b)

Figure 15. Number of safe and not safe samples by month for E. coli at freshwater monitoring sites (a) and Enterococcus at brackish water monitoring sites (b) in 2021. These data are for regular monitoring program samples.

CSO Event Monitoring

In addition to the regularly scheduled sampling days, three times in 2021, we added sampling days following CSO events to capture daily changes in water quality following the events (Table 9). Daily samples were collected for up to five days after a known CSO event to see how the bacteria levels change (Table 9). During each of these CSO monitoring periods, there were three regularly scheduled sampling days (5/3, 7/14 and 10/26). The results of these sampling days are included in the graphs in the previous section as well as this section.

Table 9. Information regarding consecutive sampling following CSO events.

CSO Date	CSO Location	CSO Volume (Gallons)	Number of consecutive monitoring days	Monitoring Dates
4/29/2021	Haverhill GLSD Lowell	Unknown 2,880,000 83,830,000	5	4/30, 5/1, 5/2, 5/3*, 5/4
4/30/2021	Lowell	2,600,000		
7/12/2021	Haverhill GLSD, Lowell Nashua	Unknown 7,257,000 38,890,000 76,000	4	7/13, 7/14*, 7/15, 7/16
10/26/2021	Haverhill Lowell	Unknown 50,000	4	10/26*, 10/27, 10/28, 10/29

**Days were regularly scheduled sampling days, and therefore data from these days appear in the graphs in this section as well as the previous section.*

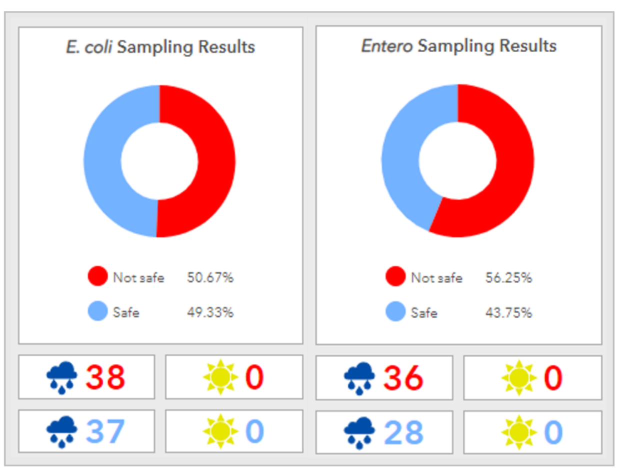
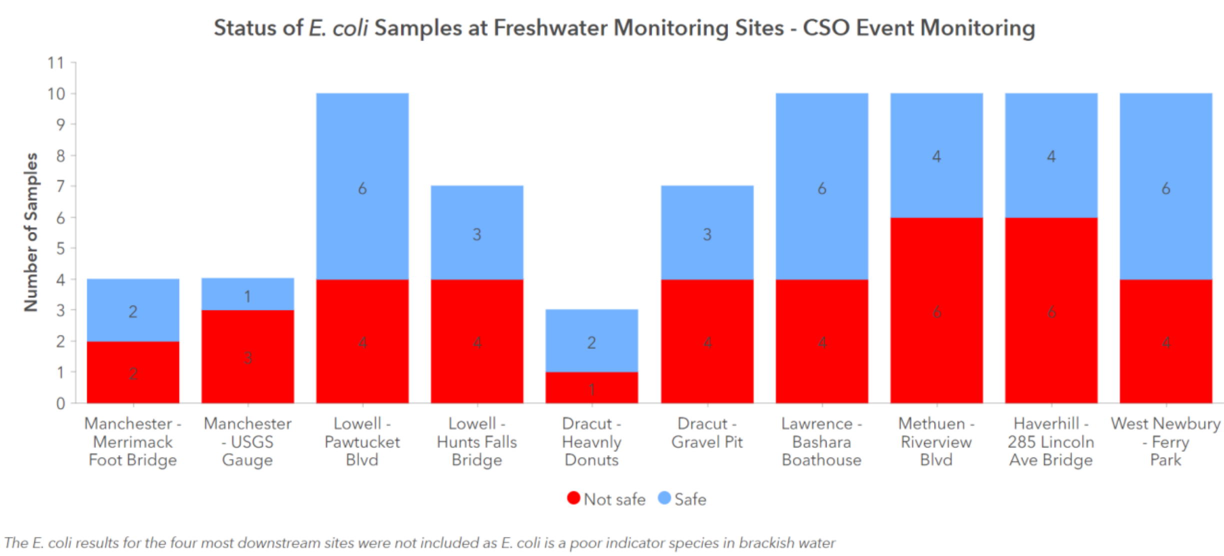


Figure 16. Summary of E. coli concentrations for all freshwater sites and Enterococcus concentrations for all brackish water sites for CSO event sampling days in 2021.

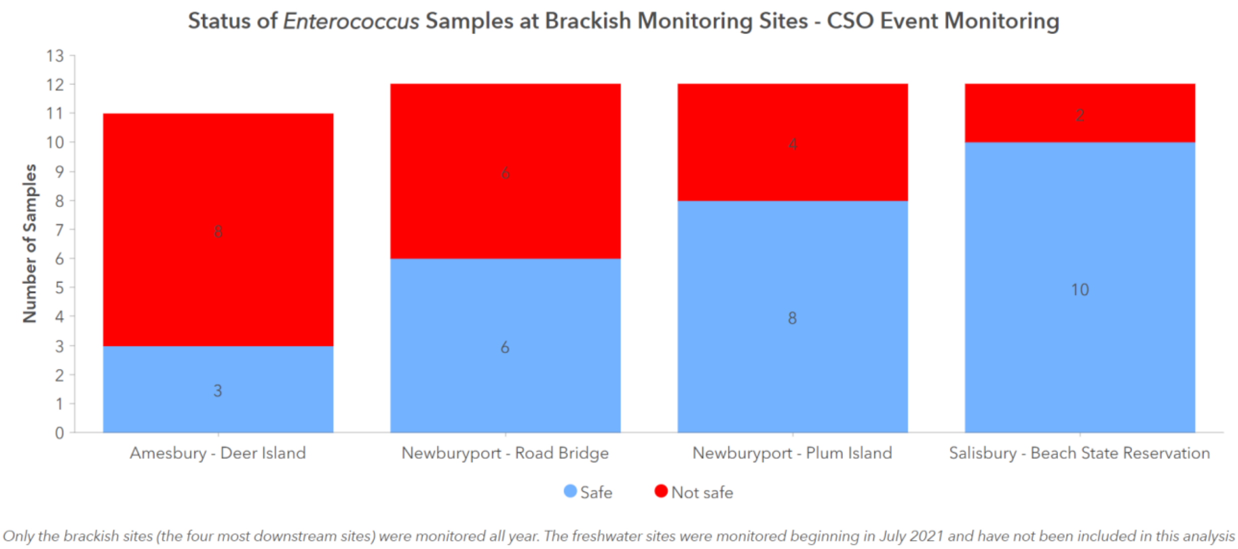
For *E. coli* during CSO event monitoring, 38 out of 75 samples (51%) were considered unsafe for recreational use, while for *Enterococcus*, 36 samples out of 64 samples (56%) were considered unsafe for recreational use (Figure 13). Of the unsafe samples, 100% occurred during wet weather events. This shows a strong relationship between wet weather events and unsafe bacteria concentrations.

However, because CSO events are triggered by wet weather, it is difficult to separate the impact of CSO-sourced bacteria and stormwater runoff-sourced bacteria when assessing the sites this way. In the regional profile section, site specific and time specific analysis is provided, showing, after each CSO event we sampled, how many days each site was unsafe as well as which sites were impacted by which CSO events.

When assessed by site, all sites are impacted by wet weather and/or CSO events but not for the entire period of time that we collected samples after each event (4-5 days, Figure 17). When looking at trends from upstream to downstream, the most downstream sites have a smaller percentage of unsafe days than the upstream site (20% and 33% in Salisbury Beach and Newburyport Plum Island, respectively vs. 25-60% in the upstream sites). This is likely because they are farther away from the CSO sources and the urban areas where significant rainfall occurs, and bacteria likely die before reaching these sites.



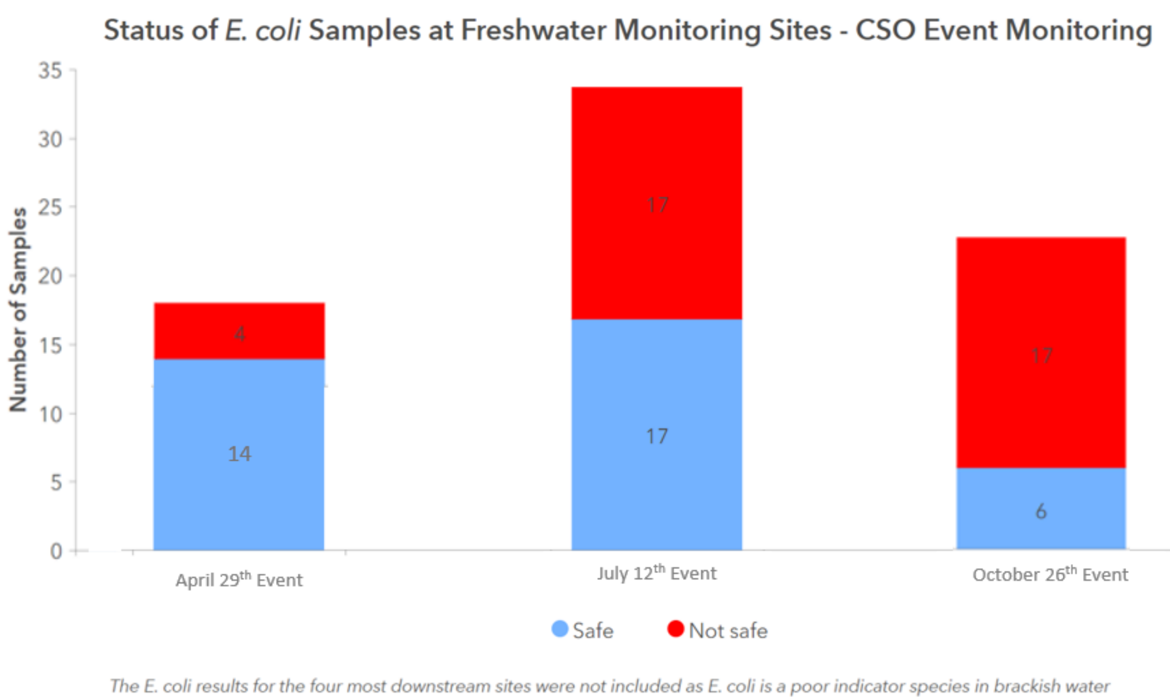
(a)



(b)

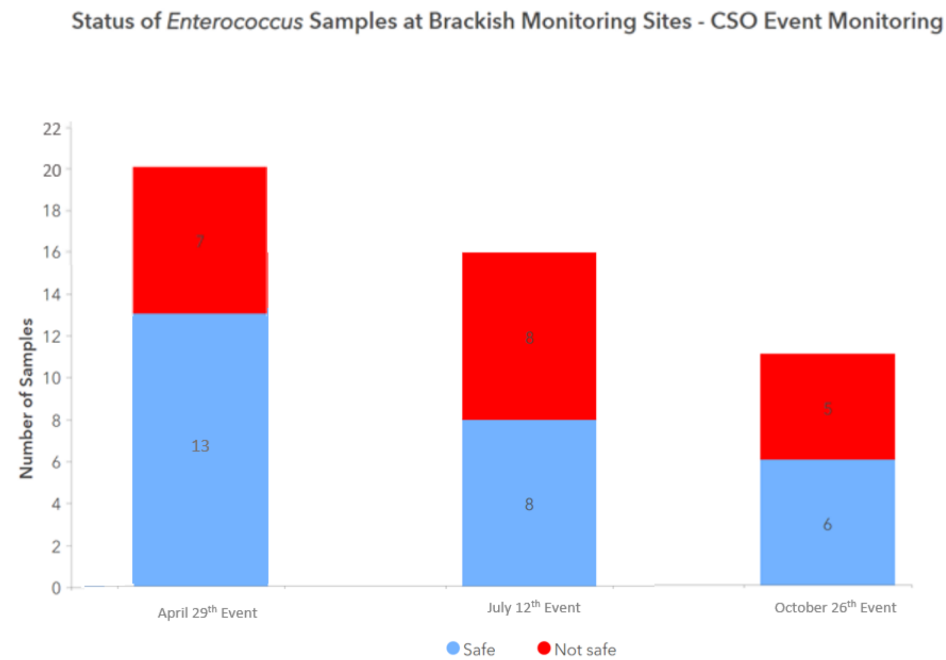
Figure 17. Number of safe and not safe samples by monitoring site for E. coli at freshwater monitoring sites (a) and Enterococcus at brackish water monitoring sites (b) in 2021. These data are for CSO event monitoring samples.

When assessed by CSO event, there were 58 unsafe samples and 64 safe samples. This sharp increase in unsafe samples is to be expected since we were targeting known CSO events. However, the data also shows that more than half of the samples showed safe conditions, reinforcing that the conditions vary depending on the size and location of a CSO.



(a)

2021 MONITORING PROGRAM RESULTS



Only the brackish sites (the four most downstream sites) were monitored all year. The freshwater sites were monitored beginning in July 2021 and have not been included in this analysis

(b)

Figure 18. Number of safe and not safe samples by month for E. coli at freshwater monitoring sites (a) and Enterococcus at brackish water monitoring sites (b) in 2021. These data are for CSO event monitoring samples.

In the fall of 2021, MRWC and the Boston University School of Public Health carried out a survey to understand the recreational uses of the Merrimack River and associated health risks from bacteria contamination. As part of this effort, a model will be created to estimate bacteria concentrations in the Merrimack River in near-real-time. This model for E. coli will support efforts to develop a notification system to alert community members about water quality conditions in the Merrimack.

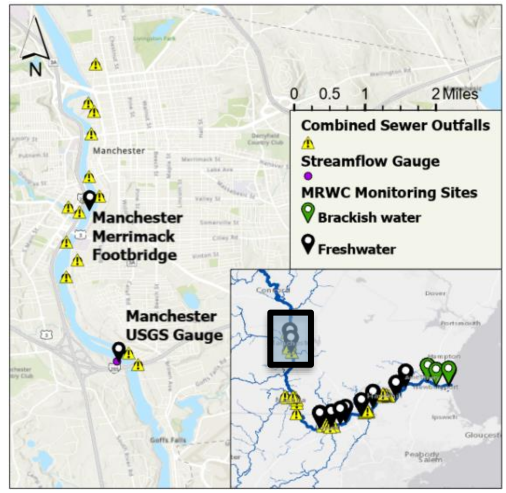
REGIONAL PROFILES

By grouping each of the sites into regions, we can better understand the potential impacts cities and towns within those regions and upstream of them may have on bacteria concentrations. Each regional profile shares information on our monitoring locations, CSO infrastructure, and an analysis of the bacteria data for that region.

Greater Manchester, New Hampshire

Monitoring Sites

- Merrimack Foot Bridge (river mile 70.6)
- USGS Gauge (river mile 67.9)



Known CSO Infrastructure

- Manchester has 15 CSO outfalls
- Manchester contributes the second largest volume of CSOs to the Merrimack compared to all other combined systems on the Merrimack (average of 221 million gallons per year)
- The Merrimack Foot bridge site, the most upstream site of our monitoring network, is downstream of some CSO outfalls, and upstream of others
- The USGS Gauge site is located at the USGS streamflow gauge and downstream of all but one CSO outfall
- Site selection is based on a variety of factors, with access to the river being the biggest limitation. These sites are located where they are due to the limited number of access locations and bridges with sidewalks crossing the Merrimack in this area.

Water Quality in the Greater Manchester Region

MRWC began sampling in Manchester starting in July 2021, so we have a limited data set to analyze. Overall, 33% of the samples collected in greater Manchester have *E. coli* levels that were above the safe limit (Figure 19). All samples that were above the safe limit were collected during or after wet weather. We see an increase in the number of unsafe samples from the upstream site (Manchester Foot Bridge) to the downstream site (Manchester USGS Gauge).

Manchester is the most upstream combined sewer system which means these sites are only influenced by Manchester CSO events. In 2021, the Manchester wastewater treatment plant was not reporting individual CSO events, so we do not know for certain which of these samples were influenced by a CSO event. However, annually, Manchester is one of the largest contributors of CSO volume to the Merrimack. Therefore, we assume that a CSO event likely occurred during many of these rain events. And since many of the CSOs in Manchester are located between our two monitoring sites, this may explain the larger number of unsafe samples in the downstream site compared to the upstream site. Recently, we have seen that Manchester has upgraded their system, so we look forward to being able to compare individual events with our sampling data in the future.

In summary, the majority of samples in this area are safe, and all are safe when collected more than 72 hours after a rain storm, which suggests that this area is safe for recreation when a rain storm did not recently occur. However, more data is needed to improve the confidence and accuracy of this conclusion.

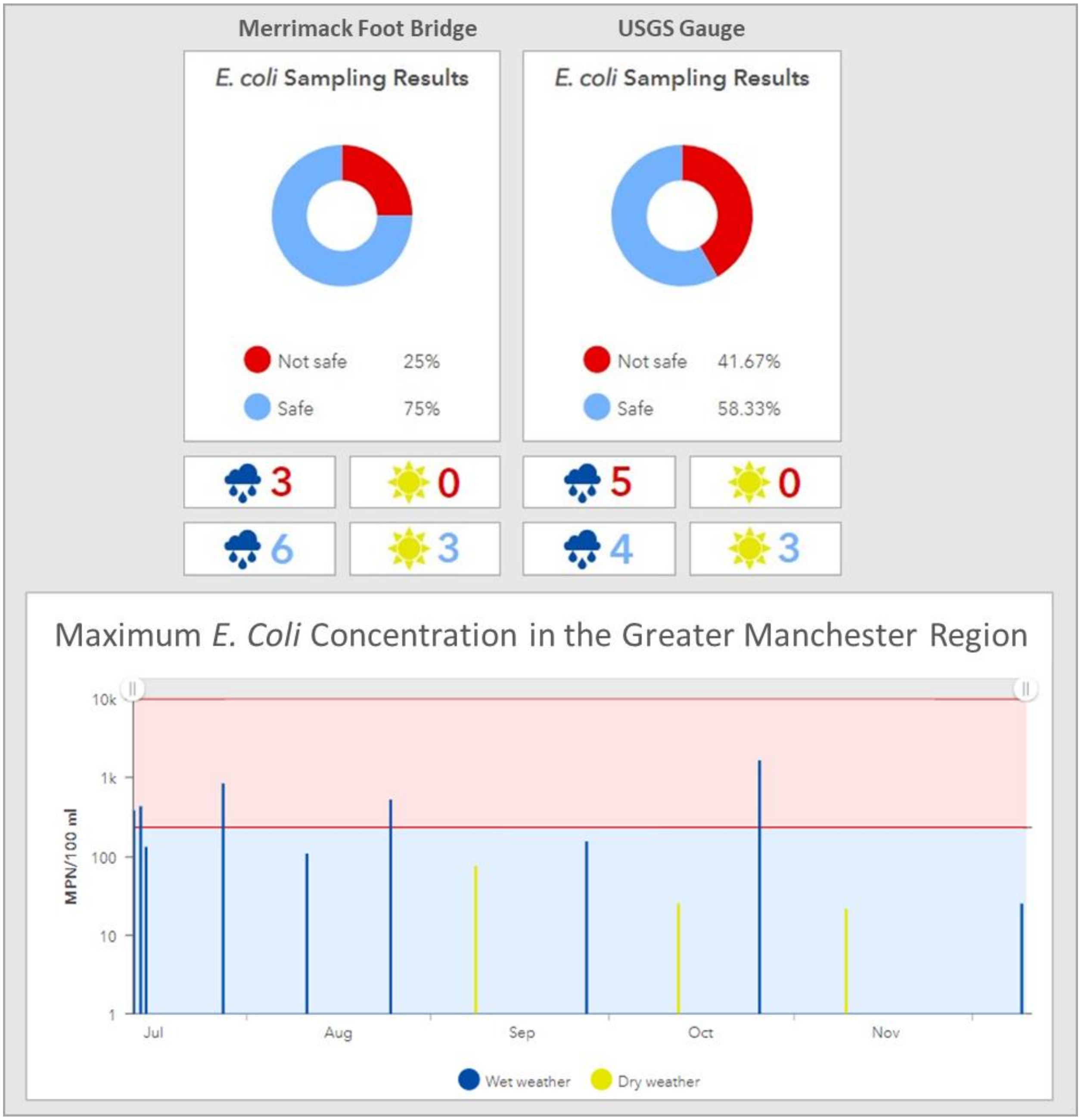


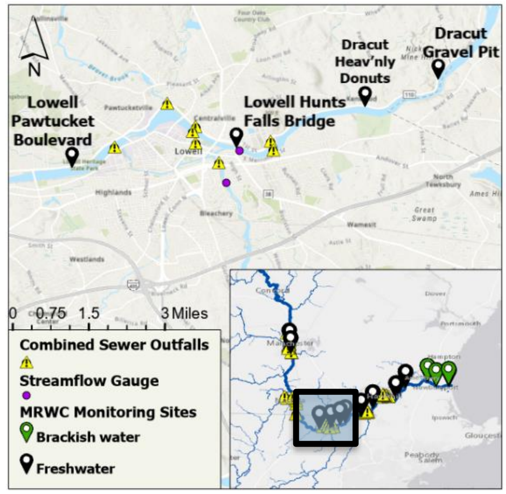
Figure 19. Results of E. coli sampling at the sites within the Greater Manchester region.

The circle graphs at the top indicate safe (blue) and unsafe (red) samples at each site. The number below the circle charts show the percentage and count of samples that are safe and unsafe, and whether they occurred during wet or dry conditions. The time series shows the maximum concentration samples collected on each sampling day in this region.

Greater Lowell, Massachusetts

Monitoring Sites

- Lowell Pawtucket Boulevard (river mile 47.8)
- Lowell Hunts Falls Bridge (river mile 43)
- Dracut Heav'nly Donuts (river mile 36.4)
- Dracut Gravel Pit (river mile 34)



Known CSO Infrastructure

- The Lowell Regional Wastewater Utility has 8 CSO outfalls
- Greater Lowell is one of the largest contributors to Merrimack each year in terms of CSO volume (average of 222 million gallons per year)
- The Pawtucket Boulevard site is downstream of all Manchester and Nashua CSO outfalls
- The Hunts Falls Bridge site is downstream of all of Manchester and Nashua CSO outfalls and most of Lowell's CSO outfalls, and located at the USGS streamflow gauge, just downstream of the confluence of the Concord River
- The Dracut sites are downstream of all Manchester, Nashua and Lowell CSO outfalls

Water Quality in the Greater Lowell Region

We began sampling at the Hunts Falls Bridge site and moved the Dracut site from Heav'nly Donuts to the Gravel pit during July 2021, so we have fewer total samples at each of these sites compared to the Pawtucket Boulevard Site. We found that 25% of samples collected in this region were above the safe limit for *E. coli* (Figure 20). All 17 samples above the safe limit for *E. coli* were collected during wet weather conditions, and 15 out of those 17 were collected within three days following a CSO event upstream.

The larger percentage of unsafe samples at Dracut Gravel pit (38%) compared to Heav'nly Donuts (10%) is mainly due to the time periods each site was sampled, not the location of the sites. We switched to sampling at the Gravel Pit in July, which is when the majority of large rain events started occurring and high bacteria concentrations were more commonly found.

By comparing results between Pawtucket Boulevard and Hunts Falls Bridge during consecutive monitoring days following a CSO event in July and October, we can compare the influence of Nashua and Lowell's CSOs on these sites (Figure 20, A and B). In July, a CSO occurred in both Nashua and Lowell, and we see high concentrations across both sites for 3 days following the event (Figure 20, A). In October, a CSO occurred only in Lowell, and we see lower concentrations upstream at Pawtucket Boulevard and higher concentrations downstream at Hunts Falls Bridge (Figure 20, B).

Based on these data, *E. coli* levels were always safe during dry weather conditions. *E. coli* levels were unsafe in 47% of samples collected during wet weather conditions, and in 36% of samples collected within three days of a CSO occurring upstream. By comparing sampling following two CSO events, we can compare impact on bacteria levels from CSOs and stormwater in Nashua to CSOs and stormwater in Lowell.

In summary, just because there is rain or a CSO upstream, it does not mean the river is unsafe to use in this location. After significant rain events, however, bacteria levels in this region may stay unsafe for up to three days.

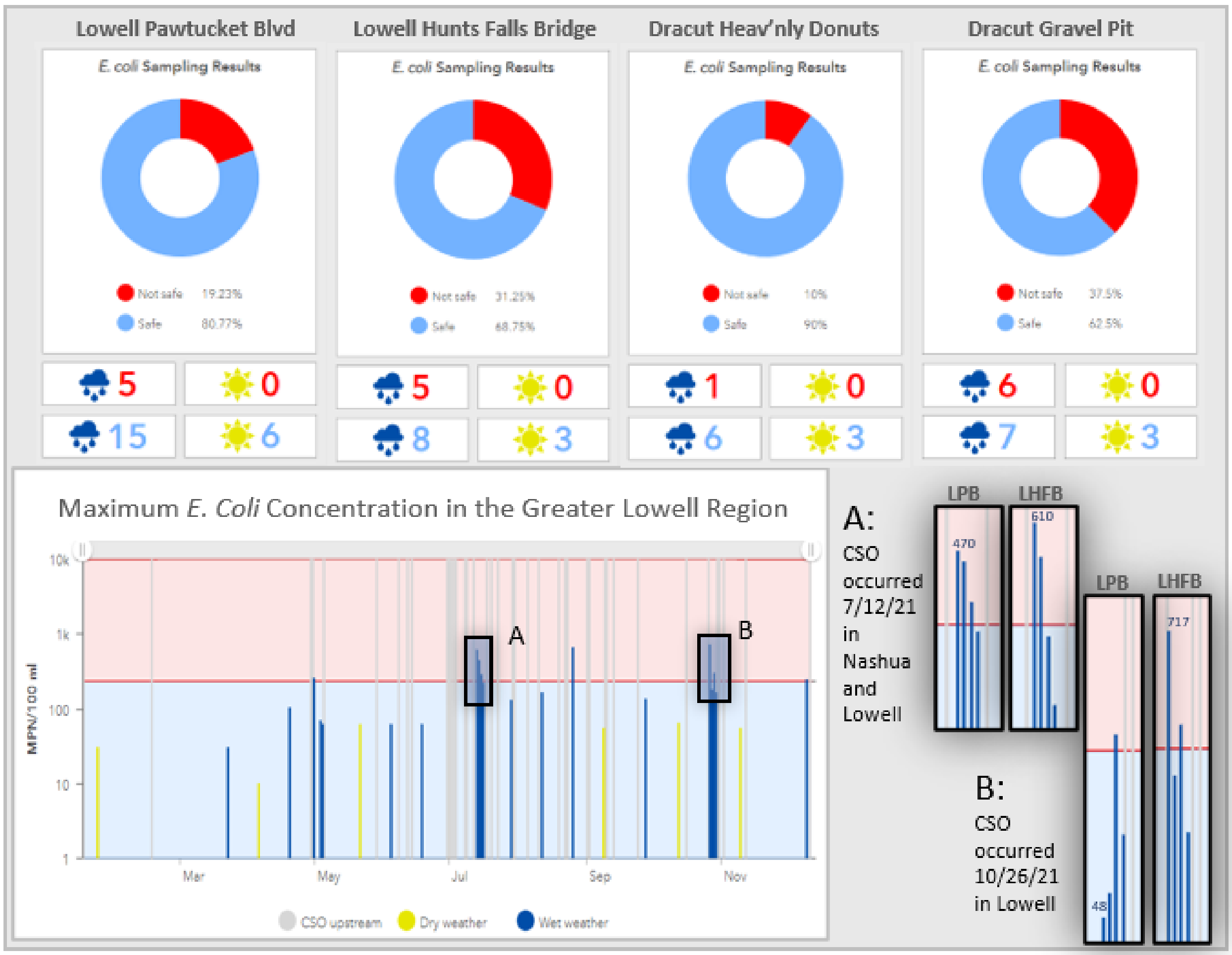


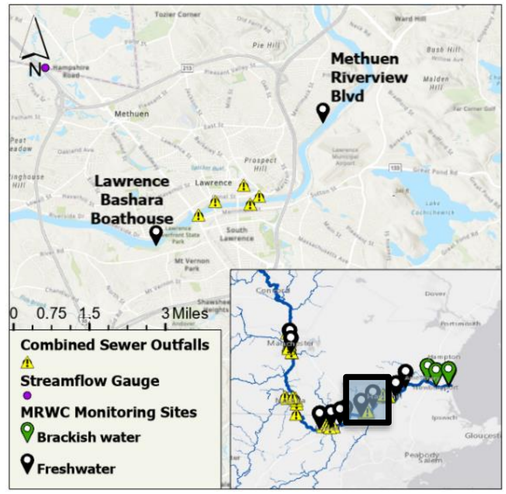
Figure 20. Results of E. coli sampling at the sites within the Greater Lowell region.

The circle graphs at the top indicate safe (blue) and unsafe (red) samples at each site. The number below the circle charts show the percentage and count of samples that are safe and unsafe, and whether they occurred during wet or dry conditions. The time series shows the maximum concentration of samples collected on each sampling day in this region, relative to upstream CSO events shown by grey lines. Insets A and B show enlarged sections of this graph, when continuous monitoring occurred following a CSO event in July (A) and October (B). The insets show only sampling results from Pawtucket Boulevard (LPB) and Hunts Falls Bridge (LHFB) sites in Lowell.

Greater Lawrence, Massachusetts

Monitoring Site Names

- Lawrence Bashara Boathouse (river mile 29)
- Methuen Riverview Boulevard (river mile 26.2)



Known CSO Infrastructure

- The Greater Lawrence Sanitary District (GLSD) has 5 CSO outfalls
- GLSD contributes the third largest volume of CSOs to the Merrimack each year compared to the other combined systems in the watershed (average of 45 million gallons per year)
- The Lawrence Bashara Boathouse Sampling Site is located upstream of all GLSD CSO outfalls, and the Methuen Riverview Boulevard site is located downstream of all GLSD CSO outfalls
- Both sites are located downstream of all Manchester, Nashua, and Lowell CSO outfalls

Water Quality in the Greater Lawrence Region

In Greater Lawrence, 26% of samples analyzed for *E. coli* were above the safe limit (Figure 21). Of the unsafe samples, four were collected from the Lawrence site, and 10 were collected from the Methuen site. One of the ten unsafe samples from Methuen was collected during dry weather. All four unsafe samples at the Lawrence site were collected during wet weather and within three days following a CSO in Lowell; the other 14 samples collected in Lawrence during wet weather were safe.

Methuen is downstream of five GLSD CSO outfalls. However, CSOs alone do not fully explain the high concentrations found in Methuen nor the difference in concentrations when compared to the Lawrence site. We continuously sampled at both sites for four days following two CSO events, one on July 12, when a CSO occurred in Nashua, Lowell and GLSD, and one on October 26, when a CSO occurred in Lowell. When a CSO occurs at GLSD, we would expect noticeably higher concentrations at the Methuen site than the Lawrence site, given their positions downstream and upstream from GLSD, respectively. We see that Methuen showed the expected higher concentrations following the July 12 event, then decreased over time. There was also a surprisingly high spike at the Lawrence site for only one day (2,200 MPN/100 mL, Figure 21, A) which may be linked with the Lowell CSO upstream but is surprising in that it only occurs on one day. Unexpectedly, when a CSO did not occur at GLSD but did occur in Lowell on October 26, we see noticeably higher concentrations at the Methuen site than at the Lawrence site (Figure 21, B). Of all the unsafe samples collected at the Methuen site, 7 were collected when there was no CSO from GLSD, and two were collected when there were no CSOs anywhere upstream. We do know that the EPA recently found an illicit sewer connection upstream of our Methuen sampling site, which likely is contributing to some of these high concentrations. However, because not all samples collected during dry weather were high, stormwater from the urban areas upstream are likely also contributing to the high concentrations at this site.

In summary, it is likely that a combination of sources of bacteria are contributing to bacteria contamination at the Methuen site, leading to more frequent unsafe conditions here than most other sites that we monitor. The Lawrence site is safe a large percentage of the time, except following CSOs that occur upstream.

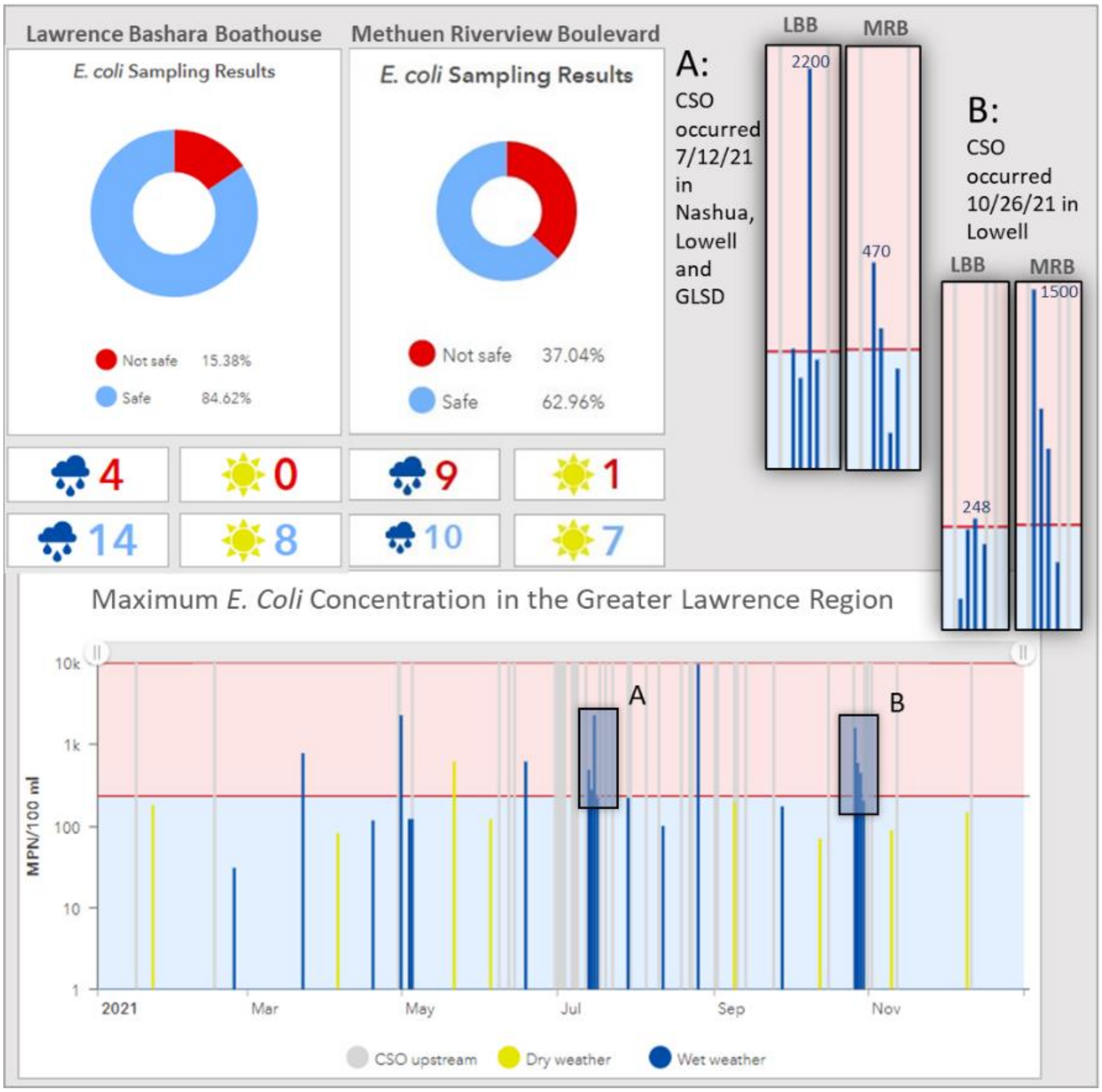
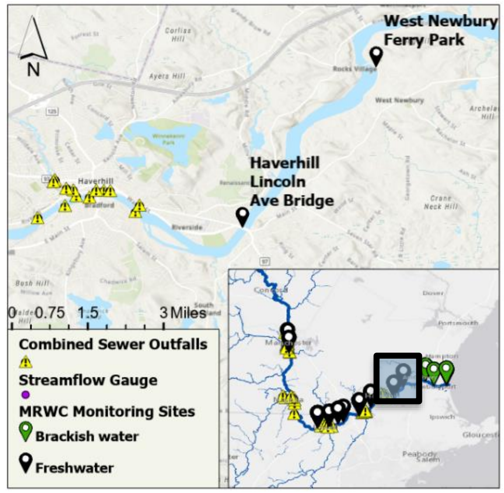


Figure 21. Results of E. coli sampling at the sites within the Greater Lawrence region.

The circle graphs at the top indicate safe (blue) and unsafe (red) samples at each site. The number below the circle charts show the percentage and count of samples that are safe and unsafe, and whether they occurred during wet or dry conditions. The time series shows the maximum concentration of samples collected on each sampling day in this region, relative to upstream CSO events shown by grey lines. Insets A and B show enlarged sections of this graph, when continuous monitoring occurred following a CSO event in July (A) and (B).

Greater Haverhill, Massachusetts



Monitoring Site Names

- Haverhill Lincoln Avenue Bridge (river mile 16.2)
- West Newbury Ferry Park (river mile 12.4)

Known CSO Infrastructure

- Haverhill has 14 CSO outfalls
- Haverhill contributes the greatest number of CSO events per year on average, but contributes the second lowest volume compared to the other combined systems (average of 33 million gallons per year)
- Both the Haverhill and West Newbury monitoring sites are downstream of all Haverhill CSO outfalls

Water Quality in the Greater Haverhill Region

In the Greater Haverhill region, 26% of *E. coli* samples were above the safe limit. All of the unsafe samples collected from Haverhill (6) were collected during wet weather conditions and within 3 days following a CSO event in Haverhill and either GLSD or Lowell (Figure 22). Haverhill has the greatest number of CSO events per year compared to all other combined sewer systems on the Merrimack. But while they are frequent, they are significantly smaller than those from GLSD or Lowell. We sampled one day in 2021 when a CSO event was occurring in Haverhill and no other CSO communities (July 28). The *E. coli* levels on this day from both Haverhill and West Newbury sampling sites were within safe limits. It is possible the bacteria from the CSO had not yet moved downstream at the time we collected samples, that the CSO was not large enough to cause elevated levels, or because CSOs in Haverhill are typically small.

Three out of eight of the unsafe *E. coli* samples collected at the West Newbury site were collected during dry weather conditions. Because West Newbury is closer to the coastal region and sometimes may have higher salinity, *Enterococcus* is also an important measure for fecal contamination. We began sampling for *Enterococcus* at the West Newbury site in July 2021, so the data are limited and representative of the wetter part of the year. During this time, 10 out of 11 samples collected at this site were above the safe limit for *Enterococcus*. These included all samples collected in wet weather and 3 out of 4 collected in dry weather conditions. Our volunteers and staff have noticed that there is a flock of geese that typically spend time in the river upstream of this site. This region also has some agricultural land along the river, among other potential sources. Further research is needed to determine whether the geese or other human-related sources are contributing to these high concentrations at the West Newbury site.

In summary, concentrations at the Haverhill site are most often within safe limits, except when there is sufficient rain to trigger a CSO in Haverhill *and* either Lowell or Lawrence. High bacteria concentrations at the West Newbury site require further investigation.

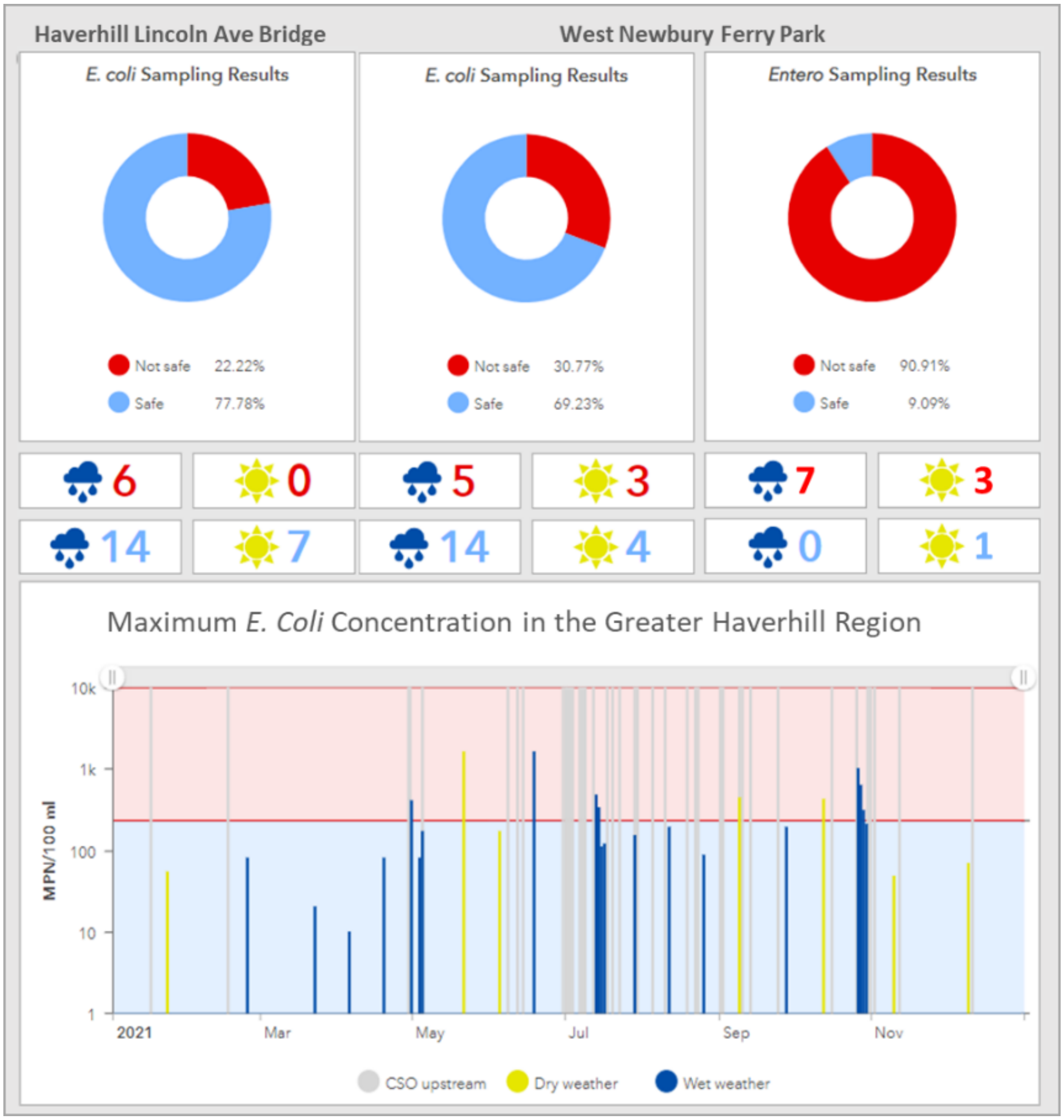


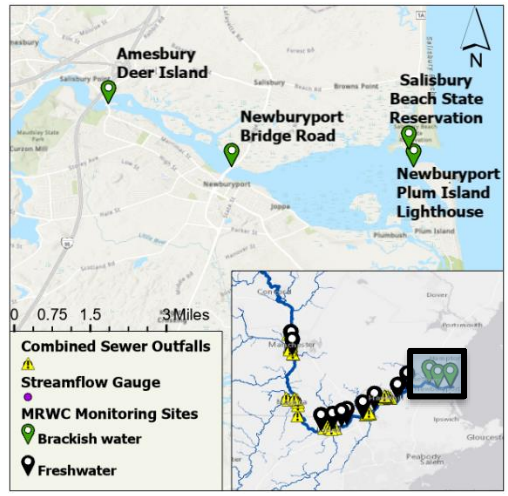
Figure 22. Results of E. coli sampling at the sites within the Greater Haverhill region, and results of Enterococcus sampling at the West Newbury Ferry Park site.

The circle graphs at the top indicate safe (blue) and unsafe (red) samples at each site. The number below the circle charts show the percentage and count of samples that are safe and unsafe, and whether they occurred during wet or dry conditions. The time series shows the maximum concentration of E. coli from samples collected on each sampling day in this region, relative to upstream CSO events shown by grey lines. We do not currently have all data for CSO occurrences in Haverhill for 2021, so grey lines indicate a CSO event at GLSD, Lowell or Nashua.

Coastal Region, Massachusetts

Monitoring Site Names

- Deer Island (river mile 5.7)
- Newburyport Road Bridge (river mile 3.5)
- Plum Island (river mile 0.7)
- Salisbury Beach State Reservation (river mile 0.7)



Known CSO Infrastructure

- There are no combined sewer outfalls within this region. All sites within this region are downstream of all CSO outfalls contributing to the mainstem of the Merrimack
- These sites may also be influenced by separated sewer systems, where stormwater flows directly to the river untreated during all rain events.

Water Quality in the Coastal Region

Enterococcus is a more reliable indicator of fecal contamination in brackish water than *E. coli*. At these sites, average salinity during our sample collection ranged from 0.73 to 4.82 ppt, so we use *Enterococcus* as the indicator for fecal contamination (Figure 23).

In the coastal region, 30% of samples were above the safe limit for *Enterococcus*. 31 of the 34 samples above the safe limit were collected during wet weather sampling. As we move from upstream (Deer Island) to downstream (Salisbury Beach), there are fewer unsafe samples at each site.

There are no CSO outfalls in this region. However, this region is downstream of all CSOs on the mainstem of the Merrimack. Of the unsafe samples collected in this area, 92% were collected within four days following a known CSO event upstream. Of the three that were not collected following a CSO event, one was collected during wet weather conditions. Of all the samples collected within five days of a CSO event, 43% were unsafe and 57% were safe. A similar percentage (40%) of samples collected during wet weather conditions were unsafe, compared to 60% safe. This suggests that CSO events and wet weather upstream continue to be a useful indicator for safety of using the river, as only a slight majority of samples collected during these conditions were within safe limits.

When looking closer at samples collected in four days following CSO events, there appears to be an obvious impact of CSOs, or rain events large enough to trigger CSOs, on bacteria concentrations in the area (Figure 23 A, B, C). Following the April 29 and April 30 CSO events in Lowell, GLSD, and Haverhill, concentrations increased above the safe limit two days after the event, and most sites dropped below the limit by four days after the event (Figure 23, A). The July 12 CSO event in Nashua, Lowell, GLSD and Haverhill yielded similar results, where concentrations were above the limit one day following the event, and most sites dropped below the limit by three days following the event (Figure 23, B). The October 26 event in Lowell and Haverhill yielded different results, where concentrations increased above the limit at some sites, but not all, two days following the event, and did not fall below the limit by the third day (Figure 23, C). This may be because these were smaller events, and occurred farther away (an event did not occur in GLSD). It is difficult to attribute these results entirely to CSOs, as all of these sites are downstream of CSOs, but also larger CSOs occur during larger rain events, which also contribute more runoff and bacteria to the river.

The two samples that were over the safe limit and were collected during dry weather and without a CSO event were collected in Amesbury Deer Island, one on January 22 and one on December 9. The sample in January was collected within an hour of high tide. Because this sample is not consistent with our other data points in terms of tidal influence, we do not find it useful to use this single data point as an indicator for potential bacteria sources. In July we changed our sampling protocol so that samples are always collected within 2 hours before low tide (as the tide is going out). The sample from December was just over the limit (62 MPN/100 mL).

In summary, it is difficult to pull apart the influence of CSO contributions and wet weather contributions in this region because these sites are downstream of all CSO outfalls and close to the Haverhill CSOs, which experience a CSO almost every time it rains.

Overall, the majority of samples collected in this area are within safe limits for *Enterococcus,* suggesting it is typically safe to recreate in the river in these areas. However, rain and CSO events likely contribute to high concentrations for approximately four days following a CSO event.

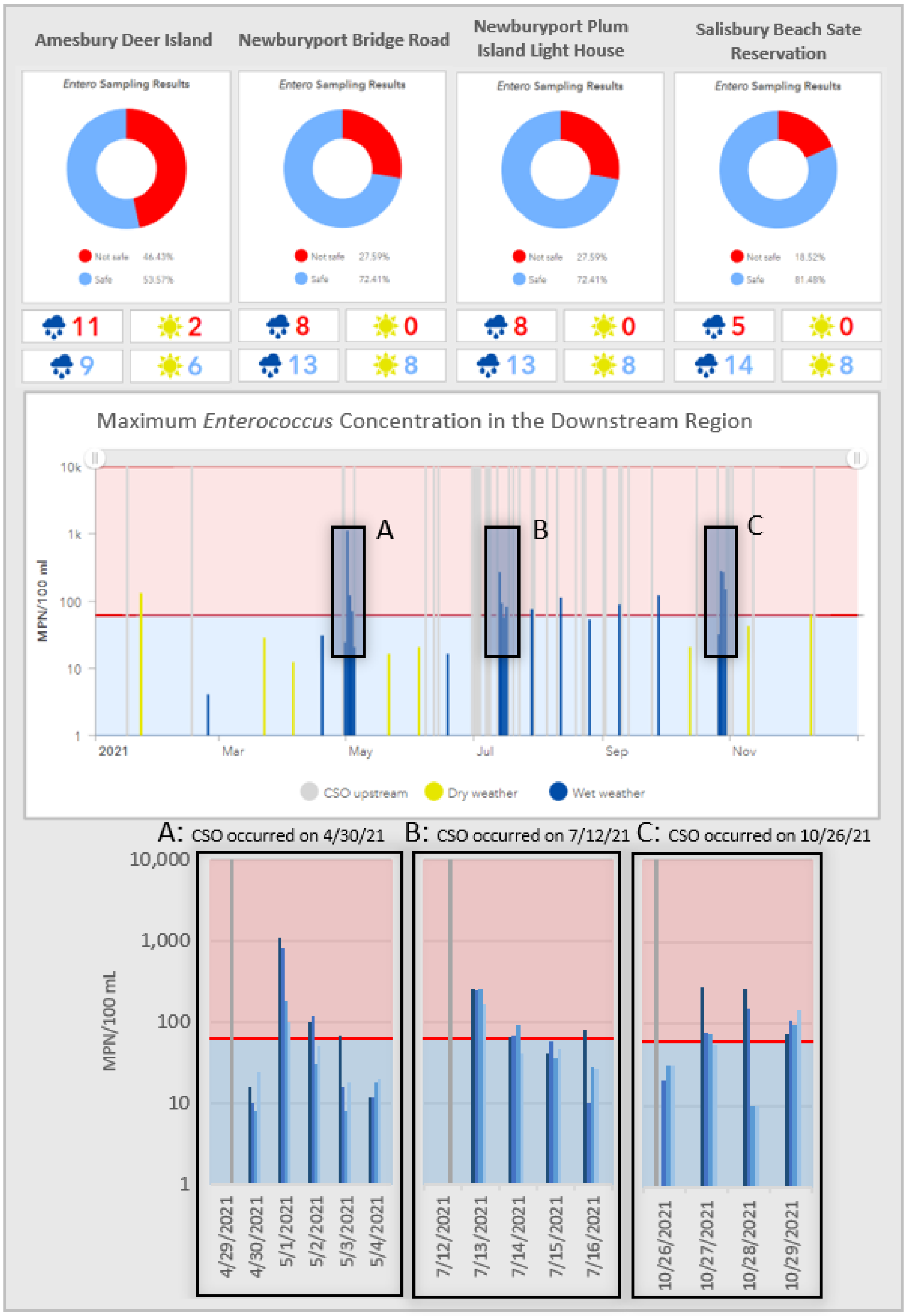


Figure 23. Results of Enterococcus sampling at the coastal sites.

The circle graphs at the top indicate safe (blue) and unsafe (red) samples at each site, relative to the EPA limit for recreational use (61 MPN/100 mL for Enterococcus). The number below the circle charts show the percentage and count of samples that are safe and unsafe, and whether they occurred during wet or dry conditions. The time series shows the maximum concentration of Enterococcus from samples collected on each sampling day in this region, relative to upstream CSO events shown by grey lines. We do not currently have all data for CSO occurrences in Haverhill for 2021, so grey lines indicate a CSO event at GLSD, Lowell or Nashua. Insets A, B and C show enlarged sections of this graph, when continuous monitoring occurred following a CSO event on April 40, 2021 (A), July 12, 2021 (B) and October 26, 2021 (C). All E. coli and Enterococcus data can be explored on our online dashboard (visit Merrimack.org for more info).

DATA QUALIFICATIONS

There are some sampling data that merit mention for quality assurance purposes. There were two sampling days when field blanks returned contaminated: October 28 and July 28. On October 28, the sample and blank contained similar concentrations of *E. coli*, but both levels were considered reasonable compared to the upstream and downstream samples. For the sample on July 28, we confirmed that the volunteer did not collect the blank sample correctly. We have since modified our program so that in addition to ensuring field blanks make up 10% of the total samples collected, at the start of each new six-month commitment for volunteers, all volunteers collect a field blank so that any additional training or investigation can be implemented immediately.

We have experienced challenges with the Hach Pro meters, and it should be noted that prior to July 2021, units on total dissolved solids (either parts per thousand or parts per million) and conductivity (either micro-Siemens or milli-Siemens per centimeter) measurements with the Hach Pro were filled retroactively by MRWC staff based on reasonableness of the recorded values. We have since modified our program to provide volunteers with additional equipment and training to ensure units are recorded correctly.

DATA-DRIVEN SOLUTIONS FROM MRWC

While these data allow us to better understand what percentage of samples are safe or unsafe, there is more work to be done to better understand if we can make better correlations between rain events and CSO events, as well as their influence on the river's water quality. We would like to investigate not just if it rained within 3 days of sampling, but how much and where, and if that determines whether the river is safe or unsafe for recreational use. Similar analysis is still needed for CSO events - not just if one happened upstream, but how large it was, how long it lasted, and how far away it was from the sampling site - and if those factors can determine how safe or unsafe the bacteria levels are.

While understanding when to avoid the river is important, we would prefer Merrimack enthusiasts didn't have to avoid the river at all! We are working on a variety of approaches to reduce bacteria sources and prevent them from reaching the Merrimack in the first place. We are coordinating with municipalities to develop watershed-based plans and implement green infrastructure which will capture stormwater runoff and mitigate nonpoint source pollution before it reaches the Merrimack and its tributaries. These practices can also be used to reduce flooding and make our communities more climate resilient.

We are in a pivotal moment for infrastructure improvements in our country. Not since the Clean Water Act in 1972 has the federal government invested so much money in repairing our infrastructure, water and sewer infrastructure included. We are advocating to ensure the money from future federal and state funding reaches our communities. We are hopeful that this influx of funding, combined with the awareness we have been building around CSOs, will begin to bring solutions to the Merrimack.

ACKNOWLEDGEMENTS

MRWC would like to thank our amazing 2021 volunteers for spending their early mornings to collect data and grab samples in the Merrimack. After these samples are collected, the EPA Region 1 Laboratory processes our samples free of charge. Rain or shine, warm or cold, our dedicated volunteers and partners at the EPA make this program a success!

MRWC would also like to thank our technical reviewers for their comments and suggestions to improve this report: Jill Carr, MassBays National Estuaries Partnership; Beth Haley and Dr. Wendy Heiger-Bernays, Boston University School of Public Health; and Chris August, ACV Enviro and MRWC Board Member.

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- The Theodore Edson Parker Foundation
- The Norwin S. and Elizabeth N. Bean Foundation
- The Rogers Family Foundation
- The Fuller Foundation
- New England Biolabs Foundation
- Volunteer NH

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APPENDIX

Daily Combined Sewer Overflow Volumes (Gallons)				
Date	Haverhill CSO Volume[2]	GLSD CSO Volume[3]	Lowell CSO Volume[5]	Nashua CSO Volume[4]
1/12/2018	34,202	-	540,000	-
1/13/2018	33,382	-	140,000	-
1/23/2018	437,437	1,480,000	6,630,000	-
2/5/2018	41,084	-	1,110,000	-
2/10/2018	77,106	-	330,000	-
2/11/2018	61,847	-	10,610,000	-
3/2/2018	100,297	-	7,120,000	-
4/16/2018	7,481,933	18,510,000	40,970,000	-
4/25/2018	153,706	-	-	-
4/26/2018	81,390	-	340,000	-
4/27/2018	14,192	-	-	-
5/3/2018	10,051	-	-	-
5/6/2018	15,501	-	-	-
5/15/2018	32,588	-	130,000	-
6/4/2018	38,434	-	-	-
6/5/2018	8,143	-	-	-
6/18/2018	224,260	-	2,410,000	13,000
6/24/2018	21,557	-	-	-
6/25/2018	144,503	-	3,650,000	-
6/27/2018	-	-	-	1,000
6/28/2018	101,261	-	2,140,000	13,000
7/3/2018	-	-	920,000	-
7/6/2018	105,176	-	-	-
7/14/2018	-	-	10,000	-
7/17/2018	1,293,550	789,000	9,530,000	51,000
7/22/2018	10,084	-	-	-
7/26/2018	476,256	2,418,000	10,770,000	-
7/27/2018	203,151	-	-	870,000
8/2/2018	47,201	440,000	7,620,000	-
8/4/2018	10,933	-	-	8,000
8/7/2018	61,098	-	-	-
8/9/2018	-	-	1,560,000	-
8/11/2018	3,946,070	25,960,000	27,870,000	3,000
8/12/2018	-	-	910,000	733,000
8/14/2018	2,660,343	965,000	3,960,000	2,005,000
8/17/2018	-	-	11,600,000	765,000
8/18/2018	90,452	-	10,000	-
8/22/2018	914,568	2,330,000	2,830,000	-
9/6/2018	-	1,574,000	9,210,000	-
9/10/2018	242,436	-	2,050,000	1,000
9/11/2018	-	-	3,180,000	10,000
9/18/2018	19,370,228	27,090,000	40,240,000	10,752,000

Daily Combined Sewer Overflow Volumes (Gallons)				
Date	Haverhill CSO Volume[2]	GLSD CSO Volume[3]	Lowell CSO Volume[5]	Nashua CSO Volume[4]
9/25/2018	-	-	-	6,000
9/26/2018	668,652	929,000	7,370,000	355,000
9/27/2018	-	-	3,750,000	-
10/1/2018	-	-	-	1,000
10/11/2018	3,368,297	7,780,000	22,510,000	977,000
10/13/2018	2,242	-	-	-
10/16/2018	2,553	-	-	-
10/23/2018	76,088	-	240,000	-
10/27/2018	67,843	-	-	-
10/29/2018	81,317	-	-	-
11/2/2018	4,408,541	-	-	14,000
11/3/2018	-	1,640,000	22,250,000	1,212,000
11/6/2018	47,609	-	-	-
11/9/2018	294,404	-	620,000	-
11/10/2018	-	-	3,010,000	-
11/13/2018	297,372	1,150,000	3,420,000	-
11/16/2018	85,280	-	-	-
11/26/2018	1,333,164	-	5,280,000	-
11/27/2018	-	-	12,530,000	-
12/2/2018	99,087	-	2,300,000	1,000
12/16/2018	55,435	-	400,000	2,000
12/21/2018	91,121	-	290,000	1,000
1/1/2019	136,984	-	-	-
1/24/2019	3,565,486	5,580,000	42,970,000	3,912,000
2/24/2019	41,915	-	-	-
3/15/2019	563,151	930,000	6,170,000	84,000
4/12/2019	53,550	-	-	-
4/15/2019	348,616	800,000	8,560,000	87,000
4/20/2019	2,112	-	-	3,000
4/22/2019	103,461	-	5,710,000	5,000
4/23/2019	12,807	-	6,380,000	3,000
4/26/2019	173,906	-	4,750,000	4,000
4/27/2019	1,268,051	-	11,660,000	283,000
5/2/2019	74,095	-	-	-
5/19/2019	106,368	-	-	1,000
5/26/2019	6,134	-	-	-
5/28/2019	1,181	-	-	-
6/2/2019	290,920	930,000	25,030,000	1,224,000
6/5/2019	133,761	-	-	1,255,000
6/6/2019	2,658,430	4,140,000	23,980,000	2,019,000
6/11/2019	74,881	-	750,000	-
6/13/2019	58,327	-	-	-
6/20/2019	131,854	-	820,000	13,000
6/25/2019	-	-	-	2,000
6/29/2019	-	-	-	182,000
6/30/2019	174,529	-	8,220,000	-

Daily Combined Sewer Overflow Volumes (Gallons)				
Date	**Haverhill CSO Volume**[2]	**GLSD CSO Volume**[3]	**Lowell CSO Volume**[5]	**Nashua CSO Volume**[4]
7/6/2019	3,579	-	-	344,000
7/11/2019	2,379,706	4,780,000	3,400,000	3,689,000
7/12/2019	20,277	220,000	4,020,000	-
7/17/2019	2,547,861	430,000	2,890,000	-
7/22/2019	88,262	-	-	-
7/23/2019	294,696	-	13,010,000	-
7/31/2019	-	-	-	3,117,000
8/7/2019	4,101,393	14,250,000	23,090,000	744,000
8/8/2019	604,900	-	4,570,000	-
8/13/2019	203,907	-	-	-
8/17/2019	323,620	-	-	-
8/18/2019	449,451	-	-	-
8/21/2019	4,428,380	-	-	10,000
8/28/2019	77,991	-	4,670,000	316,000
8/29/2019	-	-	5,970,000	-
9/26/2019	17,656	-	-	-
10/7/2019	49,506	-	300,000	-
10/16/2019	33,443	-	-	-
10/17/2019	9,507,118	19,210,000	43,700,000	1,138,000
10/23/2019	301,843	-	-	-
10/27/2019	59,558	-	8,450,000	-
10/31/2019	63,301	-	-	-
11/24/2019	116,451	-	3,560,000	3,000
12/9/2019	2,094	-	-	-
12/14/2019	8,036,934	6,500,000	22,400,000	172,000
1/25/2020	656,133	-	9,550,000	562,000
2/7/2020	9,094	-	-	-
2/27/2020	214,447	-	5,970,000	-
3/24/2020	8,084	-	-	-
3/29/2020	244,504	-	530,000	7,000
4/3/2020	68,691	-	-	-
4/9/2020	150,124	-	8,300,000	-
4/13/2020	23,735	-	-	-
4/21/2020	20,100	-	-	-
5/1/2020	106,377	-	-	-
5/15/2020	-	-	-	13,000
5/30/2020	687	-	-	-
6/6/2020	200,313	22,000	-	-
6/11/2020	6,570	-	-	-
6/21/2020	-	-	5,730,000	-
6/24/2020	601,370	60,000	-	26,000
6/28/2020	2,235,771	-	-	-
6/29/2020	11,030	-	-	-
7/1/2020	-	-	-	5,000
7/14/2020	468,482	-	-	-
7/17/2020	-	-	500,000	-

Daily Combined Sewer Overflow Volumes (Gallons)				
Date	**Haverhill CSO Volume**[2]	**GLSD CSO Volume**[3]	**Lowell CSO Volume**[5]	**Nashua CSO Volume**[4]
7/22/2020	481,036	1,020,000	14,530,000	75,000
7/23/2020	783,672	13,234,000	13,120,000	15,000
8/4/2020	108,289	-	-	-
8/17/2020	-	-	-	6,000
8/23/2020	359,519	3,157,000	-	-
8/29/2020	2,654	-	-	23,000
9/10/2020	2,468,895	23,910,000	47,010,000	3,785,000
9/28/2020	-	-	-	2,000
9/30/2020	2,048	-	-	-
10/13/2020	10,428	-	-	29,000
10/17/2020	133,483	-	15,550,000	15,000
11/15/2020	68,942	-	-	1,000
11/23/2020	4,378,414	8,580,000	14,500,000	3,000
11/26/2020	-	-	-	1,000
11/30/2020	17,934	-	-	5,300
12/1/2020	137,772	-	-	-
12/5/2020	38,254	-	3,570,000	15,000
12/12/2020	-	-	-	7,000
12/25/2020	195,294	-	17,930,000	42,000
1/16/2021		2,160,000	16,850,000	282,000
2/16/2021		-	-	4,000
4/29/2021		2,880,000	83,830,000	-
4/30/2021		-	2,600,000	-
5/5/2021		200,000	11,490,000	39,000
5/29/2021		-	1,900,000	-
6/8/2021		-	-	26,000
6/12/2021		-	-	1,000
6/15/2021		-	-	131,000
6/30/2021		-	2,170,000	54,000
7/1/2021		-	-	86,000
7/2/2021		-	-	37,000
7/3/2021		4,820,000	5,680,000	-
7/4/2021		-	2,550,000	-
7/7/2021		570,000	-	-
7/8/2021		-	1,960,000	-
7/9/2021		26,950,000	74,940,000	4,307,000
7/12/2021		7,257,000	38,890,000	76,000
7/18/2021		840,000	9,730,000	1,346,000
7/20/2021		-	-	1,000
7/23/2021		-	-	5,000
7/29/2021		-	-	4,073,000
7/30/2021		840,000	11,780,000	-
8/5/2021		-	400,000	-
8/10/2021		-	-	11,000
8/19/2021		2,700,000	33,960,000	25,000
8/22/2021		-	2,770,000	-

Daily Combined Sewer Overflow Volumes (Gallons)				
Date	Haverhill CSO Volume[2]	GLSD CSO Volume[3]	Lowell CSO Volume[5]	Nashua CSO Volume[4]
8/23/2021		-	-	102,000
9/1/2021		-	9,110,000	68,000
9/2/2021		35,040,000	74,650,000	923,000
9/9/2021		-	200,000	916,000
9/10/2021		-	40,000	-
9/13/2021		290,000	8,860,000	14,000
9/24/2021		-	-	4,000
10/4/2021		-	100,000	-
10/5/2021		-	4,950,000	-
10/16/2021		-	-	2,000
10/26/2021		-	50,000	-
10/30/2021		680,000	10,330,000	10,000
10/31/2021		-	5,130,000	1,000
11/12/2021		7,760,000	31,650,000	4,556,000
12/11/2021		-	-	19,000