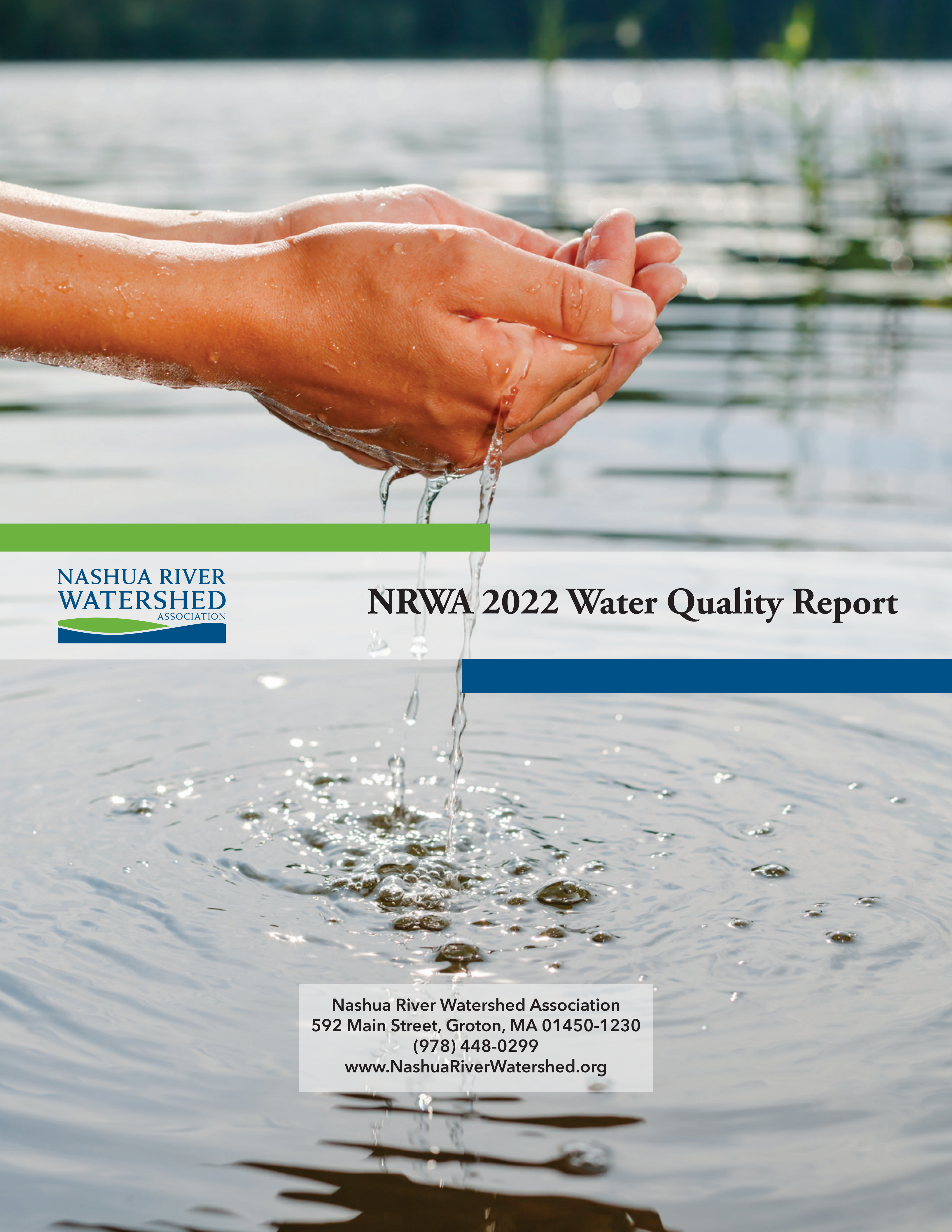

NASHUA RIVER
WATERSHED
ASSOCIATION

NRWA 2022 Water Quality Report

Nashua River Watershed Association
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DEDICATION

The Nashua River Watershed Association would like to recognize all of the individuals and organizations that support and facilitate our Water Monitoring Program. We are indebted to each of our water-monitoring volunteers: a dedicated and cheerful crew who truly care about the state of our watershed. We are also extremely grateful for the financial support of our members and funders. Our water-monitoring work is specifically funded by: Bemis Associates Inc., Bristol Meyers Squibb, MA Department of Environmental Protection, MA Division of Ecological Restoration, the Fieldstone Foundation, Inc., the Fleetwing Charitable Foundation Trust, the Greater Lowell Community Foundation, and Nypro Inc.

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INTRODUCTION

The Nashua River watershed encompasses 538 square miles across 32 communities in Massachusetts (MA) and New Hampshire (NH). The river runs for 56 miles from its origins in central MA before joining the Merrimack River in Nashua, NH. Its main tributaries include the: North Nashua, South Nashua, Nissitissit, Squannacook, Whitman, Quinapoxet, and Stillwater Rivers. The Wachusett Reservoir intercepts the Quinapoxet and Stillwater Rivers; Reservoir waters are released at the head of the South Nashua River. The watershed contains four significant urban areas (i.e., Clinton, Fitchburg, Leominster, and Nashua) and is otherwise characterized by exurban towns, with approximately 62% of the watershed forested and 11% used for agriculture.

In the 1960s, the Nashua River was one of the ten most polluted rivers in the United States, with major pollutants deriving from outfall pipes at paper and other mills in urban areas. Today, industrial discharge is less of a problem and the river is remarkably less polluted. This restoration is largely attributable to a grassroots clean-up and conservation campaign, initiated by Marion Stoddart, founder of the Nashua River Watershed Association; and to passage of critical environmental protection legislation, especially the federal Clean Water Act (CWA). In 2022, people regularly boated, swam, and fished in the river, and diverse wildlife could be observed in or near its waters.

Though the river is visibly cleaner today, it is still negatively impacted by certain human activities, especially nonpoint-source pollution (i.e., pollution from dispersed sources like stormwater flowing over parking lots), combined sewer overflows (CSOs), and illicit point-source discharges.

In the 1960s, water in the North Nashua River changed color according to the color of paper being dyed on a given day (left photo). In present day, water quality is vastly improved, but some problems still linger. In the right photo, as part of a collaborative project with the National Park Service and the US Geological Survey, volunteers collect dragonfly larvae from Pepperell Pond, an impoundment on the Nashua River mainstem; the larvae will be analyzed for mercury content. Photo by Emma Lord

POINT VS. NON-POINT POLLUTION:

Point-source pollution comes from one single location or point, like a pipe that is discharged from a factory or water treatment plant. Nonpoint-source pollution (NPS) cannot be traced to a single source. Instead, it comes from multiple points on the landscape and enters waterways at different locations. Often NPS travels overland in stormwater runoff. One NPS example is: herbicide washed during a rainstorm from many lawns in a town and carried by stormwater to a nearby stream. Another NPS example is: failing septic systems that leak untreated wastewater into the groundwater table, which may eventually feed a river. Point-source pollution can be an easier problem to fix because it has only one source versus the multiple, often hidden sources of NPS pollution. Point-source pollution is strictly controlled through a permitting program under the federal Clean Water Act (CWA). Nonpoint source pollution is not regulated, but rather managed through a voluntary CWA grant program.

A cornerstone of the Nashua River Watershed Association (NRWA) is monitoring water quality throughout the watershed and using this data to strategically restore ecological integrity in degraded portions of the river system. Both the MA Department of Environmental Protection (MA DEP) and the NH Department of Environmental Services (NH DES) also use NRWA water-quality data to inform decisions about which waterbodies should be listed as impaired (and thus targeted for restoration) under the CWA.

The NRWA water-monitoring program includes two parts: 1) monthly monitoring of routine parameters during the growing season and 2) special projects that target critical data gaps. A Quality Assurance Project Plan, most recently updated in 2023, ensures that all NRWA water monitoring is conducted according to strict quality-control objectives and provides accurate, high-quality data. Each programmatic area of the water-monitoring program is outlined below and explored in detail later in the report.

ROUTINE WATER-QUALITY MONITORING

Last year, 2022, marked the 30th year of the NRWA's routine water-monitoring program. NRWA uses the program to track typical water-quality conditions in our waterways and identify significant deviations from baseline conditions that could indicate water-quality problem areas.

Each year, NRWA monitors about 30 sites across the watershed and relies on a cadre of about 50 committed, highly capable volunteers to collect and analyze water samples. At each site, once a month from April through October, monitors collect *in-situ* data on water temperature and conductivity and obtain grab samples for dissolved oxygen (DO) and bacterial analysis.

USEFUL ABBREVIATIONS

CWA = United States Clean Water Act (33 U.S.C. Chapter 26)
CSO = Combined sewer overflow
DO = Dissolved oxygen
MA DEP = Massachusetts Department of Environmental Protection
MA SWQS = Massachusetts Surface Water Quality Standards
NH DES = New Hampshire Department of Environmental Sciences
NH SWQR = New Hampshire Surface Water Quality Regulations
NPS = Non-point source pollution
NRWA = Nashua River Watershed Association
US EPA = United States Environmental Protection Agency
WWTP = Wastewater treatment plan

The Wachusett Reservoir and its tributaries (including the Stillwater and Quinapoxet Rivers) in the southern portion of the Nashua River watershed are water-supply sources for 2.5 million people in the MA

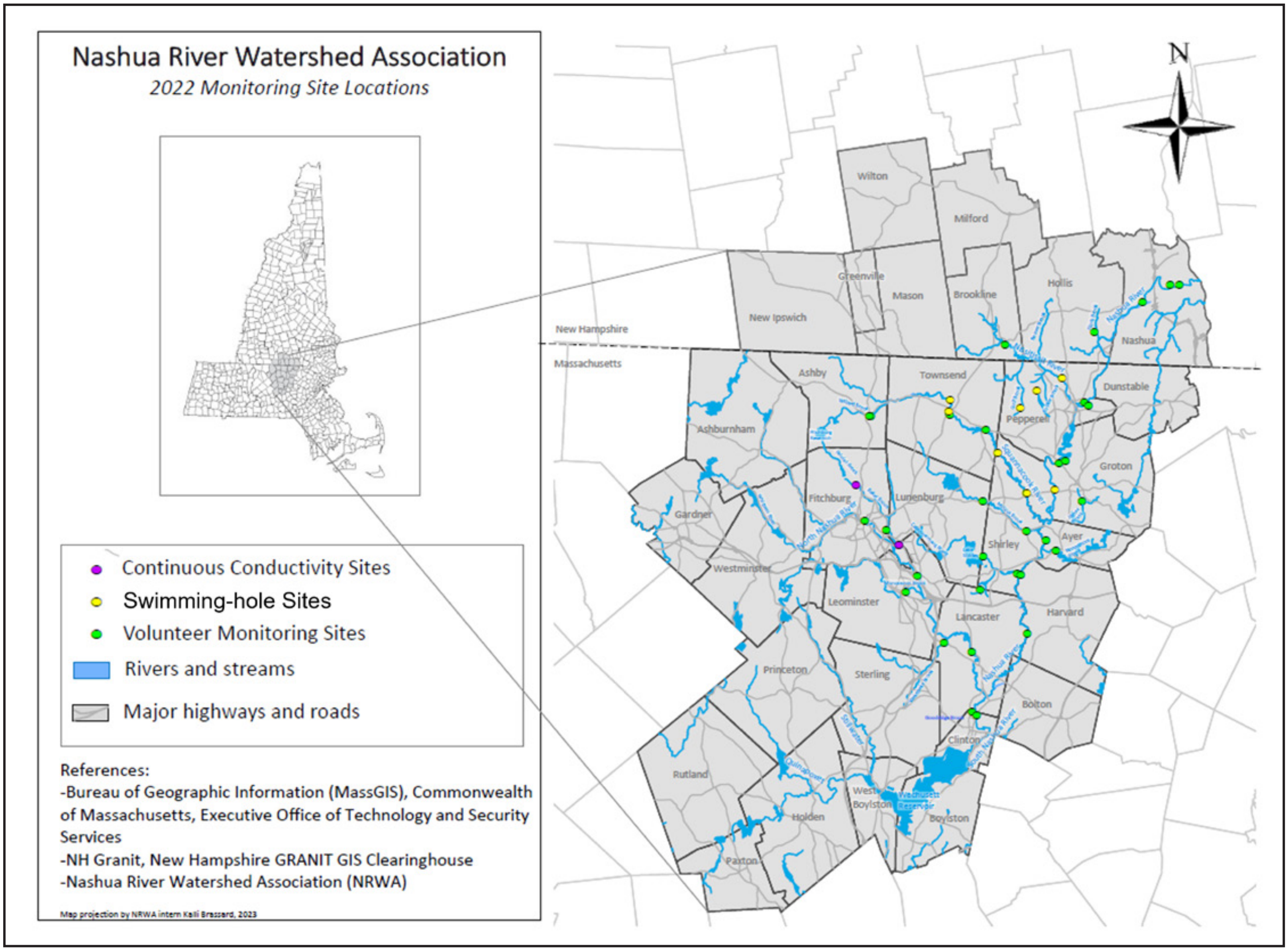


Figure 1. Water-quality monitoring sites in the Nashua River watershed in 2022.

Water Resources Authority (MWRA) public water system in eastern Massachusetts. The MA Department of Conservation and Recreation's Division of Water Supply Protection is responsible for monitoring water quality in the tributaries of the Wachusett Reservoir watershed, and conducts weekly water-quality sampling. The NRWA chooses to focus our routine water-quality monitoring program in the downstream portion of the watershed that is not otherwise routinely monitored.

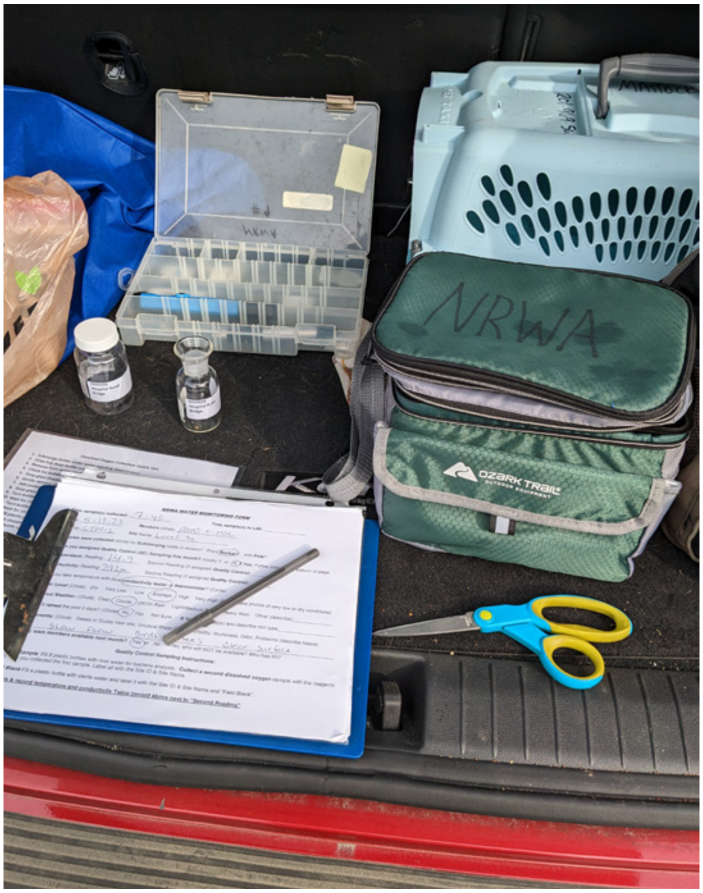
A volunteer uses a bucket to obtain a water sample from the South Nashua River, just downstream from the Wastewater Treatment Plant in Clinton, MA. Photo by Jeff Groom

SPECIAL PROJECTS

When water-quality problem areas or data gaps are identified, NRWA initiates special projects to address the issue. Special projects in 2022 included: a) bacterial sampling at informal swimming holes; b) continuous water-temperature loggers in coldwater fish resource streams; and c) continuous conductivity loggers in roadside streams to monitor potential impacts from road salt.

WHAT DO WE STUDY?

In 2022, NRWA collected data on four different water-quality parameters in the watershed's rivers and streams: *Escherichia coli* (*E. coli*, a bacteria species), DO, water temperature, and conductivity. Each of these parameters provides specific information about the physical, chemical, and biological state of the waterways, as explored below.



Volunteers prepare their water-monitoring kit for sampling from the Nashua River mainstem in Devens, MA. Photo by Dawn McCall

E. COLI

E.coli is a bacteria species that lives in the intestines of humans and other warm-blooded animals. Though the vast majority of *E. coli* individuals are harmless and in fact associated with a healthy microbial gut biome, some strains contain DNA that can lead to gastrointestinal illness in animals if accidentally consumed. The higher the *E. coli* concentration in surface water, the greater the likelihood of illness.

E. coli can enter surface waterways by multiple routes, principally: CSOs; leaking sewer pipes; overland stormwater flow that picks up animal waste and flushes it into streams; failed septic systems that contaminate groundwater; and potentially, wastewater treatment plants that are non-compliant with their water-quality permits.

NRWA volunteers collect monthly *E. coli* samples at our 30 routine monitoring sites during the growing season. In 2022, NRWA received a three-year grant from the Great Lowell Community Foundation to conduct more intensive *E. coli* sampling at swimming holes in several watershed communities. From June through August, NRWA staff collect *E. coli* samples every two weeks from 7-8 locations on the Nissitissit, Squannacook, and Nashua Rivers where swimming is common, but bacteria levels are not otherwise tested.

DISSOLVED OXYGEN

Many aquatic animals, plants, and other organisms require oxygen to survive. Relatively high DO concentrations usually indicate a healthy riverine ecosystem (though extremely high DO can indicate nutrient enrichment and be associated with nuisance plant blooms). DO is intimately connected with water temperature. As temperatures rise, oxygen evaporates more readily from the water surface, leaving less oxygen dissolved in the water column. Certain species, especially some fish and macroinvertebrates, can only survive in cold, oxygen-rich water. Each month of the growing season, NRWA volunteers collect and analyze DO samples from the 30 routine monitoring sites.

Pete Steeves collecting a dissolved oxygen sample from Reedy Meadow Brook in Pepperell, MA in August 2022. Pete was a volunteer water-quality monitor for the NRWA for 18 years before retiring from the program last year. We are indebted to Pete and others like him for their dedication to monitoring the health of our watershed. Photo by Max McCormick

WATER TEMPERATURE

Temperature is a key driver of many aquatic processes. Every species is adapted to, and can only tolerate, a particular range of temperatures. As a result, temperature structures species diversity in the watershed. Additionally, rates of biological and chemical reactions tend to increase with water temperature. For example, metabolic rates in cold-blooded animals (e.g., fish and turtles) and plants are faster in warm than in cold waters. Temperature also impacts physical processes. In particular, more oxygen can be dissolved in cold, versus warm, water. Conversely, mineral and salt concentrations in water tend to increase with temperature. Finally, the toxicity of some compounds (e.g., ammonia, insecticides) increases with water temperature.

NRWA tracks watershed water temperature using two methods. First, volunteers use portable meters to measure water temperature at each of our 30 monthly monitoring sites. Second, in partnership with the United States Geological Survey, Trout Unlimited, and MA Wildlife, NRWA has 14 continuous temperature loggers deployed in coldwater fish resource streams. NRWA and its partners are specifically using the continuous temperature loggers to identify coldwater fish refugia. The continuous-temperature data are not discussed in this report.

CONDUCTIVITY

Technically, conductivity refers to the ability of water to conduct electricity. In practical terms, conductivity measures the concentration of salts and other ions in water. Baseline conductivity varies across waterways due primarily to local differences in groundwater flow patterns and types of rocks present (when water flows through weathered rock bits, it dissolves the rock into its component ions). Deviations from baseline conductivity levels can indicate pollutant discharge into a waterway. Conductivity also increases with temperature. For this reason, conductivity is typically converted to specific conductance, which is a temperature-adjusted version of conductivity. Importantly, there is a tight, positive relationship between the amount of road salt (a source of chloride ions) running into a stream and specific conductance. Road salts have been implicated in a variety of negative impacts to aquatic life (e.g., smaller fish hatchlings, altered amphibian sex ratios, increased mortality of micro-invertebrates, and increased susceptibility to harmful algal blooms; Rapp Learn 2017).

NRWA volunteers take *in-situ* conductivity readings at our 30 routine monitoring sites each month from April through October. Additionally, NRWA has two continuous conductivity loggers installed in tributaries to the North Nashua River in Fitchburg, as part of the Eastern Massachusetts Continuous Conductivity Collaborative. We use these loggers to track how conductivity changes with season.

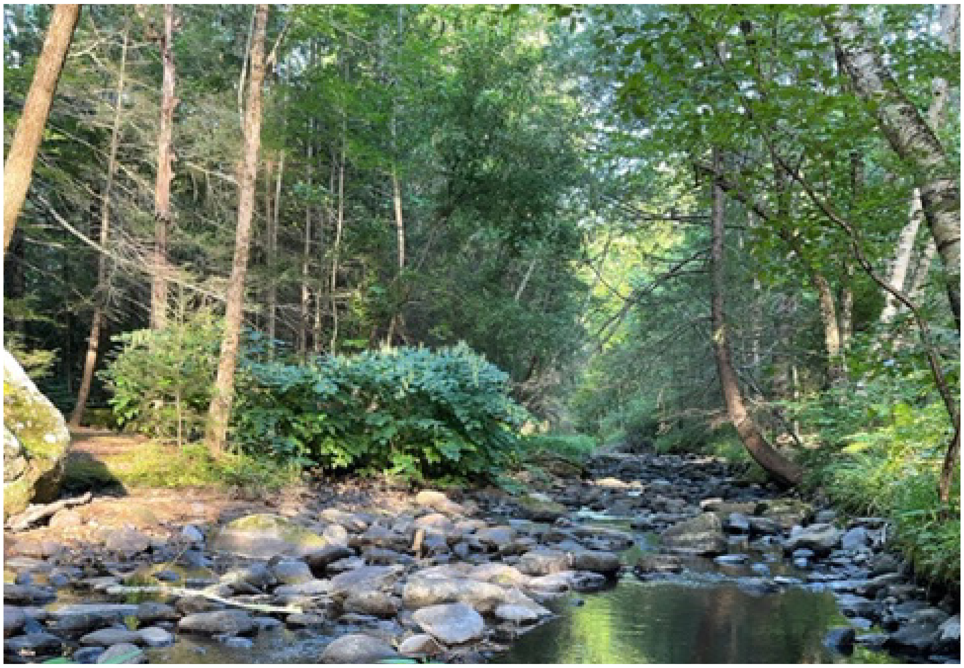
WHAT DID WE FIND?

DROUGHT

Throughout the 2022 growing season, the Nashua River Watershed, like much of New England, experienced a severe drought. The drought started in early May, with a streak of 10-12 days without any rain (NCEI 2023). It quickly worsened, so that by

July, the entire watershed was at a Level 3 Critical Drought (in MA) or Severe Drought (in NH), which lasted through the summer (MA DMTF 2023; NH DES 2022a-c). In the heart of the watershed at the Fitchburg Airport, no rain fell for 22 and 23 days in August and September, respectively (NECI 2023). Each of these months, the cumulative amount of rain that did fall was only 1.28 inches. The drought slowly abated during the fall; by January, the drought was gone (MA DMTF 2023; NH DES d,e).

The Nissitissit River near Mill Street in Pepperell, MA in mid-August 2022. The Nissitissit River is a coldwater fish resource and a significant tributary to the Nashua River. The River did not dry entirely, but became very low during the drought. Photo by Nan Quintin



Willard Brook, just upstream from Damon Pond in Ashby, MA, in mid-August 2022. Willard Brook is also a coldwater fishery, which feeds the Squannacook River. Photo by Barbara Fox Miles

This drought strongly affected our riverine ecosystems. Though water levels in the Nashua River mainstem were somewhat lower because of the drought, the mainstem was largely buffered from the worst drought effects by large, periodic releases from the Wachusett Reservoir into the South Nashua River (USGS 2023a) and discharges from Wastewater Treatment Plants (WWTPs) and other permitted point-sources along the primary rivers. Many other tributaries and headwater streams, however, dried entirely or were nearly dry. At the USGS stream gauge on the Squannacook River in West Groton, the water level was at near-record lows by mid-August 2022, when water height was 1.21 ft (USGS 2023b). (Similarly low levels had only occurred three previous times in the gauge's 15-year history, in: 2015, 2016, and 2020. The lowest ever recorded was 1.04 ft in September 2016).

Severe droughts can negatively impact water quality. When less water is present in streams, the water tends to heat up faster and retain less oxygen, and pollutants are more concentrated. Similarly, stormwater entering streams tends to contain higher pollutant loads, since these amass on the landscape in-between rain storms. In turn, fish, amphibians, invertebrates, and other aquatic life suffer. We explore the 2022 drought in more detail later in this report.

WHAT DO ALL THESE NUMBERS MEAN?

Both Massachusetts and New Hampshire used recommendations from the US Environmental Protection Agency (US EPA) to develop safe *E. coli* standards for their respective Surface Water Quality regulations. Safe thresholds under these regulations are defined in terms of statistical calculations across multiple samples, making it difficult to interpret the meaning of any single *E. coli* sample. To facilitate interpretation of *E. coli* data in this report, we compare single-sample *E. coli* values to the EPA's Beach Action Value (BAV), which is a separate tool used to help land managers decide when to close beaches based on single bacteria samples. This tool is considered conservative, in that the threshold is low enough to protect humans against brief exposure to high bacterial concentrations. The BAV and state regulatory thresholds were developed from the same EPA research. The BAV that applies to both MA and NH is 235 cfu/100 ml.

Some figures also reference the STV - a secondary-contact threshold. This threshold derives from the MA Surface Water Quality Standards for Class C waters. Class C waters are impaired enough that they are considered safe only for secondary-contact recreation (e.g., boating or fishing, but not swimming). We include this threshold in the graphs solely for visual reference: no waters in the Nashua River watershed are technically categorized as Class C.

E. COLI

In 2022, the Nashua River watershed's rivers and streams contained *E. coli* levels that were generally safe for human recreation. Out of 197 water samples, 153 samples (or 78%) had *E. coli* concentrations < 235 cfu/100 ml, the EPA's BAV threshold. As expected, *E. coli* levels varied across space and time (**Figure 2 and 3**), but several sites were persistent hot spots and additional sites require further scrutiny (**Figure 4**).

We draw three overarching conclusions from the 2022 *E. coli* data:

1. *E. coli* concentrations appear strongly tied to rainfall. This connection is well-established in the water-monitoring world, but was especially impactful in 2022 given the extreme drought. One way to understand this connection is to compare *E. coli* concentrations from "wet" versus "dry" sampling events. We define a "wet" sampling event as one where ≥ 0.25 in. of rain falls during the three days preceding sampling. Conversely, a "dry" event occurs when < 0.25 in. of rain falls during the three

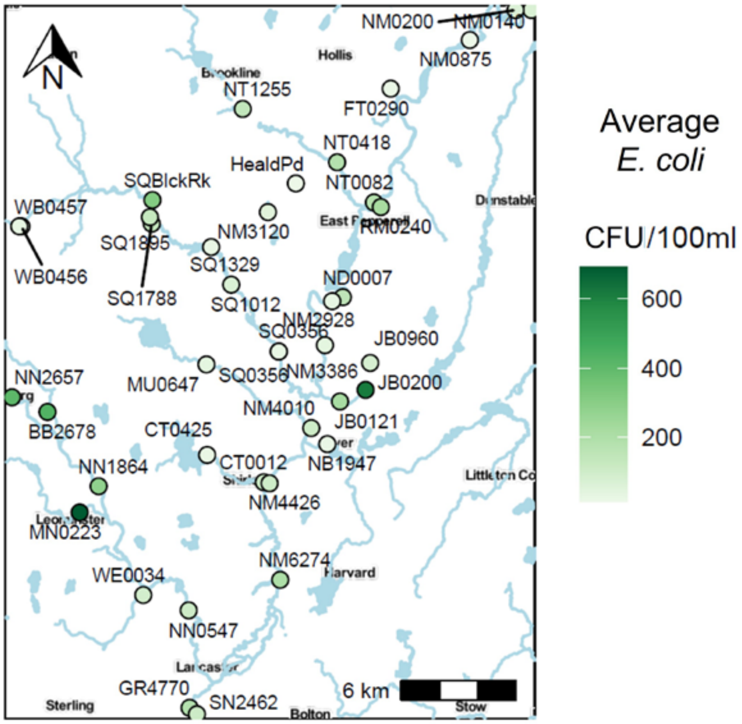


Figure 2. Average 2022 *E. coli* concentrations at each sample site in the Nashua River watershed. Concentrations above 235 cfu/100 ml are considered unsafe for human recreation. Note: Each James Brook (JB) site and the SQBlckRk site were sampled only once or twice.

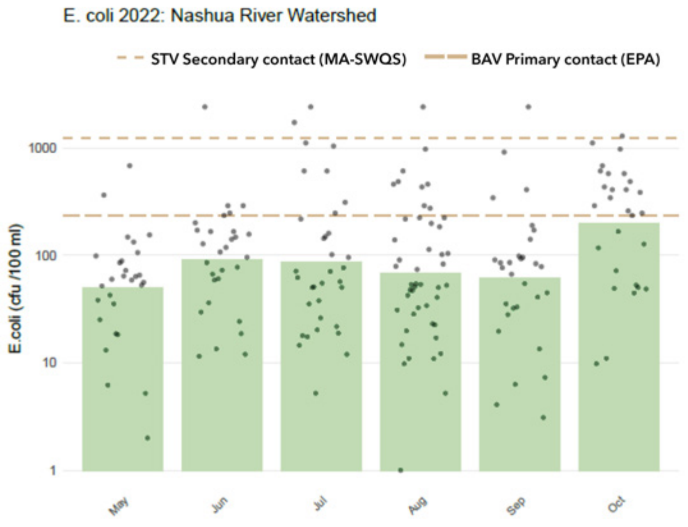


Figure 3. For 2022, *E. coli* concentrations by month in the Nashua River watershed. BAV Primary contact = the Beach Action Value, derived by the EPA and set at 235 cfu/100 ml. Values above this threshold are considered unsafe for primary human recreation (e.g., swimming, bathing). STV Secondary contact = Statistical Threshold Value for secondary contact, derived from the MA Surface Water Quality Standards and set at 1,260 cfu/100 ml. Values above this threshold are considered unsafe for secondary-contact human recreation (e.g., boating, fishing). Numerous samples were unsafe for primary contact recreation from July through October; though the majority of samples collected in 2022 were still safe for recreation. Four samples were > 2419 cfu/100 ml, but their exact concentrations are unknown.

days before sampling. For 2022, two out of nine sampling events were “wet.” These occurred in mid-July and October.

Of the 44 unsafe samples, 23 (52%) were collected during the two “wet” sampling events, while 121 (79%) of safe samples were collected during the seven “dry” sampling events **(Figure 5)**. In particular, in October 2022, just after 1.4 to 2.2 inches of rain fell upon the watershed, a full 57% of *E. coli* samples were unsafe for human recreation (**Figure 6**).

Just how is rainfall connected to bacteria in surface water? There are two likely principal pathways. First, storms can overwhelm the capacity of some municipal sewer systems, causing sewage to overflow into stormwater systems, which discharge directly into the river. Second, as stormwater flows downhill over land, especially over impervious surfaces, it picks up the remnants of any animal waste on those surfaces and deposits that waste in our waterways. During a drought, over consecutive rainless days, animal wastes accumulate on the landscape. When rain finally falls, it flushes the accumulated wastes into our streams and rivers. Since *E. coli* can survive

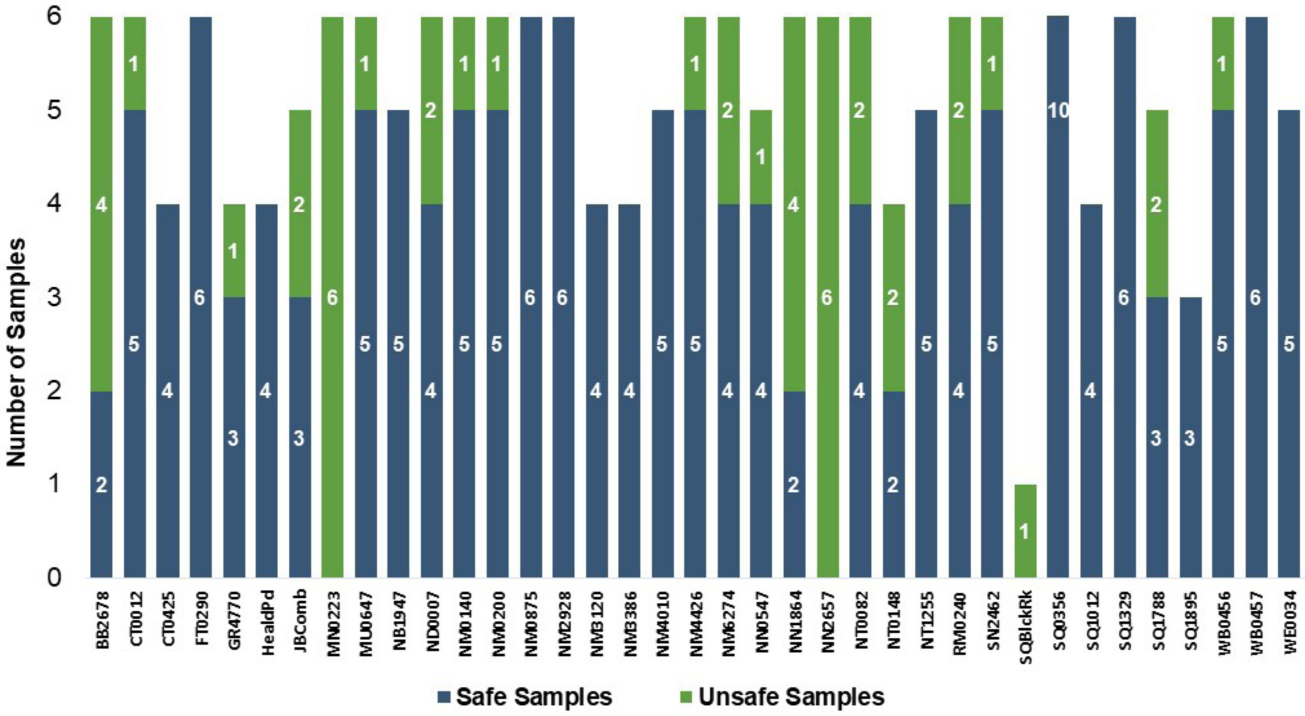


Figure 4. Safe vs. unsafe *E. coli* samples by site in 2022. The water from most sites was generally safe for human recreation throughout the season. A few unsafe “hot spots” are readily apparent (e.g., MN0223).

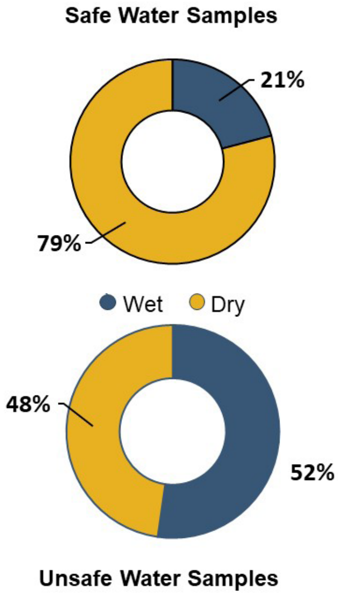


Figure 5. For 2022, *E. coli* samples categorized according to whether the water in the sample was safe for human recreation. Within each category, samples are further classified by the amount of rain that fell during the three days before the sample was collected. "Wet" = ≥ 0.25 inches of rain; "Dry" = < 0.25 inches of rain.

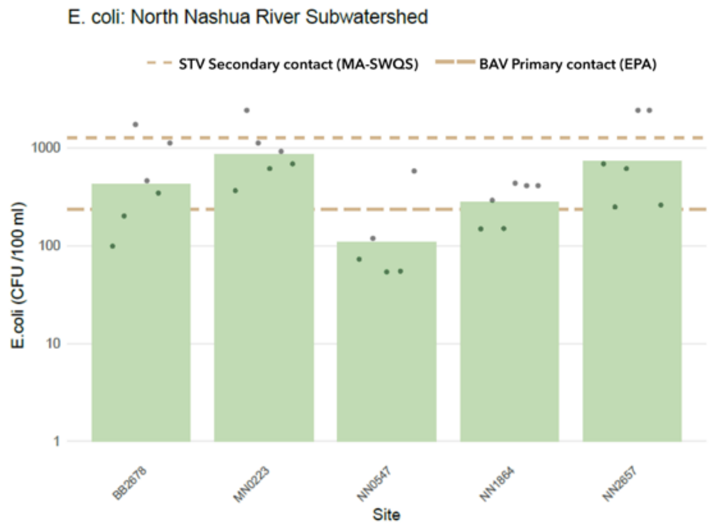


Figure 7. *E. coli* sampled from the North Nashua River subwatershed in Fitchburg, Leominster, and Lancaster, MA in 2022. Note: the highest value for MN0223 and the two highest values for NN2657 were actually >2419.6 cfu/100 ml, but the exact concentration is not known. The threshold lines indicate whether the sample was safe for contact recreation (i.e., below the BAV line) or non-contact recreation (i.e., below the STV line).

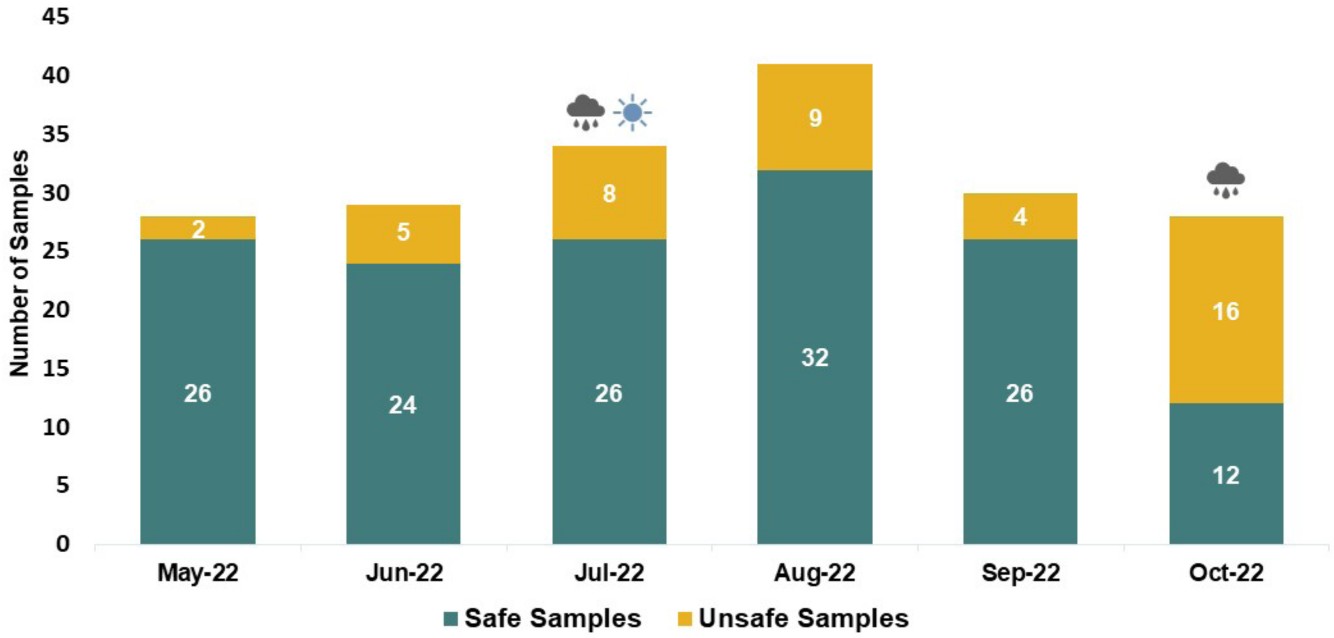


Figure 6. The proportion of 2022 *E. coli* samples that were safe for recreation in each month across all sample sites. The rain cloud symbol denotes a "wet" sampling event. The first sample date in July was a "wet" event; later July sample dates were "dry" events (symbolized by the sun symbol).

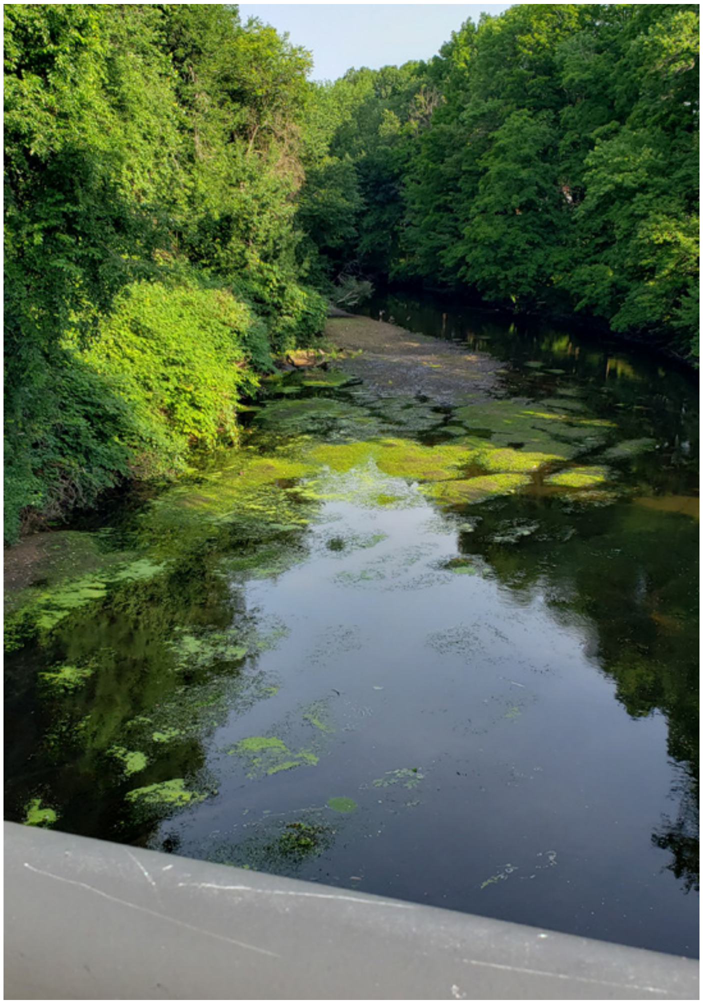
COMBINED SEWER OVERFLOWS (CSOS)

Starting in 2022, MA municipalities with CSOs are required by law (314 CMR 16.00) to notify the public when a CSO discharges. Any person can sign up to receive CSO notifications. Fitchburg is the only community in the Nashua River Watershed that still has CSOs. For Fitchburg, the sign-up sheet can be accessed here: http://www.ci.fitchburg.ma.us/1002/CSO-Notification. Fitchburg's 2022 notifications suggest that some of Fitchburg's CSOs are very sensitive and are activated at relatively low rainfall volumes. NH does not have a similar law requiring CSO notification, but more can be learned about the City of Nashua's CSOs here: https://www.nashuanh.gov/842/Combined-Sewer-Overflows.

varied environmental conditions over long periods (e.g., 8 months) in soil and water (Lim et al 2010), this can amount to large numbers of live *E. coli* entering waterways when rain follows an extended drought.

2. Point sources of *E. coli* continue to negatively impact the watershed. Specifically, the wastewater treatment plant (WWTP) and eight remaining Combined Sewer Overflows (CSOs) in Fitchburg appear to be directly linked to high bacteria levels in the North Nashua River (**Figure** 7). At the Leominster Main Street Bridge (NN1864), directly downstream from the Fitchburg WWTP, four of six samples in 2022 were unsafe for recreation. All six samples from Riverfront Park (NN 2657), which is in close downstream proximity to five CSOs, were unsafe for recreation.

3. Non-point source pollution likely explains both persistent and flashy *E.coli* spikes elsewhere in the watershed. For example, Baker Brook (BB2678), which drains into the North Nashua in Fitchburg, had *E. coli* levels higher than 1100 cfu/100 ml during the two "wet" sampling events. No WWTP or CSOs are located along Baker Brook, but extensive parking lots and other impervious surfaces line its western bank for about 1.2 miles upstream of the sample site. During rainstorms, *E. coli*-contaminated runoff from those parking lots may drain relatively quickly into Baker Brook.



The North Nashua River at Main Street in Leominster, MA. This site is located downstream from the three Combined Sewer Overflows and the Fitchburg Wastewater Treatment Plant. Both *E. coli* and conductivity were high in water collected from this site in 2022. Photo by Kathleen Bowse-Hatfield

HOT SPOTS

We classify four 2022 sites as "hot spots," due to repeatedly high *E. coli* concentrations at these sites. All four hot spots are in the North Nashua River subwatershed and are located in a heavily urbanized landscape, within the cities of Fitchburg and Leominster. Two sites draw samples from the North Nashua River: Riverfront Park (NN2657) and Leominster Main Street

Bridge (NN1864); and two sites are on tributaries to the North Nashua: Monoosnoc Brook (MN0223) and Baker Brook (BB2678). We briefly explore the conditions at each hot spot.

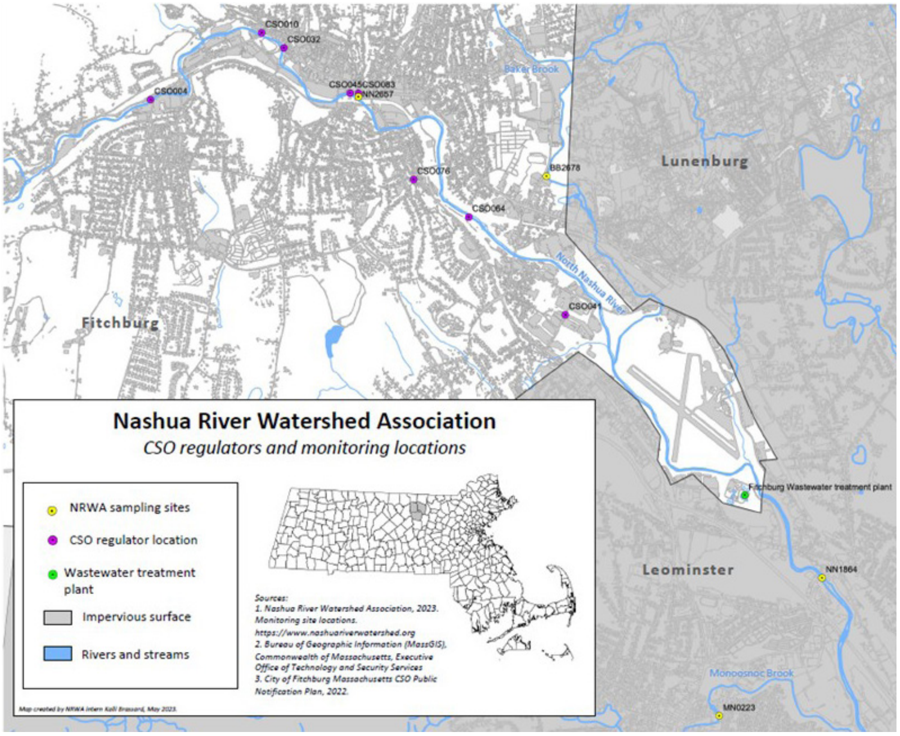
Fitchburg Riverfront Park and Leominster Main Street Bridge

Evidence suggests that *E. coli* concentrations at these two hot spots are heavily influenced by point-source discharge into the North Nashua River. For Riverfront Park, discharge derives from five extant CSOs directly upstream from the sample site, with the closest, known as Punch Brook, only about 135 ft upriver. Three additional CSOs and the Fitchburg Wastewater Treatment Plant discharge into the North Nashua between Riverfront Park and the Leominster Main Street Bridge. (**Figure 8**)

About eight miles further downstream is the next sample site in Lancaster at Pellechia Conservation Land (NN0547). For 2022, only one of five samples at Pellechia were unsafe, suggesting that by the time the river reaches Pellechia, enough clean water has entered the waterbody to dilute Fitchburg's high *E. coli* loads. The site's landscape context also plays a role. Though the Leominster WWTP discharges into the river upstream from Pellechia, the WWTP is about seven miles from Pellechia. Also, there are no additional CSOs between the Leominster Main Street Bridge and Pellechia; and the river flows through forest land for most of this stretch. Thus, little additional *E. coli* may be entering the North Nashua River between the Leominster WWTP and Pellechia.

Fortunately, Fitchburg is actively executing a plan to separate the sewer and stormwater components of its eight remaining CSOs. Specifically, of the five CSOs upstream of Riverfront Park, one should be deconstructed by the end of 2023, three by the end of 2025, and the last by the end of 2026. Of the three between Riverfront Park and the Leominster Main Street Bridge, two should be separated by early 2028, and the final by the end of 2029. In other words, within seven years, we should see dramatic improvements in *E. coli* concentrations in the North Nashua River.

The City of Fitchburg has already achieved significant improvements in reducing bacterial loads since signing the 2012 Consent Decree which required the City to develop and implement a plan to eliminate its CSOs. This can be seen in long-term *E. coli* data from both Riverfront Park and Main Street Bridge, which show apparent declines in average *E. coli* levels after 2012 (**Figure 9**). Both sites continue to have major *E. coli* spikes, however, and the North Nashua River is listed as impaired for *E. coli* under the CWA (MA DEP 2021a). It is thus critical to track these sites as the final eight CSOs are decommissioned, to make sure that *E. coli* levels decline as expected, and if not, resolve any remaining *E. coli* problems.



Sources:
1. Nashua River Watershed Association, 2023. Monitoring site locations. https://www.nashuariverwatershed.org
2. Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services
3. City of Fitchburg Massachusetts CSO Public Notification Plan, 2022.

Map created by NRWA intern Kelli Brassard, May 2023.

Figure 8. The eight Combined Sewer Overflows in Fitchburg, MA, mapped in relation to four NRWA water-quality sampling locations and the Fitchburg Wastewater Treatment Plant.

Monoosnoc Brook, Leominster

NRWA monitors have recorded very high *E. coli* concentrations in

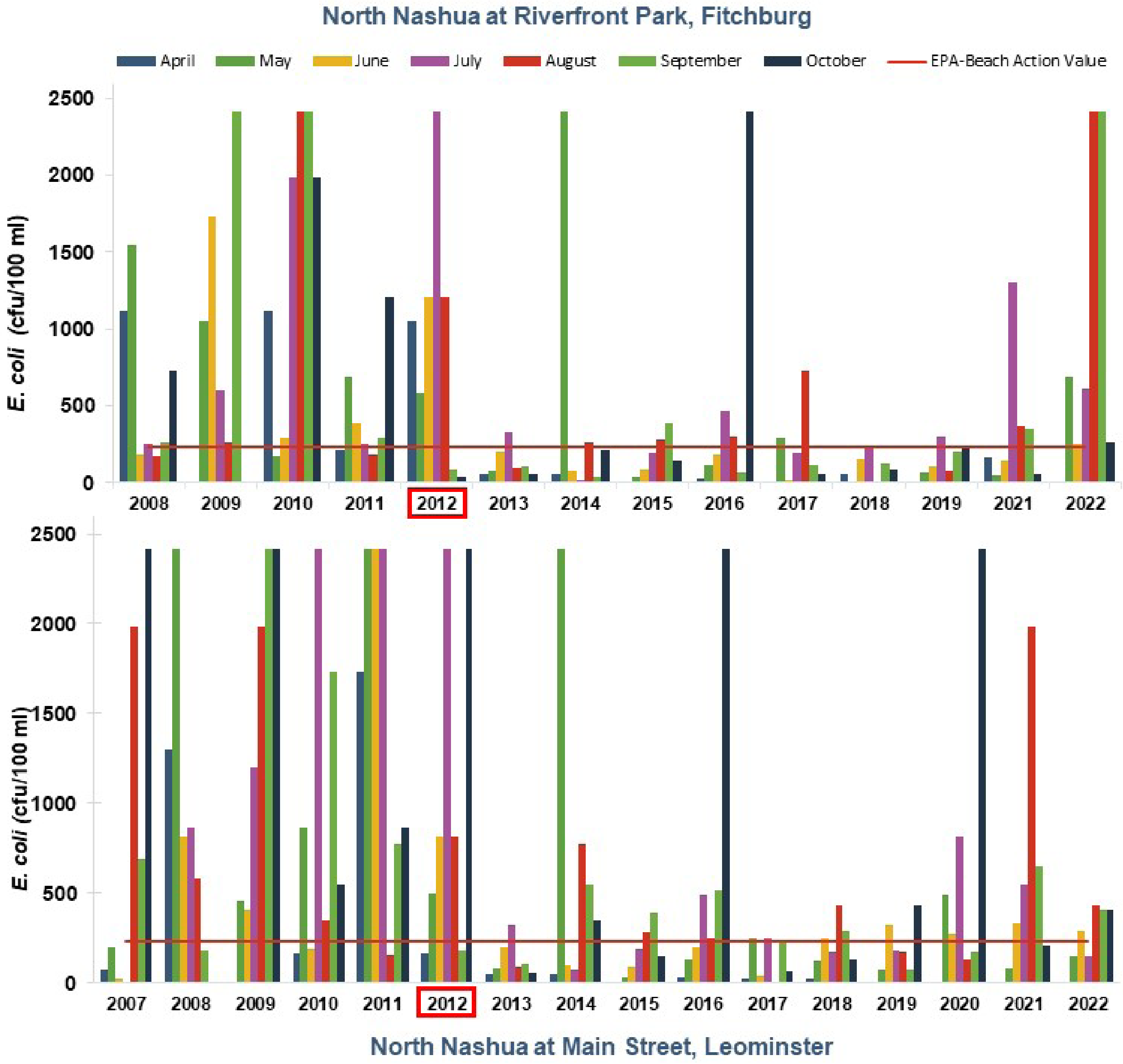


Figure 9. *E. coli* levels at two sites on the North Nashua River from 2007 through 2022. Top: Riverfront Park in Fitchburg, MA. Bottom: Main Street Bridge, downstream, in Leominster, MA. In 2012, Fitchburg signed a Consent Decree with the EPA detailing a plan for decommissioning the City's remaining CSOs. Note: all values graphed at 2419.6 cfu/100 ml were actually > 2419.6 cfu/ 100 ml, but the exact concentration is unknown. EPA - Beach Action Value = the threshold above which water is not considered safe for contact recreation.

Monoosnoc Brook near Water Street since 2007 (site: MN0223). This trend continued in 2022, with all six samples containing unsafe *E. coli* levels, and two of these samples having concentrations higher than 1400 cfu/100 ml (**Figure 10**). Monoosnoc Brook is listed as impaired for *E. coli* under the CWA (MA DEP 2021a).

In 2014, 2016, and 2019, the City of Leominster and NRWA collaborated to discover the *E. coli* source, conducting: dye tests, visual inspections, microbial-source tracking, and spatially intensive bacterial sampling. The COVID pandemic interrupted the investigation before a source was definitively identified. A leaking sewer pipe in a certain neighborhood is the suspected source. The City, with NRWA's support,

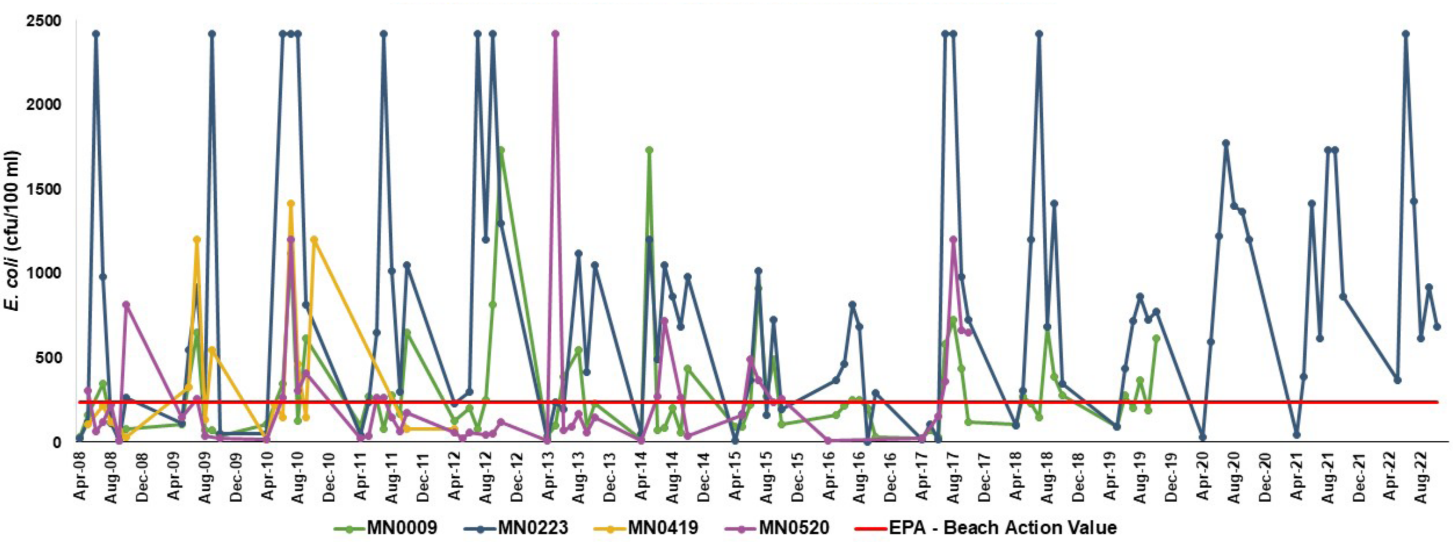


Figure 10. *E. coli* concentrations from four sites on Monoosnoc Brook, Leominster, from 2008 through 2022. MN0520 is furthest upstream; MN0009 is furthest downstream. Site MN0223 is one of the 2022 *E. coli* "hot spots." Note: all values graphed at 2419.6 cfu/100 ml were actually > 2419.6 cfu/ 100 ml, but the exact concentration is unknown. EPA - Beach Action Value = the threshold above which water is not considered safe for contact recreation.

intends to resume its search for the source in 2023 and resolve the issue in the near future.

Baker Brook, Fitchburg

In 2022, four of six samples from Baker Brook contained unsafe *E. coli* levels; two of the unsafe samples registered more than 1100 cfu/100 ml (**Figure 7**).

Despite having no WWTPs or CSOs that discharge directly into Baker Brook, the Brook has suffered from intermittently high *E. coli* levels, since at least 2020 (**Figure 11**) and is designated impaired for *E. coli* under the CWA (MA DEP 2021a).

It is possible that illicit point-source discharges are responsible for some of the bacterial contamination. It is also likely, however, that runoff from the surrounding landscape contributes much of the *E. coli* found in Baker Brook. From approximately Pearl Street, southward along the John Fitch Highway for about 1.2 miles, the Brook is bound on its western bank by impervious surfaces. A sand pit and residential

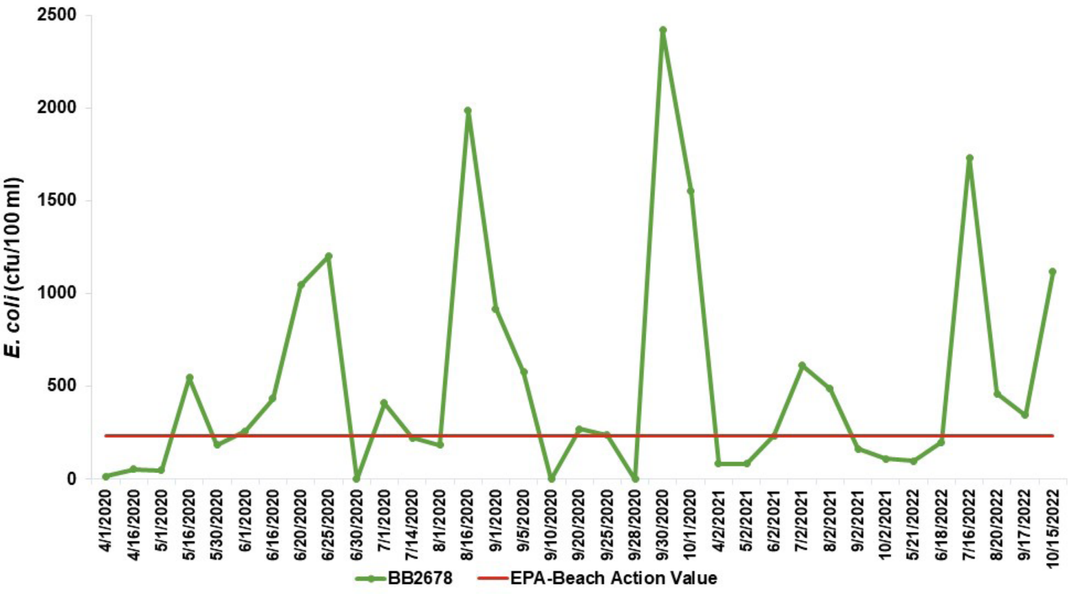


Figure 11. *E. coli* results from Baker Brook in Fitchburg, MA, from 2020 through 2022. EPA - Beach Action Value = the threshold above which water is not considered safe for contact recreation. Note: the 9/30/2020 *E. coli* value was actually > 2419.6 cfu/ 100 ml, but the exact concentration is unknown.

neighborhoods border the Brook's eastern bank for about half of this stretch. Runoff from impervious surfaces can carry human and animal wastes directly into waterways.

SITES TO WATCH

Five other sites experienced intermittent high *E. coli* spikes in 2022, but have less consistent and/or intense histories of *E. coli* contamination. NRWA will closely observe *E. coli* trends and site conditions at these locations in 2023, to determine if the spikes were anomalies or representative of water-quality at each site. We briefly evaluate each "Watch" site below.

Nissitissit River, Pepperell

E. coli levels spiked several times in late summer / early fall of 2022 across two of three sampling sites on the Nissitissit River (NT0418 & NT0082; **Figure 12)**. One spike was during the October "wet" weather sample event; but the other two were during "dry" sample days in August. Both sites were in Pepperell, in the lower half of the subwatershed. Although the Nissitissit flows through two relatively small towns and by some farm fields, it is buffered for about 6.8 of its 9.2-mile length by largely intact forest (i.e., forest that is at least 200-feet wide, on both banks of the river). There are no known pollution discharges or obvious *E. coli* sources. Possible sources include wildlife, failed septic systems, and agricultural runoff. Water levels in the Nissitissit were extremely low due to the drought during the high *E. coli* period. The less water in the system, the more highly concentrated any bacteria will be; thus: the high bacterial levels can be partly attributed to low flow. NRWA will sample for *E. coli* in the Nissitissit with greater frequency in 2023 as part of our swimming-hole water-quality project. Having a more detailed dataset will help us better understand how bacteria levels change over time in this coldwater fishery.

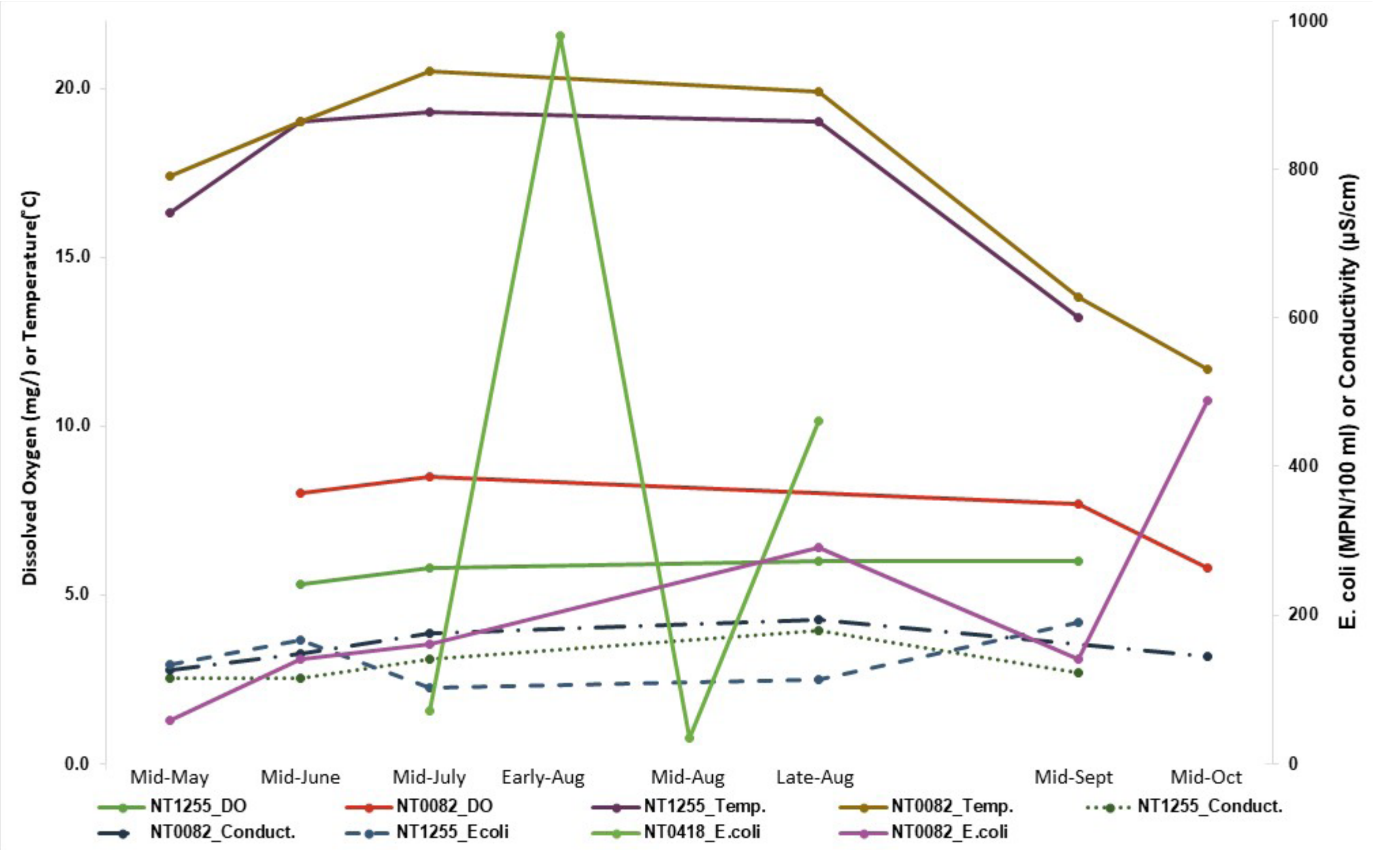


Figure 12. Nissitissit River 2022 sampling results for *E. coli*, conductivity, DO, and water temperature. NT1255 is in Brookline, NH. NT0418 & NT0082 are farther downstream in Pepperell, MA. Though *E. coli* spiked during the summer in Pepperell, the other parameters did not exhibit corresponding spikes.

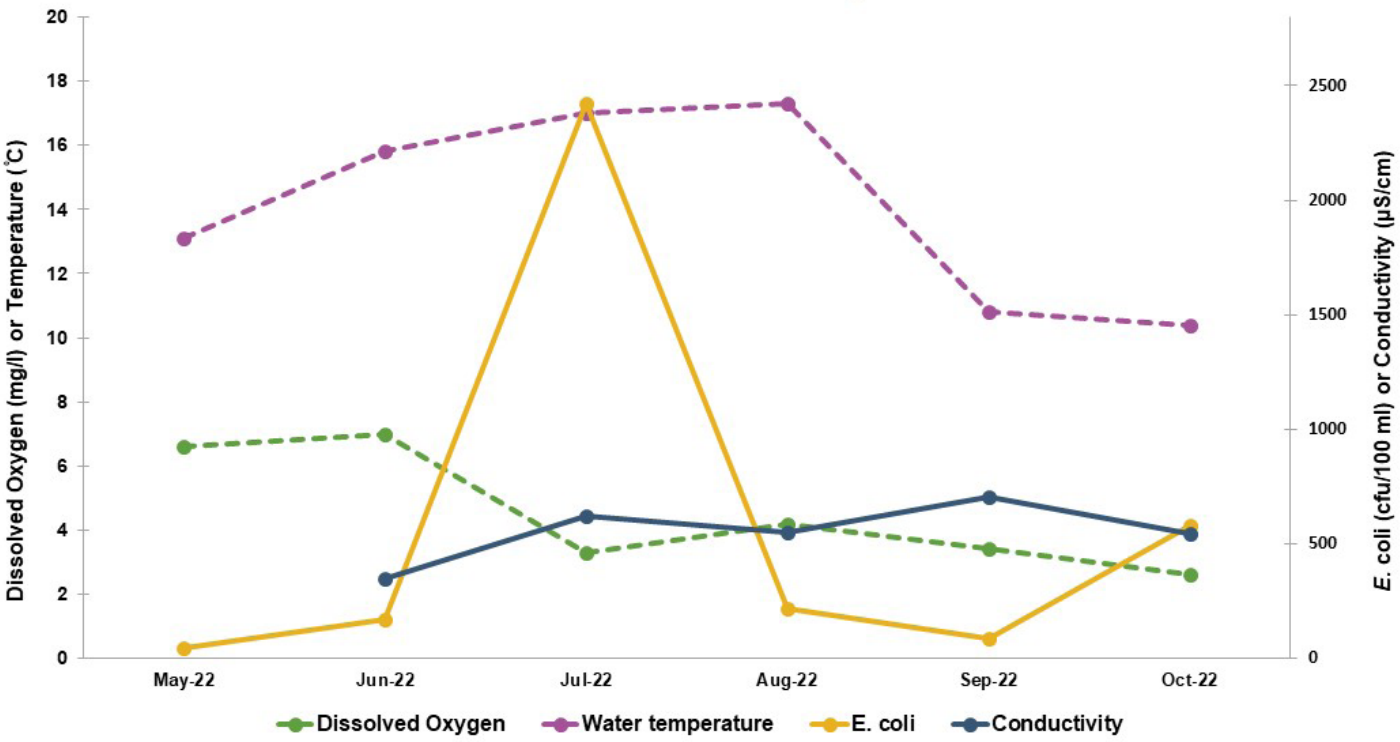


Figure 13. Nod Brook (Groton, MA) water-quality results from routine, monthly monitoring. Nod Brook experienced high *E. coli* and conductivity levels, and low DO in 2022. Note: the July *E. coli* value is actually > 2419.6 cfu/100 ml, but the exact concentration is unknown.

Nod Brook, Groton

In 2022, two of six *E. coli* samples from Nod Brook were unsafe (i.e., > 2419 and 579 cfu/100 ml); both spikes occurred during a wet-sampling event (**Figure 13**). Nod Brook flows largely through a forested section of Groton before entering the Nashua River. As with the Nissitissit, there are no obvious *E. coli* sources, but low water levels, agricultural runoff, wildlife, and/or failed septic systems may be responsible.

James Brook, Groton

James Brook was severely affected by the 2022 drought. The Brook dried completely in its upper reaches by mid-summer, causing our monitors to shift their sampling location further and further downstream as the season progressed. Across the sampled sites, two of five *E. coli* tests were unsafe, with values of 524 and 613 cfu/100 ml, respectively. Both of the *E. coli* spikes in James Brook occurred during wet-weather sampling events, suggesting a build-up of fecal matter that flushed into the system during the storms**.** The Brook is listed as impaired for *E. coli* and DO under the CWA (MA DEP 2021a

A volunteer uses a telescoping pole to reach James Brook in Groton, MA for an *E. coli* water sample. Photo by Janet Sheffield

James Brook flows through downtown Groton, several farms, and a patchwork of residential and wooded areas. To ascertain the potential impact of the farms and the effectiveness of on-farm pollution mitigation, the MA DEP and US EPA are in the midst of a three-year intensive sampling program for James Brook under the USDA's National Water Quality Initiative. NRWA data, in combination with the DEP initiative will help us better understand the dynamics of *E. coli* and other water quality parameters in James Brook in the near future.

Reedy Meadow Brook, Pepperell

E. coli concentrations were close to or above the EPA-BAV threshold for three of six 2022 samples at Reedy Meadow Brook, including one exceptionally high value of 1046.2 cfu/100 ml. Since NRWA started sampling Reedy Meadow Brook in 2019, 15 of 39 samples (i.e., 38%) were > 235 cfu/100 ml. This suggests a pattern of elevated *E. coli* in the Brook that deserves additional investigation. Reedy Meadow Brook flows through a mosaic of forest, wetlands, exurban residential land, and farms before reaching a medium-density subdivision just before the sample site. With such varied land-use, the *E. coli* source could equally well be from house lots, farm fields, or wildlife on undeveloped land. A critical first step in addressing this issue will be to determine if the *E. coli* comes mostly from humans, wildlife, or domestic animals. Another important step will be to determine where along the Brook's length, the *E. coli* problems begin.

Still River Depot Road, Harvard, MA

E. coli concentrations at this site on the Nashua River mainstem (NM6274) were close to or above the EPA-BAV threshold for three of six 2022 samples, including one particularly high value of 1299.7 cfu/100 ml. This is the first mainstem site sampled after the North and South Nashua Rivers converge in Lancaster. The nearest upstream sites, however, typically had lower *E. coli* concentrations than were found at Still River Depot Road. This site is embedded in the Oxbow National Wildlife Refuge and land-use is consequently quite rural for about 3.5 miles upstream from the site. However, multiple agricultural fields are located between the upstream confluence and the sample site. The high *E. coli* may result from agricultural runoff, wildlife, or some other source. If the problem persists, additional sampling will be needed upstream from the site to identify the source(s).

ADDITIONAL COMMENT

Willard Brook, a tributary to the Squannacook River, is listed under the CWA as impaired for *Enterococcus*, an alternative bacteria group used, like *E. coli*, to signal fecal contamination in freshwater streams. This listing is partly due to high fecal bacteria levels obtained by the MA Department of Conservation and Recreation from Damon Pond, an impounded section of Willard Brook in Ashby, MA. Damon Pond has consistently been closed to swimming in recent years, due to unsafe bacteria levels.

NRWA monitors test Willard Brook for *E. coli,* both upstream from, and in, Damon Pond. In 2022, all six upstream samples were below the EPA-BAV of 235 cfu/100 ml. In Damon Pond, only one of six samples exceeded this threshold and was 248.1 cfu/100 ml. These are relatively low contamination numbers for a stream that is listed as impaired for bacterial contamination. However, Damon Pond was closed intermittently to swimming in 2022, so fresh inputs of human fecal matter may have been minimal.

CONDUCTIVITY

Neither the MA Surface Water Quality Standards (MA SWQS) nor the NH Surface Water Quality Regulations (NH SWQR) contain a standard for conductivity. As a loose rule-of-thumb, aquatic life generally thrives, however, where conductivity is less than 500 µS/cm (Mathur 2015; Clements and Kotalik 2016). But conductivity can exceed this threshold due to either natural processes, like weathering of the underlying rocks, or anthropogenic causes, like pollution from WWTPs, septic systems, stormwater runoff, or road salting. In fact, conductivity and chloride from road salts are positively and strongly correlated. Consequently, large parking lots and roads may be key drivers of high conductivity. The MA SWQS and the NH SWQR share the same chloride standard: 860 mg/l for acute exposure and 230 mg/l for chronic exposure.

Overall, conductivity in the Nashua River watershed was quite variable across space and time, and seemed highest in late summer (**Figures 14 and 15**), possibly because streamflow was lowest at this point in the season and salts in the streams are therefore most highly concentrated (Daley et al. 2009; Murphy and Sprague 2019; Chien and Pierce 2018). This reasoning is supported by continuous conductivity data from Fitchburg's Falulah / Baker Brook system (**Figure 16**), which suggests a negative relationship between stream flow and conductivity, possibly indicating that large precipitation pulses dilute and/or flush salts in/from streams.

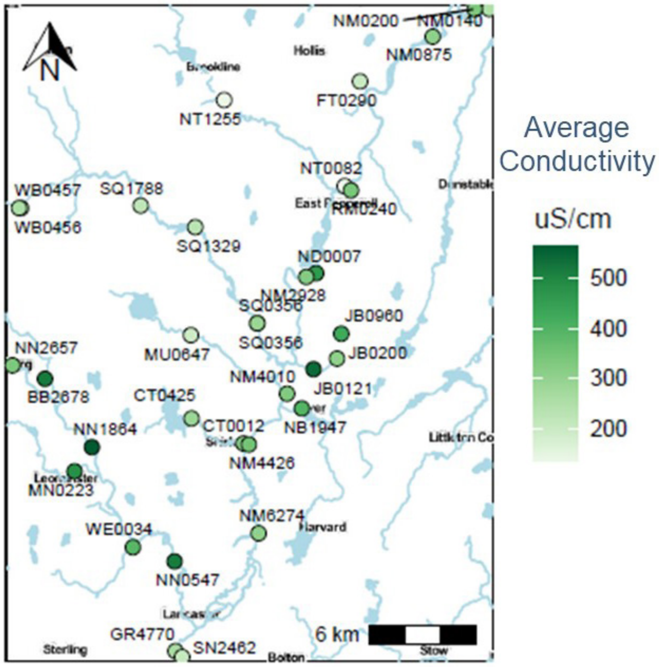


Figure 14. Average 2022 conductivity at each monthly sample site in the Nashua River watershed. Note: Each James Brook (JB) site was sampled only once or twice.

Chloride concentrations, calculated from conductivity using the method developed by MA DEP (MA DEP 2022), were generally safe throughout the watershed in 2022. The average chloride concentration (±1 SD) from routine, monthly monitoring was 87.4 ± 46.6 mg/l; chloride ranged from 17.0 – 251.3 mg/l. One sample exceeded the chronic chloride exposure limit: Nod Brook (ND0007) in September 2022 was 251.3 mg/l. The September sample from Baker Brook (BB2678), which was 226.0 mg/l, almost exceeded the chronic criterion.

For the continuous logger data from Baker and Falulah Brooks in Fitchburg, no chloride values (calculated from the daily mean specific conductance) exceeded the acute or chronic chloride standards. For Baker Brook, the mean chloride concentration (±1 SD) was 93. 5± 28.6 mg/l, and the range was 24.5 – 139.2 mg/l. For Falulah Brook, located upstream from Baker Brook, the mean concentration (±1 SD) was 23.11 ± 3.5, and the range was 16.4 – 31.4 mg/l. Note that the Baker Brook logger was about 1.27 miles downstream from the monthly Baker Brook sample site and that the Brook passes through a large wetland complex between the two sample sites.

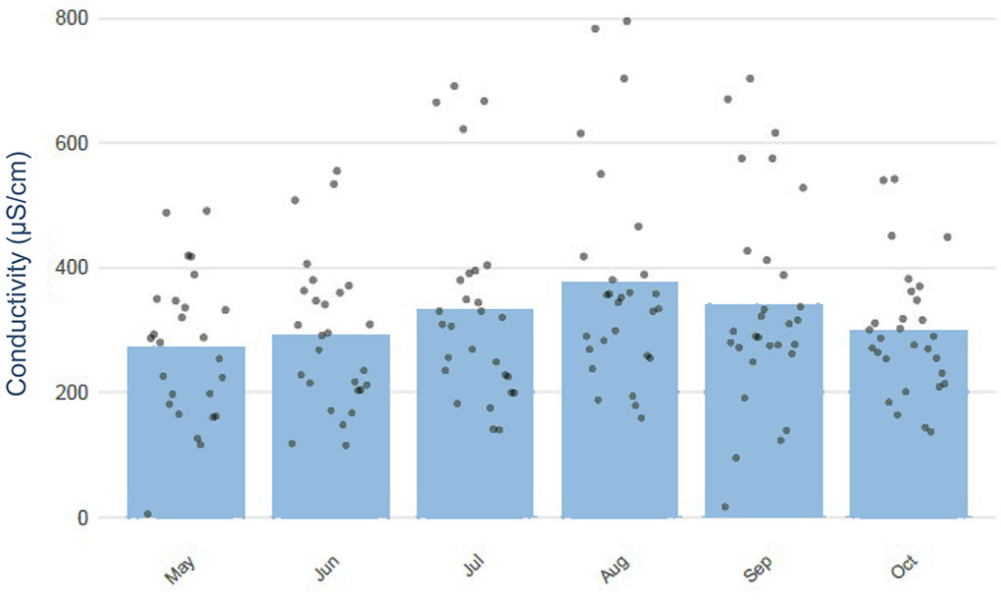


Figure 15. Conductivity at routine, monthly sample sites in the Nashua River watershed, segregated by month.

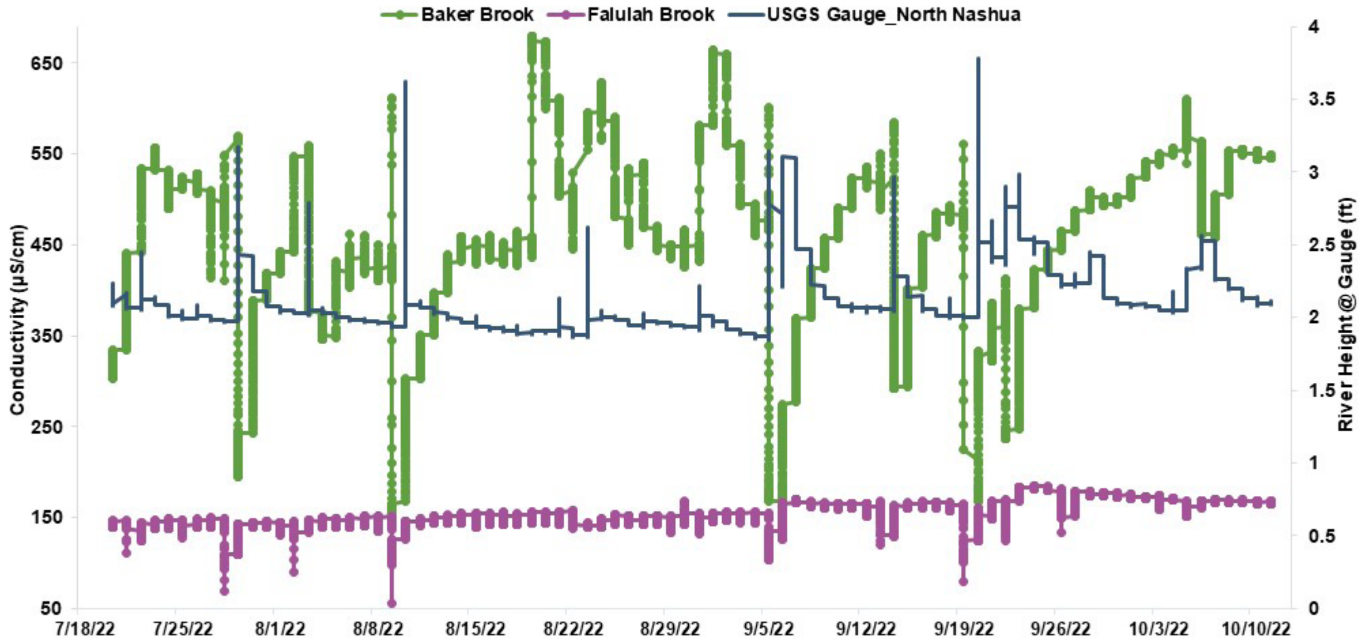


Figure 16. Continuous conductivity at two sites in the North Nashua River subwatershed. Falulah Brook flows into Baker Brook, which discharges to the North Nashua River. Conductivity was recorded every 15 minutes. Water height at the Harvard Street USGS stream gauge (Station #01094400)in the North Nashua River also shown for reference (USGS 2023c).

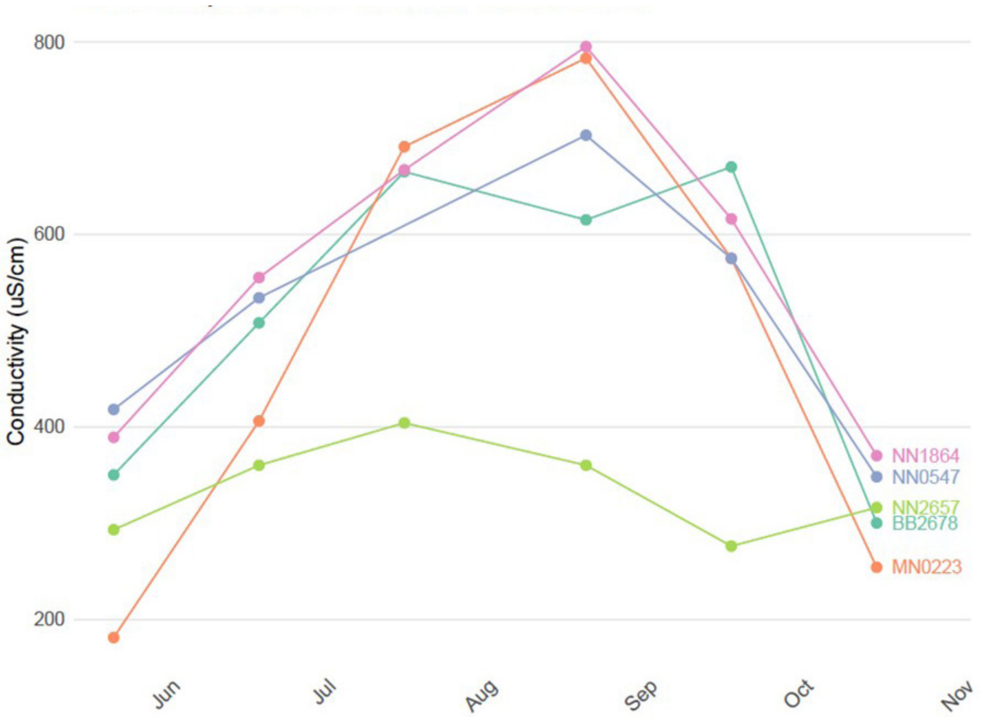


Figure 17. Conductivity at monthly sample sites in the North Nashua River subwatershed in 2022. Upstream to downstream on the North Nashua River, the sites are: NN2657, NN1864, NN0547. MN0223 is on Monoosnoc Brook; BB2678 is on Baker Brook.

AREA OF CONCERN

North Nashua River Subwatershed

Parts of the North Nashua River (Leominster Main Street Bridge and Pellechia in Lancaster) and two of its tributaries (Baker and Monoosnoc Brooks) had elevated conductivity throughout the summer (**Figure 17**). At these four sites over this period, conductivity ranged from 508 - 795 µS/cm. For the North Nashua subwatershed, evidence suggests that the elevated conductivity is due to pollution and not to geologic weathering. Conductivity at two upstream sample locations (Falulah Brook and Riverfront Park [NN2657]) appeared markedly lower than those at their respective downstream locations (Baker Brook [BB2678] and Leominster Main Street Bridge [NN1864]) throughout the summer (**Figures 16 and 17**). Land-use between these up- and downstream locations is urbanized, with extensive networks of roads, parking lots, and other impervious surfaces in close proximity to the river and brooks. In Fitchburg, the WWTP, eight remaining CSOs, and possibly other stormwater conveyances discharge directly into the North Nashua River. These urban land-uses seem to be contributing to the high conductivity found in the North Nashua River, Baker Brook, and probably also Monoosnoc Brook.

SITE TO WATCH

Nod Brook, Groton

Conductivity was above 500 µS/cm during the late summer and fall in Nod Brook (**Figure 13 - page 15**). Calculated chloride in Nod Brook also exceeded the chronic exposure threshold in September, but was below 200 mg/l for the other five 2022 samples. Nod Brook flows through an exurban landscape of woodlands, residences, and some farm fields. It also flows by the old Groton dump, just before entering the Nashua River. It is not clear if the elevated conductivity and chloride resulted from these land uses, underlying geology, or the contents of the old dump. NRWA is working with a local citizens group to more fully investigate the potential impacts of the dump on stream and river water quality.

DISSOLVED OXYGEN

The MA SWQS use 5 mg/l and 6 mg/l of DO as thresholds for warmwater and coldwater fisheries, respectively, meaning that fish adapted to coldwater habitat thrive where DO is > 6 mg/l and other fish flourish where DO is > 5.0 mg/l. Other organisms, like aquatic insects also benefit from DO concentrations above these thresholds. The NH SWQR use 5 mg/l as a minimum DO threshold for waters in our watershed.

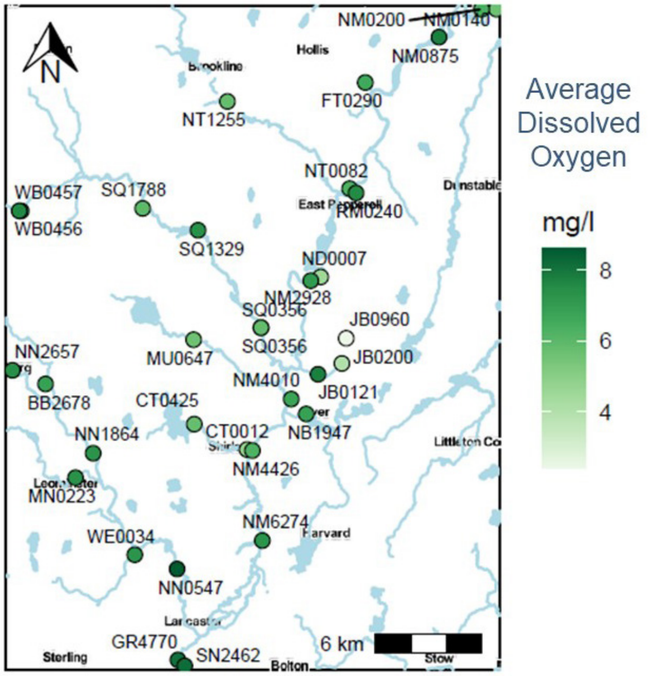


Figure 18. Average 2022 dissolved oxygen concentrations at each monthly sample site in the Nashua River watershed. Sites in the North Nashua River subwatershed include: NN2657, NN1864, NN0547, MN0223, BB2678, and WE0034. Note: Each James Brook (JB) site was sampled only once or twice.

Though a few sites across the watershed had DO levels that were repetitively below the 5 mg/l threshold, DO was surprisingly high in the North Nashua River subwatershed at sites that were otherwise plagued by elevated *E. coli* and conductivity (**Figure 18**). Except as noted below, DO was also generally high in the Nashua Mainstem, with an average DO of 6.8 mg/l and a mode (i.e., the most common result) of 7.5 mg/l. This is positive news for fish in the watershed, since even species that rely on coldwater for parts of their life-cycle benefit immensely from having access to suitable and productive warmwater habitat during the growing season (Armstrong et al. 2021).

Another positive highlight: the Fitchburg and Clinton WWTPs did not seem to negatively impact river DO in 2022. Samples collected just downstream from these plants ranged from 6.5 – 9.4 mg/l, with an average DO of 7.7 mg/l and a mode of 7.0 mg/l.

North Nashua Subwatershed

Even though sample sites in the North Nashua River, Baker Brook, and Monoosnoc Brook all had problematic *E. coli* and conductivity results, DO was above the 6 mg/l coldwater-fishery threshold at all sites in the subwatershed, on all dates, except one (**Figure 19**). The July sample from Riverfront Park in Fitchburg was the exception, but even this sample (i.e., 5.6 mg/l) was above the 5 mg/l warmwater fisheries threshold. This is especially relevant for Baker Brook because this stream is a designated coldwater fish resource. According

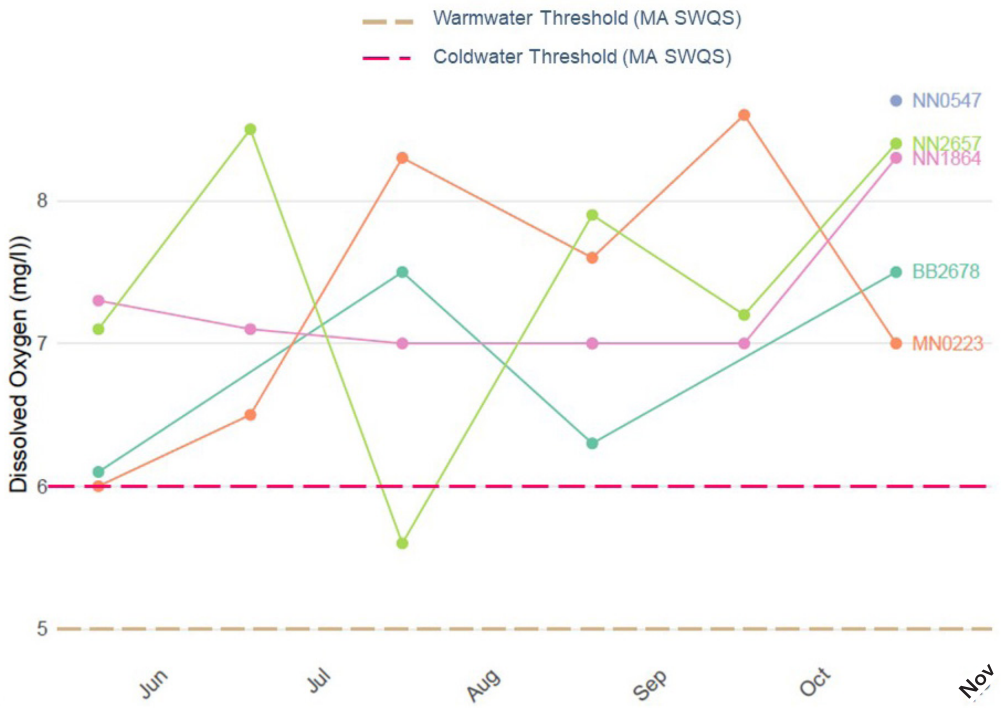


Figure 19. Dissolved oxygen concentrations from routine sample sites in the North Nashua River subwatershed in 2022. Only the July sample from Riverfront Park (NN2675) was below the coldwater fishery threshold.

to MA Wildlife, no coldwater fish were found in Baker Brook during the most recent fish sampling event in 2002 (MA DEP 2021b), but our 2022 data suggest that partial conditions may exist for the Brook to serve as suitable habitat for these species. Further, Baker Brook is fed by Pearl Hill and Falulah Brooks, two streams that originate in forested landscapes and flow mostly through forest and low-density residential land-use before reaching Baker Brook. The headwaters of Falulah Brook are specifically conserved to protect surface water quality (albeit for drinking water reservoirs). Thus, water entering Baker Brook at its upstream limits is expected to be of relatively high quality. Mitigating the impact of the impervious surfaces adjacent to Baker Brook's western bank could potentially have an enormous impact on water quality in the Brook.

COLDWATER FISHERIES

Coldwater fish resources (CFRs) are streams and rivers in which reproducing coldwater fish specialist species have been found. These are sensitive habitats, whose cold waters should contain high DO levels (i.e., > 6.0 mg/l). (The term CFR is a regulatory term in MA (under 310 CMR 5.00); NH uses the term "coldwater fishery" in a non-regulatory sense. For simplicity, we refer to coldwater fisheries in this report as CFRs). Heading west from the Atlantic Ocean, the Nashua River watershed is the first major watershed to contain a dense network of CFRs, due greatly to the large tracts of intact forest that are still found in our watershed. In general, the 2022 DO samples obtained from CFRs in the Nashua River watershed were indeed > 6.0 mg/l (**Figure 20**). Encouragingly, this included Flint Brook in Hollis, NH, which is listed under the CWA as impaired for DO (NH DES 2022f). Flint Brook is managed by the NH Fish and Game as a Wild Trout Fishery catch and release stream. (https://www.wildlife.state.nh.us/fishing/trout-mgt.html)

As expected, however, samples taken from in, or just downstream from, dam impoundments on CFR streams often had DO concentrations below the cold- (and sometimes warm-) water fishery thresholds (e.g., Mulpus Brook - MU0647; Squannacook River - SQ0356). Samples from two additional CFR streams, not drawn from impoundments, also had DO levels repeatedly below the coldwater threshold in 2022: *Catecunemaug Brook* in Shirley, MA and the *Nissitissit River* in Brookline, NH and Pepperell, MA.

The affected stretch of the Catecunemaug runs from the Lake Shirley dam to the Nashua River. Of the nine DO samples taken from its two sites in 2022, five were < 6.0 mg/l; of these, two samples had DO concentrations of 3.7 mg/l. These low DO values were not anomalies: the Catecunemaug is designated as impaired under the CWA for DO and is described as Not Supporting Aquatic Life due in part to previous

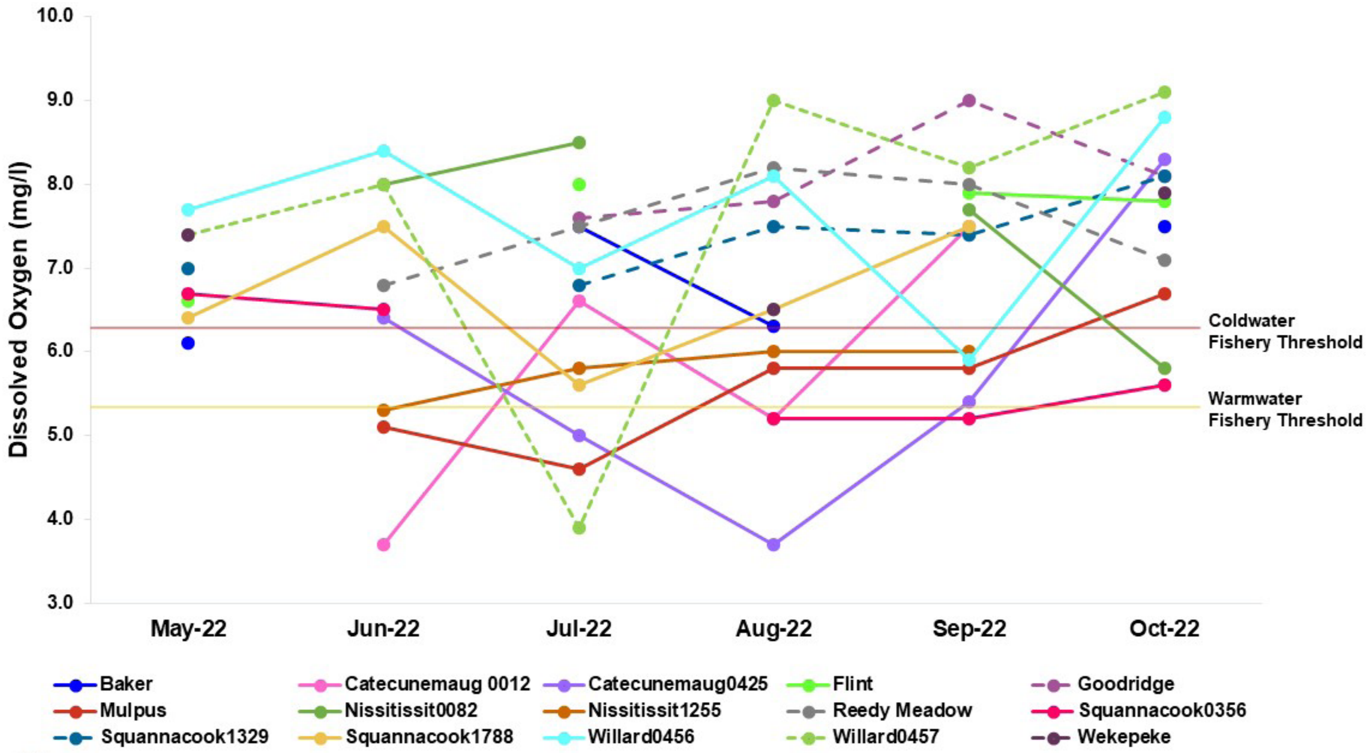


Figure 20. Dissolved oxygen concentrations at Coldwater Fish Resource streams in the Nashua River watershed in 2022. Coldwater-adapted fish species thrive in water with DO > 6.0 mg/l. Aquatic life is generally not supported where DO < 5.0 mg/l.

low DO measurements (MA DEP 2021a, b). NRWA has recorded DO values in this stretch of the stream as low as 2.6 -3.8 mg/l on multiple occasions since 2008.

Three of nine DO samples from the Nissitissit River were slightly lower than the coldwater threshold. Two from a site near Bohannon Bridge Road, just outside of Brookline's town center (NT1255), had DO values of 5.3 and 5.8 mg/l, respectively. One from farther downstream, just above the convergence with the Nashua River in Pepperell (NT0082), had a value of 5.8 mg/l. NRWA similarly recorded occasionally low DO values from the Nissitissit River from 2015 through 2019. (DO was not tested in 2020-2021). Two values were quite low (i.e., 2.6 and 3.4 mg/l), but the other three were moderately low: 5.4, 5.8, and 5.8 mg/l. The DEP uses a Nissitissit River site in Pepperell as a reference for high-quality habitat for benthic macroinvertebrates. Though occasionally low DO values are not overly concerning, it is important to continue tracking this parameter, to maintain habitat quality for fish, insects, and other aquatic life.

Typically, low DO in streams is caused by one or more of the following conditions: water is stagnant (i.e., not aerated via physical mixing); abundant nutrients cause plant blooms, which eventually die and decompose (with decomposition using much of the remaining DO); few aquatic plants are present to produce oxygen; or water temperatures are high (warm water retains less oxygen than cold water). For both the Catecunemaug and Nissitissit, further investigation is needed to understand why these streams experience low DO. As noted in a later section, however, both streams regularly experience high water temperatures.

OTHER SITES TO WATCH

James Brook, Groton

James Brook dried very early in the 2022 season and water levels were relatively low throughout the season, concentrating pollutants and creating conditions unfavorable to aquatic life. This was reflected in the summer DO samples for James Brook, which were 2.4 and 4.0 mg/l for June and July (no sample was taken in August due to the drought). These low DO values continue a longer-term trend of low DO in the upper James Brook subwatershed, which flows through farms and downtown Groton. In fact, James Brook is already listed as impaired for DO (MA DEP 2021a).

Nod Brook, Groton

From July through October, Nod Brook had DO concentrations < 5 mg/l (**Figure 13 - page 15**). NRWA tested DO at Nod Brook during one previous year: 2019. In 2019, DO was 3.9 mg/l in July, but otherwise above the 5.0 mg/l warmwater threshold. The low DO levels from 2022 and 2019 are concerning. In 2023, NRWA will closely monitor DO in Nod Brook to accumulate longer-term data on the Brook and determine if this is a persistent pattern.

Nashua River Mainstem: Main Street, Nashua

In June and July 2022, DO sampled at the Main Street Bridge in Nashua, NH (NM0140) was 2.9 and 3.5 mg/l, respectively, which is well below the warmwater fishery threshold of 5.0 mg/l. For the previous five years for which we have data (2014-2018), DO at this site was below 5.0 mg/l only once (out of 33 samples), in July 2017, when the value was 4.7 mg/l. The sample site is located in the impoundment of the Jackson Mills dam, so low DO values are somewhat expected. (Water in the impoundment is relatively still, allowing it to warm; warm water holds less oxygen than cold water).

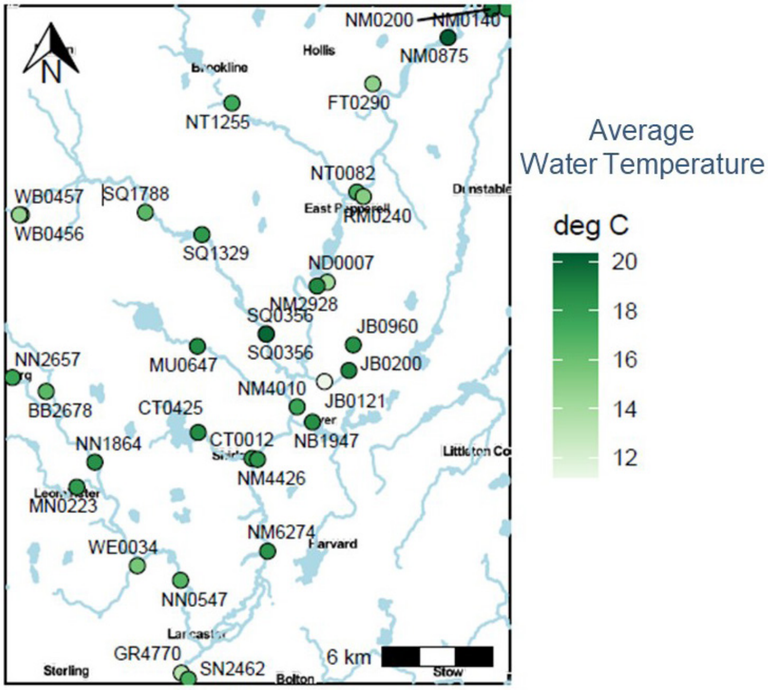


Figure 21. Average 2022 water-temperature readings at each monthly sample site in the Nashua River watershed. Note: Each James Brook (JB) site was sampled only once or twice.

A volunteer tests temperature and conductivity at Flint Brook in Hollis, NH. Flint Brook is a coldwater fishery that drains directly into the Nashua River. Photo by Denise White

WATER TEMPERATURE

The MA SWQS thresholds for water temperature are < 20 ⁰C and < 28.3 ⁰C for cold- and warm-water fisheries, respectively. Temperatures exceeding these thresholds are considered to be detrimental to aquatic life adapted to, respectively, cold- and warm-water habitats. NH has no specific numeric standard for temperature.

In 2022, all of NRWA's water-temperature readings were < 28.3 ⁰C, including in the Nashua River mainstem (**Figure 21**). For five of ten CFRs tested, temperature readings were consistently colder than the 20 ⁰C coldwater-fishery threshold (**Figure 22 - page 23**). These sufficiently cold CFRs were: Baker Brook (Fitchburg, MA), Flint Brook (Hollis, NH), Goodridge Brook (Clinton, MA), Reedy Meadow Brook (Pepperell, MA), and Wekepeke Brook (Lancaster, MA) . Interestingly, Wekepeke Brook is categorized as impaired due to temperature under the CWA (MA DEP 2021a).

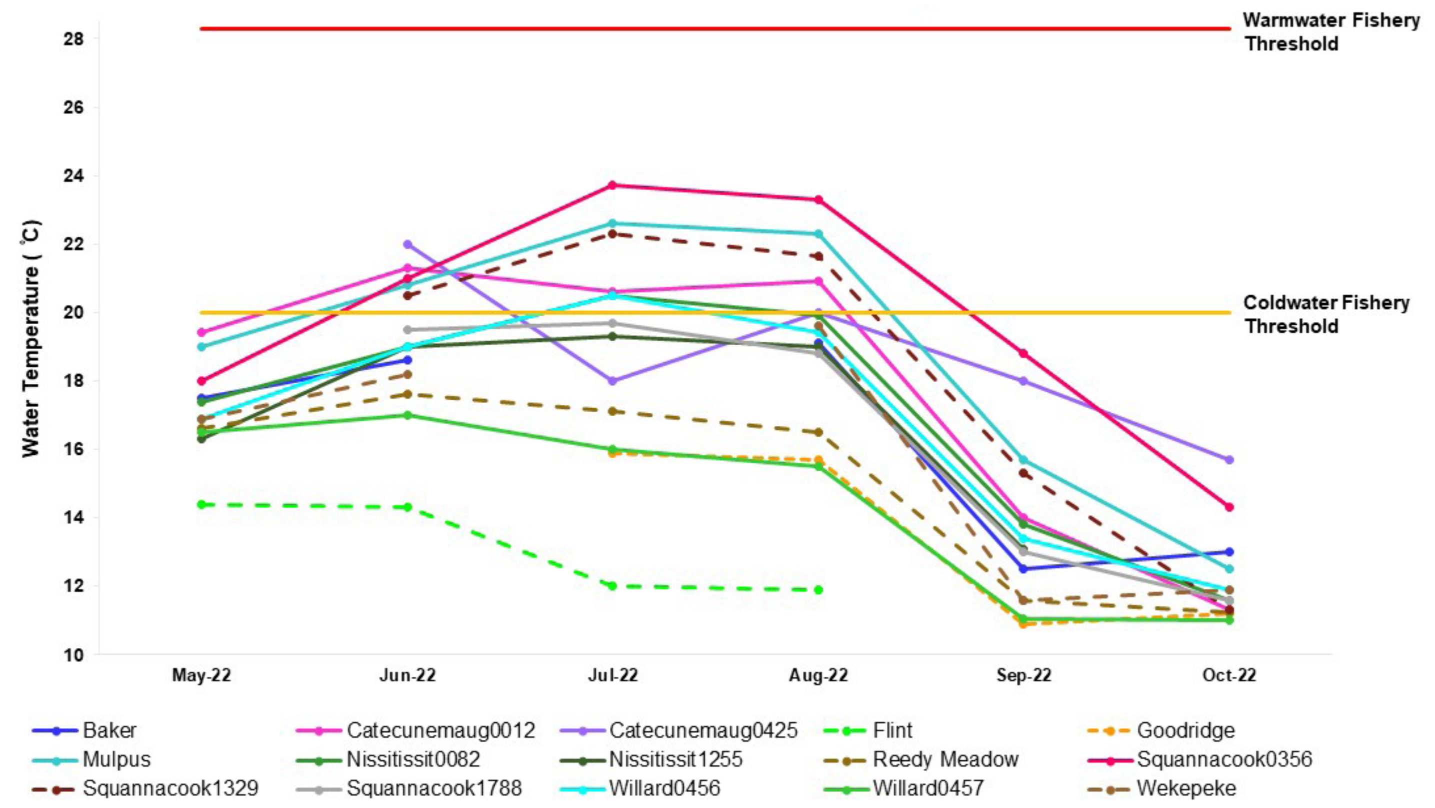


Figure 22. Water temperature at Coldwater Fish Resource streams in the Nashua River watershed in 2022. Coldwater-adapted fish thrive in waters with temperatures below 20 ^{0}C.

After the Bartlett Pond dam was removed from Wekepeke Brook in 2014, just upstream from our sample site, NRWA expected to see water temperatures decrease in the Brook in subsequent years. But temperatures downstream from the former dam have yet to demonstrate a clear, persistent response to dam removal. NRWA data from 2015 to 2022 indicate that summer water temperatures have topped out at about 21.5 ^{0}C for three of these eight years. In 2021, NRWA planted 110 willow seedlings adjacent to Wekepeke Brook in the former Bartlett Pond. Ideally, as these seedlings grow, they will shade the Brook and help reduce water temperatures in this CFR.

The other five CFRs had summer water temperatures between 20 and 28.3 ^{0}C. For two of these (i.e., Nissitissit River and Willard Brook), one of twelve readings each was slightly elevated, to 20.5 ^{0}C. The single, elevated temperature reading from Willard Brook was measured in Damon Pond, a dam impoundment, so it is not representative of flowing water temperatures in Willard Brook. All of the temperature readings from the flowing portion of Willard Brook were < 20 ^{0}C.

The Nissitissit, but not Willard Brook, is listed as impaired for temperature under the CWA (MA DEP 2021a). For the Nissitissit, the impairment decision was made primarily based on temperature data taken from below the Millie Turner Dam, before the dam was removed in 2015. Nevertheless, NRWA data from 2016 to 2022, show that summer water temperatures along the length of the Nissitissit regularly exceeded 20 ^{0}C during our monthly water monitoring. For each of these years, the maximum temperature NRWA recorded ranged from 19.0 to 23.8 ^{0}C.

At the remaining three CFRs (Catecunemaug Brook, Mulpus Brook, and Squannacook River), water temperatures were consistently above 20 ^{0}C during the summer. (Except for readings taken at the most upstream and unimpounded site on the Squannacook [SQ1788], where temperatures ranged from 11.6-19.7 ^{0}C in 2022). Otherwise, for all three streams, the elevated temperatures were obtained either within a dam impoundment or just downstream from one, where water temperatures are expected to be higher, compared to unimpeded river stretches (Zaidel 2021).

Nevertheless, all three are listed as impaired for temperature under the CWA (MA DEP 2021a). NRWA currently has continuous temperature loggers monitoring water temperature in free-flowing sections of Mulpus Brook, and the Nissitissit and Squannacook Rivers, among other streams. These data will help us better understand temperature fluctuations in the CFRs.

MANAGEMENT IMPLICATIONS

POSITIVE NEWS

The 2022 water-monitoring data provides reasons to celebrate, especially when viewed against the backdrop of the historical, polluted conditions in the Nashua River watershed. From Ayer through the City of Nashua, the Nashua River mainstem (where we sampled) had *E. coli,* conductivity, DO, and temperature conditions that were generally safe for human recreation and conducive to warm-water-adapted aquatic life. (Low DO in the dam impoundment at the Main Street Bridge in Nashua, NH was an exception).

Despite the severe drought, five of the ten Coldwater Fish Resource streams sampled had DO and temperature levels consistently within the range favorable to coldwater fish species. These included Baker Brook (Fitchburg, MA), Flint Brook (Hollis, NH), Goodridge Brook (Clinton, MA), Reedy Meadow Brook (Pepperell, MA), and Wekepeke Brook (Lancaster, MA). We discuss Baker Brook, which flows beside the largely impervious strip malls of the John Fitch Highway, separately below.

Flint, Goodridge, and Reedy Meadow Brooks are situated in exurban landscapes, where residential-development pressure has been high in recent years. To maintain the high-quality fishery habitat in these Brooks, land conservation and restoration, especially in the greenways along the Brooks, is critical. Equally important, any development that occurs in these subwatersheds should be designed using Low Impact Development principles and emphasize green infrastructure.

Though Reedy Meadow Brook had excellent DO and temperature levels, it also had unsafe *E. coli* concentrations during part of the growing season. In recent history, NRWA has only sampled Reedy Meadow Brook since 2019, so it is difficult to ascertain the extent of the *E. coli* problem. Additional sampling is needed. Upstream land-use may be implicated: the Brook flows through a number of farm fields and some residential neighborhoods before reaching the sample site. The *E. coli* source could be from animals or humans and from anywhere upstream; important first steps in resolving the issue will be to identify the host species and isolate the problematic area(s).

Because Wekepeke Brook has a history of impairment due to high water temperatures, we view this year of lower water temperatures (11.6 - 19.6 ⁰C) and higher DO (6.5 - 7.9 mg/l), as a positive step, which will ideally be continued in future years. Much of Wekepeke Brook flows through forest, but parts of it and its tributaries flow through commercial and residential sites and/or are impounded by small dams. The subwatershed deserves additional examination, with an eye to identifying sites where restoration or nature-based solutions for stormwater would be appropriate and could be used to further improve habitat quality in this CFR.

CRITICAL FOCUS AREAS

Monoosnoc Brook, Leominster

E. coli levels in Monoosnoc Brook near Water Street have been strikingly high for over 16 years. We know, based on DNA testing that NRWA conducted in 2014, that the bacteria derive from humans, not wildlife. There is also strong evidence suggesting that a leaky sewer pipe in this neighborhood is the source of the *E. coli*. This source needs to be definitively pinpointed and repaired.

Baker Brook, Fitchburg

Baker Brook is a Coldwater Fish Resource that did not, as of 2002, contain any reproducing coldwater-adapted fish (MA DEP 2021b). Baker Brook is listed under the CWA as impaired for *E. coli*, but not for DO or water temperature (MA DEP 2021a). Our 2022 water-monitoring data supports this categorization:

E. coli (and conductivity) levels in Baker Brook were quite high, while DO and temperature were within the ranges appropriate for a CFR. Unlike other places in Fitchburg, Baker Brook does not have any WWTPs or CSOs that discharge directly into the stream. While some *E. coli* may originate from unknown illicit discharges or leaky sewer pipes, runoff from the massive areas of impervious surface close to the Brook must also be a source of both *E. coli* and the high salt concentrations indicated by the elevated conductivity.

Baker Brook is fed by water that flows out of three drinking water reservoirs and through forested and relatively low-density exurban land before reaching the built-out parts of Fitchburg. In other words, presumably high-quality water enters Baker Brook from Falulah Brook only about two miles upstream from our sample site. This, in conjunction with the undeveloped, approximately half-mile-long, Laurel Bank Conservation Area along Baker Brook's eastern bank likely explains why DO and temperature remained within the range suitable for coldwater fish in 2022.

Because of these positive water-quality and landscape-context indicators, Baker Brook represents a great opportunity for stream restoration. To realize this opportunity, a first step would be additional water testing to confirm whether the elevated *E. coli* and conductivity values are from point or non-point sources. Second, DNA testing would confirm if the *E. coli* is from humans or wildlife. Finally, in cooperation with landowners and the City, suitable impervious sites along the Brook's western bank could be identified for de-paving and installation of green infrastructure to better retain and filter stormwater that contains salts, *E. coli*, and other pollutants known to run off from parking lots and roads (e.g., nickel, chromium, copper, zinc, petroleum hydrocarbons). Similarly, appropriate sites could be targeted for greenway restoration along the Brook.

North Nashua River, Fitchburg & Leominster

For *E. coli* and conductivity, the North Nashua River (in addition to Baker Brook and Monoosnoc Brook, which are in the North Nashua subwatershed) was essentially the hottest spot sampled in the watershed. Certainly, the eight remaining CSOs and the WWTP in Fitchburg contribute to the unsafe *E. coli* levels. The City of Fitchburg has legally agreed to disconnect the remaining CSOs by 2030, which will improve water quality in the North Nashua. Baker Brook itself, which discharges into the North Nashua just upstream from the Fitchburg WWTP and our sample site at the Leominster Main Street bridge, also contributes to the high *E. coli* and conductivity levels in the North Nashua. It is highly likely that these are not the only sources of salts and bacteria in the North Nashua, however. Runoff from impervious surfaces in the urban cities of Fitchburg and Leominster (and elsewhere upstream) likely carries these and other pollutants into the North Nashua, though illicit discharges are also possible. Just as with Baker Brook, therefore, any restorative actions that can be taken to replace impervious surfaces near the River with green spaces should help to "slow the flow" of runoff, filter out pollutants, and provide shade in and near the River. These changes would help to both improve water quality and reduce flooding in the North Nashua.

Catecunemaug Brook, Shirley

The portion of Catecunemaug Brook that runs from the Lake-Shirley outlet to its confluence with the Nashua River, is a relatively short (2.7 mile) stretch of Brook in close proximity to downtown Shirley. But this stretch retains a wildness that provides good fishing, boating, and wildlife-viewing opportunities, with relatively easy access for people in Shirley, Devens, and Ayer. Despite this wildness and designation as a Coldwater Fish Resource, Catecunemaug Brook is listed as Not Supporting Aquatic Life because of DO and temperature impairments and a lack of reproducing coldwater fish.

At least part of the temperature and DO impairment in Catecunemaug Brook can be explained by the presence of two dams, one at Lake Shirley's outlet and the other at Phoenix Pond. Water in dam impoundments is more stagnant than in a flowing stream, which allows the sun to heat the water to higher temperatures. When this warm water eventually flows downstream, it retains that heat for an average of 0.8 miles beyond the dam (Zaidel et al. 2021). Since oxygen evaporates out of warm water

A volunteer uses a hand-held meter to test temperature and conductivity in Catecunemaug Brook just downstream from the Lake Shirley Dam in Shirley, MA. Photo by Gaynor Bigelbach

The Squannacook River in Townsend, MA. The two photos are taken at the same location, approximately one month apart. The top photo is from July; the bottom from June. Water levels in the Squannacook fell throughout the summer and early fall, due to the critical drought in 2022. Photo by Rob Templeton

faster than cold water, impoundments also are associated with lower DO. To improve DO and temperature conditions in this CFR, a holistic assessment of potential options for mitigating the effects of these two dams could be undertaken. Alternative mitigation strategies could range from better regulating releases from a dam so as to better mimic natural, seasonal flow patterns; to partial or complete dam removal. Any such assessment would need to be conducted in full collaboration with the dam owner and consultation with abutters.

Squannacook and Nissitissit Rivers (Townsend, MA; Pepperell, MA & Brookline & Hollis, NH)

The Squannacook and Nissitissit Rivers are designated as federal Wild and Scenic Rivers. This designation is assigned to rivers with exceptional natural, cultural, and recreational values. Both of these rivers are also designated as Coldwater Fish Resources, but neither currently hosts a reproducing population of coldwater fish, likely related to acute and chronic high temperatures in both rivers (an observation supported by our 2022 water-monitoring data). The Nissitissit River also experienced repeated spikes of *E. coli* in 2022.

To combat the high temperatures in both rivers, especially in the face of climate change and the increasing development pressures in the exurban communities through which these rivers run, it is critical that the rivers' greenways be maintained and even expanded. Mature trees and shrubs buffering the rivers will shade their waters, slow the rate of overland stormwater flow (allowing runoff to cool before reaching the river), filter out additional pollutants (like *E. coli*), and allow for groundwater recharge (which is an important source of cool water to both rivers in certain locations).

The Squannacook River also has several dams which, as our monitoring data show, are associated with warmer water temperatures. As with the Catecunemaug, a holistic assessment of mitigation options for these dams would be useful in the Squannacook subwatershed.

For the Nissitissit River, additional investigations are needed to determine why *E. coli* was spiking in 2022 and whether this was an anomaly or an on-going problem. The first step will be to collect and analyze *E. coli* samples along the length of the river and more frequently in time, to pinpoint the specific spatial and seasonal stretches where *E. coli* is spiking. DNA testing to determine if the *E. coli* derives from humans, domestic animals, or wildlife is also needed. Once the source is identified, additional steps can be taken to ameliorate the problem.

Nod Brook and James Brook, Groton

Both Nod Brook and James Brook in Groton, MA are relatively short streams that had multiple water-quality problems in 2022. Both streams had unsafe *E. coli* spikes, low DO, and relatively high conductivity. Whereas James Brook flows through downtown Groton and farm fields, Nod Brook flows through a more rural part of Groton, including through residential, forested, and a small area of agricultural land. Nod Brook also flows by the old town dump, right before it converges with the Nashua River. Whereas the upper portion of James Brook dried up early in 2022 and remained dry, Nod Brook flowed throughout the drought. Both streams warrant additional consideration, but with tailored approaches.

James Brook would likely benefit enormously from restoration of a wider wooded buffer in the agricultural fields through which it flows and additional nature-based solutions to stormwater flows in downtown Groton (e.g., daylighting the Brook, a parking-lot rain garden). To some extent, this would also help with the known flooding problems on Broadmeadow Road. This could also help offset problems arising from the Brook being confined to a straight, apparently ditched channel through much of its upper reaches. Where streams flow through straight ditch-like channels, they experience less turbulence and thus lower DO, than free-ranging channels with meanders, riffles, and rocky waterfalls.

For Nod Brook, there are no obvious solutions to the water-quality problems it experienced in 2022; nor has it yet been determined if these problems extend beyond 2022. The old town dump is the only known suspected source. Additional observation and perhaps testing are needed to determine the extent (in space and time) and/or source of the problems.

FINAL WORDS

In 2022, NRWA staff and volunteers collected data from 877 individual samples of surface water in the Nashua River watershed (excluding continuous-logger data). This is a huge accomplishment and provides extremely useful insight into the status of our waterways. Nevertheless, this data represents only a portion of the streams and river segments in the watershed. And the work of addressing the problems identified in this annual report is only just beginning. The NRWA depends on supporters like you to watch over and care for all of the streams in the watershed; to be our eyes and ears, informing us of potential issues; and to spread the word about the important work we are all doing to protect and restore the watershed. Thank you for that support.

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