Charles River Watershed Association

Flagging Program Results 2022

Overview of Flagging Program

Charles River Watershed Association's (CRWA) Flagging Program is designed to provide up-to-date water quality information to boaters in the Lower Charles River. In 2022, CRWA monitored water quality by using notifications of combined sewer overflows, cyanobacteria bloom advisories, and model predictions of *E. coli* concentrations to determine if the river was boatable at a given point in time. Eleven boathouses in the Charles River Lower Basin participated in the program by flying blue flags on days the river was boatable, and red flags on days the river was unlikely to meet water quality standards for boating.

Weekly water samples were taken at each reach to record the actual *E. coli* concentrations and determine the accuracy of the model predictions. Results from the water samples are recorded with antecedent rainfall. As in past years, a positive correlation between rainfall amount and *E. coli* concentration was observed this year. This season, however, had less rainfall than normal and the Charles River watershed was in drought conditions, receiving 11.89 inches of rain from May to the end of October. Therefore, the majority of red flags flown this season were due to a cyanobacteria bloom advisory that lasted over 3 weeks in one reach, and elevated bacteria levels due to increased levels of stormwater runoff into the Charles.

Public Notification

Flags were flown at 11 boathouses this season (Figure 1). These boathouses resided in 4 different reaches, labeled Reach 2 through Reach 5. All of these boathouses participated throughout the entire season. Flag colors were communicated via email, CRWA's flagging website, and through Twitter. Statistical models are used for the four reaches of the Charles River Lower Basin, which line up with the sample sites (1NBS, 2LARZ, 3BU, and 4LONG). If the statistical model predicted that there was greater than a 65% chance that water quality will exceed 630 cfu/100mL, then a red flag was flown. If the statistical model predicted a less than 65% chance that the water quality will exceed 630 cfu/100mL , then a blue flag was flown. Between May 2nd and October 23rd, the models predicted red flags for a total of 12 days. The website was updated daily to represent any changes in flag color.

Red flags were flown at all boathouses due to combined sewer overflows (CSO) on two occasions throughout the season. Due to Massachusetts Department of Public Health recommendations, red flags are flown at all locations for 48 hours following a CSO. Red flags were flown at Reach 5 boathouses due to a cyanobacteria bloom advisory on one occasion during the Flagging Program season.

CRWA Public Notification Program & Sampling Locations

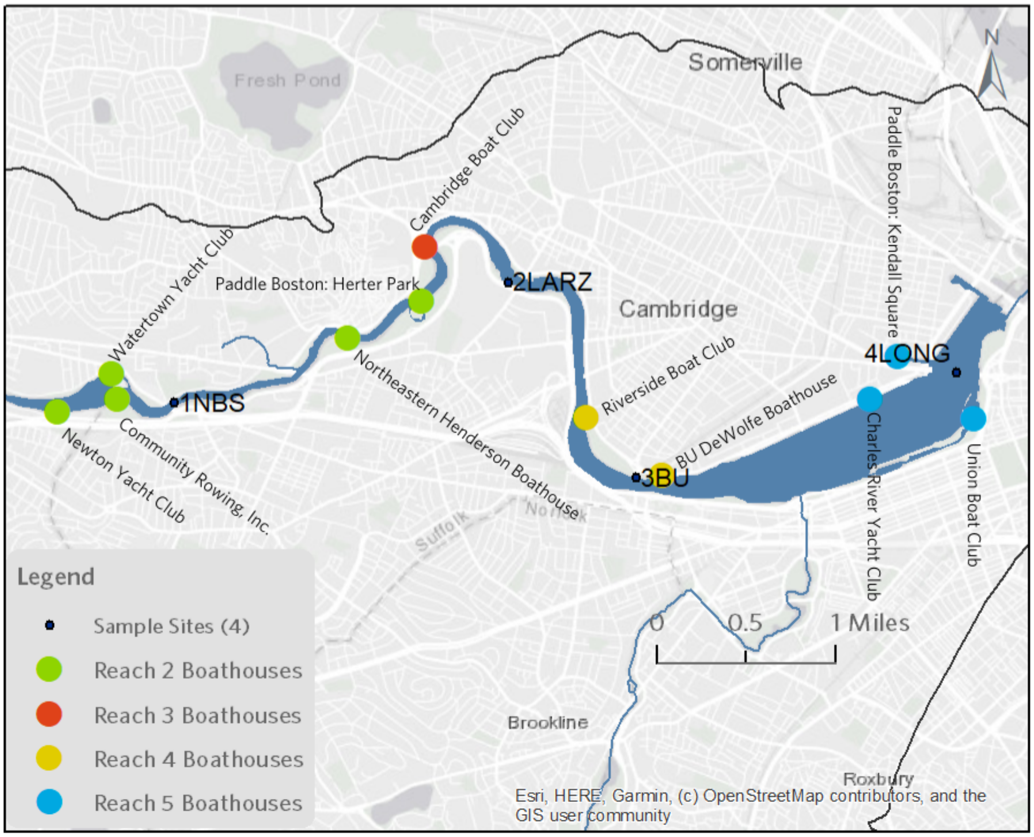

Figure 1. Map of sampling locations and participating boathouses in the Charles River Lower Basin.

In an effort to raise awareness and continue effective communication of the program, we updated and translated our program fact sheet for the four most common languages in the Charles River watershed: Chinese, Creole, Portuguese, and Spanish. Additionally, after receiving feedback from partner boathouses last year, we purchased and distributed smaller (2'x3') red and blue flags.

Flags Flown

The majority of the Flagging season was safe for boating on the Lower Charles, with blue flags flown between 86% and 92% of the time, depending on the location (Figure 2). Reach 5 boathouses had the most red flags flown (14%), all of which were due to the 3-week long cyanobacteria bloom in June and July. The majority of red flags for the other reaches were due to precipitation events.

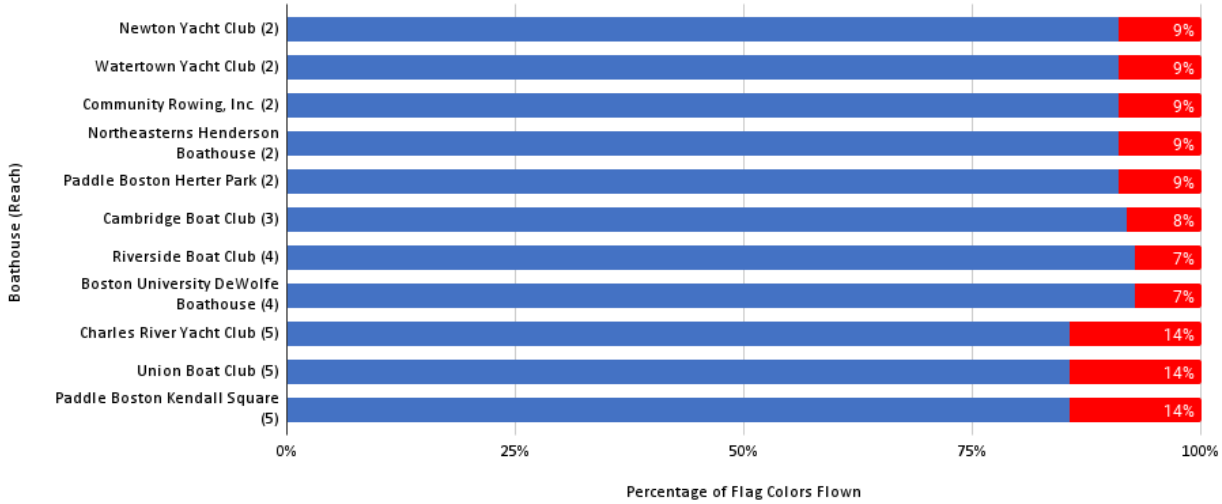

Figure 2. Percentage of red and blue flags flown at each boathouse from May 2 to October 23. Blue represents the percentage of days a blue flag was flown at each boathouse. Red represents the rest of the percentages of days where a red flag was flown either due to model predictions, combined sewer overflows, a cyanobacteria bloom, or a combination of factors.

CSOs

Red flags were flown at all boathouses due to combined sewer overflows (CSOs) on two separate occasions, June 27th and October 14th. A total of 410,000 gallons of sewage was discharged into the Charles River from CSO location CAM005, which discharges downstream of the Eliot Bridge across from Mount Auburn Hospital. This is comparable to 2020 where the Charles River watershed was in drought conditions and had only two CSOs. Due to Massachusetts Department of Public Health recommendations, red flags are flown at all locations for 48 hours following a CSO. We monitor for CSOs using three different websites, checking the Cambridge CSO page, the Boston Water and Sewer Commission (BWSC), and the Massachusetts Water Resource Authority (MWRA).

Sampling Results

CRWA conducted weekly sampling of the Charles River between May 5th and October 13th. Sampling protocol included recording water temperature and depth as well as collecting water samples at four sites. The water samples were delivered to G&L Laboratory in Quincy to be analyzed for *E. coli* concentrations. On each date, samples were collected manually from a boat at the center of the channel and upstream of the bridge at North Beacon Street Bridge (1NBS), Larz Anderson Memorial Bridge (2LARZ), Boston University Bridge (3BU), and Longfellow Bridge (4LONG) (Figure 1).

About 11% of all samples collected were duplicated to ensure quality standards. The field duplicates were then evaluated using CRWA's data quality objectives (DQOs): An *E. coli* sample meets DQOs when the relative percent difference between a sample and its duplicate is below 100%, or if the results were within 100 cfu/mL of each other. All of the field duplicates this season met CRWA's DQOs.

2022 Sampling Results
There were 22 sampling events between May 5th and October 13th. Excluding field duplicates, a total of 88 samples were collected and used in this analysis.

Effective January 2022, there are new Massachusetts Surface Water Quality Standards for primary and secondary contact recreation. Water meets the standard for Primary Contact if the geometric mean *E. coli* concentration of all samples collected within a 90-day period is below 126 cfu/100 mL and no more than 10% of the samples exceed the statistical threshold value (STV) of 410 cfu/100 mL. Our flagging program runs for about 180 days out of the year, so samples were divided into two 90-day periods.

Out of the 52 samples collected in the first 90-day period, the geometric mean bacteria concentration was 71 cfu/100 mL and less than 5 samples exceeded the STV of 410 cfu/100 mL, so it met the Primary Contact standard. Looking at each site individually in the first 90-day period, 4LONG had the lowest geometric mean bacteria concentration (33 cfu/100 mL) and 1NBS had the highest geometric mean bacteria concentration (193 cfu/100 mL). Every site except for 1NBS met the standard for Primary Contact; site 1NBS met the standard for Secondary Contact. Water meets the standard for Secondary Contact if geometric mean *E. coli* concentration of all samples collected within a 90-day period is below 630 cfu/100 mL and no more than 10% of the samples exceed the statistical threshold value (STV) of 1260 cfu/100 mL.

Out of 36 samples collected in the last 90-day period, the geometric mean was 77 cfu/100 mL and less than 4 samples exceeded the STV of 410 cfu/100 mL, so it met the Primary Contact standard. Looking at each site individually in the last 90-day period, 4LONG had the lowest geometric mean bacteria concentration (37 cfu/100 mL) and 1NBS had the highest geometric mean bacteria concentration (139 cfu/100 mL). 4LONG and 2LARZ met the standard for Primary Contact, while 1NBS and 3BU did not meet the standard for Primary Contact, but did meet the standard for Secondary Contact.

The low *E. coli* levels at 4LONG can be attributed to the change in the geography of the river at that sample site. The river gets much wider and deeper at the 4LONG sample site compared to the three other sample sites. The *E. coli* concentrations get diluted at this location. This year, the geometric mean bacteria concentration was higher at 3BU than 2LARZ, which is a change from previous years when the geometric mean bacteria concentration was higher at 2LARZ than 3BU. We could not deduce an explanation for this, but will keep an eye on this in the future to see if this trend continues.

Comparison of Old and New Water Quality Standards
Out of all samples collected and using the previous MassDEP standards, 100% met the Single Sample Standard for Secondary Contact (1,260 cfu/100 mL), or boating standard, and 89% met the previous Single Sample Standard for Primary Contact (235 cfu/100 mL), or swimming standard. 4LONG had the lowest geometric mean bacteria concentration (35 cfu/100 mL) and 1NBS had the highest geometric mean bacteria concentration (169 cfu/100 mL).

This year's program took place during a relatively dry season, with a total rainfall of 11.89 inches throughout the Flagging season. There were a total of 3 wet weather events coinciding with weekly sampling. A wet weather event is defined as 0.25 inches of rain or greater within 48 hours before the sample was taken. During this flagging season, the Charles River was in drought conditions. Compared to the last drought year in 2020, the number of wet weather events is comparable.

Dry weather samples met the boating and swimming standards more often than wet weather samples and had a lower *E. coli* concentration geometric mean (Table 1) for all samples collected. This trend was consistent throughout all sampling sites. Increased rainfall causes more runoff containing bacteria like *E. coli*, as well as other contaminants, to flow into the river, increasing the concentration. The higher number of samples taken during wet weather events this summer resulted in overall higher bacteria levels for the season.

Weather	% Met Boating Standard	% Met Swimming Standard	Geometric Mean (cfu/100mL)
Wet	**100%**	**67%**	**143**
Dry	**100%**	**92%**	**69**

Table 1. Water quality parameters for samples taken during wet weather events vs. dry weather events using the MassDEP water quality standards pre-2022.

There are a couple of major differences between the old and new standards. Because you are not analyzing a single sample, you cannot determine a percentage of samples that meet the standard. Instead, the whole group of samples either meets or does not meet the standard. Additionally, due to the 90-day interval period, the data has to be analyzed in two separate groups. Because of the small sample size for wet weather events, we did not assess the difference between wet weather and dry weather events. This new standard method was likely not intended for such a small sample size.

Effect of Drought Conditions
The correlation between the amount of rainfall and bacteria levels can be seen when comparing this year's results to previous years. A major drought impacted the Charles River and its watershed beginning in May 2022 and lasted past the end of the Flagging season. The most recent comparable drought years were 2016 and 2020, so results from these three flagging seasons and the intermediate years were compared (Figure 3). Previous years data

used the wet weather definition of 0.2 inches of rain or greater within 72 hours of when a sample was taken. This old wet weather definition was applied to the data from 2020 to 2022 when being compared to previous years data.

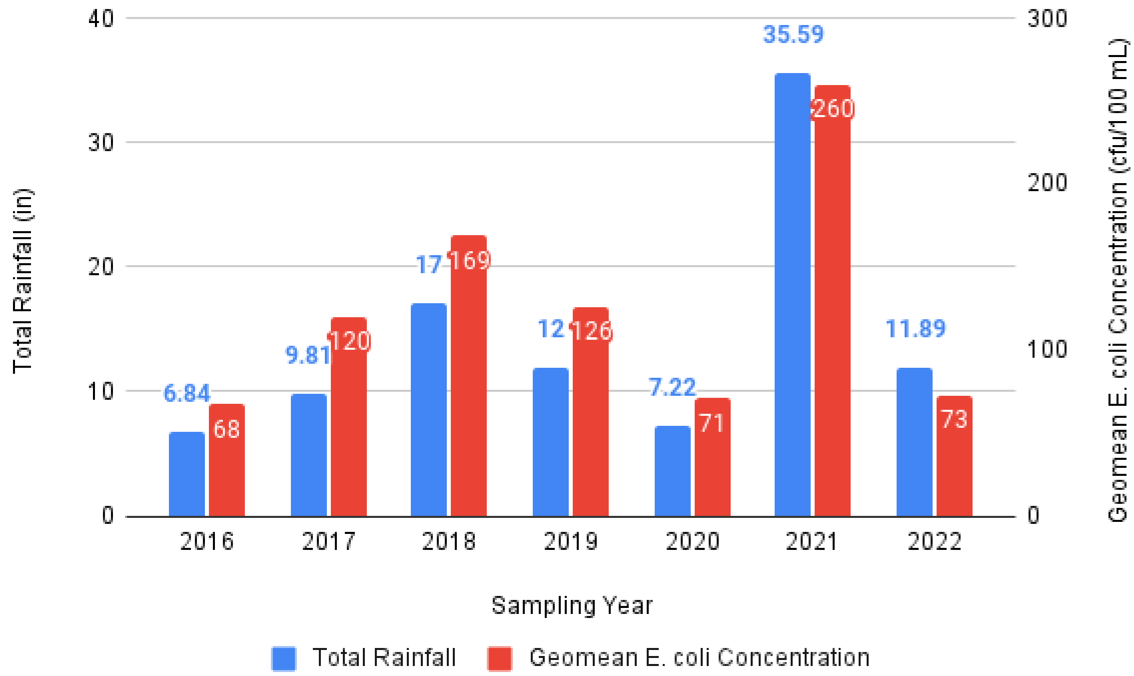

Figure 3. Geometric mean of E. coli concentrations and rainfall totals for each year from 2016 to 2022.

During the 2016 and 2020 Flagging seasons, only two sampling events took place during wet weather events each year. During the 2022 Flagging season, eight sampling events took place during wet weather events. 2017, 2018, 2019, and 2021 were all non-drought years and had 6, 14, 10, and 14 sampling events take place during wet weather events, respectively. 2016 and 2020 had the lowest total rainfall amounts during the sampling season (Figure 3). 2022 had more total rainfall than 2017 even though 2022 was a drought year and 2017 was not. The distribution of precipitation was greater towards the end of the flagging season and there were more intense storms that delivered more rain likely due to the effects of climate change. 2016, 2020, and 2022 had the lowest geometric mean bacteria concentrations, and the geometric mean concentrations of bacteria for non-drought years was significantly higher (Figure 3). Overall, the geometric mean *E. coli* concentration for drought years was 71 cfu/100 mL, while the geometric mean for non-drought years was 161 cfu/100 mL. When looking at both *E. coli* concentration and total rainfall, a clear relationship can be seen, even on an interannual timescale.

The geometric mean *E. coli* concentration for samples taken during wet weather events was also higher than for samples taken during dry weather events for every year except 2016. 2016 had a wet weather geometric mean of 53 cfu/100 mL and a dry weather geometric mean of 70 cfu/100 mL, which is an insignificant difference. During the 2017-2022 sampling periods, there were multiple rain events throughout the seasons. The 2016 Flagging season only had 3 sampling events take place during wet weather events, and these sampling events were all consecutive towards the beginning of the season. A possible explanation is that the higher frequency of rainfall in the 2017-2022 seasons caused pollutants to be flushed into the river more frequently, resulting in higher *E. coli* concentrations in samples taken during wet weather events than were found in the 2016 season.

Model Performance

Statistical models are used to predict the likelihood that water quality will be in violation of the state geometric mean boating standard (630 cfu/100 mL) at each sampling reach. CRWA has four models corresponding to each sample site and a specific 'reach' of the Lower Basin (Figure 1). Every hour, the models use rainfall and river flow to make predictions. Weather parameters are measured at CRWA's weather station located on the Lower Charles near Community Boating, and flow data is obtained from the USGS gauge 800 feet downstream from the Moody Street Dam in Waltham. These models allow CRWA to produce real-time water quality forecasts, while the *E. coli* analysis requires at least 24 hours between sample collection and result reporting. CRWA's models were updated before the 2020 season to calibrate weather conditions to sample results collected from 2017 – 2019. These equations were used during the 2021 and 2022 seasons to predict red and blue flags (Table 2). Red flags made up 8% of total model predictions for 1NBS, 8% of predictions for 2LARZ, 6% of predictions for 3BU, and 0% of predictions for 4LONG.

Variable	Meaning
A	**Rainfall in previous 24 hours (inches)**
B	**Rainfall in previous 24-48 hours (inches)**
C	**Rainfall in previous 48 hours (inches)**
D	**Days since last rainfall**
E	**Streamflow (cubic feet per second)**
F	**Photosynthetic Active Radiation**

Reach	Model Equation[1]
2	**0.3531A - 0.0362D - 0.000312F + 0.6233**
3	**0.267A + 0.1681B - 0.02855D + 0.5157**

[1] These linear equations provide a decimal output number, which is converted to a threshold percentage. This threshold percentage represents the probability of an *E. Coli* exceedance. If the threshold percentage is equal to or exceeds 65%, the model predicts a red flag.

4	**0.30276A + 0.1611B - 0.02267D - 0.000427F + 0.5791**
5	**0.1091C - 0.01355D + 0.000342E + 0.3333**

Table 2. Model equations used to predict bacteria concentrations for each reach with a list of each variable used and its meaning.

An analysis of the model predictions was conducted after the end of the season to determine their reliability. To do this, model results were compared to the *E. coli* concentration results from sampling. The model was determined to have an error when *E. coli* concentrations were below the state geometric mean boating standard, but the model predicted that a red flag would be flown (false positive), or when *E. coli* concentrations were above the state geometric mean standard, but the model predicted that a blue flag would be flown (false negative).

There were a total of 6 model errors out of 87 total samples taken. Of these errors, 2 were false negatives and 4 were false positives. 1NBS and 2LARZ were tied for the most model errors (2) and 3BU and 4LONG had the fewest model errors (1) (Figure 4). On average, the models were about 93% accurate. The false negative model errors occurred after or during wet weather events. In each case, the sampled *E. coli* concentration exceeded 630 cfu/100 mL when the model predicted a blue flag. This indicates that the model equations may need to be slightly altered to take into account the impacts of rainfall after a certain amount of time. The false positives all occurred near the beginning or end of rainfall, so the accuracy of the models may vary by a few hours from actual water quality conditions. The model equations can be adjusted to take these issues into account for the next Flagging season as well as the finalization of updated water quality standards.

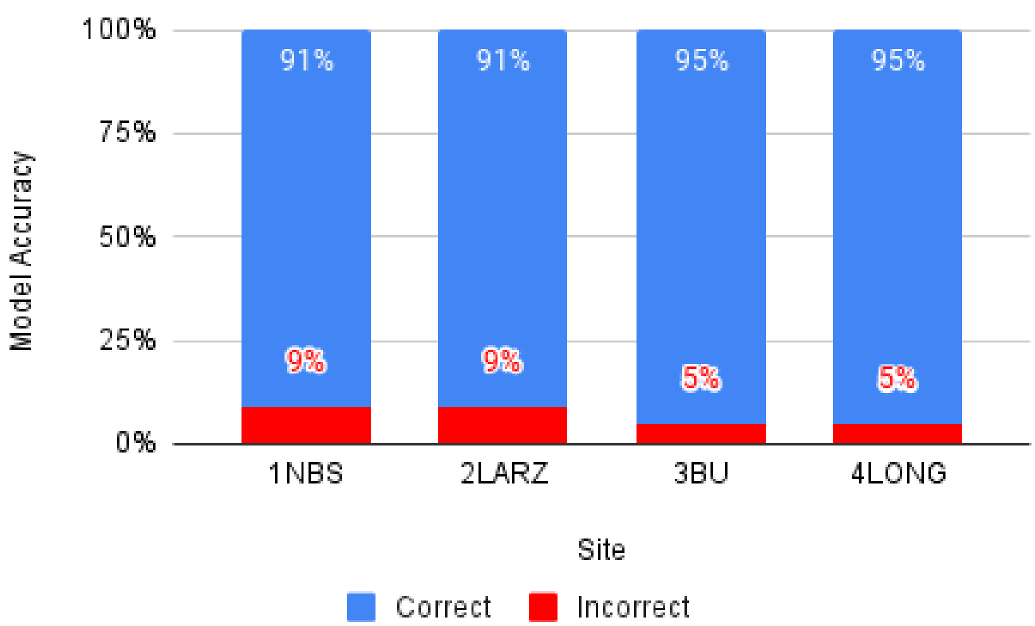

Figure 4. Model accuracy for flag color prediction at each sampling site.

Program Evaluation

Overall, CRWA had a successful Flagging season in 2022 and kept boaters on the Charles River informed of the water quality. At each sample site, the majority of samples taken met both the old and new boating and swimming standards which can be attributed to the drought that took place this summer, since little rainfall led to less stormwater pollution and a corresponding decrease in *E. coli* concentrations. The majority of the red flags flown were because of the cyanobacteria bloom advisory that lasted for 22 days, and because of elevated bacteria levels due to increased levels of stormwater runoff into the Charles. The models that predicted the bacteria concentrations at each reach had an average accuracy of 93%, which is relatively high for this type of model.

CRWA plans to continue this valuable program in the 2023 season, beginning in May. The water quality models will be updated using the new surface water quality standards, and calibrated with past data. In 2020, CRWA partnered with the Code for Boston group to update our model website. The CRWA flagging website predicts the flag colors at each boathouse hourly, and updates automatically online. A twitter bot that tweets flag color updates was also developed and was launched at the beginning of the 2021 season. We look forward to continuing to use this notification system within our program and making even more boaters aware of the Charles River water quality.