Charles River Watershed Association

Flagging Program Results 2020

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 2020, CRWA monitored water quality by using model predictions of *E. coli* concentrations, cyanobacteria levels, and notifications of combined sewer overflows 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 not boatable. A twelfth boathouse, Cambridge Boating Club, joined the Flagging Program in the middle of this season.

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 were compared with the amount of rainfall leading up to the time of sample collection. As in past years, a positive correlation between rainfall amount and *E. coli* concentration was found. This season, however, had less rainfall than normal and the Charles River watershed was in drought conditions. Therefore, the majority of red flags flown this season were due to cyanobacteria blooms.

Public Notification

Flags were flown at 12 boathouses this season (Figure 1). Eleven of these boathouses participated through the entire season, and one boathouse was added to the program in early October. Flag colors were communicated via email, CRWA's website, and social media. 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 the state geometric mean standard (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 the state geometric mean standard, then a blue flag was flown. Between June 8 and October 18, the models predicted red flags on a total of 11 days. The website was updated daily for changes in flag color.

Red flags were flown at all boathouses due to a combined sewer overflow (CSO) on June 28 and June 29. The CSO occurred on June 28 at 3:10 PM and 1.33 inches of rain fell during this rainstorm. Due to Massachusetts Department of Public Health recommendations, red flags are flown at all locations for 48 hours following a CSO. Red flags were also flown at boathouses during cyanobacteria blooms. On June 25, a public health advisory was put into effect and red flags were flown due to high levels of cyanobacteria in the water. There were 108 days during this season's Flagging Program where red flags were flown due to a cyanobacteria bloom, and the bloom continued through the end of the flagging program.

CRWA Real-Time Public Notification Program Sampling Locations

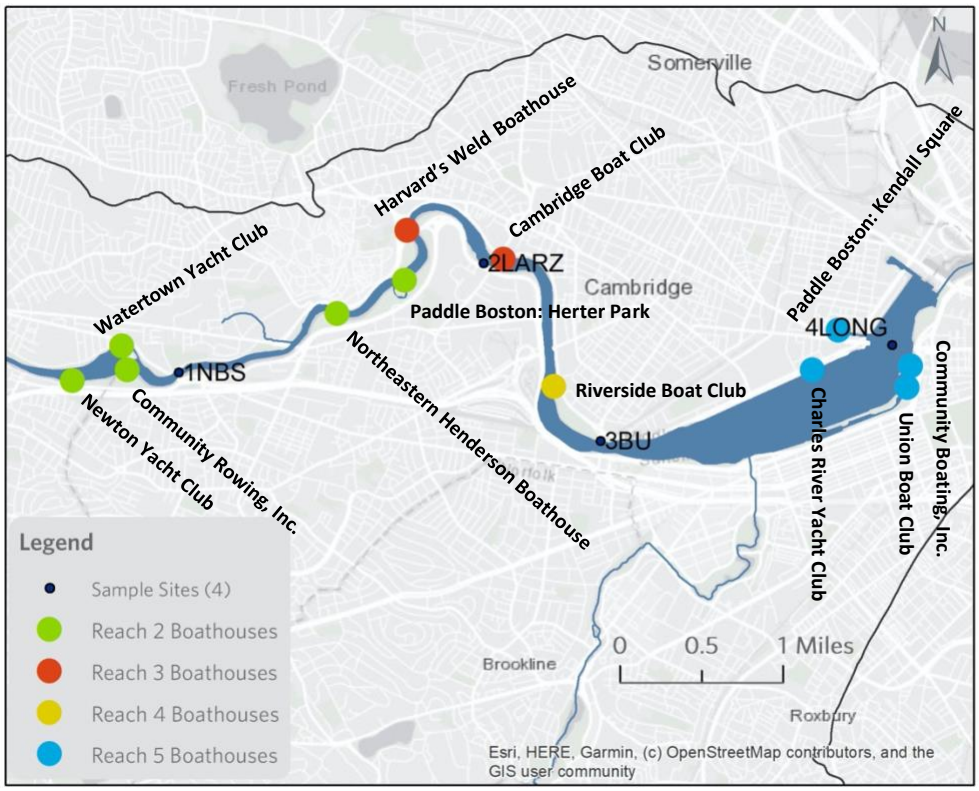

Figure 1. Map of sampling locations and participating boathouses in the Charles River Lower Basin.

Flags Flown

During the 133-day flagging season that lasted from June 8 through October 18, blue flags were flown about 66% of the time, and red flags were flown about 34% of the time. If the model predicted both red flags and blue flags in the same day, then whichever flag color was more common during typical boating hours (5 am – 7 pm) was counted. Reaches two, three, and four all had the fewest red flags flown (9) and reach five had the most red flags flown (108) (Figure

2). The majority of red flags flown at reaches two, three, and four were due to *E. coli* contamination that was predicted by CRWA's statistical models. The majority of flags flown at reach five were due to the presence of cyanobacteria.

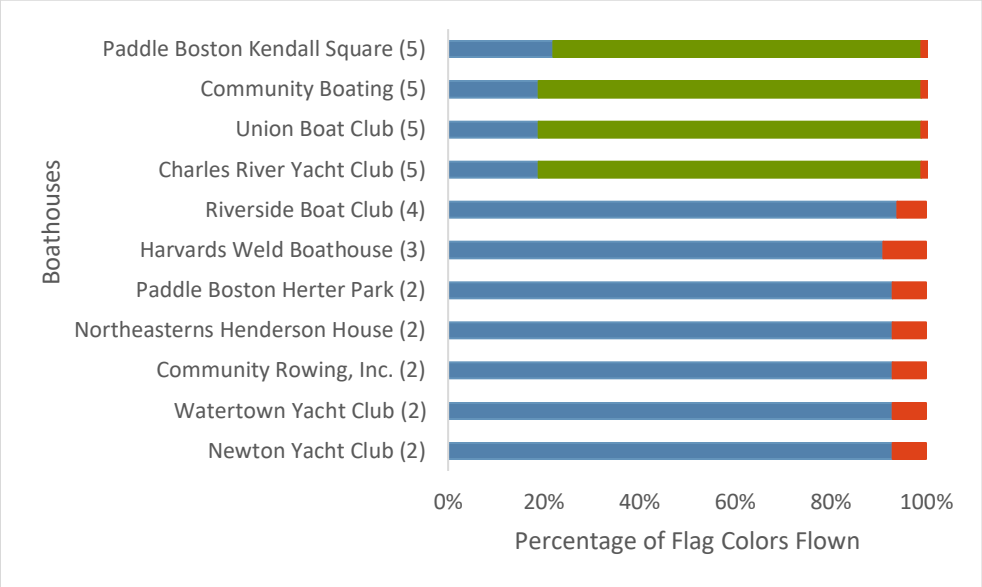

Figure 2. Percentage of red and blue flags flown at each boathouse from June 8 to October 18. Blue represents the percentage of days a blue flag was flown at each boathouse. Green represents the percentage of days a red flag was flown at each boathouse solely due to a cyanobacteria bloom. Red represents the rest of the percentage of days a red flag was flown, either due to model predictions, combined sewer overflows, or a combination of factors. Numbers in parentheses represent the reach each boathouse is in.

Sampling Results

CRWA conducted weekly sampling of the Charles River between June 8 and October 18. 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 Beach 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.

2020 Sampling Results

There were 18 sampling events between June 8 and October 18. Excluding field duplicates, a total of 78 samples were collected. Out of all samples collected, 97% met the Single Sample Standard for Secondary Contact (1,260 cfu/100 mL), or boating standard, and 75% met the Single Sample Standard for Primary Contact (235 cfu/100 mL), or swimming standard. 4LONG had the lowest geometric mean bacteria concentration and 1NBS had the highest geometric mean bacteria concentration (Figure 3). 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 Charles River acts more like a lake at this location, and the *E. coli* concentration gets diluted as a result.

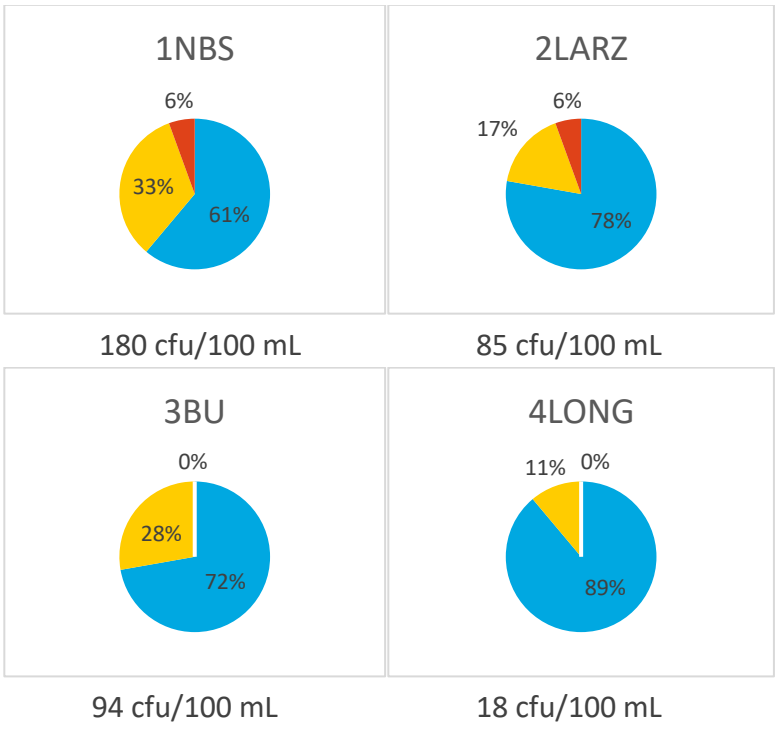

Figure 3. Percentage of samples collected at each site that passed different standards. Blue represents the samples that passed both the swimming (235 cfu/100 mL) and boating (1260 cfu/100 mL) standards. Yellow represents samples that passed the boating standard, but not the swimming standard. Red represents samples that failed both the boating and swimming standards. Geometric mean *E. coli* concentrations for each sample site are shown underneath its corresponding pie chart.

This year's program took place during a drought, with only 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 of when a sample was taken. 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). 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 dry weather events due to the drought this summer resulted in overall lower bacteria levels for the season.

Weather	% Met Boating Standard	% Met Swimming Standard	Geometric Mean (cfu/100 mL)
Wet	88%	13%	466
Dry	100%	93%	42

Table 1. Water quality parameters for samples taken during wet weather events vs. dry weather events.

Cambridge Boat Club

Cambridge Boat Club (CBC) was added as a sample site in September of this season. In order to determine which model the boathouse would use for its flag predictions, samples were taken at the boathouse in the center of the channel. Six total samples were taken, with two of them taking place during wet weather events. The *E. coli* concentrations were compared with the concentrations at 1NBS and 2LARZ for the same date to determine whether CBC belongs in reach two (with 1NBS) or reach three (with 2LARZ). The bacteria concentrations at CBC most closely resembled the concentrations at 2LARZ, so CBC will be included as a boathouse under reach three in the coming years (Figure 4).

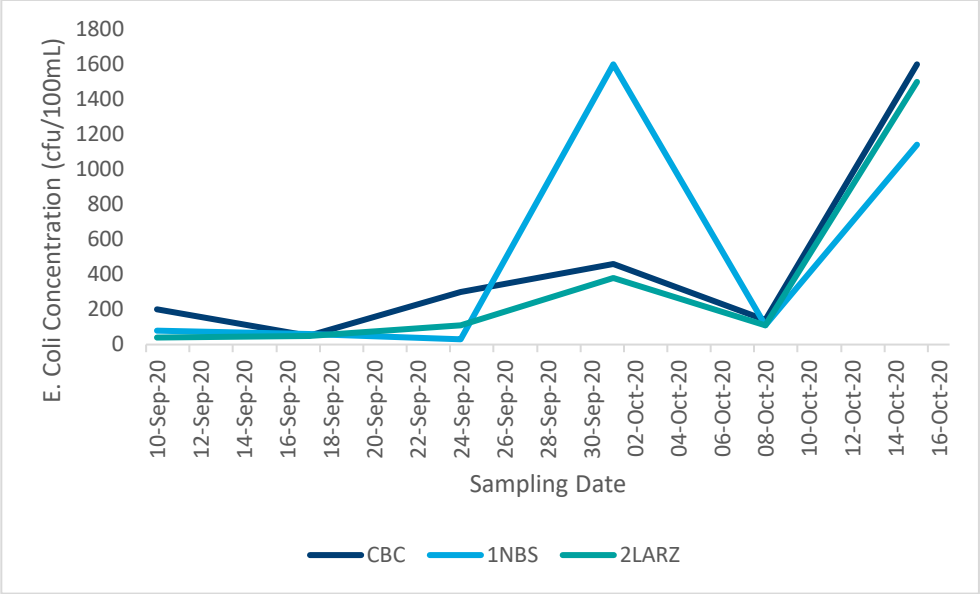

Figure 4. *E. coli* concentrations on a given date from samples taken from CBC, 1NBS, and 2LARZ.

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 June 2020 and lasted past the end of the Flagging season. The most recent comparable drought year was 2016, so results from these two flagging seasons and the intermediate years were compared. 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 2020 data when being compared to previous years data.

During the 2020 and 2016 Flagging seasons, only three sampling events took place during wet weather events each year. 2017, 2018, and 2019 were all non-drought years and had 6, 14, and 10 sampling events take place during wet weather events, respectively. 2016 and 2020 had the lowest total rainfall amounts during the sampling season (Figure 5). This trend correlates to the bacteria concentrations for each year. Both 2016 and 2020 had the two lowest geometric mean bacteria concentrations, and the geometric mean concentrations of bacteria for non-drought years was significantly higher (Figure 5). Overall, the geometric mean *E. coli* concentration for drought years was 69 cfu/100 mL, while the geometric mean for non-drought years was 137 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 2017-2020 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. The higher frequency of rainfall in the 2017-2020 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.

Another effect of drought on the Flagging program was the persistence of cyanobacteria blooms in the Lower Charles River Basin. During the drought years of 2016 and 2020, 46% and 83% of sampling events took place when a cyanobacteria alert was in effect, respectively. In the non-drought years of 2017-2019, an average of 14% of sampling events took place during a cyanobacteria alert.

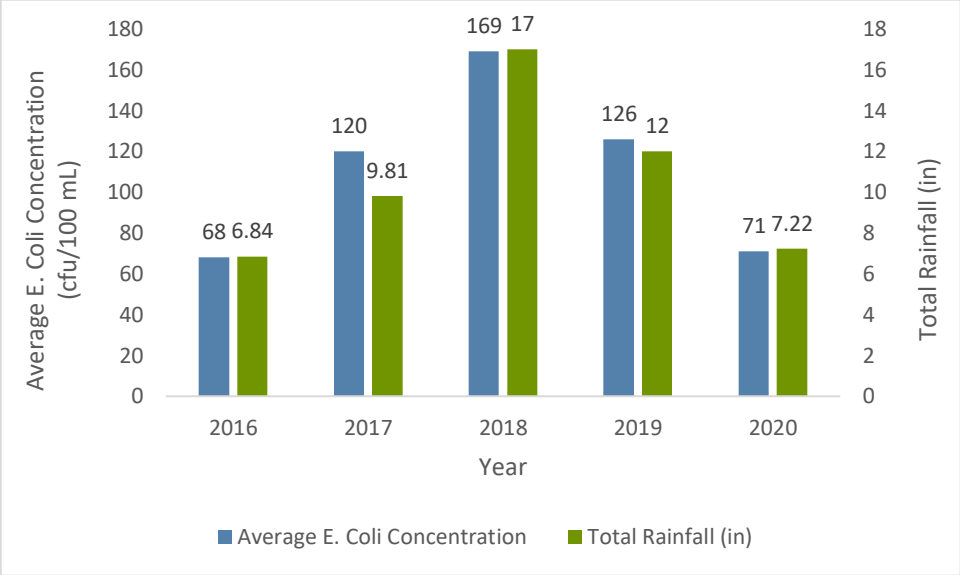

Figure 5. Geometric mean of *E. coli* concentrations and rainfall totals for each year from 2016-2020.

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 at 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. The newly developed equations were used during the 2020 season to predict red and blue flags (Table 2). Red flags made up 6% of total model predictions for 1NBS, 8% of predictions for 2LARZ, 5% of predictions for 3BU, and 0% of predictions for 4LONG.

Variable	Meaning
A	Rainfall in Previous 24 hours (in)
B	Rainfall in Previous 24-48 hours (in)
C	Rainfall in Previous 48 hours (in)
D	Days since rain
E	Streamflow (cfs)
F	Photosynthetic Active Radiation (uE)

Reach	Model Equation
2	0.3531A - 0.0362D - 0.00032F + 0.6233
3	0.267A + 0.1681B - 0.02855D + 0.5157
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 72 total samples taken. All of these errors were false negatives. 1NBS had the most model errors (3) and 4LONG had the fewest model errors (0) (Figure 6). On average, the models were about 92% accurate. All of the model errors occurred

when a sample was taken during wet weather events after rainfall had concluded. 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 don't take into account exactly how long after a storm bacteria concentrations stay elevated. The model equations can be adjusted to take this issue into account for next Flagging season.

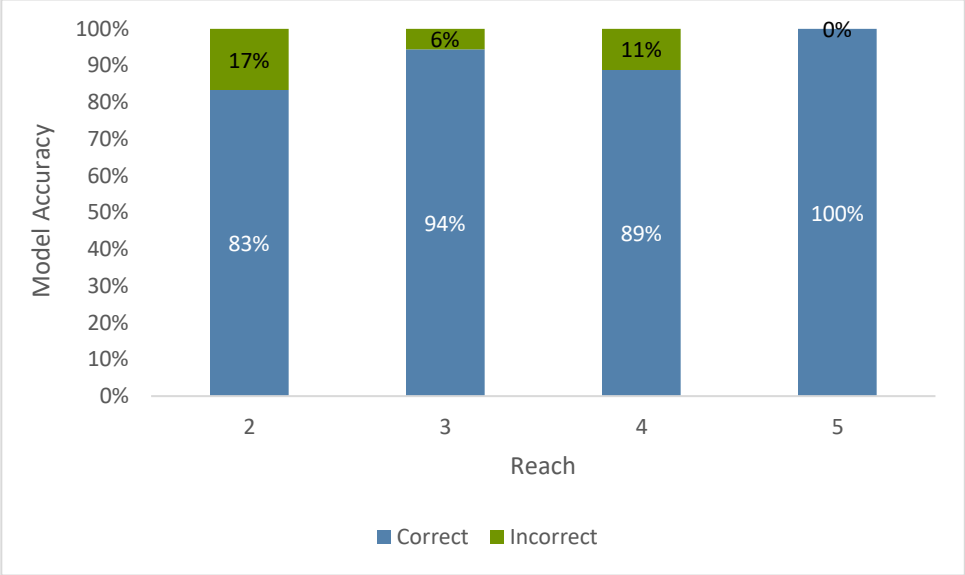

Figure 6. Model accuracy for flag color prediction at each sampling reach.

Program Evaluation

Overall, CRWA had a successful Flagging season in 2020 and kept boaters on the Charles River informed of the water quality. At each sample site, the majority of samples taken met both the 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. Red flags were only flown a majority of the time at the boathouses in reach the Lower Basin because of the cyanobacteria bloom advisory that lasted for a majority of the summer and through the end of the flagging season. The models that predicted the bacteria concentrations at each reach had an average accuracy of 92%, which is high for a physical model.

CRWA plans to continue this valuable program in the 2021 season, beginning in May. The accuracy of the models will be improved for next year by taking into account how long *E. coli* concentrations stay elevated after a rainfall event has stopped. In addition, our website will have enhanced notification abilities next year. This year, CRWA partnered with the Code for

Boston group to update our model website. Though this was not ready to launch during the 2020 Flagging season, we expect to launch it this winter. The newly updated 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 will be launched in 2021. We look forward to integrating these updates into our program and making even more boaters aware of the Charles River water quality.