Flagging Program Results 2023

Overview of Flagging Program

Since 2007, Charles River Watershed Association's (CRWA) Flagging Program has provided real time estimates of bacterial water quality to inform boaters about health risks in the Lower Charles River. In the Charles River, bacterial water quality, and the associated risk of exposure to pathogens, is influenced by weather conditions and varies by location. The flagging program relies on a water quality model that predicts *E. coli* concentration based on environmental conditions (e.g., flow rate, rainfall). Monitoring and modeling occur at four reaches (sample locations shown in Fig. 1). In 2023, twelve boathouses participated in the program by flying blue flags on days conditions are safe for boating, and red flags on days where the model indicated *E. coli* concentrations were likely to exceed safe boating standards. Red flags are also flown for boathouses downstream of a combined sewer overflow for 48 hours after the end of the discharge, and when cyanobacterial bloom advisories are in effect.

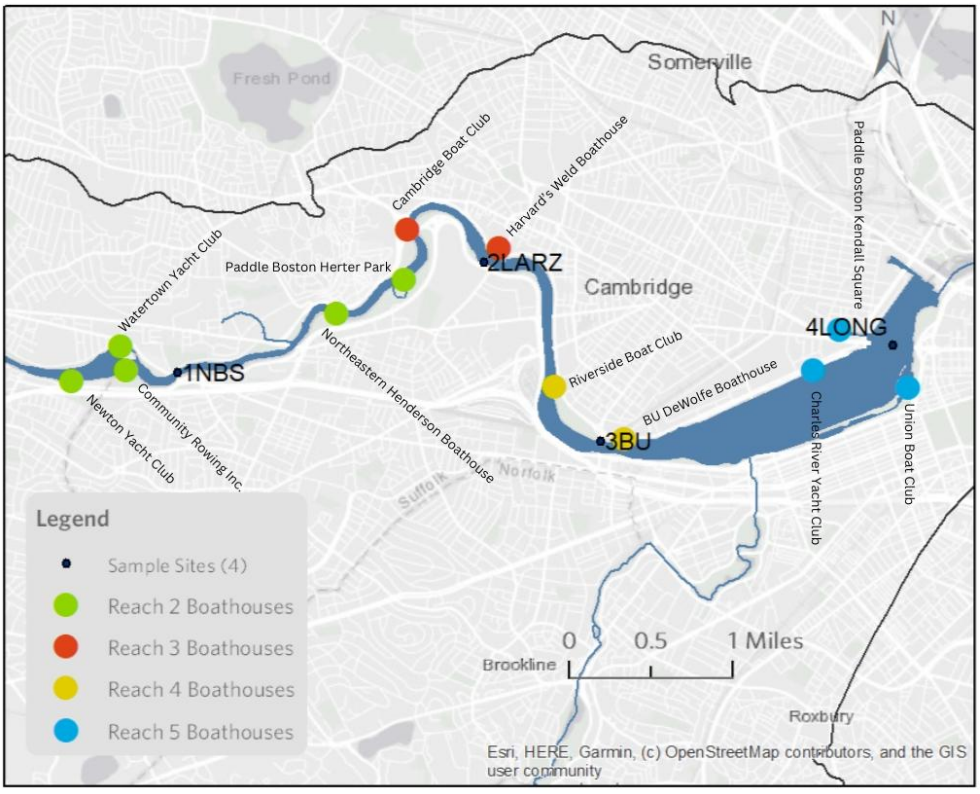

Figure 1. Map of sampling locations and participating boathouses in the Charles River Lower Basin.

In 2023, weekly water samples were taken at each reach to monitor *E. coli* concentrations. *E. coli* results are used to evaluate model performance. *E. coli* results are paired with antecedent rainfall to understand the relationship between wet weather and bacterial water quality. As in

past years, wet weather in 2023 was associated with increased *E. coli* concentrations. 2023 was a particularly wet season with nearly 25 inches of rainfall. This precipitation resulted in 29 Combined Sewer Overflows releasing over 60 million gallons of partially treated sewage into the Lower Basin.

Overview of Public Notification

Flags were flown at 12 boathouses this season (Figure 1). These boathouses resided in 4 sections of the river, labeled "Reach 2" through "Reach 5". Flag colors were communicated via email and CRWA's flagging website. Four calibrated models were used to correspond to the four sample sites (1NBS, 2LARZ, 3BU, and 4LONG). When the statistical model predicted that there was greater than a 65% chance that water quality will exceed 630 CFU/100mL[1] at a given location, 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. The website was updated daily to represent any changes in flag color. Between May 1st and October 22nd, the models predicted red flags for a total of 24 days.

Red flags were flown at all boathouses residing in reaches 3, 4, and 5 due to combined sewer overflows (CSO) on numerous occasions throughout the season. Due to Massachusetts Department of Public Health recommendations, red flags are flown at all affected locations for 48 hours following a CSO. Red flags were prepared to be flown at boathouses if a cyanobacteria bloom advisory was issued. There were no cyanobacteria bloom advisories in the Lower Basin during the Flagging Program season.

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, CRWA developed a new public service announcement video highlighting the importance of the Flagging program.

Overview of Sampling

CRWA conducted weekly sampling at each reach between May 11th and October 19th. Sampling protocol included recording water temperature and depth. 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).

To assess data quality, 10% of all samples were collected in duplicate. These field duplicates were 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.

[1] Former state geometric mean water quality standard for secondary contact recreation. This is derived from the Surface Water Quality Standards 314 CMR 4.05(3)(c)4.a.

Flagging Results

Blue flags were flown for the majority of the flagging season. Boathouses flew blue flags between 86% and 95% of the time. Reach 5 was the safest reach for boating with only 5% of days requiring red flags. Reach 3 was the least safe with 14% of days requiring red flags. Red flags at Reach 3 were a result of both model predictions and CSO events.

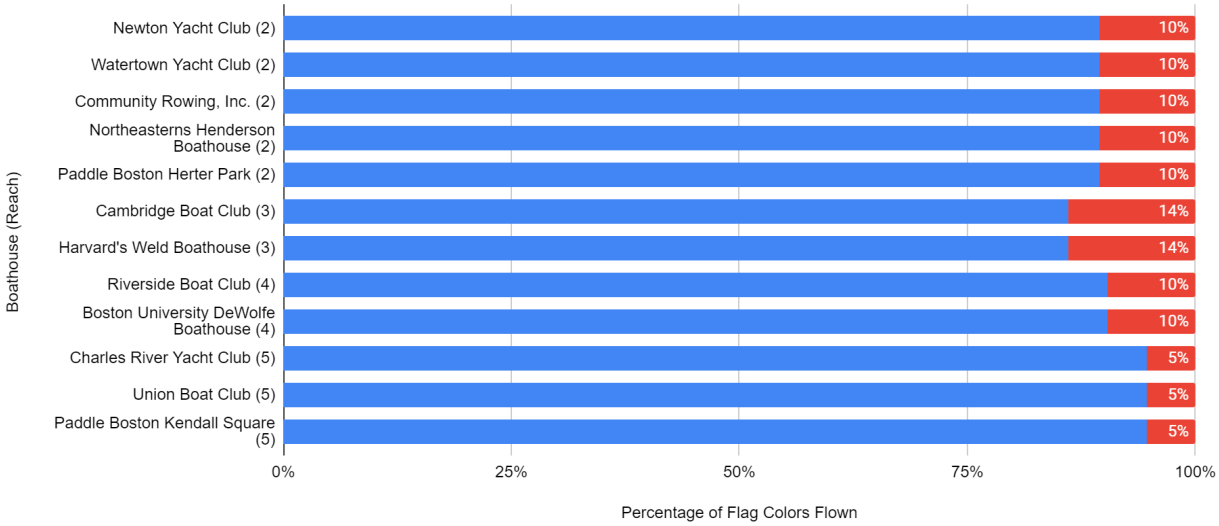

Figure 2. Percentage of red and blue flags flown at each boathouse from May 1st to October 22nd; bar color corresponds to flag color.

CSO Impact on Flagging Results

Red flags were flown in reaches 3, 4 and 5 due to combined sewer overflows (CSOs) on 29 separate occasions. 2023 CSO activations discharged 61 million gallons into the Charles during the flagging season. This was a large increase in CSOs, compared to 2022 where the Charles River watershed was in drought conditions and had only two CSOs. We monitor for CSOs using three different websites from Cambridge, the Boston Water and Sewer Commission (BWSC), and the Massachusetts Water Resource Authority (MWRA) (Figure 3).

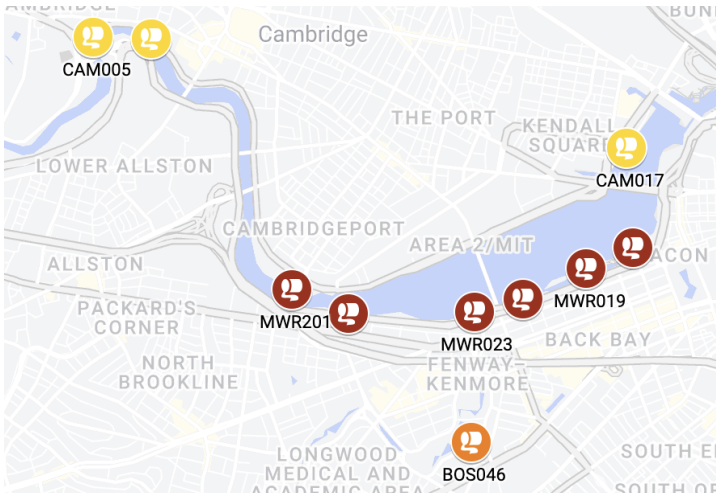

Figure 3. Location of CSOs affecting the Lower Basin.

Sampling Results

There were 23 sampling events between May 11th and October 19th. Excluding field duplicates, a total of 92 samples were collected and used in this analysis. A summary of these sampling results is provided below in Table 1. Of the 92 samples, only four (4%) exceeded boating standards (1260 CFU/mL)[2]. More than half of all samples exceeded bacterial thresholds for swimming (235 CFU/mL)[3].

Table 1. Summary of *E. coli* sampling results.

Location	Boating (%)	Swimming (%)	Geomean (CFU/100 mL)
1NBS	91%	35%	318
2LARZ	96%	26%	449
3BU	100%	48%	207
4LONG	96%	83%	103
Total	96%	48%	235

Effective January 2022, there is an updated process by which the Massachusetts Department of Environmental Protection (MassDEP) assesses whether or not a waterbody meets surface water quality standards (SWQS) for primary recreation[4]. These standards have limited applicability to

[2] While no single sample maximum exists for secondary contact, CRWA has long used 1,260 CFU/100 mL as a threshold for evaluating boating safety. This is derived from the Surface Water Quality Standards 314 CMR 4.05(3)(c)4.b which requires that no more than 10% of samples exceed 1260 CFU/100 mL for Class C waters.

[3] This primary contact threshold is set by the Massachusetts Department of Public Health https://matracking.ehs.state.ma.us/Environmental-Data/recreational-water/index.html

[4] Massachusetts Department of Environmental Protection. 2021. "Surface Water Quality Criteria for Bacteria: Implementation Guidance for the Protection of Human Health in Waters Designated for Primary

our flagging program as they do not include secondary contact recreation (e.g., boating). Under the revised standards, the geometric mean *E. coli* concentration of all samples collected within a 90-day period must be below 126 CFU/100 mL and no more than 10% of samples can 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. The results are shown in Table 2 below:

Table 2. Comparison of *E. coli* results to revised SWQS.

Period	Samples (n)	Geomean*	> STV (n)	> STV (%)	Result
May - July	48	166	10	21%	Fails SWQS
August - October	44	342	16	36%	Fails SWQS

Wet Weather Impacts

This year's program took place during a relatively wet period, with nearly 25 inches of precipitation. Of 23 sampling events, five captured wet weather conditions[5]. At all locations, wet weather *E. coli* concentrations were significantly elevated compared to dry weather concentations (Table 3, Figure 4A).

The effect of wet weather can also be seen when comparing seasonal water quality between years. In CRWA flagging data, bacterial contamination is highly correlated to seasonal rainfall (Figure 4B). As captured by the geometric mean, wet years like 2021 and 2023 have significantly higher E. coli concentrations compared to dry years like 2016 and 2020.

Table 3. Summary of 2023 *E. coli* results by dry and wet conditions for each site. Wet Boating (%) corresponds to the percentage of samples that passed the boating standard during wet weather. *Geomean is the geometric mean.

Location	Wet Geomean*	Dry Geomean*	Wet Boating (%)	Dry Boating (%)	Wet Swimming (%)	Dry Swimming (%)
1NBS	529	276	80%	94%	0%	44%
2LARZ	833	378	80%	100%	0%	33%
3BU	821	141	100%	100%	0%	61%
4LONG	270	78	80%	100%	60%	94%

Contact Recreation." https://www.mass.gov/doc/bacteria-surface-water-quality-criteria-for-bacteria-implementation-guidance-for-the-protection-of-human-health-in-waters-designated-for-primary-contact-recreation-cn-5630/download.

[5] A wet weather sampling event is defined as 0.25 inches of rain or greater within 48 hours before the sample was taken.

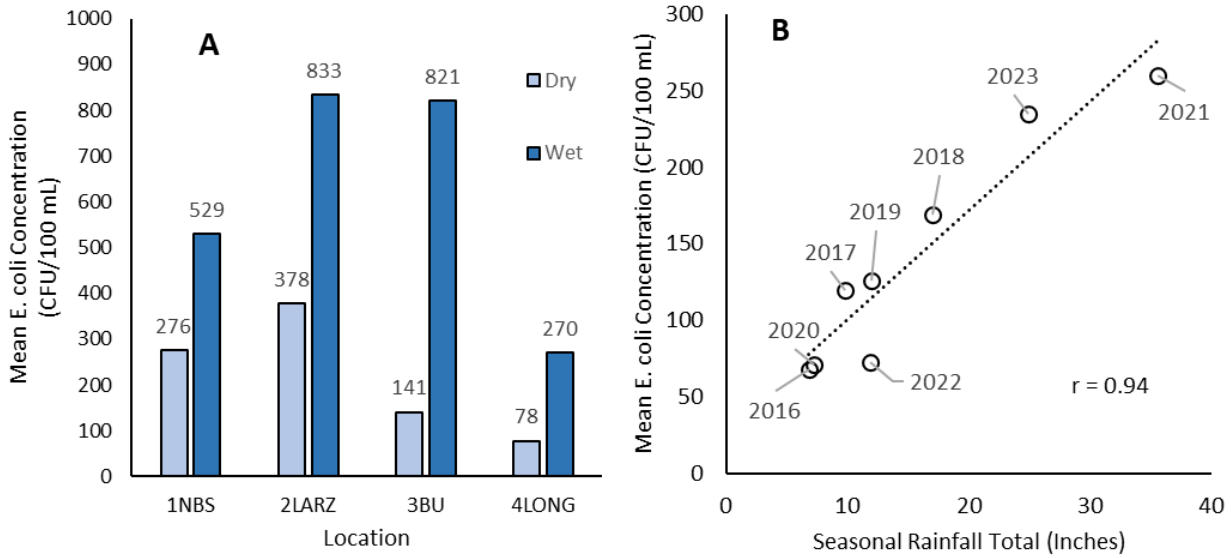

Figure 4: (A) Bar plot showing wet and dry weather geometric mean *E. coli* concentration at each sampling location. (B) Seasonal mean *E. coli* concentration plotted against seasonal rainfall totals for 2016-2023.

In examining the effect of wet weather on interannual trends it is important to acknowledge that the wettest years do not necessarily include the greatest proportion of wet weather samples. For example, 2022, a drought year, included eight wet weather sampling events while 2023, a wet year, had only five. Despite this variability, the interannual trend is quite clear, seasonal precipitation is highly correlated (r=0.94) to mean *E. coli* concentrations.

Model Performance

Statistical models are used to predict the likelihood that water quality will be in violation of the previous 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 hourly 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, 2022 and 2023 seasons to predict red and blue flags. An equation summary can be found at the end of this document.

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 13 model errors out of 92 total samples taken, with all 13 errors being false negatives (instances in which blue flags were flown but *E. coli* samples exceeded 630 CFU/100 mL). 2LARZ had the most model errors (7) while 4LONG had the least (0) (Figure 5). On average, the models were about 86% accurate. 7 out of the 13 false negative model errors occurred after or during wet weather events. 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 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.

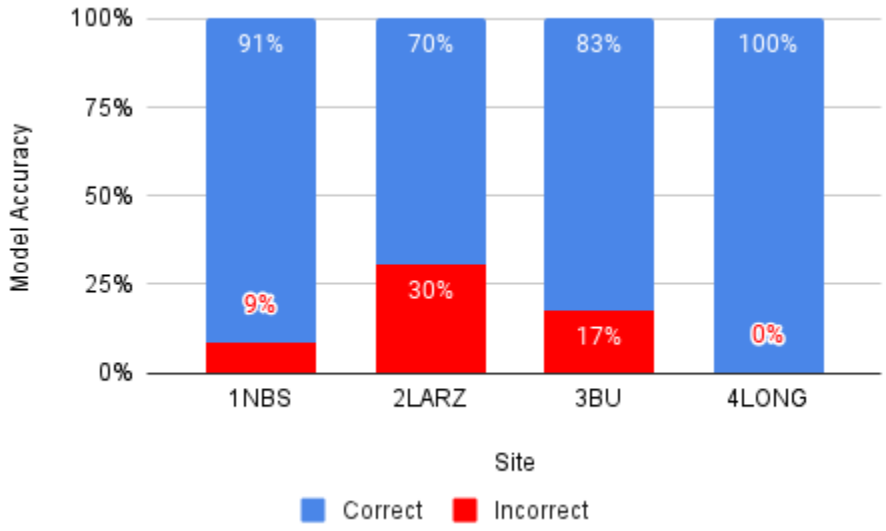

Figure 5. Model accuracy for flag color prediction at each sampling site.

Program Evaluation

Overall, CRWA had a successful Flagging season in 2023 and kept boaters on the Charles River informed of the water quality. At each sample site, there was an increase of samples taken that exceeded both the boating and swimming standards, which can be attributed to the frequent rain events that took place this summer. Since an increased amount of rainfall led to more stormwater pollution and numerous CSOs, the corresponding increase in *E. coli* concentrations was observed. Red flags were flown quite often at the boathouses in each reach, with the exception of Reach 5, because of the drastic amount of rainfall and frequent CSOs. These events occurred throughout the whole summer and through the end of the flagging season. The models that predicted the bacteria concentrations at each reach had an average accuracy of 86%, which is relatively high for this type of model.

CRWA plans to continue this valuable program in the 2024 season, beginning in May. The accuracy of the models will be improved for next year by decreasing the lag time of the model predictions and taking into account how long *E. coli* concentrations stay elevated after a rainfall

event has stopped. The water quality models will use best environmental modeling practices and will be calibrated with past data. In 2020, CRWA partnered with the Code for Boston group to update our model website. We expect to continue to work with them to improve the model for the next Flagging season. The CRWA flagging website predicts the flag colors at each boathouse hourly, and updates automatically online. 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.

Equation Summary

Model Equations

Reach 2: $Y = 0.3531A - 0.0362D - 0.000312F + 0.623$

Reach 3: $Y = 0.267A + 0.1681B - 0.02855D + 0.5157$

Reach 4: $Y = 0.30276A + 0.1611B - 0.02267D - 0.000427F + 0.5791$

Reach 5: $Y = 0.1091C - 0.01355D + 0.000342E + 0.3$

Where the Variables A-F are defined as follows:

Variable	Model Input
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

Table 4: Model prediction and sample results.

	Model Prediction				E. coli Concentration					
Sample Date/Time	**1NBS**	**2LARZ**	**3BU**	**4LONG**	**1NBS**	**2LARZ**	**3BU**	**4LONG**	**48-hr Rainfall**	**Wet/Dry**
5/11/2023 9:23:00	60.3%	62.3%	57.6%	61.5%	200	210	70	60	0.00	Dry
5/18/2023 9:50:00	59.9%	62.3%	57.1%	59.7%	150	160	30	40	0.00	Dry
5/25/2023 8:57:00	60.8%	62.6%	58.3%	61.2%	200	170	40	170	0.03	Dry
6/1/2023 8:56:00	59.8%	62.4%	57.0%	59.6%	220	180	20	15	0.00	Dry
6/8/2023 8:35:00	62.6%	62.3%	61.0%	59.2%	240	330	30	40	0.00	Dry
6/15/2023 8:29:00	64.6%	64.7%	61.9%	60.4%	1600	220	300	60	0.12	Dry
6/22/2023 8:57:00	59.8%	62.3%	57.2%	59.4%	270	160	80	80	0.00	Dry
6/29/2023 8:43:00	62.4%	63.2%	61.1%	59.8%	1600	310	520	70	0.53	Wet
7/6/2023 8:53:00	60.3%	63.3%	58.2%	60.5%	580	450	210	90	0.22	Dry
7/13/2023 8:44:00	60.1%	62.1%	57.6%	60.1%	290	780	620	40	0.00	Dry
7/20/2023 8:37:00	60.7%	62.2%	58.4%	60.4%	220	500	200	60	0.00	Dry
7/27/2023 8:35:00	60.3%	64.4%	60.0%	63.3%	240	360	640	420	0.88	Wet
8/3/2023 8:41:00	60.8%	62.6%	58.1%	61.7%	210	400	360	80	0.00	Dry
8/10/2023 8:39:00	61.9%	66.2%	62.9%	66.1%	580	1000	1020	1480	1.32	Wet
8/24/2023 8:46:00	60.3%	62.1%	58.0%	61.0%	330	820	500	140	0.00	Dry
8/31/2023 8:52:00	62.8%	62.2%	61.4%	61.7%	310	800	1100	100	0.83	Wet
9/7/2023 9:14:00	61.1%	62.0%	59.1%	59.8%	180	880	120	30	0.00	Dry
9/14/2023 9:27:00	62.7%	62.2%	61.2%	60.9%	600	4500	1000	330	0.58	Wet
9/21/2023 9:00:00	61.5%	62.3%	59.7%	63.5%	300	500	320	600	0.00	Dry
9/28/2023 8:40:00	62.0%	62.2%	60.3%	62.1%	340	280	150	150	0.00	Dry
10/5/2023 9:01:00	62.0%	62.2%	60.3%	62.1%	320	1200	330	230	0.00	Dry
10/12/2023 8:32:00	62.6%	62.1%	61.2%	60.9%	130	940	280	100	0.00	Dry
10/19/2023 8:27:00	63.0%	62.1%	61.7%	59.7%	330	260	160	70	0.00	Dry