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Wastewater treatment plant operators report high capacity to support wastewater surveillance for COVID-19 across New York State, USA

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HIGHLIGHTS

- Sixty-two percent of respondents report capacity to pull grab samples using current resources.
- Knowledge of detecting COVID-19 in wastewater is higher than for other substances.
- The larger the treatment plant, the more frequently they can test.

ABSTRACT

Wastewater surveillance for infectious disease expanded greatly during the COVID-19 pandemic. As a collaboration between sanitation engineers and scientists, the most cost-effective deployment of wastewater surveillance routinely tests wastewater samples from wastewater treatment plants. To evaluate the capacity of treatment plants of different sizes and characteristics to participate in surveillance efforts, we developed and distributed a survey to New York State municipal treatment plant supervisors in the summer and fall of 2021. The goal of the survey was to assess the knowledge, capacity, and attitudes toward wastewater surveillance as a public health tool. Our objectives were to: (1) determine what treatment plant operators know about wastewater surveillance for public health; (2) assess how plant operators feel about the affordability and benefits of wastewater surveillance; and (3) determine how frequently plant personnel can take and ship samples using existing resources. Results show that 62% of respondents report capacity to take grab samples twice weekly. Knowledge about wastewater surveillance was mixed with most supervisors knowing that COVID-19 can be tracked via wastewater but having less knowledge about surveillance for other public health issues such as opioids. We found that attitudes toward wastewater testing for public health were directly associated with differences in self-reported capacity of the plant to take samples. Further, findings suggest a diverse capacity for sampling across sewer systems with larger treatment plants reporting greater capacity for more frequent sampling. Findings provide guidance for outreach activities as well as important insight into treatment plant sampling capacity as it is connected to internal factors such as size and resource availability. These may help public health departments understand the limitations and ability of wastewater surveillance for public health benefit.
1. Introduction

Wastewater surveillance, i.e. the routine and continuous testing of wastewater for public health benefit, has been a public health tool for decades with most common application prior to the COVID-19 pandemic related to the surveillance of poliovirus (Kilaru et al., 2021). The emergence of COVID-19 has brought this method to the forefront of available surveillance tools because of the ability to detect inactive viral fragments of SARS-CoV-2 (the virus that causes COVID-19) in wastewater (Pulicharla et al., 2021). Testing of wastewater for SARS-CoV-2 has been implemented around the world in communities (Naughton et al., 2021; Yeager et al., 2021), universities (Harris-Lovett et al., 2021; Reeves et al., 2021), and buildings (Colosi et al., 2021). These applications recover samples at different points along the wastewater stream, but the most accessible sampling point for most communities is the wastewater treatment plant (WWTP) (Calle et al., 2021). The WWTP is connected to all the sewers leading to the facility, represents the entire upstream population, and is convenient, making it an ideal place to sample (Wu et al., 2021). Essential participants of wastewater surveillance at treatment plants include the plant personnel, but not much is known about plant personnel and their knowledge, attitudes, and capacity to participate in wastewater surveillance for public health benefit.

Wastewater can be sampled using different methods including the taking of twenty-four-hour composite samples (hereafter 24 h composite) and grab samples. The taking of 24 h composite samples involves a sampler that pools wastewater into a single sample over a specified time, most commonly twenty-four hours (Ahmed et al., 2021). Grab sampling involves taking one wastewater sample at a specific time (Diwan et al., 2013) and has been shown to be at least somewhat comparable to composite sampling for SARS-CoV-2 results (Rafiee et al., 2021). Other methods include passive sampling, where an absorbent device is placed in the wastewater stream and the water is absorbed over a specified time (Hayes et al., 2021). In our survey, we refer to grab samples and passive samples in the same question regarding capacity (hereafter grab samples).

Wastewater surveillance for COVID-19 in the US has been implemented in many states including Kentucky (Holm et al., 2022) and New York (Larsen et al., 2021). Various municipalities, counties, and states have used the results from wastewater surveillance to make public health policy decisions during the COVID-19 pandemic (Gerba and Glennon, 2020). In addition, many media outlets report rises and declines in wastewater detection of SARS-CoV-2 to increase public health awareness (Abraham et al., 2020). The usefulness of this method for informing viral transmission and the spread of other diseases has led the US Centers for Disease Control (CDC) to develop a National Wastewater Surveillance System (NWSS) that was implemented in 2021 across several states (Kirby et al., 2021). In late 2021, the CDC expanded the program with the intent to scale to 500 treatment plants across the country taking samples twice per week (CDC, 2021).

As wastewater surveillance for public health has rapidly expanded across the US into statewide (Ai et al., 2021) and national programs (Kirby et al., 2021), more treatment plants are being enrolled with the assumption that the personnel have the training and equipment to take and ship samples without additional equipment, funding, or training. Still, there is uncertainty regarding the level of burden that taking samples of wastewater for public health places on treatment plants. Can sampling wastewater at the treatment plant be maintained using existing water treatment plant personnel and infrastructure or is more support needed? There has been little study of treatment plant personnel to see what capacity these facilities possess to take on added testing for public health; this is one question our study helps address.

Wastewater infrastructure in New York State (NYS) is aging with many cities and villages needing updates to treatment plants and sewer systems (DEC, 2008). There are 639 municipal treatment plants reported by the NYS Department of Environmental Conservation (DEC) serving over 1600 municipalities and providing sewer services to an estimated 15 million people (80% of the state population) (DEC, 2008). WWTPs are owned and operated in different ways depending on the municipality; some are owned by the local government while others are privately owned (DEC, 2015). Staffing also varies with treatment plant personnel working for the local government in some municipalities and others working for private firms hired to run the plant for the community (DEC, 2022b).

WWTP personnel are required to be certified in NYS and are usually engineers (DEC, 2022a). The NYS DEC is the primary regulator of treatment plants particularly carrying out policy and inspections related to state and Federal Clean Water Act requirements (DEC, 2022b). Treatment plants also must comply with US Federal laws such as water quality standards and antidegradation statutes (EPA, 2022). These antidegradation statutes are a combination of state and Federal laws that treatment plants must follow, with state inspectors handling oversight (EPA, 2022). As part of their duties, operators take samples at the treatment plant to ensure they are in compliance with water quality standards and to assess the effectiveness of treatment systems’ removal of harmful elements such as fecal coliform (Suh et al., 2009). There are no regulatory requirements in NYS that direct sampling frequency, but there are normative practices. The regularity of sampling at treatment plants in NYS is ancestrally linked to the permitted discharge capacity with plants over five million gallons per day often sampling twice weekly, plants between one and five million gallons per day sampling once weekly with a dedicated sampler, and plants below one million gallons per day sampling monthly (DEC, personal communication). Given that treatment plants regularly sample wastewater for environmental compliance, sampling wastewater for public health surveillance could potentially fit within these current activities. This leads us to the present study where we ask treatment plant operators about their knowledge, attitudes, and capacity to take samples for public health surveillance.

As part of the NYS effort to establish a statewide wastewater surveillance network, we surveyed treatment plant operators in NYS about their knowledge, attitude, and practices regarding wastewater testing for public health benefit. Our objectives were to: (1) determine how much knowledge wastewater treatment plant operators have of wastewater surveillance for public health; (2) identify operators’ attitudes toward testing wastewater for infectious diseases; and (3) assess the capacity of wastewater treatment plant operators in NYS to take and ship samples of wastewater to labs for analysis.

2. Materials and methods

2.1. Survey design and distribution

We surveyed the knowledge, attitudes, and practices of wastewater treatment plants in NYS regarding wastewater surveillance to track
COVID-19. Knowledge questions measured respondents’ awareness that COVID-19 can be tracked through wastewater (Table 1). We also asked about knowledge of testing opioids because of its relevance as an emerging public health issue and its ability to be monitored via wastewater (Gushgari et al., 2019). Attitude questions measured respondents’ perceptions as to the affordability of wastewater surveillance and whether the respondent felt it could benefit their community (Table 1). Practice questions assessed where wastewater surveillance for COVID-19 or for other substances was happening during the summer of 2021. In addition, we assessed capacity for treatment plants to participate in wastewater surveillance for public health (Table 1). We pre-tested the questionnaire with 10 participants to check technology and distribution methods. For the full question list, please see the supplemental data (Appendix 1).

The survey was built in Qualtrics and sent out via mass email to respondents with nonresponses followed up by phone. The survey was not sent to plant operators in DEC Region 2 (New York City) because it is considered a separate CDC jurisdiction. In total, 385 potential respondents were contacted. This procedure was conducted between July 15, 2021, and October 31, 2021. The survey design was approved by the institutional review board of Syracuse University under exempt status. Respondents had the option to report results for more than one treatment plant if they were responsible for multiple plants. Results for these plants were separated by treatment plant with an indicator used in the analysis to identify the response as coming from the same respondent. Since respondents could fill out the survey for multiple plants, there may be bias from these multiple responses. We address this below with our robustness checks.

2.2. Statistical analyses

We tested the association between knowledge and attitudes about wastewater surveillance and how frequently treatment plants can take and ship samples using chi-square tests for independence. We also tested to see if there were differences in the frequency that treatment plants can take and ship samples by region using chi-square tests for homogeneity of response between DOH and DEC regions.

To understand what influences the frequency that treatment plants can take samples, we fit an ordinal regression. We chose this model because our three response variables for capacity (24 h composite sampling, grab sampling, and shipping samples) were ordered categories for the number of days per week that each respondent reports. We collapsed the do not know/unsure category into the response for no capacity because uncertainty about sampling frequency may be similar to lack of ability. We also compared results with and without the collapsed response with no change in coefficients determining to include the collapsed results in our final models. The model statement is:

\[
\Pr(y > K - 1) = \logit^{-1}(X\beta + c_{K-1})
\]

We calculated the probability that a change in one of the predictor variables, represented by the matrix \(X\), will result in a change in the outcome by moving up or down \(K\) levels. The response is noted by \(y\), and \(\beta\) is the vector of coefficients. \(c_{K-1}\) represents the distance between any two adjacent levels and how this impacts the probability that \(y = K\). The levels of \(K\) include: “no ability to test, once weekly sampling, twice weekly sampling… up to Daily.”

Numerous factors might influence a treatment plant’s sampling frequency. We adjusted analyses for the size of the treatment plant using the average daily flow in millions of gallons per day. Daily flow is a good indicator for population served by the treatment plant, and we used it also as an indicator for both differences in WWTP funding as well as available personnel. Daily flow was obtained from DEC records for each treatment plant (DEC, 2022c). We also adjusted analyses for whether the plant was within a US Census designated urban area or not by matching the location of the plant with reported urban status (US Census, 2021). This status might also indicate differences in resources that the plant might have access to. We also included several questions from our survey as covariates. We included whether the plant has tested any pathogens in the past as experience.
with testing may be associated with different capacity. We also included whether the respondent knows about COVID-19 or opioid surveillance since this could be an indicator for different training levels that might vary across plants. We included whether the plant reports having geospatial information systems (GIS) data of the plant’s service area as a covariate because lack of these data might indicate reduced resources at the plant. We also include whether the respondent indicated that the plant has public or private partners that it already works with for testing. The existence of such partners could be related to greater capacity to sample. We also considered whether the plant was part of a network of treatment plants because this could indicate the ability for resource and personnel sharing between plants that might change capacity to sample more frequently. Last, we included a control in our model for potential response bias from operators that work at plants that participated in the NYS wastewater surveillance program for COVID-19 in 2020 or 2021. Participation in the program might be associated with greater perceived sampling capacity. Covariate statistics and rationale are collected in Table 2.

2.3. Robustness checks

There were some responses that were incomplete from our survey. We received 116 surveys with 98 complete surveys. For the chi-square tests and other analyses, missing responses were left out. This varies for each question with some having more missing responses than others due to incomplete surveys that were terminated at different points. Non-response values were also left out of percentage calculations. For the ordinal regression, 17 survey responses were removed because they did not answer the dependent variable for 24 h composites or grab sampling, and 18 survey responses were removed because they did not answer the shipping question leaving 99 and 98 observations for these respective analyses.

For the ordinal regression, we tested whether past participation in previous COVID-19 surveillance programs bias our results. There was no significant difference in model results from this variable. For surveys filled out for more than one plant by the same individual, we tested whether there was some bias from those responses. Four respondents filled out the survey for more than one plant. There was variation within the respondent’s answers for many questions including whether testing was happening at the plant. We tested two methods of controlling this: one was to include a fixed effect for whether the response was part of a multi-plant response and the second was to run the model with a random effect for each respondent. There was not much difference in model results using these methods, as strength and direction of effects were similar. Further, the Akaike information criteria (AIC) of the fixed effect models were lower than for the random effect models (AIC for the fixed-effect 24 h composite model is 268.23 and the AIC for random effects 24 h composite model is 275.4). Therefore, we report the results of the model with a fixed effect for multi-plant response since it was the most parsimonious.

The other source of potential bias in our results was whether we received more respondents from one region of NYS than another. In addition, since we did not employ a random sampling strategy, we wanted to ensure our results were not spatially biased. We conducted a test for spatial clusters among our

Fig. 1. Map of all survey respondents (n = 116) across the four regions of the NYS Department of Health.
responses using the Average Nearest Neighbors approach for spatial clusters comparing the observed responses to the actual distribution of treatment plants in NYS (Fortin et al., 2002). We found that there was no spatial clustering of our responses based on a comparison of the spatial point pattern to a random pattern across NYS ($p = 0.17$, threshold $\alpha = 0.1$). The test indicated good distribution of responses across the state. All analyses were conducted in R version 4.1.1 (R Core Team, 2021) and the “MASS” package was used for the ordinal regression (Venables and Ripley, 2002).

3. Results

Of the 385 contacts that were attempted, 116 total surveys were returned providing a response rate of 30.1% representing 18.2% of all the municipal wastewater treatment plants identified by the DEC. The map of all respondents across NY Department of Health Regions (DOH) is displayed in Fig. 1. We used DOH regions in addition to DEC regions for our analyses because public health surveillance at treatment plants is funded and supervised by the DOH with support from DEC. There was good distribution of responses by size across treatment plants when comparing the average size of treatment plants across the state (Fig. 2).

3.1. Knowledge of wastewater surveillance

We found that 85% of respondents knew that COVID-19 can be detected in wastewater (Fig. 3). For knowledge of opioid testing, 54% of respondents knew that opioids can be detected in wastewater samples (Fig. 3). Knowledge of wastewater surveillance was not associated with any other variables suggesting homogenous knowledge across NYS regions and

Fig. 2. Average daily flow for respondents’ treatment plants v. all plants in NYS.

Fig. 3. Knowledge of wastewater testing for COVID-19, opioids, and the cost of surveillance. More respondents were aware that COVID-19 can be detected in wastewater than respondents who knew that opioids can be detected. Most respondents did not have knowledge about how much wastewater testing costs.
independent of other variables we tested (chi-square tests were insignificant for $\alpha = 0.05$). In addition, knowledge regarding the cost of wastewater testing was relatively low; 29% of respondents indicated they knew a little about cost and 68% report they did not know about the costs of surveillance. Only 3% reported they "knew a lot" about the cost of wastewater surveillance (Fig. 3 and Table 3).

### 3.2. Attitude toward wastewater surveillance

We had two questions regarding attitudes toward wastewater surveillance. The first asked about how the respondent felt regarding the affordability of wastewater testing for public health. We found that attitudes were associated with testing capacity (Fig. 4, $p$-value < 0.01). Respondents that strongly agreed with the affordability of wastewater testing reported being able to take 24 h composite samples and grab samples more frequently whereas respondents who moderately or strongly disagreed with the question reported testing frequency of two or fewer days per week for 24 h composite samples (Fig. 4). Respondents that strongly agreed with the affordability of wastewater testing were more likely to report being able to ship samples three to five days per week whereas those reporting insufficient personnel to ship were less likely to indicate that they strongly agree with the affordability of wastewater testing (Fig. 4).

The second attitude question we asked was how the respondent felt about the benefits of wastewater testing for their community. We found this was highly associated with grab sample capacity (chi-square = 42.52, $p$-value < 0.01) and shipping capacity (chi-square = 48.52, $p$-value < 0.01) (Fig. 5). Respondents who strongly agreed with this statement were more likely to report being able to take grab samples three or five times per week whereas those who strongly disagreed reported only being able to take grab samples once per week. For shipping, respondents who strongly agreed that wastewater testing was beneficial for their community were more likely to report being able to ship samples three or five times per week whereas those that disagreed reported being able to ship only twice per week (Fig. 5). We also found that this attitude was not significantly associated with capacity to take 24 h composite samples (chi-square = 24.11, $p$-value = 0.24).

### 3.3. Capacity to take and ship samples

Reported capacity to take and ship samples varies across NYS DEC and DOH regions. We found that there was an association between being able to ship samples more frequently and the DOH region the treatment plant was within (Table 4). The Capital District and New York City regions reported the lowest capacity for shipping samples while the Western Region and Metropolitan Area reported higher capacity (chi-square = 39.059, $p$-value = 0.003). For DEC region, there were differences between most regions for both sampling and shipping capacity (Table 4). We found that DEC region was associated with the frequency of taking 24 h composite samples and shipping samples (24 h composite samples Chi-square = 56.182, $p$-value = 0.013 and shipping samples chi-square = 71.761, $p$-value = 0.003). There was only marginal association between DEC region and frequency for taking grab samples (chi-square = 46.950, $p$-value = 0.085). We found that DEC Regions 3 and Region 9 reported the highest capacity for shipping samples whereas Region 6 reported the lowest capacity for shipping samples while the Western Region reported the lowest capacity for shipping samples whereas the Capital District and Central New York regions reported higher capacity (chi-square = 39.059, $p$-value = 0.003). The Capital District and Metropolitan Area reported higher capacity (chi-square = 39.059, $p$-value = 0.003). The Capital District and Metropolitan Area reported higher capacity (chi-square = 39.059, $p$-value = 0.003). The Capital District and Metropolitan Area reported higher capacity (chi-square = 39.059, $p$-value = 0.003).

We also compared regions to see if there were differences in operator capacity to take samples twice per week. We selected twice per week for this comparison because the CDC NWSS has implemented a twice weekly sampling standard. We found no significant difference between treatment plant operators’ responses across DOH or DEC regions and their ability to take and ship 24 h composite or grab samples at least twice per week (Table 4).

From our ordinal regression models, we found that size was associated with treatment plant capacity to take and ship samples. The size of the treatment plant was significantly associated with greater frequency of taking 24 h composite samples ($\beta = 0.842, p$-value = 0.012) and moderately associated with greater frequency for shipping samples ($\beta = 0.519$, $p$-value = 0.03).
There was no significant association between size of the treatment plant and frequency for taking grab samples ($\beta = 0.394$, $p$-value $= 0.213$). The most significant difference between capacity and size were for plants reporting either no equipment to take 24 h composite samples or capacity to do it once per week (Fig. 6). There was also a large association for size and capacity between plants that can sample 24 h composites twice per week as opposed to three times per week with larger plants more likely to report greater frequency (Fig. 6).

In addition to size, the other important predictor of treatment plant sampling frequency was if the respondent reported they were part of a multi-plant network. Respondents that supervised more than one treatment plant reported greater capacity to take 24 h composite samples ($\beta = 3.219$, $p = 0.001$), greater capacity to take grab samples ($\beta = 2.841$, $p = 0.001$) and greater capacity to ship samples ($\beta = 1.242$, $p$-value $= 0.042$, Table 5).

If a treatment plant tested for any pathogen in the past, we found moderate support that they have capacity to take 24 h composite samples more frequently than plants that have never tested for pathogens in the past ($\beta = 1.895$, $p$-value $= 0.061$). We also found moderate association between knowledge of COVID-19 being detected in wastewater and ability to take 24 h composite samples more frequently ($\beta = 1.279$, $p$-value $= 0.063$) but no association between knowledge and grab sample frequency or shipping frequency (Table 5). No other covariates that we tested were significantly associated with the frequency that plants report capacity to take and ship samples ($\alpha = 0.05$).
4. Discussion

4.1. Knowledge of wastewater testing

We found that most respondents knew that wastewater can be tested for COVID-19, which was expected due to high media attention (Abraham et al., 2020). Knowledge was also higher than published results of surveys from the same time period (2021) that found that in one community, 49% of respondents did not know whether the coronavirus that causes COVID-19 could be detected in wastewater (Holm et al., 2022). Further, a nationwide study in the US found that 42% of respondents did not know wastewater could be used to track COVID-19 (Lajoie et al., 2022). Our results may be suggestive that wastewater treatment plant operators have more specialized knowledge or awareness of recent trends, such as public health surveillance through wastewater, than the general public. The cost of wastewater surveillance was less understood by respondents; most operators in our study (68%) had no knowledge of the cost of testing (Fig. 3).

The lack of knowledge about cost of testing wastewater for public health purposes was likely driven by the infrequency of smaller plants testing wastewater beyond DEC regulatory needs, although this may also be linked to over-representation in our survey response of plants that have never participated in testing before (n = 104, 90%, Table 3). This lack of knowledge combined with most respondents uncertainty or lacking opinion about the affordability of wastewater testing (n = 58, 50%, Table 3) might provide a good opportunity for education and outreach programs. Operators do not appear to have pre-conceived notions about cost for this kind of program and may be more open to learning about it. This, in addition to findings that communities support increased public health surveillance methods

![Fig. 6. Frequency of taking and shipping samples is associated with treatment plant size. Treatment plants of larger size report higher capacity to sample more frequently using 24 h composite samples and ability to ship samples more frequently than smaller plants. There is not much difference between sampling frequency using grab methods and treatment plant size.](image)

Table 4
Chi-square results for capacity and NYS regions. We compared sample and shipping frequency (days per week) and also if the plant could take and ship samples at least twice per week, which is the current CDC standard for the NWSS Program. There were differences in frequency by regions suggesting some regions have greater capacity to sample more times per week, however, there were no differences between regions for sampling twice per week.

| Comparison                                      | X² statistic | p-value |
|-------------------------------------------------|--------------|---------|
| DOH region and 24 h composite sample frequency  | 19.759       | 0.181   |
| DOH region and grab sample frequency            | 22.930       | 0.086*  |
| DOH region and shipping frequency                | 39.059       | 0.003***|
| DEC region and 24 h composite sample frequency  | 56.182       | 0.013***|
| DEC region and grab sample frequency             | 46.950       | 0.085*  |
| DEC region and shipping frequency                | 71.761       | 0.003***|

Notes: *p < 0.1, **p < 0.05, ***p < 0.01.

Table 5
Model results for the ordinal regressions. Standardized coefficients, standard errors, t-values, and p-values are reported.

| Variable                        | β    | SE     | t-value | p-value |
|---------------------------------|------|--------|---------|---------|
| Average flow (log)              | 0.842| 0.334  | 2.519   | 0.012***|
| Urban                           | 0.462| 0.468  | −0.987  | 0.324   |
| Tested in past any pathogen     | 1.895| 1.013  | 1.871   | 0.061*  |
| Know COVID can be detected      | 1.279| 0.681  | 2.056   | 0.040***|
| Know opioids can be detected    | 0.336| 0.447  | 0.753   | 0.453   |
| Part of multi-plant network     | 3.219| 0.961  | 3.349   | 0.001***|
| Part of NYS network             | −0.859| 0.801  | −1.072  | 0.284   |
| Presence GIS data               | 0.261| 0.499  | 0.523   | 0.601   |
| Public Partners                 | −0.087| 0.483  | −0.180  | 0.857   |
| n                               | 99   | 99     | 1.107   | 0.290   |
| AIC                             | 268.229| 289.334| 323.159|

Notes: *p < 0.1, **p < 0.05, ***p < 0.01.

Fig. 6. Frequency of taking and shipping samples is associated with treatment plant size. Treatment plants of larger size report higher capacity to sample more frequently using 24 h composite samples and ability to ship samples more frequently than smaller plants. There is not much difference between sampling frequency using grab methods and treatment plant size.
such as through wastewater (Holm et al., 2022), provides a supportive environment for recruiting treatment plants for testing. Lastly, outreach efforts can capitalize on educating operators regarding the broad reach that public health surveillance can have. Nearly half of respondents (46%, Fig. 3) did not know that opioids can be detected in wastewater. There have been few studies on public awareness of wastewater surveillance, with existing studies suggesting that awareness of wastewater testing for opioids and illicit drugs is low (Lajoie et al., 2022). Research has shown broad support for public health action to address the opioid epidemic (Cook and Worcman, 2019) and educating the public and treatment plant personnel about testing wastewater for opioids could be an important communication tool for increasing awareness.

4.2. Attitudes about testing benefits

Regarding attitudes about the affordability and benefits of wastewater testing for public health, most respondents were uncertain or did not have an opinion about the cost of testing (50%, Table 3), and many were uncertain or had no opinion about the benefits of testing (35.35%, Table 3). We found that respondent’s attitude toward affordability was linked to the capacity of their treatment plant to test. Respondents that worked at plants with greater capacity to test wastewater were more likely to moderately or strongly agree that wastewater testing was affordable whereas if they reported less frequent testing capacity, the respondents were more likely to disagree that testing is affordable (Fig. 4). This suggests that available resources of the plant personnel may influence their attitude about the costs of testing; treatment plants that have greater resources and ability to test may be more likely to view a public health testing program more favorably. Attitudes about the benefits of testing for respondents’ communities was slightly less tied to capacity to take 24 h composite samples, but it was linked to ability to take grab samples and to ship samples as seen in the greater correlation between those questions (Fig. 5).

These findings support efforts for direct outreach to treatment plants to inform them about testing costs and requirements as well as potentially providing resources such as additional personnel or equipment to plants that report reduced capacity to test. This could also be a result of response bias where respondents with less capacity to test were predisposed to think that testing is expensive or not beneficial. Follow-up surveys may be needed to better understand this association. It is important for treatment plant operators to be kept informed about data collected at their plant and how it is used since they are essential partners in testing activity. Programs that seek treatment plant operators as partners should therefore establish and maintain lines of communication to keep operators involved as testing occurs and results are reported. Ongoing outreach may be a critical part in building and maintaining a wastewater surveillance system long-term. Capacity for testing is directly linked to resource and regional differences across NY.

4.3. Regional differences in testing capacity

We found that there were some regional differences regarding the frequency that treatment plants can take samples. Treatment plants reported greater sampling frequency in the DOH Western Region and Metropolitan Area and reported lower frequency in the Capital District and Central New York DOH regions (Table 4). There was a similar association for DEC regions where testing frequency was not homogenous across the regions (Table 4). An important distinction is that the frequency was associated with regional differences and could be linked to differences in resource distribution, personnel, and other factors, however, the capacity to take samples twice per week was not associated with regional differences (Table 4). This means that treatment plants can participate in public health testing regardless of region if the testing is once or twice per week. If testing were to expand beyond twice per week, then there might be additional needs from treatment plants in some regions to take on more frequent testing. Twice weekly testing has been found to be adequate for establishing public health trends for COVID-19 and infectious diseases (Feng et al., 2021). Even less frequent testing is needed for opioids and other substances (Gushgari et al., 2019). Our findings suggest most treatment plants in NYS can take 24 h composite samples at least once per week (54.31%, Table 3) and grab samples at least once per week (56.9%). The differences across respondents’ answers regarding the frequency of testing is directly associated with treatment plant size.

4.4. Testing capacity and treatment plant size

Our ordinal regression models support significant association between greater treatment plant size and greater frequency to take and ship 24 h composite samples but no significant association for frequency to take grab samples (Table 5). These results support using different methods, such as grab sampling, in settings where the treatment plant may either lack equipment or resources to take 24 h composite samples. Although some research has shown these methods to be equitable for testing COVID-19 (Rafigee et al., 2021), findings are not yet conclusive to support any one sampling method over another (Ahmed et al., 2021; Curtis et al., 2020). The finding that plant size was an important predictor of testing frequency (Fig. 6) suggests that testing capacity is directly associated with differences in funding, personnel, and equipment that depend on plant size. On-site equipment may vary and be tied to variation in treatment plant capacity and the type and age of the treatment system, as past studies have shown (Bertanza et al., 2022). Other studies on wastewater treatment by utilities have found links between capacity to sample, frequency, and the type of surveillance (Muga and Mihelcic, 2008) suggesting that the optimal sampling frequency for COVID-19 testing may not be compatible with current regulatory standards, equipment limitations, and personnel. Knowing that smaller treatment plants may require additional resources to test more frequently could inform resource distribution for both NYS and other states looking to expand wastewater surveillance to different communities.

Findings were consistent with current normative practices at treatment plants based on discharge capacity with larger plants (five million gallons per day and higher) most likely sampling twice weekly as part of meeting permit requirements (DEC, personal communication). This might explain the large difference in sampling frequency seen in Fig. 6 where sampling once weekly or greater is more likely for plants of larger size. These larger plants were also more likely to have dedicated sampling equipment, making splitting samples and participating in additional sampling more likely (DEC, personal communication). Government public health organizations may seek to offer or provide sampling equipment to plants with reduced capacity or equipment. Additionally, treatment plants that were part of a network and administered together can take samples more frequently, which can help with selecting sampling locations since these kinds of treatment plants may be able to share resources such as personnel.

Returning to our objectives, we found that most treatment plant operators were knowledgeable about testing wastewater for COVID-19 (Fig. 3), but they were less knowledgeable about costs and testing for opioids. We also found evidence that operators’ attitudes toward public health testing of wastewater were associated with their treatment plant’s capacity to take samples and therefore participate in such a program (Figs. 3 and 4). Finally, we found that capacity to take samples was directly associated with the size of the treatment plant where larger plants were capable of testing more frequently, likely due to greater funding, personnel, and resources (Fig. 6). The findings of our study are most generalizable to NYS with results applicable across all NYS regions. Generalizing beyond NYS is possible for some findings particularly those related to testing frequency. We find testing frequency is directly associated with treatment plant size and whether the plant exists in a network of other plants. These two factors are relevant in other states across the US and may be applicable in other countries as well. Generalizing findings should consider the similarity of treatment plant systems in other states and countries. Other findings may be relevant regarding knowledge and attitude, but they should not be considered the same in other places unless they can be validated through similar studies or through outreach.
Our study has limitations that also influence generalizability. First, while we had good distribution of responses across DOH and DEC regions, there were a few DEC regions that were less represented including Regions 1, 5, 6 and 8 (Table 2). This is likely due to the lack of contact information within some of these regions. Future studies in NYS and in other states should seek to obtain as much contact information as exists and perhaps include an extended phase of contact information gathering. Further, a random sampling plan could also improve the results of future studies. While our sample design did result in good spatial distribution, this is not guaranteed for other projects. Another limitation relates to our question design. We combined the sampling techniques of the grab sample and passive sampling (such as the Moore swab) into one question. These two methods should have been separated, especially as new evidence suggests the Moore swab may be more sensitive (Rafiee et al., 2021). One other limitation is that we did not ask in our survey what the role of the respondent was at the plant. There may have been differences in responses, for example knowledge of testing, that may have been linked to differences between operators and supervisors. Future surveys should investigate whether knowledge may vary based on variables like years of experience, job position, and whether the respondent has administrative duties.

One other finding that is important for future public health efforts to expand the use of wastewater-based epidemiology is the importance of educating operators and including them as meaningful participants in this kind of public health program. Participation and capacity were linked to resource differences, but most operators were knowledge able and reported capacity to participate. It is up to the public health agencies that seek to use wastewater surveillance to ensure that treatment plant personnel are 1) kept informed and involved in making sampling plans to ensure the best approach is used for their situation, and 2) receive results from the samples that they collect. This cooperation between health agencies and treatment plant operators can help avoid issues such as burnout or apathy toward participation and improve long-term sustainability of a wastewater surveillance program. Overall, wastewater treatment plants reported capacity to participate in public health surveillance activity and there are opportunities to educate and train personnel regarding the benefits for communities.

5. Conclusions

- Wastewater treatment plant personnel were knowledgeable about the ability to track COVID-19 through wastewater sampling.
- Attitudes about the affordability of wastewater testing for public health and its benefits to respondents’ communities was linked to the frequency that the respondents’ plants can take samples with agreement in the benefits associated with more frequent testing capacity.
- Larger treatment plants can test more frequently than smaller treatment plants, however, majority of treatment plants can take at least two samples per week, using existing resources, which means participation in expanded testing programs could be widespread.
- We found that 47% of respondents can take 24 h composite samples twice weekly, 62% of respondents can take grab samples twice weekly, and 39% of respondents report capacity to ship samples twice weekly.

CRediT authorship contribution statement

Dustin T. Hill: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Hannah Cousins: Investigation, Methodology, Writing – review & editing.

Bryan Dandaraw: Investigation, Methodology, Writing – review & editing.

Catherine Faruolo: Investigation, Methodology, Writing – review & editing.

Alex Godinez: Investigation, Methodology, Writing – review & editing, Software.

Syt Jong Run: Investigation, Methodology, Writing – review & editing, Software.

Simon Smith: Investigation, Methodology, Project administration.

Megan Willkens: Investigation, Methodology, Writing – review & editing.

Shruti Zirath: Investigation, Methodology, Writing – review & editing.

David A. Larsen: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Abraham, M.M., Chakraborty, P., Baharat, G.K., Roy-Banu, M., 2020, December 14. Monitoring of Community Wastewater for Early Signalling the Spread of COVID-19 in Chennai City. The Energy Research Institute. https://www.teriin.org/policy-brief/monitoring-community-wastewater-early-signalling-spread-covid-19-chennai-city.

Ahmed, W., Bivins, A., Berthas, P.M., Ribby, K., Gwynn, P., Sherron, S.P., Simpson, S.L., Thomas, K.V., Verhagen, R., Kitajima, M., Mueller, J.F., Korjakis, A., 2021. Intraday variability of indicator and pathogenic viruses in 1-h and 24-h composite wastewater samples: implications for wastewater-based epidemiology. Environ. Res. 193 (October 2020), 110531. https://doi.org/10.1016/j.envres.2020.110531.

Ai, Y., Davis, A., Jones, D., Lemeshow, S., Tu, H., He, F., Ru, P., Pan, X., Bohrerova, Z., Lee, J., 2021. Wastewater SARS-CoV-2 monitoring as a community-level COVID-19 trend tracker and variants in Ohio, United States. Sci. Total Environ. 801, 149757. https://doi.org/10.1016/j.scitotenv.2021.149757.

Bertanza, G., Boiocchi, R., Pedrazzani, R., 2022. Improving the quality of wastewater treatment plant monitoring by adopting proper sampling strategies and data processing criteria. Sci. Total Environ. 806, 150724. https://doi.org/10.1016/j.scitotenv.2021.150724.

Calle, E., Martinez, D., Brugués-i-Pujolràs, R., Farreras, M., Salgu-Grau, J., Puero-Ros, J., Coronas, L., 2021. Optimal selection of monitoring sites in cities for SARS-CoV-2 surveillance in sewage networks. Environ. Int. 157. https://doi.org/10.1016/j.envint.2021.106768.

CDC, 2021. National Wastewater Surveillance System (NWSS). Centers for Disease Control and Prevention. https://www.cdc.gov/healthywaste/surveillance/wastewater-surveillance/wastewater-surveillance.html.

Colosi, L.M., Barry, K.E., Kotey, S.M., Porter, M.D., Poultier, M.D., Ratliff, C., Simmons, W., Steinberg, L.J., Wilson, D.D., Morse, R., Zimick, P., Mathes, A.J., 2021. Development of wastewater pooled surveillance of severe congregate living settings. Appl. Environ. Microbiol. 87 (12) e00433-21.

Cook, A.K., Woernan, N., 2019. Confronting the opioid epidemic: public opinion toward the expansion of treatment services in Virginia. Health Justice 7 (1). https://doi.org/10.1186/s40582-019-0095-8.

Curtis, K., Keeeling, D., Yetka, K., Larson, A., Gonzalez, R., 2020. Wastewater SARS-CoV-2 Concentration and Loading Variability From Grab and 24-Hour Composite Samples.
