Wastewater Surveillance to Inform Public Health Decision Making in Residential Institutions

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ABSTRACT

Testing sewage (wastewater-based surveillance, or WBS) for pathogens is an increasingly important tool for monitoring the health of populations. During the COVID-19 pandemic, some residential institutions including colleges, prisons, and skilled nursing facilities used facility-level wastewater data to inform their pandemic responses. To understand how these early adopters used WBS data in decision making, we conducted in-depth, semistructured interviews with multiple decision makers at 6 residential institutions in the United States (universities, prisons, and nursing homes) encompassing a total of more than 70 000 residents and staff about interpretation, uses, and limitations of these data. We found that WBS data were used in extremely diverse ways. WBS combined with clinical surveillance informed a wide range of public health actions at residential institutions, including transmission reduction measures, public health communications, and allocation of resources. WBS also served other institutional purposes, such as maintaining relationships with external stakeholders and helping alleviate decision makers' pervasive stress. Recognizing these diverse ways of using WBS data can inform expansion of this practice among institutions as well as development of community-scale systems.

KEY WORDS: COVID-19, institutions, public health decision making, SARS-CoV-2, wastewater-based surveillance

Wastewater-based surveillance (WBS) emerged as a tool to support public health decision making during the COVID-19 pandemic.[1,2] Broadly, WBS consists of regularly collecting samples of wastewater from sewer pipes or from the influent to wastewater treatment plants, sending the samples to a laboratory (which is generally operated by a private company, a public health department, or a research group) for analysis, and returning the data to decision makers and/or the public. Data about concentrations or quantities of SARS-CoV-2 RNA in wastewater can complement clinical surveillance by revealing population-wide trends in infection occurrence, including asymptomatic infections, that are unbiased by individuals' participation in and access to clinical testing. WBS can potentially provide early warning of outbreaks.[3,4] Since early 2020, some residential institutions including colleges and universities, prisons, and skilled nursing facilities have used WBS as part of their pandemic response.[5] Faced with limited resources, multiple uncertainties, and high expectations for protecting their resident populations, these early adopters wrestled with using WBS data to help them make urgent public health decisions in real time. These institutions' use of WBS data provides a rich source of experience for understanding the opportunities, challenges, and requirements of effectively integrating WBS into public health action. This study aimed to uncover the specific uses of WBS for public health decision making in residential institutions during the COVID-19 pandemic.

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This work was partly supported by the Catena Foundation. Dr Korfmacher is partly supported by the National Institute of Environmental Health Sciences P30 001247.

The authors gratefully acknowledge the interviewees who generously shared their time to reflect on their experiences during a particularly challenging time.

The authors have no conflicts of interest to disclose.

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DOI: 10.1097/PHH.0000000000001636

Methods

Throughout the COVID-19 pandemic, the authors facilitated professional networks of WBS practitioners working to use wastewater data about SARS-CoV-2. Specifically, the authors convened and facilitated working group discussions that consisted of public health decision makers, wastewater agency staff, researchers, and other interested parties who met

regularly to discuss new developments, share information and ideas, and brainstorm solutions to challenges. We drew from these networks to select key informants from a range of residential institutions including prisons, universities, and a skilled nursing facility. The key informants chosen for this study were professionally responsible for health of populations within their institutions and were early adopters of WBS. Key informants can serve as proxies for their organizations, and interviews with key informants can be used to understand institutional decision making.[6] We conducted in-depth, semistructured interviews with 11 key informants at 6 institutions in the United States that utilized WBS for SARS-CoV-2 for at least 6 months between 2020 and 2022. The institutions ranged in size from 1000 to 35 000 residents and staff (3 universities, including a small private college, a mid-sized public university, and a large public university system; 2 state prisons, including one with a building layout not conducive to social distancing and one with more potential for isolating ill residents but with a medically vulnerable elderly population; and a privately operated skilled nursing facility). All had limited ability to clinically test residents and employees, and clinical testing strategies varied over the course of the pandemic. WBS frequency at these institutions ranged from daily testing at numerous on-site locations to twice-per-week testing at a single location, and many of the institutions changed their approach over the course of the pandemic. Sample collection at the different institutions was performed by institutional staff, students, or local wastewater agency staff, and samples were sent either to academic research groups or to commercial laboratories for analysis. The laboratories provided data to institutional decision makers either as a concentration of SARS-CoV-2 per volume wastewater or as a positive/negative "signal" (indicating detection or nondetection of SARS-CoV-2 in wastewater). Payment systems for WBS included self-funding, external funding from a research group, and funding from a state agency. In total, respondents were responsible for public health decision making for more than 70 000 institutional residents.

We interviewed the respondents at each institution via videoconferencing lasting 60 to 90 minutes. Open-ended interview questions asked respondents to describe their experiences with WBS at their institutions; to reflect on how the added value, interpretations, and uses of the data changed over the course of the pandemic; and to describe the challenges or barriers to using the WBS results to inform decision making. Interviews were recorded, transcribed, and coded by hand and using Microsoft Word for common themes.

The research protocol for interviewing key respondents was approved by institutional review boards at UC Berkeley (CPHS Protocols 2020-11-13796 and 2021-06-14387) and University of Rochester (Submission ID MOD00011215).

Results

Interview respondents uniformly reported that WBS complemented their institution's clinical surveillance efforts. For example, the prisons and the skilled nursing facility could legally mandate regular clinical testing of staff but not of residents, and respondents noted that despite offering testing for all new residents and at regular intervals, residents' willingness to get tested declined over the course of the pandemic. Not all the universities could mandate clinical testing of students and staff, but even for the ones that did, there was not complete compliance with the testing rules. Respondents unanimously appreciated that WBS was not subject to these constraints, noting that "you can't hide from wastewater" and "you don't have to ask people to poop. It's going to happen." WBS was valued for providing information about the entire population at lower cost than clinical testing.

Respondents reported that WBS in conjunction with clinical surveillance informed 3 categories of responses: public health actions, communications, and/or relationships with stakeholders outside the institution (Table). Respondents at 5 of the 6 institutions believed that they avoided more severe outbreaks in their facilities by acting rapidly on wastewater data. All respondents except one noted that wastewater data provided a leading indicator of COVID-19 cases, even in facilities that provided regular clinical surveillance testing for a majority of residents and staff. Respondents frequently used this early warning provided by WBS to ramp up measures to reduce transmission within the facility, for example, by implementing scheduled time slots for staff to use break rooms to avoid crowds of people gathering. They also used this early warning from wastewater to avoid outbreaks by allocating more resources for contact tracing and clinical testing in the short term, ordering more protective equipment (ie, buying and requiring use of N95 masks instead of surgical masks), and reorganizing staff roles to minimize social contact for residents and staff who were most at risk of severe disease.

In addition to these varied uses of WBS data, respondents from both of the prisons stated the importance of WBS for reducing the stress felt by staff who were responsible for residents' health during a pandemic. One respondent said, "Every night when I get [wastewater data] that says 'no positive signal' I

TABLE
Uses of WBS Data in Conjunction With Clinical Surveillance Data for Public Health During the COVID-19 Pandemic

Institutional Public Health Actions	Communications	Stakeholder Relationships
• Inform frequency, location, and timing of clinical surveillance testing • Inform proportion of population to test clinically • Confirm case-positive staff members are not at the facility or confirm case-positive student moved out of dormitory • Allocate additional funding for contact tracing and clinical surveillance • Adjust length of quarantines, (eg, shorten quarantine durations if no wastewater signal for several days) • Support social distancing (eg, establish strict schedules for use of common spaces) • Give higher-risk staff members tasks with less resident contact to reduce risk of transmission • Plan and obtain needed supplies (ie, order personal protective equipment) • Mandate more protective equipment for staff (ie, N95 masks instead of surgical masks) • Resume social programming after a COVID-19 exposure	• Advise health staff with patient contact to be on the lookout for potential symptoms • Inform residents' personal protective behaviors (ie, handwashing, masking, social distancing) • Provide reassurance that clinical surveillance strategy is adequate for timely identification of cases • Justify or explain public health actions (eg, social distancing, masking) • Encourage voluntary clinical testing • Provide reassurance to decision makers and clinical practitioners that there is not a hidden outbreak emerging	• Initiate discussions with health department to determine when to come out of "outbreak" status • Raise surrounding community's confidence in the institution's pandemic response efforts • Document due diligence in public health care of residents in case of a lawsuit • Demonstrate institution's technical expertise and data-driven public health responsiveness • Show that the resident population did not pose a public health risk to the surrounding community

Abbreviation: WBS, wastewater-based surveillance.

sleep better . . . . [WBS] helped me maintain my mental health."

All respondents reported that receiving a positive wastewater signal was most useful when it was accompanied by contextual information, including historic associations of wastewater data with clinical case data, an accurate map of the sewershed, and the ability to identify which individuals frequented each building. They also reported effective and timely data visualizations to be helpful for decision making. Historic associations of wastewater data with clinical case data were useful because respondents learned how wastewater data correlated with known cases in their facilities. Thus, the wastewater data became more useful as they accumulated a longer time series of wastewater data points. Conversely, respondents described how a lack of contextual information made it difficult to effectively use wastewater data. For example, without accurate maps of the network of pipes that contributed to the wastewater at the sampling location, respondents expressed they were unable to pinpoint the region of the facility that the sample represented, which hampered their ability to act on the data. In addition, respondents noted that not being able to identify the individuals who had frequented a particular sewershed where sampling had occurred also impeded effective decision making based on WBS data. In these cases, respondents noted changing the sampling strategy to try to alleviate some of these concerns, for example, by changing the sampling location to a place where the pipe network was well mapped.

Interestingly, wastewater data were particularly valued as confirmation of nontransmission of disease within the resident population. For example, when one of the infected students was removed to isolation and their dormitory's wastewater no longer displayed a positive signal, decision makers were reassured that they had taken appropriate action. When staff tested positive at the skilled nursing facility or the prisons, WBS was especially useful in ascertaining whether the staff member had transmitted the virus to any residents. At the prisons, respondents reported that a trend of negative wastewater signals allowed them to shorten quarantine times and resume social programming (educational, visits, recreational time) for residents after exposure to a COVID-19–positive staff member, which was critical for residents' overall well-being.

Although we sought different perspectives by interviewing informants with different roles at each institution, these multiple informants generally gave consistent responses about WBS data uses. One

exception was the nursing facility, where a head nurse reported that WBS was not useful because it did not identify which residents were ill. In contrast, the chief executive officer of the same facility emphasized that although WBS could not identify sick individuals, it was still tremendously valuable for their long-term planning for staffing, resources, and policies. Thus, the utility of WBS varied on the basis of the decision maker's scope of influence.

At the start of the pandemic, none of the respondents were familiar with WBS. Partnerships with researchers and other public health professionals helped them learn to interpret and use this new kind of data. All respondents reported expanding their use of wastewater data over time, as pandemic conditions, available resources, and their knowledge changed.

Discussion

Most early advocates for WBS initially expected that the primary value of WBS would be to help target limited clinical surveillance resources effectively, for example, by using wastewater data to indicate when a residential building had an infected individual inside and following up with clinical testing for all building residents.[7] However, we found that the uses of WBS data in varied settings under evolving pandemic conditions were in fact extremely diverse. Our results indicate that the utility of facility-scale WBS varied on the basis of pandemic status, institutional resources, and characteristics of the resident population. The findings suggest that WBS may be most valuable when:

1. *Case rates are low or nonexistent*. WBS can cost-effectively and noninvasively confirm nontransmission and quickly identify whether infections are increasing. Conversely, when case rates are high, respondents were already in "outbreak mode" and doing everything within their power to reduce disease transmission, so the wastewater data did not add as much value the decision process.
2. *Clinical testing resources are limited*. Wastewater results can indicate when to expand clinical surveillance testing. Several respondents noted that if they had the resources to test every person in their facility every day for COVID-19, they would—but barring this possibility, WBS provided information about the whole population at a small fraction of the price of testing each individual.
3. *The population is medically fragile or the consequences of disease high*. The early warning provided by WBS is particularly valuable when the health consequences of an outbreak are high. This is clearly the case in an assisted living facility. Although university students are typically less vulnerable, the potential for a high case rate to close the institution for the semester was a costly outcome that WBS helped avoid.
4. *Isolation and quarantine are particularly challenging*: The economic, mental health, and reputational costs of isolation vary, with particular challenges in prisons and nursing homes (eg, limited ability to move/isolate residents). Respondents from universities expressed that isolating students could affect their institution by incentivizing students to live off campus or to not enroll in school for a semester. In these cases, WBS provided another layer of information in addition to clinical surveillance to help prevent outbreaks that could necessitate unpopular decisions.
5. *The resident population mixes regularly with "outsiders."* WBS can provide an early signal of infections transmitted from new residents, staff, or visitors. However, if there is not a clearly defined resident population, and if there is no way to know who has visited the sewershed (as in a college campus with buildings open to the public), WBS data were used more for

Implications for Policy & Practice

- WBS can inform public health decisions at residential institutions in diverse ways.
- Uses of WBS depend on institutional characteristics, decision makers' ability to take action, and the resources available.
- In general, WBS data can provide a much lower cost snapshot of overall infection prevalence within a given sewershed than clinical surveillance testing alone.
- State and national WBS systems should support residential institutions' wastewater monitoring efforts by developing resources to help interpret WBS data and provide technical support as pandemic conditions evolve (eg, new variants, vaccine uptake, prevalence of clinical testing). Technical support could include information on developing a WBS strategy (including location and frequency of wastewater testing), sample collection, laboratories for sample analysis, guidance on data interpretation, or facilitation of professional networks of WBS practitioners at facilities.
- Further research and guidance are needed on the uses of data, cost-effectiveness, and ethics at facility-level and community scales.

communications and to provide context for clinical surveillance data than for directing institutional public health actions.

6. *Residents share spaces and have regular close contact*. Colleges, nursing homes, and prisons are of particular concern because transmission can happen very quickly.
7. *Institutions have a high level of responsibility for residents*. Residential institutions may bear moral (vulnerable population), legal (state responsibility for prisoners' well-being), and reputational (prospective students, parents, and trustees of universities) responsibility for their populations' health. WBS may help decision makers demonstrate to internal and external stakeholders that they are acting cautiously in recognition of this responsibility.
8. *The facilities' sewer network is conducive to wastewater collection*. Well-mapped sewer pipes and accessible sampling locations are key to successful WBS. Conversely, without a clear understanding of the sewershed that contributes to a wastewater sample, data are less actionable. Several respondents noted that some buildings at their facilities do not have accurate as-built sewer maps, which limited their ability to accurately interpret WBS data.

Our findings are limited by the sample size of respondents and diversity of institutions represented. However, it is clear from these early adopters' reflections that the potential for WBS data use by residential institutions is extremely diverse and that those uses extend far beyond initial expectations that it would simply help target clinical testing efforts. It is also evident that WBS use varies on the basis of multiple institutional characteristics and the changing context of the pandemic over time.

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