Colorado National Wastewater Surveillance System Center of Excellence (NWSS CoE)

Lessons Learned in Building-Level Wastewater Surveillance

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Preface

The purpose of this document is to offer guidance and encouragement to public health professionals interested in building-level wastewater sampling. We aim to share the lessons we learned while starting a building-level wastewater surveillance program during the COVID-19 pandemic. As you read through these lessons, remember that each wastewater surveillance program has unique circumstances. You will likely encounter unique challenges that we did not have to face.

Rather than viewing this document as a rigid set of dos and don'ts, consider it a flexible reference to help you anticipate and address potential issues in your situation. If there's one takeaway from this document, let it be this: **You can do this!** Embarking on wastewater surveillance may seem daunting due to its unprecedented scale, but it's an achievable endeavor. Embrace the unknowns and don't wait for every detail to be perfect. Perfection can slow down your progress.

As you go through our experiences, you'll notice that our **responses to challenging situations played a crucial role in shaping our program** and establishing best practices and protocols. Take, for instance, Lesson 7 (No Two Manholes are the Same). We purchased samplers based on immediate availability and the knowledge that supply chain issues were likely to make it impossible to purchase them in the very near future. When we discovered that variability in manhole construction rendered the equipment less than optimal, we didn't let it impede our progress. Instead, we made do with what we had so that we could continue collecting samples. Now, we have a protocol in place to evaluate potential sample collection sites so that we are better prepared in the future.

Even with careful planning, the initial stages of your program may have their rocky moments — that's a natural part of the process. However, this does not mean you should not plan at all or you should allow your worries to hinder your progress. Plan as much as possible with the information you have and equip yourself and your team with flexibility so that changes to the plan are an expected part of the journey. Then, take action and start collecting samples. Each day of delay could mean missing the chance to collect valuable data crucial for enhancing your program.

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Program Background

The University of Denver is a private academic institution located in Denver, Colorado. During the COVID-19 pandemic, we had 13,000-15,000 students enrolled in both graduate and undergraduate programs, along with about 2,600 employees. Approximately 3,000 of our students lived in on-campus housing. Like many other higher education institutions, managing the spread of COVID-19 while keeping students in classrooms presented significant challenges.

During the pandemic, our institution sought innovative solutions to manage the spread of COVID-19. In the summer of 2020, we initiated the use of wastewater monitoring alongside high-frequency PCR testing (performed on campus by our Molecular Diagnostics Laboratory) and contact tracing. The first wastewater sample was collected upon the return of students in the fall. This data became instrumental in determining the frequency of required testing and identifying potential outbreaks.

Our approach to wastewater surveillance involved monitoring levels of SARS-CoV-2, the virus that causes COVID-19, in wastewater from residential dorm buildings. Upon detecting an increase, we promptly required residents to undergo clinical testing. Our in-house rapid-result PCR clinical tests enabled us to swiftly identify COVID-19 cases, often before symptoms appeared, and isolate infected community members.

A distinctive feature of our campus wastewater surveillance program is the presence of an on-site molecular diagnostics laboratory. While we initially utilized a third-party analytical lab to process wastewater samples, we transitioned to processing samples on campus to optimize resources and improve turnaround time. This shift allowed us to refine our laboratory best practices for wastewater testing, an effort that is continually evolving. Currently, we are assessing various wastewater sample collection devices and PCR instruments, informing future best practices in these areas.

In conclusion, our campus wastewater surveillance program played a pivotal role in managing the impact of COVID-19 within our community. As we continue to refine our methods, we look toward future advancements in wastewater testing to enhance our ability to detect and respond to potential outbreaks of many communicable diseases.

Section 1: Lessons Learned in Wastewater Sample Collection

Lesson 1: Build Strong Partnerships Early On

What We Observed/Experienced

When we first ventured into using wastewater surveillance as part of our COVID-19 response on campus, we had limited experience and few connections in this field. We relied heavily on the support of individuals and organizations in our region who shared their specialized knowledge, many of whom now serve on the Colorado National Wastewater Surveillance System Center of Excellence advisory board.

Because we started our program during the COVID-19 pandemic, we were already collaborating with state and local health departments regularly. We discussed our program with them during our regular meetings. They provided valuable guidance and connected us with individuals in our state who were interested in or had experience with wastewater surveillance. These connections were instrumental in our success and our ability to make contributions to the body of knowledge in this field. Without them, we would not have been able to seek advice and feedback from people who had run across various issues before.

Recommendations

You may not have the same level of initial connections as we did, and that is perfectly fine. The Colorado National Wastewater Surveillance System Center of Excellence receives inquiries from organizations in areas where such programs are scarce. **Building a community where none exists is a significant role of the Centers of Excellence sites**.

If you're considering wastewater surveillance, there are essential relationships you must establish, even if you're only in the early stages of exploring the idea:

- **Health departments**: Engage with health departments at all levels in your area, including state, municipal, and county health departments. You'll likely need the state laboratory to test your samples, and they can help navigate issues and ensure you are complying with any local regulations. Their understanding of your program's goals and trust in your ability to deliver high-quality results can be a significant asset to your program's success.
- **Local wastewater utilities**: Unless the sampling location is on your institution's property, you must obtain permission to access and collect samples from public sewers. More importantly, these departments may have insight into selecting sample sites, given their knowledge of your local wastewater systems. We recommend establishing a connection and asking for a facility tour to understand how wastewater is processed in your community, especially if you're aiming to establish community-level surveillance.
- **Other organizations in your area**: When contacting the entities mentioned above, inquire if they know of others using wastewater surveillance in your region. These connections are invaluable during the planning phase. Reach out to them, visit their sites, and learn from their experiences.
- National Wastewater Surveillance System (NWSS): Engage with NWSS, the national entity responsible for advancing wastewater surveillance as a public health tool. In addition to working with NWSS Centers of Excellence sites like ours and your state health department, seek their support for data sharing, analysis, and insights at a national level.
- **Communities of practice**: Explore various communities of practice that meet regularly to discuss specialized aspects of wastewater surveillance. You can find more information on our educational resources webpage.

Once you've established these connections, schedule regular meetings to discuss progress and findings. Given the rapidly evolving nature of this field, ongoing communication is essential to stay up to date with local changes and evolving wastewater surveillance methods.

Most importantly, remember that **the wastewater surveillance community thrives on knowledge sharing to enhance methodologies and expand the number of programs contributing to national data. As your program grows, continue to engage with the community and share your learnings and observations for the benefit of all.**

Lesson 2: Cold Weather Woes

What We Observed/Experienced

The first several times that we attempted sample collection during cold weather, we had multiple near losses of equipment and unexpected complications. The reasons that cold weather has such a dramatic impact on sample collection processes and equipment are:

- Sewers are always warm, even in cold weather conditions. When the warm air from the sewer meets the cold air from above, fog is created. The fog makes it very difficult to see inside manholes which can hinder the ability to properly place equipment.
- In temperatures below freezing, metal and plastic become brittle and easy to break. Even simple equipment like plastic specimen containers become fragile.
- When cold precipitation lands on a warm manhole cover, it runs off until it reaches a nearby surface cold enough to freeze it. This causes dangerous black ice to form in the area immediately surrounding the manhole.
- Spray bottles (often used for sanitation solutions) do not work properly in freezing temperatures.

Recommendations

Whenever possible, avoid collecting samples on very cold days. Our protocol is that no samples are collected when the temperature is below –10F. Consider setting a threshold for your program but be open to adjusting that threshold based on your experiences and the weather patterns in your area.

If you must collect samples in cold weather:

- Wear warm gloves with a good grip over your disposable gloves so that you can easily grasp frozen metal surfaces. Be prepared to either dispose of these gloves or have a protocol in place for sanitizing them after each use.
- Bring several dry towels with you so that you can very quickly wipe condensation off metal surfaces before it freezes. You can also lay towels on the ground surrounding the manhole to create traction and provide surfaces that your equipment won't slip off easily. We've also had success using carpet squares to increase traction in the area surrounding the manhole.
- Handle metal and plastic parts with caution to prevent breaking them. If hardware (i.e. screws and bolts) are frozen in place, do not try to force them open. You can easily strip or break hardware by using too much force in cold conditions.
- If you normally use spray bottles to sanitize equipment, formulate an alternate plan for sterilizing both your gear and the vials in the field.
- Be extremely cautious about ice that may be difficult to see surrounding the ground nearest the manhole. A slip and fall incident while attempting to remove a manhole cover (which can be up to 250 pounds in weight) would be catastrophic. If weather in your area warrants, consider investing in special equipment (i.e., boot crampons) to reduce risk.

Lesson 3: Rain

What We Observed/Experienced

As long as you are collecting samples from a closed sewer system (ask your wastewater utilities department about this) where storm drainage does not enter the sewers, rain will not be problematic for your sample quality. It does, however, cause issues during the collection process because it potentially dilutes sanitizer solutions to the point that they are no longer effective.

Recommendations

If at all possible, avoid collecting samples during heavy rainfall. If you must collect samples during rainfall, have a plan for decontaminating your equipment and the sample collection containers in a manner that won't be negatively impacted by the rainwater. Some ideas include:

- Sanitize the sample and your equipment inside a vehicle (we used the back of a large van). Be sure to do this on a surface that can easily be sanitized when you are done (i.e. a plastic tarp).
- Use sanitation methods that are not susceptible to dilution.
- Bring a large container (e.g., an oversized cooler or plastic storage tub) and put all equipment and your sample into it when you've completed the collection. Sanitize the contents of the container (and the container itself) when you can do so indoors or in a covered area.

Lesson 4: Balancing Costs and Equipment Maintenance

What We Observed/Experienced

During testing, we noted that one sample collection site had results with very high viral counts consistently for a prolonged period. Because we had been leveraging all the tools that we had to contain the spread of SARS-CoV-2 in this particular building and because there was a significant difference in the number of known cases in the building vs. the number of cases we expected to see with a wastewater viral count that high, we started to question if the result was valid or if there was something else involved in producing it. (Currently, subject matter experts do not unanimously agree on the correlation between viral counts in wastewater and the number of cases. Exercise utmost caution when attempting to apply this logic to your findings. Viral loads in patients can vary significantly depending on factors such as the pathogen, stage of infection, and variant type.)

To investigate more fully, we started by looking at the composite sampler we had deployed at that location. The sampler was taken apart and we cleaned all of the inline filters and tubing thoroughly before replacing it. The next result from this site demonstrated a very low viral count and confirmed that earlier results were likely the result of viral material left inside the composite sampler.

Many of our sampling sites would go several weeks without having any samples that detected SARS-CoV-2. Because of that, we decided to attempt to cut costs and to reduce the amount of time spent at each sampling site by cutting back on the frequency of sampler cleaning. The flaw in our logic was that rather than cutting the cleaning frequency at all sites, we should have adhered to manufacturers recommended cleaning frequency at sites which produced samples with high levels of SARS-CoV-2.

Recommendations

To the extent possible, always follow manufacturer recommendations for the cleaning and maintenance of your sampling equipment.

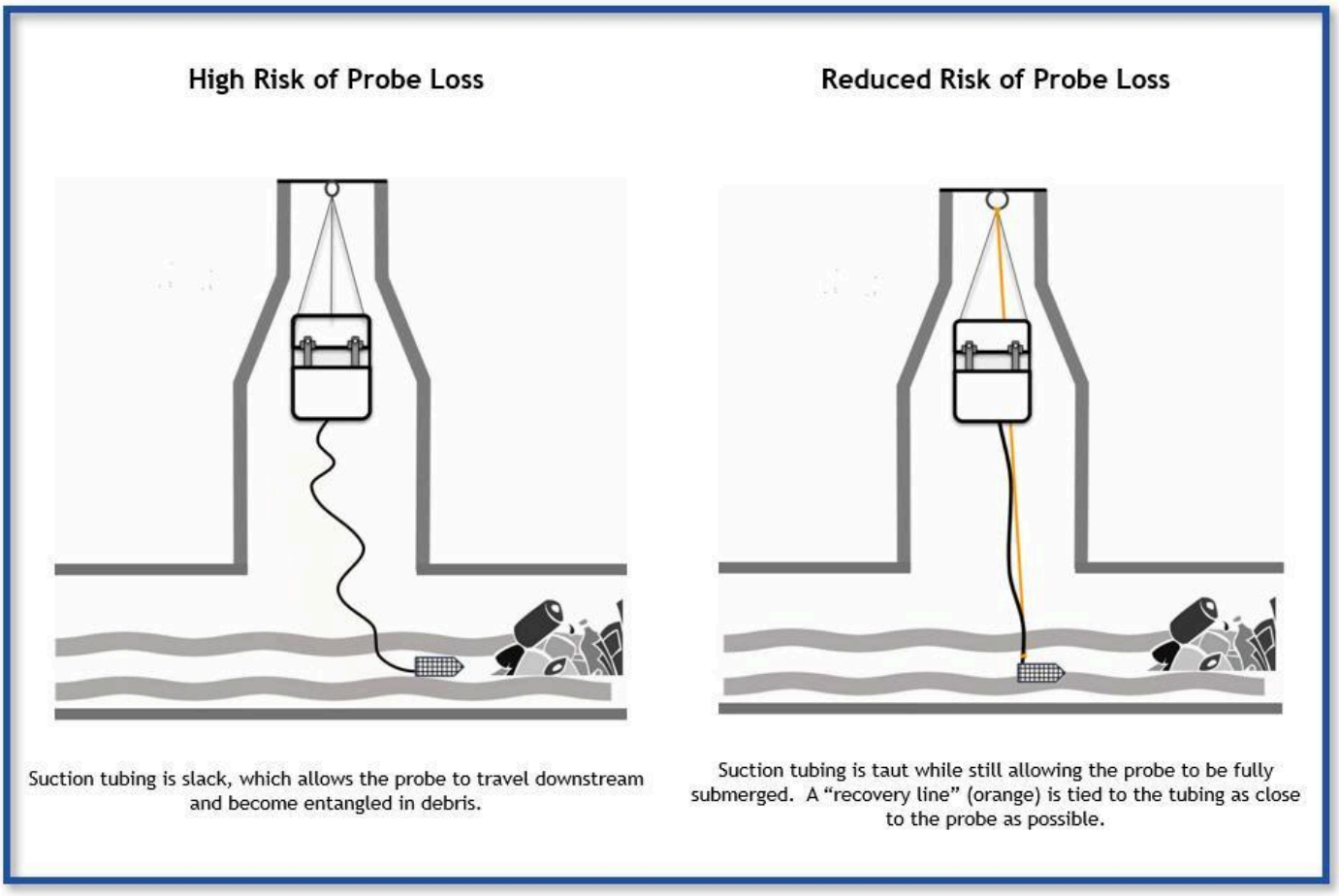
Additionally, become extremely familiar with your test results and trust yourself if you sense something is wrong. If not for the fact that we had team members who were watching results very closely at that time, we may not have questioned the prolonged high viral count. The more familiar you are with your data, the easier it will be for you to identify atypical patterns.

Lesson 5: Lost Sampling Equipment

What We Observed/Experienced

Regrettably, we've faced challenges with our sampling equipment either getting lost in the sewer or coming very close to it. This has occurred in two distinct ways:

1. **Debris**: The presence of unexpected debris and trash in the sewers, often not visible from a manhole, has been a recurring issue. As this debris accumulates downstream, it forms large piles and easily entangles with sampling equipment, such as the probes on autosamplers. Retrieving the equipment became impossible at times, necessitating the involvement of a trained professional capable of sewer entry. Unfortunately, this added delays and negatively impacted our efforts to build relationships with municipal wastewater partners (who are understandably not happy about things being lost in the sewer). Even when the equipment was recovered, it had suffered damage, requiring repair or replacement.
2. **Traffic:** Another source of equipment loss stems from vibrations caused by traffic driving over manhole covers. These vibrations shift the position of suspension brackets. While the vibrations alone aren't enough to make the system fall into the sewer, removing the manhole cover releases downward pressure, causing the system to plunge into the sewer as you stand helplessly watching.



Recommendations

When leaving sampling equipment unattended in a sewer, consider the following precautions:

- **Adjust tubing length**: Minimize the tubing length between the autosampler and probe to keep the probe horizontal and submerged in the flow. Longer tubing may lead to the probe moving down the sewer line, getting jammed, or lodging itself on debris during retrieval.
- **Recovery line:** In some environments, a separate recovery line (rope tied to the tubing connected to the probe) can be beneficial. Connect the line to the tubing just above the probe to aid in recovery. Losing the probe can be problematic, clogging as it travels down the sewers, but probes are typically designed to allow for water flow so the damage is less significant than losing the tubing, which causes much more significant blockages in our experience.
- **Resist the urge to save falling equipment**: If the entire system falls into the sewer, resist the urge to jump in after it. Attempting to catch it can result in severe injuries. Instead, let it fall and have a long grab pole with a hook ready for equipment retrieval. Do not enter the sewer yourself for safety reasons.
- **Avoid manholes on busy streets**: See Lesson 8: Manholes on Busy Streets for more on this subject.

Section 2: Lessons Learned in Choosing a Sample Collection Site

Lesson 6: Never Trust the Blueprints and Schematics

What We Observed/Experienced

Sewer schematics, building plans, and other documentation used to determine the best sample collection sites for your program are rarely accurate. This is because as soon as a building is completed, changes start being made both to the building itself and the surrounding area. Even if you can access sewer schematics and/or building blueprints that are "up to date," always verify what you see by visiting the site in person.

We encountered this issue in two different scenarios. In the first, we had chosen a specific manhole near a residential dorm based on schematics and blueprints, expecting samples to contain wastewater from one wing of that dorm. However, upon arriving to install a sampler, we discovered wastewater from several buildings in the area converged at that point.

In the second scenario, we found no sewer flow from a fully occupied building when we arrived at a manhole. These discoveries rendered both sites unusable for our purposes, prompting us to go back to the drawing board to find a different site.

Recommendations

- **Site visits**: Always make multiple trips to sites you are considering sampling and collect grab samples before investing in expensive equipment or committing to a long-term program at a site. While on your initial site visit, be sure to find out if there are large laundry or kitchen facilities in the building. Detergents and surfactants introduced to the wastewater by these facilities can degrade the quality of your samples.
- **Monitor initial results closely:** A reliable way to find out if there may be influent from other buildings is to carefully observe the results of your first few tests at the site for signs that you are receiving wastewater from unintended sources. Signs of this include:
  - Unexplained high levels of the target pathogen from samples collected during hours when you know the monitored building should be empty.
  - Pathogen levels that do not correlate with the number of clinically verified cases in the building. Exercise caution with this, as there is currently no standard formula to determine the number of cases in a building based solely on wastewater. Perform more tests before drawing conclusions.
- **Metal detectors**: If you are struggling to find sewer lines or suspect the presence of one that is not clearly visible, try using a metal detector (assuming sewer lines in your area are made of cast iron or other metals). We leveraged this method and found it to be very effective.

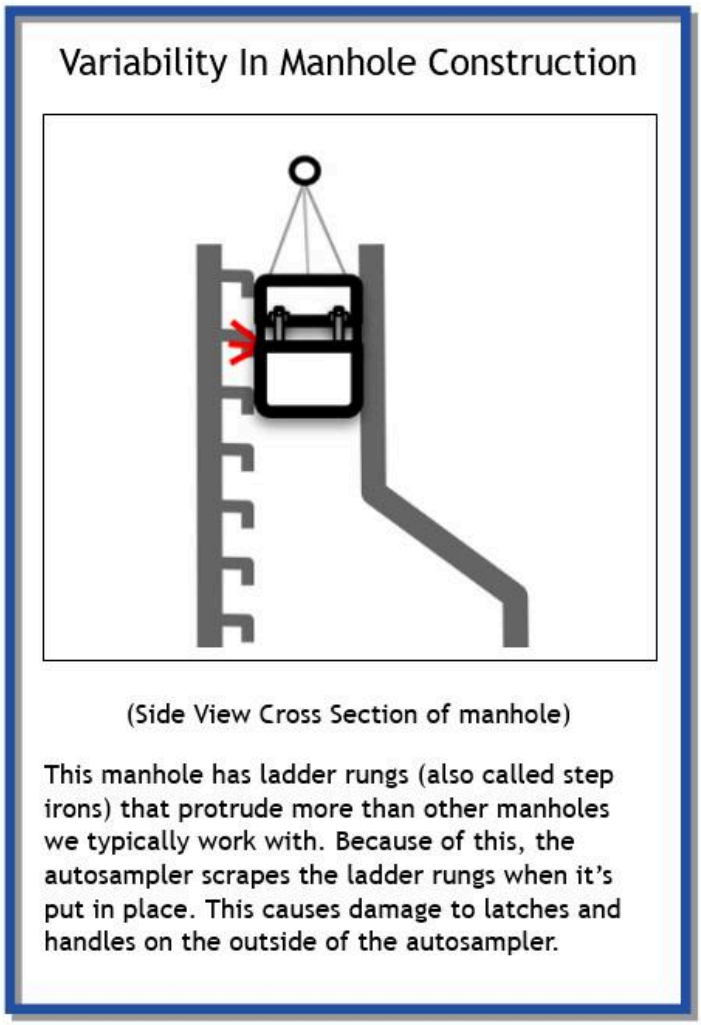
Lesson 7: No Two Manholes Are the Same

What We Observed/Experienced

Over time, the design of manholes has changed and improved. Because of this, you may find that, depending on when they were installed, some manholes are slightly different than others. This variation in design had impacts that caused us some difficulties that you could easily avoid.

The first time we ran into a variation in manhole design, we arrived at a manhole to deploy an autosampler and found that the step irons (the individual rungs that make up the ladder in a manhole) were slightly deeper than they were at our other collection sites. Because of this, each time we lowered an autosampler at that location, the clips and handles on the side of the autosampler body would rub against the step irons and over time, become damaged. We became concerned that if the latches holding the autosampler parts together were to break, the bottom sections of the sampler could drop into the sewer and travel downstream. Ultimately, the only solution for this problem was to order a smaller autosampler to deploy at this site.

In the second instance, we unintentionally swapped manhole covers. Until that point, we did not realize that the covers varied in size. Luckily, we were able to correct this issue but we nearly lost a manhole cover because of it.



Recommendations

- **Measure first**: Before purchasing sampling equipment, visit the collection sites that you are considering using (or the sites you have already selected) and measure the diameter of the manholes. Don't forget to account for anything that protrudes from the walls such as the ladder. When you are purchasing your sampling equipment, make sure that your sampler will fit into your smallest manhole.
- **Select adjustable suspension brackets:** If they are available, we recommend purchasing adjustable suspension brackets to secure your samplers. Changes in temperature, humidity, etc. can cause very slight expansion and contraction of the manholes which will affect the stability of your sampler.
- **Adjust suspension brackets at each visit:** Each time you visit your sampling sites, take a few minutes to adjust the suspension brackets to ensure that they are in a stable position. As discussed in Lesson 8, vibrations from traffic and expansion/contraction due to weather conditions will move the brackets slightly.
- **Don't swap manhole covers**: You might be tempted to take a nearby manhole plate and swap it out with another. Although we have done this, you should make sure that the manhole plate is not smaller, or it will fall through when setting it in place. Size differences can be very minor.

Lesson 8: Infrequently Accessed Manholes

What We Observed/Experienced

Sewer manholes are not opened very often. They may not have been accessed for many years before your first visit. We found that accessing the manholes could be difficult because they had large amounts of salt, sand, and other debris that had been forced down into the small gap around the edge of the manhole cover, making it impossible to get the leverage needed to remove the cover with a standard manhole cover tool.

We also found that some manhole covers had vegetation that was covering them completely.

Recommendations

Bring the following tools with you on your site visits and sample collections:

- A small flathead screwdriver – you can use this to scrape out debris from the gap around the edge of the manhole cover
- Scissors and/or pruning shears in case you need to cut back overgrown vegetation

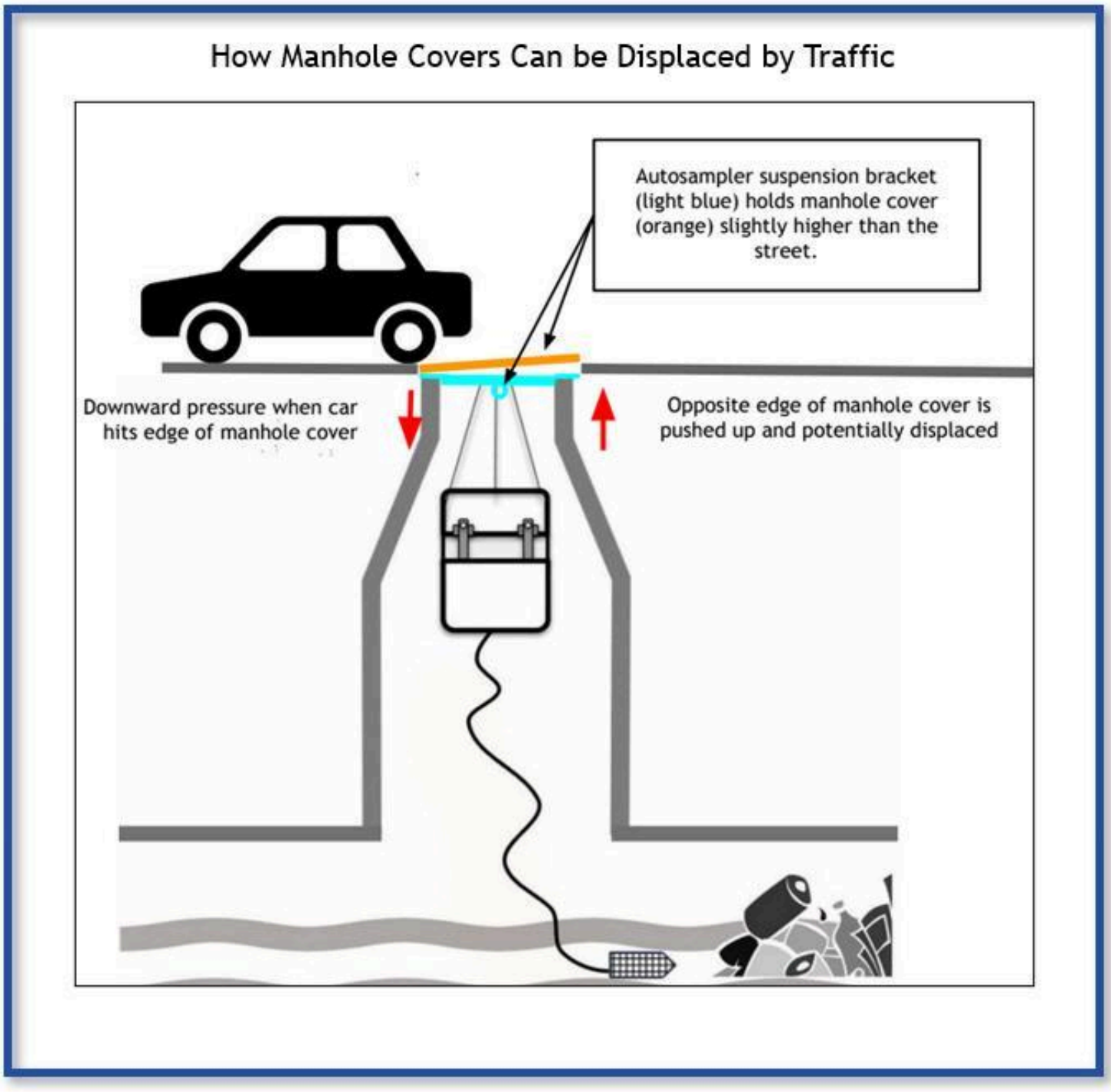
Close up of debris that may make manhole cover removal difficult

Lesson 9: Manholes on Busy Streets

What We Observed/Experienced

At one point during the COVID-19 response, we were notified by our Campus Safety department that a manhole cover at one of our sampling sites located on a frequently traveled street had been removed and left several feet away from the manhole. The first time this happened, we assumed that this was the result of a prankster. The second time it happened, we started to think that this might be related to our sampling equipment.

With the help of our Campus Safety department, we set up a few small experiments where we altered the placement of the suspension bracket holding our autosampler in place and then drove over the manhole cover at various speeds and from various angles. We found that the exact combination of speed of travel, the angle at which the vehicle hit the manhole cover, and the orientation of the suspension brackets could result in the vehicle pushing the manhole cover up and out of the manhole and onto the street.

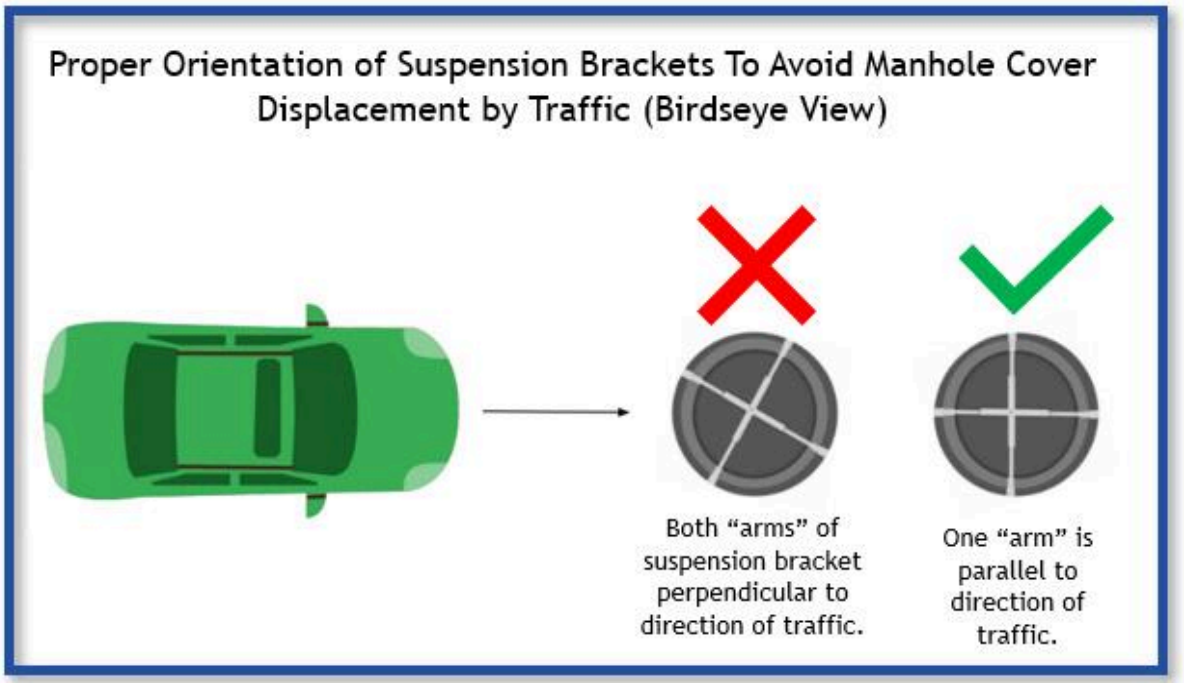


Since we cannot control the speed of traffic or the angle at which people drive over the manhole, we started placing the suspension brackets that hold the autosamplers in a manner so that they were parallel with the direction of traffic. To date, this solution has worked well.

Recommendations

Try to avoid using sites where the manhole cover is located on a busy street. In addition to the situation we described above, you will also face other challenges, such as the need to have traffic control personnel on hand each time you collect a sample because your collection will cause a major disruption to traffic. If you absolutely must collect samples from a manhole on a busy street, try to use sampler types that don't utilize suspension systems that could result in a manhole cover being displaced by traffic. Passive samplers are usually good for this purpose since they are often held in place without any brackets. Grab sampling can also be used in these areas since no equipment is left inside a manhole.

If all else fails and you are forced to put an autosampler in a manhole on a busy street, try to orient the suspension brackets so that one arm runs parallel to the direction of traffic.



Section 3: Lessons Learned in Public Health Actions Based on Wastewater Surveillance Test Results

Lesson 10: Know Your Testing Site *and* the People in It

What We Observed/Experienced

In one particular case, after receiving a wastewater test result with a high level of SARS-CoV-2, we called in residents of the dorm where the sample was collected for clinical testing. However, the number of positive tests produced from that effort was very low. Initially, we were very confused about how this could be the case. After several hours of detective work we identified a positive test result from a food service employee who worked in the commercial kitchen in that building. Based on that positive case combined with the wastewater results showing a high viral count, we called in all of the food service workers who worked in that kitchen for mandatory testing. Unsurprisingly, their test results came back with a very high number of positive tests.

In hindsight, it would have made the most sense for us to require the food service employees to report for mandatory testing at the same time as the residents. If we had done so, we would have had a clear picture of those who were involved in the outbreak and those who were at risk of developing COVID-19 as a result of close contact. We would have also been able to control the outbreak several days earlier than we did and prevent the unnecessary spread of SARS-CoV-2.

Recommendations

Understand the population in the building: As you are considering various sample collection sites, do not forget to find out as much information as you can about who is in the building you are monitoring to help decide when it is best to sample. Questions to ask include:

- When are people typically in the building (both hours and days)?
- Are certain groups of people in the building at specific times of the day (i.e., participants in a day program are in the building from 8 a.m. to 5 p.m. on weekdays but residential program participants live on site)?
- Is the population segmented inside the building (i.e., residents over the age of 80 live on one floor)?
- Is the group of individuals fairly stable (i.e., residents or employees who typically stay for more than a week) or does it vary based on seasons or other factors (i.e., short-term residents or seasonal employees)?
- Are there groups of people in this building who may have traveled recently (potentially putting them at increased risk for contracting an infectious illness) for something like a work-related conference or a school-related field trip?
- Are any of the activities that occur in this building known to increase the risk of contracting an illness (i.e., dining rooms where people are sitting closely and eating can increase the risk of contracting respiratory viruses)?
- Is there any clinical data available for this group (i.e., are employees required to report that they have contracted an infectious disease?)?
- Do the people using this building all leave for a break (i.e, a lunch break where dining facilities are in a separate building or an extended holiday break) and what time frame does this typically occur in?

Consider scheduling sample collection for a time when you expect the peak flow based on the population of the building. For example, if you are sampling at an elementary school and lunch begins at noon consider

collecting a grab sample shortly after noon or schedule your composite sample to collect for the hours of the school day.

Schedule sampling times at the same time of day (or for the same collection period, i.e, 7 hours of a school day) as often as possible. This will help establish a trend. If a sample is not able to be collected at the same time, share that information with the analysts to help with data interpretation.

Don't act on wastewater results alone: Never take a public health action without having clinical data to support the wastewater results. Evaluating wastewater data with clinical data is essential for understanding trends of illness in an area. This information can help you to correctly identify who might be involved in an outbreak.

Use what you know to focus limited resources: While your organization may not be able to support mandatory individual testing at the same level that we did, you can still use all of the information you have about the people inside a building to focus limited resources on those who are most likely contributing to test results demonstrating a high viral count. For instance, if you know that administrative and executive employees mainly occupy the building you are monitoring Monday-Friday from 7 a.m. to 5 p.m. and that custodial and security employees are in the building on weekday evenings from 6 p.m. to 3 a.m., you can use sample collection time to determine which population is experiencing an outbreak and focus your time and efforts on notifying this group.

Conclusion

Throughout the compilation of this paper, we grappled with the vulnerability of sharing our mistakes, fearing potential criticism. Nevertheless, our unwavering belief in the inevitability of mistakes as part of the learning process prevailed. We are firm in our conviction that not sharing these errors would adversely impact the field of wastewater surveillance. Despite the wealth of knowledge gained on this journey, we acknowledge that our understanding represents only a fraction of the unknowns in this field. There is much more to discover, and with the proliferation of programs worldwide, we anticipate ongoing advancements.

For those embarking on the implementation of a wastewater surveillance program, expect questions from your organization's leadership regarding its post-pandemic utility. It is imperative to emphasize that starting such a program now provides the opportunity to establish baselines, comprehend the behaviors of those under your care, and ensure the functionality of protocols and equipment. Acting promptly enables the use of wastewater data to prevent future public health emergencies. Waiting until an emergency is underway would render the program useful only after months, perhaps years.

Looking ahead, we envision numerous opportunities to refine wastewater surveillance practices and techniques for the collective benefit of the public health community. We extend an invitation for you to join us on this ongoing journey.