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Strengthening Public Health Surveillance Through Wastewater Testing:

An Essential Investment for the COVID-19 Pandemic and Future Health Threats

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An Essential Investment for the COVID-19 Pandemic and Future Health Threats

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Executive Summary

Exploring Potential Strengths and Challenges of Using Wastewater Testing to Control COVID-19 in Latin America and the Caribbean.

A New Role for an Old Public Health Tool

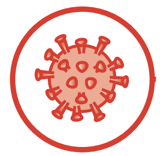
Historical uses

Polio

Antimicrobial resistence

Current use

COVID-19

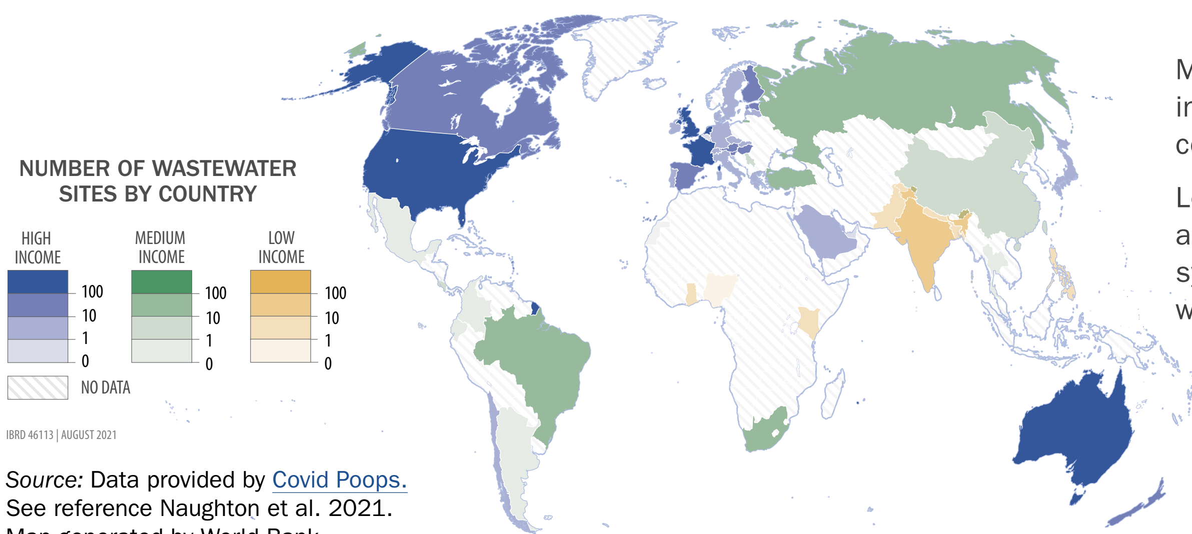


- Low cost
- Population based
- Early detection

Future uses

- Emerging infections
- Pandemics
- Over 70 endemic diseases
- Drugs, toxins, pesticides

3,000+ Testing Sites Active in 58 Countries Worldwide



Source: Data provided by Covid Poops.
See reference Naughton et al. 2021.
Map generated by World Bank.

More than 85 percent of sites are in high- or upper-middle-income countries.

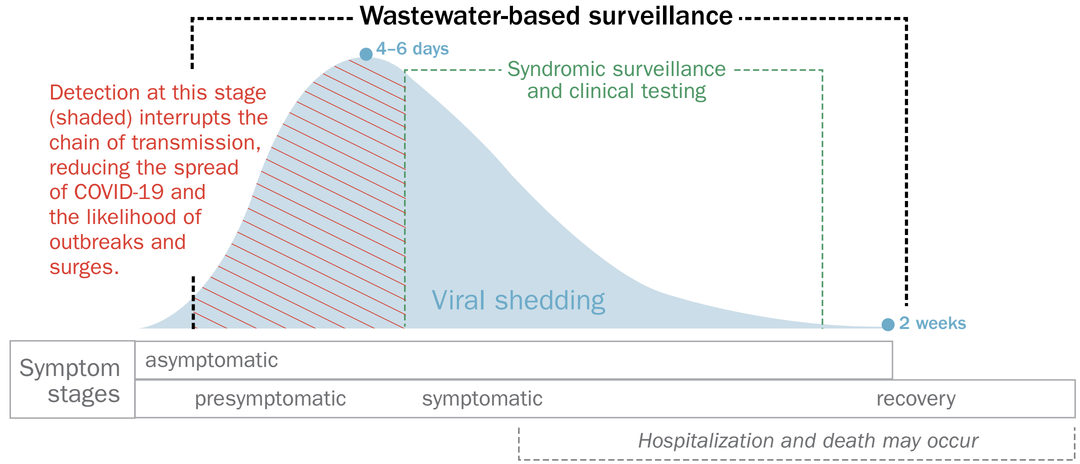
Lower-income countries, including areas without a sanitary sewerage system, can also benefit from wastewater testing.

Executive Summary

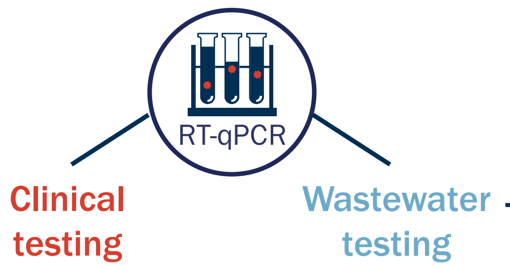
How It Works

An Early-Warning Tool

Early in the current pandemic, SARS-CoV-2—the virus that causes COVID-19—was discovered in human feces. The virus is detectable in stool as soon as people become infected, days before they develop symptoms and even if they remain asymptomatic. Viral shedding is highest in the first few days of infection, and people can spread the virus before they know they have it.



The Method



The real time reverse transcription-polymerase chain reaction (RT-qPCR) assay is so sensitive that it can detect minute levels of SARS-CoV-2 genetic material, even when feces is diluted with rainwater or industrial effluent.

Accessible for all communities

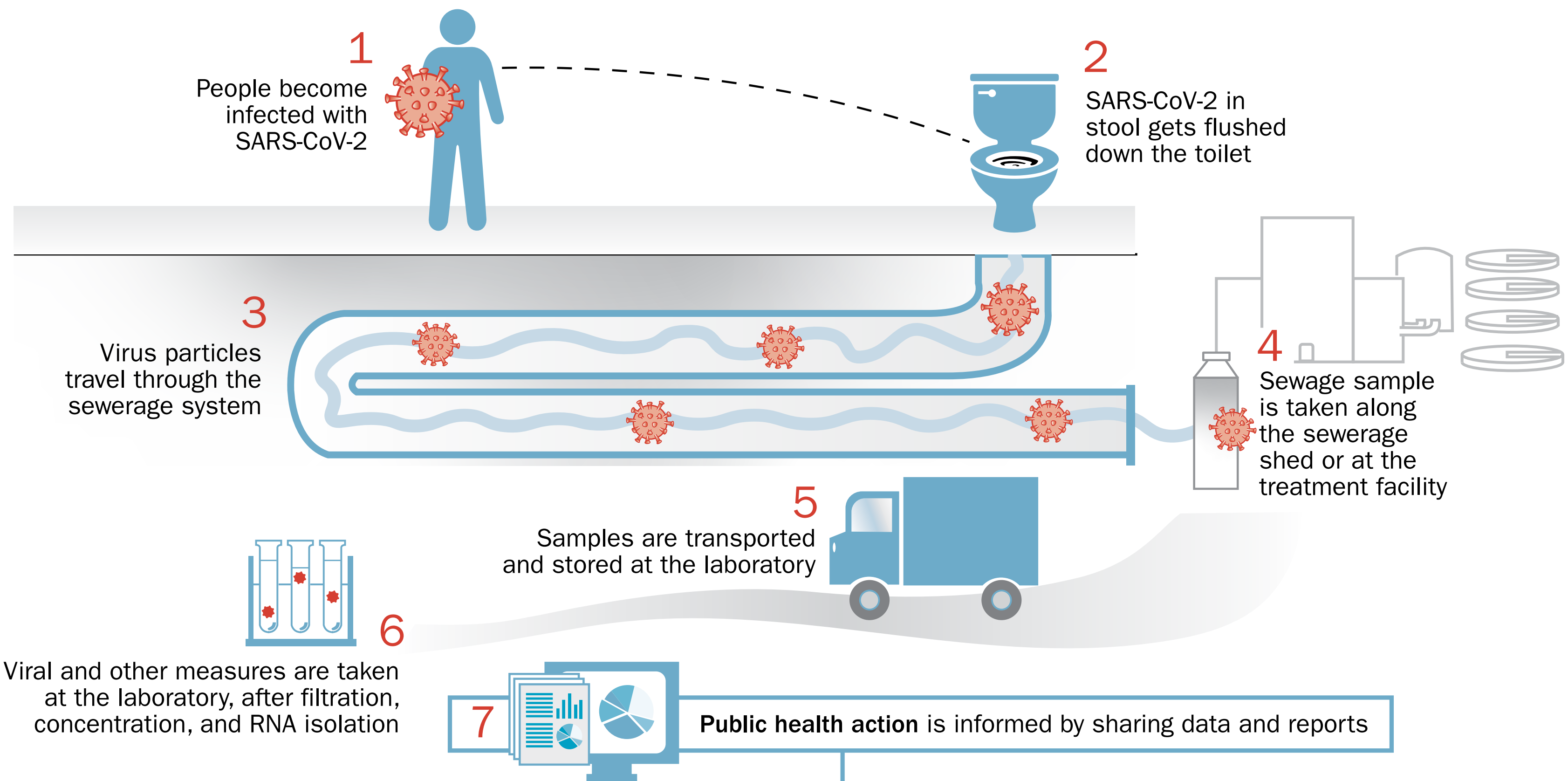
Testing can be done on samples collected anywhere that wastewater flows or is treated—outlets at specific locations, wastewater lagoons or open trench systems, or large treatment facilities in areas with well-developed collection systems.

Complementary form of surveillance

Wastewater testing complements (not replaces) other methods of public health surveillance.

Executive Summary

Steps for Wastewater Testing



Openly and transparently share to engage the public in prevention and control measures

Who
Public, policy actors, and journalists

Interpret results alongside other surveillance data

Who
Local, regional, national, and international public health along with environment and wastewater collaborators

Advance wastewater science and our understanding of COVID-19

Who
Researchers, students, and informed public

Strengths and Benefits

Supports early and broad detection
Infection at all stages is detected, including asymptomatic cases

Supports sustainable surveillance*
Wastewater testing costs less than clinical testing and requires no effort by local residents

Supports control
Early detection enables control by quickly identifying outbreaks and waves

Supports equity and population-based surveillance
Wastewater testing includes everyone and enables focus on vulnerable populations

*A typical national wastewater testing strategy costs US$1 per person for the first year. However, costs can vary from US$0.20 to over $3 per person depending on the proportion of the population served by wastewater treatment facilities, the frequency of testing, and other factors.

Challenges and Limitations

Measurement and reporting best practices need development.

Improvement needed: Quality assurances among the various analytical methods to measure SARS-CoV-2 in wastewater need to be improved.

Challenge: Many factors influence the amount of measurable viral material in wastewater, resulting in wide day-to-day variation in signal within and between sites.

Interpreting results requires collaboration and coordination.

Improvement needed: Public health, testing labs, and wastewater utilities must work together to ensure wastewater testing provides actionable intelligence.

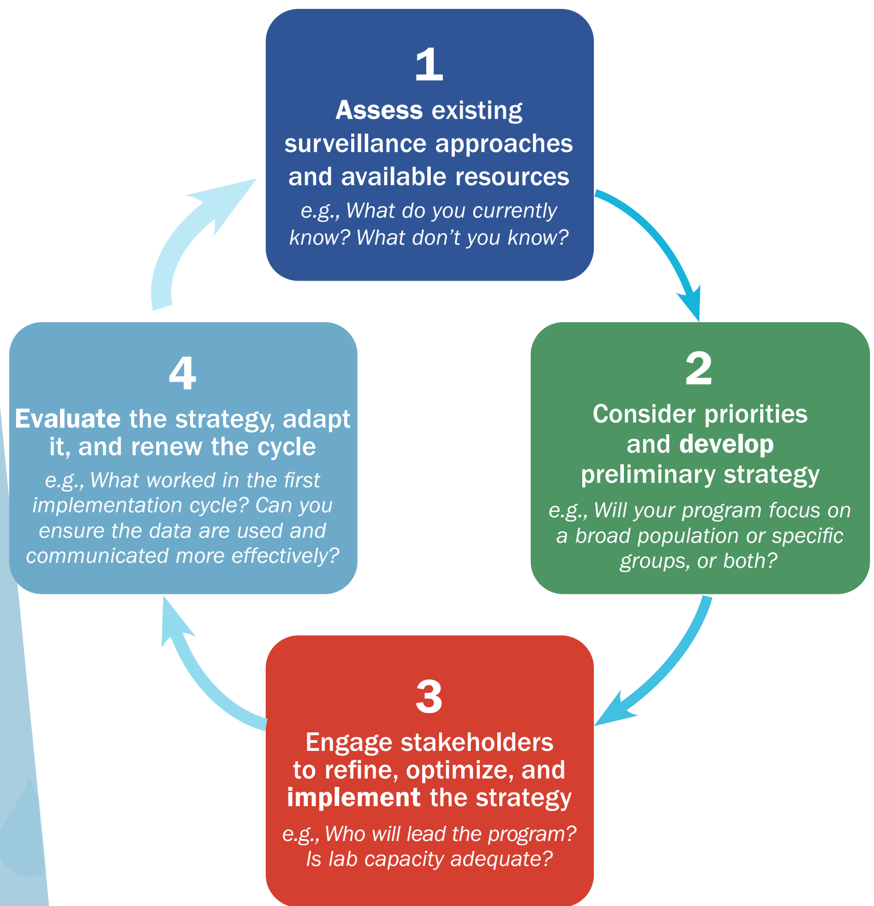
Challenge: Like any interagency effort, a wastewater testing program is a chain where strength comes from every link.

Wastewater testing programs need sustainable infrastructure.

Improvement needed: Local programs need support to transition from pilot programs to expanded, organized, and sustainable surveillance systems.

Challenge: In the rapid growth of wastewater testing during this pandemic, most new programs have been pilot projects by academic laboratories.

Steps to Success



Beyond COVID-19

The success of wastewater testing during the COVID-19 pandemic has highlighted this approach as a multifaceted tool with potential roles *beyond* the current pandemic.

- **Wastewater can be a lens into the *broader health* of our communities.** A single sample can be analyzed for a variety of pathogens: influenza, hepatitis A, polio, and other diseases. And wastewater testing can help a community monitor local exposure to drugs, toxins, pesticides, and other chemical compounds.
- Building the partnerships and infrastructure needed for successful wastewater testing can take time. But **investments today can reap long-term benefits by strengthening a country's ability to mount a *timely, well-informed public health response* for a range of issues.**
- Wastewater testing is part of a One Health approach that explicitly integrates human, animal and environment health with **an endpoint of improving *global health security* and achieving gains in development.**

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Acknowledgments

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KWPF
KOREA-WORLD BANK PARTNERSHIP FACILITY

GWSP
GLOBAL WATER SECURITY & SANITATION PARTNERSHIP

1 Situation Overview

The Need for Improved Surveillance Strategies for COVID-19

Photo credit: Xavi Guatemala er Donat

Since early 2020, an outbreak of the coronavirus disease (COVID-19) caused by the 2019 novel coronavirus (SARS-CoV-2) has spread rapidly across the world. Latin America and the Caribbean remains an epicenter of the pandemic, with some of the world's highest death rates. All countries in the region have been impacted, and more than 1.5 million people have died. With its relentless social and economic consequences, COVID-19 threatens to undo recent decades of progress on health outcomes in Latin America and the Caribbean and diverts attention from work on remaining health sector challenges.

The Path to Endemicity

Although global vaccine coverage is increasing, highly transmissible variants present challenges for the control of the pandemic. Inequities in disease burden from COVID-19 will remain challenging in many areas. Like other regions, Latin America and the Caribbean can expect outbreaks and surges for the foreseeable future. Vigilance and planning will be critical to enable early detection and management of local outbreaks, which will occur more often in disadvantaged communities and can overwhelm local health care.

Countries must address the ongoing need for public health surveillance of current and new health threats. There are opportunities and lessons from COVID-19 that can help countries better prepare for the future.

Wastewater Testing: An Emerging Surveillance Tool for COVID-19

Studies have shown that most people infected with SARS-CoV-2 shed the virus in their stool, usually before their symptoms start (Zhang et al. 2020; Stanoeva et al. 2021). In areas with sanitary sewers, when someone with COVID-19 goes to the bathroom they flush the virus into the wastewater system. Testing wastewater can—at a relatively low cost—show where the virus is circulating and whether the number of infected people in a local area is increasing or decreasing.

This report explores the value, potential, and challenges of wastewater testing for SARS-CoV-2 in Latin America and the Caribbean, including in areas without a sanitary sewerage system. Providing examples from across the world, the report also outlines what countries should consider in creating a national wastewater surveillance program as part of their broader efforts to control the impacts of COVID-19.

2 Why Conduct Wastewater Testing for SARS-CoV-2?

A New Role for an Old Surveillance Tool

Photo credit: UN Women/Ryan Brown

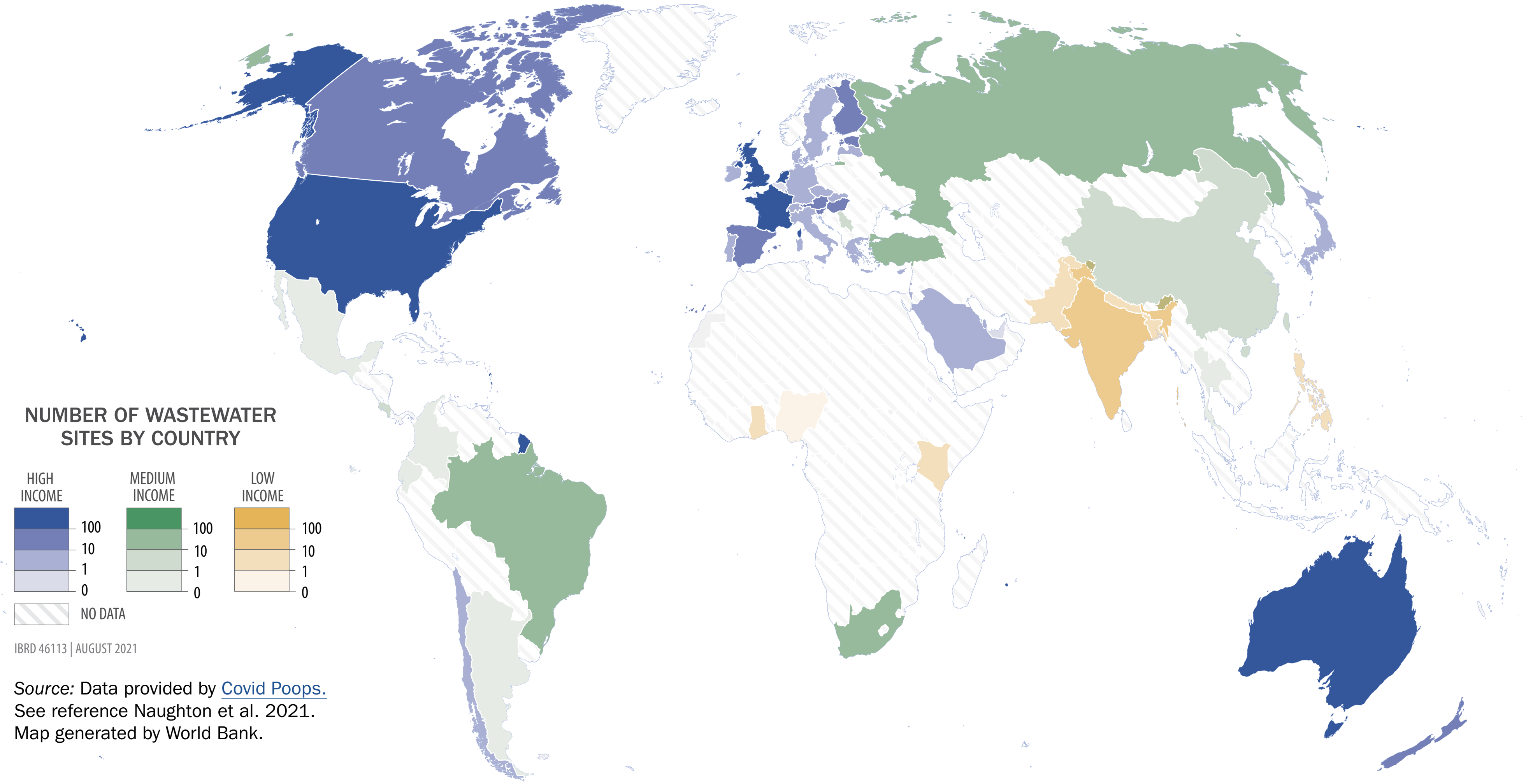
Wastewater testing has a long history of informing public health action. In the past, it has been used to monitor health threats such as polio and antimicrobial resistance (Zhang et al. 2020; Stanoeva et al. 2021). These experiences laid the groundwork for the rapid development of methods to test wastewater for COVID-19. This has positioned wastewater surveillance within the core toolkit for modern surveillance systems globally.

Early Warning, Relatively Low Cost

In the first months of the pandemic, SARS-CoV-2 was discovered in feces, and researchers in several countries identified SARS-CoV-2 in wastewater (Bivins et al. 2020). The potential for wastewater to act as an early warning system for COVID-19 outbreaks spurred academic laboratories worldwide to begin testing wastewater in their regions. Throughout the first summer of the pandemic, in 2020, an acceleration in the number of wastewater testing sites confirmed the early detection of SARS-CoV-2 in a range of settings, from municipal wastewater systems to university campuses and elsewhere (Keshaviah et al. 2021).

Compared with clinical testing, wastewater testing is a relatively affordable and timely COVID-19 surveillance tool that is well-suited for all countries (Keshaviah et al. 2021). These qualities have helped fuel the expansion of wastewater testing throughout the pandemic. As of December 2021, there are more than 3,000 testing sites worldwide (Naughton et al. 2021a). However, most sites are in wealthier countries (figure 1). In September 2021, wastewater testing was being performed in 55 countries: 36 (65 percent) were high-income countries, 11 (20 percent) were upper-middle-income countries, 8 (15 percent) were lower-middle-income countries, and none were low-income countries (Naughton et al. 2021b).

Figure 1. World Map of Wastewater Testing by Country



Source: Data provided by Covid Poops.
See reference Naughton et al. 2021.
Map generated by World Bank.

Uses the Same Trusted Assay as in Clinical Testing

The method of testing wastewater for SARS-CoV-2 is the same as in clinical testing: real time reverse transcription-polymerase chain reaction, or RT-qPCR, the most accurate and sensitive laboratory method for detecting SARS-CoV-2.

In clinical testing, an individual provides a nasal mucus or saliva sample. At the laboratory, the RT-qPCR process amplifies the genetic material from the sample. Next, primers or sequences of genetic material specific to SARS-CoV-2 are added. The primers fluoresce (light up) if SARS-CoV-2 is present. When a new variant of concern is identified, scientists develop new primers for the variant's specific mutation and genetic sequence.

Fortunately, the RT-qPCR test, or assay, can be performed on any type of sample, including wastewater. The assay is so sensitive that it can detect minute levels of SARS-CoV-2 genetic material, even when feces is diluted with rainwater or industrial effluent (Wu et al. 2021).

Suitable for Many Settings

Testing for SARS-CoV-2 can be conducted on samples taken anywhere that wastewater flows or is treated. In communities with well-developed collection systems, like those in larger cities throughout Latin America and the Caribbean, wastewater testing is most often performed at wastewater treatment facilities. Conjugate living settings—buildings where people live in close proximity such as university residences, prisons, and long-term care facilities—are also common collection sites for COVID-19 surveillance. Use of wastewater testing is also increasing in less developed or site-specific sanitation systems such as wastewater lagoons, open-trench sewage collection, trucked wastewater, and airplane collection systems.

Wastewater surveillance requires people from different disciplines to work together.

Samples can be taken anywhere there is wastewater.

Photos credit: Escuela Superior Politécnica del Litoral (ESPOL) / Luis Domínguez

There is a balance and trade-off between different types of sample collection locations, with large and small populations providing complementary uses and affordability (figure 2). In a big city, a single sample from a large treatment facility may cover a million people or more, thereby providing a very efficient measure of the overall level of SARS-CoV-2 circulating in a population. But that test provides little information about where specifically the virus is circulating and where specifically there may be new risk of transmission.

Conversely, testing in a neighborhood or area with a less well-developed wastewater system often requires more sampling because each test represents a small population. But measuring SARS-CoV-2 in a small population can help signal the beginning of a new outbreak or a surge in a specific population. That specific population can then be targeted for individual clinical testing to identify people who are asymptomatic or early in their infectious period.

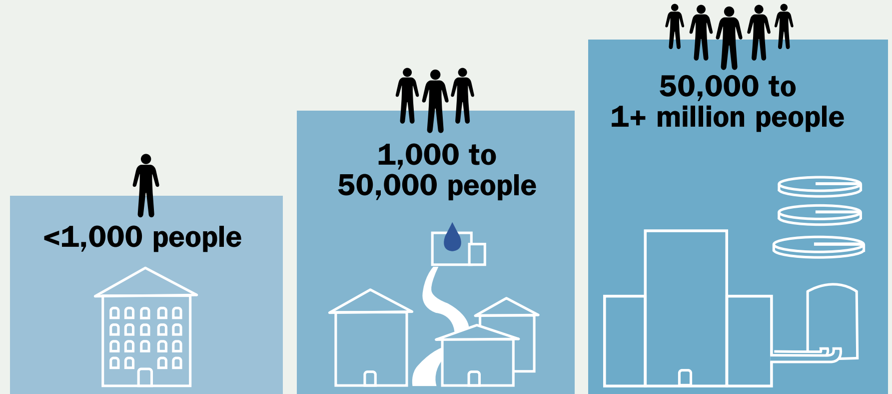
There are now examples worldwide of wastewater testing in small populations—from hundreds of people to tens of thousands—where early identification of outbreaks and surges has led to enhanced clinical testing, public health control and, ultimately, a break in the spread of COVID-19 (Manuel et al. 2021).

Addresses the Four Key Drivers of the Pandemic

To contain and control COVID-19, countries need multifaceted strategic plans. For testing, there is no one-size-fits-all approach. Population-level surveillance activities, such as wastewater testing, are an underappreciated but vital component of national planning for pandemic preparedness and response.

Wastewater testing has gained attention because it has the potential to address four key factors driving the challenges of this pandemic (figure 3).

Figure 2. The Population Size of the Sample Location Leads to Different Public Health Action



BUILDINGS and FACILITIES	UPSTREAM or COMMUNITY SITES	WASTEWATER TREATMENT PLANTS
Value: Identifies new clusters and outbreaks, which then triggers investigation and action.	**Value:** Mobilizes resources (temporary testing sites) to "hot spot" areas.	**Value:** Improves population-wide surveillance of new waves, variant detection, and effect of prevention efforts.
How: Congregate settings (prisons, university residences, group homes, long-term care) use wastewater testing to identify new infections before individual cases are diagnosed. Then, all residents are offered COVID-19 testing and transmission can be interrupted by isolating people who test positive, often before they develop symptoms.	**How:** Wastewater testing helps hard-to-reach and "hot spot" neighborhoods and communities through early identification of outbreaks and surges.	**How:** Wastewater testing strengthens other surveillance approaches, particularly where clinical testing is limited. In turn, better information and planning promotes vigilance and adherence to public health measures such as clinical testing, physical distancing, and immunization campaigns.
Cost: > US$0.3 per test per person*	**Cost:** US$0.006 to $0.3 per test per person.	**Cost:** US$0.0003 to $0.006 per test per person.

* Based on a cost of US$300 per wastewater test. See page 42, Estimate Cost and Required Resources, for more details on estimating testing costs.

Figure 3. Drivers of the COVID-19 Pandemic and How Wastewater Testing Addresses Them

When wastewater testing is implemented

Drivers of the Pandemic	*Benefits of Wastewater Testing*
COVID-19 is:	
Difficult to detect Response to infection varies from no symptoms to extreme illness and death	***Supports broad detection*** Infection at all stages is detected, including asymptomatic cases
Difficult to diagnose Diagnosis is resource intensive and requires that people have capacity, opportunity, and motivation	***Supports sustainable surveillance*** Wastewater testing costs less than clinical testing and requires no effort by local residents
Difficult to control Spread occurs early during infection and by people who are asymptomatic	***Supports control*** Early detection enables control by quickly identifying outbreaks and waves
Difficult to equitably and completely measure Case detection is poor for some groups (many cases are not diagnosed), leading to inequitable health burden	***Supports equity and population-based surveillance*** Wastewater testing includes everyone and has the ability to focus on vulnerable populations

COVID-19 is:

1) **Difficult to detect.** The severity of the disease varies widely. Infected people may have no symptoms at all or become extremely ill and eventually die.

2) **Difficult to diagnose.** Individual diagnostics are expensive, making it hard for countries to sustain their diagnostic infrastructure as case numbers climb.

3) **Difficult to control.** Once an outbreak or wave takes hold, disease spread is hard to control. Transmission commonly occurs early in a person's infection and by people who are asymptomatic. Variants of concern are increasingly transmissible. Identifying outbreaks, surges, and waves as soon as possible is, therefore, critical.

4) **Difficult to equitably and completely monitor.** Inequities across population groups run through all aspects of this pandemic. From a public health perspective, there are inequities in case detection, surveillance, and burden of disease. COVID-19 has been challenging to prevent, control, and treat for entire populations and for hard-to-reach groups, particularly in low- and lower-middle income countries. Outbreaks spread quickly in dense informal settlements (box 1). Effective medical care has reduced deaths from COVID-19 by over 50 percent where such care is available. However, inequities in access to health care are pervasive in Latin America and the Caribbean and are exacerbated during outbreaks when local health care facilities become overwhelmed.

Wastewater testing offers a relatively low-cost way to help countries meet these four challenges (for more on costs, see below, as well as section 4, Towards a National Wastewater Surveillance Program). By filling important gaps in the surveillance toolbox, wastewater testing enables broad-based, sustainable, early, and equitable (population-wide) detection of COVID-19 spread. Figure 3 outlines these benefits, and we briefly expand on them in the pages that follow.

Photo credit: U.S. Pacific Fleet

Clinical testing, as shown here, has been the mainstay of COVID-19 surveillance. Wastewater testing complements clinical testing for broad-based, sustainable, early, and equitable (population-wide) detection of COVID-19 spread.

Box 1. Villa 31: Outbreaks Isolate Dense Informal Neighborhoods

In Greater Buenos Aires, which was ground zero of the COVID-19 pandemic in Argentina, low-income neighborhood "villas" were being hit the hardest at the beginning of the COVID-19 crisis. There were two main factors driving the high vulnerability of villas:

1) **Crowded living conditions.** More than 10 people can live in the same crowded, confined household with close contact, and often without easy access to clean water and sanitation.

2) **High dependence on informal economic activities.** Compliance with lockdown policies is challenging without economic support or stability.

For instance, Villa 31 is the oldest of the villas in Buenos Aires. It developed in the 1940s on the remains of Villa Desocupación, a settlement built after the economic crisis of '29 by European immigrants and destroyed by the Argentine authorities in 1935. When it was founded, Villa 31 collected mainly immigrants, and it was one of the few villas in Buenos Aires not to be demolished. In these densely populated and poor neighborhoods, the virus spread quickly, leading to periods of mandatory isolation from the rest of the city. During the isolation, authorities carried out mass testing programs revealing spread of the virus between 5 percent and 10 percent of the population.

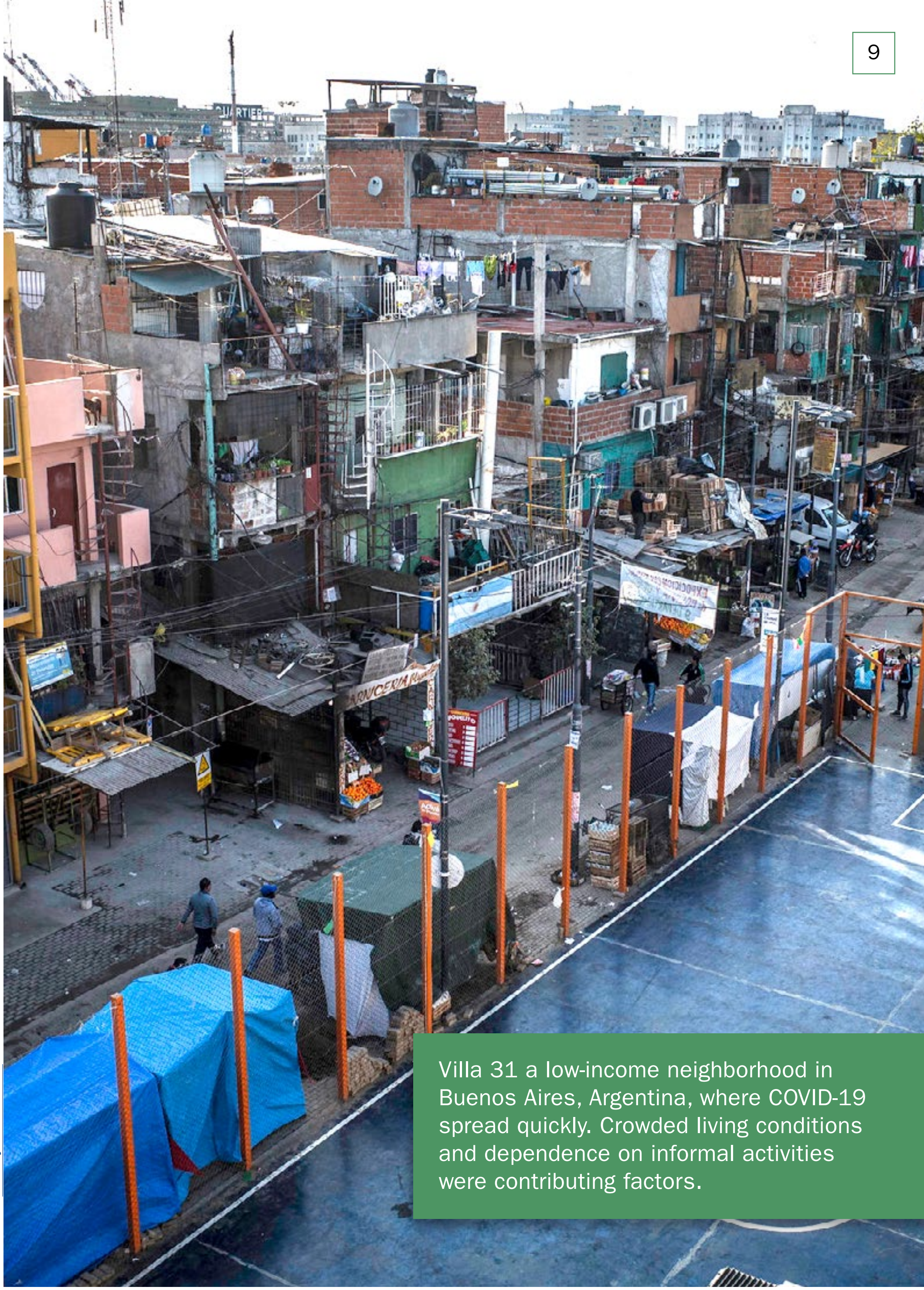


Photo credit: Jimmy Baikovicius

Villa 31 a low-income neighborhood in Buenos Aires, Argentina, where COVID-19 spread quickly. Crowded living conditions and dependence on informal activities were contributing factors.

Supports Broad, All-Stage Detection

Wastewater testing includes people at all stages of illness, making it a valuable tool for early detection of outbreaks. As shown in figure 4, people excrete SARS-CoV-2 in their stool before they develop symptoms or if they remain asymptomatic, and viral shedding is highest in the first few days of infection, when people are in the early stages of the disease. Other types of surveillance—such as testing people who are sick or hospitalized—only capture cases after people have developed symptoms, although contact tracing does identify people who are pre- or asymptomatic.

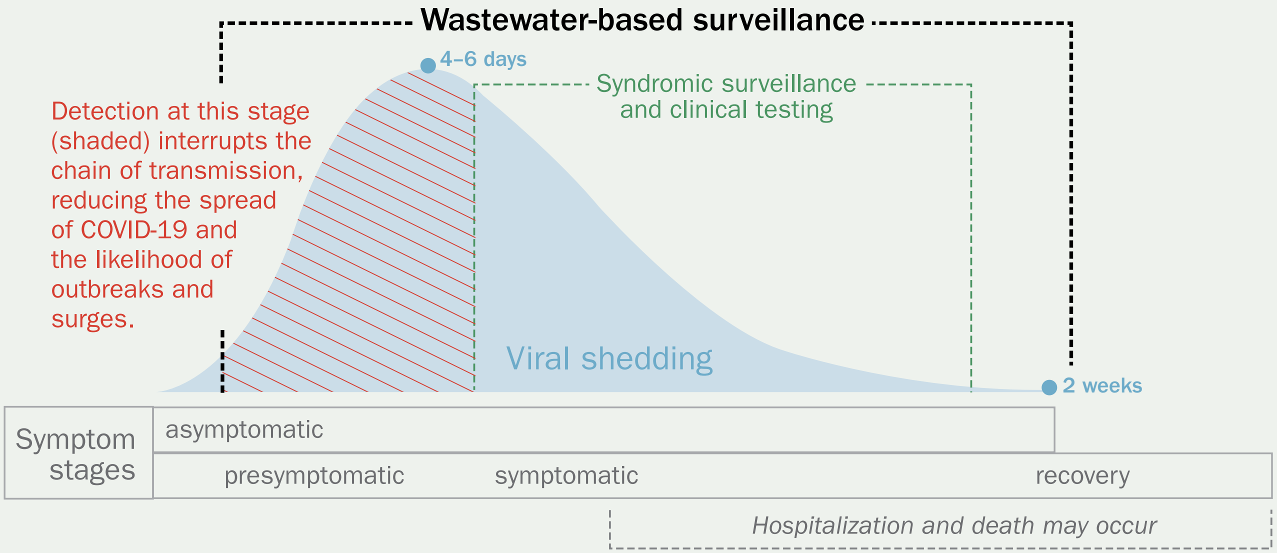
For early outbreak detection, wastewater testing must be done frequently and at the right locations. For more on this topic, see How Wastewater Testing Is Performed in section 3, Wastewater Surveillance Toolbox.

Supports Sustainable Surveillance

Wastewater testing is less resource-intensive than clinical testing and does not need clinical services and clinical laboratories that are stretched with many pandemic demands. Instead, wastewater testing uses wastewater engineers and municipal utility staff. The diagnostic assay (RT-qPCR) for wastewater testing follows the same approach as clinical testing, but the tests are performed by environmental testing laboratories (figures 5 and 6).

Wastewater testing also requires no effort on the part of people who are included in this COVID-19 surveillance (WHO 2020a, 2020b). Clinical testing requires people to have both physical and mental capability to get a clinical test, along with sufficient opportunity and motivation. Motivation for clinical testing has been found to be highest during

Figure 4. Wastewater Testing Identifies People Throughout Acute COVID-19 Illness



Note: Viral shedding time frames are approximate.

Centrifuge that is used to concentrate wastewater samples prior to measuring the level of SARS-CoV-2. Wastewater testing requires more measurement steps compared to clinical tests of SARS-CoV-2.

Photo credit: AySA

the peak of COVID-19 waves, but testing continues to be essential during periods of low transmission to identify new outbreaks and surges (Hasell et al. 2020).

The resource requirements for wastewater testing are typically much lower than for clinical testing. The total cost of clinical testing increases considerably during surges and waves, whereas for wastewater testing the cost generally remains constant (figure 7). This is because clinical testing costs are proportional to the number of people tested, while wastewater testing costs are proportional to the number of sites sampled, which does not change greatly with the number of people covered by the test. Wastewater testing is typically performed two to three times each week, but the frequency can increase or decrease depending on the level of circulating SARS-CoV-2 and also local characteristics of the wastewater system.

The cost of implementing and maintaining a wastewater testing program can vary 10-fold or more. A starting point for planning a national wastewater testing strategy is US$1 per person for the first year. However, costs can vary from US$0.20 to over $3 per person depending on the proportion of the population served by wastewater treatment facilities, the frequency of testing, and other factors (Hart and Halden 2020; Gawlik et al. 2021; Keshaviah et al. 2021). Section 4, Towards a National Wastewater Surveillance Program (Phase 2 – Develop) describes more about resource requirements and, briefly, how costs can be estimated.

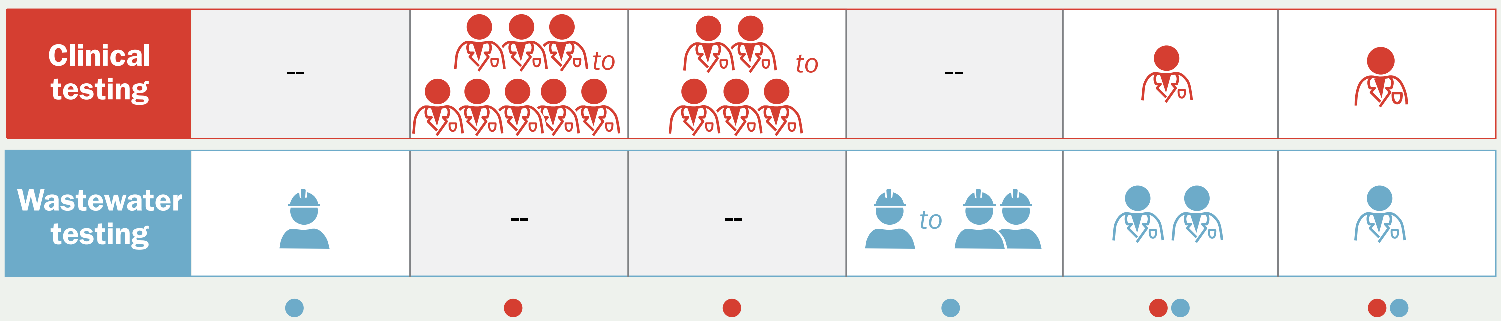
Various countries and regions start small, by piloting wastewater testing at a few sites, and then expand to additional sites after they have established the necessary infrastructure, including logistics and integration with the public health surveillance system.

Figure 5. Resource Requirements for Clinical Testing Versus Cost of Wastewater Testing

Supplies, lab equipment, and assay requirements for testing

	Laboratory equipment	Assay reagents
Clinical testing	$$ *to* $$$	$$$ *to* $$$$$
Wastewater testing	$	$

Human resources requirements for testing



Municipal and environmental staff

Staff are required to maintain sample equipment; take, store, and transport samples; and collect wastewater system and environmental characteristics.

Clinical staff

Clinical staff vary depending on the amount of testing. At times of high infection, there are demands on clinical staff for both testing and caring for ill patients.

Clinical laboratory staff

Laboratory staff vary depending on the amount of testing. Laboratory staff may have increased demands for other clinical tests during COVID-19 waves.

Environmental laboratory staff

Some settings have centralized testing that covers many sites. Other settings perform testing locally or regionally, requiring more laboratories, but with less transportation and fewer transportation delays.

Analysts and IT staff

Data analysts perform the complex task of interpreting and correlating both clinical and wastewater test results. IT staff ensure information systems for holding, analyzing, and visualizing data are reliable and integrated across agencies.

Public health staff

Staff interpret wastewater test results along with other surveillance data to assess the level of current and future COVID-19 transmission. Staff then develop and implement response plans.

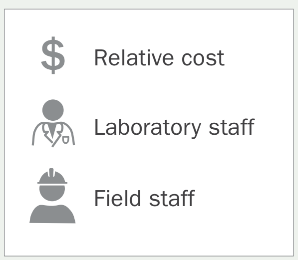


Figure 6. Clinical and Wastewater Testing Resources

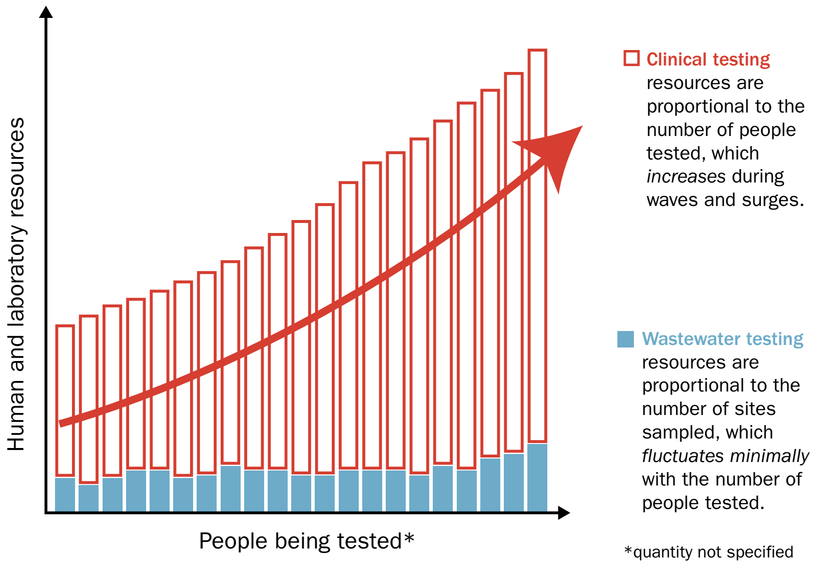
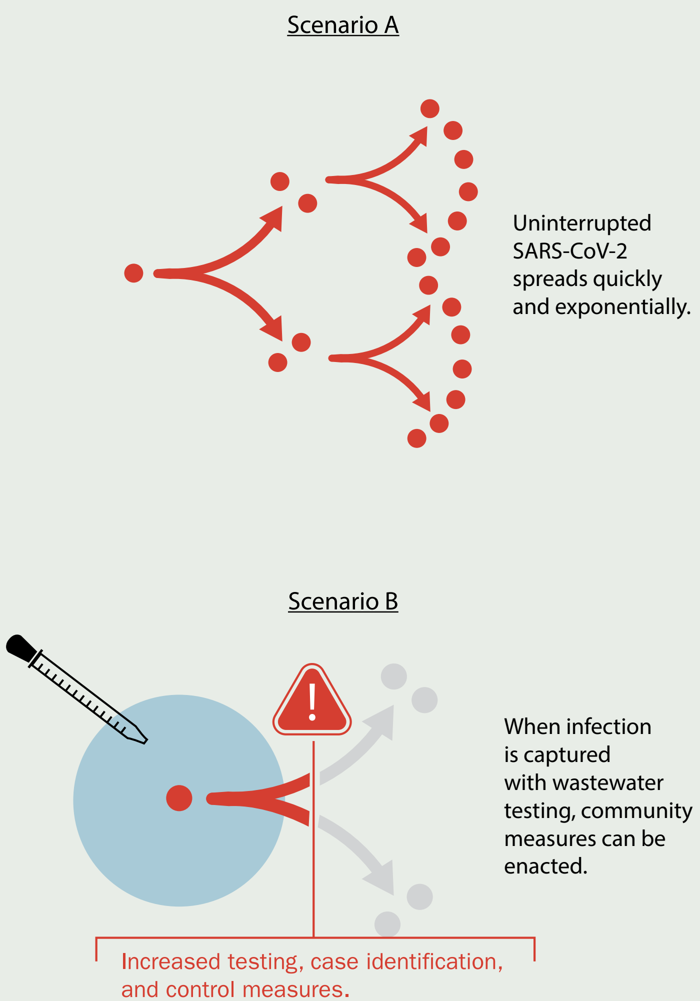


Figure 7. Early Identification of Surges and Waves is Critical for Control



Supports Control of Outbreaks, Surges, and Waves

Wastewater testing has identified clusters of cases before they progress to sustained transmission. This critical early warning of potential outbreaks and surges has allowed public health officials to engage communities and quickly implement control measures (figure 7). As shown in figure 2, wastewater testing can help control COVID-19 in settings with small to large populations. In section 3, we describe four different uses of wastewater testing that are used worldwide to control COVID-19.

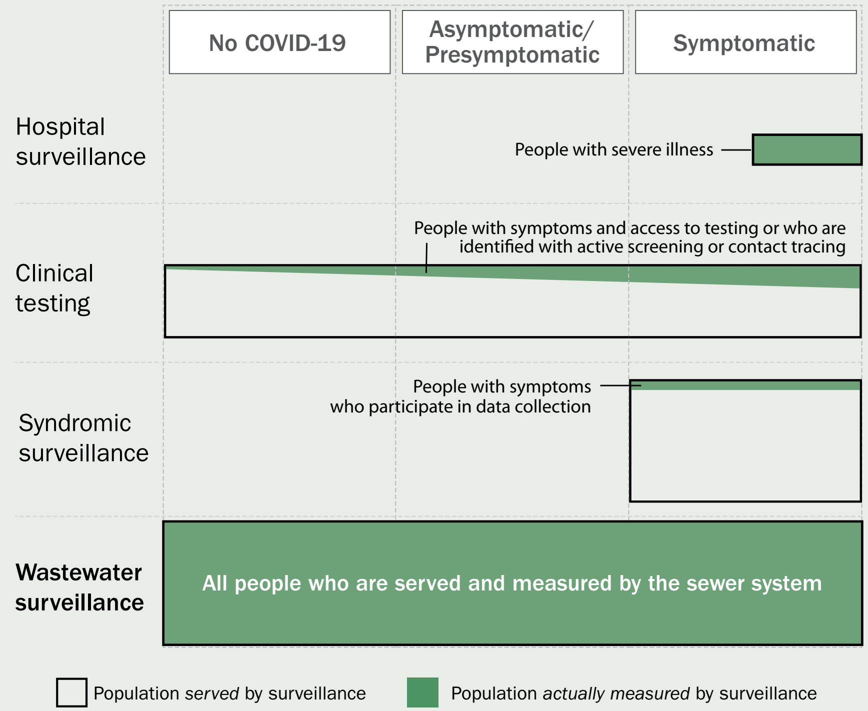
Supports Equity and Population-Based Surveillance

Wastewater testing can be used for broad populations or with a focus on hard-to-reach and underserved groups. Because it captures everyone who uses that wastewater system, wastewater testing includes people who lack access to clinical testing for COVID-19. Vulnerable populations can be specifically targeted by collecting wastewater from neighborhoods or congregate settings with a higher risk of COVID-19.

Up to 100 percent of people in a defined area can be captured by wastewater testing, depending on the type and extent of the sewerage system. As illustrated in figure 8, other approaches to COVID-19 surveillance cover much smaller proportions of the population:

- Hospital surveillance captures people with COVID-19 who become severely ill and receive hospital care, approximately 5 percent of people with COVID-19 overall. This approach works well to create a population-based estimate of severe disease where there is good access to health care. The proportion of people hospitalized has been lower for younger people, although transmission is more common among them.
- Clinical testing captures an estimated 10 percent to 50 percent of people with COVID-19, depending on how available testing is in the area, how actively testing is being promoted, and what stage of the pandemic the local area is experiencing. Some groups are less likely to get tested, and there are concerns that voluntary testing will decline as the pandemic wanes locally.
- Syndromic surveillance captures people who have and report symptoms of COVID-19. This approach is well suited for specific populations, such as schools and workplaces. Between 20 percent and 70 percent of people with COVID-19 have symptoms (lower proportions among younger people), but less than 1 percent of the general population are likely to participate in ongoing syndromic surveillance, such as reporting symptoms through a smartphone app.

Figure 8. Population Coverage of COVID-19 Surveillance Approaches



Note: For specific populations, locate wastewater testing sites in high-risk neighborhoods, difficult-to-reach communities, and conjugate living (long-term care homes, prisons, university residences, etc.)

Wastewater is a Lens into the Health of Our Community

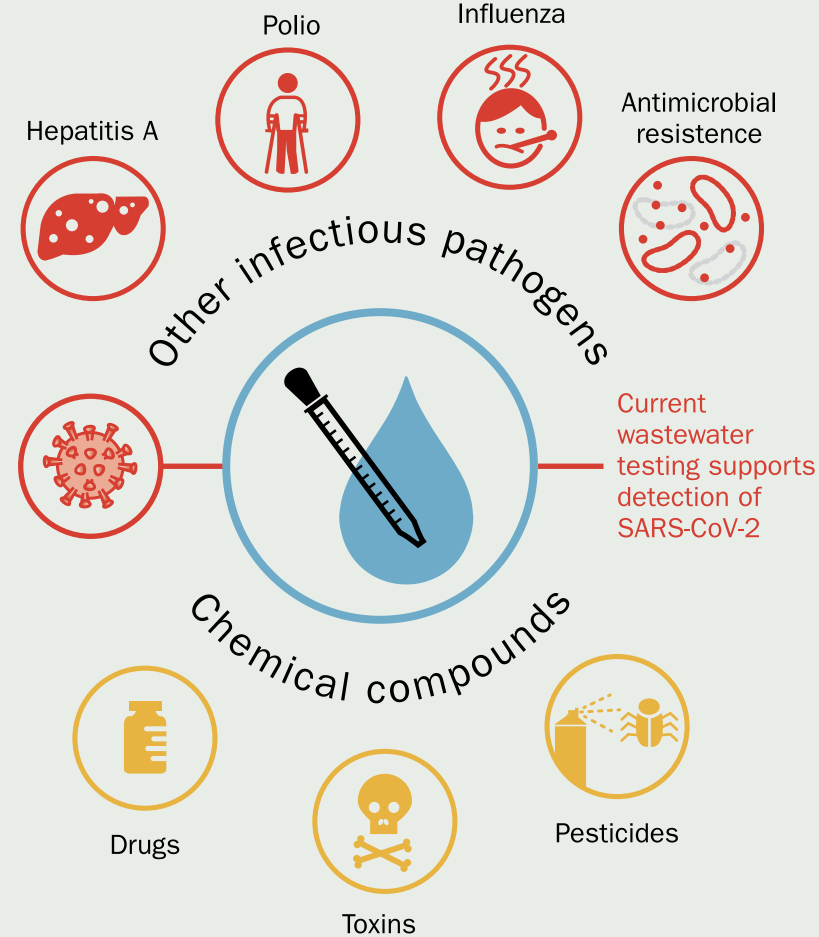
The emergence and success of wastewater testing during the COVID-19 pandemic has highlighted its potential as a multifaceted public health surveillance tool with roles beyond the current pandemic (figure 9).

Wastewater is described as an "underground" surveillance tool that complements "above ground" surveillance by providing a lens into the broad, hidden health of our communities in two ways. First, much of what we eat or ingest comes out in our feces, including drugs, toxins, pesticides, and other chemical compounds that we have been exposed to. There is an increasing appreciation through metagenomics (the study of microbial communities) that our health is reflected in our feces. Second, a variety of infectious pathogens—causing influenza, hepatitis A, polio, or other diseases beyond COVID-19—are excreted in feces. A single wastewater sample can be analyzed for multiple pathogens to provide insights into infection trends in a community.

Beyond human health, wastewater testing is part of the One Health approach that explicitly integrates human health, animal health, and environmental health with an endpoint of improving global health security and achieving gains in development (World Bank 2021a; World Bank 2021b). Seventy-five percent of emerging infectious diseases in humans have their origin in animals (Ogden et al. 2017).

The next section, Wastewater Surveillance Toolbox, outlines how wastewater testing is being used in the current pandemic, how it is performed, what resources are required, and what challenges to expect in implementing a wastewater testing program for COVID-19.

Figure 9. Uses of Wastewater Testing Beyond the Current Pandemic



3 Wastewater Surveillance Toolbox

The Requirements, Strengths, and Challenges of Implementing a Wastewater Surveillance Program for COVID-19

Photo credit: JEC / WATERLAT GOBACIT, Paraguay

In this section, we outline what's involved in carrying out wastewater testing and highlight both the strengths and current limitations of this tool. We describe four uses of wastewater testing for SARS-CoV-2: early detection of outbreaks and surges, population-wide surveillance, specific population surveillance, and variants of concern surveillance. For each type of use, we present a real-world example among the increasing number of examples worldwide. In each case example, wastewater testing has informed public health action to control the spread of COVID-19.

In examples worldwide, wastewater testing has resulted in policy action leading to an interruption or reduction of COVID-19 transmission. This outcome has convinced local officials that their early efforts to pilot wastewater testing yielded a valuable return on investment. For example, numerous university campuses that used wastewater testing in the 2020 academic year identified asymptomatic cases of

COVID-19 in student residences. These efforts were so successful that, in some jurisdictions, wastewater testing labs have had difficulty meeting the growing demand for university surveillance in 2021.

At the same time, there are concerns that wastewater testing requires further development before moving into widespread use. Critics have several concerns. First, for each use case that shows benefit, there are likely more situations where wastewater did not provide value over existing COVID-19 surveillance approaches. Evaluations have consisted of reviews of case reports and may be biased towards describing benefit (Manuel et al. 2021). Second, despite the rapid development of wastewater surveillance during the pandemic, much development and evaluation of the method is still underway. Third, many programs are challenged to migrate from pilot projects led by academic laboratories to scaled, sustainable programs managed by public health or other government agencies.

How Wastewater Testing Is Performed

Figure 10 illustrates the basic steps in wastewater testing as a COVID-19 surveillance tool.

Of key importance is the last step: After the samples are analyzed, the findings must be communicated to local, regional, national, and international public health and environmental agencies where they can be interpreted alongside other COVID-19 data. Data should also be widely shared with researchers and others worldwide to advance our understanding of COVID-19.

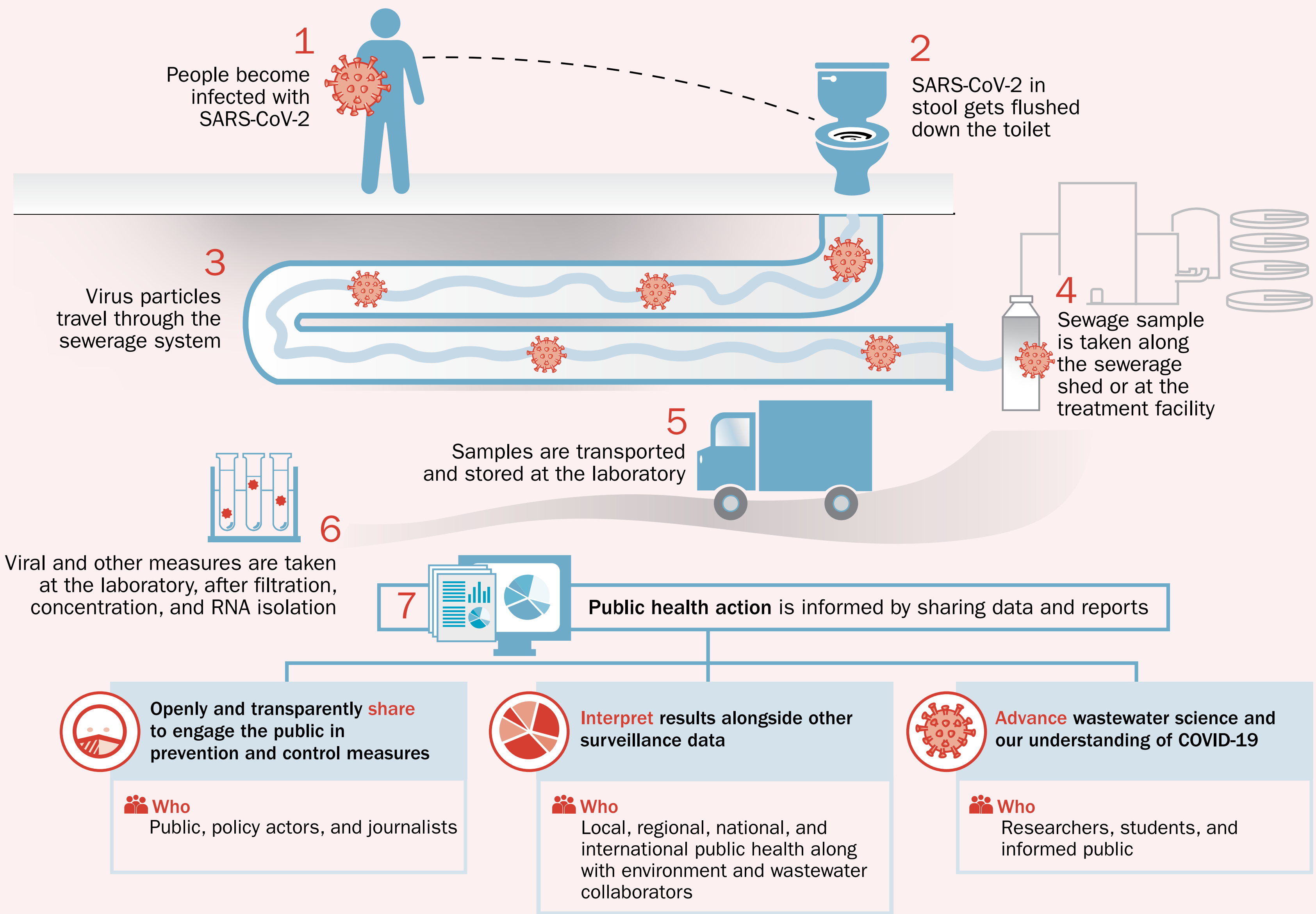
Wastewater testing is "local" in terms of where samples are collected, but the steps necessary to use that testing to inform a public health response—the analysis, interpretation, communication, and decision-making—require careful coordination with regional, national, and even international agencies and expertise. The critical role of these partnerships is a theme throughout this report.

Collaboration and coordination among wastewater testing partners are critical for the success of wastewater testing programs. Many programs have struggled during the high demands of the pandemic to form highly integrated teams among the key partners: municipal wastewater utilities, wastewater testing laboratories, and public health.

Sampling from free-flow sewage is used for surveillance of neighborhoods, university campuses and, in some settings, large institutions such as hospitals and nursing homes.

Photo credit: AySA

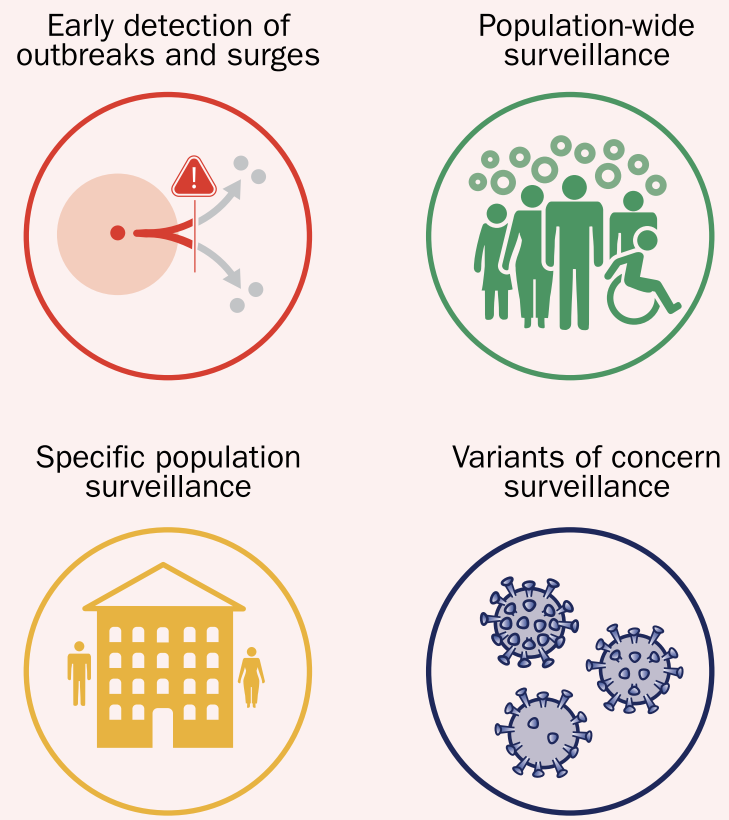
Figure 10. Steps for Wastewater Testing



Four Uses of Wastewater Testing

Based on its key attributes—early identification of viral circulation and population-wide surveillance—there are four current uses of wastewater testing in the COVID-19 pandemic (figure 11) (Keshaviah et al. 2021; Manuel et al. 2021; WHO 2020a, 2020b).

Figure 11. Four Uses of Wastewater Testing



Early Detection of Outbreaks and Surges

Because SARS-CoV-2 RNA can be detected in wastewater before a community or population has any laboratory-confirmed clinical cases of COVID-19, wastewater testing is being used to detect outbreaks before there is confirmed transmission and to identify surges or waves where there is established transmission. The level of detection varies depending on wastewater system characteristics and assay method but ranges between 1 and 50 new COVID-19 cases per day for a population of 100,000 people (Wu et al. 2021).

See the case example from Yellowknife, Northwest Territories, Canada.

Population-Wide Surveillance

Because wastewater testing provides population-wide data (everyone who uses the sewerage system is included), it is being used to complement other forms of surveillance to inform the need for and monitor the effectiveness of prevention and control measures such as vaccination.

See the case example from the Netherlands.

Specific Population Surveillance

Because wastewater testing can also be performed at targeted sites, it is ideally suited for early detection in specific populations and congregate settings such as long-term care facilities, correctional facilities, shelters, university residences, and workplaces. People who are missed by clinical testing can be included in wastewater testing.

See the case example from the University of Arizona, United States.

Variants of Concern Surveillance

Wastewater testing can assess the prevalence of variants of concern (VOC), using the two-step approach typically used in testing of clinical samples. First, wastewater samples can be screened for virus variants using clinical RT-qPCR testing. The RT-qPCR test for variants can examine mutations in one or more VOC, or it can look for the RNA sequences for a specific variant (Lee et al. 2021). Second, RNA from a given sample can be fully sequenced to confirm the specific type of a known variant and potentially detect new mutations. For wastewater testing, near-complete SARS-CoV-2 genomic sequences can be determined using metagenome assays, also known as the consensus community genome (Landgraff et al. 2021).

Countries have varying levels of capacity to test for VOCs in the clinical setting. Sequencing can be performed on a population sample or on a subset of screen positive tests among groups of concern such as travelers, people with severe illness, or those with high viral load. A strength of wastewater testing is the ability to provide a population-wide assessment for VOCs in countries that would otherwise be able to examine only specific populations. In the clinical setting, population-wide assessment of VOCs is challenging and costly, whereas wastewater testing for VOCs is less resource-intensive because one assessment can cover an entire population.

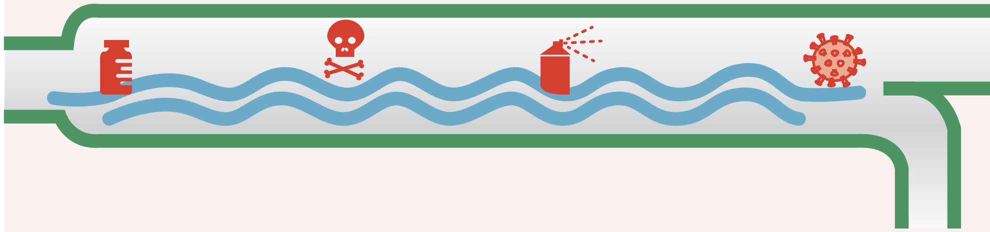
See the case example on nationwide VOC surveillance from the United States.

Potential Future Uses

In addition to the four ways wastewater testing is mainly being used for COVID-19, other potential uses have been identified:

- **Later-stage surveillance.** Monitoring for outbreaks, surges, and re-emergence of SARS-CoV-2 once widespread vaccination coverage has been achieved
- **Monitoring of other pathogens and health risks.** Applying wastewater testing to other pathogens and health risks such as antimicrobial drug resistance and drug monitoring for illegal drug use (Zuccato et al. 2005)

Wastewater is described as an "underground" surveillance tool that compliments "above ground" surveillance by providing a lens into the broad, hidden health of our communities.



Early Detection of Outbreaks and Surges — Yellowknife, Northwest Territories, Canada

Context. Municipal testing in a remote community in Northern Canada, population 20,000

Situation overview. As a remote community, the city of Yellowknife has been able to maintain COVID-19 “zero” for month-long stretches. On December 9, 2020, with still very few cases (all imported) and no community transmission, Yellowknife reported positive wastewater test results. In response, the territories’ Chief Public Health Officer issued an announcement and expanded clinical testing in the community. Approximately 1,500 recent travelers were all contacted by phone and/or email and encouraged to be tested, even if they were asymptomatic. In addition, anyone with symptoms was also advised to seek testing. On December 10, five clinical cases were identified in recent travelers who then had their self-isolation period extended, and their contacts were traced and quarantined. No additional COVID-19 cases were reported, and SARS-CoV-2 RNA in wastewater dropped to undetectable levels.

Value in surveillance strategy. Wastewater offers municipalities an early warning system when or if they can achieve a low level of COVID-19 cases. In Yellowknife, the territorial public health office was concerned that recent travelers do not always self-isolate, as required. They felt that wastewater testing undoubtedly averted sustained community transmission.

Challenges and lessons learned. As a small remote community, Yellowknife did not have the ability to analyze its wastewater samples locally. Samples are flown to Winnipeg, Manitoba, and tested at Canada’s National Microbiology Laboratory, more than 1,500 km away. Turnaround times were up to a week to 10 days. Since then, the local Yellowknife environmental lab has added RT-qPCR and GeneXpert testing to its capabilities. The Yellowknife program has proven so useful it has expanded to other, much smaller communities in the Northwest Territories, from a tiny community with only 250 people to the hamlet of Tuktoyaktuk located within the Arctic Circle. Most participating communities are on trucked sewage: household holding tanks are emptied regularly and trucked to sewage lagoons. In these communities, samples are collected as the trucks discharge.

Source: Health and Social Services, Government of the Northwest Territories, 2021; Heather Hannah, personal communication, November 2021

Photos credit: Heather Hannah

Above: Yellowknife’s GeneXpert assay provides local PCR results quickly.

Left images: Permanently frozen ground (permafrost) in the remote Canadian north means sewage is above ground or trucked. Despite the testing challenges, wastewater-based epidemiology is a cornerstone of COVID-19 surveillance.

Case Examples of Uses

Population-Wide Surveillance — Rotterdam, the Netherlands

Context. Population-wide testing in a European city, population 400,000

Situation overview. The Dutch are leaders in wastewater-based surveillance and were one of the first settings to isolate SARS-CoV-2 in wastewater. Wastewater testing in Rotterdam began as a research project to identify its added value and assess whether detected SARS-CoV-2 reflected clinical COVID-19 infection. Six local and national partners collaborated closely on testing, interpretation, and public health action. Early success showed that wastewater surveillance reliably identified SARS-CoV-2 before clinical case resurgence, and the program was integrated into public health practice.

Wastewater testing is performed three times each week at nine wastewater sites: four pumping stations and five treatment plant influents of different city areas. A careful match was made via zip-codes with the population served and the clinical surveillance data. Wastewater and clinical test results are analyzed after adjustment for sewage flow and population, while clinical tests are adjusted for test delays and the number of tests. Models of wastewater data were developed by comparing results to wastewater tests. The city continues to monitor COVID-19 using both clinical and wastewater surveillance.

Value in surveillance strategy. Wastewater surveillance provides Rotterdam with valuable information beyond what clinical testing can provide. Benefits of added value include:

- **Early identification of resurgence.** In September 2020, wastewater surveillance provided a six-day advance warning. Since then, clinical testing increased and by December 2020 the advanced warning narrowed to 1.5 days.
- **Identification of under-testing in one city area.** In response, the program added 10 clinical testing locations including the use of mobile "test buses" to improve access.
- **Additional evidence.** Local authorities value an assessment of COVID-19 status in city areas that is independent of clinical tests or syndromic surveillance.

Challenges and lessons learned. Rotterdam's program initially faced challenges with their supply chain for wastewater collection and testing; the complex data analyses that involved examining and correlating both clinical and wastewater test results; and the limited number of wastewater collection sites located across the city, which did not allow a surveillance of the complete city in high resolution.

Key lessons learned are that success depends on these factors:

- Collaboration between local public health and water authorities
- Normalization of clinical data for test delays and number of tests
- Normalization of sewerage data for flow and population
- Continuous evaluation of sewerage data versus incidence data
- Frequent sampling to support trend analysis of the normalized SARS-CoV-2 concentration in wastewater

Source: https://storymaps.arcgis.com/stories/8888f5bfb4704180afeda3d476f2aa63

Photo credit: Pouw Vervoer

Mobile test center to improve access when wastewater testing showed more SARS-CoV-2 infections than were being detected by clinical tests.

Specific Population Surveillance — University of Arizona, United States

Context. Campus residence testing at the University of Arizona, population 9,000

Situation overview. The University of Arizona has a diverse campus population, with students coming from many US states.

The University of Arizona performed wastewater testing three times per week as students returned to campus in August 2020. On August 24, classes began. On August 25, a first positive wastewater test was reported. Through enhanced clinical testing over the next four days, three clinical cases were identified. The residents were isolated, and no further cases were identified.

Value in surveillance strategy. The initial successful use of wastewater testing coupled with clinical testing provided confidence that the early warning system could avert outbreaks. The experience led to expanded monitoring of 13 dormitories in early September. Additional positive wastewater tests and clinical cases were identified following the Labor Day holiday on September 7. Of these cases, 70 percent were asymptomatic at time of diagnosis.

Challenges and lessons learned. There are many reports of wastewater surveillance on university and college campuses with similar reports of early detection of SARS-CoV-2 leading to enhanced testing and outbreak control. A review of wastewater testing at 25 campuses identified a wide range of experiences including unexpected challenges and rapid learning and adaptation of programs and expectations. Collaboration—both within and outside the institution—was found to be essential (Harris-Lovett et al. 2021).

Source: University of Arizona, Water & Energy Sustainable Technology Center, 2020.

Photo credit: JR P

University of Arizona campus, Tuscon, where wastewater testing began in August 2020.

Variants of Concern Surveillance — Nationwide Program, United States

Context. Variants of concern testing in the United States, representing over 90 million people in all 50 states and territories.

Situation overview. In the summer of 2021, Biobot was awarded a contract by the US Department of Health and Human Services (HHS) in partnership with the Centers for Disease Control and Prevention (CDC) to measure the amount of COVID-19 circulating in communities by testing wastewater samples from across the United States.

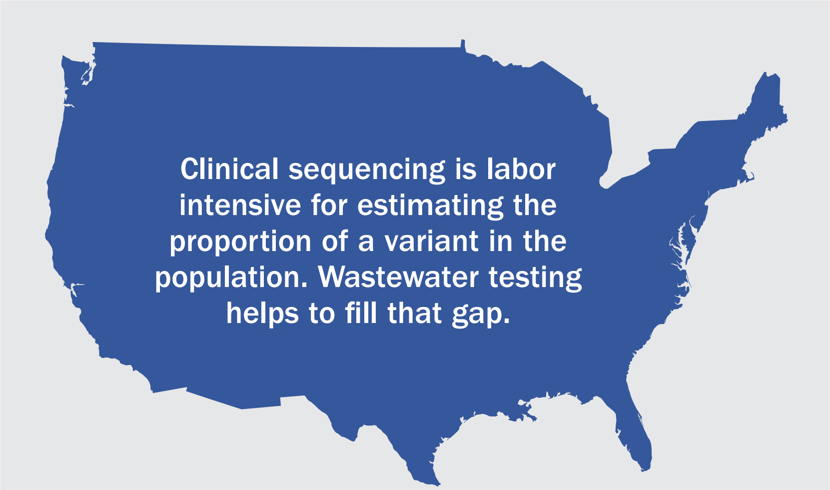
Variant of concern surveillance was performed during two key periods and using two approaches: monitoring for the alpha variant using RT-qPCR from mid-March to early June 2021, and genomic sequencing to monitor for delta, alpha, and other variants during June and August 2021, while Biobot was working with HHS. Biobot is a private-sector analytics firm specializing in wastewater-based epidemiology and they partnered with Ginkgo Bioworks on the genomic sequencing efforts, with Biobot performing sample preparation and data analysis and Ginkgo Bioworks performing the sequencing.

The RT-qPCR monitoring was performed on 753 samples from 83 locations for select Biobot customers, including wastewater treatment plants and buildings. In this targeted analysis, Biobot looked at three mutations that are specific to the alpha variant. The results included both the total viral titer found in the sample, and the percentage that was composed of alpha vs. non-alpha virus (Lee et al. 2021). Genomic sequencing was performed on over 2,000 wastewater samples collected from hundreds of wastewater treatment plants across all 50 states in the United States.

Value in surveillance strategy. Monitoring new variants of concern is important because they can be more transmissible or virulent than the original SARS-CoV-2 strain or previous variants. As the alpha variant was gaining ground in communities at different speeds in the spring of 2021, understanding the proportion of virus circulating attributable to the alpha variant was very useful information for public health officials and decision-makers. It helped them gauge the magnitude of the risk of viral spread in their communities and informed how they should allocate resources. Clinical sequencing of SARS-CoV-2 is labor intensive and is often performed in specific populations such as hospitalized patients, posing challenges when estimating the proportion of a variant in the population. Wastewater testing helps to fill that gap.

Challenges and lessons learned. The preliminary results confirmed the promise of leveraging wastewater-based surveillance as a tool to complement genomic surveillance as an additional method to detect and quantify variants of concerns (e.g., alpha, delta), as well as other rarer variants (e.g., mu, lambda).

Source: Biobot



People and Partnerships Required

Interpretation of wastewater testing results relies on collaborative expertise at the local level where testing is performed. The three main partners are personnel from local public health, municipal wastewater utilities, and wastewater testing laboratories (figure 12).

Public health staff understand different approaches to COVID-19 surveillance. They know how to interpret wastewater tests for SARS-CoV-2 alongside traditional infectious disease metrics that are being used to monitor COVID-19. They also develop and implement a public health response considering the likelihood of further transmission, available resources, and intervention effectiveness.

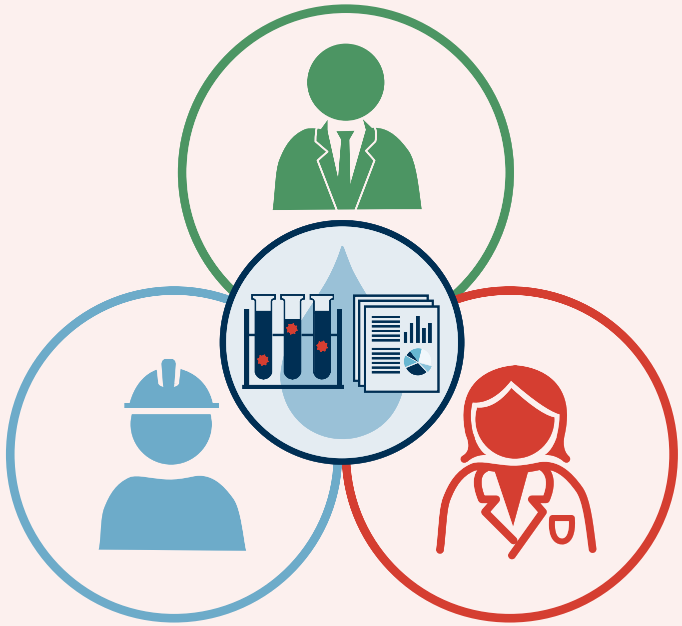
Municipal wastewater utilities staff understand the wastewater system and factors that potentially affect RNA transit time and viability. Municipal staff collect wastewater samples and contribute data on wastewater flow, temperature, and other measures that are used to adjust and calibrate viral detection levels.

Wastewater laboratory staff (wastewater engineers, scientists, and technicians) understand the assay performance characteristics and the relationship between the wastewater systems, sample collection, and the reported virus level. They perform RT-qPCR tests for SARS-CoV-2 and other regularly excreted viruses. Wastewater labs report viral levels to public health after standardization, calibration, and multiple quality control assessments.

At the beginning of the pandemic, wastewater engineers and scientists typically led the development of pilot programs. Engaging public health staff is essential, as public health holds responsibility for translating COVID-19 surveillance into public health action. As wastewater testing programs developed throughout the pandemic, a key characteristic of successful programs has been the close and effective collaboration among partners.

Environmental surveillance is complex and requires additional supporting partners and expertise such as data scientists, supply-chain expertise, and a learning system approach to project management. Data analysis is an example where expertise spans the three major partners but also includes advanced modeling approaches from additional partners.

Figure 12. Three Disciplines for Wastewater Surveillance Success



Implementation Challenges

Methods and practices in wastewater testing for pathogens such as polio have been developed over several decades. With the rapid expansion of wastewater testing in the COVID-19 pandemic, some important challenges have emerged.

Three issues have been identified: the need for best practices in measurement and reporting to account for expected variations in viral signal, the need for multidisciplinary collaboration and coordination, and the need for sustainable program infrastructure (figure 13).

These challenges, described in more detail below, require attention at the local, regional, national, and international levels.

Photo credit: AySA

Figure 13. Implementation Challenges

Measurement and reporting best practices need development.

Improvement needed: Quality assurances among the various analytical methods to measure SARS-CoV-2 in wastewater need to be improved.

Challenge: Many factors influence the amount of measurable viral material in wastewater, resulting in wide day-to-day variation in signal within and between sites.

Interpreting results requires collaboration and coordination.

Improvement needed: Public health, testing labs, and wastewater utilities must work together to ensure wastewater testing provides actionable intelligence.

Challenge: Like any interagency effort, a wastewater testing program is a chain where strength comes from every link.

Wastewater testing programs need sustainable infrastructure.

Improvement needed: Local programs need support to transition from pilot programs to expanded, organized, and sustainable surveillance systems.

Challenge: In the rapid growth of wastewater testing during this pandemic, most new programs have been pilot projects by academic laboratories.

Measurement and Reporting Best Practices Need Development

Measurement variation is typical for environmental surveillance systems such as wastewater testing, and methods to improve COVID-19 measurement are rapidly being developed. Many factors influence the quantity of viral material in wastewater and thus the quantity of viral RNA that can be measured at any given testing site. Wide day-to-day variation in signal is often observed within and between sites.

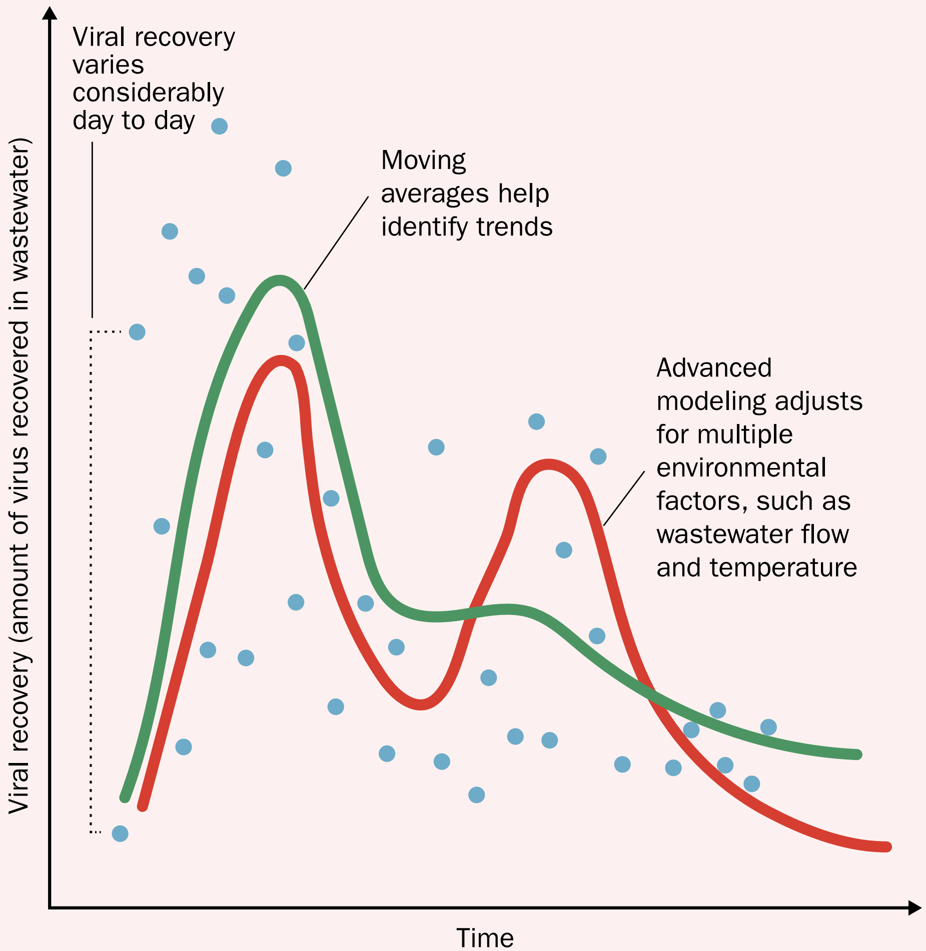
The factors that affect test results are grouped into three categories (figure 14, figure 15):

- **Variations between people.** The level of viral RNA excreted in stool rapidly increases during early illness, then plateaus before decreasing as the disease runs its course. Wastewater testing captures excreted RNA during all these phases, and a single person's stool RNA will enter the sewerage system over several days or weeks. The overall level of RNA excreted or entering the wastewater system varies depending on people's age, fecal excretion patterns, and other individual characteristics.
- **Variations in wastewater infrastructure and the environment.** Across wastewater systems, there are differences in the transit time and quantity of RNA that remains intact between the points where an individual's stool enters the system and where the sample is collected. These differences arise from variation in the size and design of sewershed, infiltration of groundwater (seeping into sewer pipes), rainfall draining into combined sewers, the use of holding tanks and pumping stations, the fragility of the viral RNA, and factors such as temperature or substances that affect the integrity of the viral RNA or inhibit viral identification.
- **Variations in sample collection and method of measuring SARS-CoV-2 viral load.** Wastewater samples can be collected from utility holes for free-flowing street sewage, influent (where sewage enters a collection basin or reservoir), or primary sludge in wastewater treatment plants, among other settings. An increasing number of sampling approaches are available, including a "grab" sample of wastewater, a passive sample that absorbs viral particles on a membrane that is kept in free-flowing wastewater, and autosamplers that capture small amounts of wastewater at specific time intervals. SARS-CoV-2 adheres to feces particles, and higher virus recovery levels can be found when testing waste sludge as compared with liquid effluent.

Each sampling approach has its own advantages and limitations. There are also different approaches to transport, store, and concentrate a sample prior to RNA extraction and measurement. Across the world, measurement of SARS-CoV-2 is largely being performed using RT-qPCR or RT-d(d)PCR with similar primers, although with a wider variation in calibration, quality assurance, and standardization approaches.

Figure 14. Factors Affecting Day-to-Day Variation in Measurement

Figure 15. Key Influences for Wastewater Measurement



Best practices for measurement and reporting are not firmly established, although there is rapid progress. There are several approaches to improve the variation in wastewater measurement including:

- **Identifying the optimal sampling method or frequency.** Variation in viral measurement may be reduced by sampling continuously or testing frequently. Measurement can be performed on both solid or liquid waste. New sites can begin by testing frequently and using different sampling approaches. Initial data analyses can then identify the optimal testing frequency and the most reliable sampling approach.
- **Viral recovery adjustment** (standardizing or normalizing measurement). SARS-CoV-2 virus measurement can be adjusted for standard compounds or wastewater flow rate. Compounds used for adjusting SARS-CoV-2 measurements include viruses such as pepper mild mottle virus that occurs worldwide and is shed by people with and without COVID-19.
- **Smoothing and modeling.** Wastewater results can be smoothed by reporting moving averages, in a similar approach to reporting 7-day moving averages for clinical tests. More complex modeling uses the same approach as viral recovery adjustment but can include multiple adjustment measures, lag periods and interactions and other measures of variability described in the previous section. Advanced statistical and machine learning (artificial intelligence) are used when many parameters are modeled.
- **Quality control and assurance.** There are many steps in quantification of viruses in wastewater, including sampling, transportation, storage, measurement, and reporting. Each step has the potential to generate measurement error. Quality control and assurance standards have been proposed and they are used in some jurisdictions (Ontario Ministry of the Environment, Conservation, and Parks 2021).

An open-science approach to wastewater surveillance seeks to rapidly advance measurement and reporting best practices through transparent and accessible knowledge (National Academies of Sciences, Engineering, and Medicine 2018). Sharing surveillance data within and between programs and countries provides a key resource to understand the key sources of measurement variability. There are several data models and repositories to facilitate standard data storage and open data access following FAIR data sharing principles (for example, see the Public Health Environmental Surveillance Open Data Model [PHES-ODM]; the Global Water Pathogens Project; and the Norman Database System, SARS-CoV-2 in sewage [SC2S]).

Interpreting Results Requires Collaboration and Coordination

Interpretation of wastewater testing results is challenging because the signal (the level of detectable viral RNA) is affected by many factors, as described above. Public health staff are often unfamiliar with wastewater testing as a COVID-19 surveillance tool and are burdened with many other surveillance priorities and tasks during this pandemic. As a result, it may be difficult for them to find time to coordinate their activities with wastewater scientists. In many jurisdictions, public health, environmental science, and wastewater utilities personnel have had limited opportunities to collaborate before this pandemic. In addition, their different disciplinary approaches—the fact that they do not "speak the same language"—can add to the challenges of collaborating. These key partners need to understand their common goals and be supported with clear coordination of all the moving parts involved in wastewater testing, so that the program results in timely, actionable public health intelligence.

Testing Programs Require Sustainable Infrastructure

Before the COVID-19 pandemic, few jurisdictions worldwide had established wastewater testing programs for specific viral disease. Programs developed during this pandemic have typically been pilot projects by academic laboratories. A limited number of countries and world regions have begun organized programs:

- The European Commission has instituted wastewater testing for SARS-COV-2 as part of their Member State surveillance program under the Health Emergency Preparedness and Response Authority (HERA) Incubator program for variant surveillance. Throughout the European Union, 600 wastewater testing sites were planned by the end of July 2021, with 6,000 sites planned for a fully-implemented system (Gawlik and Medema 2021; European Commission 2021).
- The United States has incorporated SARS-CoV-2 testing into the National Wastewater Surveillance System (CDC 2021). As well, the United States recently announced national funding for wastewater assessment of variants of concern in 320 sites covering 100 million people (Government Technology 2021).
- In Australia and New Zealand, the Collaboration on Sewage Surveillance of SARS-CoV-2 (ColoSSoS) Project is integrating wastewater testing data with clinical surveillance data (Water Research Australia 2020).
- Canada has over 250 testing sites that cover all provinces and two territories (Manuel et al. 2021).

For jurisdictions without this kind of national or international support, there is a need to develop a clear roadmap to scale or sustain pilot projects.

Use Examples in Latin America and the Caribbean

Ecuador: Building Local Capacity for Wastewater Testing for Control of COVID-19

Background and objective

In March 2020, Ecuador was one of the countries worldwide worst-hit by COVID-19, and the city of Guayaquil, in Guayas Province, was the epicenter of the outbreak. Case counts in Guayas reached over 4,300 per week in a population of 3 million. While the pandemic subsided locally, it spread nationwide, and Ecuador's COVID-19 death toll climbed (32,000 confirmed by August 2021).

From the outset, delays in case reporting were evident in Ecuador, like many other countries, making it difficult for the government to assess the true scope of the pandemic in real time and hindering efforts to stay ahead of the virus. In late June 2020, the World Bank and Biobot, a global analytics firm specializing in wastewater epidemiology, partnered to help address this problem. The initiative had two objectives: build local capacity in Guayaquil to perform wastewater testing for SARS-CoV-2, and develop technical guidance on how to spread this capacity in lower-middle-income countries.

Local partners and project roles

To successfully implement the capacity-building activities, the World Bank and Biobot worked with four main local stakeholders:

- **Empresa Municipal de Agua Potable y Alcantarillado de Guayaquil (EMAPAG),** a municipal water authority in Guayaquil that oversees water and wastewater activities. In this project, EMAPAG was responsible for providing financial support for wastewater analysis and coordinating the activities.

Photo credit: Anthony Surace

View of the city of Guayaquil, Ecuador

- **Interagua,** a private concessionary that runs Guayaquil's drinking water, wastewater, and rainwater drainage systems under a 30-year contract with EMAPAG. Interagua was responsible for selecting sampling locations, providing information on catchment areas, and collecting the samples.
- **Escuela Superior Politécnica del Litoral (ESPOL)**, a local research university that also engages in service contracts. ESPOL joined the project to participate in the laboratory analysis phase of the activities.
- **Comité de Operaciones de Emergencia (COE) Provincial,** the emergency operations committee and the main entity responsible for the local COVID-19 response in Ecuador. More recently, this role—including the role of public health authority for local COVID-19 response—has shifted to the COE Cantonal.

Activities

The main activities focused on capacity building for sample analysis. ESPOL and the Biobot team met weekly online to discuss methods. To identify optimal lab methods, ESPOL conducted a number of experiments, reviewing the design and results jointly with Biobot. ESPOL also developed virus quantification methods for viral titers with guidance from Biobot. At the end of the project, a method verification test was conducted to validate the sensitivity and precision of the lab methods.

Results and lessons learned

- **Capacity building.** As a result of the project, ESPOL developed the capacity to reliably detect and quantify SARS-CoV-2 in wastewater.
- **Data use.** In September 2020, the key project partners met to present the outcomes of the Guayaquil wastewater testing initiative. Both EMAPAG and the COE Cantonal showed interest in using wastewater-based data, especially to support COVID-19 case estimates. At the end of the project, ESPOL closed a one-year contract with EMAPAG to analyze 520 samples in different areas of Guayaquil. This contract is a testament that Ecuador has built wastewater testing infrastructure with sufficient laboratory capacity and local leadership.
- **Challenges.** Two main challenges were the identification of a lab for sample preprocessing and the coordination among all the actors involved. The coordination issue was solved by designating a program coordinator to lead the effort and ensure a smooth flow of information among the partners. From a technical perspective, although there are numerous published papers to learn from and commercially available analytical kits for part of the wastewater analysis process, it is difficult to select and develop methods from scratch in a lab that does not have experience in wastewater surveillance Bringing in technical expertise (in this case Biobot) was important to guide the development of laboratory methods.

Argentina: Mobilizing Quickly for Wastewater Testing for COVID-19 Control (and Beyond)

Background and objective

The first case of COVID-19 in Argentina was reported on March 3, 2020, and by the end of June 2020, the country of 44 million inhabitants had reported more than 62,000 infections and 1,200 deaths due to COVID-19, with the City and Province of Buenos Aires as ground zero for the pandemic and the most affected areas in Argentina, with more than 90 percent of cases and 50 percent of deaths.

As part of its innovation and technological development strategy before the pandemic started, the GBA water and sanitation operator, Agua y Saneamientos Argentinos S.A. (AySA), had acquired PCR equipment to develop capacity in molecular methods applied in the wastewater field. Therefore, AySA was able to quickly mobilize its personnel to initiate applying these methods for COVID-19. In July 2020, with initial advice from KWR (a water research institute based in the Netherlands) and the sanitation and wastewater treatment regional entity in Murcia, Spain (ESAMUR), AySA was sampling and analyzing sewage in an area representing over 90 percent of the Buenos Aires population, and sharing the results with the National Ministry of Health, as inputs into decision-making.

Local partners and project roles

AySA is responsible for the delivery of drinking water and sanitation services to over 14 million people, and this wastewater surveillance program was itself responsible for sampling, storage, processing, and analysis of sewage with its own PCR equipment and laboratory personnel. To successfully initiate and ramp up its wastewater surveillance program, AySA also worked with two main stakeholders:

- The National Ministry of Health receives the information and knowledge generated by AySA's Central Laboratory. This information is used to inform public health decision-making at the national level.
- The Dr. Carlos Malbrán National Administration of Health Laboratories and Institutes (ANLIS Malbrán), a medical research institute under the National Ministry of Health based in Buenos Aires, initially brought support to AySA in calibrating methods and protocols (for example, by providing a surrogate virus control to help with quantification early on).

Activities

AySA collects samples directly from manholes situated at the outlet of 43 sewersheds across the Buenos Aires region, as well as at the inlet of six wastewater treatment plants. The sampling strategy includes weekly samples at every treatment plant and bi-weekly samples at every

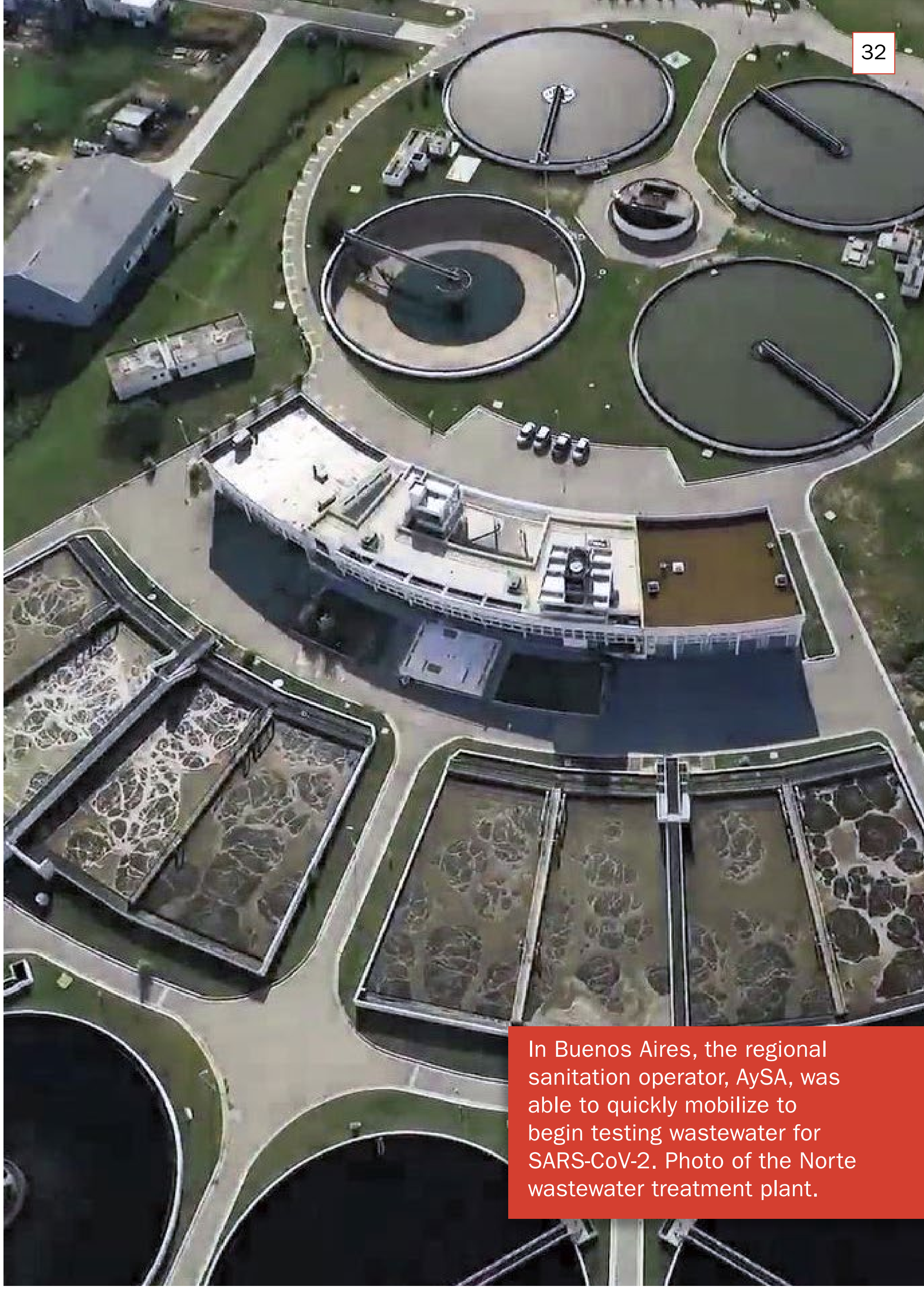


Photo credit: AySA

In Buenos Aires, the regional sanitation operator, AySA, was able to quickly mobilize to begin testing wastewater for SARS-CoV-2. Photo of the Norte wastewater treatment plant.

manhole. Grab samples taken at the time when sewage flow is at its peak during the day (verified by analyses of E. coli loads throughout the day) were preferred over composite samples, after a careful analysis of both methods in terms of viral loads and potential dilution effects.

As a result of the positive interaction between AySA and the ANLIS Malbrán, these partners entered in October 2021 into a longer-term framework agreement to continue developing new protocols and research opportunities related to other viruses such as the poliovirus and to the rise in antimicrobial resistance. It is the objective of this collaboration to jointly generate new knowledge and information critical for decision-making with health authorities.

AySA also aspires to share this experience with other water and sanitation service providers across Argentina in partnership with the Federal Council of Water and Sanitation Entities (COFES). A first capacity-building activity and knowledge exchange was successfully conducted with the Mar del Plata municipal operator (OSSE Mar del Plata), which has now embarked on a similar path with the support of the Dr. Juan H. Jara National Epidemiological Institute based in the same city.

Results and lessons learned

- **Expansion (and benefits) beyond COVID-19.** Both water and health actors have seen the potential of wastewater-based surveillance to help better respond, recover, and plan not only for the current COVID-19 outbreak in Buenos Aires and Argentina, but also for future pandemics and other threats to public health. AySA is incorporating wastewater-based surveillance into its overall risk management system and strategy and has realized through this recent experience that the development of molecular biology capacity in its laboratories can also help improve wastewater treatment operations.
- **Challenges.** The initiative experienced two main challenges. Low availability of imported inputs during the pandemic impacted the ability to perform the RT-qPCR tests. The procurement of some chemicals was so complicated at times that AySA invested in research to identify alternative products that would allow them to continue testing on a weekly basis. For example, aluminium chloride (not readily available in Argentina) was replaced with polyaluminium chloride (PAC), used by AySA in its drinking water treatment facilities, and protocols were adjusted accordingly. The second challenge was finding a balance between investing the time needed to establish sampling and testing protocols (a lengthy process in itself), responding to the pressure to innovate in these difficult times, and continuing to respond to daily emergencies as part of a water and sanitation utility's primary responsibilities.

4 Towards a National Wastewater Surveillance Program

Overview of the Surveillance Program Cycle.
Estimating Costs and Resource Requirements

Photo credit: Magdalena Wiklund

Countries worldwide, including Latin America and the Caribbean, are at different stages in implementing wastewater surveillance for COVID-19. Few if any jurisdictions have well-developed programs. Most low-income countries have not begun testing, despite uniform agreement that these countries have the most to benefit from wastewater testing, given its low resource requirements compared with other surveillance approaches.

Regardless of a country's experience with wastewater testing, the process of designing a testing strategy at the national level is cyclical, with four key phases (figure 16):

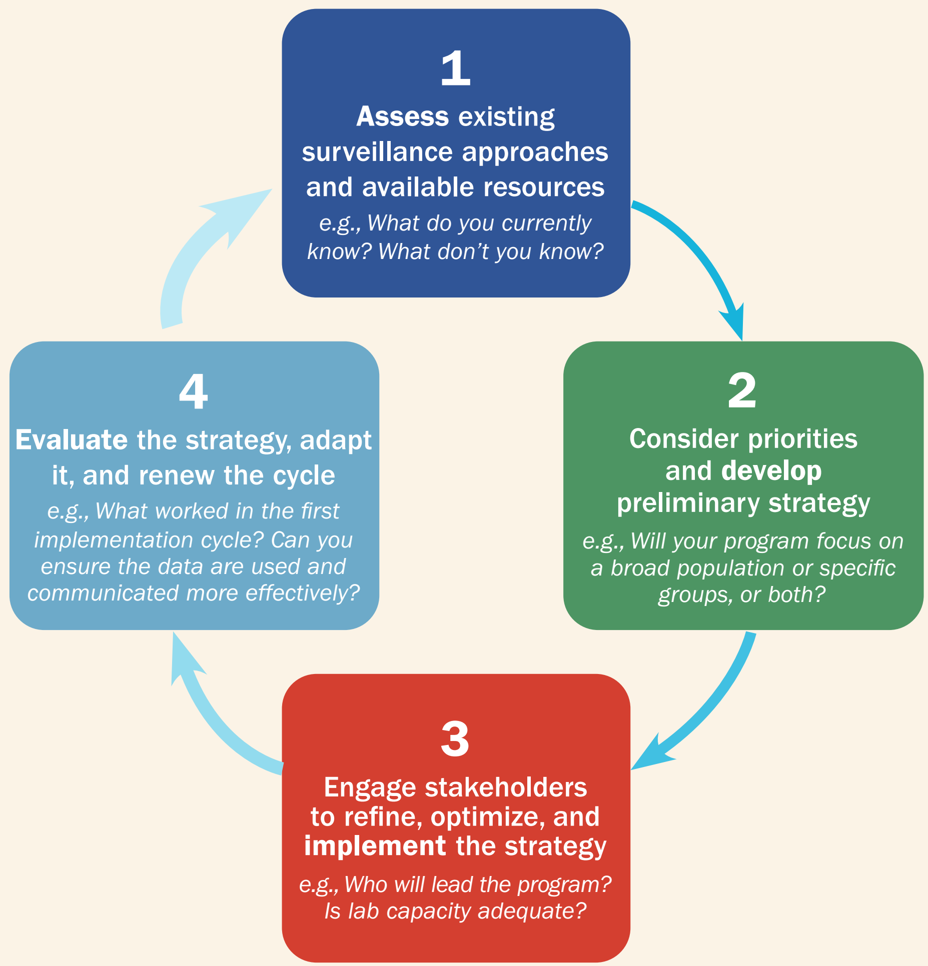
1) **Assess** existing surveillance approaches and available resources
2) Consider priorities (goals, objectives, and outcomes) and **develop** a preliminary strategy
3) Engage stakeholders to refine, optimize, and **implement** the strategy
4) **Evaluate** the strategy, adapt it (based on findings and new realities), and renew the cycle.

Strategies will vary depending on a country's current COVID-19 surveillance strategy. Countries with few surveillance gaps and underdeveloped infrastructure for wastewater testing may be best served by starting with pilot sites. Pilot programs can, for example, help develop partnerships between public health, wastewater testing labs, and municipal wastewater utilities. In other countries, it may be imperative to implement a wastewater testing program widely if there are concerns about large gaps in COVID-19 surveillance or the ability to sustain resource-intensive clinical testing.

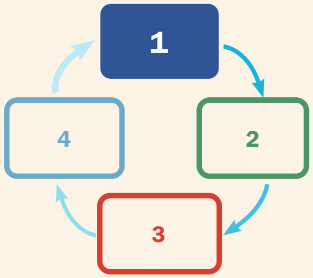
Here we outline the four implementation phases. In each phase, the planning process will be informed by:

- The types of surveillance data already available
- The country's capacity to collect, analyze, and interpret wastewater tests, with the necessary collaboration among partners
- The country's ability to successfully implement strategies.

Figure 16. Phases of a Wastewater Surveillance Strategy



Phases of a Wastewater Surveillance Strategy



Assess Phase 1

- Current surveillance inventory
- Wastewater system inventory
- Human resource inventory
- Information systems inventory
- Inventory of political and public receptivity

Phase 1 — Assess

Take an inventory of existing and emerging surveillance approaches and available resources. Identify gaps and needs

Prior to starting or expanding a wastewater testing strategy, it's essential to take an honest inventory of your country's current COVID-19 surveillance activities and capacity. This assessment can identify current pinch points (areas of weakness) and blind spots (data gaps). Consider this inventory from two viewpoints: the country's overall surveillance approach for COVID-19 and the role of wastewater testing within that overall strategy. How would wastewater testing add to your current surveillance strategy?

The assessment should consist of five inventories: an inventory of current surveillance data, a wastewater system inventory, a human resource and capacity inventory, an analytic and information system inventory, and an inventory of policy and public receptivity.

Current Surveillance Inventory

What surveillance for COVID-19 does your country (or community) currently perform?

Put your surveillance sources together and develop a blueprint of:

- What you currently know
- What you currently don't know
- What you would like to know more about.

Consider how the potential strengths of wastewater testing could fill in your surveillance gaps. Look at your current data system with these elements in mind (figure 17):

- Timeliness
- Population-wide surveillance
- Specific population surveillance
- Available resources
- Variants of concern

Figure 17. Questions for a Surveillance Data Inventory

Timeliness
Are there delays in reporting of clinical tests? Is clinical testing missing new outbreaks or surges? Do you currently have enough lead time to respond to outbreaks and surges when they are identified?

Population-wide surveillance
Are there current gaps in testing coverage? Do you anticipate ongoing challenges in maintaining testing capacity and uptake? As a complementary source of data, does wastewater testing support public health action?

Specific population surveillance
Are "hot spots" (outbreaks in campuses, hospitals, prisons, low-income neighborhoods) difficult to detect? Are some populations difficult to reach? Are there equity concerns (surveillance gaps for disadvantaged populations)?

Available resources
What are the start-up and ongoing costs, including in-kind contributions and human resources, for wastewater surveillance? Are there sufficient resources given that clinical testing is an ongoing requirement?

Variants of concern
Is there sequencing capacity to identify variants of concern and calculate their prevalence and spread?

Wastewater System Inventory

How is wastewater collected and treated in your communities? Consider the wastewater system from two critical perspectives:

- **Percent of the population served by wastewater facilities.** Wastewater testing can be performed in almost any type of wastewater system from large, well-developed treatment facilities that cover 1 million people to wastewater trucks and lagoons or even raw, untreated sewage trenches. Countries have fewer implementation issues when most of the population is served by wastewater treatment facilities, but wastewater testing can also be considered for areas with low facility coverage. Populations or neighborhoods that lack formal wastewater treatment may also face a higher COVID-19 burden and, as we described in section 3, wastewater testing can help to address these inequities.
- **Number of testing sites.** The cost and infrastructure for wastewater testing is highly related to the number of testing sites. Testing at a single treatment facility can cost the same whether the facility serves a city with 1 million people or a town of 1,000 people. A first step is to calculate the number of testing sites in your country's program, which may include both population-wide surveillance and surveillance of specific high-risk groups such as conjugate living spaces or underserved neighborhoods. Start to consider site accessibility and sampling methods. Sites with limited access will require more people and effort to sample (human resource inventory). However, there is much sampling innovation for auto and passive samplers that is quickly reducing sampling effort.

Economies of scale can be realized if a single laboratory can serve many testing sites. For example, the Netherlands performs all wastewater testing from a national laboratory. Similarly, data and analytics services can serve entire countries or even multiple countries. The Wastewater Sphere is a project that integrates and develops visualization approaches for worldwide wastewater data (Global Water Pathogens Project 2021).

The number of tests performed can be reduced by pooling samples or using sentinel sites. Pooling is the combining of samples from communities or neighborhoods that share similar transmission risk and no known COVID-19 cases. If SARS-CoV-2 is detected, the original samples can be tested to locate the source of infection. Sentinel surveillance of wastewater focuses on populations where outbreaks, surges, or new variants are likely to first appear before spreading. Sentinel surveillance can be used in populations with high risk of new cases or transmission such as migrant communities or travelers, in areas where there is low immunity (low vaccination coverage), or in groups with high risk of complications or adverse events (hospitals, communities with older people).

Human Resource Inventory

Who performs or can perform wastewater sampling, testing, analysis, and communication?

A wastewater surveillance program requires a diverse group of people with different areas of expertise in the right numbers. We have described the three main disciplines involved (see section 3): public health staff, wastewater engineers and scientists, and municipal wastewater utilities staff. An essential requirement is the ability of these disciplines to work together.

In addition, a range of other people are needed to support wastewater surveillance, including the people who work in program planning, transportation of samples, information system support, advanced data analyses and modeling, and communication services. Key personnel required for a successful wastewater testing program can be identified by tracing the seven steps in figure 10, from sample collection to public health action.

Photo credit: AySA

A wastewater sample goes through several stages of solid separation, concentration, and viral extraction before the sample—shown here from Argentina—is ready for analysis.

Information Systems Inventory

What information systems are available or needed to support data collection, analyses, communication, and sharing?

For wastewater testing to provide early warning of COVID-19 outbreaks and surges, rapid and wide dissemination of test results is critical. It's important to understand and address the information challenges that may hinder your country's ability to quickly publish, interpret, and make use of the testing data.

Several common information challenges exist with wastewater testing. First, quality control and standardization to account for measurement variability are complex. Furthermore, analyses and data visualization to interpret the data can be more sophisticated than for other COVID-19 surveillance data. Lastly, wastewater data must be integrated and disseminated across different decision-making departments. Approaches to assist data analyses and interpretation are increasingly available but it is important to realize that, as an environmental surveillance approach, wastewater testing requires the support of modern information systems and advanced analytics.

Inventory of Political and Public Receptivity

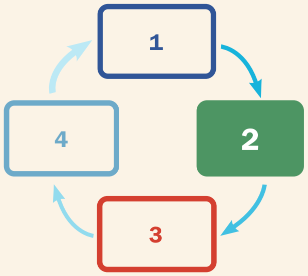
How ready for and receptive to wastewater surveillance are the government and the public?

Are your country's political, government, and social environments supportive of wastewater testing? Wastewater testing is unfamiliar to many people, many may not know that SARS-CoV-2 is excreted in feces, and this lack of awareness may be a barrier to support. Wastewater testing has few privacy concerns because the results represent an entire community, not specific individuals. Nevertheless, there are ethical concerns that wastewater testing may stigmatize communities if the purpose and outcomes of the testing are not well communicated.

Anticipate potential concerns by raising awareness through public media and have a robust communication plan in place. Run a pilot of wastewater testing, if needed, and review any communications and ethics issues that emerge. To be effective, any type of public health surveillance program needs to build and maintain public trust.

As a multidisciplinary, multiagency program, wastewater testing requires buy-in from a number of government departments and political organizations that may not be familiar with the approach. Faced with a proposed new program, potential partners will want to critically appraise the role of wastewater surveillance. Be sensitive to the reality that agencies will conduct such reviews and consider their priorities in the setting of competing and limited resources, with an uncertain pandemic course. The approach to assessing a new technology or surveillance approach will vary by agency and discipline. Some agencies will want "definitive proof" of the effectiveness of wastewater surveillance, and what constitutes evidence for one group will differ from another.

To conduct a multidisciplinary appraisal of wastewater testing, it is important to first develop consensus on how the potential value of the program will be assessed and how the results will be applied. During the pandemic, there has been a shift from "science in action" to "science for action" (Jasanoff 2015). In a "science for action" assessment, wastewater testing needs to meet two criteria: Does it withstand scientific scrutiny? And does it provide a basis for timely action? Another, similar approach uses four criteria to assess the use of science for decision-making: relevance, credibility, legitimacy, and positioning for use (Belcher et al. 2016, 2021).



Develop Phase 2

Set goals and objectives

Gather your team

Consider these key implementation questions

Estimate costs and required resources

Ensure results will inform public health action

Phase 2 — Develop

Consider priorities and develop a preliminary program

The assessment in phase 1 should help you articulate clear priorities for a wastewater surveillance program. For example, do you want data for a broad population or for specific groups or locations?

Set Goals and Objectives

In line with national and local priorities, create your overall goals for wastewater testing. Goals should focus on reducing the burden of disease in the community or for specific groups or areas. Then develop short-term, medium-term, and long-term objectives for the program, describing more specifically what the program aims to achieve.

In setting goals and objectives, be realistic about what to expect from wastewater testing. Remember that:

- Wastewater testing complements rather than replaces other surveillance approaches.
- Partnerships and infrastructure can take time to develop if they do not already exist.
- Test results can be difficult to interpret (see Implementation Challenges in section 3).
- You may need to balance short-term and long-term objectives. Wastewater testing may offer long-term solutions for monitoring a range of health risks beyond COVID-19, and building capacity for wastewater testing may have other long-term benefits.

At this point, also consider your evaluation strategy (see Phase 4, below). How will you know your wastewater testing program is successful? Develop at least a preliminary evaluation plan before you start testing. This will help to identify implementation challenges early, increase the likelihood of the program's success, and improve the quality of your evaluation data.

Gather Your Team

Gather your team of wastewater, laboratory, and public health personnel (see People and Partnerships Required in section 3) and identify a lead organization. Wastewater engineers have typically led these initiatives, but successful programs are closely integrated with public health to ensure the data are used to inform public health measures to control the spread of COVID-19.

Organize the program's support structures. To help the program run smoothly, get agreement and clarity on roles and responsibilities across the team.

- **Accountability structures.** Who is responsible for decision-making as the program proceeds?
- **Steering or advisory structures.** What additional expertise or oversight will the program need?
- **Implementation structures.** Any program that involves multiple organizations needs to be clear about where responsibilities lie for each part of the program plan. How will your program get support from each of the organizations involved?
- **Reporting and public health action structures.** How will the testing results be communicated and to whom? How will decisions be made on the public health response? Are the necessary structures in place to support the public health response?

Consider These Key Implementation Questions

Which populations will you sample, and how often?

To meet the program's goals and objectives, will testing be population-wide or focus on priority populations, or a mix of both? It may be important to adopt a flexible strategy that can react and adapt to changing conditions.

The optimal frequency for wastewater testing is not well established. Typically, testing is performed two to three each week. More frequent testing (and/or more testing sites) allows more rapid detection of pathogens. Testing is often performed frequently when starting a new testing site to form a baseline for interpretation. Frequent testing can also improve your team's ability to interpret the daily variations in wastewater signal, particularly during periods of ongoing COVID-19 transmission.

How will cross-cutting issues be addressed?

With the implementing partners, revisit the team's preliminary thinking on how the scope of the wastewater testing program could be affected by each of the following areas:

- **Laboratory infrastructure, capacity, and supply chain.** It takes time to build national and local lab capacity and validate testing protocols, especially when supply chain and logistics are limited. The safe implementation of a testing strategy requires secure supply chains for purchase, procurement, and distribution of necessary materials—including reagents, and personal protective equipment. Consider what is needed to support secure supply chains. Consider collaborating with countries or tapping into the private sector. Within the capacity and the goals of the strategy, what is the realistic volume of tests that can be analyzed daily and weekly? Is there a streamlined process for receipt of samples and reporting of results?
- **Human resources.** Consider human resources across each of the three main partners—public health, municipal utilities and wastewater testing laboratories. Are sufficient clinical staff available to support targeted testing in response to a spike in infections identified by wastewater surveillance? Additional personnel required include administrative and other clerical personnel, data managers and analysts, transportation, and systems managers, among others.

- **Transportation networks.** The delivery of high-quality samples and rapid turnaround of test results depends, in part, on the efficient movement of wastewater samples to the labs for analysis. Consider what is needed to support efficient delivery of samples in appropriate storage.
- **Surveillance infrastructure and data communication.** To ensure surveillance activities are useful and actionable, consider whether all key supports are in place: reliable and integrated data collection; laboratory information system; database or data repository, analyses, and visualization; and dissemination of results. Can data generated by testing lead to timely action?

Estimate Costs and Required Resources

Costs and resources required for wastewater testing are commonly estimated using simple spreadsheet calculations based on the number of sites, frequency of testing, and estimates of equipment and reagent costs. Costs are estimated per person or per site for a time period, such as one year. Box 2 shows a typical example of how to calculate per-person costs. The result of the estimate is US$0.50 per person per year for wastewater testing for a population of 100,000, not including the cost of sampling, transportation, and interpretation. A similar calculation is used to estimate the cost per wastewater testing site per year. Using cost estimates from a country survey, the European Union estimated the annual cost for each site in their member states to be US$30,000 (25,000 euro) (Gawlik et al. 2021), which translates to a cost range of US$3 per person for a site covering 10,000 people to US$0.3 for a population of 100,000.

In addition to operating costs, start-up costs include the sampling equipment, lab testing equipment, and information technology to manage test results data and integrate the data into public health reporting and surveillance systems. The European Union estimated that each member country spent between US$1 million and $3.5 million to initiate a wastewater surveillance program (Gawlik et al. 2021). In Germany, the development of their CORONA Warn program cost US$26.5 million ($0.3 per person) with an estimated monthly cost of US$3.5 million to $4.9 million ($0.04 to $0.06 per person/per year). In Ontario, Canada, the start-up and operating cost was US$0.7 per person for the first year of their new SARS-CoV-2 wastewater testing program (US$10 million for a population of 14.7 million) (Manuel et al. 2021).

Estimated costs (operating and startup) vary considerably depending on calculation inputs or actual realized costs. Countries and international programs have begun to collaborate on best practices for standard reporting and information technology, with the expectation that these technologies can be shared with low-income countries. Lower human resource costs in low-income countries may result in lower program costs.

The World Health Organization recommends that wastewater surveillance costs be compared with the societal costs avoided through timely public health action resulting from well-implemented surveillance systems (WHO 2020a). As well, comparing the costs of wastewater testing and clinical testing has informed countries about the relative return on investment for establishing a wastewater surveillance program. Based on the average cost and level of clinical testing, countries in Latin America and the Caribbean spent approximately US$14.5 per person for clinical testing in 2020/21 (Box 3), more than 10 times the estimated cost of establishing wastewater surveillance in the first year.

Box 2. An Example of Estimating the Cost of Wastewater Testing for a Population

Cost per COVID-19 wastewater test (cost per test):
US$300

Frequency of wastewater testing (tests per year):
100 (approximately 2 x per week)

Catchment size (people per testing site):
100,000 per site

$$\textit{Wastewater testing cost per person} = \frac{(\textit{cost per test}) \times (\textit{tests per year})}{\textit{number of people in sewage catchment}}$$

$$= \frac{\$300 \textit{ per test} \times 100 \textit{ test per year}}{100{,}000 \textit{ people per site}} = \$0.50 \textit{ per person per year}$$

Box 3. An Example of Estimating the Cost of Clinical Testing for a Population

In Latin America and the Caribbean, September 2020 to September 2021, costs by country

Cost per test:
approximately US$40, range $20 to $100

Number of tests:
approximately 29 to 94 tests per 100 people

Lowest estimated cost of clinical testing in Latin America and the Caribbean

Cost per clinical test:
US$20

Number of tests per year:
29 tests per 100 people

$$\textit{Clinical testing cost per person} = (\textit{cost/test}) \times (\textit{tests/person/year})$$

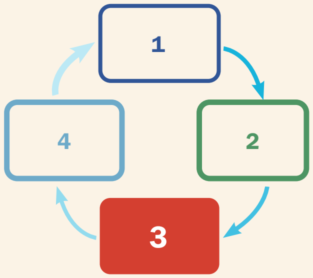
$$= \$20/\textit{test} \times 29 \textit{ tests}/100 \textit{ people} = \$5.80 \textit{ per person per year}$$

Ensure Results Will Inform Public Health Action

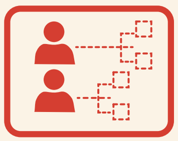
The purpose of wastewater testing as part of COVID-19 surveillance is to inform a country's public health response. It's important to prepare for how the data will be analyzed, reported, interpreted, and used. Several key factors can affect the usability of the data.

- **Multidisciplinary approach.** Analysis and interpretation require a multidisciplinary approach with public health, municipal utilities, and wastewater engineering staff working closely together to understand and report the data. Many jurisdictions worldwide report both the importance of good partnerships between disciplines, the lack of well-established partnership prior to the pandemic, and the challenge of developing those partnerships during the pandemic when public health can be overwhelmed by demands that exceed their capacity (Manuel et al. 2021; WHO 2020a).
- **High-quality assays are critical.** SARS-CoV-2 RNA results are affected by many environmental and wastewater system variables, as outlined earlier (see Implementation Challenges in section 3). Best practices are still emerging. Build quality control and assurance into your surveillance program by participating in validation studies. The viral testing signal can vary between sites and variations in quality and interpretations are expected, particularly during testing at new sites. Be transparent regarding the performance of wastewater testing to build trust and establish. The goal is to improve assay quality and interpretation over time.
- **Establish a response plan before testing begins.** As we've noted, it's critical to establish how reports will be used and by whom. Are there processes already in place for communicating environmental health risks such as drinking water advisories? Existing processes may provide a roadmap for communicating the outcomes of wastewater surveillance for COVID-19.

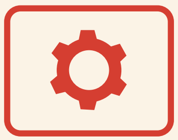
Photo credit: IMF Photo/Raphael Alves



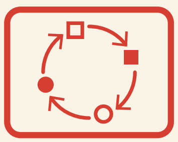
Implement Phase 3



Engage stakeholders and refine your strategy to optimize implementation

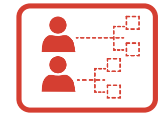


Pilot and scale, or launch a coordinated widespread program



Strengthen, Adapt, Sustain

Phase 3 — Implement



Put the wastewater surveillance initiative into action. Engage stakeholders to optimize the strategy

Engage Stakeholders and Refine Your Strategy to Optimize Implementation

When a general strategy has been developed—that is, you have identified the population to be tested—the next key phase is to broaden the scope of stakeholders engaged as you prepare to fine tune and implement the strategy.

Engaging the implementation partners should begin once the general approach has been defined. This will help cultivate ownership and buy-in of the strategy and improve the chances of success in every phase of the cycle.

Putting your strategy into action involves the following steps (figure 18):

1) The testing team and supplies
2) Collection of samples and system/environmental conditions
3) Transportation, storage, concentration, RNA isolation
4) Measurement and quality control
5) Data management and analyses
6) Data dissemination, interpretation, and public health control measures.

Figure 18. Putting Your Strategy Into Action

The testing team and supplies

Ensure the necessary staff, transportation processes, testing supplies, and information technology systems are adequate and ready.

Collection of samples and system/ environmental conditions

Decide where and how the samples will be collected (who will collect the wastewater sample and what equipment will be used). If possible, collect wastewater and environmental characteristics (i.e., wastewater flow rates, wastewater and ambient temperatures, rainfall). Also consider collecting information about the population served by the wastewater collection system (i.e., population size and clinical COVID-19 tests for people within the sewage catchment area).

Transportation, storage, concentration, RNA isolation

Decide how the samples will be transported to the testing lab and stored at the facility. Is there adequate refrigeration for storage, while samples go through several filtration and concentration steps?

Measurement and quality control

Establish quality control and quality assurance methods at the testing lab, where RNA is isolated and RT-qPCR is performed. Decide what quality checks will be conducted. Decide on the method of calibration and whether repeated measures or validation studies will be performed to ensure the results are consistent and reliable.

Data management and analyses

Ensure that key data are assembled including RNA results, quality assurance, and wastewater system and environmental conditions (see Phase 2, above). Perform analyses to improve the interpretation of the findings. Analysis includes adjustment and normalization of wastewater systems and environmental conditions. Use laboratory management and information systems with standard data dictionaries and quality control metrics.

Data dissemination, interpretation, and public health control measures

Share data openly with local stakeholders. Compare results to other COVID-19 surveillance information by collaborating with epidemiologists, municipal and wastewater utility staff, and wastewater laboratory staff. Interpret the data and develop public health control measures as needed. Share data with other stakeholders more broadly, including the research community and worldwide public health scientists who analyze wastewater results from multiple sites to further understand and improve wastewater surveillance methods and interpretation.

Pilot and Scale, or Launch a Coordinated Widespread Program

During the pandemic, most jurisdictions worldwide began SARS-CoV-2 wastewater surveillance with pilot projects. These programs were often led by highly engaged academic labs working with their existing municipal utility partners. A critical feature for success was early outreach to public health staff and close collaborations with all partners. Pilot sites then transitioned to larger, organized programs led or supported by the government agencies who oversee regional or national wastewater treatment. These agencies coordinated the progressive growth of programs by onboarding new collection sites. Wastewater tests were performed by either scaling existing academic laboratories or by adding other academic or commercial laboratories.

Other jurisdictions successfully started wastewater surveillance programs using larger, multisite testing. These programs either already had well-organized wastewater treatment networks, or they operated treatment facilities at multiple sites. They needed larger testing capacity at onset, which required either commercial or academic laboratories with sufficient testing capacity. As for all successful programs, close collaboration with public health was critical.

Strengthen, Adapt, Sustain

Each wastewater sampling site has unique local characteristics. When a testing program brings a new sampling site onboard, there is a period of understanding how best to collect samples, how the local wastewater system affects viral recovery, and how the wastewater reports compare to clinical reports. As well, the program will often involve new collaborations of people working together from different organizations and disciplines. Put together, this amounts to a period of strengthening, where your program should see quick efficiency gains and improved understanding of wastewater test results.

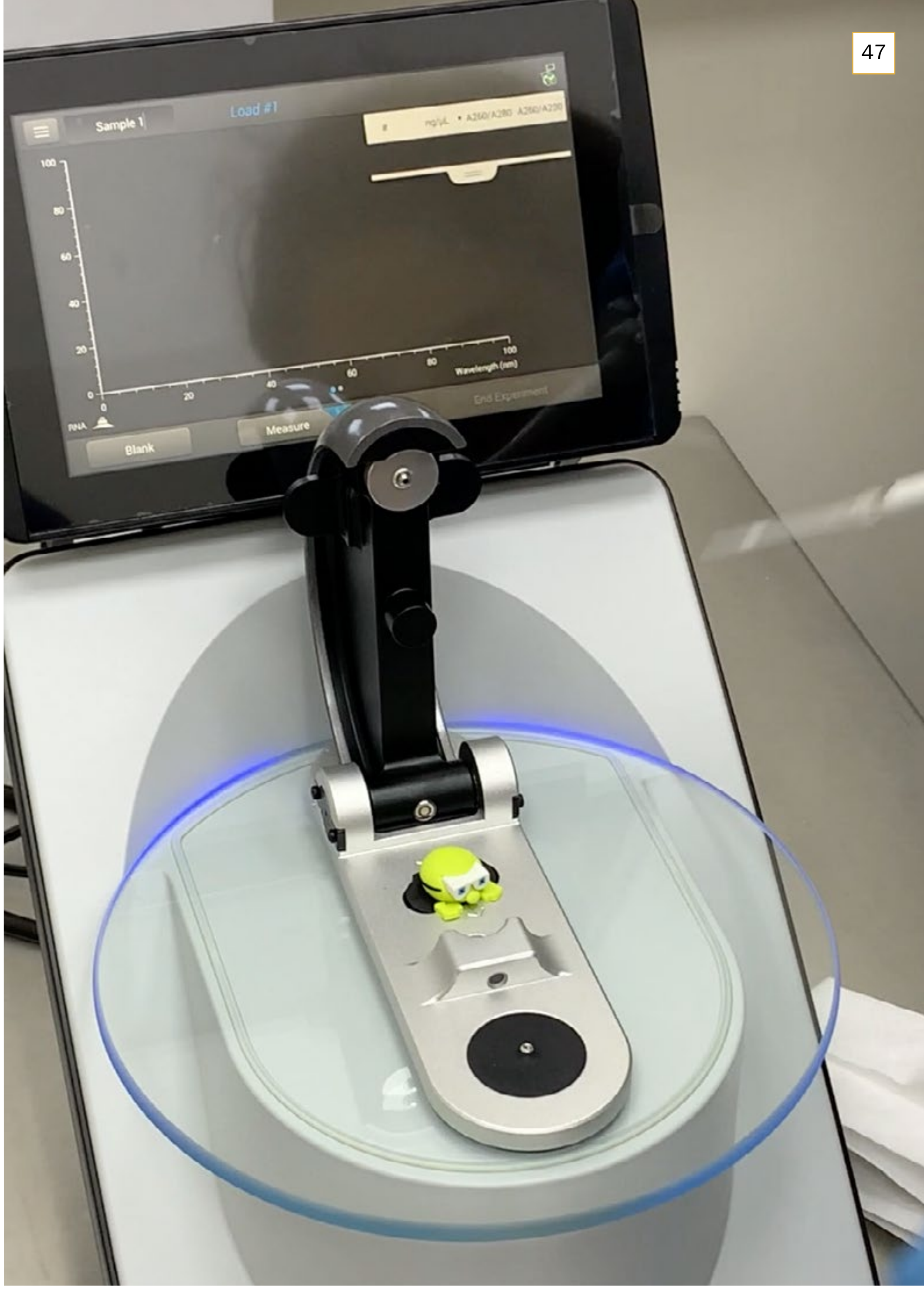


Photo credit: AySA

Financing

Consider how you will finance wastewater testing. The success of a testing strategy can leverage individual and institutional resources, from municipal agencies who will assist in obtaining samples to public health officials who will implement policy based on the surveillance findings. However, improved public health surveillance requires long-term, sustained, stable financing—usually led from national and regional levels.

Wastewater testing during the pandemic began worldwide as pilot or research projects with programs transitioning to longer term programs. In some settings pilot projects have stopped, despite success, because they have not been able to secure long-term funding. There are different models for sustained funding with financing and in-kind resources shared between national, regional, and local municipalities. Local universities, businesses, and institutions also fund wastewater testing for their setting, after they perform cost analyses that show that wastewater testing can provide a favorable return on their investment. However, larger programs typically rely on national and regional funding for most costs including laboratory testing and information systems. Local municipalities can fund testing in some settings and municipalities often share costs for sampling and incorporating test findings into local public health policy.

Adapting to Innovation

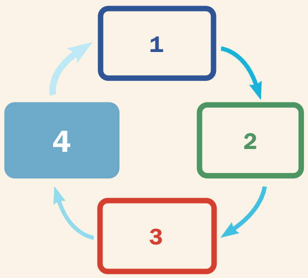
The practice of wastewater testing has quickly developed over the pandemic, and innovation will likely continue at a rapid pace. New programs can expect to modify their approaches in the coming years.

An example is the initial reliance on costly autosamplers that used eclectic pumps to siphon off sewage samples (Schang et al. 2021). Early in 2021, researchers in Australia began testing low-cost “torpedos” with absorbable membranes that were placed in the sewage flow to passively sample wastewater (Kreier 2021). Within five months, as testing sites adopted the new practice, over 2,500 torpedoes were exported around the world, and open-source instructions to make the torpedoes using 3-D printers allowed additional sites to quickly adopt them as well. Canada’s successful program in the remote Northwest Territories has begun using and evaluating GeneXpert PCR analyzers, which allows them to perform SARS-CoV-2 measurement in wastewater locally, rapidly, and with few technical considerations (Heather Hannah, personal communication, November 2021; see also the Yellowknife case example in section 3). Similar innovation is occurring throughout the wastewater surveillance system.

Emerging Diseases and Other Health Threats

The effort to develop a wastewater surveillance system has potential benefits beyond the current pandemic. Much of the work and cost of wastewater testing is related to sample collection, transportation, treatment, and reporting. These processes can largely be reused to test wastewater for other pathogens and chemicals that are excreted through stool or urine. Opioid use, antimicrobial drug resistance, influenza, hepatitis A, and polio are among the examples of health risks that can be monitored through wastewater surveillance (Bade et al. 2019; Bosch et al. 2008; Gracia-Lor et al. 2017; Łuczkiewicz et al. 2010; Sinclair et al. 2008; Vitale et al. 2021; WHO 2003).

Further, the approach to detect SARS-CoV-2 in wastewater can be used for air and surface testing, which also have the potential to identify pathogens not excreted in stool (Cherrie at al. 2021). SARS-CoV-2 and other pathogens can also be identified by their proteins rather than their RNA. Wastewater contains many more viral protein particles than RNA particles, which suggests that protein assays to detect SARS-CoV-2 may be even more sensitive than the current RNA assays (Neault et al., 2020).



Evaluate

Phase 4

Purpose of the program

Utility of the data

Cost and acceptability of the strategy

Feasibility, flexibility, and sustainability

Barriers and facilitators

Potential adaptations for the next cycle

Equity and ethical issues

Phase 4 — Evaluate

Evaluate the program, adapt it (based on findings and new realities), and renew the cycle

Wastewater strategies need to be critically and comprehensively evaluated to understand their successes and challenges and, if necessary, to adapt or refine the strategy. Consider the development and implementation of strategies as an iterative process, cycling again through the four phases used to initiate the wastewater surveillance program.

A careful evaluation will prepare you to improve the strategy where needed and be ready to adapt it to the rapidly changing COVID-19 landscape. Established recommendations for evaluating surveillance systems build on seven key areas (adapted from Groseclose and Buckeridge 2017):

- Purpose of the program
- Utility of the data
- Cost and acceptability of the strategy
- Feasibility, flexibility, and sustainability
- Barriers and facilitators
- Potential adaptations for the next cycle
- Equity and ethical issues

Purpose of the Program

Revisit the purpose and the objectives of the program. For many wastewater surveillance programs, the primary purpose is to guide immediate action for public health prevention and control. However, additional purposes may be relevant, such as providing reassurance that COVID-19 is not increasing during periods of low transmission and establishing baseline data for epidemiologic research and for surveillance for other health risks and future pandemics.

Utility of the Data

After the data from testing are collected, analyzed, and acted upon, your evaluation can begin to answer key questions: Did the testing strategy provide the required data? Did the data support decision-making?

If the data collected did not prove useful for the intended purpose, it is important to review possible explanations. Are the explanations possible to address? If so, how? Examine possible solutions in the context of other considerations, including acceptability, feasibility, and added costs.

To guide your evaluation of data utility, examine these aspects of surveillance performance:

- **Data quality.** Were the data complete and valid? Were quality assurance and control performed, and what were the results?
- **Sensitivity, specificity, and positive predictive value.** Did wastewater testing accurately identify new outbreaks, surges, and waves?
- **Stability.** Were data collected, managed, and provided without failure (reliability) and were data operational when needed (availability)?
- **Standards use.** Were information technology standards used for data exchange and messaging?
- **Availability.** Were wastewater data available to all stakeholders? Were data publicly available? Were data held in a confidential and private manner when required?
- **Timeliness.** Were wastewater measures available to public health decision makers in a timely fashion? Were there time delays between any steps in the surveillance process?

Cost and Acceptability of the Strategy

Wastewater strategies are designed to fit within specific budgets and serve specific purposes. Costs anticipated pre-implementation should be reviewed against the realized (actual) costs of implementing the strategy.

This review should investigate areas where realized costs were higher or lower than anticipated. It is important to consider why costs deviated.

- Are there areas where costs could be saved in the future? Identify the potential for economy of scale when transitioning pilot programs to large scale programs.
- Where were excess expenditures most common in terms of types of cost (e.g., personnel, materials) and when they were incurred (e.g., coordination, sampling, transport, analysis)?

Look also at costs more broadly, not only financial but also the human, lab, and other community resources required for efficient, effective implementation. An inefficient testing strategy is a strain on limited health resources.

- Was implementation of the testing strategy an efficient use of resources?
- Can efficiency be improved, for example by making use of new technologies?

Feasibility, Sustainability, and Flexibility

If a strategy is to be repeated, or a new strategy implemented in its place, it's important to examine whether the next iteration will be feasible and sustainable. The current evaluation will help you consider key questions:

- What strain did the wastewater testing strategy impose on human resources and lab capacity? Is this something that can be maintained?
- What materials and supplies were required? Are supply chains for diagnostic materials stable?

Barriers and Facilitators

In implementing the wastewater strategy, what barriers had to be overcome? What factors supported implementation?

These questions are best answered through qualitative assessments—engaging with the people involved in implementing the strategy to learn what helped them carry out their tasks, what got in the way, and what would make a difference in the future.

Open or structured discussions—with personnel involved in implementation and with persons being tested—are useful to identify both supportive and negative aspects of the implementation, drawing on a range of experiences and perspectives. Often, respondents provide useful insights and offer possible solutions to common barriers.

Findings should be used to support and reinforce facilitators and to remove or at least mitigate potential barriers to improve the strategy's efficiency, and utility.

Potential Adaptations for the Next Cycle

Wastewater surveillance is rapidly improving. An evaluation of your wastewater strategy should include reviewing your current practices against the best practices worldwide. Discussion with other wastewater testing programs is a good step in that process.

With the rapidly changing COVID-19 landscape, strategies cannot remain stagnant. They need to be responsive to important innovations that can shift the accuracy, cost, and efficiency of surveillance approaches. Your evaluation should help you prepare to adapt the next iteration of the strategy to benefit from new methods, technologies, or other innovations.

Equity and Ethical Issues

Representation and coverage of the entire population is a potential benefit of wastewater testing, compared with clinical testing and other approaches. Was this potential realized? If not, why?

More specifically, key questions to ask—and learn from—include:

- What was the population coverage of the wastewater testing sites?
- Were the included populations representative of the entire population?
- Was equity achieved? Did sampling include groups (such as informal settlements, prisons, and long-term care homes) that were at increased risk or more vulnerable to increased health burden?
- Did any ethical issues arise? Did anyone or any group experience harm from the surveillance strategy?

The Process Is Cyclical

In the context of a continuing, changing pandemic, a repetitive strategic cycle is vital to ensure efficient delivery of scarce resources, maximize population health, and mitigate the social and economic impacts of COVID-19.

An iterative process—of assessing your resources, renewing or redesigning a strategy around identified priorities, engaging with key players to give your implementation the best chance of success, and re-evaluating the processes and outcomes—will help your surveillance approaches respond to new conditions and new opportunities.

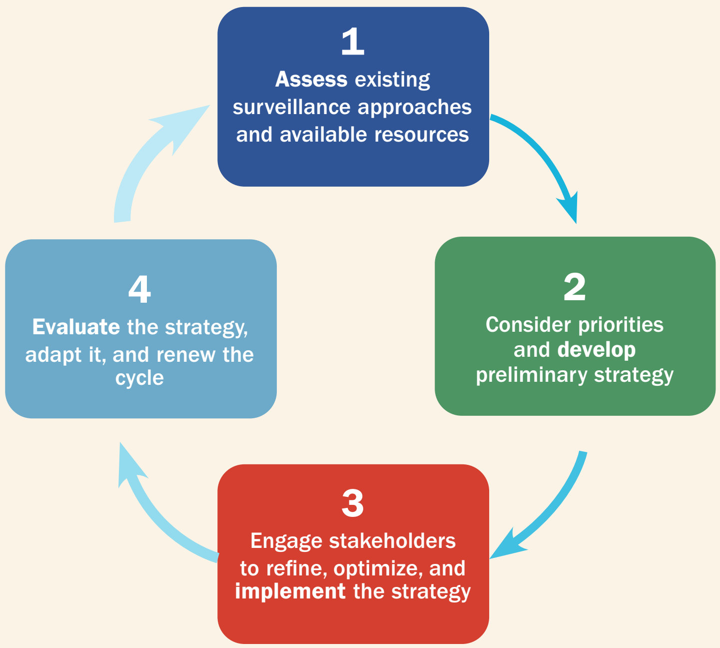
First iteration: When a thorough evaluation has been performed, the process of prioritizing populations, developing and optimizing a strategy, and implementing the strategy repeats.

Subsequent iterations: This process can be expedited in comparison to the first iteration, using the experience and knowledge gained. While expedited, this process should not be avoided. Priorities shift and so, too, do available resources. What is needed now? What is realistic?

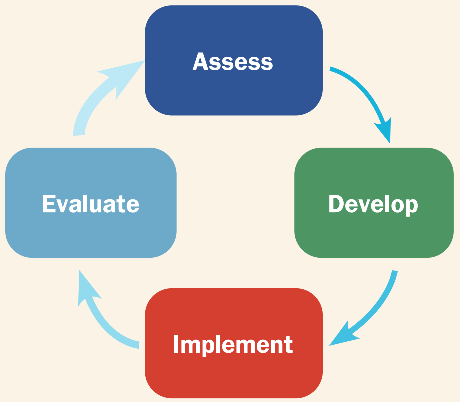
In the real world, of course, it's not always possible to implement and evaluate surveillance in tidy, distinct phases. There will be lots of messy overlap, lots of "building the plane in the air" moments, as there have been throughout this global pandemic.

Despite these challenges, a well-designed and thoughtfully executed wastewater testing strategy can be a productive part of any country's surveillance toolkit to respond to and control COVID-19.

First iteration



Subsequent iterations
This process can be expedited in comparison to the first iteration, using the experience and knowledge gained.



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