A Sanitary Sewer Evaluation Study Approach for COVID-19 Infection Rate Prediction

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Introduction

While using the principles and techniques of flow metering in sanitary sewer collection systems is not new, using them to track the spread of COVID-19 most certainly is. In the early 2000s, sewershed testing served as communal urinalysis for examining loadings of illicit drugs and prescription medications to wastewater treatment plants (WWTP). At the time, many in society viewed this testing as an invasion of privacy. However, the current COVID-19 pandemic has prompted a rebalancing of safety and privacy needs.

Several municipalities recently began testing for COVID-19 at WWTPs; however, evaluating targeted sewersheds may be more effective and provide more accurate data than that collected at WWTP. This white paper will explain how the analysis of sanitary sewer infiltration and inflow (I/I) in sewersheds may be used to track and predict COVID-19 spread in a community.

Background

Municipalities testing for COVID-19 at WWTPs have reported spikes in COVID-19 cases approximately two weeks after high mass rates were observed. Because sewersheds service more specific areas/demographics than WWTPs, high mass rates (compared to similar sewersheds) indicate the strong likelihood of COVID-19 spread in defined areas. The purpose of the sewershed approach to wastewater epidemiology is to determine where to focus mitigation resources to prevent further spread within these areas.

The strategic selection of sewer manholes that delineate sewersheds is paramount to the accurate analysis of the mass rate of COVID-19 in the sewer collection system. The sewershed should be representative of a specific use, such as residential or commercial. Very small sewersheds may not have a steady flow, or they may contain yet undissolved stool. Large sewersheds are more cost-effective to test, but not necessarily any more informative. Just as in an I/I study, the more flow meters deployed throughout the collection system, the more data is collected and therefore the higher the confidence of the conclusions that may be drawn from the data.

Figure 1: Inspecting sewer flow

Requirements

Effective evaluation of a sanitary sewer collection system requires:

- Crew to inspect sewer flow (see Figure 1)
- GIS to store data and support analysis
- Inventory of sanitary sewer or combined sewer assets with conveyances (a map of sewer gravity and force mains)
- Cadastral (parcel) map with parcel type (residential, commercial, industrial, etc.) and, preferably, demographic attributes
- Flow meter equipment or the means to measure flow velocity in the sewer system
- Means to sample flow in the sewer pipe
- Rain gauge in the area of study in order to mitigate the impact of wet weather flows on the collection system

Sewershed Size

Large Sewersheds

The size of a sewershed determines where the grab samples are taken and the flow meters are installed. The example in Figure 2 depicts large sewersheds. Large sewersheds require fewer sampling visits and fewer flow meter sites to maintain, resulting in overall lower lab costs. While some spatial and demographic variation of rates of infection may be discerned from such large sewersheds, the results would not be much better than testing at WWTPs.

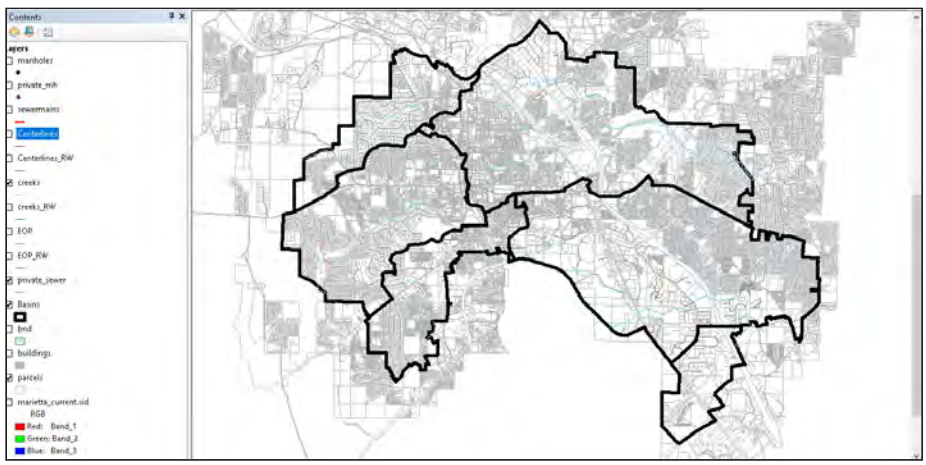

Figure 2: Large sewersheds in a city

Small Sewersheds

The RNA copies of COVID-19 reside in stool, and small sewersheds may not experience enough flow to completely mix the solids. Therefore, the example shown in Figure 3, a residential area with homogenous parcel types, may be too small for accurate sampling. Additionally, because flow in a sanitary sewer is typically diurnal in residential areas, the mass of COVID-19 RNA copies may more resemble "plug flow" than "completely mixed" in small sewersheds. For this reason, testing single facilities such as nursing homes or schools would be better served by saliva or mucous composite testing. Figure 4 provides a mix of sewersheds.

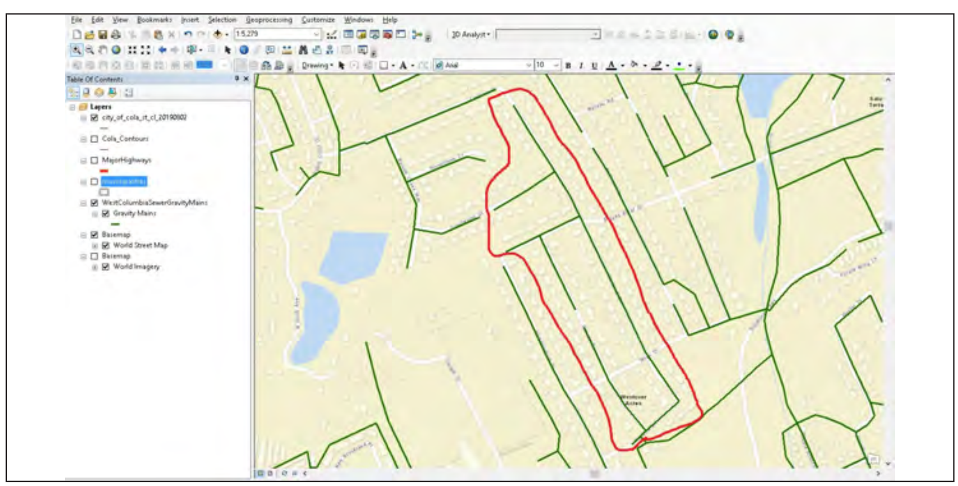

Figure 3: Small sewershed in a residential area

Sewershed Demographics

Sources of sewer flow also must be considered. When sampling multiple sewersheds, it may be advantageous to delineate sewersheds with similar sources of sewer flow. In Figure 5, the sewershed is likely large enough in size to have completely mixed flow. However, the hotel in the southern portion may skew results. If hotels are closed due to COVID-19 guidelines, then this sewershed still may be characterized as residential.

Depending on the goal, some sewersheds, such as those servicing hospitals (see Figure 6), are not suitable for sampling. In the example below, the gravity mains of the sewershed drain from a hospital. If testing a hospital is desired, then this sewershed would be a good source of data and may provide the baseline data needed to infer infection spread in the general population. However, sewersheds servicing hospitals will always have skewed testing results. Additionally, diurnal flow patterns will not be present in sewersheds with hospitals because they operate around the clock.

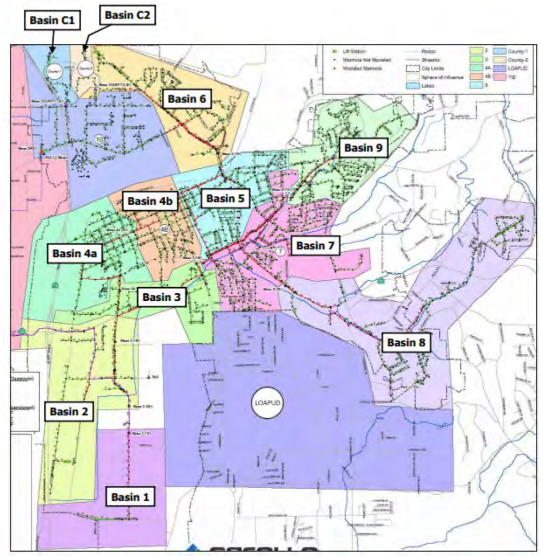

Figure 4: Mix of sewersheds likely to produce balanced costs and results

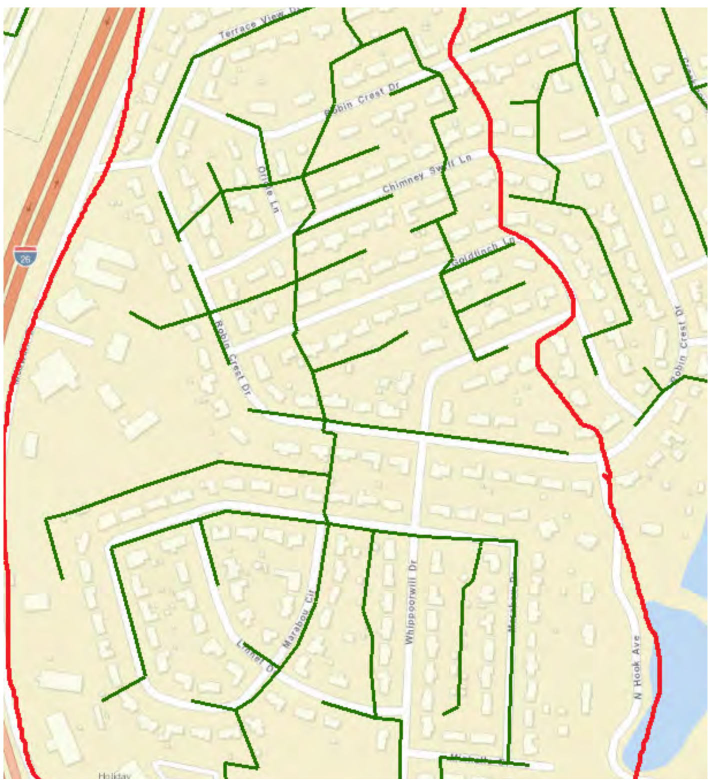

Figure 5: Sewershed with mostly homogenous sources of flow

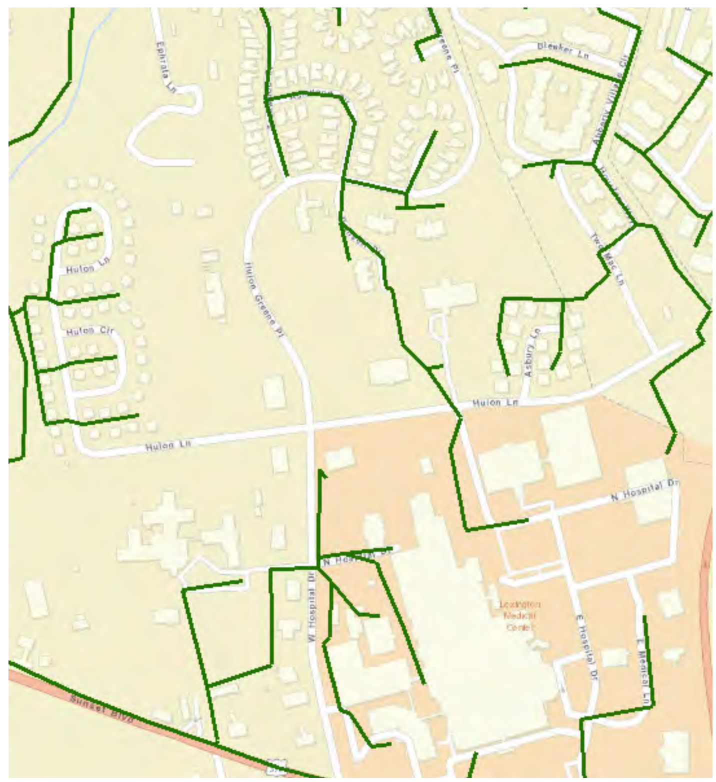

Figure 6: Sewersheds with a hospital

Sensors and Procedures

COVID-19 testing of sewersheds requires the following equipment (at a minimum):

- Velocimeter to measure flow velocity (Figure 7)
- Measuring stick to measure pipe diameter
- Container for collecting water samples

Figure 7: Handheld flow velocity meter

Typically, for sanitary sewer I/I studies, flow meters are installed in manholes (Figure 8) to continuously measure the velocity of flow. There are several technologies for measuring velocity, including pressure, level floats and doppler (Figure 9), and each has its advantages and disadvantages. Maintenance, surcharging, flow reversals and accuracy must be considered when choosing flow meters for specific situations and manhole access.

Figure 8: Flow meter installed in a manhole

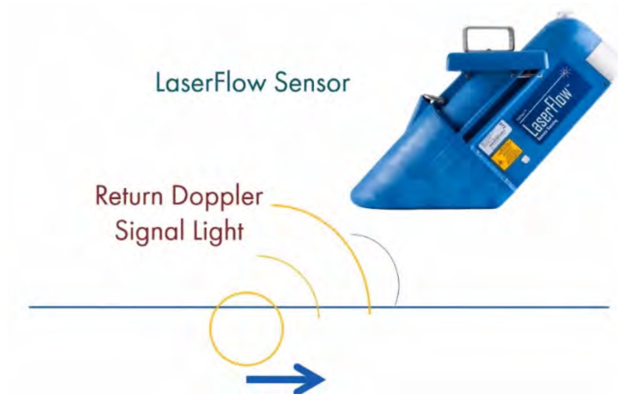

Figure 9: Doppler flow meter

The diameter of the pipe at the end of the sewershed is used to calculate the flow of water. Lab testing of grab samples will identify the number of COVID-19 RNA copies in each liter, which then may be converted to a mass rate for the given flow. The mass rate can then be converted to the total load over a specific time period (daily, for example) to apply to the population of the residents in the sewershed. Using a daily mass rate will smooth out any diurnal flow patterns. Note that grab samples should be taken at or near the same time each day.

As an example, the velocity is measured as 2.0 ft/s in a 36" pipe flowing half full. Daily flow volume of the sewershed is then 163,000 gal/day. Assume the grab sample lab results showed 100 RNA copies per liter and an average residential occupancy of 3.4 persons per parcel.

Assume a GIS analysis shows that there are 500 parcels in the sewershed. However, with census data (such as TIGER data), one need not make assumptions about the population of the sewershed. Then, the RNA copies per person per day equals 2,500.

What does this number mean? On its own, not very much; it only indicates the severity of infection of a sewershed when compared to similar sewersheds. This is why tested sewersheds should, as often as possible, have homogeneous parcel types to support comparisons between similar demographics/uses. Resources can be focused on testing and contact tracing in the areas where the highest infection rates are predicted to occur.

Mass Balance

The above procedure for determining the mass rate of a sewershed applies to a sewershed above the larger sewershed. Figure 10 shows how sewersheds might interrelate by flow. For example, the mass rate calculation of sewershed 3 in the figure may be calculated by subtracting out the mass rates of sewersheds 1 and 2. Sewershed 5's mass rate would then be calculated by subtracting out the sum of sewersheds 1, 2, 3 and 4. This is the reason it is important to take grab samples at about the same time of day because the diurnal flow patterns may vary throughout the day.

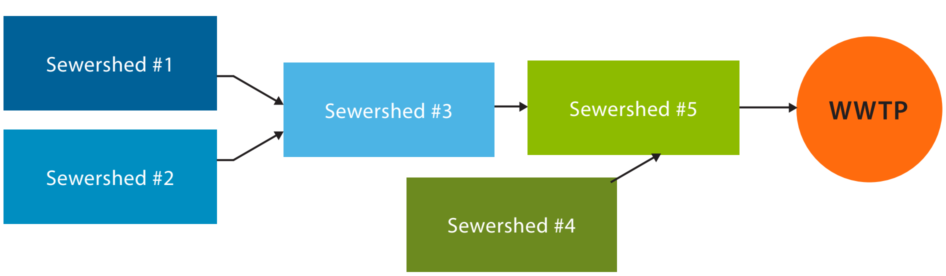

Figure 10: Flow hierarchy in a networked sewer collection system

The flow rate equation is given by Q=vA, where
Q = Flow
v = Measured velocity
A = Cross-sectional hydraulic area of the pipe

For a round pipe flowing full, A=πr^2, where
r = Radius of the pipe at the end of the sewershed

Then, M=Qct, where
M = Mass per day
Q = Flow
c = Concentration of RNA copies of COVID-19
t = Time period (24 hours)

Then the mass per day of COVID-19 RNA would be:
$Q = (2\ fps)(\frac{1}{2}\pi 18in^2) = 14.1$ cfs
M = (14.1 cfs) (200 copies/l) (24hrx60minx60sec) = 8,626,068 RNA copies per day

Wet Versus Dry Weather

Ideal sampling conditions are during dry weather. During a wet weather event, precipitation creates runoff, some of which enters the sewer collection system as I/I. When that happens, the sewer flow increases and the concentration of COVID-19 RNA copies is diluted. To measure the mass rate of RNA copies, the I/I rates must be subtracted out. First, a flow meter must be installed to continuously measure the sewershed flow. Then, several periods of dry weather must be measured to establish the baseline dry weather diurnal flow pattern. Typically, rain gauges installed in the vicinity of the sewersheds will help to determine if storm events are large enough to produce runoff. If the wet weather event is large enough, then the I/I can be subtracted from the sewershed flow. In the example below, the graph shows the dry weather flow, storm event hyetograph and resulting I/I into the sewer collection system.

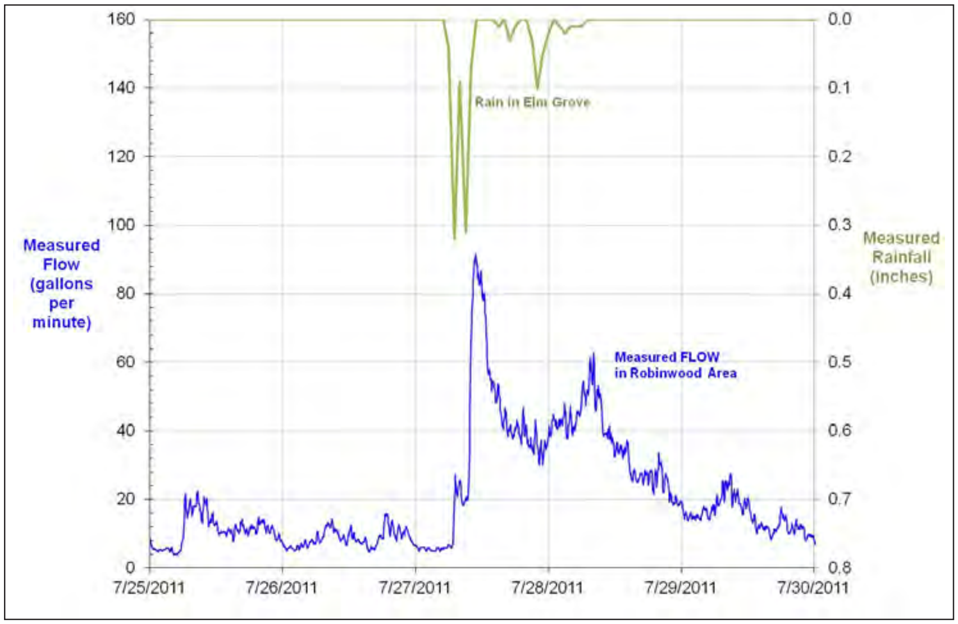

Figure 11: Subtracting out I/I to measure correct mass rate of Covid-19 RNA copies

Manual Versus Automated Sampling

Much less labor-intensive than manual sampling, automated continual sampling uses a flow meter and an automated sampler. Only one crew visit is needed to retrieve multiple samples that were automatically collected. Automated sampling can be configured according to a schedule or triggering event (such as amount of flow). Also, when determining the mass balance of sewersheds downstream of other sewersheds, automated samplers help with collecting samples at the same times. Multiple samples in different conditions can reveal variance patterns of daily mass loading and identify the optimal days and/or timeframes for sampling.

Considerations

- Mass of copies per parcel: Consider using TIGER and census data to more accurately approximate the population in the sewershed.
- Diurnal flows if testing during wet weather: Subtract I/I before using concentrations of RNA copies and verify equipment function (see Figure 12).
- Parcel types in the sewershed: Exclude non-local sources of stool samples (i.e., hotels) and sources that may skew results (i.e., hospitals).
- Virus shed rates: Because virus shed rates may differ between individuals and the period of infection, the sewershed must be large enough to create completely mixed conditions and average out these variances.

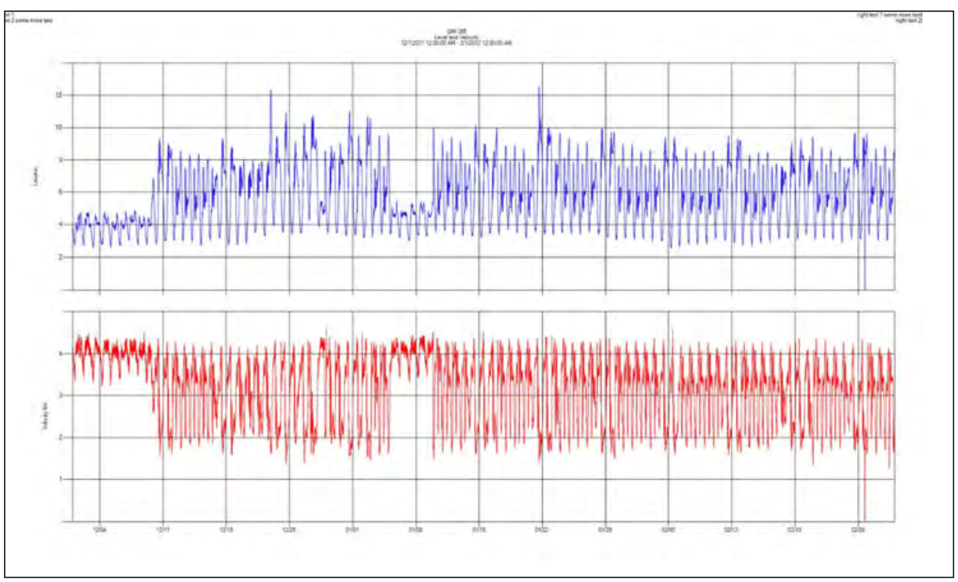
Figure 12: Diurnal dry weather flow pattern showing a possible problem of the level float

Key Points

Value of Testing Using a Sewershed Approach

The sewershed approach of testing for COVID-19 spread tests many people quickly and relatively inexpensively. This composite test is more general than saliva or mucus composite testing, but more specific than stool composite testing at the WWTP.

Spatial Prediction of Infection Rates

Because sewersheds delineate areas of communities, COVID-19 loadings may be shown spatially. Also, because there is a spatial component to the sewershed approach, a demographic analysis may determine the demographic attributes that produce the most/least loadings of RNA copies of COVID-19.

Prioritized Testing Materials and Contact Tracing Resources

Resources for battling this pandemic are not infinite. Resources such as individual testing materials and contact tracing must be prioritized. Knowing where and on whom to focus these resources would multiply the effects of these resources.

Conclusion

The sewershed approach for COVID-19 testing can help predict hot spots and prioritize testing and contact tracing resources. Better informed communities can be increasingly proactive about developing policies and deploying mitigation resources.

Keys

- The analysis may indicate where health departments should focus testing and contact tracing.
- The analysis may show trends relating demographics to COVID-19 infection rates.
- The analysis may indicate if a future infection spike will occur and the locations of potential hot spots.
- While privacy may be a concern (as it has been in the past), the COVID-19 pandemic has made communities more amenable to sewershed testing.

Woolpert has performed sanitary sewer evaluation surveys (SSES) for dozens of clients, installed hundreds of flow meters and analyzed thousands of miles of sanitary sewer collection systems. The Woolpert team can help communities track the spread of COVID-19 and prioritize resources for mitigating the effects of COVID-19.

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