Monitoring Sewer Solids for Covid-19 Virus, Investigation of Sampling Methodology

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- BSE Agricultural Engrg. Wash. State Univ. 1971
- MSE Hydraulic Engrg., Wash. State Univ. 1973
- PhD Civil Engrg., Caltech 1977
- Faculty CEE, Univ. Michigan 1977-2018
- Research Interests-Variety of flow and transport issues in hydraulic systems, including two-phase flows
- Attending these conferences since 1995

CONTEXT

- Since the beginning of the Covid pandemic, interest in surveillance of virus, including through wastewater collection systems
- Cov-2 genetic material detectable in human feces, monitoring for virus RNA fragments
- Interest in wastewater monitoring to provide early warning for waves of infection outbreak
- Most sampling done at WWTPs, typically using 24-hour composite samples; recognition that solids measurement is more effective
- Some sampling within sewer collection system, generally using grab samples or longer time composite samples; results in smaller sewersheds provides more uncertainty

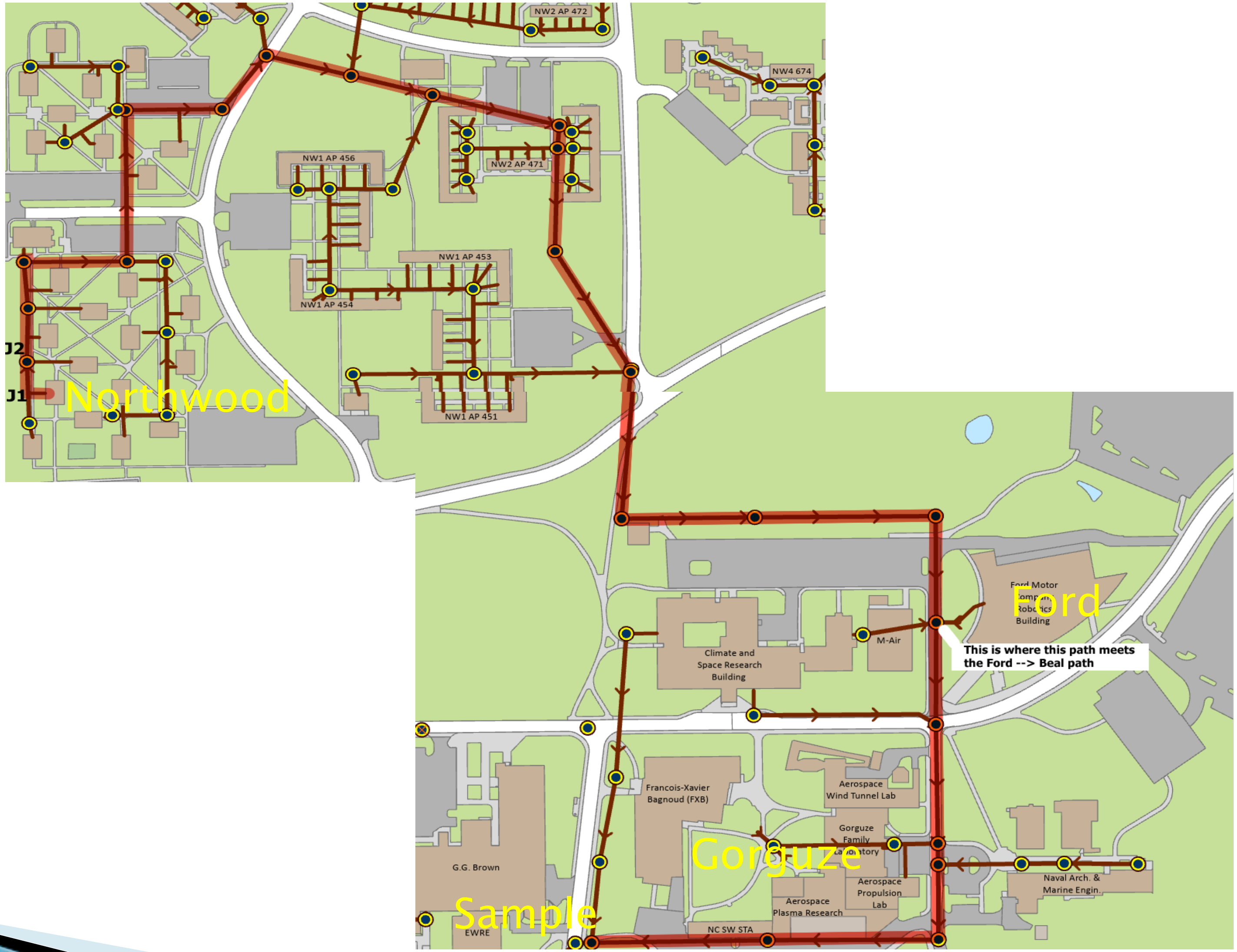
RESEARCH METHODOLOGY

- Investigate sampling in small sewersheds
- Introduce tracers via toilet flush at different injection points to observe time of travel and tracer dispersion
- Two tracers: rhodamine dye generally introduced into liquid phase and BCoV generally mixed with solids (cat food) to simulate fecal transport
- In-situ fluorometer obtained continuous record while BCoV involved automatic sampler collecting over 5-minute interval and compositing three successive samples
- Injection points (Gorguze, Ford, and Northwood) were located 285, 428 and 1441 m upstream from sampling location; Northwood near upstream end of sewer, while Gorguze and Ford entered main sewer through short side connection
- Flow meter installed at sampling location, temporarily mounted in access manhole; first flow meter not acceptable, flow velocity measured during later experiments*

DATA INTERPRETATION

- Toilet flush approximates an instantaneous point source to 1-D dispersion equation
- For uniform flow $C(x,t) = \frac{M}{A\sqrt{4\pi D_L t}} \exp(-\frac{(x-Ut)^2}{4D_L t})$
- Note that Gaussian distribution is in space but sampling typically at location, convert time to space*
- Don't have uniform flow, so approximations
- Travel time = time to center of mass t_{50}
- In Gaussian distribution $\sigma^2 = 2\ D_L t$
- Using distribution properties
- $D_L = \sigma^2/2\ t_{50} = [(t_{90} - t_{50})U/1.2816]^2/(2\ t_{50})$ or $[(t_{50} - t_{10})U/1.2816]^2/2\ t_{50})$
- D_L =constant needs x > about 200 D, satisfied for all sources*

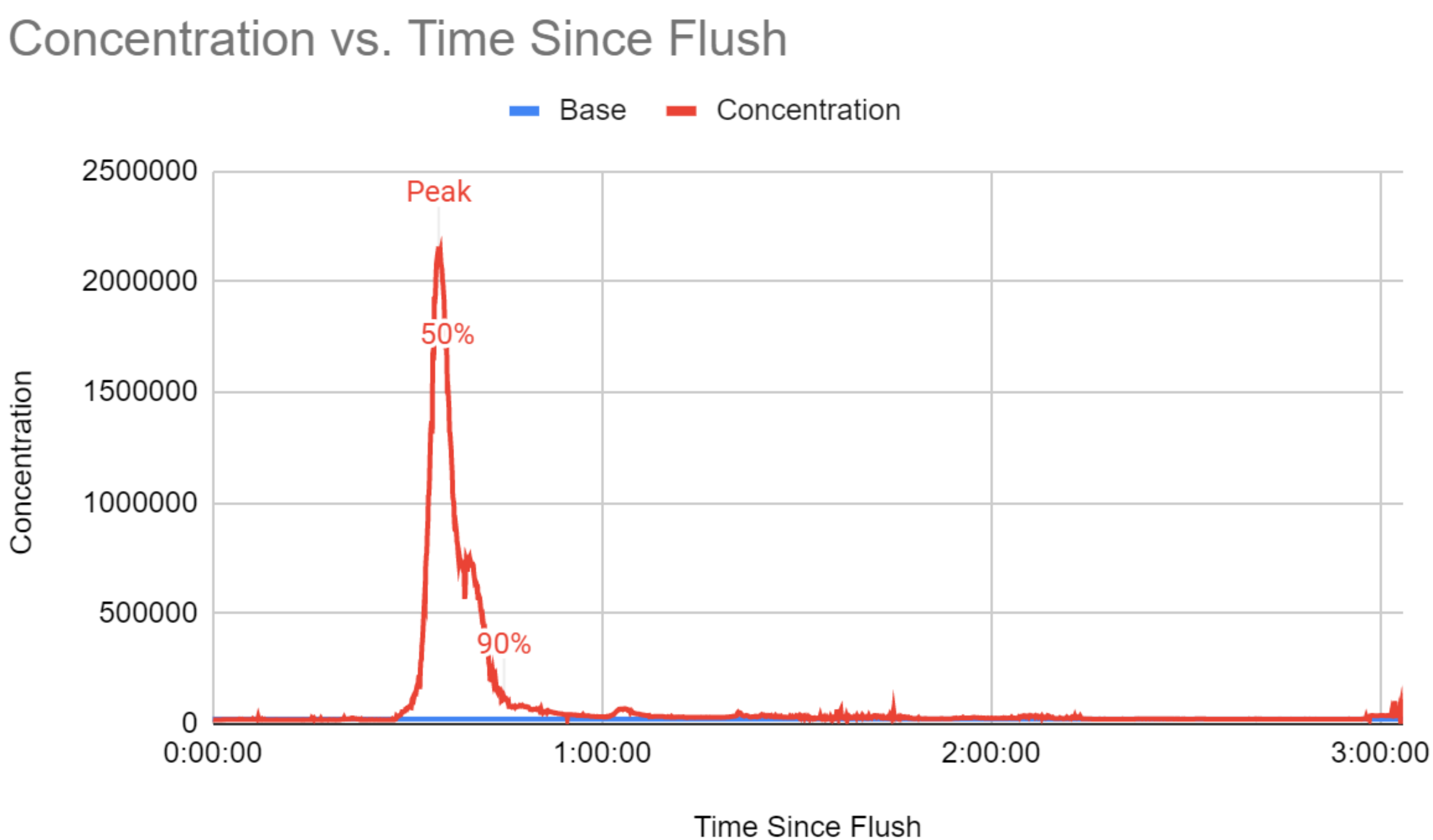
SCHEMATIC OF SYSTEM



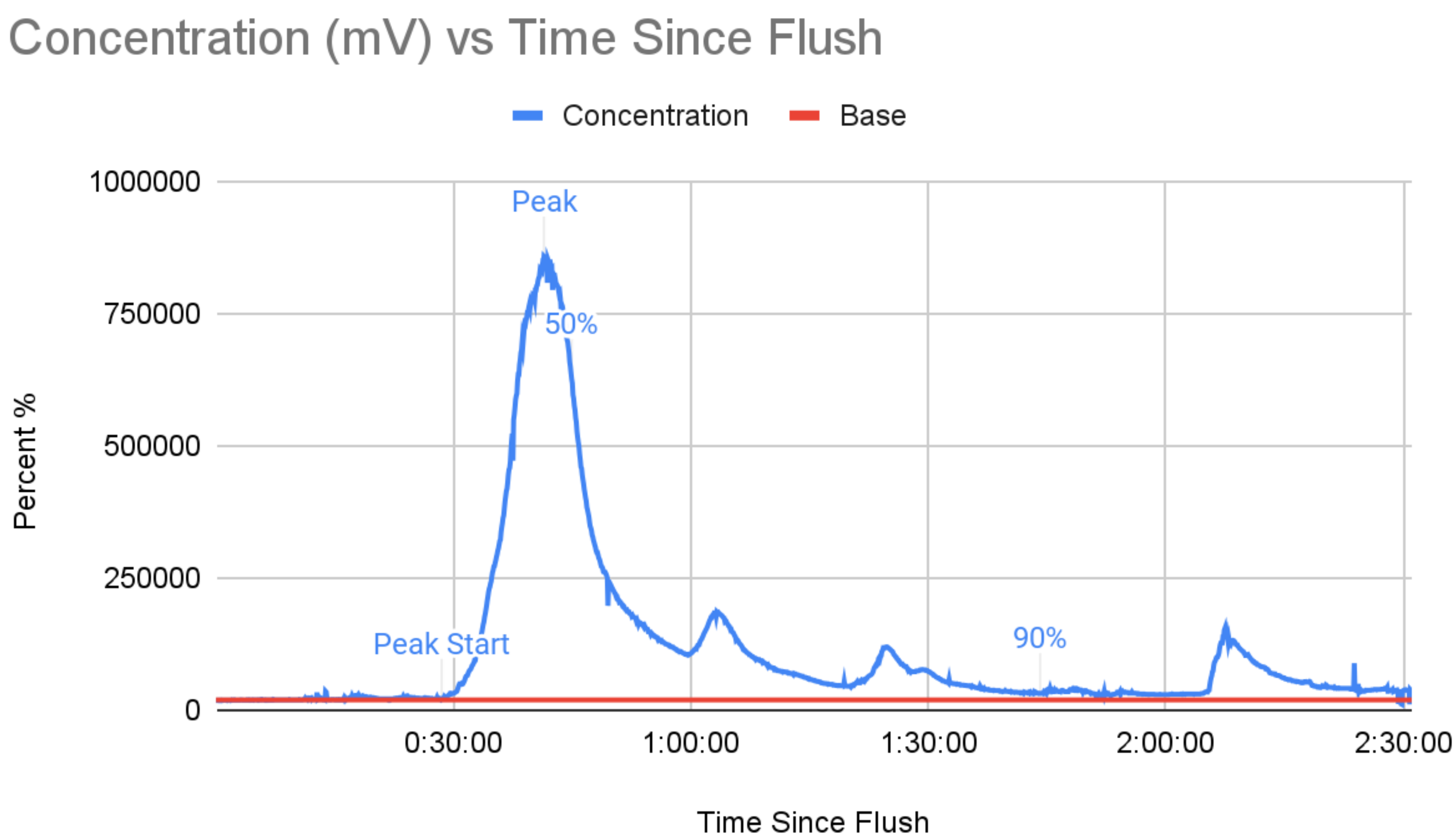
System Details

- Sewer system layer in University GIS contains information on manholes and connecting pipes. Extract slope, length and diameter of each pipe segment
- If flow rate is known, can estimate pipe velocities and therefore travel times
- Flow is only measured at downstream measurement location
- Most flow comes from Northwood
- Ford and Gorguze tie into main sewer through short (~ 25 m building lead with little flow)

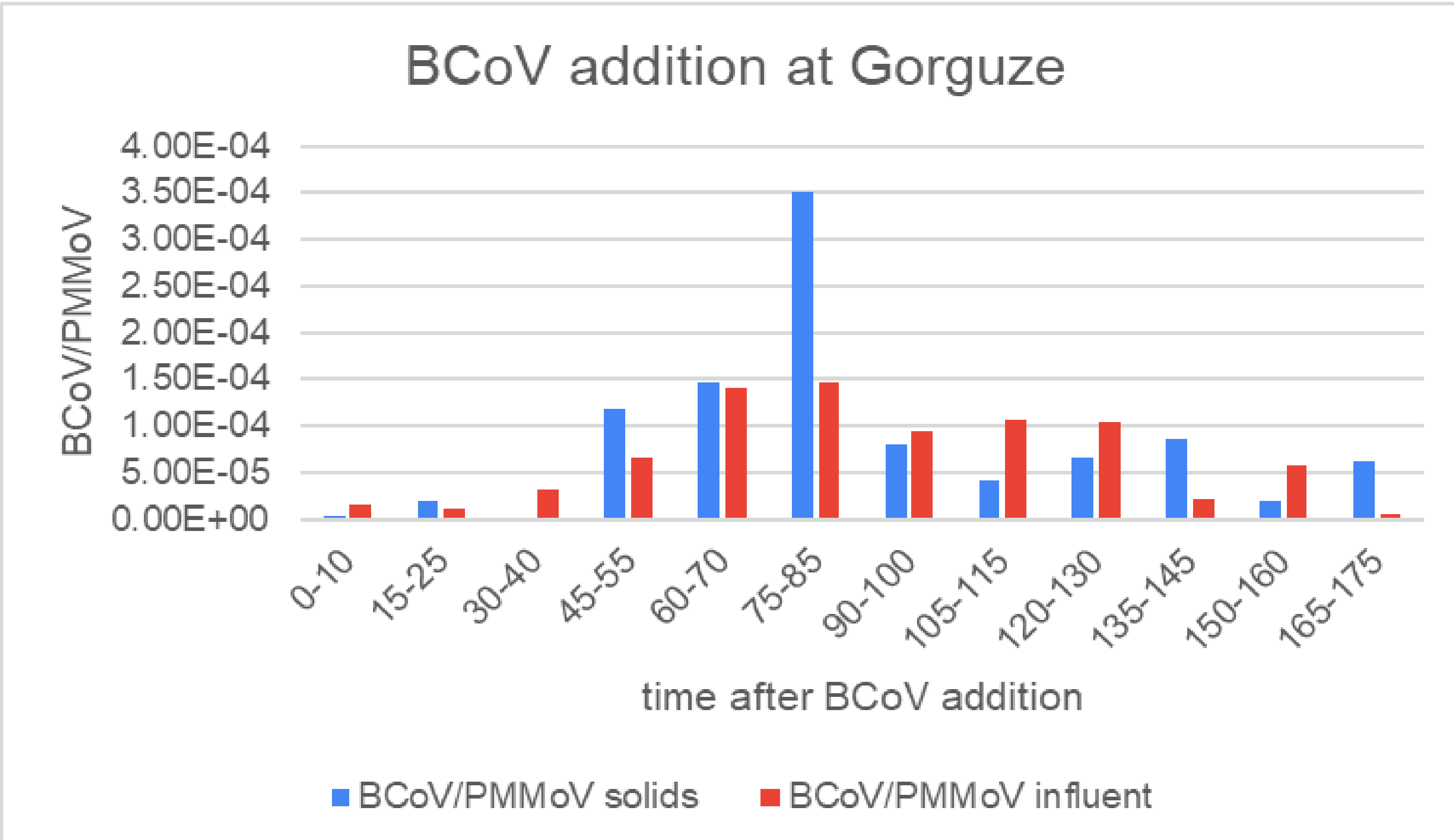
"GOOD" DYE RESULT



"TAIL" ON DYE DISTRIBUTION



BCoV MEASUREMENT



SAMPLING ISSUES

- Initial experiments performed with only Rhodamine to observe response
- Later added BCoV to flow in liquid phase, tended to move with dye
- When BCoV and Rhodamine mixed with cat food, both sorbed to cat food, odd dye distributions most of the time
- Tried to first flush dye then follow up about two minutes later with flush of BCoV and cat food, sometimes results looked fine, other times similar to both tracers in same flush
- Travel time from Gorguze was usually longer than Ford although shorter path length and same path at downstream portion, only possible if slow transport first section
- Hard to get a good velocity measurement at sample location with other instruments in manhole*
- Presence of paper towels and sanitary wipes in sewer

FINAL EXPERIMENTAL PROTOCOL

- Final experiments were run with initial flush with Rhodamine, wait two hours by which time, the dye was generally almost gone at monitoring station, then flush BCoV mixed with cat food
- Only required one sampling instrument in manhole at a time
- Appearance of measurement results was much improved
- Combine these measurements to deduce system behavior
- Use data to compute an estimate of travel time and dispersion coefficient
- Assess effect of solids on BCoV transport

TRAVEL TIME ESTIMATES

- For most measurements, recorded velocities were in a narrow range
- Discharge at measurement location was estimated at about $0.028 m^3/s$ based on conditions in upstream pipe segment
- Initially that flow rate was assigned to each segment of the Ford path, velocity for each segment was used for travel time and summed to 23.1 minutes; observed values are 37-45 minutes
- Relative contributions to flow were assigned to all buildings and analysis repeated with an increase in travel time to 42.3 minutes
- Gorguze travel time increased to 47.3 minutes, greater than Ford
- Northwood travel times also became more consistent with observations*

Implications

- Sensitivity of travel time was investigated to changing base discharge by 1/3X and 3X which altered computed travel times from 23.1 minutes to 9.5 and 190 minutes, respectively
- Velocities in each pipe segment were computed using T. Camp's hydraulic elements chart
- Demonstrates that results are quite sensitive to estimate of flow distribution in local sewer
- Expect that any analysis of sewer system for virus surveillance would not implement a detailed flow monitoring effort.
- Especially important for sewer segments that have small flows through them as in the short connections from Gorguze and Ford in the present study

Dispersion Coefficient Estimates

- One-dimensional longitudinal dispersion coefficients full pipe and two-dimensional turbulent flow obtained by classical analysis as 5.05 u_*D and 5.93 u_*h from Taylor and Elder, respectively. These should be somewhat low for the current application of partially-full sewer flow*
- Two literature reviews of computed dispersion coefficients for experiments with about the same diameter slope and discharge suggest values of about 0.10 m^2/s
- Computations using t_{50} and t_{90} as discussed earlier and a path average velocity of the total length divided by travel time yield average dispersion coefficients of 0.085, 0.058 and 0.096 m^2/s for Gorguze, Ford and Northwood, respectively
- Using the velocity estimated for the downstream reach would increase these values somewhat but not all experiments have measured velocities*

Observations

- Travel time is probably not a crucial quantity for application to virus surveillance
- Dispersion coefficient may be more critical to help define a sample interval if it is desired to capture a single event since the sample interval should not be much greater than σ, in order to ensure that an event is not missed
- Depends on specific sampling objectives

Other Observations With BVoC Tracer

- Observations of liquid- and solid-phase concentrations almost always showed the peak BCoV concentration occurred in the same sample interval; This is most likely due to partitioning between those phases after the sample was collected
- When BCoV was added in a liquid phase, no cat food, travel times were quite consistent with the fluorescent dye experiments. It was noted that cat food pellets were observed to be reasonably intact in the collected samples
- Partitioning also appeared to be present when dye and BCoV were mixed together with the cat food, where dye profiles displayed two distinct peaks with the second dye peak consistent with the BCoV peak. It was visually confirmed that Rhodamine dye was strongly sorbed to the cat food.

Observations (continued)

- In most cases, the peak Rhodamine and BCov concentrations occurred in the same 15-minute period as the peak BCoV concentration occurred
- Not universally true and in some cases, peak BCoV concentration occurred at times on the order of twice the time to peak dye concentration. Spread of tracer about the same for both in these cases
- Attributed to delayed solids transport due to low flows in the connecting segment between building and main sewer for Ford and Gorguze (especially)
- In cases where BCoV peak lagged behind dye peak, the spread of the BCoV tracer was increased as expected; this is demonstrated in the BCoV profile presented earlier

CONCLUSIONS

- The theoretical framework for the travel time and dispersion coefficient estimate requires an assumption of uniform and steady flow. Those conditions are not met in the current study. However, the estimates for these transport properties are realistic compared to observations
- The crucial issue is the estimate of system flow rate and its distribution within a sewer network. It seems unlikely that a detailed flow monitoring study would be mounted for this type of application, but a careful analysis of the sewershed would be necessary to estimate a reasonable flow distribution. In particular, knowledge of conduits with low flows seems to be critical.
- The effect of solids transport, given the results of choosing cat food as a surrogate for human feces, does not appear to be critical, probably due to the high moisture content and relatively low specific gravity of the solids.

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Thank You