

# Wastewater-based Epidemiology: From Fringe Science to Multi-\$Billion Public Health Decision-Making Tool



*"Plugging Into the Information Highway Below Our Feet"*  
**20 Years in 15 Minutes**

**Rolf Halden, PhD, PE**

Biodesign Center for Environmental Health Engineering

The Biodesign Institute, Arizona State University

OneWaterOneHealth.org – A Nonprofit Project of the Arizona State University Foundation

AquaVitas, LLC – An Arizona State University Startup Company

Partnerships for Environmental Public Health (PEPH) Webinar, December 3, 2021

# Acknowledgements

## Biodesign Institute & Center for Environmental Health Engineering, Arizona State University

Erin Driver, Adam Gushgari, Matthew Scotch, Arvind Varsani, Efrem Lim, Simona, Krabeger, Devin Bowes, LaRinda Holland, Rafaela Fontenele, Nivedita Biyani, Joshua Steele, Varun Kelkar, Sangeet Adhikari, Kathleen Click, Alyssa Carlson, Allison Binsfeld, Sonja Savic, Jillian Wright, Bridger Johnston, Akhil Mahant, Melanie Newell, Dianne Price, Carrie Joseph, Diego Nova, Indrayudh (Indro) Mondal, Marcus Denetdale, Rahul Kumar, Erin Clancy, Jake Zevitz, Peyton Watkins, Jasmine Nguyen, Dona John, Kaxandra Nessi, Tyler Perleberg, and Allan Yanez AND MANY OTHERS



## City of Tempe Collaborators

Rosa Inchausti, Wydale Holmes, Stephanie Deitrick, William Manning, Richard Dalton, Christopher Garcia, Andrea Glass, Phillip Brown, Hillary Cumming, Jeremy Mikus, Drew Rostain, Darrel Duty AND MANY OTHERS

**Sponsors:** Named & Unnamed

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# Historical Perspective

## ISOLATION OF *B. TYPHOSUS* FROM SEWAGE AND SHELLFISH.

BY

W. JAMES WILSON, M.D., D.Sc.,

PROFESSOR OF HYGIENE AND PUBLIC HEALTH, QUEEN'S UNIVERSITY, BELFAST; WATER EXAMINER TO BELFAST WATER BOARD.

W. J. Wilson, *ISOLATION OF B. TYPHOSUS FROM SEWAGE AND SHELLFISH. Br 346 Med J. 1, 1061–1062 (1928)*

## POLIOMYELITIC VIRUS IN SEWAGE

WITHIN the past two years it has become increasingly apparent that poliomyelitic virus may be readily isolated from the stools of human patients during acute and convalescent stages of this disease. Many reports now testify to the ease with which this can be accomplished.<sup>1</sup> Consequently, whenever poliomyelitis occurs within a city, there is at least an opportunity for this

J. R. Paul, J. D. Trask, C. S. Culotta,  
*POLIOMYELITIC VIRUS IN SEWAGE. Science. 90, 350 258–259 (1939)*

## Presence of therapeutic drugs in the environment

Ettore Zuccato, Davide Calamari, Marco Natangelo,  
Roberto Fanelli

*The Lancet. 355, 1789–1790 (2000)*

Venkatesan & Halden, 2014. *Environ. Sci. Pollut. Res.* 22 (3), 1577–1586

## Population Health Data (Obtained from Sewage)

- Chemical/biohazard in communities
  - Quantity is proportional to levels in untreated wastewater
- Human exposure (biomarkers)
- Economical and accessible epidemiological data
- **Anonymous**

$$\text{Per-capita Exposure} = \frac{\text{Quantity of chem-bio agent}}{\text{Population}}$$

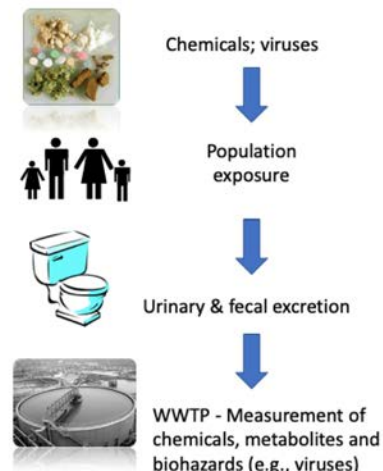
*Environ Sci Pollut Res*  
DOI 10.1007/s11356-014-2963-1

DEVELOPMENTS AND APPLICATIONS OF ENVIRONMENTAL SPECIMEN BANKS FOR MONITORING EMERGING CONTAMINANTS

United States National Sewage Sludge Repository at Arizona State University—a new resource and research tool for environmental scientists, engineers, and epidemiologists

Arjun K. Venkatesan • Hansa Y. Done • Rolf U. Halden

Received: 29 January 2014 / Accepted: 21 April 2014  
© Springer-Verlag Berlin Heidelberg 2014

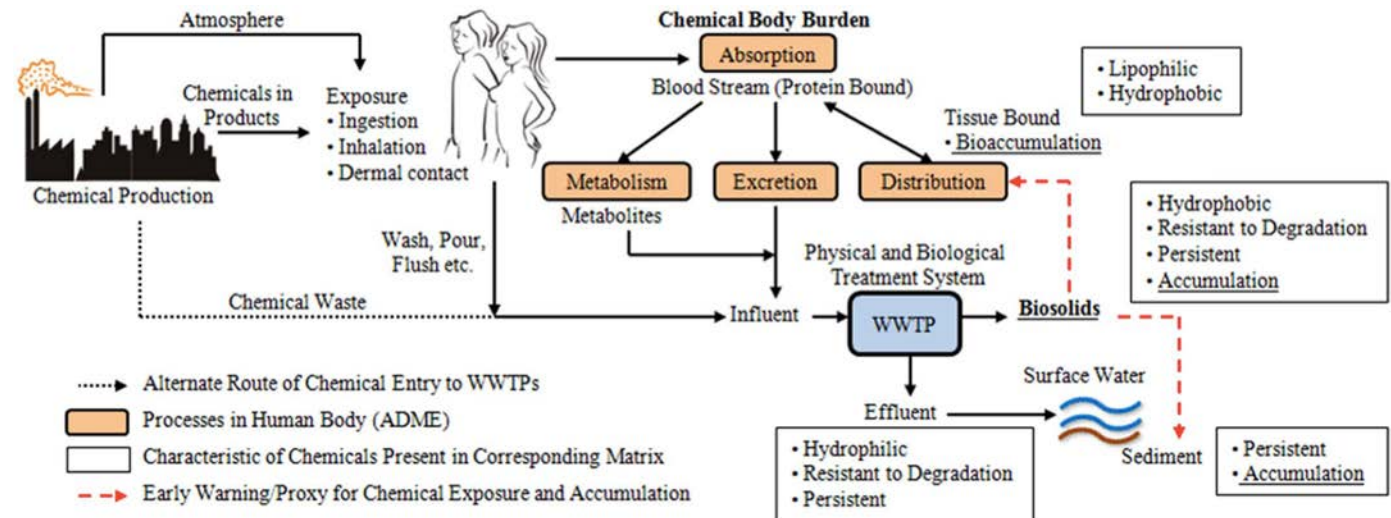


## Presence of SARS-Coronavirus-2 RNA in Sewage and Correlation with Reported COVID-19 Prevalence in the Early Stage of the Epidemic in The Netherlands

Gertjan Medema\*, Leo Heijnen, Goffe Elsinga, Ronald Italiaander, and Anke Brouwer

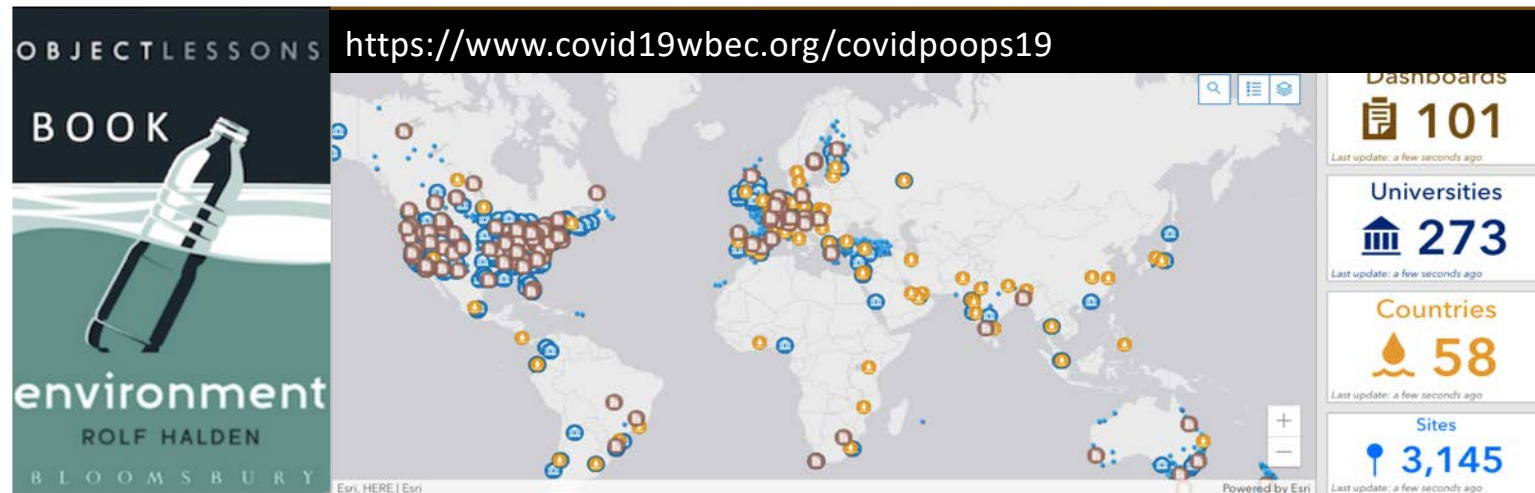
G. Medema, L. Heijnen, G. Elsinga, R. Italiaander, A. Brouwer, *Presence of SARS-376 Coronavirus-2 RNA in Sewage and Correlation with Reported COVID-19 Prevalence in the 377 Early Stage of the Epidemic in The Netherlands. Environ. Sci. Technol. Lett. 7, 511–516 378 (2020)*

# From Vision to Reality



Venkatesan & Halden, 2014. *Environ. Sci. Pollut. Res.* 22 (3), 1577-1586

- Academic
- For profit
- Nonprofit
- Government labs
- RADxrad program



# Human Health Observatory (HHO) at Arizona State University

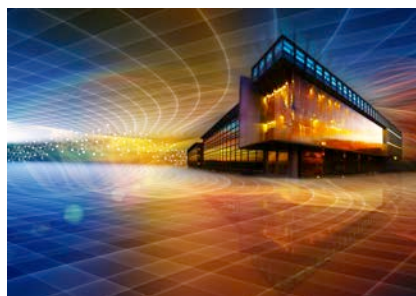
*... An Early Warning System Established in 2006*

- >500 WWTPs globally; >400 in U.S.

Representative of 15,000+ U.S. plants

Unbiased national estimates

- >12% of U.S. pop.; >40M people
- >250M people worldwide
- Largest archive in the U.S./world
- Anonymity through size



HAVE/WANT SAMPLES?  
**rolf@owoh.org**



*Environ. Sci. Technol.* 2014. 48, 3603–3611

Venkatesan & Halden, 2014. *Environ. Sci. Pollut. Res.* 22 (3), 1577-1586



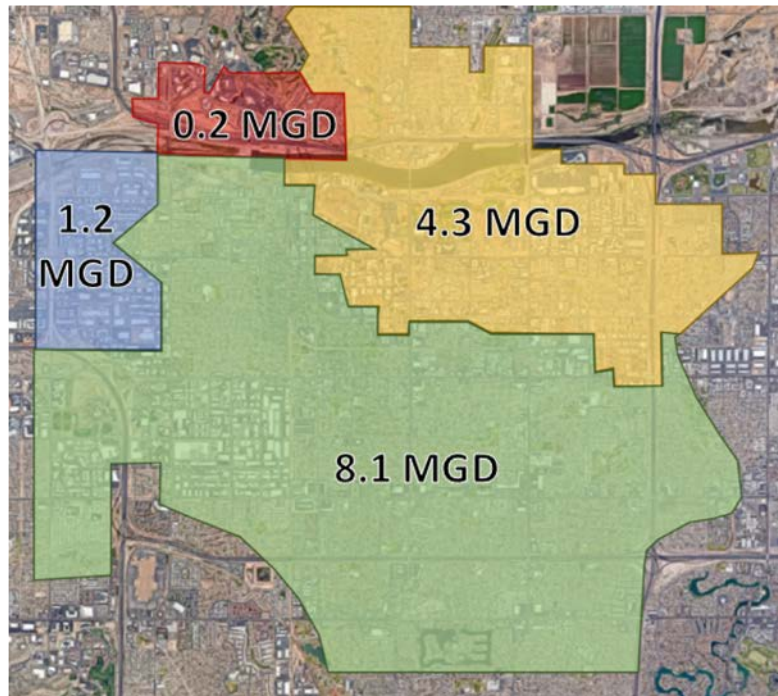
# World's 1<sup>st</sup> WBE-informed Open Access Opioid Dashboard



Arizona State University

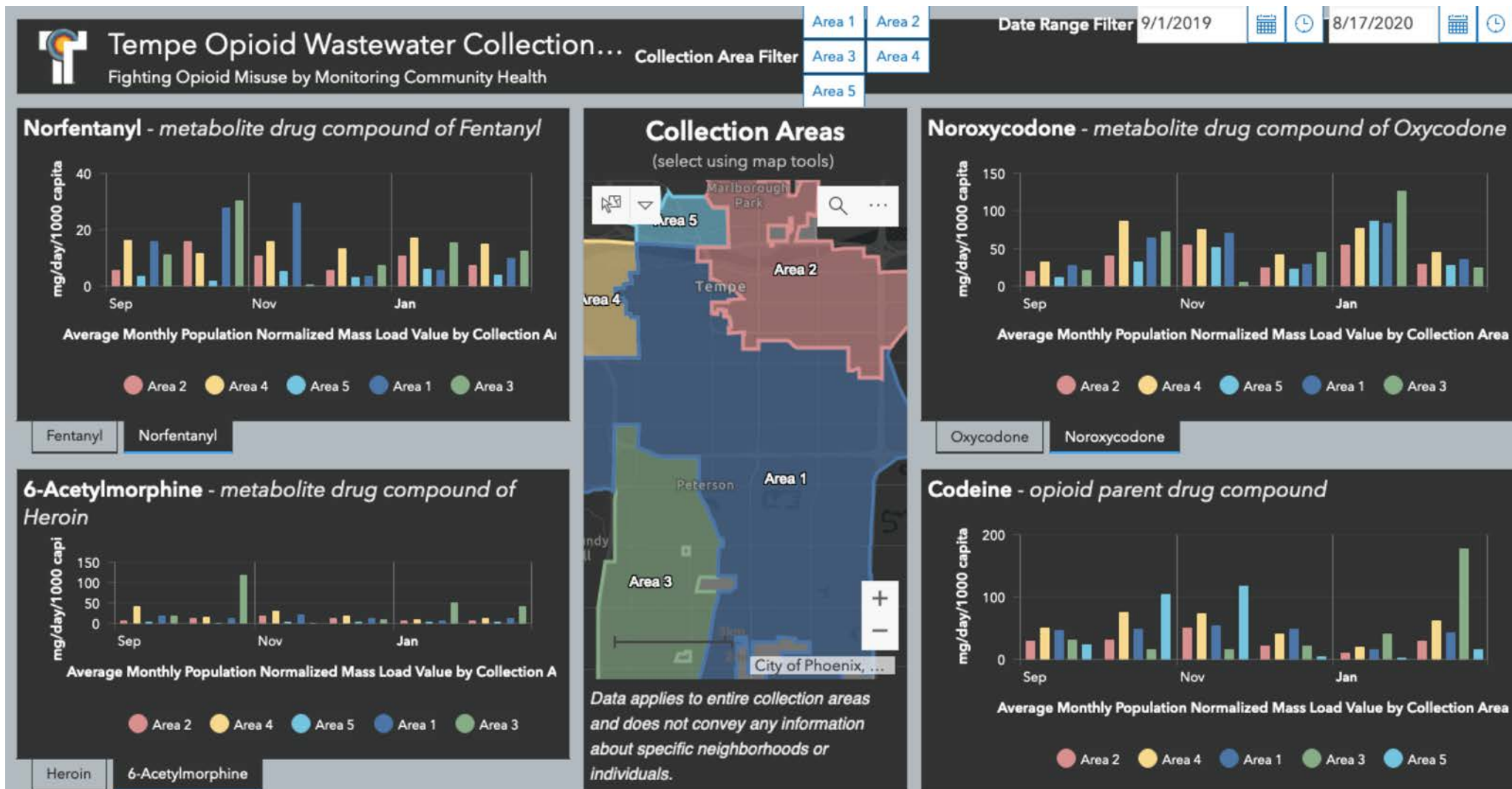
Center For

Environmental Health Engineering



- **2018 - Present**
- 2015 Visioning workshop
- First U.S. municipality to use WBE data in strategy development and implementation
- Addressing opioid addiction, marijuana use, and alcohol consumption
- Funding from City of Tempe and Arizona State University
- City-wide capture of wastewater representing 185,000 contributing residents
- Collaborative partnership with government, academia, industry professionals





Story Map (How wastewater measurements are done): <https://arcg.is/PKWuz>  
 Dashboard (Opioid consumption in Tempe at the neighborhood level): <https://arcg.is/ey0Ha>

**Developed 2018; Launched 2019**

# 2019: Tracking Infectious Diseases with ASU's HHO

R. Halden (Presenter)

Matthew Scotch

Arvind Varsani



2019: US Nationwide  
Infectious Disease  
Monitoring Network

Surveillance of known  
disease agents &  
discovery of 1000s of  
new DNA & RNA viruses



*Human Health Observatory (HHO) at Arizona State University's Biodesign Institute*

**NATURE MEDICINE** | VOL 24 | OCTOBER 2018 | 1484-1490 | [www.nature.com/naturemedicine](http://www.nature.com/naturemedicine)





<https://covid19.tempe.gov/>

## World's 1<sup>st</sup> WBE-informed Open Access Public COVID-19 Dashboard, April 2020 - Present

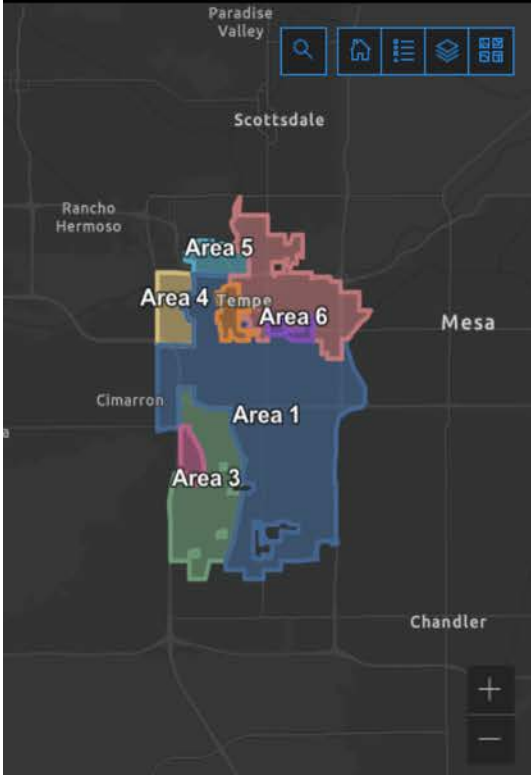


COVID-19 Wastewater Results

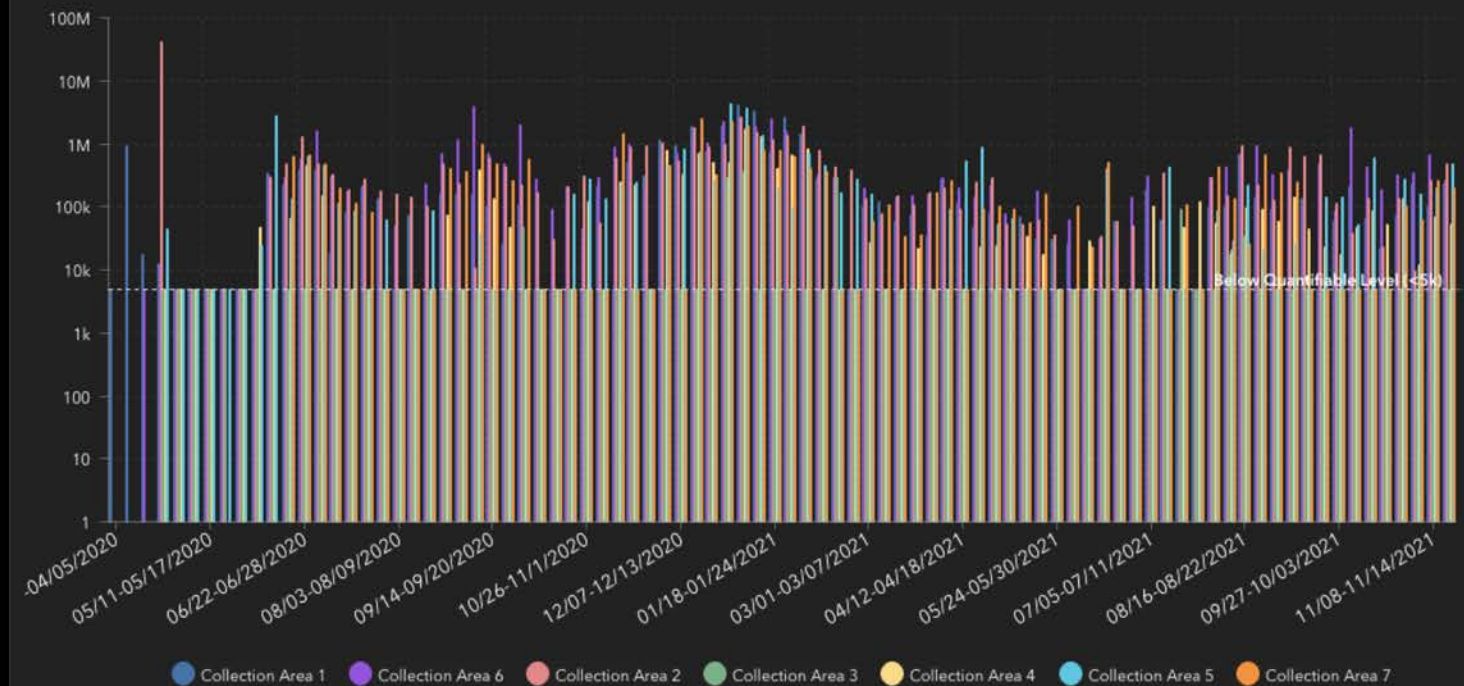
doi: <https://doi.org/10.1101/2021.07.29.21261338>

Select area(s) to filter  
No category selected

Select date range  
4/1/2020 - 11/21/2021



Average Weekly Results COVID-19 Virus Genome Copies per Liter of Wastewater





# STATES ACTIVELY PARTICIPATING IN COVID-19 WASTEWATER TESTING WITH OWOH



**ONE**WATER  
HEALTH

A Nonprofit Project of the ASU Foundation:  
"We are dedicated to serve and protect vulnerable  
communities and environmental quality"



# Federal WBE Initiative

WBE data on  
>40 States  
>33M Americans  
twice a week

## Nationwide Wastewater Surveillance for COVID-19

AquaVitas, LLC, a wastewater analytics company spun out from Arizona State University and focused on wastewater-based epidemiology for contaminants, narcotics and contagious elements, such as SARS-CoV-2, today announced an agreement with the U.S. Departments of Health and Human Services (HHS) and the Centers for Disease Control and Prevention (CDC) for a nationwide study of wastewater for SARS-CoV-2 viral elements.

Under the terms of the agreement, HHS will fund the procurement and testing for SARS-CoV-2 in wastewater samples from treatment plants of large and small communities across the U.S. Under Phase 1 of the contract, wastewater from up to 100 treatment plants that serve 10% of the US population will be tested. Phase 1 will last six weeks.



Phase 1 (100 Cities) Completed in early 2021; unique opportunity for sequencing to understand coronavirus evolution and spread  
**[covid19@aquavitas.com](mailto:covid19@aquavitas.com)**

# Ethical Issues

- Authorization
- Data access
- Data use
- Data/Sample ownership
- Public health priorities
- Who benefits?
- What are the risks?

## Wastewater Monitoring Raises Privacy and Ethical Considerations

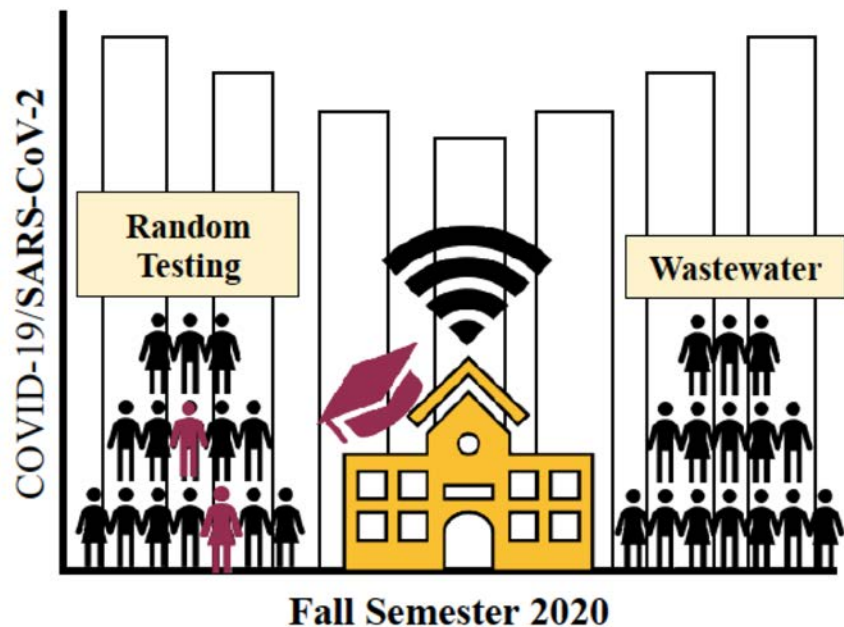
Danielle Jacobs<sup>1</sup>, Troy McDaniel<sup>2</sup>, *Member, IEEE*, Arvind Varsani,  
Rolf U. Halden<sup>3</sup>, Stephanie Forrest<sup>4</sup>, *Life Fellow, IEEE*, and Heewook Lee

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**Abstract**—Analysis of municipal wastewater, or sewage for public health applications is a rapidly expanding field aimed at understanding emerging epidemiological trends, including human and disease migration. The newly gained ability to extract and analyze genetic material from wastewater poses important societal and ethical questions, including: How to safeguard data? Who owns genetic data recovered from wastewater? and What are the ethical and legal issues surrounding its use? In the U.S., both corporate and legal policies regarding privacy have been historically reactive instead of proactive. In wastewater-based epidemiology (WBE), the pace of innovation has outpaced the ability of social and legal mechanisms to keep up. To address this discrepancy, early and robust discussions of the research, policies, and ethics surrounding WBE analysis and genetics are needed. This article contributes to this discussion by examining ownership issues for human genetic data recovered from wastewater and the uses to which it may be put. We focus particularly on the risks associated with personally identifiable data, highlighting potential risks, relevant privacy-enhancing technologies, and appropriate ethics. This article proposes an approach for people conducting WBE studies to help them systematically consider the ethical and privacy implications of their work.



# Cost of Population Health Monitoring



Comparison of High-frequency In-Pipe SARS-CoV-2 Wastewater-Based Surveillance to Concurrent COVID-19 Random Clinical Testing on a Public U.S. University Campus

Jillian Wright<sup>1,2</sup>, Erin M. Driver<sup>1</sup>, Devin A. Bowes<sup>1,2,3</sup>, Bridger Johnston<sup>1</sup>, Rolf U. Halden<sup>1,3,4,5\*</sup>

WBE provides data at  
~1.4% of cost of random  
clinical testing

Jillian Wright<sup>1,2</sup>, Erin M. Driver<sup>1</sup>, Devin A. Bowes<sup>1,2,3</sup>, Bridger Johnston<sup>1</sup>, Rolf U. Halden<sup>1,3,4,5\*</sup> 2021 (Undergoing Minor Revision)



# Detecting (Undetected) Viruses & SARS Variants

 [Comment on this paper](#)

## High-throughput sequencing of SARS-CoV-2 in wastewater provides insights into circulating variants

 Rafaela S. Fontenele,  Simona Kraberger, James Hadfield, Erin M. Driver, Devin Bowes, LaRinda A. Holland,  Temitope O.C. Faleye,  Sangeet Adhikari, Rahul Kumar, Rosa Inchausti, Wydale K. Holmes, Stephanie Deitrick, Philip Brown, Darrell Duty,  Ted Smith, Aruni Bhatnagar, Ray A. Yeager II, Rochelle H. Holm, Natalia Hoogesteijn von Reitzenstein, Elliott Wheeler, Kevin Dixon, Tim Constantine,  Melissa A. Wilson,  Efrem S. Lim,  Xiaofang Jiang,  Rolf U. Halden,  Matthew Scotch,  Arvind Varsani

**doi:** <https://doi.org/10.1101/2021.01.22.21250320>

An 81 nucleotide deletion in SARS-CoV-2 ORF7a identified from sentinel surveillance in Arizona (Jan-Mar 2020). *Journal of Virology*. 2020. Holland *et al.* Link: <https://jvi.asm.org/content/94/14/e00711-20>

High-throughput sequencing of SARS-CoV-2 in wastewater provides insights into circulating variants. *medRxiv*. 2021. Fontenele *et al.* Link: <https://www.medrxiv.org/content/10.1101/2021.01.22.21250320v1>

### JOIN FREE SEQUENCING WWTP NETWORK:

Contact: [rolf.halden@asu.edu](mailto:rolf.halden@asu.edu) (Subject Line: NIH SARS SEQUENCING)

# WBE Pros & Cons

## PROS

- Broadly applicable
- Fast
- Comprehensive
- Inexpensive
- Early-warning tool
- Chemicals & biohazards
- Easy to implement
- Trend analysis is easy
- Data are actionable
- Direct readout of intervention

## CONS

### Data are...

- Location-specific
- Can be difficult to interpret
- Don't reflect population on septic

### Data quality is dependent on...

- Sewer type, size, temperature,...
- Sewer chemistry (odor control, rain)
- Sampling strategy used (e.g., grab)
- Stability of analytes of interest



# Bottomline

## Wastewater-based Epidemiology (WBE)

- Produces actionable population health data
- Data are complex and easily misinterpreted or overinterpreted
- Requires transdisciplinary collaboration
- Requires municipal & population buy-in
- Societal framework still in its infancy (legal, ethical, moral implications)
- Allows nations, states, cities & communities to proactively manage health
- Will save much more money than it costs to implement (great return-on-investment)
- Now has many practitioners but few experts due to its multi-disciplinary nature
- Is here to stay
- Research and nonprofit activities offer free participation for states, cities, communities (SARS-CoV-2 levels, trends, variant RNA sequencing, etc.)

Contact info: [halden@asu.edu](mailto:halden@asu.edu)



# References

## Opportunity, Limits & Economy of WBE:

Hart, O. E. and Halden R.U. 2020. Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges. *Science of the Total Environment*. 730: 138875.

<https://doi.org/10.1016/j.scitotenv.2020.138875>

## Opportunities & Limitation of SARS-CoV-2 Variant Sequencing:

Fontenele, R.S.; Kraberger, S.; Hadfield J.; Driver E.M.; Bowes D.; Holland, L. A.; Faleye, T. O. C.; Adhikari, S.; Kumar, R.; Inchausti R.; Holmes W. K.; Deitrick S.; Brown, P.; Duty, D.; Smith T.; Bhatnagar<sup>1</sup> A.; Yeager II, R. A.; Holm, H. R.; Hoogesteijn von Reitzenstein N.; Wheeler, E.; Dixon, K.; Constantine, T.; Wilson, M. A.; Lim, E. S.; Jiang X.; Halden, R. U.; Scotch, M.; Varsani, A. High-throughput sequencing of SARS-CoV-2 in wastewater provides insights into circulating variants. *medRxiv* 2021.01.22.21250320; <https://doi.org/10.1101/2021.01.22.21250320>.

Holland, L., E. Kaelin, R. Maqsood, B. Estifanos, L. Wu, A. Varsani, R. U. Halden, B. Hogue, M. Scotch, and E. Lim An 81 nucleotide deletion in SARS-CoV-2 ORF7a identified from sentinel surveillance in Arizona (Jan-Mar 2020). *J Virology* 94(14):e00711-20. [PMC7343219](https://doi.org/10.1128/JVI.00711-20);  
<https://jvi.asm.org/content/jvi/early/2020/04/30/JVI.00711-20.full.pdf>

## World's First WBE-informed, Public Access COVID-19 Dashboard:

Tempe COVID-19 Dashboard: <https://covid19.tempe.gov/>

[Comment on this paper](#)

## Unrestricted Online Sharing of High-frequency, High-resolution Data on SARS-CoV-2 in Wastewater to Inform the COVID-19 Public Health Response in Greater Tempe, Arizona

Devin A. Bowes, Erin M. Driver, Simona Kraberger, Rafaela S. Fontenele, LaRinda A. Holland, Jillian Wright, Bridger Johnston, Sonja Savic, Melanie Engstrom Newell, Sangeet Adhikari, Rahul Kumar, Hanah Goetz, Allison Binsfeld, Kassandra Nessi, Payton Watkins, Akhil Mahant, Jake Zevitz, Stephanie Deitrick, Philip Brown, Richard Dalton, Chris Garcia, Rosa Inchausti, Wydale Holmes, Xiao-Jun Tian,  Arvind Varsani,  Efrem S. Lim, Matthew Scotch, Rolf U. Halden


doi: <https://doi.org/10.1101/2021.07.29.21261338>

This article is a preprint and has not been peer-reviewed [what does this mean?]. It reports new medical research that has yet to be evaluated and so should not be used to guide clinical practice.



Article

## Pan-Enterovirus Amplicon-Based High-Throughput Sequencing Detects the Complete Capsid of a EVA71 Genotype C1 Variant via Wastewater-Based Epidemiology in Arizona

Temitope O. C. Faleye <sup>1</sup>, Erin Driver <sup>1</sup>, Devin Bowes <sup>1</sup>, Sangeet Adhikari <sup>1</sup>, Deborah Adams <sup>2</sup>, Arvind Varsani <sup>3</sup>, Rolf U. Halden <sup>1,4</sup> and Matthew Scotch <sup>1,\*</sup> 

<https://www.mdpi.com/1999-4915/13/1/74>