The Future of Wastewater Sensing

Workshop
November 2nd and 3rd, 2015

Organized by
Dr. Lauren Withycombe Keeler and Dr. Cynthia Selin

Center for Nanotechnology in Society
School for the Future of Innovation in Society
Arizona State University

ASU BIODESIGN INSTITUTE
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Introduction to the Workshop

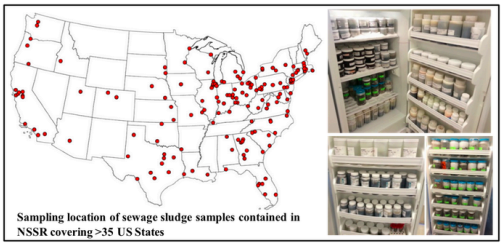
The Future of Wastewater Sensing

Introduction

Thank you very much for participating in the Future of Wastewater Sensing workshop. This workshop is part of a collaboration between Arizona State University's Center for Nanotechnology in Society in the new School for the Future of Innovation in Society, the Biodesign Institute's Center for Environmental Security, LC Nano, and the newly awarded Nano-enabled Water Treatment (NEWT) Systems NSF Engineering Research Center. The Center for Nanotechnology in Society is currently in its 11th year and throughout its lifetime has catalyzed, facilitated and participated in dozens of collaborations between social scientists, natural scientists and engineers at ASU and beyond, focusing on the anticipatory governance and responsible innovation of emerging technologies. In keeping with this tradition, in the Future of Wastewater Sensing workshop we will explore how technologies for studying, monitoring, and mining wastewater and sewage sludge might develop in the future, and what consequences may ensue for public health, law enforcement, private industry, regulations and society at large. The workshop will pay particular attention to how wastewater sensing (and accompanying research, technologies, and applications) can be innovated, regulated, and used to maximize societal benefit and minimize the risk of adverse outcomes, when addressing critical social and environmental challenges.

Background

Wastewater treatment in itself is nothing new. However, new research indicates that wastewater – which was once was viewed as a problem to be solved – may also hold a wealth of opportunity. That opportunity, in the form of potential information and latent material value, lies in a number of places, including raw wastewater (sewage), the solid byproduct of wastewater treatment known as "sewage sludge," treated sewage sludge or "biosolids" deemed fit for application on land, liquid byproducts, the treated water, and the bacteria that live in the waste and in treatment facilities, to name a few. Technological advancement, particularly in the area of (tandem) mass spectrometry, is enabling the collection of resources and information from these places, with findings proving to be intriguing, informative, lucrative and controversial. A closer look at wastewater (and other places mentioned above) can provide information about the exposure of a community to environmental toxins, the actual presence of toxins in the environment, trends in recreational and prescription drug use, and potentially the source of illicit drug manufacturing, and the emergence of epidemics. These places may also be places to reclaim resources, including metals and critical nutrients like phosphorus. A few select examples from ASU and beyond are summarized below and more detailed readings are provided at the end of this packet.



US National Sewage Sludge Repository

Dr. Halden has brought to ASU from Johns Hopkins University the National Sewage Sludge Repository (Venkatesan et al. 2015), a continuously growing collection of currently 200+ municipal sewage sludges from around the United States. Samples archived in the repository are available for analysis by outside researchers in an effort to "(i) identify and

prioritize emerging contaminants, (ii) provide spatial and temporal trends of contaminants, (iii) inform and evaluate the effectiveness of environmental policy-making and regulations, and (iv) estimate ongoing exposures and body burdens of mass-produced chemicals in human society."

GRAPHIC BY MICHAEL NORTHROP/BIODESIGN INSTITUTE/ASU; (LID) ASP, INC./DOLLARPHOTOCLUB.COM; (GOLD) CLEARVIEWSTOCK/ISTOCKPHOTO

Mining Sewage Sludge

Using mass spectrometric and economical analyses, ASU researchers have characterized sewage sludges including those contained in the National Sewage Sludge Repository, discovering a latent value in nutrients in elemental chemistry (e.g., precious metals and phosphorus) of nearly US$13 million per year in the sludge produced by a city of a million people, including US$2.6 million in gold and silver. (Westerhoff et al. 2015)

Photo credit: http://news.sciencemag.org/environment/2015/01/sewage-sludge-could-contain-millions-dollars-worth-gold

Monitoring Prescription and Illicit Drug Use

New techniques enable the identification of the presence and quantity of prescription and illicit drugs in wastewater streams as well as the metabolites of recreational alcohol and cigarette consumption. When samples are collected over time, patterns of drug and substance (ab)use emerge. The identification of these substances in wastewater before and after treatment can inform treatment design, help determine the discharge of these substances back into the environment, and provide epidemiological data on population health and behavior (Burgard et al. 2013; Venkatesan and Halden, 2014).

Workshop Design

This workshop will explore plausible futures for wastewater sensing with the explicit goal of informing how research and development in the field is carried out today. To explore these plausible futures, we will use a number of tools from scenario planning. Scenarios are a way to consider what might happen in the future based on a systemic exploration of driving forces, critical uncertainties, and important actors and activities that are shaping the future. They are not intended to predict the future and they make no claims about what future is most likely to occur. Rather, they are intended to be reflexive devices that help inform decision-making in the present. Results of the workshop should assist researchers at ASU and beyond with researching and applying in an ethical and socially just fashion, emerging wastewater sensing and monitoring technology to maximize public benefits and minimize unnecessary risks.

Acknowledgements

The workshop organizers would like to thank Patty Ryan and Deron Ash for their invaluable help in organizing this workshop. Thank you to all those who participated in pre-workshop interviews. This workshop is funded by the National Science Foundation under cooperative agreement #0531194.

The Future of Wastewater Sensing and Monitoring

Signals and Emerging Themes

From interviews and literature there emerge a number of important themes regarding the future of wastewater sensing. These themes are indicated in anonymous quotes and offer insights into what might be driving, hampering or otherwise affecting innovation in the field.

Applications for Wastewater Sensing Technologies

Doing traditional sensing and monitoring better:

"You need to know the state of the stuff that is coming in, the state of the stuff coming out, and what's happening in between." [referring to sensing wastewater before, during and after treatment]

"Trying to understand the nature of what's going on the land and what's coming off the land and how that's affecting water systems." [e.g. referring to fertilizer or other chemicals that runoff it the sewer system]

As an early warning system:

"There's a role for sensors to just tell me if there's a failure of some kind or some boundary...there's problems potentially building up within the system that need to be somehow alleviated."

To detect phosphorus and other elements at low levels and in real time:

"…it would be great if there was an accurate and selective electroprobe for phosphorus and even some way to sense it."

"it's about metal detection in water in real time, detection of other anions such as sulfate, chloride, nitrite, real time."

To inform community and public health decisions:

"For a hospital or a hospital system or even a single practitioner or a public health authority, if they have the birds eye view of what their community is struggling with, it's going to allow them to allocate their budgets in a far better way."

"…it's essentially doing diagnostic work on populations in real time. Anything we can measure would be helpful. We cannot only measure what the problem is, but we can also measure the success of interventions that are implemented in different areas."

Beyond the Treatment Plant

Sensing at the source:

"What I would love is to be able to have the sensors in urinals and toilets and be able to see the change in chemistry in urinals and toilets."

Low cost sensing for the masses

"…something that is not ridiculous expensive where it ends up only in a few hands. Something that is relevant to the world…"

"I think it would be wonderful where deployments are happening or in refugee camps. We can have some sort of sensor system that constantly measures the runoff so that we get real time information."

Judging Wastewater Sensing: Things to Consider

Privacy

"The question remains who owns the data? What is it used for? Who's making money with this?"

"Who is controlling the sensor, what is the purpose, what type of data is being collected?"

"The fourth amendment in terms of unlawful searches. What would be considered?" [If tracing illicit drugs up the sewer system to their sources.]

"…there will be groups that are concerned about property values and real estate. There are groups, people who may or may not want their water tested. Or they may or may not want indemnity from anything that's found in the water."

Technical considerations

"If you build a sensor as a controlling mechanism, but you get variable readings, and you don't get consistent readings for what is really there, then the reliability is suspect, you end up ignoring the sensor."

"That it's reliable and how much it takes to run."

"That the method is consistent at different locations, different time periods."

"If it's an online system, it should be easy to use, operate, and calibrate."

Cost – Benefit

"Rather than saying what can we do with our latest widget, saying what are the challenges we really face with wastewater and what do we need to address those challenges."

"There's a real danger of jumping on a bandwagon and investing a lot into something that we think is an issue while totally ignoring things that probably are an issue."

"Cost of personnel time and maintenance time are important."

Lessons from Analogous Technologies

When thinking about the future implications of a technology or its use, there are lessons to be learned from technologies of the past. A number of participants were asked what technologies hold lessons for wastewater sensing and how might we learn from these technologies. Below are a few select examples.

Geiger Counter

"…within two days of the Fukushima Daiichi nuclear power plant meltdown, there were about 3 independent DIY networks set up…to do radiological testing…based on their Geiger counters. Those Geiger counters were so cheap…Now the government is saying the perimeter is safe and this other perimeter is not. But if people have their own instrument in hand and it disagrees, as it did frequently in that situation, with what the government says, then they may not pay attention to what public health authorities are telling them to do. And it causes confusion…Not all expensive and cheap technologies are created the same. I think if there are no barriers to using the technology, for example, if the sensors are really cheap or even if there's a cheap version that isn't as good, we will not be able to control how people use them."

Image credit: Wikipedia Commons
https://upload.wikimedia.org/wikipedia/commons/4/40/Geiger_counter.jpg

Air Quality Monitor

"The US embassy in Beijing has contracted with an air quality company in California and they have their own air sensors on the embassy and they put out their own data. So the data coming form the US embassy is very different than the data being published officially in China. So it's providing the Chinese some food for thought, some advocacy power there. Simply because there is another sensor system set up and they are not getting the information from one source."

Image credit: Wikipedia Commons
https://upload.wikimedia.org/wikipedia/commons/2/25/NSW_EPA_air_quality_monitoring_station.jpg

Infant Screening Test

"Newborn screening cards, for example" [brought up] "… questions around who owns the blood spot, the DNA profile associated with it…We have a technology that has saved thousands and thousands of children's lives and it's so cost efficient in terms of its application. Yet, in some jurisdictions it's completely distrusted and Texas for example had to destroy 5 million of their cards because they hadn't put the right regulatory framework in place to protect." This analogy draws attention to privacy and consent issues when it comes to the collection of health information. It was intended as a cautionary tale about implementing an appropriate regulatory framework and consent protocol when data is collected, so that people do not feel they have been tricked, and so that valuable data is not lost. What the regulatory

framework looks like will depend on the granularity of the data being collected. While population level data may not raise issues of privacy, innovations that lead to this data may pave the way for further refinements that get closer to individual data and this should be considered at the outset.
Image credit: Wikipedia Commons
https://upload.wikimedia.org/wikipedia/commons/1/16/Phenylketonuria_testing.jpg

National Ecological Observatory Network

"National Ecological Observatory Network…it's sort of trying to do some large-scale sensing of different ecological habitats. That could maybe be a more positive story…in terms of how they're trying to understand changes in ecosystems and changes in climate through different techniques. That's probably a case where sensing is probably a must, because they have to do things over wide areas and long periods." The network could serve as a model for wastewater sensing in that it integrates sensing data from across the continent, allowing for integrated observation of ecological change over time. This could be applied using wastewater sensors to observe changes in public health or contaminants in the environment.
Image credit: www.neoninc.org

Workshop Agenda

Workshop Day 1
Monday, November 2nd, 2015
ASU Tempe Campus, McCord Hall, Oasis Room, 4th Floor

8:00 AM	**Registration**
	Coffee and Breakfast
8:30 AM	**Welcome**
	Introductions
	Current state of wastewater sensing research and development – Rolf Halden and Paul Westerhoff
	Brainstorm Part 1
	Break
	Brainstorm Part 2
	Predetermines and Uncertainties
12:00 – 1:00 PM	**Lunch**
1:00 – 5:00 PM	**Scenario Matrix**
	Instructions for Building Scenarios
	Break
	Building Scenario End States
	Progress Reports
	Developing Scenario Stories
5:00 – 6:00 PM	**Happy Hour with Activity** – *cash bar*
6:30 – 8:00 PM	**Dinner at Engrained with Activity**

Workshop Agenda

Workshop Day 2
Tuesday, November 3rd, 2015
ASU Tempe Campus, McCord Hall, Oasis Room, 4th Floor

8:00 AM	**Coffee and Breakfast**
8:30 AM	**Reflections from Day 1**
	Prepare Scenario Presentations
	Present Scenarios!
	Break
	Strategic Implications
	Reflection and Conclusion
12:00 PM	**Workshop Concludes**

Campus Map

McCord Hall

All workshop activities will take place at McCord Hall in the Oasis Room on the 4th Floor. Unfortunately the fourth floor requires key card access. Beginning shortly before 8AM someone from CNS will be stationed at the elevator bank at the east end of McCord Hall and will give you access to the 4th floor. If you arrive before we have someone stationed at the elevator or you enter through a different entrance you can take the elevator to the 3rd floor and the folks at the WP Carey reception desk can give you access to the 4th floor. If these options do not work or you need additional assistance you can call Lauren Withycombe Keeler on her cell at 480-290-5172.

Engrained

Dinner on Monday evening will take place at Engrained, a campus restaurant using organic, locally sourced ingredients, located on the second floor of the Memorial Union (indicated as MU on the map below).

The Graduate

Most out-of-town participants are staying at The Graduate, located on the southwest corner of College and Apache. The walking route from The Graduate to McCord Hall is indicated on the map below.

Interactive Campus Map with McCord Hall highlighted available at:
http://www.asu.edu/map/interactive/?id=120&mrklid=62951

Participant List

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Treavor Boyer	University of Florida	thboyer@ufl.edu

Participant Profiles

LTC Hugh Bailey serves as the chief of the Maneuver Support branch at the Army Medical Department Health Readiness Center of Excellence. His responsibilities there include analysis of future Department of Army capability requirements and development of short, mid, and long term solution strategies to meet needs in areas of occupational and environmental health exposure mitigation and protection of service member health and safety while deployed in contingency operations around the world. He is a registered professional engineer in Washington State and holds a master's degree in environmental and water resource engineering from the University of Texas.

Simona Balan is a Senior Scientist at the Green Science Policy Institute (GSP), and has been with GSP since 2013. She graduated with a BSc in Geosciences and Astrophysics from Jacobs University Bremen, and has a Ph.D. in Environmental Sciences, Policy and Management from UC Berkeley. GSP is a nonprofit in Berkeley, California whose mission is to facilitate responsible use of chemicals to protect human and ecological health. At GSP, Simona leads projects on trying to reduce the use of Six Classes of chemicals of concern, including fluorinated chemicals, flame retardants, and antimicrobials; and advises international committees on candle flame requirements for television enclosures.

Robert Bastian is a Senior Environmental Scientist with EPA's Office of Wastewater Management in OW. Since joining EPA in 1975 after spending three years on active duty as an officer in the U.S. Army Corps of Engineers, he has dealt with a wide range of wastewater infrastructure and residuals management issues associated with municipal wastewater treatment facilities, such as innovative treatment processes, wastewater and biosolids reuse, disinfection practices, decentralized wastewater treatment, water quality benefits of wastewater treatment, on-site power production and energy recovery, toxics control, etc.

Diana M. Bowman is an Associate Professor in the Sandra Day O'Connor College of Law and the School for the Future of Innovation and Society at Arizona State University, and a visiting scholar in the Faculty of Law at KU Leuven. Diana's research has primarily focused on the legal and policy issues associated with emerging technologies, and public health law. Diana earned her BSc, a LLB and a PhD in Law from Monash University, Australia. In August 2011 she was admitted to practice as a Barrister and Solicitor of the Supreme Court of Victoria (Australia).

Treavor Boyer is an Associate Professor in the Environmental Engineering Sciences Department at the University of Florida. He joined UF in August 2008 after completing his Ph.D. in environmental engineering at the University of North Carolina at Chapel Hill. Treavor's research interests span drinking water and wastewater treatment with emphasis on sustainable engineering approaches. Treavor is the recipient of a National Science Foundation CAREER Award, and is currently involved in two EPA national centers on nutrients and small water systems.

Dan Burgard is an associate professor of chemistry and an affiliated member of the Environmental Policy and Decision Making (EPDM) program at the University of Puget Sound in

Tacoma WA as well as an affiliate associate professor at the University of Washington-Tacoma. Dan received his bachelors in chemistry from Colorado College in 1996 and his PhD in chemistry from the University of Denver in 2006. Current research involves wastewater-based epidemiology to determine drug use trends in communities. This work uses chromatography and mass spectrometry to determine trace levels of drug metabolites in urban wastewater.

Hansa Done, PhD, is a recent graduate from ASU's Biological Design program and completed her dissertation with Dr. Rolf Halden in Biodesign's Center for Environmental Security.

Olga Epshtein is a management consultant in the water division of Arcadis, and a first-year PhD student in the Biological Design program at ASU.

Heather Finden graduated from Arizona State University with a Bachelor's of Science in Environmental Resources. Employed by the City of Phoenix for 14 years, she is currently serving as the Water Services Project Coordinator for the Water Services Department's Environmental Services Division. Additionally, she manages the wastewater compliance group which is responsible for the environmental monitoring and regulatory compliance associated with the City's two wastewater treatment plants and water reclamation plant. Heather represents the City of Phoenix on the Multi-City Sub Regional Operating Group (SROG) Technical Advisory Committee.

Randy Gottler is a Deputy Water Services Director managing the Environmental Services Division in the City of Phoenix Water Services Department. His responsibilities include over sight of the Department's environmental compliance programs including field sampling, laboratory services, permit management and reporting, air quality, hazardous materials, industrial pretreatment, and stormwater. He currently serves as Co-chair of the Arizona Panel on Emerging Contaminants, Chair of the Maricopa Association of Governments Water Quality Advisory Committee, serves on the Arizona Department of Health Services Environmental Laboratory Advisory Committee and as Coordinator on Standard Methods for the Analysis of Water and Wastewater. Randy has over 35 years of experience in environmental monitoring and compliance.

David H. Guston is Founding Director and Professor in the School for the Future of Innovation in Society at ASU, where he is also Co-Director of the Consortium for Science, Policy and Outcomes and principal investigator of its NSF-funded Center for Nanotechnology in Society (CNS-ASU) and director of its associated Virtual Institute for Responsible Innovation (VIRI). Professor Guston is widely published on the politics of science and technology, technology assessment, and the anticipatory governance of emerging technologies. He is a fellow of the AAAS (2002), served as co-chair of the GRC on Science and Technology Policy (2008), and is founding editor-in-chief of the *Journal of Responsible Innovation* (2013). He holds an A.B. from Yale and a PhD in political science from MIT.

Rolf Halden is a Professor in the School of Sustainable Engineering and the Built Environment, and Founding Director of the Biodesign Institute's Center for Environmental Security, the Biodesign CES Fee-for Service Mass Spectrometry Facility, and the Human Health Observatory (HHO) and U.S. National Sewage Sludge Repository (NSSR) at Arizona State University. Rolf has 20 years of experience in environmental monitoring, human health

assessment and sustainability science. Many of his peer-reviewed works deal with wastewater metrology for public health protection and for advancing sustainability.

Ian Illuminato is a consultant with Friends of the Earth US. Ian's work is focused on the safe and sustainable development of nanotechnologies. Ian coordinates Friends of the Earth's nanotechnology campaign and is a liaison member of the International Organization for Standardization's (ISO) Nanotechnologies Technical Committee (TC 229). His writing has appeared in publications including the Journal of Nanoparticle Research, Journal of the American Chemical Society and the European Journal of Oncology. He has also appeared in numerous media outlets including the New York Times, Scientific American, Business Week and Reuters. Additionally he has served on the Executive Committee of Friends of the Earth International. Ian has a B.A. degree in Human Ecology from the College of the Atlantic in Bar Harbor, Maine.

LTC Eric J. Kelly serves as the Chief, Force Health Protection for the U.S. Army Special Operations Command at Fort Bragg, North Carolina. In this position, he oversees diverse occupational, environmental, and public health programs to ensure the health of those within the command. He received a bachelor's degree in Chemical Engineering from West Virginia University and a master's degree in Environmental Engineering from the University of North Carolina in 2007. During his career, LTC Kelly has served in various environmental health related positions and locations throughout the world. He currently resides in Pittsboro, North Carolina.

Andrew Maynard is a professor in the School for the Future of Innovation in Society. His research and professional activities focus on risk innovation, and the responsible development and use of emerging technologies. A well-known science communicator, Maynard writes a regular column for the journal Nature Nanotechnology, and is the creator of the YouTube channel Risk Bites. He also co-chairs the World Economic Forum Global Agenda Council on Nanotechnology.

John Middaugh. Prior to retiring in 2013, Dr. Middaugh was the Interim Chief Health Officer, Southern Nevada Health District, Las Vegas, Nevada; from 2008 to 2011, he was Director of Community Health. He was the Florida State Epidemiologist, Florida Department of Health, from 2006 to 2008. He was the Alaska State Epidemiologist from 1980 to 2005. Board-certified in Internal Medicine, and Public Health and Preventive Medicine, Dr Middaugh began his career in public health in 1975 with the Centers for Disease Control and Prevention. He has conducted numerous epidemiologic studies of human health effects from environmental exposures to heavy metals, industrial chemicals, and persistent organic pollutants.

Amit Pramanik has almost 30 years of experience in environmental engineering both in the USA and overseas on projects funded by municipalities, industry, multi-lateral agencies (World Bank, Asian Development Bank, U.S. Agency for International Development), and other organizations. He has a civil engineering bachelor's degree from the Indian Institute of Technology, Kharagpur, and master's and doctorate degrees in Civil and Environmental Engineering from Virginia Tech. Dr. Pramanik worked with and consulted for various companies and water/wastewater treatment facilities. He joined the not-for-profit Water Environment Research Foundation (WERF) in 1997. He currently serves as the Interim Managing Director as

well as the Director of Research of WERF, with oversight and responsibility for WERF's portfolio of research and coordination with collaborative partner organizations. He is the director of the EPA funded WERF National Center for Nutrient Management and Resource Recovery.

Channah Rock is an Associate Professor at the University of Arizona in the Department of Soil, Water, and Environmental Science. Dr. Rock also maintains a joint appointment as a University Cooperative Extension Water Quality Specialist and is facilitating a research driven Water Quality Extension Program. Currently, Dr. Rock is working on several projects relating to the microbial evaluation of water quality for the protection of public health as well as promoting water reuse as a safe and practical resource for the Southwest. She possesses a wide variety of experiences in molecular microbiology and wastewater treatment. She has been extensively involved in community education and outreach and works with various stakeholder groups related to public perception of water resources including recycled water. Dr. Rock serves as vice president for WateReuse Arizona and is currently facilitating working group(s) of the Steering Committee for Arizona Potable Reuse (SCAPR) as well is a member of the Arizona Panel for Emerging Contaminants (APEC).

Cynthia Selin is scholar of socio-technical change, responsible innovation and foresight methodologies. Currently a Fellow in the Management Engineering Department at the Technical University of Denmark, Dr. Selin conducts research into the evolving practices of scenarios, with a special interest in the role of design thinking, mediation, and visualization. She is an Assistant Professor at Arizona State University in the School for the Future of Innovation in Society and the School of Sustainability. She is also a Senior Scholar in the Global Institute of Sustainability at ASU. Dr. Selin is also an Associate Fellow at the Saïd Business School, University of Oxford where she teaches in the Oxford Scenarios Programme.

Joshua Steele is a PhD student in civil engineering studying sewage epidemiology and its applications for improving health informatics at ASU's Center for Environmental Security. His interests are primarily in programming, statistics, and GIS. Joshua is using these tools to develop an online web application that can show quantifiable biomarker data from biosolids within a sewershed. This information can then be compared between sewersheds across states and countries to compare community exposure to pesticides, consumption of alcohol, nicotine, and drugs.

CW4 Mo Tyson has been in Army Intelligence for 20 years, with multiple deployments throughout the world. CW4 Tyson works for the Army's Intelligence Center at Fort Huachuca in the Capabilities Development Division. He is currently leading a research project for the Army Intelligence Center looking at how the Army can prepare to conduct missions in Megacities.

Arjun Venkatesan is a post-doctoral research associate at the Center for Environmental Security at the Biodesign Institute, Arizona State University (ASU). He received his Ph.D. at ASU (2013) and his Master of Science at University of Nevada, Las Vegas (2009), in the field of Environmental Engineering. His research activities are focused on the occurrence and fate of unsustainable chemicals in the environment and on the application of sewage metrology approaches to understand the chemical footprint and sustainability of urban centers.

Paul Westerhoff is a full professor in the School of Sustainable Engineering and the Built Environment at Arizona State University and the Senior Advisor to the ASU Provost on Science and Engineering. He has over 185 journal publications on his research related to fate of nanomaterials in water, using nanomaterial-based technologies for water and reuse treatment, reactions and fate of oxo-anions, plus characterization, treatment and oxidation of NOM and micropollutants. He is the recipient of several awards including the ASU Outstanding Doctoral Mentor for 2015, 2013 ARCADIS/AEESP Frontier in Research Award, and 2006 Paul L. Busch Research Award from Water Environment Research Foundation Endowment for Innovation in Applied Water Quality Research. Currently, he directs a 9-university EPA network on the lifecycle of nanomaterials and Deputy Director of a newly awarded NSF/ERC on Nanoenabled water treatment technologies.

Brett Waterman is Manager of Environmental Projects with Freeport McMoRan, which produces copper, gold, molybdenum and cobalt from mines throughout the Americas, Africa and Indonesia. Brett has extensive experience related to hydrometallurgy and mine water treatment. Brett's role is to manage water treatment and residual resource technology, including development and operation of multiple new-technology pilot plants and full-scale plants to treat mine impacted waters. Another important focus of his work is water management related to minimizing water treatment at Freeport sites.

Dave White is associate professor in the Arizona State University School of Community Resources and Development and Director of the ASU Decision Center for a Desert City. His research has been published in dozens of scientific journal articles and featured in popular media including *The New York Times*. Dr. White is a recipient of the President's Medal for Social Embeddedness from Arizona State University and the Celebrating Natural Resources Award from the University of Idaho. He received his Ph.D. in Forestry from Virginia Tech.

Lauren Withycombe Keeler is a postdoctoral fellow in the Center for Nanotechnology in Society in the School for the Future of Innovation in Society at Arizona State University. She has a PhD in Sustainability from ASU and comes to CNS by way of Leuphana University in Lüneburg, Germany. In her research and teaching Lauren uses future studies methods to explore the possible, desirable and undesirable impacts of emerging technologies to inform responsible innovation, anticipatory governance, and broader and more informed public participation in building a sustainable future.

Background Literature

Venkatesan, A. K., Done, H. Y., & Halden, R. U. (2015). United States National Sewage Sludge Repository at Arizona State University—a new resource and research tool for environmental scientists, engineers, and epidemiologists. *Environmental Science and Pollution Research*, *22*(3), 1577-1586.

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