Introduction

In bus depots across India's national capital territory of Delhi, public transport buses must be washed before they are sent out for service. In the West Delhi depot, around 45 of the 125 buses lined up in the large parking lot are washed with treated wastewater each day. In Delhi and other metropolitan regions of India, bus depots have relied on groundwater for their water source, but levels are declining markedly. In 2015, state governments and the courts started discussing new measures to curb groundwater use in city parks, construction projects, industries, and bus depots.[1] Around the same time, government leaders, private company chairpersons, and water board officials were developing and experimenting with small-scale treatment systems that could produce usable water from wastewater. In West Delhi, very near the bus depot, a pilot wastewater treatment plant was built by a private company on land housing the city's largest centralized wastewater treatment plant in the locality of Keshopur.[2] In July 2015, Delhi's chief minister, Arvind Kejriwal, well known for his proposals to increase piped water to all households in Delhi, presided over the opening ceremony for this pilot treatment project. Kejriwal took a long sip of the treated water from this pilot plant to draw media attention to treated wastewater and to emphasize its usability. When the

Delhi government ordered all bus depots to stop drawing groundwater in 2017 and use treated wastewater for all their cleaning activities, the Delhi Jal Board (Delhi Water Board) constructed a connector pipeline from the pilot project to the Keshopur bus depot across the street and initiated one of the first experiments in wastewater reuse for the city.

One of my first visits to a project involving reuse of treated wastewater was to the Keshopur bus depot. My research colleague and I sought interviews with the depot staff after hearing that they were using treated wastewater supplied by the small pilot project across the street. On the day of our unscheduled visit, we hoped to at least talk to a few people at the gate, to learn about what was occurring inside the depot. We were happy to find that the reception official at the depot was willing to lead us to an office where several staff members including managers, accountants, and supervisors were gathered. After explaining our research interest, we began the interview in a conversational format, with several staff members answering our questions separately and together. Our conversations then segued into discussions on the depot's varied water supplies, the costs for each supply and historical details on getting the pipeline established from the pilot project across the street. During these discussions, I noticed that the depot staff were generating locational understandings of wastewater and reuse and describing their knowledge of the qualities of the waters supplied to them. They were basing their understanding on daily contact and usage and defining different water supplies in relation to water purification, sewage treatment infrastructures, and the microbial reactions occurring within the latter. They were describing the trace metals, substances, and pathogens in treated wastewater. It became clear to me during our interviews that seeing and smelling water qualities and using the treated water for a specific purpose were behaviors that supported the pilot wastewater treatment project across the street. While research on wastewater reuse has emphasized the disgust or yuck factor, wherein treated water is considered repugnant, unusable, and even harmful, it appeared to me that these employees were breaking through the disgust factor and creating knowledges and situations in which wastewater could be valued as a resource. They were voicing their perception that the treated wastewater from the small pilot project was of better quality than the water they received in tanker trucks from the large, centralized treatment plant.

Their experiences touch on insights and challenges in the emerging field of wastewater reuse. In water-stressed regions such as parts of India, the southwestern United States, eastern China, Israel and Arab countries, Namibia, Singapore, and Australia, communities are looking for new water sources to meet ongoing demands and to adapt to changing water cycles and climate change. Wastewater reuse now appears attractive as a less explored but potentially beneficial option. Treated wastewater can provide a water supply for human needs and ecosystems. This book supports the emerging interest in wastewater reuse by describing human engagements with treatment and recycling across several states within India. These innovative projects display variations in technologies, water budgets, and small and large infrastructures.

Yet wastewater reuse poses challenges across the spectrum of human cultural practices and machine functions.[3] These challenges underscore the fact that wastewater is an undervalued resource; on the world stage, treated wastewater accounts for barely 3 percent of water used worldwide. While in many countries, centralized wastewater treatment systems have extensively piped sewerage networks, an accoutrement of pumping stations, bioreactors, filtration and disinfection devices, and ancillary equipment such as backup generators, in India most facilities are deficient in one respect or another and 70 percent of wastewater runs untreated into surface and groundwater. These deficiencies have pushed authorities and concerned citizens to look for other ways to procure water. Authorities and concerned citizens are finding that the most promising way to address both the challenges of water scarcity and the deficiencies of centralized systems is to experiment with decentralized wastewater treatment machines and optimize them to produce reusable water. Across a diverse set of cases, I found that individuals and communities were willing to use grades of treated wastewater when they were directly treating or managing the treatment of these waters and using the reused water for specific purposes. I argue that decentralized experimentation leads to greater acceptance of wastewater reuse.

This argument builds upon a growing body of literature regarding human cultural attitudes and perceptions about reusing wastewater. Public acceptability is a significant problem in the United States, Australia, and other highly industrialized countries. Fielding, Dolnicar, and Schultz found that acceptance of recycled water decreases as human contact with it increases.[4] A community's disgust surrounding wastewater may prevent the expansion of potential uses and applications of treated water. Taking a more optimistic approach, Scruggs has argued that public acceptance of potable reuse is possible but depends on the history of water scarcity, citizen experience with drought and water reuse, community size, the way a project is introduced and by whom, communication strategies, and trust in the officials and entities introducing a project.[5] Members of businesses and communities are identifying and labeling gray, black, and reuse waters. As Barnes has argued for irrigation water in Egypt and Walsh has explained for conceptions of groundwater in Mexico, water is not simply water, but becomes different waters over time and space.[6] Wastewaters are similarly defined as plural and differentiated.

By reusing wastewater, additional water is added to the supply chain to increase on-site availability for communities and businesses. To get to on-site reuse, communities and businesses experimenting with wastewater treatment systems struggle with scale when treating the water to a reliable standard. These communities and businesspersons experimenting with reuse have questions: How much wastewater is needed to reach optimal treatment with an on-site machine? Can a decentralized or modular unit achieve the effluent standards assigned to centralized systems? When I visited the experimental community of Auroville in the state of Tamil Nadu, where community members were deeply engaged with experiments in sustainable architecture, water, and energy, I was able to talk in detail with the director of Auroville's Center for Scientific Research. As he explained, scale is critical:

> We know that in Auroville. We knew that we had to take care of our own energy requirements. The same applies and will have to be done with our own recycling of wastewater. We cannot expect the government to do it for you [us]. We will have to come back to a model which decentralizes it. The thing is how far you decentralize. There is an optimum. If you do it on an individual scale at the household, it doesn't work. We found that out. It is too costly, too complex, too many things. So you have to come back in a cluster design. We have to do that. This is a role that we have to work on. This is a road we have to work on in the future. The tech is less of a problem, high tech or natural. If you come down to a sizeable cluster or quantity of waste-

> water that you can maintain, fantastic. There awareness becomes important. You come back to water consciousness. No spoiling, making sure that everything works, repairing taps that leak. Nothing that the government is going to take care of. Huge effort. The way forward!"

The challenges involved with building and sustaining decentralized infrastructures involve optimization, maintenance, and repair. Machine operators articulate the requirements of running and repairing machines and describe how problems develop when technologies fail to work according to plan. Engineers relate their methods for adjusting and managing sewage and its biochemistry and concentration to reach optimal treatment conditions. The bacteria that digest and degrade wastewater need suitable working environments. Managers and supervisors must make sure that bacteria can thrive and digest biological matter within machine phases. Anaerobic bacteria thrive without oxygen, while plenty of oxygen must be supplied to aerobic bacteria. If the right scales are achieved, experimenters hope that decentralized or on-site treatment systems can avoid the problems that plague centralized systems: the over-expenditures on long-distance pipes to carry sewage; the energy-intensive pumping systems; the dilution of sewage from rainwater and runoff; and the corruption that degenerates public services and trips up regulation and monitoring.

THE HUMAN-MACHINE-MICROBE PERSPECTIVE

Wastewater reuse is not a new idea, but the integrative study of this activity requires new framing. A new framing must consider the disciplinary and professional lenses that have informed the wastewater sector, including environmental engineering and public administration. It must contextualize the approach within local and regional water availability using water science and hydrology. It must investigate the social organizations of governance and the circular economy using approaches in the social sciences. The framing must bring microbiology into the purview to consider the role of microbes in wastewater digestion.

To do this, I create a human-machine-microbe perspective, drawn specifically for Indian histories, politics, and economics but applicable with modifications to other countries and contexts. I use data collected from wastewater engineers, consultants, designers, operators, community representatives, business managers, and regulators to understand the social and professional activities involved with treating wastewater and running microbial machines. I draw from the understanding of the hydrosocial cycle and from studies of human-machine interactivity to form the theoretical perspective. I contribute to discussions on decentralization and the multilayered arrangements of water governance in India. I focus on treatment and reuse systems in businesses and large institutions and within housing communities, leaving aside the more complicated domain of industrial treatment.

The established notion of the hydrosocial cycle considers wastewater a socio-natural or socially embedded substance. It brings together hydrology, or water science, and the social sciences and directs attention to the ways the society—its key actors and institutions—shape water meanings and uses through infrastructures and technologies. In the hydrosocial cycle considered here, consumption practices turn potable and non-potable water into wastewater and then wastewater is transformed into other waters, and some is reused. Waters are named and labeled at specific moments in this water cycle as they circulate from groundwater to consumption water and then to wastewater, passing through phases of treatment and through the life cycles of technologies. Microbial activities are also described as wastewater moves through treatment machines and is stored for use or discarded.

The interactions that resident groups have with machines are central to these hydrosocial cycles. Interactions may occur in a direct way as they build, operate, and maintain sewage treatment plants (hereafter I will use the acronym STP for sewage treatment plant) or as they interact indirectly through funding, decision-making, and the monitoring of projects. The notion of sociotechnical systems originally developed by Eric Trist, Ken Bamforth, and Fred Emery focused on explaining the hierarchical work design in England's coal mines. This initiated the aim of "joint optimization" between people and technology in engineered work systems and workplaces to create the best technological performance for improving the quality of human life.[7] Optimization is central to the work that wastewater treatment plant operators and communities grapple with today.

Operators and communities also bend the boundaries of "human" and "machine" when integrating parts of an infrastructure. Like Haraway's cyborgs with machinated body parts that help the body function where the organ system has failed, humans help to connect segments of infrastructure through cleaning, machine repair, and the transport of fecal waste and wastewater, at times endangering their bodies and health.[8] Operators of machines are also involved with the microbes that are integral to bioreactors. As Rose has shown, microbes are part of other species' life that humans engage with.[9] Governments include microbes in their visions of national biosecurity.[10]

I shape my perspective on human-machine interactivity by focusing on processes of optimization that involve the behaviors of microbes. Murray-Rust et al. have studied the social networks embedded in automation design by doing ethnographic fieldwork with users, trainers, designers, programmers, and engineers who embed their knowledge into a system.[11] I convey the ways engineers, STP operators, nongovernmental agencies (NGOs), government agencies, and community members view and define optimal states, processes, and outcomes. Optimization is needed to achieve desired water qualities in the out-fluent or the treated water, to achieve a standard of BOD (biological oxygen demand) generally in the range of "10" mg per liter. In some cases, optimization requires surveillance and feedback through biometric and sensor devices.[12] However optimization has a long way to go before treatment machines can be considered intelligent or "smart."[13]

Machine operators must use microbes to optimize wastewater digestion. In the human-machine-microbe perspective, machines made and optimized by humans are not networks but bio-machines. They are bioreactors. Described by one respondent as the "heart of treatment," bioreactors are designed to work by anaerobic or aerobic digestion. The systems use one or both of two kinds of bacteria. These are anaerobic bacteria, which do not need oxygen to eat the food in the wastage, and aerobic bacteria, which require oxygen to consume food and multiply. Bioreactors can be highly mechanized and energy-intensive systems or follow low-energy methods that require less maintenance. Some systems use plants and wetlands and mimic natural processes to perform bioremediation. All bioreactors involve managed or spontaneous processes in which microbiological organisms degrade or transform contaminants to less toxic or nontoxic forms.

MICROBIAL DIGESTIONS AND INFRASTRUCTURES

Infrastructures in this field of wastewater management are configured according to the qualities and quantities of human waste.[14] Contributing to the scholarship and ethnography of physical and material networks,[15] new technologies,[16] megaprojects,[17] energy grids,[18] water and sanitation facilities,[19] and solid and military waste,[20] I add the role of microbes to the analysis of machines and grids.[21] Sanitation infrastructure can be distinguished in terms of two fields of activity, wastewater management and fecal sludge management. I am primarily focusing on wastewater management. Wastewater management aims to capture the liquid waste running from toilets, bathrooms, kitchens, and other places and diverting it through pipes, treatment plants, and drains. The infrastructure for this management includes: (a) toilets; (b) pipes and sewers; (c) open or closed drains (where an open drain is referred to as a *nala* in Hindi or a *raja kaluve* in Kannada); (d) pumping stations; (e) conventional treatment plants with large bioreactors; and (f) small decentralized plants with a variety of bioreactors. The other field of sanitation, fecal sludge management (FSM), removes the waste from toilets and septic tanks, which is highly concentrated and not mixed with much water. It is removed from homes with pumps or carted away in large trucks or lorries.[22] Some solid fecal matter is transported from individual homes by manual scavengers who engage in the demeaning and dangerous tasks of solid removal with hands, wheelbarrows, and small transport devices.[23] In fecal sludge management, the infrastructure consists of dry latrines, toilets, septic tanks, and fecal sludge treatment facilities.

When wastewater flows through settlements and cities, underground pipelines may render the infrastructure invisible for a time, but open drains are a reminder that wastewaters are hard to contain and leach out from all corners of human constructed infrastructures. Once created for storm water drainage, many drains carry large volumes of wastewater. As open or underground, earthen, cement, or brick conduits they direct