Advanced Review

Illuminating elimination: public perception and the production of potable water reuse

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Given the scope of water and sanitation challenges posed by climate change and continued urbanization, potable water recycling is gaining traction as a means to expand urban water supply and decrease wastewater disposal into waterways. No longer regarded as a system by-product without value, planners increasingly consider wastewater a displaced resource in need of recirculation. The literature suggests that public perception and institutional barriers are the limiting factors to greater recapture and reuse of wastewater. Implicitly accepting water recycling as a sustainable alternative, much of the research is aimed at overcoming public opposition. However, the trend toward potable water recycling disrupts the normally hidden processes of urban water delivery, treatment, and disposal. In doing so, it provides a rare opportunity to contemplate taken-for-granted technologies of waterborne sanitation and to recognize alternative modes of managing human excrement, including composting toilets and dry sanitation. © 2016 The Authors. *WIREs Water* published by Wiley Periodicals, Inc.

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INTRODUCTION

Wastewater treatment systems, designed to preserve human and environmental health, have contributed to a rise in municipal water recycling systems. Recycled water is also known as renovated water, repurified water, or reclaimed water. Engineers currently consider water recycling 'the easiest and cheapest option for coming up with more water' (Ref 1, p. 188). This consensus is reflected in the most recent (U.S.) National Research Council's assessment of water reuse, which states, '[t]he use of reclaimed water to augment potable water supplies has significant potential for helping to meet the nation's future need' (Ref 2, p. 54). While not a new concept, potable water recycling projects are an increasingly attractive option for long-term water planners. Nevertheless, expert confidence has not smoothly translated into public acceptance of wastewater (or sludge) recycling.

Modern sewerage—specifically centralized, waterborne waste collection and treatment—is a legacy of social and political choices made in 19th century England.[3–6] Since the creation of sewerage, engineers, natural scientists, public health officials, and municipal governments have promoted a sanitary 'culture of flushing,'[7] which continues to affect water and wastewater treatment across the globe.[5,8] The beneficial role sanitation provides is widely recognized, yet most users of sanitation systems rarely stop to consider the logistical management of human excrement. In effect, 'urban life means that your shit is not your problem' (Ref 9, p. 2816).

In the latter half of the 20th century, recycled water resources arose as a means to augment or protect urban freshwater supplies.[10] Potable water recycling projects supplement drinking water supplies

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with highly treated wastewater and deliver the blended supply through the existing distribution system. Opponents of potable water recycling label these projects 'toilet-to-tap,'[11] despite the fact that toilet flushing represents only a fraction of household sewer flows (typically 25% of domestic water use in nations considering potable reuse).[12,13] Sewage also contains 'down the drain' household chemicals (e.g., detergents, fragrances) and nondomestic pollutants (e.g., heavy metals, pesticides).[14] Nevertheless, the historical association of wastewater with excreta, toilets, and sewers complicates the public's response to potable water reuse.[15] The capabilities of modern water purification processes may ameliorate public health concerns (i.e., remove contaminants); however, scholars suggest that potable water recycling's full potential remains hampered by social, cultural, and psychological responses to human waste (e.g., taboo, disgust), which are discussed below.

Until the dawn of the 21st century, the prospect for potable water recycling was considered an option of last resort;[16] however, recent expert assessments now consider the practices *safer than* conventional-sourced water supplies.[2] The sea change in opinion regarding the potential for planned potable reuse to expand municipal water supplies represents a new common sense in the industry. The transformation of wastewater into recycled water over the last 50 years occurred in the context of several (re)current trends: urbanization and demand for new water resources, the establishment of environmental institutions and promulgation of laws and policies aimed at protecting the environment, and the development of advanced water treatment technologies. The increasing interest in potable water reuse over the past 15 years has occurred in the context of continuing urbanization and the growing demand for new resources given potential effects of climate change, better understanding of the impact of effluent on the environment, the growing availability of pressure-driven water treatment technologies (i.e., reverse osmosis and microfiltration), and coordinated lobbying by proponents for potable reuse.

Projects that purposefully augment the potable water supply with recycled water remain 'relatively unusual in the world' (Ref 17, p. 158). For example, in the U.S., it is estimated that just one-tenth of 1% of municipal wastewater undergoing treatment is recycled.[2] The majority of operational potable reuse projects are located in coastal southern California, but even here, potable reuse accounts for less than 1% of the existing water reuse projects.[18] Outside of the U.S. potable reuse is less common, but examples can be found in the U.K., Australia, Belgium, Singapore, South Africa, and Namibia.[19,20] Despite demonstrated success, a number of proposals for potable water recycling in Australia and the U.S. have failed to come to fruition.[21] In the late 1990s, several projects were halted even after substantial outlays in wastewater treatment facilities and conveyance infrastructures.[10,15] As a result, direct advocacy groups were formed in the U.S. to promote and stabilize potable water recycling at home and abroad.[21,22]

The focus of this review is the history and trajectory of urban sanitation and rising interest in potable water recycling systems. To establish the parameters of potable water reuse, I provide a brief review of the most typical wastewater treatment and recycling processes. I then examine the lack of public acceptance for potable reuse as the bedrock of current social-scientific research in this area. Next, I describe the critiques of, and alternatives to, expanding waterborne sanitary technologies. The discussion indicates that some of the proposed alternatives to waterborne sanitation favor less technically sophisticated technologies, such as composting toilets. In closing, I propose that more research on alternative technologies may be preferable to continued investment in potable projects.

PROGRESSION OF WASTEWATER TREATMENT PROCESSES AND PRODUCTS

The variations in pollution loads in each sewer drainage basin means that the character of sewage varies as widely as the quality of the source waters, the diversity of the surrounding industries, consumption patterns of the community, the treatment standard of effluent required by law, and the economic and technical capabilities of plant facilities. In addition, a combination of government decisions (e.g., supra-national, national, sub-national) determines the official policies regarding treatment and disposal, which affects the quality of effluent and sludge (e.g., presence of industrial, radioactive, or synthetic chemicals). Despite this diversity, modern wastewater treatment plants combine a common 'train' of treatment processes to detoxify wastes prior to discharge or reuse. The most common purification techniques and material by-products of standard treatments are briefly described below.

Conventional Treatment

After basic screening for large debris, the simplest form of wastewater treatment is primary treatment. The goal of primary treatment is to remove suspended and undissolved solid particles and combat oxygen depletion in order to improve the aesthetic and environmental conditions associated with effluent released into waterways.[1,23] Normally, physical processes remove organic matter through gravity sedimentation and flotation (for materials such as oil or grease).[24]

Secondary treatment removes biodegradable organic matter through biological treatment, which involves the use of microorganisms to speed the breakdown of organic matter. The most common forms of biological treatment include trickling filters, activated sludge process, and stabilization ponds[23,24] followed by a secondary round of sedimentation. Secondary treatment is capable of removing 85% or more of all impurities in sewage.[15] In places where water pollution controls are established, secondary treatment typically defines the minimum standard for legal discharge of effluent into waterways. Secondary treatment produces additional solid wastes.[1] To decrease the concentration of pollutants, residual solid matter is treated through a process known as sludge digestion (i.e., anaerobic biological processes).

Conventional wastewater treatment processes are capable of removing many pollutants (e.g., heavy metals, surfactants); however, a number of contaminants are poorly removed by conventional means alone (e.g., most pharmaceuticals).[14] Advanced water treatment includes an array of complimentary processes that exceed what is possible from conventional wastewater treatment.

Advanced Water Treatment

Tertiary, or advanced, treatment entails specialized processes that 'polish' effluent to increase purity.[23] These processes can remove nutrients (i.e., nitrogen and phosphorus) and chemicals of concern (e.g., pesticides, pharmaceuticals). Tertiary treatment is applied to meet wastewater discharge criteria (i.e., prevent eutrophication in sensitive environments) or meet elevated water reuse standards (i.e., remove contaminants).[10] Tertiary treatment can include a range of mechanical, biological, and chemical processes, including air stripping, ion exchange, lime treatment, chemical coagulation and precipitation, membrane filtration, and reverse osmosis. Tertiary processes are variously applied based on the constituents present in wastewater and the purpose of additional treatment (e.g., preserve environmental quality, protect public health).[25] Tertiary processes can remove up to 99% of the impurities in sewage.[2]

Water Reuse

The level of treatment determines the quality of effluent (and sludge). Subsequently, every additional level of wastewater treatment increases the quality of the liquid by-product, which indirectly encourages water recycling. Stringent wastewater treatment requirements, originally mandated to minimize environmental harm, are costly. Substantial investments in water treatment increases the economic viability of recycling wastewater for any number of municipal, agricultural, industrial, recreational, or environmental uses.[26] By the 1970s, water planners, especially those in the U.S., began to consider treated wastewater a valuable commodity able to augment municipal water supplies through water reuse.[10,27]

Today, water planners suggest it is not a matter of *if*—but *how*—cities will take advantage of this 'new' 'rediscovered' water resource. (i.e., rate and manner of reuse).[2] The full spectrum of urban wastewater reuse includes domestic, industrial, and municipal uses that cover the gamut of potable and non-potable applications,[25] as detailed in Table 1. At the low (or no) treatment end of the spectrum, greywater systems capture household wastewater from sinks, tubs, or washing machines for domestic purposes like toilet flushing (e.g., non-potable applications). Because treatment is minimal, greywater systems do not include flows from the toilet (i.e., black water).[28] Recycled water is commonly defined as municipal wastewater treated to a water quality that makes it usable again. Recycled water quality standards, and the subsequent level of treatment, are more stringent as the level of personal contact increases. The vast majority of recycled water is used in irrigation.[10] However, spurred on by ominous forecasts, experts and governments, primarily in the U.S., Australia, and South Africa endorse potable water recycling as the most promising solution to many of the water supply or wastewater disposal challenges currently facing urban water planners.[2,19,20] Although proposals for potable water recycling face stiff public opposition, there are numerous concrete examples of operational success. The largest and most internationally recognized project is Orange County Water District's Groundwater Replenishment System,[15,21] which currently serves 2.4 million residents in the greater Los Angeles area.

Presently, most potable recycling projects include conventional treatment followed by three advanced treatment processes: microfiltration, reverse osmosis, and ultraviolet radiation with or without advanced oxidation.[2,18] Microfiltration removes bacteria, protozoa, and suspended solids by pushing water through a series of fiber membranes filled with tiny, hollow tubes. Reverse osmosis filters viruses, salts, and other chemicals by pushing water through plastic sheets. The addition of high-intensity ultraviolet light with hydrogen peroxide destroys the

TABLE 1 | The Typology of Urban Water Reuse

Technique	Definition and Characteristics
Greywater Reuse	• Onsite recycling of household wastewater from sinks, tubs, or washing machines, not including toilet water • Used exclusively for onsite non-potable applications, such as irrigation • Diverts wastewater 'off-the-grid' and diminishes wastewater return flow • Limited, if any, treatment; may contain pollutants found personal and household hygiene products; regulatory oversight varies
Dual Systems	• Recycled water is conveyed via a separate, dual 'purple pipe' distribution system • Used strictly non-potable applications such as municipal irrigation (e.g., yards, schools, parks, and crops), industrial processes (e.g., cooling water), or toilet flushing • Treatment level variable, minimum secondary
Indirect Potable Reuse	• Recycled water is deliberately blended with drinking water supply resources using an environmental buffer (i.e. attenuation and/or retention in an aquifer, reservoir, river, or lake) prior to delivery • Distributed in a single water conveyance system and used for both potable and non-potable applications • Advanced treatment to remove micropollutants and chemicals of concern
Direct Potable Reuse	• Recycled water is treated to required drinking water standards, then deliberately added to municipal drinking supply without an environmental buffer (i.e. 'pipe-to-pipe') • Distributed in a single and used for both potable and non-potable applications • Advanced treatment to remove micropollutants and chemicals of concern

remaining difficult-to-remove viruses and micropollutants. The application of advanced water treatment processes is the reason experts consider recycled water projects *safer than* conventional water supplies.[2]

Environmental Buffers

Most water recycling projects rely on so-called 'environmental buffers.' Two examples of environmental buffers used in water recycling schemes are constructed wetlands and artificial recharge. Constructed wetlands are human-designed to provide numerous beneficial services, including filtering and improving water quality as plants take up available nutrients. Artificial recharge of underground aquifers via percolation or infiltration can provide a natural filter known as soil aquifer treatment.[10] Use of environmental buffers can provide water treatment and allow for storage, but, importantly, they also bestow an additional 'kiss of nature' that is believed to make recycled water a more palatable public water supply, especially in cases of potable water recycling (Ref 29, p. A334). Water recycling that relies on environmental buffers is known as *indirect* reuse.

Solids Reuse

The goal of treatment is to clean wastewater and remove the solids, pathogenic microbes, and chemical contamination contained therein. Sewage sludge is the solid (or semi-solid) by-product of wastewater treatment.[30] Since bans on ocean dumping of sludge were put in place in the U.S. and U.K. in the 1990s, sludge is typically incinerated, landfilled, or applied to land as a soil amendment.[30,31] Land application is often preferred as the simplest and most cost-effective management strategy. In 1991, the term biosolids was developed at the request of the sewage treatment organizations in the U.S., who were seeking to rebrand sewage sludge treated to be applied to land as fertilizer.[32]

The physical properties and form of biosolids (i.e., liquid, cake, or pellet) is highly variable and dependent on levels and type of treatment.[30] By design, the contaminants removed from the water are concentrated in its by-product. Sludge contains the beneficial nutrients found in human waste (nitrogen, phosphorous, and numerous micronutrients), which can amend soils and increase yields; however, it may also contain low concentrations of pathogenic microbes, organic pollutants, and heavy metals.[32] Additional treatment of sludge can eliminate bacteria, viruses and organic pollutants, abate odors, and reduce the concentration of heavy metals and other harmful organisms.[30,33]

The engineering and management of sewage sludge has been the subject of public controversy and intense scholarly inquiry. The research in agriculture, engineering, environmental science, biology, chemistry, and public health primarily explores the composition of treated sludges, or biosolids (i.e., concentration of various pollutants and beneficial nutrients), or the environmental or public health implications of continued land application (e.g., the fate of contaminants, such as heavy metal displacement).[32] Much like plans for potable water recycling, the 'scientific and regulatory enthusiasm for biosolids recycling' (Ref 34, p. 142) is often tempered by public discomfort in communities where they are to be applied.[23,35,36]

Recirculating Residuals

Proponents of potable projects regularly emphasize the fact that wastewater is already a source of drinking water for many urbanites as effluent is routinely released into water that serves as the sources of drinking water for downstream communities.[15] Indeed, the word 'sewer' stems from the Old English word 'seaward' (Ref 1, p. 114). The de facto, or unintentional, contribution of effluent to municipal water supplies is referred to as unplanned potable reuse. The 'flush and forget mentality' has meant that this unintentional potable reuse is largely unnoticed in society.[37] The Thames River in the U.K., the Murray-Darling in Australia, the Rhine River in Europe, and the Mississippi and Colorado Rivers in the U.S. all contain sizable volumes of effluent, resulting in unplanned potable reuse for millions of downstream users. Over time, the contribution of wastewater to surface waters has increased from modest to considerable quantities. One of the concerns of wastewater discharge for humans and the broader environment is the presence of a wide range of chemicals that are not removed by conventional wastewater treatment, such as micropollutants found in personal care products and pharmaceuticals.[1,14,38] Unlike unplanned reuse, *planned* potable water recycling involves the *intentional* reuse of municipal wastewater and the application of advanced water purification treatments, such as microfiltration, reverse osmosis, and UV, which effectively remove residual nutrients and chemicals of concern.

For decades, municipalities have supplied recycled water for non-potable purposes with little or no incident or public upset, for example, in industrial applications or for irrigation. Non-potable recycled water is conveyed in a separate set of purple pipes, which is the internationally adopted color to designate the non-potable recycled water quality. The delivery of potable-quality recycled water does not require a dual distribution system, and therefore, potable reuse is arguably more efficient than non-potable operations. The development of advanced water treatment processes in recent years has meant cleaner recycled water resources, which contributes to the expansion of plans for potable water reuse in the near future. Some engineers and governments are generally accepting of potable water recycling projects.[2] However, potable projects remain contentious in communities and an object of intense research and public relations campaigning.

PARADOX OF PROGRESS: OBSTACLES TO POTABLE WATER RECYCLING

Many potable water recycling projects have been, and continue to be, interrupted and completely obstructed by public opposition.[15,39,40]As a result, much of the literature surrounding recycled water is dedicated to increasing acceptance[41,42] and 'inoculating the public' against negative messaging or scare campaigns (Ref 43, p. 337). This includes branding, social marketing, and educational strategies.[44,45] Proponents of planned potable recycling suggest that despite its advantages, the public often objects to the prospect based on misinformation, lack of knowledge, or instinctive repugnance.[40,46,47]

The literature often discusses the barriers to recycled water development—especially overcoming the so-called yuck factor.[11,46,48–50] These claims indicate that the primary obstacle to public acceptance of recycled water is the instinctive response that is associated with sewage. Popular media and scholars alike frequently attribute the lack of public acceptance to 'emotional' or 'illogical' aversions.[47,51–53] The yuck factor blames disgust, drawing primarily on the law of contagion in which the fear of recycled water is labeled irrational and unconscious. As Russell, Lux, and Hampton[54] note:

> In particular, *disgust* has become central to explanations of public responses to the recycling of wastewater, particularly for potable applications and uses where personal contact is more likely. Popular commentaries and some academic work now routinely refer to a "yuck factor," and some take for granted that it exhaustively explains public opposition when it is encountered. It is treated as an intrinsic human emotion–difficult, if not impossible, to overcome. It is often seen as further evidence of an inability to make rational judgments... (Ref 54, p. 59 emphasis in original)

The yuck factor assumes that it is the association with human waste that renders recycled water unpalatable from the public's point of view.

Although the yuck factor—psychologically 'unfounded' disgust—remains the predominant causal explanation for rejecting recycled water for drinking, a number of scholars seek to explain aversion to drinking recycled effluent based on social or cultural context.[55–60] By acknowledging that a combination of technical and non-technical (e.g., social, management, governance) issues contribute to public trust, this view emphasizes that the public is not necessarily uninformed or uneducated but are concerned that decision-makers are untrustworthy or will fail to take them seriously or actively consult with them.[54,59,61]

Some scholars contend that better-crafted messaging and marketing will be necessary for potable water recycling projects to succeed, for example, by stressing economic benefits, allying fears, or appealing to ingrained attitudes.[41,52,62] Others further that the central obstacles to public acceptance lies in our language and the way we talk about recycled water supplies, suggesting additional research aimed at assessing the effectiveness of various persuasion programs.[44] Others counter that marketing and public relations are ineffective in changing attitudes and recommend deploying new strategic tools to identify, measure, and predict the key factors that influence public decisions.[63] Although the methods and procedures for public inclusion are debated (e.g., early engagement, community dialogue, public demonstrations), a number of scholars agree that public participation is critical to effective recycled water planning.[39,64,65]

When considering the barriers to potable reuse, proponents stress that advanced water treatment processes insure absolute safety. Indeed, planned potable water recycling is *safer than* traditional water supplies, given that conventional sources are already heavily contaminated by municipal wastewaters.[2] As new technology and advanced treatment processes mitigate risk, proponents suggest that wastewater treatment processes are able to produce 'designer' water quality. Potable reuse is likewise presented in popular media as inoffensive, reliable, and preferable to other alternatives.[53,66,67]

Some argue that if people's perceptions are considered the primary challenge to water recycling, then using environmental buffers is the best strategy to avoid conflict because it makes the recycling process less visible and seemingly natural.[68] As George observes, '[r]euse works better when it involves camouflage … [the indirect blending], is a clever way of getting around fecal aversion' (Ref 37, p. 229). According to the (U.S.) National Research Council,

> [e]nvironmental buffers can play an important role in improving water quality and ensuring public acceptance of potable water reuse projects, but the historical distinction between direct and indirect water reuse is not meaningful to the assessment of the quality of water delivered to customers (Ref 2, p. 54).

At the moment, direct potable water recycling projects (which lack environmental buffers) are rare; however, they are increasingly considered a 'future imperative.'[10,24,69]

A number of contingent factors have been found to affect public responses to planned potable recycling proposals, including: social mood, the supply–demand gap, the dependence on imported water, vested interests, and information manipulation.[39,60,61] For example, opposition to potable water recycling may be motivated by issues that are hard to deal with in a directly technical manner, such as conflicts over urban and regional growth.[15,70] Seen in this way, opposition to reuse is not simply about public inability to understand risk but about urban governance more generally.[71] The broad spectrum of challenges prompts some scholars to suggest allowing for both science and emotion to drive decision making through collaborative co-learning.[72]

ADVANCING ALTERNATIVE CONFIGURATIONS

Although feasible, a number of scholars contend that a more sustainable alternative to treating all wastewater to potable water quality will require a change in current water management practices. Some scholars note the benefits of decentralized (or hybrid) systems, which incorporate greywater, rainwater, and stormwater catchment as well as water recycling.[73] Others are attentive to energy and nutrient savings in addition to water savings. For example, Sala and Serra[74] suggest that irrigation provides the maximum benefit of recycled water with the lowest adverse environmental impact because it can return the nitrogen and phosphorus to the soil for plant uptake and recycling. Reusing the available nitrogen and phosphorus provides necessary fertilizer for plant growth and reduces the need for costly wastewater treatment.

Other scholars lament that the 'preference for water-borne sewerage systems meant that little encouragement has been given to other methods of managing human body wastes' (Ref 75, p. 203). Furthermore, currently designed recycled water systems are largely incompatible with greywater and other decentralized conservation methods because the current system requires a minimum flow (i.e., velocity) of wastewater to prevent sewer blockage.[59] The production of recycled water also depends upon *waste* (i.e., sewer return flow) to contribute to supply,[75] when perhaps, 'not having wastewater – and not wasting water – would be better' (Ref 37, p. 229).

While the technological advances in wastewater treatment processes are profound when considering that flushing systems are economically and environmentally costly and out of reach for rapidly urbanizing low-income countries, a small but growing number of scholars are critical of the conventional sanitary solutions.[31,76] Sewage may be transformed into a resource, but it also remains a major source of pollution and a chronic public health threat. A poll of the readers of British Medical Journal named sanitary engineering the biggest medical advancement of the last 150 years, and yet, an estimated 2.6 billion people worldwide lack access to sanitation today.[37,77] The current sanitation crisis is largely attributable to the immense costs of centralized waterborne infrastructure. Given the scope of sanitary challenges, there is an urgent need for substitute sanitary technologies that work better for more people.

Ecological sanitation, or EcoSan, is an alternative to waterborne sanitation systems that is premised on the use of separation technologies to encourage the most efficient use of resources.[78] Proponents of EcoSan view the nitrogen, phosphorus, and potassium found in urine and feces as resources not wastes. The EcoSan systems offer an 'ecosystem approach" that displaces modern infrastructures in favor of dry (or near dry) toilets and sanitation systems. The EcoSan perspective disrupts the common sense of water-based sewage systems, but it has proven effective in both industrialized and developing countries.[78,79] Nevertheless, dry sanitation faces several significant programmatic and operational challenges, and the viability of large-scale dry sanitation systems is currently unknown.[76,80,81]

One of the fundamental governance components of dry sanitation systems is their decentralization. Primary treatment of pathogens can occur within the toilet unit, and secondary processing can occur within the community if necessary. Advocates of EcoSan argue that it reduces water-related disease and deaths and contributes to food security by 'closing the gap between sanitation and agriculture' (Ref 78, p. 433). The use of humanure to boost agricultural productivity is similar to the Industrial Era conservation model in concept. In the mid-nineteenth century proponents of the conservancy model advocated for the 'earth closet', dry sanitation, and agricultural reuse of excrement. The majority of engineers, on the other hand, favored what we now take for granted: the 'water closet' and waterborne sanitation systems.[7,82]

Prior to the installation of sanitary infrastructure, the responsibility for managing the repositories for collecting human residuals was left to residents. The euphemism 'night soil' came into use for excreta because privy vaults were emptied only at night, and wastes were typically disposed of on farmland.[1,3,5] This method was economical and beneficial; the nutrients contained in human excrement were recycled as manure and effectively kept out of the local waterways. However, it was a labor-intensive enterprise. By the early 20th century, the rising popularity of water closets overwhelmed city streets, stormwater sewers, and waterways. The use of night soil and the related practice of sewage farming were ultimately supplanted by the development of interconnected sewage systems, wastewater treatment, and artificial fertilizers.[82]

The centralized sewers urbanites have become accustomed to in the 21st century are artifacts of the late 19th-century sanitary engineers. Planned potable recycling represents a capital-intensive investment in the entrenched systems: a single pipe system that delivers potable-quality water for all household uses, including toilet flushing. Potable water recycling projects continue this custom but add the deliberate recirculation of wastewater as a portion of future water resources. As distinct from traditional modern waterworks, EcoSan systems can be built and maintained at the household and community levels. Although the mechanics are not complicated, decentralization also contains a commitment to a more flexible, interactive, grassroots approach to urban water and waste management. In this respect, the principles of EcoSan also reflect the philosophies and self-sufficient practices of the 20th century ecology movement, which called for similar management of excreta.[76,83] However, defecating into drinking water is an inveterate custom. As noted by civil engineer David Sedlak,[1] 'undoing nearly two centuries of habit and abandoning the gravity-flush toilet' presents a significant challenge for environmental engineers interested in designing alternative sanitary technologies (Ref 1, p. 260).

The toilet is an unsustainable and 'illogical form of sanitation' according to Teh[84] et al.,[5,68,80] and yet, at the moment, there are few commercially available alternative technologies[80] (Ref 84, p. 335). For example, composing toilets are 'known to be a challenging technology' in communities where they are applied[80,81] (Ref 81, p. 728). Urban density poses additional barriers for managing dry sanitation systems, as do habits, customs, and inexperience.[74,76] Given the culture of flushing, some scholars suggest that an incremental approach toward holistic humanure systems is more appropriate in places with established waterborne sanitation systems. For example, transitioning to technologies such as urine-diversion toilets that are capable of capturing the bulk of the nitrogen and phosphorus humans excrete[8] may contribute to undoing 150 years of sanitary amnesia.

FACE OUR FECES OR FLUSH AND FORGET?

Where do your flushes flow? Most people do not know. Sewers function to transport residual waste out of sight, out of mind. The average citizen in the modern city rarely reflects on the costs or consequences of waterborne sanitation. Conventional wastewater management involves a number of key social and technical components, including the continuous collection of sewage in underground pipe systems linked to treatment plants, legislative and legal controls that prescribed necessary treatment and monitoring, administrative staff in charge of oversight, and operational staff capable of dealing with the disposal, or reuse, of the liquid and solid by-products of wastewater treatment.[15] Engineers, chemists, biologists, economists, strategic planners, hydrologists, and marketing personnel are just some of the specialists who treat, manage, and direct treatment and products of modern sanitation systems. The sheer act of flushing relegates elimination to relative invisibility, contributing to what Morales et al.[9] term the urban sanitation imaginary, or the 'disconnect between sanitation expectations … and the practices required by proposed sanitation solutions' (Ref 9, p. 2816). The sanitary citizen originated in Victorian England; however, the water closet was exported along with its associated taboos and disposal woes. The influence of 'sanitary colonialism' continues to exert a normative force around the world.[5,8]

The history and trajectory of water development and wastewater treatment suggests it is probable that potable recycling projects will proliferate in the near future, especially in water-stressed cities in the U.S. For city dwellers with waterborne sanitation systems, the predominant notion is that everyone benefits from water and wastewater services and that recycling is a good thing. Yet, the reasonableness of potable water recycling currently remains open to public debate, which provides an apropos occasion for more reflective relations with our excrement, the environment, and each other. As rapidly growing urban populations butt against limited available water supplies, the sanitation challenges will be equally, if not more, difficult to overcome than the related problem of water supply. A sobering account of the ecological implications and public health trends associated waterborne sanitation, combined with information about the value of the finished compost, could possibly contribute to the development of more sustainable sanitary technologies.

CONCLUSION

Reports of future water scarcity, insecurity, and uncertainty abound. Given trends in wastewater treatment, a small but growing number of cities are intentionally supplementing drinking water with highly treated recycled water. Within the scope of potable recycling, debates over public acceptance remain at the forefront. The difficulty some municipalities have recycling the by-products of wastewater treatment demonstrates that investment in recycling is a contingent, somewhat speculative, and often controversial proposal. Cultural taboos preclude polite conversation about excrement, which serves to hamper wide-ranging understanding of the public health and environmental issues related to modern sanitary systems. Expert-designed, managed, and operated urban water and wastewater systems counterproductively signal water users to 'flush and forget.'

The vast complexity of wastewater treatment systems adds to the gap between the average persons' sanitary knowledge and any ability to participate in system design and management. A necessary prerequisite to more sustainable and equitable sanitation practices is society-wide awareness of the undeniable benefits *and* the immense costs of waterborne sanitation. A general lack of awareness limits the ability to imagine competing possibilities and makes it hard to shift to arguably better and more sustainable technologies. Truly sustainable water management must reexamine the normative dimensions of sanitary amnesia and the persistent urban ecological problems posed by centuries-old wastewater management preferences that sustain wanton consumption and elimination of resources.

Reflecting on this, the current management challenge is to mitigate the damage done by the flush toilet and diversify the range of technologies, policies, options, and participants in both the planning process and subsequent practices. Considering the long-term challenges ahead, the alternative solution, adapting to the 'out of sight, out of mind' sanitary common sense, seems a most perilous choice. Overcoming the culture of flushing will take an audacious battle of ideas, an energetic social movement, and scholars committed to investigating less wasteful and energy-intensive sanitary possibilities. Applied research dedicated to transformative, innovative, and effective technologies could potentially close the gap in access to sanitation between those who take sanitation for granted and those who lack access to basic sanitation and, in so doing, address one of the most profound inequalities in society. Altering the foundations of the circulatory systems of the city, and the behaviors of its inhabitants, is a difficult task, But it is far from impossible.

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