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DISASTERS, FINANCES, NUTRIENTS, AND CLIMATE CHANGE: A CASE FOR WATERLESS SANITATION SYSTEMS

by

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The practice of sewering (transporting with underground pipes) human excreta began in the mid-1800s and propelled the United States into the current wastewater paradigm. Water is the key element of wastewater conveyance, treatment, and disposal/reuse systems. Although this process has arguably improved quality of life, extending it to manage human excreta with water is becoming problematic due to water's increasing scarcity, mounting costs, contribution to greenhouse gas emissions, and deleterious environmental effects. This thesis sought to answer the following central research question: To what extent would an alternative means of managing human excreta benefit homeland security? Through appreciative inquiry and structured interviews with human subjects, research revealed that a method known as container-based sanitation has applications in multiple contexts. Container-based sanitation is rapidly deployable, scalable, and can be used in any situation in which traditional wastewater systems are nonoperable or nonexistent, such as disaster recovery, homelessness, and temporary encampments such as refugee camps or military bases.

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DISASTERS, FINANCES, NUTRIENTS, AND CLIMATE CHANGE: A CASE FOR WATERLESS SANITATION SYSTEMS

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ABSTRACT

The practice of sewering (transporting with underground pipes) human excreta began in the mid-1800s and propelled the United States into the current wastewater paradigm. Water is the key element of wastewater conveyance, treatment, and disposal/reuse systems. Although this process has arguably improved quality of life, extending it to manage human excreta with water is becoming problematic due to water's increasing scarcity, mounting costs, contribution to greenhouse gas emissions, and deleterious environmental effects. This thesis sought to answer the following central research question: To what extent would an alternative means of managing human excreta benefit homeland security? Through appreciative inquiry and structured interviews with human subjects, research revealed that a method known as container-based sanitation has applications in multiple contexts. Container-based sanitation is rapidly deployable, scalable, and can be used in any situation in which traditional wastewater systems are nonoperable or nonexistent, such as disaster recovery, homelessness, and temporary encampments such as refugee camps or military bases.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
CBS	container-based sanitation
CDC	Centers for Disease Control and Prevention
CISA	Cybersecurity and Infrastructure Security Agency
CSO	combined sewer overflow
EcoSan	ecological sanitation
EPA	Environmental Protection Agency
IRB	Institutional Review Board
ISO	International Organization for Standardization
NPDES	National Pollutant Discharge Elimination System
NSF	National Science Foundation
OAEC	Occidental Arts and Ecology Center
SOIL	Sustainable Organic Integrated Livelihoods
SSO	sanitary sewer overflow
WEF	Water Environment Federation
WHO	World Health Organization
WREMO	Wellington Regional Emergency Management Office
WSSCC	Water Supply and Sanitation Collaborative Council

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GLOSSARY

biosolids	The organic residual of wastewater treatment processes consisting of both municipal and industrial wastes
cholera	A bacterial disease causing severe diarrhea
day zero	The day when a water supply would run out and cease flowing from taps
ecological sanitation	A holistic practice that safely treats human feces, conserves water, recycles nutrients, and minimizes environmental impacts
excrement	Either urine or feces, the singular form of excreta
excreta	Both urine and feces, the plural form of excrement
greywater	Used water discharged from household fixtures other than a toilet (sink, shower, laundry, etc.)
humanure	Human urine and feces
open defecation	Defecating outdoors rather than into a toilet
overflow	Untreated wastewater released from a sewer into a community and the environment
paradigm	A model
sewer	Underground pipes transporting wastewater or stormwater
sewered population	People and communities connected to a wastewater system

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EXECUTIVE SUMMARY

Wastewater systems have arguably improved quality of life by protecting public health and the environment. They provide a method of sanitation that uses water to manage human excreta. However, extending the current wastewater paradigm is becoming problematic due to water's increasing scarcity, mounting costs, contribution to greenhouse gas emissions, and deleterious environmental effects.

Water is the key element of wastewater conveyance, treatment, and disposal/reuse systems. Without it, these systems would not function. Wastewater systems generate greenhouse gas emissions, which contribute (in part) to climate change. Irregular precipitation patterns will affect the water supply; therefore, water scarcity will also affect wastewater systems through water conservation efforts and increased frequency of "day zero" occurrences. Additionally, increased storm intensity and rainfall will result in the increased number and volume of sewer overflows that discharge untreated wastewater into communities and the environment. Wastewater systems are also at great risk from flooding because many assets lie underground.

As a whole, wastewater infrastructure in the United States is deteriorating and needs significant upgrades. These necessary capital improvement projects are costly, as are the ongoing operations and maintenance costs over an asset's lifetime. Local governments must finance these expensive infrastructure projects. Affordability challenges will only continue to increase as rising costs are passed through to users of a system.

Nutrients and nutrient pollution are also of concern. Humans consume food and excrete nutrients into wastewater systems. Aquatic environments that receive effluent from treatment systems that do not adequately remove these nutrients (namely nitrogen and phosphorous) suffer negative impacts such as from harmful toxic algae growth. Phosphorous is of particular importance because the world's rock phosphate reserves are declining and are predicted to be depleted in the next hundred years.

With the above concerns in mind, does the United States need to upgrade its wastewater system, or should an alternative sanitation paradigm be considered? After all,

using water to manage human excreta is one method of providing sanitation services, but not the only way. Research has revealed that ecological sanitation (EcoSan) is a philosophy that looks at this service holistically, considers the environment, and returns the nutrients in excreta to the soil. Various EcoSan technologies exist, and four human subjects who actively practice ecological sanitation were interviewed for this research. One method known as container-based sanitation is a process whereby urine and feces are deposited into a container (e.g., a five-gallon bucket) and covered with an appropriate material. Once full, the entire contents of the container are emptied into a composting system that produces a useable compost over time.

In sum, container-based sanitation is a proven method in multiple contexts. These circumstances would arise when neither water nor the wastewater systems (that rely on water in the first place) are available for use. These conditions apply under the following circumstances: disaster recovery, depressed socioeconomic conditions, and homelessness. Likewise, temporary tent cities and encampments and temporary military bases would also be appropriate uses. The beauty of container-based sanitation lies in its ability to rapidly scale up or down, depending on the need, which directly applies to disasters that result in large populations without access to safe sanitation.

Consistent with the findings, this thesis proposes the following recommendations:

1. Incorporate container-based sanitation into disaster preparedness and response plans.

2. Design and implement a pilot study for long-term, sustainable utilization of container-based sanitation.

3. Permit container-based sanitation for people and communities lacking a traditional wastewater system, or with a failed one.

4. Develop consistent regulations, policies, and guidelines across local and state jurisdictions to allow for container-based sanitation, the composting of human excreta, and the beneficial reuse of the compost.

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I must first thank Joe Jenkins, who unknowingly “inceptioned” my brain back in college, circa 2001, when I happened upon his second edition of *The Humanure Handbook* while perusing books at Coalesce Bookstore in Morro Bay, California. Certainly, Richmond Fire Chief Adrian Sheppard, former City Manager Bill Lindsay, Lisa Stephenson, and Veronica Duarte de Castro forever have my sincere gratitude for their support and nudging to apply to the CHDS master’s program in the first place—not to mention my parents who proofread my five application essays. I thank my family for their inquisitiveness and support throughout the program, despite my moodiness and angst. Thank you, Tom Mackin and Rudy Darken, for agreeing to advise me on this unconventional topic and for your patience in navigating the IRB processes; and thank you, Greta Marlatt and Marianne Taflinger, for your immense help with researching, writing, and citing. Thank you, Alisa Keesey, Laura Allen, Joe Jenkins (again), and Brock Dolman, for agreeing to be my human subjects and allowing me to use your names in this research—I appreciate you more than you know and look forward to crossing paths in real life.

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I. INTRODUCTION

Since gaining popularity around 1851, the flushing toilet propelled much of the developed world into the current paradigm of managing human excreta (urine and feces, also known as human manure or “humanure”) with water.[1] Water is the key element of wastewater conveyance, treatment, and disposal/reuse systems. Although this process has arguably improved quality of life, extending the current paradigm of managing human excreta with water is becoming problematic due to water’s increasing scarcity, mounting costs, contribution to greenhouse gas emissions, and deleterious environmental effects.

With those considerations in mind, this thesis seeks to understand to what extent an alternative means of managing human excreta would benefit homeland security. One method, known as container-based sanitation (CBS), is an alternative and acceptable method of providing sanitation services.[2] This thesis shows that although permanent large-scale adoption of CBS services is sustainable and would benefit the American homeland, there are myriad obstacles to achieving that long-term goal. However, CBS adequately addresses the following immediate homeland security concerns: disaster response and recovery, homelessness, and any situation resulting in a need for basic sanitation services where traditional wastewater systems are lacking.

A. BACKGROUND

A wastewater system as a whole comprises a sanitary sewer collection system, a treatment or resource recovery facility, and a disposal or reuse system. The United States has 17,478 wastewater treatment plants; 76 percent of the country’s population relies on them as well as the sewers and disposal/reuse systems—to which they are connected—to

[1] Jimmy Stamp, “From Turrets to Toilets: A Partial History of the Throne Room,” *Smithsonian*, June 20, 2014, https://www.smithsonianmag.com/history/turrets-toilets-partial-history-throne-room-180951788/.

[2] World Health Organization, *Guidelines on Sanitation and Health* (Geneva: World Health Organization, 2018), 181, https://www.who.int/water_sanitation_health/publications/guidelines-on-sanitation-and-health/en/.

protect public health and the environment.[3] The Cybersecurity and Infrastructure Security Agency (CISA) of the Department of Homeland Security designates water and wastewater systems as a critical infrastructure sector and recognizes water as one of four “designated lifeline functions.”[4] However, the American Society of Civil Engineers (ASCE) gives a D+ rating to wastewater infrastructure in the United States, estimating that 56 million new users will be connected to these facilities by 2032 (indicating a 23 percent increase in demand) and requiring $271 billion in funding to meet current and future needs.[5] Furthermore, as the ASCE states, “Our nation is at a crossroads. Deteriorating infrastructure is impeding our ability to compete in the thriving global economy, and improvements are necessary to ensure our country is built for the future.”[6]

In addition to a deteriorating infrastructure, another challenge to managing human excreta with water is the controversial topic of biosolids: the organic residual of wastewater treatment processes consisting of both municipal and industrial wastes. Treated biosolids must meet strict federal standards of treatment to ensure quality to protect public health and the environment.[7] Federal, state, and local regulations in the United States permit land application or landfill disposal of biosolids. However, some jurisdictions will soon prohibit the disposal of biosolids in landfills due to organics diversion regulations. For example, the states of Vermont, New Hampshire, Connecticut, Rhode Island, and California have implemented landfill organics diversion laws, and individual cities such as Austin, Boulder, New York City, San Francisco, Seattle, and Oregon Metro (the regional

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[3] American Society of Civil Engineers, *2017 Infrastructure Report Card: A Comprehensive Assessment of America’s Infrastructure* (Reston, VA: American Society of Civil Engineers, 2017), 93, https://www.infrastructurereportcard.org/wp-content/uploads/2016/10/2017-Infrastructure-Report-Card.pdf.

[4] “Water and Wastewater Systems Sector,” Cybersecurity and Infrastructure Security Agency, accessed February 16, 2020, https://www.cisa.gov/water-and-wastewater-systems-sector; Cybersecurity and Infrastructure Security Agency, *A Guide to Critical Infrastructure Security and Resilience* (Washington, DC: Department of Homeland Security, 2019), 4, https://www.cisa.gov/sites/default/files/publications/Guide-Critical-Infrastructure-Security-Resilience-110819-508v2.pdf.

[5] American Society of Civil Engineers, *2017 Infrastructure Report Card*, 93.

[6] American Society of Civil Engineers, 4.

[7] “Biosolids Laws and Regulations,” Environmental Protection Agency, May 26, 2015, https://www.epa.gov/biosolids/biosolids-laws-and-regulations.

government for the Portland area) have also adopted similar measures.[8] With these facts in mind, where does the United States go from here?

B. LITERATURE REVIEW

This literature review explores the academic debates surrounding three factors associated with benefits and shortcomings of the management of human excreta: sanitation, the benefits and consequences of modern wastewater treatment practices, and alternative means of managing human feces and urine.

1. Sanitation

A distinct corpus of literature attempts to define sanitation. In this connection, the Centers for Disease Control and Prevention (CDC) in the United States describes "basic" sanitation as "having access to facilities for the safe disposal of human waste (feces and urine), as well as having the ability to maintain hygienic conditions, through services such as . . . wastewater treatment and disposal."[9] The CDC thus implies that human excreta are waste and also that wastewater facilities are necessary infrastructure to maintain sanitary conditions. It further implies they are disposal systems. Indeed, as the Department of Homeland Security notes, wastewater qualifies as critical infrastructure in the United States and falls under the Water and Wastewater Systems Sector within CISA.[10] This description aptly applies to a developed country with the capital, capacity, and natural resources to build infrastructure that uses water as a means of conveyance.

By contrast, literature focused on sanitation practices globally, not just in the United States, reveals that modern wastewater conveyance and treatment systems are not feasible in other parts of the world. For example, Franceys, Pickford, and Reed state that the

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[8] Emily Broad Leib et al., "Organic Waste Bans and Recycling Laws to Tackle Food Waste," *BioCycle*, September 2018, https://www.biocycle.net/2018/09/11/organic-waste-bans-recycling-laws-tackle-food-waste/.

[9] "Global Water, Sanitation, & Hygiene (WASH)," Centers for Disease Control and Prevention, June 22, 2017, https://www.cdc.gov/healthywater/global/sanitation/index.html.

[10] Cybersecurity and Infrastructure Security Agency, "Water and Wastewater Systems Sector."

installation of a sewage system is not feasible in low-income communities.[11] The World Health Organization (WHO) defines sanitation as "the provision of facilities and services for the safe management of human excreta from the toilet to containment and storage and treatment onsite or conveyance, treatment and eventual safe end use or disposal."[12] Similarly, the United Nations Water Supply and Sanitation Collaborative Council (WSSCC) defines it as "the collection, transport, treatment and disposal or reuse of human excreta."[13] As such, both the WHO's and WSSCC's definitions imply that that in addition to the option to dispose of human "waste," other end uses for this material exist. Thus, the definitions supplied by the WHO and WSSCC are more farsighted than the CDC's in that they recognize that human excreta are not simply "wastes" but also valuable resources. The end-use, or reuse, of human excreta is at the core of this thesis.

2. Wastewater Infrastructure: "Flush-and-Discharge"

Literature reveals that the two main methods of managing human excreta today fall into one of two categories: those that use water and those that do not. Esrey et al. refer to these categories as "flush-and-discharge" or "drop-and-store."[14] A flush-and-discharge system resembles modern wastewater systems that convey excreta with water, and a pit latrine is an example of a drop-and-store technology. Similarly, Tilley et al. state, "There are two main types of [technologies]: dry technologies that operate without water . . . and water-based technologies that need a regular supply of water to properly function."[15]

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[11] Richard Franceys, J. Pickford, and R. Reed, *A Guide to the Development of On-Site Sanitation* (Geneva: World Health Organisation, 1992), 3, https://www.who.int/water_sanitation_health/hygiene/envsan/onsitesan.pdf.

[12] "Water, Sanitation and Hygiene (WASH)," World Health Organization, accessed July 26, 2020, http://www.who.int/topics/sanitation/en/.

[13] Barbara Evans, Carolien van der Voorden, and Andy Peal, *Public Funding for Sanitation: The Many Faces of Sanitation Subsidies* (Geneva: Water Supply and Sanitation Collaborative Council, 2009), 35, https://www.wsscc.org/wp-content/uploads/2016/04/Public-Funding-for-Sanitation-The-many-faces-of-sanitation-subsidies-2009-WSSCC.pdf.

[14] Steven A. Esrey et al., *Closing the Loop: Ecological Sanitation for Food Security* (Stockholm: Swedish International Development Cooperation Agency, 2000), 10.

[15] Elizabeth Tilley et al., *Compendium of Sanitation Systems and Technologies*, 2nd ed. (Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology, 2014), 42, https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/sesp/CLUES/Compendium_2nd_pdfs/Compendium_2nd_Ed_Lowres_1p.pdf.

Regardless of the type of system, the WHO and the United Nations International Children's Emergency Fund agree that a safely managed system exists when wastewater is treated off-site, excreta are emptied and treated off-site, or excreta are treated and disposed of in situ.[16]

Although the literature shows that wastewater infrastructure represents the primary form of providing sanitation services in developed countries, climate change imposes costs such as environmental impacts and water scarcity. Regarding energy consumption of wastewater facilities in the United States, Pabi et al. of the Electric Power Research Institute state that energy demand will increase due to increasing service capacity and more stringent regulations and estimate an annual electrical usage of 30.2 billion kilowatt-hours, or 0.8 percent of total electricity use in the nation.[17] The Environmental Protection Agency (EPA)'s 2012 Clean Water Needs Survey estimated capital expenditures of $271 billion to upgrade or build new facilities over the next 20 years.[18] Furthermore, the United States Conference of Mayors claims that local government funds 95–98 percent of water and wastewater infrastructure.[19] Finally, according to the EPA, publicly owned treatment works process 32 billion gallons of wastewater.[20]

3. Alternative Means: "Drop-and-Store"

The literature deems ecological sanitation—an acclaimed and acceptable drop-and-store, container-based method of managing human excreta—an approach to safely treat human feces, conserve water, recycle nutrients, and minimize environmental impacts. Esrey et al. argue that unlike conventional sanitation (such as wastewater), ecological

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16 World Health Organization, *Guidelines on Sanitation and Health*, 73.

17 S. Pabi et al., *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries* (Palo Alto, CA: Electric Power Research Institute, 2013), ix, https://www.epri.com/#/pages/product/3002001433/?lang=en-US.

18 Environmental Protection Agency, "Clean Watersheds Needs Survey: 2012 Report to Congress" (Washington, DC: Environmental Protection Agency, January 2016), https://www.epa.gov/sites/production/files/2016-01/documents/cwns_2012_fact_sheet_final_01_14_16_0.pdf.

19 Sara Durr, "Local Government Makes Record-High Investments in Public Water & Sewer Infrastructure," United States Conference of Mayors, November 26, 2019, https://www.usmayors.org/2019/11/26/local-government-makes-record-high-investments-in-public-water-sewer-infrastructure/.

20 "The Sources and Solutions: Wastewater," Environmental Protection Agency, accessed July 26, 2020, https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater.

sanitation (EcoSan) considers the ecosystem in that it recovers the nutrients in urine and feces and “destroys pathogens near where people excrete them . . . does not use water, or very little water . . . and can provide hygienic and convenient services at a much lower cost than conventional sanitation.”[21] Rhodes similarly advises that “as issues over the current sanitary system, e.g., water usage and excess nutrients, become ever more expensive to deal with, the introduction of ecological sanitation (ES) systems might appear a worthwhile investment.”[22] Nagy et al. agree on the importance of dry toilet systems and see the nutrient value in urine specifically.[23] As such, the consensus among experts is that EcoSan toilets either divert urine into a separate storage container or do not, and sanitize feces through drying, increased pH or temperature, or composting.

C. RESEARCH METHODOLOGY

Research for this thesis mainly employed appreciative inquiry because the research question was exploratory, and the expected output was a set of policy recommendations. As Bushe states, appreciative inquiry “is the quest for new ideas . . . [that] make available decisions and actions that weren’t available or didn’t occur to us before.”[24] This thesis aspired to determine how alternative means of managing human excreta might benefit the homeland security enterprise. Thus, a specific set of issues related to sanitation and modern wastewater systems was explored.

Toward this end, this thesis first provides a brief history of the evolution of sewers and wastewater treatment to provide the reader with insight into how the current paradigm came to be. This background information sets the foundation for a better understanding of the current issues around the practice of using water to manage human excreta. Next, this thesis examines three problem areas for wastewater systems—capital and operational

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[21] Esrey et al., *Closing the Loop*, 2.

[22] Christopher J. Rhodes, “Peak Phosphorus – Peak Food?: The Need to Close the Phosphorus Cycle,” *Science Progress* 96, no. 2 (June 2013): 142, https://doi.org/10.3184/003685013X13677472447741.

[23] Judit Nagy et al., “The Utilization of Struvite Produced from Human Urine in Agriculture as a Natural Fertilizer: A Review,” *Periodica Polytechnica Chemical Engineering* 63, no. 3 (2019): 478, https://doi.org/10.3311/PPch.12689.

[24] Gervase R. Bushe, “Appreciative Inquiry Is Not (Just about) the Positive,” *OD Practitioner* 39, no. 4 (August 2017): 30.

expense; nutrient management and pollution; and both the contribution to and impacts of climate change—identified by previous research. These three elements appear to have the most significance in assessing the problem area of wastewater infrastructure. Research for these topics included published open-source documents, such as scholarly works, and data from the Department of Energy and other credible sources such as the Water Research Foundation and American Society of Civil Engineers.

Next, because the prevention of human contact with infectious diseases is the goal of any system designed to collect, convey, treat, and ultimately dispose of or reuse human excreta, this thesis analyzes the various definitions of sanitation, and the effectiveness of these types of sanitation systems in preventing disease contamination, used in both developed and developing countries. Pertinent documents were retrieved from the Water Environment Federation, CDC, WHO, and United Nations among others.

Additionally, because preliminary research showed that small-scale waterless technology installations do exist in the United States but limited scientific research had addressed these systems, interviews were conducted with four experts. For example, the Occidental Arts and Ecology Center in Sonoma County, California, has a permitted composting toilet installation that is currently being studied. Additionally, Joseph Jenkins, the author of *The Humanure Handbook* was interviewed because he has been composting his and his family's excreta for decades and uses the material in his vegetable garden. Because of the success of his book (now in its fourth edition), Mr. Jenkins spends much time traveling abroad and teaching communities in developing countries how to safely and effectively compost humanure. This method provides the reader with insight into successful, progressive methods of managing human excreta without water.

Finally, because the goal was to contribute to homeland security, this thesis provides a set of pertinent recommendations. Although a complete paradigm shift to waterless technologies would benefit the homeland security enterprise, it would be extraordinarily complicated. However, these areas of the enterprise could immediately benefit from this shift: disaster response, homelessness, or any situation resulting in a need for sanitation services without a traditional wastewater system. Such instances include temporary encampments like refugee camps or military installations.

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II. EVOLUTION OF THE WASTEWATER PARADIGM

Modern wastewater conveyance and treatment facilities in use today reflect hundreds of years of engineering and civilization’s needs. Chapter 1 of the *Design of Municipal Wastewater Treatment Plants*, prepared by a Joint Task Force of the Water Environment Federation and the American Society of Civil Engineers, provides significant insight into the history of sanitation in the United States.[25] Author Steven Johnson explores how London’s cholera epidemic of the mid-1800s led to the creation of its underground sewer system in *The Ghost Map*, and Joseph Jenkins provides a global perspective in *The Humanure Handbook.*[26] Around the mid-1800s, communities and local governments in the United States and other developed countries unwittingly set up the beginnings of the current paradigm of managing human excreta with water: the widespread practice of wastewater conveyance, treatment, and disposal/reuse. For the United States, the country is once again at a crossroads.

A. WHAT HAPPENED YESTERDAY

The practice of sewering (transporting with underground pipes) human excreta gained popularity between the mid-1800s and mid-1900s, as a result of needing to replace then-common practices and methods to convey and treat sewage. With the advent and popularity of water closets and the flushing toilet in the mid-1800s, populations began replacing their latrines and chamber pots. Water closets gained popularity among the rich between the 1820s and 1840s but grew profoundly popular during the Great Exhibition of 1851 in London, which offered some 827,000 people “the most astonishing experience . .

[25] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, *Design of Municipal Wastewater Treatment Plants*, 2nd ed., vol. 1 (Brattleboro, VT: Book Press, 1992), 4–12.

[26] Rufus Griscom, “Big Ideas in Uncertain Times: Steven Johnson on Scientific Breakthroughs,” April 9, 2020, in *The Next Big Idea*, podcast, MP3 audio, 35:26, https://www.radio.com/media/audio-channel/big-ideas-in-uncertain-times-steven-johnson-on-scientific-breakthroughs; Joseph Jenkins, *The Humanure Handbook: Shit in a Nutshell*, 4th ed. (Grove City, PA: Joseph Jenkins, 2019), 15–20, 31–46.

. just sitting on a working toilet for the first time."[27] Between the early and late 1800s back in the United States, sewers began replacing open ditches because of nuisance sights and odors to transport both sewage and stormwater to other areas, away from users of the system.[28] The Water Environment Federation (WEF) states that between the early and late 1800s, the total population of the United States had grown from five to 76 million, and the "sewered population increased from 1 (in 1860) to approximately 25 million."[29] By 1892, 27 cities in the United States provided wastewater treatment.[30] As WEF observes, "The drastic increase in the sewered population reflects the public awareness of the link between human disease and waste disposal practices."[31] However, simply moving nuisance sights and odors to other areas led to other environmental consequences.

As is the norm in a democracy, governing bodies responded to concerns of their citizens and operational departments. Therefore, beginning in the early 1900s, wastewater treatment facilities were constructed with the main objective of removing both floating and settling matter.[32] This became known as "primary" treatment. Wastewater treatment regulations were suspended during World War II but resumed in earnest after the War with the passage of the Federal Water Pollution Control Act of 1948, the Clean Water Restoration Act of 1966, and the Federal Water Pollution Control Act Amendments of 1972. All of this legislation provided grant funding for the construction of wastewater systems across the country. The latter of these acts (broadly known as the Clean Water Act) created the EPA, which "actively participated in all aspects of water pollution control

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[27] Steven Johnson, *The Ghost Map: The Story of London's Most Terrifying Epidemic—and How It Changed Science, Cities, and the Modern World* (New York: Riverhead Books, 2006), 12.

[28] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, *Design of Municipal Wastewater Treatment Plants*, 1:4.

[29] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, 1:7.

[30] Environmental Protection Agency, *Primer for Municipal Wastewater Treatment Systems*, EPA 832-R-04-001 (Washington, DC: Environmental Protection Agency, Office of Wastewater Management, 2004), 9, https://www.epa.gov/sites/production/files/2015-09/documents/primer.pdf.

[31] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, *Design of Municipal Wastewater Treatment Plants*, 1:7.

[32] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, 1:7.

planning, including the design, construction, and operation of wastewater collection conduits and treatment facilities."[33] It also created the National Pollutant Discharge Elimination System (NPDES) permit program, which provided states with enforcement capabilities on operators of wastewater systems.

The process known as "secondary" treatment removes the suspended and dissolved material remaining in primary treated wastewater. WEF claims that between the 1970s and 1990s, the sewered population receiving secondary or higher levels of treatment "doubled from 70 to 140 million," and "untreated wastewater releases from sewered population centers were almost eliminated."[34] By the turn of the 21st century, the sewered population reached 208 million.[35]

B. STATE OF THE PARADIGM TODAY

According to the Census Bureau, over 327 million people lived in the United States as of 2018.[36] Today, the United States has 17,478 wastewater treatment plants, and 76 percent of the country's population relies on those facilities, and the sewers and disposal/reuse systems—to which they are connected—to protect public health and the environment.[37] Not only is recycled wastewater being used for irrigation, but direct and indirect potable reuse systems are gaining popularity. These systems process already treated wastewater through advanced facilities and pump it into underground aquifers (indirect) or directly into potable water systems. Additionally, a significant paradigm drift occurred around 2014.

The term "water resource recovery facility" is the latest evolution of names used by the wastewater sector and given to wastewater facilities. In 2014, WEF formally adopted

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[33] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, 1:11.

[34] Joint Task Force of the Water Environment Federation and American Society of Civil Engineers, 1:11.

[35] Environmental Protection Agency, *Primer for Municipal Wastewater Treatment Systems*, 6.

[36] "American Community Survey Demographic and Housing Estimates: 2018 ACS 1-Year Estimates Data Profiles," Table DP05, Census Bureau, accessed May 6, 2020, https://data.census.gov/cedsci/table?q=DP05&g=0100000US&tid=ACSDP1Y2018.DP05.

[37] American Society of Civil Engineers, *2017 Infrastructure Report Card*, 93.

the term and described these facilities as “utilities of the future.”[38] Not until 2017 did the United Nations publish its annual *World Water Development Report* and declare “water reuse and resource recovery from wastewater . . . a field where science and technological innovation are rapidly developing, with promising applications not only in safe reuse, but also in other nonconventional areas, such as by-products recovery, and for promoting environmental and economic benefits.”[39] Figure 1 graphically represents this description.

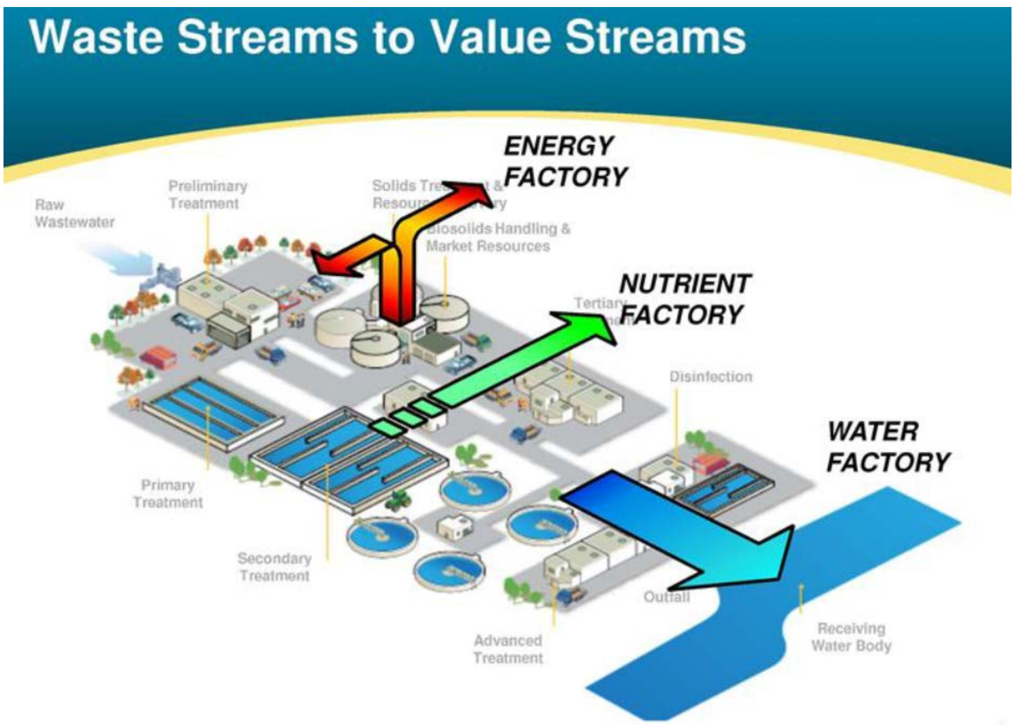

Figure 1. Graphical Representation of Resource Recovery[40]

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[38] Jennifer Fulcher, “Changing the Terms,” *WEF Highlights* (blog), May 22, 2014, https://news.wef.org/changing-the-terms/.

[39] United Nations Educational, Scientific and Cultural Organization, *Wastewater: The Untapped Resource*: *The United Nations World Water Development Report 2017* (Paris: United Nations Educational, Scientific and Cultural Organization, 2017), 125, https://unesdoc.unesco.org/ark:/48223/pf0000247153.

[40] Source: Art Umble, “Waste Stream to Value Streams: Resource Recovery Factories—The New Paradigm for Wastewater Treatment,” Challenges and Innovations in Civil and Environmental Engineering and Earth Sciences, January 2013, https://coast.nd.edu/jjwteach/www/www/2013%20Spring/Flyers/UmbleFlyer.html.

Previously used terms include sewerage works, sewage treatment plant, water pollution control plant, wastewater treatment plant, water reclamation facility, and water recycling facility. Rather than focusing on what was previously considered “waste” or only on the water flowing into wastewater treatment plants, the name change reflects the paradigm drift of recognizing the other beneficial products inherently in the wastewater itself: nutrients, biosolids, and energy. Although this may sound promising, troubling issues permeate wastewater infrastructure as a whole.

Much of this infrastructure—installed 40–50 years ago (or more than 100 in older cities) following the Clean Water Act—is operating near or beyond its expected useful life and must be rehabilitated or replaced. The *Fourth National Climate Assessment* suggests that “across the Nation, much of the critical water and wastewater infrastructure is nearing the end of its useful life.”[41] Similarly, in its *2017 Infrastructure Report Card*, the ASCE assigns wastewater infrastructure a D+ rating.[42] It states at the outset,

> Our nation is at a crossroads. Deteriorating infrastructure is impeding our ability to compete in the thriving global economy, and improvements are necessary to ensure our country is built for the future. While we have made some progress, reversing the trajectory after decades of underinvestment in our infrastructure requires transformative action from Congress, states, infrastructure owners, and the American people.[43]

These wastewater facility improvements must be paid for, both initially through capital improvement financing and continually through operations and maintenance costs throughout an asset’s life cycle.

1. Financing Wastewater Infrastructure: Local Government

The rising costs of infrastructure projects also accompany the use of wastewater. In the United States, for example, sanitary sewers and wastewater treatment facilities qualify as critical infrastructure within the guidelines of homeland security, as they protect public

[41] U.S. Global Change Research Program, *Fourth National Climate Assessment: Impacts, Risks, and Adaptation in the United States*, vol. 2 (Washington, DC: U.S. Global Change Research Program, 2018), 147, https://nca2018.globalchange.gov.

[42] American Society of Civil Engineers, *2017 Infrastructure Report Card*, 93.

[43] American Society of Civil Engineers, 4.

health and the environment. The latest EPA Clean Watersheds Survey has projected $271 billion in capital investments for publicly owned treatment works over the 20-year timeframe beginning in 2012.[44] Of this figure, $19.2 billion is for separate stormwater systems.[45] Therefore, the amount needed over this period of time for wastewater conveyance, treatment, and recycled water infrastructure alone totals $251.8 billion.

These capital project expenses can be very expensive and may place a significant burden on disadvantaged communities. Not only will wastewater utilities need to continue to replace aging infrastructure, they will also continue to face additional regulations and a growing number of system users, resulting in affordability challenges.[46] Tom Cochran, chief executive officer and executive director of the U.S. Conference of Mayors, states that "local governments are responsible for 95% to 98% of total water and sewer utility infrastructure spending each year."[47] Public utilities finance these upgrades through a combination of financing tools—namely cash from user charges, a variety of types of bonds, government loans and grants, private financing, contributions (such as from a developer), and leasing.[48] Additionally, the operations and maintenance of this infrastructure entail substantial and ever-increasing costs, resulting in a high overall total cost of ownership.[49]

2. Money Down the Drain

Estimating how much the U.S. population spends on water for flushing, doing laundry, washing, and other indoor uses can be done two ways. Regarding toilets alone, the Water Research Foundation estimates the average person flushes 14.2 gallons per day,

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[44] Environmental Protection Agency, "Clean Watersheds Needs Survey," 1.

[45] Environmental Protection Agency, 7.

[46] Water Environment Federation, *Financing and Charges for Wastewater Systems*, 4th ed., WEF Manual of Practice No. 27 (Alexandria, VA: Water Environment Federation, 2018), 240.

[47] Durr, "Local Government Makes Record-High Investments."

[48] Water Environment Federation, *Financing and Charges for Wastewater Systems*, 63–77.

[49] Water Environment Federation, 87.

or five flushes per day with an average of 2.6 gallons per flush.[50] Therefore, with over 327 million people currently in the United States, over 1.55–1.69 trillion gallons of water is flushed annually—water that could be used for other purposes like consumption or hygiene.

Interestingly, with an average cost of two dollars per every thousand gallons of water, the average household then spends only $42.24, and the average person spends $9.49 to $10.37 annually on toilet-flushed water.[51] Although this may not seem significant, the country as a whole therefore figuratively flushes $3.1–$3.2 billion down the toilet each year. However, other indoor water uses account for the total aggregated amount of wastewater produced.

Total per capita indoor water use is estimated at 58.6 gallons per day, and 137.7 gallons per day per household.[52] Therefore, considering residential production of wastewater only, indoor use produces about seven trillion gallons of wastewater annually. This represents roughly $14 billion worth of total clean water sent down the drain every year. Per household, this calculates at $100.52 annually.

3. The Issue of Nutrients

In addition, the current paradigm of wastewater conveyance and treatment results in what Karl Marx observed and referred to as the "metabolic rift."[53] Although Marx's use of this phrase was more political in his time, the essence is that the metabolic rift occurs when people ship agricultural products (and therefore nutrients) from agricultural to urban areas, consume them, and release nutrients into waterways instead of recycling them in the soil. Not only are nitrogen and phosphorous (the top two most critical nutrients for plant

[50] William B. DeOreo et al., *Residential End Uses of Water*, version 2 (Denver: Water Research Foundation, 2016), 8–9, https://www.circleofblue.org/wp-content/uploads/2016/04/WRF_REU2016.pdf.

[51] "Water Facts of Life: Ride the Water Cycle with These Fun Facts," Environmental Protection Agency, last updated February 23, 2016, https://www3.epa.gov/safewater/kids/waterfactsoflife.html.

[52] DeOreo et al., *Residential End Uses of Water*, 8.

[53] Mindi Schneider and Philip McMichael, "Deepening, and Repairing, the Metabolic Rift," *Journal of Peasant Studies* 37, no. 3 (2010): 467, https://doi.org/10.1080/03066150.2010.494371.

growth besides potassium) fouling aquatic environments by causing harmful algae and other plant growth, but also the world's phosphorous reserves are declining.

Various theorists have estimated when "peak phosphorous"—similar to peak oil production—will be realized. To illustrate, Professor Christopher Rhodes concludes that "70% of current global production stems from reserves that will be depleted within 100 years, and along with projected demand increases will result in a marked global production deficit, which by 2070 will be greater than current production."[54] To compound the matter, Dr. Dana Cordell makes the observation that only five countries control 85 percent of the world's phosphate rock, and 75 percent of those reserves are located in Morocco.[55] Considering that 80 percent of mined phosphorous becomes commercial fertilizer, and given exponential increases in the global population, some intervention will be needed to avoid this crisis and geopolitical conflict.

4. Wastewater Overflows and Decentralized Systems

In addition to peak phosphorous, surface and groundwater pollution resulting from the wastewater paradigm also presents an issue. The EPA admits that treated wastewater discharged into local bodies of water results in nitrogen and phosphorous pollution, as do septic systems that pollute surface water as well as groundwater.[56] Not only is treated wastewater discharged into the environment legally, but unpermitted releases of raw wastewater also occur.

Sanitary sewer overflow (SSO) occurs during dry and wet weather. A dry weather SSO is usually caused by an obstruction in a pipe (such as roots, accumulated grease, or sediment and rocks) or pipe failure, and a wet weather SSO occurs when rainwater and groundwater infiltrating the sewer system overwhelm the capacity of the system and

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54 Rhodes, "Peak Phosphorus – Peak Food?," 121.

55 Dana Cordell, "Towards Global Phosphorus Security through Nutrient Reuse," in *Waste Not, Want Not: The Circular Economy to Food Security: Proceedings of the Crawford Fund 2016 Annual Conference*, ed. A. Milligan (Fyshwick, Australia: Crawford Fund, 2016), 111, https://doi.org/10.22004/ag.econ.257233.

56 Environmental Protection Agency, "Sources and Solutions."

sewage escapes.[57] In a report to Congress in 2004, the EPA estimated 23,000 to 75,000 SSOs each year, totaling three to ten billion gallons of untreated wastewater released into the environment across the United States.[58]

Combined sewer overflows (CSOs) result from abnormal operating conditions of older systems where the sanitary sewer and stormwater conveyance systems are connected. In 2004, the EPA reported that there were 9,348 CSO outfalls in 32 states (including the District of Columbia), with the majority located in the Great Lakes region.[59] Additionally, the estimated total volume discharged from CSOs in 2004 was 850 billion gallons.[60]

Furthermore, decentralized systems (commonly known as “septic” systems) also contribute to surface water and groundwater pollution. Approximately 25 percent of the population is served by a decentralized system, and 6 percent of those systems fail each year, resulting in 66–144 billion gallons of improperly treated water discharging from them each year across the nation.[61]

5. Impacts on—and from—Climate Change

Wastewater facilities (and the potable water treatment and distribution systems needed in the first place) are net consumers of energy in the United States, accounting for 3–4 percent of total energy use and resulting in 45 million tons of greenhouse gas emissions annually.[62] Not only do water and wastewater systems contribute to atmospheric carbon pollution, but climate change negatively affects them, too. The U.S. Global Change

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[57] Water Environment Federation, “Access Water Knowledge: Sanitary Sewers” (Alexandria, VA: Water Environment Federation, May 2011), https://www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/collection-systems/technical-resources/ss-fact-sheet-with-wider-margins-1.pdf.

[58] Environmental Protection Agency, *Report to Congress on Impacts and Control of Combined Sewer Overflows and Sanitary Sewer Overflows*, EPA 833-R-04-001 (Washington, DC: Environmental Protection Agency, Office of Water, 2004), ES-5, https://www.epa.gov/sites/production/files/2015-10/documents/csossortc2004_full.pdf.

[59] Environmental Protection Agency, ES-4.

[60] Environmental Protection Agency, ES-5.

[61] Environmental Protection Agency, 4–11.

[62] Environmental Protection Agency, *Energy Efficiency in Water and Wastewater Facilities* (Washington, DC: Environmental Protection Agency, 2013), https://archive.epa.gov/epa/sites/production/files/2015-08/documents/wastewater-guide.pdf.

Research Program states, “There is high confidence that deteriorating water infrastructure (dams, levees, aqueducts, sewers, and water and wastewater treatment and distribution systems) compounds the climate risk faced by society.”[63] The issues of water scarcity and storm intensity are discussed below.

Water scarcity is affecting the globe due to climate change, causing irregular precipitation patterns and a growing population who is increasing demand.[64] Indeed, with a recognition of climate change’s effects, these irregular precipitation patterns and extended periods of drought affect water systems (and therefore wastewater systems) dependent on rainfall and the snowpack.[65] For example, Cape Town, South Africa, recently confronted a “day zero” problem—or the day when the water supply will run out and cease to flow from taps—for four million people.[66] Although water conservation efforts pushed day zero further out, only actual rainfall will extend it indefinitely. In the United States, California experienced a severe drought from 2012 to 2016, leading then-governor Jerry Brown to declare a state of emergency.[67] As the World Bank states, “With water scarcity expected to increase as populations grow and the climate changes, the world cannot afford to waste and contaminate its precious water resources.”[68] These examples clearly illustrate that using water to manage human excreta is a wasteful use of this precious resource.

Conversely, the number and volume of CSOs and SSOs will increase due to the increased frequency and intensity of storms and rainfall. In extreme cases, storms and

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[63] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 2:162.

[64] National Intelligence Council, *Global Trends 2030: Alternative Worlds* (Washington, DC: Office of the Director of National Intelligence, 2012), https://www.dni.gov/files/documents/GlobalTrends_2030.pdf.

[65] National Intelligence Council.

[66] Godwell Nhamo and Adelaide O. Agyepong, “Climate Change Adaptation and Local Government: Institutional Complexities Surrounding Cape Town’s Day Zero,” *Jàmbá: Journal of Disaster Risk Studies* 11, no. 3 (2019): 5, https://doi.org/10.4102/jamba.v11i3.717.

[67] “2012–2016 California Drought: Historical Perspective,” United States Geological Survey, accessed July 6, 2020, https://ca.water.usgs.gov/california-drought/california-drought-comparisons.html.

[68] Richard Damania et al., *Quality Unknown: The Invisible Water Crisis* (Washington, DC: World Bank, 2019), xviii, https://doi.org/10.1596/978-1-4648-1459-4.

hurricanes will result in widespread flooding, as was the case in Houston, Texas, following hurricane Harvey. For example, Figure 2 shows the hurricane's aftermath.

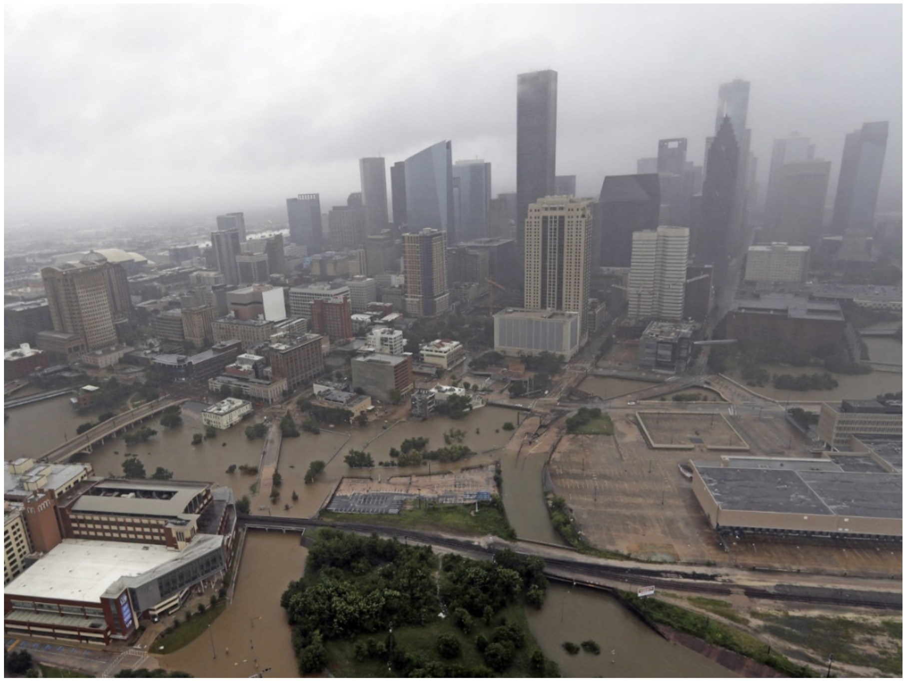

Figure 2. Flooding in Houston after Hurricane Harvey[69]

Flooding is especially troublesome for wastewater systems, primarily because the sewers and much of the infrastructure (including electrical) lies below ground. The result of this specific natural disaster on Houston's wastewater infrastructure was as follows:

- Eighteen of 39 wastewater treatment facilities and 81 pump stations were submerged underwater;
- Electrical circuits and equipment were completely saturated with water, causing system failures; and

69 Source: Rebecca Hersher, "Houston Got Hammered by Hurricane Harvey—and Its Buildings Are Partly to Blame," National Public Radio, November 14, 2018, https://www.npr.org/2018/11/14/666946363/houston-got-hammered-by-hurricane-harvey-and-its-buildings-are-partly-to-blame.

- Thirty percent of the sanitary sewer system totally flooded for nearly a week, overwhelming system capacity and resulting in broken pipes and joints.[70]

C. A CONCLUSION FOR TOMORROW

As demonstrated by the annual Water Environment Federation Technical Exhibition and Conference, an incredible industry has been built around, and significant innovation has been poured into, this current wastewater paradigm of resource recovery.[71] If the paradigm were to continue, significant progress would be made and advanced technologies developed, but is there time?

Notably, average municipal wastewater is approximately 99.9 percent water, and the remaining 0.1 percent comprises solid organic matter.[72] Therefore, the purpose of wastewater treatment is to remove as much of this 0.1 percent as possible within regulatory guidelines, from water that was treated to potable standards in the first place. Further still, and as stated in the previous section, indoor residential use generates roughly seven trillion gallons of wastewater every year in the United States, and 1.6 trillion gallons from flush toilets. Therefore,

1. 5.4 trillion gallons is considered greywater (all indoor use besides flushing), which can be applied to the location it was generated for irrigation purposes and eventual groundwater recharge; and
2. If a waterless technology replaced flush toilets, 1.6 trillion gallons of water could be saved annually to be used for consumption, hygiene, and myriad other purposes.

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70 Jim Force, “Utility Climbs Back after Hurricane Harvey,” *Municipal Sewer & Water*, January 2019, https://www.mswmag.com/editorial/2019/01/utility-climbs-back-after-hurricane-harvey.

71 “WEFTEC – Connecting the World to Clean Water,” Water Environment Federation, accessed May 14, 2020, http://weftec.org/about/about-weftec/.

72 Water Environment Federation, *Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants*, Manual of Practice No. 29 (New York: McGraw-Hill, 2005), 7.

These facts raise the question of whether wastewater systems represent the best use of water. The United States was at a crossroads in the mid-1800s—but perhaps did not realize it—and according to the ASCE is at another one now. Should the country continue down the path of funding and constructing wastewater infrastructure, or should an alternative paradigm be considered? After all, managing human excreta with water is one method of protecting public health and the environment from this type of pollution, but as this thesis will prove, it is not the only way.

So, does the United States need a new *wastewater* system, or a new *sanitation* system?

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III. SANITATION

Sanitation aims to protect public and environmental health through the prevention of direct contact with human excreta or, in other words, to minimize hygienic risks.[73] Human fecal matter contains a variety of different pathogens while urine is typically sterile.[74] A variety of methods safely provide this service and achieve its goal. This chapter discusses ways in which sanitation is defined and practiced, as well as the barriers to accessing it. As discussed in Chapter II, sanitation services in the United States largely come in the form of wastewater conveyance, treatment, and disposal/reuse. Regarding homeland security, practitioners should be wary of the barriers to accessing adequate sanitation services in the United States and how to overcome them.

A. SANITATION DEFINED

Although sanitation services prevent direct contact with human excreta, various organizations attempt to define the actual term "sanitation." Some recognize the value of human excreta and use the term "resource" while others prefer the term "waste."

1. In the United States: Centers for Disease Control and Prevention

The CDC in the United States describes "basic" sanitation as "having access to facilities for the safe disposal of human waste (feces and urine), as well as having the ability to maintain hygienic conditions, through services such as . . . wastewater treatment and disposal."[75] The CDC thus implies that human excreta are waste and also that wastewater facilities are necessary infrastructure to maintain sanitary conditions. It further implies wastewater facilities are *disposal* systems. Indeed, as the Department of Homeland Security notes, wastewater qualifies as critical infrastructure in the United States, and

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[73] R. Otterpohl, "Options for Alternative Types of Sewerage and Treatment Systems Directed to Improvement of the Overall Performance," *Water Science and Technology* 45, no. 3 (February 2002): 156.

[74] World Health Organization, *WHO Guidelines for the Safe Use of Wastewater, Excreta, and Greywater: Excreta and Greywater Use in Agriculture*, vol. 4 (Geneva: World Health Organization, 2006), xv, https://www.who.int/water_sanitation_health/publications/gsuweg4/en/.

[75] Centers for Disease Control and Prevention, "Global Water, Sanitation, & Hygiene."

responsibility lies in CISA's Water and Wastewater Systems Sector.[76] This description suits a developed country such as the United States with the capital, capacity, and natural resources to build infrastructure that uses water as a means of conveyance.

2. Outside the United States: World Health Organization and United Nations

The WHO declares that "a safe sanitation system is a system designed and used to separate human excreta from human contact at all steps of the sanitation service chain from toilet capture and containment through emptying, transport, treatment (in-situ or off-site) and final disposal or end use."[77] Figure 3 graphically represents this description. Similarly, the WSSCC defines it as "the collection, transport, treatment and disposal or reuse of human excreta."[78] Both of these definitions imply that in addition to the option to dispose of human "waste," such material may have productive uses. Thus, the definitions supplied by the WHO and WSSCC are more farsighted than the CDC's in that they recognize human excreta as not simply "wastes" but also valuable resources.

[76] Cybersecurity and Infrastructure Security Agency, "Water and Wastewater Systems Sector."

[77] World Health Organization, *Guidelines on Sanitation and Health*, xii.

[78] Evans, van der Voorden, and Peal, *Public Funding for Sanitation*, 35.

Figure 3. The Sanitation Service Chain[79]

B. SANITATION METHODS

Two categories of "user interfaces" (e.g., toilets) exist: those that use water and those that do not.[80] Steven Esrey et al. refer to these categories as "flush-and-discharge" or "drop-and-store."[81] Either type can be designed and operated to manage human excreta safely. Regardless of the type of system (water or waterless), a safely managed system exists when wastewater is treated off-site and when excreta are emptied and treated off-site or treated in situ.

The *Compendium of Sanitation Systems and Technologies* breaks sanitation down pragmatically. It observes that

> a sanitation system is a context-specific series of technologies and services for the management of these wastes (or resources), i.e., for their collection, containment, transport, transformation, utilization or disposal . . . [and] is

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[79] Source: Kory C. Russel et al., "Taking Container-Based Sanitation to Scale: Opportunities and Challenges," *Frontiers in Environmental Science* 7, no. 190 (November 2019): 3, https://doi.org/10.3389/fenvs.2019.00190.

[80] Tilley et al., *Compendium of Sanitation Systems and Technologies*, 42.

[81] Esrey et al., *Closing the Loop*, 10.

> comprised of products . . . that travel through functional groups which contain technologies that can be selected according to the context.[82]

In other words, a safe sanitation system can take many forms, is adaptable in many different applications, and applies not only to those using water. Furthermore, this definition of a sanitation system also acknowledges human excreta as a resource.

The *Compendium* outlines nine elements of a sanitation system, regardless of whether it requires water, and uses them in a template:

1. Input Products (feces and/or urine, flush water, cover material, anal rinse water, etc.)
2. User Interface (sit down or squat toilet, urinal, bidet, pedestal, pan, etc.)
3. Input/Output Products (blackwater, compost, pit humus, stored urine, etc.)
4. Collection and Storage/Treatment ("the ways of collecting, storing, and sometimes treating the products generated at the user interface")
5. Input/Output Products (wastewater, organic material, sludge, etc.)
6. Conveyance (the method of transporting products)
7. (Semi-) Centralized Treatment (the appropriate treatment technologies applied to the products)
8. Input/Output Products (recycled water, biogas, biosolids, compost, etc.)
9. End Use and/or Disposal (methods which products are returned to the environment: irrigation or discharge water, incineration, land application, etc.)[83]

As stated previously, the WHO would describe this as the "sanitation service chain"—the steps of "containment, emptying, conveyance, treatment and end use or disposal of excreta, to achieve safe sanitation."[84] For example, Figure 4 represents the nine

[82] Tilley et al., *Compendium of Sanitation Systems and Technologies*, 10.

[83] Tilley et al., 18.

[84] World Health Organization, *Guidelines on Sanitation and Health*, 14.

elements of a sanitation system in a template, and Figure 5 represents a template for a pour flush toilet, whereby the pit's contents are manually emptied and transported for reuse.

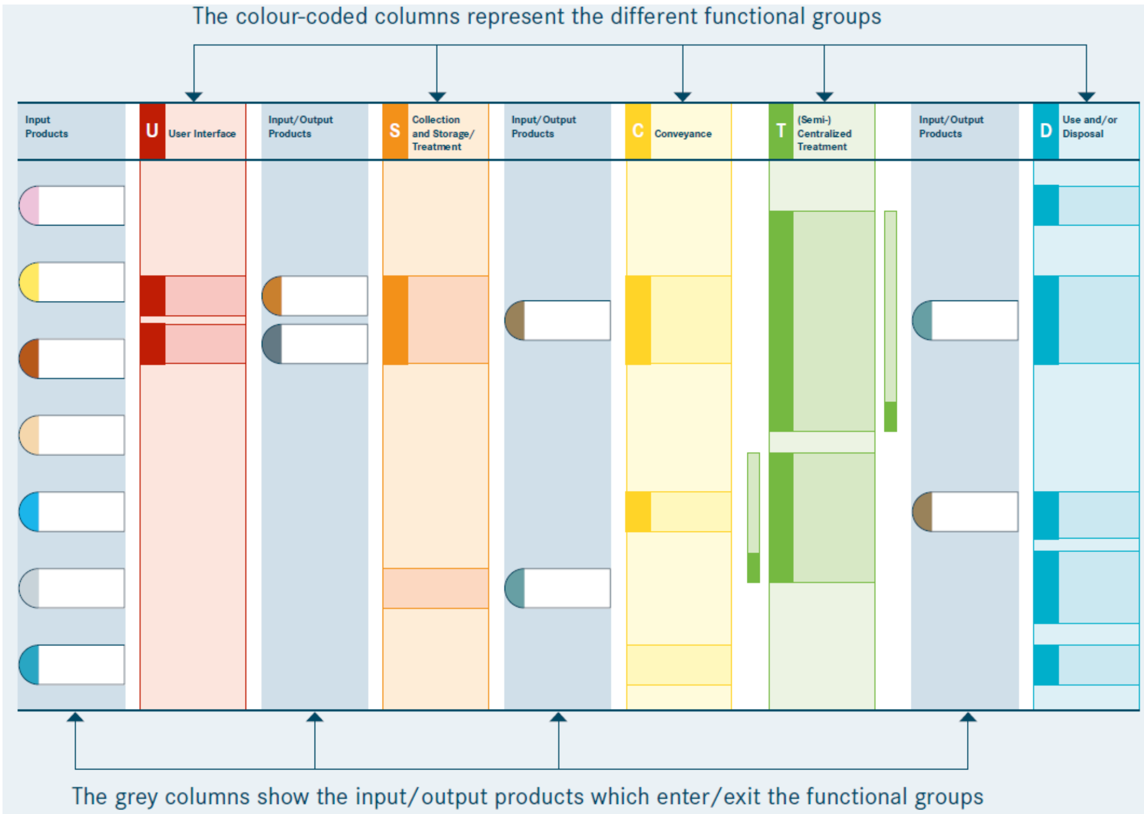

Figure 4. System Template[85]

85 Source: Tilley et al., *Compendium of Sanitation Systems and Technologies*, 16.

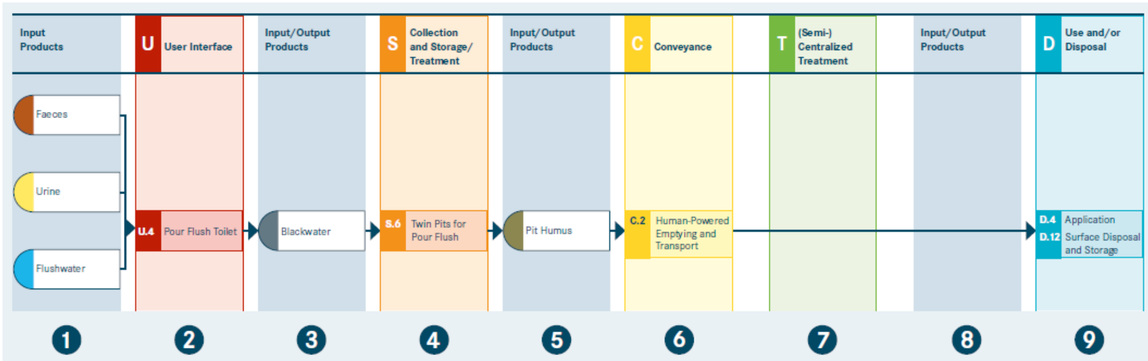

Figure 5. Example of System Template in Use[86]

Pertaining to safety, the WHO states that the "health risks associated with excreta and greywater use are linked mainly to occupational exposure of those who handle the excreta."[87] The organization further identifies the major exposure points: emptying the collection container, transporting the material, exposure at the off-site treatment facility, and handling the treated material.[88] At all four exposure points, the use of personal protective equipment such as gloves, eye protection, and other protective coverings is recommended.

1. Systems Using Water: Flush-and-Discharge

A flush-and-discharge system resembles modern wastewater systems that convey excreta with water. The WHO classifies wastewater systems into two categories: low- and high-flow rate technologies.[89] These systems may resemble a large municipal system serving hundreds of thousands of people, or medium or smaller sized communities. They may also take the form of a septic system serving one home or a cluster of buildings.

A traditional wastewater system in the United States, regardless of the specific technologies used, requires the following items:

[86] Source: Tilley et al., 18.

[87] World Health Organization, *WHO Guidelines for the Safe Use of Wastewater*, 4:73.

[88] World Health Organization, 4:76.

[89] World Health Organization, *Guidelines on Sanitation and Health*, 46.

1. a water system to provide the flush water
2. a user interface utilizing flush water
3. a collection system consisting of gravity and/or pressurized pipes to convey the wastewater
4. a system to treat the wastewater consistent with local or state regulations
5. a system to dispose of or reuse the treated wastewater and organic residuals also in accordance with local or state regulations

The benefits of a flush-and-discharge system are that they have little to no odor at the user interface (if properly cleaned) and can handle high flow volumes, while the drawbacks are the high capital and operating costs. Moreover, such systems require a constant supply of water (which is difficult and costly to adapt to rapidly growing communities), a minimum flow velocity in the sewers (to avoid solids deposition), and deep excavation (which necessitates expert design and construction of facilities) but risk leakage of untreated water escaping into the environment.[90] In sum, traditional wastewater systems require not only a source of water to begin with but also significant initial capital investments as well as ongoing operating and maintenance costs.

2. Waterless Systems: Drop-and-Store

Safe sanitation systems that do not require water to manage human excreta come in many forms. They range from primitive hand-dug pit latrines to state-of-the-art composting toilets. In October 2018, the International Organization for Standardization (ISO) published ISO 30500, a voluntary international standard for non-sewered sanitation systems. According to the American National Standards Institute (ANSI), which participated in the development of ISO 30500, the standard "provides general safety and performance requirements for the product design & performance testing of prefabricated integrated treatment units that are not attached to a network sewer or drainage system," and experts across 48 countries developed it so that "policy makers [could] rely on global

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[90] Tilley et al., *Compendium of Sanitation Systems and Technologies*, 95.

expert opinion to ensure safety of the product for [their] citizens."[91] In the United States, the National Science Foundation (NSF)/ANSI 41 standard "certifies composting toilets and similar treatment systems that do not use a liquid saturated media as a primary means of storing or treating human excreta."[92] These efforts provide a foundation for lawful alternative means of humanure management.

Waterless systems are designed either to comingle urine and feces or to divert urine—as it is high in nutrients and relatively sterile whereas feces are lower in nutrients and contain pathogens.[93] Most notably, waterless systems that model the philosophy of EcoSan appear to be an acclaimed and acceptable drop-and-store method of managing human excreta. The World Bank also acknowledges the benefits of CBS.[94] This approach safely treats human feces, conserves water, recycles nutrients, and minimizes environmental impacts.

In *Closing The Loop: Ecological Sanitation for Food Security*, Steven Esrey et al. argue that unlike conventional sanitation (such as wastewater), EcoSan considers the ecosystem in that it recovers the nutrients in urine and feces and "destroys pathogens near where people excrete them . . . does not use water, or very little water . . . and can provide hygienic and convenient services at a much lower cost than conventional sanitation."[95] Similarly, Christopher Rhodes advises, "As issues over the current sanitary system, e.g., water usage and excess nutrients, become ever more expensive to deal with, the introduction of ecological sanitation (ES) systems might appear a worthwhile

[91] American National Standards Institute, *Non-Sewered Sanitation Systems—Prefabricated Integrated Treatment Units—General Safety and Performance Requirements for Design and Testing*, ISO 30500 (Washington, DC: American National Standards Institute, 2002), https://sanitation.ansi.org/Standard/ISO30500.

[92] "Wastewater," National Science Foundation International, accessed July 26, 2020, https://www.nsfinternational.eu/water/wastewater/.

[93] Rhodes, "Peak Phosphorus – Peak Food?," 132; World Health Organization, *WHO Guidelines for the Safe Use of Wastewater*, 4:31, 34.

[94] World Bank, *Evaluating the Potential of Container-Based Sanitation* (Washington, DC: World Bank, 2019), xiii, https://documents.worldbank.org/curated/en/299041550179057693/Evaluating-the-Potential-of-Container-Based-Sanitation.

[95] Esrey et al., *Closing the Loop*, 2.

investment."[96] In a journal article pertaining to fertilizers, Judit Nagy et al. agree on the importance of dry toilet systems and see the nutrient value in urine specifically.[97] As such, the consensus among experts is that EcoSan toilets may divert urine into a separate storage container and sanitize feces through drying, increased pH or temperature, or composting.

Similar to wastewater systems, waterless systems also contain key themes to consider. Following the sanitation chain, then, a waterless system consists of the following elements:

1. a source of cover material (or not)
2. a dry toilet or other container (such as a vault or pit)
3. a system or process of emptying the toilet or container
4. a system or process of conveying/transporting the contents
5. a system or process of treating the material, off-site or in situ, so it may be safely disposed of or reused consistent with pertinent regulations

Benefits of a waterless systems include low capital and operating costs, the use of locally sourced materials, independence from the water supply, and adaptability to all types of users; in contrast, the drawbacks include the potential presence of odors and flies and visibility of the excreta pile, depending on the type of sanitation system.[98] Although waterless technologies and systems do not require water to operate and have lower capital and operating costs, they do have significant considerations such as training to manage these types of systems and minimizing exposure to human excreta.

C. BARRIERS TO SANITATION

At least two variables bar access to adequate sanitation: socioeconomic factors or natural or manmade disasters.

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[96] Rhodes, "Peak Phosphorus – Peak Food?," 142.

[97] Nagy et al., "Utilization of Struvite Produced from Human Urine," 478.

[98] Tilley et al., *Compendium of Sanitation Systems and Technologies*, 45.

1. Socioeconomic Factors

Although the United States is a developed country, far from being a third-world nation, pockets of poverty and conditions prohibit people and communities from accessing adequate sanitation. One clear example is the condition arising from homelessness. Another lesser-known example, along the U.S.–Mexican border, is what some refer to as the "colonias," communities existing in an "extra-legal" realm (i.e., a grey area of the law). Although varying definitions exist among different U.S. government agencies (e.g., the Department of Housing and Urban Development, EPA, and Department of Agriculture), colonias are generally defined as low-income, unincorporated communities along the southern U.S. border, "characterized by substandard housing, inadequate roads and drainage, substandard or no water and sewer facilities, and no garbage disposal services."[99] These communities lie in all four southern border states, but most are in Texas. The *U.S. News and World Report* maintains that "about 900 of the state's 2,300 or so colonias are concentrated in the Rio Grande Valley's Hidalgo County—one of the fastest-growing counties in Texas."[100]

In contrast to colonias, which are specific communities, homelessness pervades the nation and has become a major health concern. Margot Kushel states, "In many parts of the United States, stable or increasing numbers of people have been experiencing homelessness."[101] An estimated three million people experience homelessness each year in the United States, and one-third of them live in unsheltered locations.[102] One study found that "open defecation is relatively common in the urban core of a major American

[99] Elliot C. Smith and John Hutton, *US-Mexico Border: Issues and Challenges Confronting the United States and Mexico*, GAO/NSIAD-99-190 (Washington, DC: Government Accountability Office, 1999), 15, https://www.gao.gov/assets/230/227572.pdf.

[100] Gaby Galvin, "On the Border, Out of the Shadows," *U.S. News & World Report*, May 16, 2018, https://www.usnews.com/news/healthiest-communities/articles/2018-05-16/americas-third-world-border-colonias-in-texas-struggle-to-attain-services.

[101] Margot Kushel, "Hepatitis A Outbreak in California—Addressing the Root Cause," *New England Journal of Medicine* 378, no. 3 (2018): 212.

[102] Drew Capone et al., "Open Defecation Sites, Unmet Sanitation Needs, and Potential Sanitary Risks in Atlanta, Georgia, 2017–2018," *American Journal of Public Health* 108, no. 9 (September 2018): 1238, https://doi.org/10.2105/AJPH.2018.304531.

city."[103] San Francisco has seen a steady increase in reported cases of human feces in public areas.[104] To illustrate the exigency of the health concern due to open defecation, in October 2017, then-governor Jerry Brown "issued an emergency proclamation" due to the outbreak of Hepatitis A in San Diego's homeless population, the worst outbreak of this disease in the United States in 22 years.[105]

2. Disasters

In addition to the risk of flooding mentioned in Chapter II, traditional wastewater systems are also vulnerable to earthquakes. This section describes events experienced in Haiti and New Zealand, as well as the response to non-functioning wastewater systems.

Following a magnitude 7.0 earthquake in Haiti on January 12, 2010, the United States Agency for International Development estimated that 1.5 million people were displaced into approximately 15,000 camps.[106] Thereafter, the Haitian Ministry of Health announced a cholera outbreak, which resulted in 800,000 suspected cases and over 9,700 deaths.

New Zealand experienced the Canterbury earthquake sequence—four earthquakes that occurred between September 2010 and December 2011. The four earthquakes, which measured magnitudes of 7.1, 6.2, 6.0, and 5.9, respectively, damaged 528 of Christchurch's 1,700 kilometers of sewer pipes and approximately 100 sewage pump stations.[107] Immediately following the second earthquake, then-mayor Bob Parker announced that

[103] Capone et al., 1240.

[104] Ben Gilbert, "People Are Pooping More Than Ever on the Streets of San Francisco," *Business Insider*, April 18, 2019, https://www.businessinsider.com/san-francisco-human-poop-problem-2019-4.

[105] "Governor Brown Declares State of Emergency to Increase Supply of Hepatitis A Vaccines," State of California, October 13, 2017, https://www.ca.gov/archive/gov39/2017/10/13/news20018/index.html.

[106] Ryan B. Stoa, "Water Governance in Haiti: An Assessment of Laws and Institutional Capacities," *Tulane Environmental Law* 29, no. 2 (Summer 2017): 246.

[107] Mark C. Quigley et al., "The 2010–2011 Canterbury Earthquake Sequence: Environmental Effects, Seismic Triggering Thresholds and Geologic Legacy," *Tectonophysics* 16 (March 2016): 228–74.

"sanitation and access to clean water was still the biggest problem the city faced."[108] The region experienced a sanitation crisis directly linked to the natural disaster.

In response to both natural disasters, various groups implemented container-based sanitation. Two non-profits in particular, Sustainable Organic Integrated Livelihoods (SOIL) and GiveLove, implemented dry toilets and humanure composting in an effort to mitigate the public health and environmental crises in Haiti.[109] In New Zealand, the Wellington Regional Emergency Management Office (WREMO) acknowledged the chaos related to sanitation management following the earthquakes. Thus, WREMO initiated a trial to understand the community's reaction to using container-based sanitation. According to WREMO, "The trial demonstrated that households and workplaces could safely and hygienically use a compost toilet exclusively for a month."[110] Excreta collected and treated in Haiti were (and continue to be) transformed into useable compost, but the toilet contents in the WREMO trial were ultimately disposed of in a landfill.

While GiveLove continues its efforts educating communities about dry toilets and sustainable humanure composting around the world, SOIL has kept its focus on similar ongoing and sustainable practices in Haiti. In New Zealand, a group of citizen permaculture practitioners, known as Relieve, formed "in response to the Christchurch earthquakes, where [they] co-initiated an effort to provide information and support to the people in Christchurch who were doing without their usual sewerage systems."[111] Therefore, all three organizations have continued the effort of turning short-term emergency solutions into long-term sustainable ones.

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108 Lucy Rickard, "Battered Christchurch Faces Water, Health Problems," *Sydney Morning Herald*, February 23, 2011, https://www.smh.com.au/world/battered-christchurch-faces-water-health-problems-20110223-1b4wo.html.

109 "About Soil," Sustainable Organic Integrated Livelihoods, accessed February 9, 2020, http://www.oursoil.org/who-we-are/about-soil/; "Our Projects," GiveLove, accessed May 18, 2020, https://givelove.org/haiti/.

110 Wellington Regional Emergency Management Office, *Report on a Trial of Emergency Compost Toilets* (Wellington, New Zealand: Wellington Regional Emergency Management Office, 2013), ii, https://www.civildefence.govt.nz/assets/Uploads/CDEM-Resilience-Fund/CDEM-Resilience-Fund-2012-01-final-report.pdf.

111 "About Us," Relieve, accessed May 18, 2020, https://www.composttoilets.co.nz/about-us/.

IV. HUMAN SUBJECTS RESEARCH

Interviews were selected as the means for obtaining the information in this qualitative study. As Leedy, Ormrod, and Johnson state, “Interviews can often yield a rich body of qualitative information.”[112] Qualitative data gained from four individuals who practice alternative means of managing human excreta with waterless or near-waterless systems assisted in understanding their personal experiences, challenges, and insights into those practices.

A. METHODOLOGY

The interview format aimed to obtain facts and subjective information from four human subjects, using an approved Institutional Review Board (IRB) protocol. The current status of knowledge about alternative sanitation practices is limited in the United States. This study is important because alternative means of managing human excreta other than using water are possible, but these practices are largely unknown, misunderstood, or ignored.

The specific focus of the interviews was on individuals and their specific practices, and the research design contained the characteristics of a phenomenological study:

- The purpose was to understand an experience from the participants’ points of view.
- The focus was on a particular phenomenon as it is typically lived and perceived by human beings.
- The methods of data analysis were to search for meaningful concepts that reflect various aspects of the experience.[113]

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[112] Paul D. Leedy, Jeanne Ellis Ormrod, and Laura Ruth Johnson, *Practical Research: Planning and Design*, 12th ed. (New York: Pearson, 2019), 244.

[113] Leedy, Ormrod, and Johnson, 236.

1. Interview Design

All guidance used in planning and conducting the interviews for this qualitative study was found in *Practical Research: Planning and Design*.[114] General interview questions designed to obtain qualitative data were developed. The human subjects selected had hands-on experience with practicing alternative methods of sanitation. No information about the study was provided to participants other than what was found on the consent form (see Appendix A). Signed consent forms were collected prior to each interview, and phone interviews were recorded. Immediately afterward, an interview was transcribed verbatim and sent to the participant to provide an opportunity to confirm its accuracy. Transcriptions of the interviews appear in Appendices B–E.

2. Participants

Convenience sampling was used to select the participants in this study as they were "easily accessible individuals who [could] provide insights related to central research questions."[115] These participants were selected because previous research for this thesis revealed they practiced alternative means of sanitation. Four were selected in the interest of time, and the responses provided revealed many commonalities, as well as some differing points of view, that will lead to fruitful discussion later in this chapter.

The participants' names are used here, which is important because all four are educators in this extremely narrow field of study, and they all acknowledged their enjoyment of teaching others how to safely manage excreta without (or using very little) water. All consented to using their names in this thesis:

Alisa Keesey is the program director for the non-profit organization GiveLove. She received a Bachelor of Arts in international relations from San Francisco State University, a master of science in international agricultural development from the University of California, Davis, and a master of arts in cultural anthropology from the University of California, Santa Cruz. Additionally, Alisa "collaborates with a diverse group of

[114] Leedy, Ormrod, and Johnson, 245–53.

[115] Leedy, Ormrod, and Johnson, 242.

organizations to link ecosan programs with holistic programming that integrates livelihoods, sustainable land use, food security, and local resiliency in the context of climate change."[116]

Brock Dolman is a co-founder and program director of the Occidental Arts and Ecology Center since 1994. He received his Bachelor of Arts from the Biology and Environmental Studies Department at the University of California, Santa Cruz. Brock "has taught Permaculture and consulted on regenerative project design and implementation internationally in Costa Rica, Ecuador, U.S. Virgin Islands, Spain, Brazil, China, Canada, Zimbabwe, Tanzania, Democratic Republic of Congo, Cuba and widely in the U.S."[117]

Joseph "Joe" Jenkins is the author of *The Humanure Handbook*, now in its fourth edition. He has been composting his and his family's excreta for 43 continuous years and uses the finished compost in his food garden. Joe travels internationally, teaching communities in developed and developing countries how to manage their humanure safely.

Laura Allen is a co-founder of Greywater Action. She earned a Bachelor of Arts in environmental science, a teaching credential, and a master's degree in education. Laura is the author of *The Water-Wise Home: How to Conserve and Reuse Water in Your Home and Landscape* and *Greywater*, *Green Landscape*, and has coauthored other publications. Laura has also "presented widely on greywater reuse, including at the Water Smart Innovations Conference, Bioneers, California Environmental Health Association conference, and California Landscape Contractors Association conference."[118]

3. Interview Questions

The following interview questions were asked of each participant:

1. How long have you worked with your system?

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[116] "Our Team," GiveLove, accessed May 12, 2020, https://givelove.org/our-team/.

[117] "Brock Dolman," Occidental Arts and Ecology Center, accessed July 26, 2020, https://oaec.org/about-us/staff/brock-dolman/.

[118] "Greywater Action—for a Sustainable Water Culture," Greywater Action, accessed May 12, 2020, https://greywateraction.org/about/.

2. Why did you choose to start using this system?

3. What benefits do you realize by using this system?

4. Do you detect any odors generated from your system? Describe.

5. What do you find to be difficult to manage with your system?

6. What do you do with the material in your system?

7. If composted, describe the method you use to compost the material.

8. Do you detect any odors generated from your composting practices? Describe.

9. If composted, what do you do with the finished compost?

10. Is there anything else you would like to state for the record?

B. RESULTS

Following the interviews, the results were summarized and compiled according to each question number as follows:

(1) How long have you worked with your system?

Alisa Keesey: Ten years (container-based sanitation and composting).
Brock Dolman: Two years (for the experimental composting toilet systems: Clivus Multrum, Phoenix, and EcoTech Carousel).
Joe Jenkins: Forty-three years (container-based sanitation and composting).
Laura Allen: Fifteen years (container-based sanitation and composting).

(2) Why did you choose to start using this system?

Alisa Keesey: For personal use. She needed a container toilet for camping or living where there were no toilets, and she did not want to use a pit latrine or go outside. For professional purposes, she used container toilets as part of emergency development work in Haiti where there were no toilets.

Brock Dolman: When the Occidental Arts and Ecology Center was founded, it inherited the legacy of a place with a long history and reputation for exploring compost toilets, such as the Farallones and Clivus Multrum models. The center has a history of being involved in the whole water cycle, and composting toilets was a natural fit for what it calls its "conservation hydrology portfolio." Additionally, due to the septic system's poor leach-field percolation rates, anything it can do to reduce the demand on the septic system is helpful. Last, the center prefers to have an output of the system—compost to feed back into the soil for plant health and carbon sequestration. The quality of the compost produced by its three toilet installations is currently being studied by the Sonoma County and Regional Water Quality Control Board.

Joe Jenkins: It was a matter of not having plumbing or running water in his old farmhouse. Also, due to poor soil quality from the previous owners' farming practices, he needed high-quality, nutrient-rich compost for his garden.

Laura Allen: She wanted to save water, recycle nutrients, and have a system that was easy to manage in her home.

(3) What benefits do you realize by using this system?

Alisa Keesey: It is a superior user experience to that of a pit latrine or going outside because it is private, completely odor- and fly-free, and hygienic. It also replicates a sit-down toilet and does not require water to flush. She enjoys the added benefit of recycling nutrients and making very rich humanure compost.

Brock Dolman: The benefits are attempting to use less water (although each toilet uses about one cup of water to flush), ideally using less electricity, reducing demand and stress on septic leach-field systems, and producing an output of organic material that feeds back into the soil food web on the site to sequester more atmospheric carbon. Additionally, the installations are used for education and demonstrations for the research center.

Joe Jenkins: First and foremost, it provides sanitation. Second, he produces a high-quality compost for his garden. One unintended benefit is that by becoming a subject-matter expert, he is invited to teach his method in the United States and in many countries around the world.

Laura Allen: The benefits include water savings and zero reliance on the sewer system (coupled with greywater reuse), not to mention it manages excrement safely and ecologically and recycles nutrients.

(4) Do you detect any odors generated from your system?

Alisa Keesey: When done correctly, it is completely odor free, but if not managed correctly, there will be odors. There must be a proper carbon mixture.

Brock Dolman: No, there is zero odor coming from the toilets themselves.

Joseph Jenkins: There is no 100 percent odorless situation when one is defecating, whether using a flush or dry toilet. However, generally speaking, yes, it is completely odorless. The toilets need to be properly managed.

Laura Allen: There are not any odors when managed properly. There might be non-offensive earthy smells when one lifts the lid. If there is an unpleasant odor, replacing the bucket with an empty one solves the problem.

(5) What do you find to be difficult to manage with your system?

Alisa Keesey: Currently, in Sub-Saharan Africa and in many developing world contexts, the biggest challenge is getting the fine cover material that is processed at the right particle size. A lot of people like the compost toilets, but arranging for the inputs on a seasonal basis is difficult. That is the biggest challenge: organizing and processing cover material into the right size and shape to compost correctly. Industrial agricultural shredders are good tools for doing this at scale. For home use, rice hulls used for animal bedding can be found in quantity at local feed stores and make a perfect cover material.

Brock Dolman: The three installations require the addition of carbon material in the composting chamber and have had mechanical issues with the pumps and grinders. In the case of the legacy Farallones toilet, people mainly use it for urination, so balancing the moisture content and carbon-to-nitrogen ratio becomes challenging.

Joe Jenkins: The main logistical difficulty in general for the communities he has taught is providing the cover material, though personally he has access to fresh sawdust in his community. He sees a lot of opportunity in creating carbon cover material on a global scale. Grinding up cardboard and paper products makes great cover material.

Laura Allen: There is an extra step in using container-based sanitation. A flush toilet requires only flushing and routine cleaning and experiences an occasional clog. It does not require going outside to empty a bucket. Emptying does not require a lot of time but involves additional effort.

(6) What do you do with the material in the system?

Alisa Keesey: It is composted using a traditional batch method.

Brock Dolman: The toilet material is transported to composting chambers unique to each of the three installations.

Joe Jenkins: The toilet contents are all composted along with other items such as food scraps.

Laura Allen: It is composted one of two ways: slowly at a lower temperature in a 55-gallon drum or more quickly in a hot compost pile.

(7) Describe the method you use to compost the material.

Alisa Keesey: The toilet contents are mixed with layers of dry straw or hay, or grass in rectangular bins that are four cubic meters long and one meter high. Once there is an established layer, the new material is incorporated into the hot active center of the pile and then covered. She calls it the volcano method.

Brock Dolman: The composting happens within the toilet vaults themselves. The Phoenix utilizes vermicomposting, which means worms are added to the composting chamber.

Joe Jenkins: Everything is composted in square rectangular walled bins. His bins are all made from wood, but around the world, other materials might be used, such as wire fencing, straw bales, blocks, bricks, bamboo, reeds, anything that contains the toilet material, and any other material being composted, in a vertical pile above ground.

Laura Allen: Humanure is either composted in a 55-gallon drum or in a hot pile in a three-foot by three-foot pile on top of soil. The drum method is the lower-temp, longer-time method. The pile is a hotter, quicker method. Alternating requires two piles.

(8) Do you detect any odors generated from your composting practices?

Alisa Keesey: No. If there is an odor from the compost pile, it is because it was mismanaged somehow. Humanure composting is complex because new material is constantly being added until a bin is full. Teaching people to manage a dynamic system and ensuring continuity of that training (whether it be in a school, an institution, or a house) is challenging.

Brock Dolman: There is either no odor at all or an earthy smell.

Joe Jenkins: Similar to the toilets, no, not if it is managed correctly. It will smell bad if not correctly managed.

Laura Allen: The only odors detected are when the buckets are being emptied. However, when the compost is covered with a cover material, there is no odor per se.

(9) What do you do with the finished compost?

Alisa Keesey: The compost is used in kitchen gardens and in agroforestry projects to grow shade trees. One of her largest projects was a massive garden used for growing tomatoes and bananas to sell at the market. In one instance, in Uganda, the humanure compost was dried into pellets, which she then brought home to use in her own garden for summer crops and citrus trees.

Brock Dolman: Compost samples are sent to UC Davis and Stanford for analysis. If deemed acceptable and non-pathogenic, compost is applied in a thin layer in a dedicated area of the forest, then covered with leaves and allowed to become part of the forest floor.

Joe Jenkins: The compost produced at his home is used in his food garden. The compost produced at his business location is used for horticulture (landscaping) or food-bearing trees and shrubs. Producing a useable compost takes two full years, one year to build a pile and one year to let it rest, so he has not stayed long enough in one place when teaching and traveling abroad to know what the end use was. In one example, in Haiti, he went back to visit a refugee camp in what would have been the third year, for documentation, but everything was gone. Anecdotally, he heard a farmer paid for the compost and hauled it all away. Joe sees a challenge in educating urban people on how to use the compost to grow things.

Laura Allen: She sees a difference in what can legally be done with the compost and what is safe and effective. Different locations have different regulations. Some locations have codes that require the compost to be buried a certain depth around non-edible plants. Other places do not regulate it at all. She uses her compost in her garden. In the case of the 55-gallon drum, the compost is usually not great quality so she adds that back into a hot pile.

(10) Is there anything else you would like to state for the record?

Alisa Keesey: There is huge potential to scale up humanure systems all over the world, and this would go a long way in making cleaner environments and protecting groundwater pollution. The only thing standing in the way is people's attitudes about recycling their own wastes, and "it's only a waste if you waste it." Additionally, there is some very compelling evidence that if all the nutrients in urine and feces were recycled, the need for chemical fertilizers could be eliminated. Alisa enjoys teaching humanure composting because it applies in many different contexts.

Brock Dolman: Society will benefit if there are more options than wastewater systems, especially if humanure compost toilets can be implemented safely. He believes humanure toilets get an unfair disadvantage because of the ignorance on the permitting and engineering side of things, so he wants to give them a "fair shake."

Joe Jenkins: First and foremost, dry toilets and composting can be an extremely valuable emergency management practice. He also believes there should be a pilot program or somewhere it is being implemented for people to understand how it works. It would be smart to have a chipper, shredder, or grinder to grind up cover material in quantities.

Laura Allen: The bucket toilet is a great option for disaster preparedness. Some places are using a two-bucket system, one for urine and one for feces. Urine can simply be poured out, which she views as a good option because feces not mixed with urine would require less cover material. However, a two-bucket system is harder to manage for daily use; therefore, she recommends a one-bucket system for the home.

C. DISCUSSION

The interview responses revealed several common themes, as well as some differences of opinion and practices among the participants. The common themes were as follows: years of experience; sanitation and hygiene; toilet technologies and content processing; water and energy; nutrient recycling, education, and other benefits; end uses of compost; odors and system management; emergency preparedness and response.

(1) Years of Experience

The years of experience among the participants ranged from two to 43 years. While Brock indicated he had about two years of experience with the installations currently being studied at the Occidental Arts and Ecology Center (OAEC), he had experience with the legacy Farallones toilet that was already in operation on site before he arrived in 1994. Therefore, all participants each have over a decade of experience utilizing alternative sanitation methods and a combined experience using their systems totaling over 94 years.

(2) Sanitation and Hygiene

All participants indicate they are managing their excreta in a safe and hygienic manner.

(3) Toilet Technologies and Toilet Content Processing

All participants are utilizing a waterless or near-waterless toilet technology. Three of the four use a drop-and-store bucket system that requires no water, and the fourth operates vacuum flush toilets that require about one cup of water per flush. Composting is the process to treat the toilet contents across the four participants, although the method of composting varied.

Alisa, Joe, and Laura all practice a thermophilic or "hot" composting method. Laura's 55-gallon drum method, along with the Clivus Multrum, Eco-Tech Carousel, and

Farallones toilets that Brock manages, uses a lower-temperature composting process. The end product of all systems is a useable compost product, despite the type of composting process.

(4) Water and Energy

All four participants expressed some desire to conserve water or energy. Three of the four participants explicitly stated the reason they began using their system was to save water; however, Joe indicated he began out of necessity. All four cases realized the benefit of water savings. Regarding energy, Brock indicated that the OAEC was mindful of the water–energy nexus but that it might not have reduced its electrical demand given the technology-intensive toilet systems. Although Laura's system does not require electricity, she did acknowledge the extra work involved in emptying buckets, which requires more effort to manage the system.

(5) Nutrient Recycling, Education, and Other Benefits

All four participants either explicitly or implicitly stated that the benefit of their system was the recycling of nutrients. All utilize the finished compost product and its nutrients in a beneficial manner. In general, other highlighted benefits, in addition to water and energy savings, include an acceptable replication of a traditional flush toilet, a useable compost product, carbon sequestration, and the educational component of their practice. All four participants are educators of some variety and teach others in the United States or abroad.

(6) End Uses of Compost

All four participants beneficially reuse their finished compost product for agriculture, horticulture, or agroforestry. Alisa, Joe, and Laura apply the compost to their food gardens, fruit bearing trees and shrubs, and/or landscaping. Alisa's efforts abroad and Brock's practices at the OAEC include applying the finished compost to forests. Additionally, some of the communities Alisa worked with used the compost to grow crops to sell.

Unfortunately, Joe does not know the end use of compost at locations where he has taught abroad because the time to produce compost exceeds the time he spends at each location.

(7) Odors and System Management

All four participants acknowledged the necessity of some form of system management. Both the low-tech bucket systems and tech-heavy experimental systems required attention to prevent odor. Participants indicated explicitly or implicitly a need for proper carbonaceous cover material to maintain an ideal moisture content and carbon-to-nitrogen ratio. Dry toilets and composting practices are dynamic, biological systems that appear to require a combined art and science in routine maintenance. Alisa stated that training, and continuity of the training, is essential for an odor-free system. Finally, Joe was pragmatic during his interview on May 5, 2020, when he stated, “There’s no 100% odorless situation when there’s shit coming out of your ass.”

Unrelatedly, but not surprisingly, the technologically intensive systems Brock described have had mechanical issues that needed resolving during startup and periodically thereafter.

(8) Emergency Preparedness and Response

All three participants using a bucket toilet believe their type of system is a valuable tool for emergency situations. Joe and Laura stated this explicitly. Joe and Alisa indicated the biggest challenge abroad is securing an acceptable cover material and further recommended using some sort of chipper, shredder, or grinder technology to produce a carbonaceous cover material of appropriate size in quantity for the scale required. Alisa pointed out that a major obstacle to the adoption of a bucket system is peoples’ attitudes toward their own excreta.

V. CONCLUSION

The central research question for this thesis was exploratory in nature and sought to understand to what extent an alternative means of managing human excreta would benefit homeland security. This chapter summarizes those findings and includes additional insights. Next, policy recommendations are outlined, followed by suggested areas for further research.

A. SUMMARY

This thesis argues that another sanitation paradigm contributes ancillary benefits for homeland security related to disaster response, refugees, and the homeless. The information presented in this thesis can be summarized in four distinct categories: cognitive control and paradigm shifts, effects of the wastewater paradigm, alternative methods, and the bottom line.

1. Cognitive Control and Paradigm Shifts

Decision making and behavior adaptation occur through a process known as cognitive control and allow humans to modify the world around them.[119] The practice of sewering human excreta rose exponentially in the 20th century, which gave birth to the current wastewater paradigm. As discussed in Chapter II, sewers were built to convey sight and odor nuisances away from population centers. This, however, led to environmental pollution, which then caused humans to create and build wastewater treatment systems. Over time, as technologies improved and regulations became more stringent, the quality of water being discharged into the environment from wastewater facilities improved as well.

[119] David G. Rand and Jonathan D. Cohen, "The Rise and Fall of Cognitive Control," *Behavioral Scientist*, July 7, 2017, https://behavioralscientist.org/rise-fall-cognitive-control/; David G. Rand et al., "Cyclical Population Dynamics of Automatic versus Controlled Processing: An Evolutionary Pendulum," *Psychological Review* 124, no. 5 (October 2017): 626, https://doi.org/10.1037/rev0000079.

Although on the surface this may sound promising, the reality is that the wastewater paradigm is actually fraught with serious issues. So why continue using such a flawed system? David Rand and Jonathan Cohen frame it best:

> Consider the scourge of pollution in the mid-twentieth century. Pollution engendered efforts to develop both physical and social technologies (including regulatory legislation) to mitigate the problem—efforts that surely relied on the exercise of cognitive control. Those efforts notably improved the environment, which has benefited everyone. However, that very improvement has obscured the importance of sustained control-based efforts. In its place emerged a trend towards returning to technologies that caused the problem in the first place.[120]

They state that "cognitive processes have long been conceptualized as lying along a continuum from automatic to controlled."[121] Automatic processes are "hard-wired" and result in decreased flexibility to adapt to changing conditions whereas "controlled processes, conversely, involve more deliberation and thought—requiring greater investment of time and effort—but allowing a greater degree of flexibility and sensitivity to specifics and/or circumstances of the particular decision."[122] As they relate to wastewater, controlled processes resulted in the creation of sewers and treatment facilities and sustained ongoing innovations in those fields. However, automatic processes have allowed the wastewater paradigm to continue without considering why conveying human excreta with water might be troublesome in the first place.

2. Effects of the Wastewater Paradigm

The existing paradigm has resulted in serious financial, environmental, and climatic concerns. Much of the wastewater infrastructure in the United States is severely aged, requiring over $250 billion in capital costs between 2012 and 2032. It will be local government that must supply funding for 95–98 percent of those costs (as well as the lifetime operations and maintenance costs of those facilities), which will result in affordability challenges when the outlays are passed on to the users of the system.

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[120] Rand and Cohen, "The Rise and Fall of Cognitive Control."

[121] Rand et al., "Cyclical Population Dynamics of Automatic versus Controlled Processing," 626.

[122] Rand et al., 626.

Next, treatment facilities produce an effluent of an acceptable quality mandated by their NPDES permit and discharge this treated wastewater into the environment. Depending on the level of treatment, the effluent may still contain levels of nitrogen and phosphorous that contribute to nutrient pollution and can result in such deleterious environmental effects as harmful algal blooms. In addition, wastewater conveyance and treatment systems are not perfect. A treatment plant experiencing a process upset may discharge partially treated wastewater into the environment, which is a violation of its NPDES permit. Similarly, blockages and wet weather result in sewer overflows, which also release untreated wastewater into communities and the environment.

Phosphorous, specifically, ranks absolutely as a “below-the-horizon” homeland security issue. Mined rock phosphate largely becomes fertilizer used to grow crops, which are transported away from the areas they are grown, which humans then consume to excrete nutrients (phosphorous) into wastewater systems. As phosphorous becomes depleted from agricultural soils, more fertilizer must be applied. Depletion is one main reason the world’s phosphorous reserves are in decline and will likely be depleted within the next 100 years. As “peak phosphorous” approaches, geopolitical conflicts will likely occur around these rock phosphate deposits, with Morocco having the largest reserves.

Pertaining to climate change, wastewater infrastructure contributes to greenhouse gas emissions but will also be affected by increasing storm severity. As the U.S. Global Change Research Program observes, “Deteriorating water infrastructure compounds the climate risk faced by society . . . [and] extreme precipitation events are projected to increase in a warming climate and may lead to more severe floods and greater risk of infrastructure failure in some regions.”[123] Conversely, prolonged periods of drought will result in water scarcity, potentially leading to increased day-zero occurrences. Wastewater systems rely on water to function properly; however, water needed for consumption and hygiene is arguably a more critical use of this resource. Therefore, alternative means of providing sanitation services should be considered as sanitation systems requiring the use of water to function become less feasible.

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[123] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 2:154.

3. Alternative Methods of Sanitation

Wastewater systems are one way of practicing acceptable sanitation; however, they are not the only way. For example, the *Compendium of Sanitation Systems and Technologies* outlines "a huge range of information on tried and tested technologies" and a helpful reference for "persons/experts who have detailed knowledge about conventional high-end technologies and require information on infrastructure and different system configurations."[124] Indeed, the four human subjects interviewed for this thesis provided their perspectives.

All four subjects have used an alternative to traditional wastewater systems, and all four are practicing safe sanitation with their individual systems. Three of the four subjects practice container-based sanitation: they urinate and defecate into a bucket and use a carbonaceous cover material to absorb moisture and mitigate odors. Full buckets are emptied into a composting bin, and over time, a useable compost product is applied to edible gardens and landscaping. The fourth subject is trialing three compost toilet systems, which are part of an official study in partnership with local governments and universities in Northern California.

4. The Bottom Line

Alisa Keesey stated during her interview on May 4, 2020, that "it's only a waste if you waste it." Humanure contains nutrients that can, and should, be returned to the soil. The benefits of doing so are numerous, including atmospheric carbon sequestration and decreased reliance on chemical fertilizers. Even though the "resource recovery" paradigm shift in the industry is starting to focus more on nutrient recovery, wastewater systems are still largely open-loop systems that neither fully capture all nutrients nor return them to the soil, whereas closed-loop systems (such as container-based sanitation) do. For example, see Figure 6.

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[124] Tilley et al., *Compendium of Sanitation Systems and Technologies*, 7.

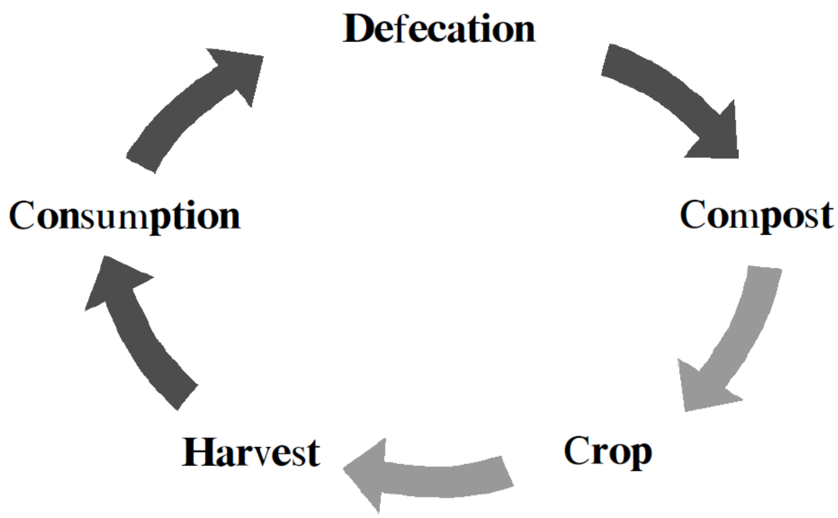

Figure 6. Closed-Loop System[125]

Directly relating to homeland security in a hands-on and meaningful way today, container-based sanitation is a proven method in multiple contexts. These circumstances would arise when neither water nor the wastewater systems reliant on water are available for use. These conditions are evident under at least three circumstances: disaster recovery, depressed socioeconomic conditions, and homelessness. Upon further reflection, it is applicable to temporary tent cities and encampments, as well as temporary military bases. The beauty of container-based sanitation lies in its ability to rapidly scale up or down, depending on the need, which is directly applicable to disasters resulting in large populations without access to safe sanitation. It is also very inexpensive to deploy compared to a traditional wastewater system, which can benefit severely disadvantaged communities (like the colonias) that cannot afford the costs associated with wastewater or septic systems. Figure 7 represents one such toilet, but many types and styles exist.

[125] Source: Esrey et al., *Closing the Loop*, 63.

Figure 7. A Container Toilet[126]

Last, container-based sanitation provides for privacy and dignity, compared to open defecation and use of public latrines. This feature is especially important for women and children. To illustrate,

> two recent reports from the Bill and Melinda Gates Foundation on gender and sanitation noted that in-home CBS services provide women and girls with a private, safe space to use the toilet and manage menstruation and pregnancy. By contrast, open defecation and public sanitation options expose women and girls to high risks of violence and harassment as they travel to defecation locations, often at night.[127]

126 Adapted from "Loveable Loo Compost Toilet Kit," Loveable Loo Store, accessed June 29, 2020, https://loveableloo.store/products/loveable-loo-composting-toilet.

127 Russel et al., "Taking Container-Based Sanitation to Scale," 3.

Therefore, container-based sanitation could help mitigate this inequity after a disaster, for the homeless, and for severely disadvantaged communities.

B. RECOMMENDATIONS

Consistent with the findings above, this thesis proposes the following recommendations:

1. Incorporate container-based sanitation into disaster preparedness and response plans.
2. Design and implement a pilot study for long-term, sustainable utilization of container-based sanitation.
3. Permit container-based sanitation for people and communities lacking a traditional wastewater system, or with a failed one.
4. Develop consistent regulations, policies, and guidelines across local and state jurisdictions to allow for container-based sanitation, the composting of humanure, and reuse of the compost.

First and foremost, emergency responders need to know what to do when a wastewater system is rendered inoperable. A bucket with a seat and toilet paper is good for emergency preparedness, but sanitation guidelines must be extended beyond that when wastewater services are not available for several days, weeks, or months. Container-based sanitation combined with composting is a proven method to provide this service in other countries. For planning purposes, the *Sphere Handbook* standards should be consulted when constructing public toilets. It states, “Communal toilets are an immediate solution with a minimum ratio of 1 per 50 people, which must be improved as soon as possible. A medium-term minimum ratio is 1 per 20 people, with a ratio of 3:1 for female to male toilets.”[128]

[128] Sphere Association, *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, 4th ed. (Geneva: Sphere Association, 2018), 118, https://spherestandards.org/wp-content/uploads/Sphere-Handbook-2018-EN.pdf.

Second, in support of a paradigm shift, pilot studies of waterless sanitation systems should be performed. Research has revealed how little is known in the United States about these technologies. Pilot studies should be designed and implemented to provide homeland security practitioners with scientific understanding of how waterless systems function, provide safe sanitation, and benefit the environment.

Third, due to the successful implementation of container-based sanitation, both in and outside the United States, it should be implemented for people and communities lacking traditional wastewater infrastructure. This system also applies to any temporary encampment such as for the homeless, a music festival, refugee camps, or military bases and outposts. Figure 8 represents a toilet used in one such instance. Although urinating and defecating into a bucket and then composting the material may seem offensive to some, they represent an improvement over open defecation.

Figure 8. Toilet Used at the Standing Rock Protest[129]

Last, container-based sanitation and the composting of humanure appear to reside in a grey area of the law—either not addressed at all or regulated inconsistently across local

[129] Source: "Standing Rock," GiveLove, accessed June 29, 2020, https://givelove.org/standing-rock/.

and state jurisdictions. These conflicts and inconsistencies should be resolved and allow for this practice. People and communities desiring to implement container-based sanitation and humanure composting should be allowed to do so in a safe and consistent manner. It should be noted, however, that federal regulations do outline acceptable methods of treating wastewater biosolids but do not address the need stated here.[130]

C. FURTHER RESEARCH

This thesis argues in support of waterless sanitation methods and outlines critical issues relating to existing wastewater systems. However, the management of water used for other plumbing fixtures like sinks and showers was not addressed. Therefore, a primary area for further research is greywater systems. In addition, commercial and industrial dischargers of wastewater were not discussed but warrant further study.

Next, while the noun and verb "compost" was used generally (and extensively) throughout this paper, it was not explored in detail. For example, a proper balance of carbon and nitrogen appears to be a key indicator of successful composting and odor mitigation, both for a dry toilet and the compost pile itself. Related to large-scale implementation, Joe Jenkins and Alisa Keesey acknowledged in their interviews the requirement to produce carbonaceous cover material in quantity and at the right particle size. These two topics should be explored to further the understanding of these subjects, as well as develop a "how-to" guide for producing high-quality compost similar to that shown in Figure 9. Another area that should be revisited is the Occidental Arts and Ecology Center's composting toilet installation study (see Chapter IV). The Center anticipates the study will have published information in 2021 or 2022.[131]

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[130] Environmental Protection Agency, "Biosolids Laws and Regulations."

[131] Occidental Arts and Ecology Center, "First Compost Toilet Research Samples Sent to the Lab!," *OAEC News* (blog), January 16, 2020, https://oaec.org/first-compost-toilet-research-samples/.

Figure 9. Finished Humanure Compost[132]

Regarding affordability, research indicated that both initial capital costs and ongoing operations and maintenance of traditional wastewater systems were more expensive than alternative sanitation services.[133] However, the true cost of building and operating waterless sanitation systems compared to wastewater systems was not analyzed. The type of waterless technologies selected would depend on local materials and preferences, and the type of wastewater conveyance and treatment facilities would also depend on similar variables.

Also warranting further attention when considering a new sanitation paradigm are the taboos and varying attitudes around “shit.” In her interview on May 4, 2020, Alisa Keesey opined that “the only thing standing in the way is people’s attitudes about recycling their own wastes.” To illustrate, Sarah Jewitt observes that two types of cultures exist: “faecophilic” and “feacophobic,” where the former “tolerate [s] the handling of shit,” and

[132] Source: “Village Compost Toilet System in Santo Village, Leogane, Haiti, Part 1 of 2,” December 2014, GiveLove, video, 10:30, https://givelove.org/video-gallery/.

[133] Russel et al., “Taking Container-Based Sanitation to Scale,” 2; Tilley et al., *Compendium of Sanitation Systems and Technologies*, 33.

the latter considers it “abhorrent.”[134] Author Joseph Jenkins uses the term “fecaphobia” in observing that “people believe that it’s dangerous and unwise to use human excretions for making compost.”[135] Assuming that the majority of the U.S. population could be classified as fecaphobic suggests the need for additional research to explore ways to overcome people’s attitudes toward human excrement.

Last, different research questions could be used for the above topics. The purpose of using an exploratory question for this thesis was to enlighten the reader as to what sanitation possibilities exist outside using water as a means to manage human excreta. Other research questions are prescriptive, descriptive, evaluative, and predictive. Some examples of potential questions are as follows:

(1) Prescriptive

“How can the United States transition from traditional wastewater management systems to an alternative means of managing human waste?” This question assumes that wastewater systems are troublesome to begin with, and other solutions need to be, or should be, implemented. It also aims to understand the obstacles to a fundamental paradigm shift in how human excreta are managed.

(2) Descriptive

“How are waterless sanitation systems being implemented in the United States and abroad?” This question may very well already be answered, although the research may yield some interesting and applicable information.

(3) Evaluative

“Are wastewater systems the optimal method for managing human waste in the United States?” Asking this question would prompt an assessment and evaluation of current wastewater management practices across the country. It is a very broad question

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[134] Sarah Jewitt, “Geographies of Shit: Spatial and Temporal Variations in Attitudes towards Human Waste,” *Progress in Human Geography* 35, no. 5 (2011): 610, https://doi.org/10.1177/0309132510394704.

[135] Jenkins, *Humanure Handbook*, 162.

that would require further refinement, as well as a specific tool for evaluation with criteria—such as water scarcity, energy usage, operations and maintenance costs, and capital costs—for a comparison with alternative systems.

(4) Predictive

"What are the impacts to homeland security in transitioning to an alternative means of managing human waste?" This question aims to understand the consequences (good and bad) of a fundamental paradigm shift in how human excreta are managed. The broad question would require being narrowed down to a specific thing, such as the water supply, aquatic environments, agriculture, or jobs.

APPENDIX A. CONSENT FORM

Naval Postgraduate School
Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled *Sanitation, Finances, Nutrients, and Climate Change: A Case for Humanure Management*. The purpose of the research is to obtain specific subjective insights from individuals familiar with systems that manage human excreta by other means than water (waterless systems). The following are five key pieces of information:

1) Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you would otherwise be entitled, and you may discontinue participation at any time without penalty or loss of benefits to which you otherwise would be entitled.
2) There is a minimal risk of breach of confidentiality.
3) The alternative to participating in this study is to not participate.
4) The requirements for this study include an in-person or telephone oral interview which is not expected to last more than one hour. No more than ten human subjects will be interviewed.
5) With your consent the interviews will be audio recorded to ensure all information is captured. Audio recordings and personally identifiable information will be transcribed onto a Word document located on a laptop issued by the Center for Homeland Defense and Security program at the Naval Postgraduate School in Monterey, CA.

   ☐ I consent to be audio recorded.

   ☐ I do not consent to be audio recorded.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. Records and data will be stored and maintained at the Naval Postgraduate School. Only myself and my two thesis co-advisors will have access to these documents. Your information collected as part of the research, even if identifiers are removed, will not be used or distributed for future research studies.

If you consent to be identified by name in this study, any reference to or quote by you will be published in the final research finding only after your review and approval. If you do not agree, then you will be identified broadly by discipline and/or rank, (for example, “fire chief”).

☐ I consent to be identified by name in this research study.

☐ I do not consent to be identified by name in this research study.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Rudy Darken (831) 656–7588 darken@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831–656-2473, lgshattu@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

☐ I consent to participate in the research study.

☐ I do not consent to participate in the research study.

________________________________ ________________________________

Signature of Participant Date

APPENDIX B. INTERVIEW WITH ALISA KEESEY

Date: May 4, 2020

1. How long have you worked with your system?

To clarify, I don't have a compost toilet at home, but I use a compost toilet at my home when I'm traveling. I do compost all my own kitchen scraps and some yard waste and horse manure at home.

2. Why did you choose to start using this system?

I started using the system because in Haiti, I was working as an emergency development worker, and in our compound we didn't have any toilets at all. . . . I was taught by Joe Jenkins and Hamish Skermer on how to set up emergency toilets for relief workers like myself, and so we just started building toilets . . . [call dropped]. [Call resumed] I tried the system camping in Baja, California, because I bought the *Humanure Handbook*. So I was familiar with it. I tried it out because I needed it in places where I was camping or living where there were no toilets, and I didn't want to use a pit latrine or go outside. But it was only in 2010 when I started to take it seriously as something that could be used in disasters for emergency sanitation at scale. I worked with Joe Jenkins and Hamish Skermer to think about how you scale up this very small-scale Lovable Loo toilet system into something that could manage excreta for thousands of people on site. That developed into me studying decentralized sanitation, using compost-based approaches.

3. What benefits do you realize by using this system?

At the most basic level, I can say and I know many other people will say it, it's a superior user experience than a pit latrine or going outside because you're able to have privacy, and it's completely odor free. It's very hygienic. When you add the sawdust or rice hulls, it's everything about replicating a sit-down toilet. You could sit down and instead of flushing with water, we use what we call a dry flush. We put sawdust or rice hulls on top, and you don't see anything, you don't smell anything, and there are no flies. In Haiti, we make very beautiful toilets. We made them as pieces of art. There were airy bathrooms, and they were painted. I was personally interested . . . in the sustainability aspect of recycling the nutrients of humanure and also saving water because in so many of the places where I use the toilets—whether they be in Baja or camping or in sub-Saharan Africa—you are not going to carry water for five kilometers and then flush it anywhere. So I was very interested in the water-saving aspect of the technology, and then being a professional composter, I've always been involved in some kind of composting. I really like the added benefit of making very rich humanure compost.

4. Do you detect any odors generated from your system?

Never, and the beauty of a humanure system, I'll clarify. . . when done correctly, it is completely odor free. At one point, Jimmy Carter and Rosalyn Carter came to the Santo [community project in Haiti] project, because it was built by the Jimmy Carter and Rosalyn Carter foundation [in the Leogane community]. They built these 300 households in Haiti. They were transitional housing for earthquake victims and displaced families. I wasn't there, but I heard from our staff that Rosalyn and Jimmy Carter went and looked at all the compost bins, and they said, "What is it that's going on here? What are you doing here?" They had no idea that the bins were full of toilet materials. The ambassador of Iceland and some other high-profile Ugandan government officials came to our site because they had seen photos of the site in the slum. They didn't understand that it could be completely odor free, even a very big public site that had something like 16 cubic meters of fresh toilet material. There's no odor. But if you don't manage it correctly, it's just what you would think it would smell like. It will smell like shit. If you use a proper carbon mixture you could actually eat a sandwich or your lunch, or drink your coffee right on top of it. You would never, never know what was there.

5. What do you find to be difficult to manage with your system?

Currently in sub-Saharan Africa and in many developing world contexts, the biggest challenge is getting the fine cover material that's processed at the right particle size. A lot of people like the compost toilets, but arranging for the inputs on a seasonal basis can be hard. You need either sawdust, or rice hulls, or sugarcane bagasse, or other fine carbon material, and then you need a vast supply of cut grass or hay or crop residues.

That's the biggest challenge, . . . organizing and processing your cover material into the right size and shape to compost correctly. Industrial agricultural shredders are good tools for doing this at scale. To manage a composting toilet itself . . . composting doesn't happen in the toilet; it happens in the compost bin . . . [with] fine sawdust. We usually collect fine sawdust from local timber milling places or furniture shops. Animal bedding is used as cover material, the same stuff you would use for horses. This fine sawdust is perfect for a compost toilet system, and I think you can buy 10 cubic feet for seven dollars in the U.S. We bought two five-ton truckloads of this at Standing Rock. They actually use it in North Dakota, South Dakota, and Minneapolis on the roads during the winter trying to get traction on ice. But it's also animal bedding. That's also what is used at the big events in Europe like Glastonbury, some kind of fine mulch or sawdust.

The other thing that works really well, and you can buy them in the United States, especially in California where I live, are these giant bags of rice hulls. Horses really like to use that as bedding, and that is a perfect particle size to do composting. So when we're in the United States and we're setting up a little compost toilet system at someone's house, because I work with off-grid communities in the Santa Cruz Mountains, that's what I tell them to use. I tell them to go down to your animal feed store and buy the fine shavings or the rice hulls. They're between $7–10 a bag, and that would last a regular household months, two or three months, because they're big bags.

6. What do you do with the material in the system?

As soon as the containers are full . . . for normal families they would probably fill two five-gallon containers a week for a small family, and a school would move up to the 15-gallon size, and depending on how many hundreds of kids, you would get 10–15 containers a week. So what we do is use a traditional batch-composting method.

7. Describe the method you use to compost the material.

We mix the toilet matrix with layers of dry straw or hay or grass. For example, at the schools, our bins are four cubic-meter-long rectangles, about a meter high. Once we have an established layer, we tend to integrate the new material into the center. We kind of open it. We call it the volcano method. We open into the hot active area, because we have a dry biological sponge perimeter on the sides, so we open the inside, we integrate the new material on the inside, then we spread the stuff we moved away back in, and then we cover with the fresh layer. So it's not exactly like making a layer cake but it's more like integrating new material into the existing compost matrix, like the hot active zones, if that makes sense.

8. Do you detect any odors generated from your composting practices?

That's a no, never. I manage many different projects in East Africa. The more challenging work has been working with schools, because sometimes the NGOs will look at the system . . . and they learn and then it's very simple, and then they implement it like in an intuitive way and not in a scientific way. So we always say the devil's in the details. If you start treating this like dumping trash like "Oh I have a container, and I'm just going to empty it in a bin, and I'm just going to cover it a little". . . . Essentially, we use wire mesh bins in some places where there are termites where you can't build with pallets. That's why we switched to bricks in Africa. Every once in a while you'll find a little bit of a smell and I'll say, "Well what happened?" Then we find out some kids emptied a container, or a new custodian came on and wasn't taught the proper technique. If you spread the toilet material to the edge of a wire mesh bin, it's predictable you're going to have exposed toilet material. So the proper composting method really matters. In batch composting, if you're making regular manure, you mix your manure and feedstocks, you wet them, and then you build a batch. It's a static pile or batch. Humanure composting is a little bit more complex because you're constantly adding new material until the bin fills. That's the challenge: teaching people to manage a dynamic system; and that there's continuity of that training whether it's a school, or an institution, or a house. We have a number of old women and men over 70 managing their own toilets at home. Farmers are already used to work, and they love it. They say "Oh, it's so easy, and now I can have a toilet in my house," which is very revolutionary for some people in Kenya, Uganda, and Central America. We have a lot of adoption of the system by older people because they're too old to use a pit latrine, to go out in the night and to squat. So they build Joe Jenkins' Loveable Loo, they bring it in their house, and they manage the system themselves.

9. What do you do with the finished compost?

We're using it in kitchen gardens and in agroforestry projects to grow shade trees at Santo in Haiti. The largest project we did had a massive garden, and they were growing tomatoes to sell on the market . . . and bananas. So they're using household gardens to plant basic food and market crops. I use it in my own garden. In fact, I just brought a lot of humanure from Uganda, which we now pelletize—I could send you some photos—to make it easier to transport. . . . Although that's a little bit different product, you don't have as much microbial activity in it. I grow tomatoes, basil, summer crops. . . . I use it in garden boxes in my backyard, and I have a lot of citrus trees.

10. Is there anything else you would like to state for the record?

I think there's a huge potential to scale up humanure-type systems all over the world. I think it would go a long way in making cleaner environments and protecting groundwater pollution. I think the only thing standing in the way is people's attitudes about recycling their own wastes. We say it's only a waste if you waste it. There's some very compelling evidence that if we recycled all the nutrients in urine and feces, we could eliminate the need for chemical fertilizers. I enjoy teaching humanure composting because I think there's a huge potential to apply it in many different contexts.

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APPENDIX C. INTERVIEW WITH BROCK DOLMAN

Date: May 5, 2020

1. How long have you worked with your system?

The system that you're probably thinking about is a current research study going on right now, that we got permitted by the county of Sonoma and the Regional Water Board to compare three different models of toilet. We are a retreat center, so we have guest housing and a large meeting hall. Two of our guest houses each have three rooms with two beds in them, so they support six people per building. Our meeting hall can seat 100 people if need be. We have three different systems in those three buildings, and each of those systems more or less need to be NSF 41–certified, although we ended up with a European model with a SWANS certification that was allowed as comparable. We have a system called a Clivus Multrum, which is sort of the long-standing one that originally came from Europe, probably 40 years ago, and has been in the U.S. . . . that's in the meeting hall. Then, we have one called Phoenix, which is made out of Whitefish, Montana, by a guy who used to work for Clivus and improved it in his own way. Then, we have one from Sweden called the Eco-Carousel, or maybe it was Norway, which rotates like a merry-go-round and has four chambers. Every one of the systems isn't truly waterless.

They have a vacuum-flush-based system, which is needed because in all three cases of the location of where the actual toilet is, which was designed in the buildings before we got the compost toilet permit . . . it's directly overhead of the unit, so it can't just receive with gravity. The one in the meeting hall has three toilets hooked up together with one line, so they need to be plumbed. They all have a varying amount of water. I don't know exactly on each but it's about a cup or less, maybe a third of a cup of water. Basically, it's just enough to lubricate. When the vacuum flush hits, it's like being on an airplane. In one case, the technology is a lot more like a marine toilet on a ship where a vacuum flush device that creates the suction pulls the material in and then has a macerator pump associated with the system. So it grinds it all up and discharges into the top of the three different systems. The Phoenix and Eco-Carousel . . . I think we're going on just about our second year of the study. The Clivus Multrum in the new building, which was the last to be built, is in maybe just about a year. So those three . . . for our testing purposes are somewhat new to us, and they're fairly high tech. They've got a vacuum flush with the macerator pump, and they're connected to electricity, and they've got a little bit of water, and there's various fans and pumps. Some have sump pumps to pump up the excess leachate that gets to the bottom back up on the surface to irrigate, in the case of the Phoenix.

They're fairly complicated in some respects compared to having read the *Humanure Handbook*, which is just five-gallon buckets, the ultra-low-tech version and kind of home scale, backyard scale, couple of family members scale. We're kind of commercial borderline, not municipal, but of a magnitude. That's the study we're interested in, in all honesty, on the systems that are more formalized and mechanized. There are paid staff that are managing them, and monitoring them, and therefore the permit compliance versus individuals in the home.

2. Why did you choose to start using this system?

A couple of things. . . . Our property in Occidental, western Sonoma County, from the 70s . . . the mid-70s . . . 1974 till 1990, it was actually known as the Farallones Institute. If you're researching the history of compost toilets in the U.S., you'll very quickly find yourself to a book called *The Toilet Papers* by Sim Van der Ryn. The toilet that they made very popular, that's often around the world now known as the Farallones toilet, is a double vaulted toilet where you have a building, and underneath it there are two chambers . . . primarily made out of typically cinder blocks with a foundation, maybe it would be wood . . . and then you enter the door and you drop your contribution vertically straight down in. Sometimes there's urine separation, sometimes not. It's probably a meter by a meter by a meter in the space below. So it takes, depending on how many people are using it, six months to a year to fill up. And once one is full, you close that one off, and then people go use the one that's next door. You fill it up. Once that second one is full, you go below and you take off the back wall on this thing. You shovel out the material from the first one. The material on the bottom could be one to two years old, and the material on top is one year to six months. You shovel that typically into a secondary chamber, series of chambers, like three by three by three boxes if you will, in a cascade. It's a low temperature, long-time mouldering toilet. So that toilet that's featured in the toilet papers—the Farallones also was one of the first places to install Clivus Multrums in the mid-70s, and it was a was a Peace Corps training facility. It was an alternative energy-appropriate technology research facility.

We inherited the legacy of a place that had a long history and reputation for exploring compost toilets. Some of us personally, like myself, had lived with compost toilets before we started the center, which is now 25 years ago, and have had different models from five-gallon buckets to different versions. I had worked on and managed compost toilets internationally, especially in Latin America for many years, and now subsequently Asia and Africa. I think we collectively have personal history with them in some cases, international work-travel history with them, and the site had a long history with them. I run a Water Institute at OAEC and we have been very involved in other aspects of the water cycle from water supply, and often storage, and rainwater harvesting and stormwater to the "wastewater" side of life. We are involved in the rewriting of Chapter 16.a. on the Uniform Plumbing Code on the greywater in California, to legalize greywater for residential use in California a number of years ago with a group of people . . . so the laundry-to-landscape and branch drain types of systems. We have a history of being involved in the whole portfolio of parts of the water cycle. It's a natural fit to what we call our conservation hydrology portfolio.

Where we live, we're on-site wastewater, we're not hooked to a municipal system, so everything is some form of septic system. We have about seven or eight. Our perc [olation] rates here are really bad, and our well is very low producing. Anything we can do to use less water, and not have to put water into an expensive system where the leach field doesn't perform well, is a benefit to the overall site. We have additional incentives, if you will, to explore for our actual function of the site . . . compost toilets, as well as model it as a tool in the toolbox, if you will. Not to say everyone should do this, but there are certain locations and applications that work better. I think the other piece of that really is the water–energy nexus . . . really understanding how much electricity is linked to water supply and wastewater disposal, and wanting to engage in reducing the energy demand side. We had talked a lot about this with ourselves. Although, ironically, the three systems we put in all use electricity, and I don't think we reduced our electrical footprint there. The final thing is we prefer to have an output of the system that is a compost that we could use to feed back in soil, for plant health and carbon sequestration.

3. What benefits do you realize by using this system?

These systems we're using are a bit more high-tech with the electricity with the water piece on them. We do have experience and an on-site system that uses zero electricity, zero water, and is entirely gravity-fed low-tech. While that system is not formally part of the study per se, it is a legacy system that's somewhat permitted. It's kind of a side project that I'll get to in a second. I think in that regard, the benefits are attempting to use less water, ideally using less electricity, reducing demand and stress on septic leach-field systems, and producing an output of organic material that feeds back into the biology on our site, the soil food web on our site, to grow more plants, which can then do photosynthesis to sequester more atmospheric carbon. Then there's the education and demonstration piece of it for our research center.

4. Do you detect any odors generated from your system?

No. When you go to use the three models being trialed, you walk in the bathroom and there's a porcelain throne right there with a little bit of water in it. If we didn't put signage up you wouldn't smell or tell there's anything other than your using a toilet. You push this button and you're like, "Why am I on an airplane? What's up with this flush?" But other than that, on the front end, for the user experience, there's zero odor. You're not opening a lid, like in the dry toilets that are truly dried or gravity fed where you open the lid, and if you want to look in there you can see right down on it, whoever was there before you. There's a distancing to them. We have kind of colloquially made up this idea that we have our G & G criteria. The first G is government. We're trying to make sure we're working on something that's in compliance and meets a set of standards, health and safety standards, around reduction of fecal coliform and certain parasites and pathogens. So there's a rigor to this. It's testable. Our goal here . . . the collaborating third-party entities, Stanford University and UC Davis, develop the protocols for us. We take samples, we send them to their labs, and they're testing them with a rigorous methodology that's replicable.

Eventually, depending on the outcome of the study, our intent is to publish this so that it's peer-reviewable and thus policymakers and others can use it as part of their literature for supporting policy changes as appropriate. So government is the first G, but on the front end we talk about grandma. Which is, we want grandma to be happy on this toilet and not feel as though it's weird, like "I don't want to lift the lid," or "There's a spider down there. It smells, and there are flies," and all that kind of old classic outhouse appearance . . . which in some cases is true and in some cases is not.

5. What do you find to be difficult to manage with your system?

I think we're still getting used to them, each of the three different systems has its quirks, its pros and cons. The folks who are here on a weekly basis more or less are down there lifting the lid underneath, and are either supplementing with some additional carbon material . . . because we add wood shavings to each of them. In the Phoenix, we've actually added worms. We have a vermicompost happening down there as well. I would say all three of them have had different issues. A couple of them had mechanical issues. The vacuum-flush systems with the pumps, and the macerators, and the mechanism on the toilet in a couple of them broke early on . . . or we had to fix, or we've had to replace… so there's a little, there's some sort of mechanical annoyances about it. Once you get the material into the digesting units and let biology do what it wants to do, it all seems to be going along really well. The amount of liquid in the system is an issue. In the meeting room, we also set up urinals, and they're waterless urinals. So at least the men standing up can use a waterless urinal, and that urine goes down to the system but doesn't come with the cup of the flush of water every time. So, it reduces the total volume of water in that system, which feels like it's good to us.

In the system not part of the study, that's been there since the mid-70s [the Farallones toilet], that one is in an area where people have already done their number-two business. It tends to be a toilet that gets a lot more number-one usage, and thus the liquid, thus the nitrogen, is a big issue. At some point balancing your carbon–nitrogen ratios by adding material is important. We've got some urine diversion on that toilet, where there's a seat and you sit down, and there's a hole on the front end, and there's one for the back end, and they go to separate places. That helps with smell, to be honest with you. My experiences with compost toilets at every scale I've worked with them, is it's all about carbon–nitrogen ratio. When there's too much moisture, i.e., urine with nitrogen that can get anaerobic, you start getting that smell to it, that ammonia smell. So that's always a dance. That nitrogen is so critical because it's required to break down the carbon, so we needed a certain amount. So it's biology on the toilets is where the fun part is. I'm less interested in the physics and mechanics of them. I'm a biologist.

6. What do you do with the material in the system?

The ones that are part of the study, the plan is . . . the permit is that we use them to a point where we feel like there's material at the bottom that's adequately composted. Then we sample that material according to the protocols, we send it, and the county gets a sample, which they freeze for future reference, and then the sample goes off to Davis and Stanford. If the results come back, demonstrating that the material is below the thresholds for fecal coliform and the suite of pathogens and parasites that are part of the study, then it's deemed to be a compost that's non-pathogenic. Then, we have an area because we're a rural site . . . we have a forested area that's mainly Douglas fir forest and a little understory, and we've got a designated area that's got a little bit of signage around it. We land apply it in a thin [layer] . . . we just spread it out down underneath the trees, put a little bit of woodchips on it to cover it up, and allow it to become part of that forest mulch leaf litter for feeding the trees. So, basically, our system is that it goes from toilet to tree.

7. Describe the method you use to compost the material.

In the case of the three vaults . . . they're sold as, and we're hoping that this works, that the composting is happening sufficiently within the vault itself so that by the time you get to either the bottom of them . . . or in the case of the carousel you fill up one quadrant, then you fill up the second, third, fourth . . . and by the time you get back to the first, it should be finished. Then you empty it and start filling it, as you're always kind of rotating. We've done one round of tests on the eco-carousel and on the Phoenix. The Clivus got put in later; it hasn't had enough time.

8. Do you detect any odors generated from your composting practices?

No. You can always take tours and just go down there and lift the lid. I welcome people to stick their head nearby it and waft some up on them. I'll take pictures of them because most people aren't willing to get close to the things. Yes, generally, all of the people on tour who stick their head in there go "Oh my God, it doesn't smell. That's amazing!" or "It just smells like earth. It smells like humus." The one that has the worms in it, the Phoenix, with respect to maintenance, there is a lack of any need for significant repairs on it, the performance of it. It's currently the one that I think all of us like the most, and the worm composting that's happening there is amazing. There's so many little red wigglers in there it's incredible.

9. What do you do with the finished compost?

[see #6 above]

10. Is there anything else you would like to state for the record?

I think the interesting piece . . . is that… large centralized wastewater systems have had their benefit, especially as urbanization and such got to levels where we needed to deal with it. I think that many of us have found that there are times when the scale and the outputs, and the need to discharge, and the emerging contaminants, and a whole bunch of secondary/tertiary issues are flummoxing. So anything that we as society can do to increase the diversity of options in the toolbox, and where appropriate, if humanure compost toilets can be done in a way that's safe and meets these multiple benefits, it seems as a society we would be astutely benefitting from figuring that out. On behalf of protecting public health and safety, in recognizing that in many cases much of the pollution of our rivers and lakes and near shore waters often has to do with the discharge of the so-called wastewater systems, that only gets it to secondary levels. I think humanure toilets get an unfair disadvantage because of the ignorance on the permitting and engineering side, so we're looking to give them a fair shake.

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APPENDIX D. INTERVIEW WITH JOSEPH JENKINS

Date: May 5, 2020

1. How long have you worked with your system?

I started composting in1975, but I didn't start composting toilet material until '76. So it's been 43 continuous years.

2. Why did you choose to start using this system?

Well, it was a matter of circumstances. In '75, I lived without running water; in '76, I lived without electricity or running water. In '77 . . . actually up until '89, I lived without electricity . . . just a hand pump for water. So I was in three different locations, none of which could accommodate a water toilet, and it just kind of . . . morphed into this kind of composting process, and I've been using it ever since because I use the compost.

3. What benefits do you realize by using this system?

A: It provides sanitation. You know, you gotta do something with what comes out of your body, and flushing it is one thing you can do, but it's not the only thing. Composting happens to be another way of providing sanitation, but also I always had a garden. My first garden was an eighth of an acre in 1975, and that's when I realized how important soil fertility is. So the farm that I lived on, the farmhouse with no plumbing, it had depleted soil. It had been farmed out, and you couldn't hardly grow anything. So I had to haul in all the manure, and all the soil fertility for the garden, and that continued. Every time I had to plant a garden I had to find some way to fertilize the soil. So when I got my own property, same thing, soil was an old field, an old potato field from the bygone days, and the fertility had been kind of depleted, so I went out and got manures any place I could find them, which is a big pain in the ass . . . the first year. And by the next year, I was making my own compost, so for the last 40 years, I've only used my own compost. . . . I have some chickens too. . . . I use that chicken manure as well. It's a complete recycling system; there's no waste involved, even the wash water from the toilet receptacles gets introduced into the compost. It's a closed, contained system. Nothing goes to waste.

People in flush toilet cultures . . . you know, I talk to people around the world, and people who don't have flush toilets, or . . . there's lots of people who never had a flush toilet, nor have their ancestors, from the beginning of time. And when I talk to those people, they understand right away what I'm doing, and it's a revelation to them. . . . They say, "I didn't know you could to THAT." In flush-toilet cultures it's a whole different thing. I tell them, a compost toilet is a waste-free toilet. And they're like "What, are you talking about? It's human waste." Well, no it isn't. If you're recycling it, there is no waste. …

4. Do you detect any odors generated from your system?

You know, if you go in and use a flush toilet and defecate and then leave, someone else walks in and they're gonna smell it, you know what I mean? I mean there's no 100 percent odorless situation when there's shit coming out of your ass. Generally speaking, yes, it's completely odorless. I have one right here in my bedroom right now. I have one here all the time; I have one in the guest bedroom across the hall. And nobody smells anything. There's one downstairs in the main bathroom. I have one in my office, one in separate guest quarters out in a separate building, and as long as they are properly managed . . . you know, if you have a flush toilet and don't flush it, you'll smell it.

5. What do you find to be difficult to manage with your system?

It's not really difficult if you want to have, you know. . . . The main difficulty logistically is providing the cover material. The cover material . . . if you don't have a carbon-based material you won't have a compost toilet, in the same manner if you don't have water you won't have a water toilet. There are plenty of places in the world where people can't get water, or don't have water, but they can still have a toilet if they realize there is a different way to . . . provide sanitation. So for me, it's not a problem. That's another serendipity element. . . . When I moved onto that old farmhouse, it was on 212 acres that had no plumbing or anything. I did have electricity, but it was old and abandoned. It had no windows. I had to put windows in it. There was no heat. . . . I had to put wood stoves in it. There was a pile of sawdust down over the hill . . . on the property where they had timbered 15 years prior. So this is local . . . local sawdust that was 15 years rotting in the woods. And, in fact, I . . . added that to my first garden. I put a heavy layer of that on the soil with the wood ashes from the saw mill . . . with manures and anything I could find. But I had access to that sawdust, so when I moved to the next place and this guy built what he called a composting toilet, which was a really dumb design, we just used a five-gallon bucket, which we used and covered the contents with the sawdust, and there was absolutely no odor at all.

I'd say on a world-wide large-scale scenario, at the moment . . . there's lots of opportunities to create carbon material. You could use cardboard, paper products. . . . You could use any plant material. You can grind it up, that's the thing, you can't throw a telephone book on top of your compost pile, but if you grind it up it'd make great cover material.

6. What do you do with the material in the system?

It all goes in the compost along with a lot of other stuff.

7. Describe the method you use to compost the material.

I compost everything in a bin . . . a walled bin. . . . I use square rectangular bins here. Mine are all made out of wood. When you travel around the world, they might not have . . . they might have access to other things like . . . you can make bins out of wire, like wire fencing. You can make bins out of straw bales. You can make bins out of blocks, bricks, bamboo, reeds . . . anything, anything that will contain the toilet material and any other material you are composting in a vertical pile above ground.

8. Do you detect any odors generated from your composting practices?

It's the same situation. No, not if it's managed correctly. You know, the whole thing . . . the toilets, the compost, all that stuff will smell bad if it's not correctly managed.

9. What do you do with the finished compost?

Well myself, my personal compost I use for growing things. All my household compost goes into my garden, my food garden. I have compost up at the business . . . it's all used for horticulture. I don't have a garden up there, but occasionally I'll plant something food-bearing and I'll use the compost for that. I have trees and shrubs and everything else up there, so that's where the compost goes.

Abroad . . . the fact of the matter is it takes a year to make a compost pile, basically. . . . I mean you can make a pile in a day if you have enough stuff, but you have to wait a year for it to compost. So scenarios we've been in, we show them what to do, they build a pile for a year, then it has to rest for a year. Then, after that second year, it can be used. So we haven't had situations where it'd been into the third year. We have one school in Haiti—they had gardens on site—they were using the compost on site, and they were just well into their third year when I went back to document. I wanted to document the gardens because that's really important. And when I went back, the entire school, which was on about an acre maybe . . . had been bulldozed flat. There was nothing, nothing left. So that was my big . . . you know, where I was hoping to get a lot of documentation on the third phase. There was another big project in Haiti where we made hundreds of tons of first-class compost, but the people in the village were displaced from the earthquake . . . you know, from the city. There was a village that had been set up for them, and none of them were agricultural. So Habitat for Humanity built these little houses for them, and none of the people were into growing anything. They had these hundreds of tons of really nice compost, and nobody did anything with it. So we actually abandoned that site.

There were security issues . . . there were gangs robbing the workers. . . . The last I heard somebody from a farm came in and paid money, and just took it all . . . took all the compost. And another site we did there, same thing. We built a pile and left it, and it wasn't being used because it was a tent city, and they didn't have . . . nobody there is agricultural, they weren't . . . they needed to be trained. You can't train them until the compost is finished. You gotta train them on how to use it. Not just how to use it, but when you grow food, then they gotta be trained on what to do with the food. You know, the food is . . . preserved, it's prepared, there's all kinds of things you have to do. I liken it to teaching people how to plant apple trees. The next thing you know they got apples on the trees, which they weren't expecting and don't know what to do with them, so you gotta teach them what to do with the apples. They can make wine, they can make pies, they can them, they can freeze them.

10. Is there anything else you would like to state for the record?

First off, I think it can be an extremely valuable emergency management . . . technique. But, they really need to do some pilot program or somewhere where they are actually trying it out so people can understand how it works. . . . It would be smart to have some sort of chipper, shredder, grinder and be able to just grind up cover material in quantities, and maybe have a big dumpster to collect everything so it doesn’t . . . so it’s easy to . . . so that it can be collected without risk of any contamination, you know that sort of thing. I’ve thought about it for a long time. In fact, the first time I went to Haiti, which was 2010, that was the plan . . . to devise a dumpster with a drain, make compost in it, and see how it worked. But nothing in Haiti works. . . . The dumpster they brought me, they welded the seams and you could see daylight right through the seams. That kind of thing.

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APPENDIX E. INTERVIEW WITH LAURA ALLEN

Date: May 8, 2020

1. How long have you worked with your system?

I'd say about 15 years or so, but different iterations, not the exact same system.

2. Why did you choose to start using this system?

I chose to start using them because I wanted to save water, recycle nutrients, and have a system that's easy to manage in my home.

3. What benefits do you realize by using this system?

A lot of water savings, not being reliant on the sewer system, and nutrient recycling . . . so keeping all the nutrients on site, and managing so-called waste in a safe and ecological manner.

4. Do you detect any odors generated from your system?

Not really! I lived in a small apartment in the Los Angeles eco-village, and we took out our toilet and put in a sawdust toilet in a very small bathroom in a small apartment. You didn't smell any odor unless you actually lifted the lid. If you lifted the lid you could smell some odor, usually an earthy smell, nothing offensive. If there ever are any bad odors, which can happen, the bucket needs to be emptied. Usually, it's when it's full, or there's too much liquid, or something's not quite right. Then it's easy to deal with because you put the lid on the bucket, put in an empty bucket, and the problem is solved.

5. What do you find to be difficult to manage with your system?

You have buckets, five-gallon buckets, and they fill up about once a week per user. It's nice to have a place to put full buckets that's not very far away. When I lived at the eco-village, we had a closet, so I would just put the full buckets in the closet. Once I had four full buckets, I would empty them all at once, so I wouldn't have to do anything except for about once a month, which felt manageable but it's different. There is an extra step. If you have a flush toilet, you only have to clean your toilet, and possibly deal with a clog on occasion. You don't ever have to go outside and do anything. There is not a lot of time, but there is that additional effort involved.

6. What do you do with the material in the system?

I've done two things, and they both work. There's pros and cons to both ways. One is a bin, a feces-only bin, a 55-gallon drum. That is nice because it is totally isolated, and you can pretty much put it anywhere because it's contained in a plastic drum. It doesn't compost as well as the next one, but it's fine. You don't really get the best compost out of it, but you do get a useable material. It's pretty easy to manage. You do have to empty the bin after a year, but the material really decomposes a lot. The other way is a hot compost pile, which requires a three by three space on top of soil . . . actually two of them because you have to have alternating bins. You also need to have more material to add like green waste or food scraps. You just build this really big compost pile and it gets really hot, and it composts quicker and better. I've tested the compost; the finished product out of the hot bin versus the drum system—which actually doesn't get really hot, it's a slow compost process—and the quality of the compost is much better from my hot compost. Either one works. I sent it to a lab and tested it for fecal coliform and moisture . . . whatever the NSF 41–certification requirement for finished compost is. There's two things you test for, and it's moved into some of the codes around composting toilets. The water efficiency standard has the testing requirements for a toilet, so I just followed that to see how my toilets were doing or how my compost processors were doing. They both met the code requirements, but the hot compost did much better.

7. Describe the method you use to compost the material.

[see #6 above]

8. Do you detect any odors generated from your composting practices?

When you have the barrel system, there is a slight odor when you dump the buckets into it. It's little bit of an anaerobic smell because the bottom of the bucket gets a little moist and slightly anaerobic, usually. There is not a lot of big odor, and it's pretty short, just right when you dump it. Then, when you dump it, you add a layer of leaves or wood chips or something to cover it, so there is never raw material on the top. That's the only odor. From the hot pile, there is not a lot of odor. It’s the same thing. When you dump it, there is a brief odor of just the buckets being emptied. Then you also cover the hot pile with other material like straw or leaves. I would say odor is one of those things. . . . People have a lot of range of tolerances to odor.

9. What do you do with the finished compost?

You can do pretty much anything. There’s what you can do legally with it, and there’s what you can do with it that I feel is safe and effective. Those are often different. There are codes that require it to be buried a certain depth around non-edible plants. Other places don’t really say anything about what you can do with it. But I use it. I either add it to my other compost pile if I feel like it’s not really great compost yet, so I’ll just mix it in, and then it will go through another process. There are two things. If I do the barrel method, then there is only humanure, and it’s usually not a great quality compost because the feces and toilet paper compost much quicker than the wood chips. So it ends up being pretty wood-chippy or has a lot of wood-shavings. It’s not bad, but it’s kind of nice to let it compost a bit more and break down further. I also use it, because it’s not a lot—it really breaks down a lot. If you fill a 55-gallon drum, at the end, you only get about a third of that. I put it in an area that’s going to be a new garden bed, or put it around trees. It’s pretty easy to use up.

10. Is there anything else you would like to state for the record?

I think for disaster preparedness, the bucket toilet is a great option. In different places they are using the pee bucket and the poo bucket, because the pee you can just dump out and it doesn’t require as much carbon material to soak it up. That’s a great option. For daily use, it’s not quite as good because now you’re managing two systems. Some people it works for, and I’ve done it in the past, but after doing it for a long time I’m not interested at all in making extra work for myself. So, for in-home, I would say not having two systems is the way to go. But for when the sewer is down, and what can we do? Keeping the urine out of the system will be a lot better.

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