A FEASIBILITY STUDY OF 21ST-CENTURY SANITATION IN NORTH CAROLINA

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ABSTRACT

Sarah E. A. Long: A Feasibility Study of 21st-Century Sanitation in North Carolina
(Under the direction of Jamie Bartram)

There is growing recognition among practitioners and government officials, of the human right to safe water and sanitation. As the United States of America invests in its water and sanitation infrastructure over the next decade, it is worth exploring opportunities to the limitations of conventional systems. Sewer systems are costly to install and maintain, while septic systems are prone to poor maintenance and made challenging by not suitable soil conditions. Inspired by examples of sanitation innovation abroad, I explore what a 21st century sanitation system, that both meets sanitation gaps and improves upon conventional systems, would look like in the U.S. using the case of the state of North Carolina. I conducted a literature review of sanitation alternatives and conceptualized the design of a system that meets the health, economic, and environmental needs of a range of communities within the state. I conducted qualitative analysis of a series of interviews to examine incentives, barriers, and perceptions among key stakeholders. I explored the financial feasibility of such a system, for communities in North Carolina with a range of available resources.

Results suggest that the primary incentives for a conceptualized alternative are environmental, and economic, particularly in comparison to septic systems. The biggest advantage over septic systems would be the decreased minimum lot size due to the elimination of a septic drain field. The conceptualized alternative's capital costs are estimated to be cheaper than both sewer and septic; however, maintenance and lifetime costs were higher than the conceptualized systems, making the alternative's overall costs more expensive. The potential for

resource recovery and retrofitting existing infrastructure are, however, promising. The stakeholder responses to the conceptualized design warrant further exploration of this conceptualized system.

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CHAPTER 1: INTRODUCTION

There is growing recognition of access to safe water and sanitation as human right. The United States of America (US) will need to invest in its water and sanitation infrastructure over the next decade. Although the US has boasted 99% water and 89% sanitation service coverage for more than a decade, a deeper examination shows systems in need of repair and replacement, and over 10% (33 million) of the population on basic sanitation systems, which typically treat on site and provide less of a barrier to contaminated waste [1]. These realities present serious public health, economic, and environmental concerns

The American Society of Civil Engineers (ASCE) gave US wastewater infrastructure a nearly-failing ("D+") rating in its 2017 infrastructure report [2]. They estimate that an investment of $271 billion is needed for wastewater infrastructure to meet the growing demand of 56 million new connections to centralized wastewater treatment systems by 2032, as well as increasing the capacity of existing infrastructure and replacing antiquated systems [2]. In fact, much of the water and sanitation infrastructure is in need of renewal, creating opportunity room for innovation and design. The improvement of US water and sanitation infrastructure is such a big endeavor that it warrants an examination of our approach to sanitation, including what works, and where we can improve.

Engineers often focus on three main areas for design improvement: increasing efficiency, improving safety, and decreasing cost. The conventional engineering approaches fail to respond to gaps where inefficient, and fails to account for innovation opportunities in these gaps. Engineering philosopher Henry Petroski argues that, by the exploration of failures, we can improve our design solutions and lessen our risks of disaster caused by failed infrastructure[3]. Given the size of the US economy, one could consider any gap in sanitation coverage as a failure in design as opposed to a problem of available government funding. In this way, we can look at gaps as opportunities for gathering essential information that can help us improve technology and the systems of support around it. Such an awareness of sanitation gaps as produced from both failures in design and sociopolitical failures is increasing in the face of highly publicized cases such as Flint, Michigan, and Lowndes County, Alabama [4].

In part, this research seeks to extend this growing national awareness to consider local cases in North Carolina. In the case of North Carolina, extraterritorial jurisdictions, often used as a form of *de jure* segregation in the mid-20th Century [5], have been linked to a systematic denial of basic services including water and sewer [6]. As will be explored further, these communities include historically African American communities outside of Mebane, NC, and the Rogers Road-Eubanks community of North Chapel Hill, NC.

These gaps in access to adequate sanitation are tied to complicated and nuanced problems that require comprehensive solutions. Sanitation is a fundamental need for the anthropogenic environment, and requires a holistic and innovative approach to meet contemporary needs of communities. In fact, the ASCE recommends the further development of green infrastructure that meets economic and environmental, as well as public health needs [7]. Despite the calls by the ASCE to improve municipal sanitation infrastructure, however, there have been very few sanitation alternatives presented over the last half century.

This lack of innovative design in sanitation systems in the U.S. context is not representative of what is happening globally, however. For instance Ecological Sanitation (EcoSan), an idea from the 1990's, has been a part of discussions around sanitation development for decades [8]. It has focused on decentralized composting toilets, meeting the needs of those without access to sanitation technology as opposed to a system that would replace conventional infrastructure. The main idea of EcoSan is sanitizing urine and feces and recovering the nutrients for goods production [8]. In doing so, it meets socio-economic and environmental, in addition to sanitation, needs [8]. In addition to the Eco San is the Bill and Melinda Gates Foundation Reinvent the Toilet Challenge [9]. Since 2011, the Gates Foundation has issued grants focused on reinventing the toilet to address a lack of adequate technology to address gaps in sanitation in low and middle income countries. The projects are non-sewered sanitation approaches, and include advocating for public policy that support improved sanitation [9]. Most of these projects have focused on addressing gaps in access to sanitation in Sub-Saharan Africa, and concern onsite collection and processing [9].

Inspired by these examples, in this paper, I explore what a 21st century sanitation system that both meets sanitation gaps and improves upon conventional systems would look like in the U.S., using the case of North Carolina. To analyze the case of North Carolina, I conducted a literature review of sanitation alternatives. I then developed design criteria for a system based on a simple gap analysis for the state. I focused on specific cases where health, economic, and environmental concerns could be generalized for the state and the country. Using these criteria I developed a conceptualized design of a system that meets the health, economic, and environmental needs of a range of communities. I then conducted qualitative analysis of a series of interviews to examine the incentives, barriers, and perceptions among key stakeholders. Finally, I explored the financial feasibility of such a system for communities in North Carolina with a range of available resources.

I explore the following research questions: What would a robust sanitation alternative look like for North Carolina? Is the conceptualized system economically feasible for a range of communities in North Carolina? And what are incentives, barriers, and perceptions of this system among various stakeholders?

Background

Limitations of Conventional Sanitation

The improvement of conventional sanitation approaches, such as sewered municipal systems and septic tanks with drain fields, requires analysis of public health, economic, and environmental concerns. With respect to public health, management of human waste provides an essential barrier to the spread of disease. Failure in the management of human waste can lead to major public health crises. For instance, according to the ASCE, "deficiencies in the systems used for the pubic-provision of drinking water and handling of wastewater and storm water can trigger bacterial and viral outbreaks." Incidence of water-borne bacterial and viral illnesses has been tracked by the EPA and CDC for the last 30 years [7]. These problems are often compounded when paired with the disproportionate disease burden caused by structural inequalities such as infrastructure funding gaps. Recent reports of the return of diseases such as hookworm, previously considered eradicated, heightens concerns regarding sanitation and the possibility of water-borne illnesses[4]. Not only are failures in sanitation that cause water-borne illnesses costly in the sense of health, they are economically costly: *per capita*, worldwide effects of water-borne illness cost a projected $98 billion [7].

A deeper economic analysis reveals other ways that failures in sanitation and economic challenges are interrelated. Sewer systems, particularly pipelines and pumping stations, are expensive. For this reason, smaller municipalities have difficulties expanding these systems and repairing them, especially as the cost of retrofitting and replacement of failing infrastructure can be even more expensive. Areas that are not serviced by sewer systems often rely on septic systems, which are costly and require frequent maintenance. In their Failure to Act report of 2011, ASCE warned of the potential negative impacts of not investing in US infrastructure: "Although access to centralized treatment is widespread, the condition of many of these systems is poor, with aging pipes and inadequate capacity leading to the discharge of an estimated 900 billion gallons of untreated sewage each year [7]." Thus, there are economic challenges to providing equitable access to sanitation and, in turn, improved public health and a healthy environment.

Beyond being economically unsustainable, current wastewater management systems are proving to be environmentally unsustainable. Water is an increasingly scarce resource, and we contaminate water more than we can treat it. Other environmental challenges include that, in some areas, the physical environment restricts the performance of currently available technologies. For example, soils with poor permeability restrict the use of septic systems.

The Case of North Carolina

Given the public health, environmental, and economic effects of our current approaches to sanitation, what is getting in the way of change? To determine this let us first look at the problems of the current approach to sanitation in the US and specifically North Carolina. For the purposes of this study, North Carolina-specific water and sanitation problems are critical in underscoring the importance of exploring sanitation alternatives to our current system. North Carolina's history of droughts, particularly in the 1970s and 1980s, make it especially important to save water in areas that get rain and thus explore sanitation options that are not heavily reliant on water. On the other end of the precipitation spectrum, North Carolina has experienced notable flooding since the mid 1990's from Hurricanes Fran (in 1996), Floyd (in 1999), Matthew (in 2016), and Florence (in 2018) to name a few. It is well documented that high precipitation events and flooding adversely impact septic tank performance [10]. For areas using combined sewers, high precipitation events and flooding are also linked to water body impairment through nutrients loading and eutrophication [11].

Water and Sanitation Challenges in North Carolina

In North Carolina, over 20 percent of utilities have operating revenues that exceed expenditures, and loan payments[12]. This prevents these utilities from making essential infrastructure improvements and extensions without raising rates to an extent that could be unaffordable for users. Many of these utilities are in counties designated as “distressed” by the NC Department of Commerce, based on their average unemployment, median household income, population growth, and property tax base per capita [12] (See APPENDIX 2).

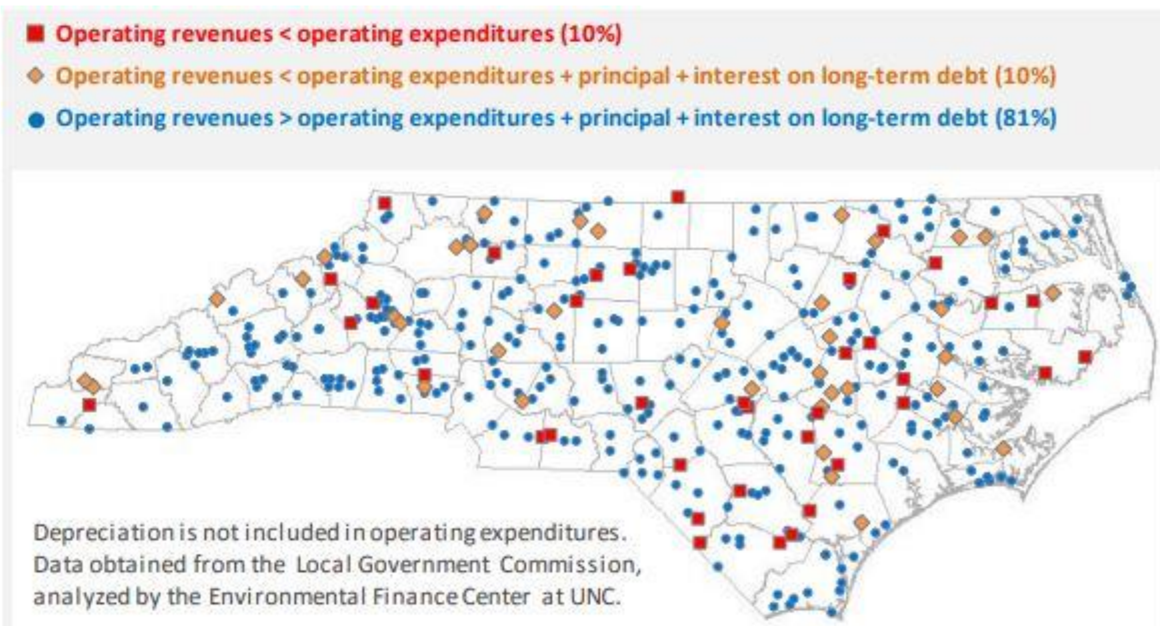


Figure 1: Water and Sewer Utilities operation revenues vs. operating expenditures in North Carolina [13]

Based on the above challenges faced by North Carolina Wastewater Treatment systems, I explored the opportunities to use dry sanitation, or a system that conveys waste without the use of water.

The Urban BioCycle

The framework of the urban Biocyle, as defined by the Ellen MacArthur Foundation, is depicted in Figure 2. Municipal dry sanitation would fit nicely into the Urban Biocyle model, reducing the total amount of waste worked. Instead this system would allow human waste to go directly from organics and recycling collection (system A) to the in-vessel to the high solids digestion and co-composting (system D). Section F of Figure 2 shows the Bio-gas utilization options including combined heat and power (CHP) systems, renewable compressed natural gas (R-CNG), and renewable natural gas (RNG) [14]. Section G shows the land application option for bio products and bio fertilizers from the treated organic waste.

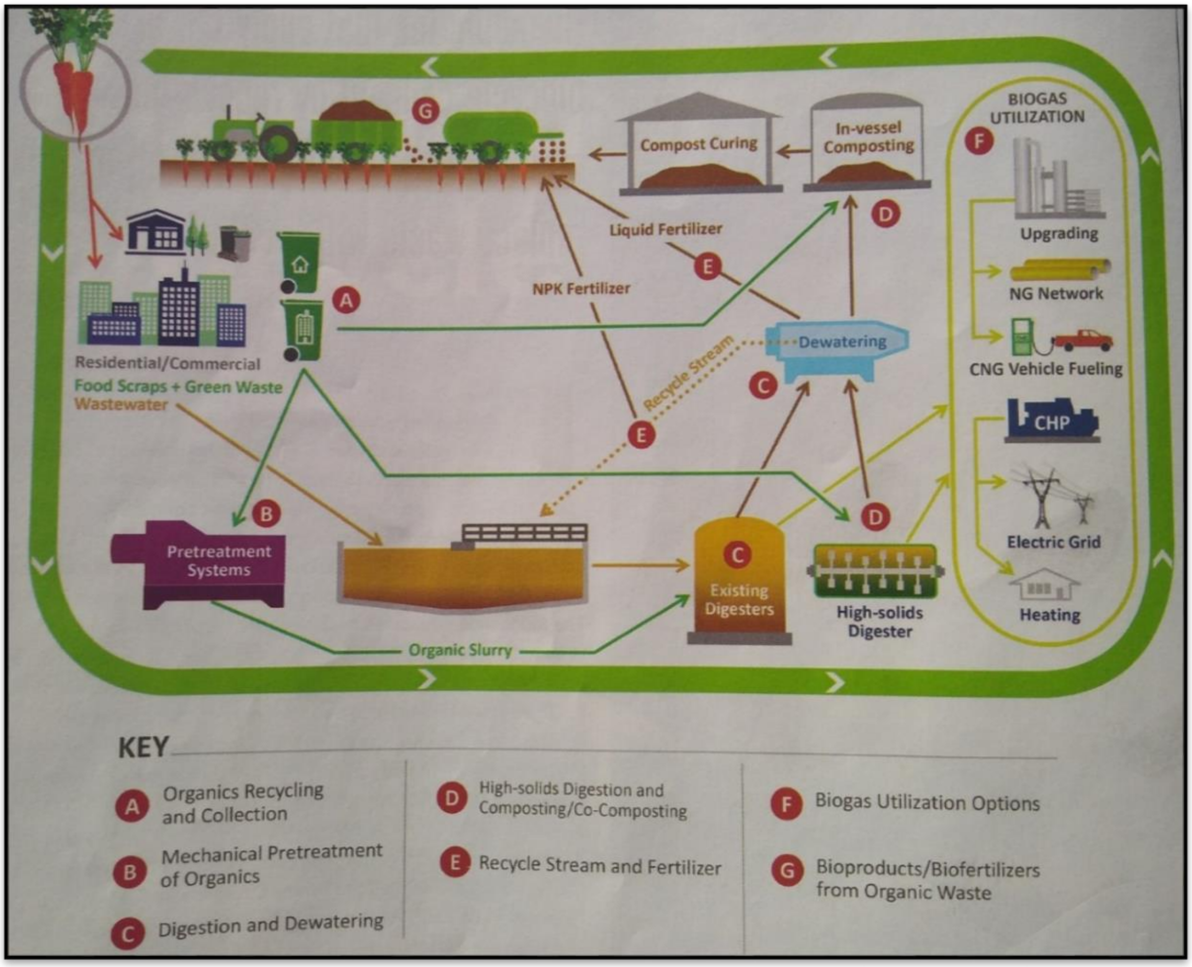


Figure 2: The Urban BioCyle. [14]

CHAPTER 2: METHODS

The research consisted of three parts: literature review and specification of a conceptual design; a quantitative financial analysis comparing the cost of conventional systems and the conceptual conceptualized alternative; as well as collection and qualitative analysis of stakeholder interviews;. The design specification was conducted first to provide a concept for discussion during the qualitative data collection, and to develop costs for the alternative dry system in the quantitative financial analysis.

Conceptual Design Development

This was a process of conceptualization and specification development, as opposed to prototype design. To address the geological and climatic concerns with water in sanitation system, I explored conceptualized alternative sanitation options. The system consists of four components, similar to the framework of Eco-Sanitation systems: user interface, collection and conveyance, storage and primary treatment, and reuse/disposal). These systems require smart design and optimization for efficiency and ease of use. For this specific design, a dry sanitation approach was explored. Dry sanitation implies that no water is used for the conveyance of waste. This particular system includes a superior user interface with household storage, pick-up, and municipal or centralized treatment.

All of these technologies exist in some form and through the study I specified which technologies would be most appropriate.

Figure 3 displays the dry sanitation system components and there order in the process. These components were specified, and optimized based on the aspects in parenthesis:

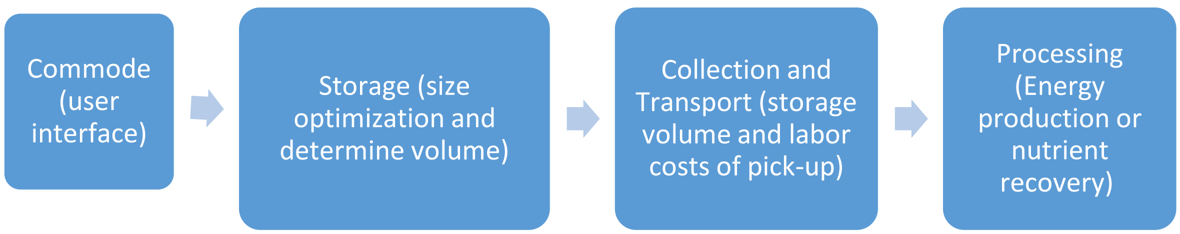


Figure 3: Conceptualized Alternative Components

The first component is the commode. This mimics the conventional, commercially available, home toilet as much as possible. Also like the conventional unit, the goal of the commode is to capture and remove waste without exposing the user. Instead of a piped system, the commode will connect to a chute that leads to the storage unit. There are two design options available: a commode with biodegradable bags, and a commode attached to a chute with suction.

Component two, Storage and Containment, consists of a storage unit at the household level. This outdoor storage is designed to reduce odor, is sealed to prevent water intrusion, and secured from pests. There are two options for this design: a removal pod storage and a single storage container. For the removable pod option, there would be one active pod and a back-up pod for over flow, or delayed service.

Component three, Collection and Transport, consists of the regular collection of the waste (in bag or pod form) by a sanitation system that transports the waste to a nearby processing center. This system requires transport logistics and modification of existing solid waste management trucks. Future research and design could explore the optimization of the collection system, including the potential use of sensors to detect the need for pick-up.

Waste Processing is the final component of the proposed conceptualized alternative. The goal of this component is to neutralize the waste and recover value through either a composting or an energy conversion process. For this project, the processing section was only explored to understand the potential waste flow and cost recovery in existing systems, as opposed to a design of a processing system.

I first developed a mind map of the conceptualized alternative sanitation system working with Dr. Jamie Bartram. This initial brainstorming process included the identification of four key components of the system, commode & collection, storage, transportation, and processing. Based on these identified components, the overarching problem, and the objectives of an alternative system, I conducted a literature review. During the interviews, there components were shown and discussed (See APPENDIX 6: INTERVIEW G).

Storage Tank Capacity

One key design component was the capacity of the storage tank (v). To determine this I used the average daily weight of feces and urine and determined the volume:

$$v = w / \rho$$

The Greek letter ρ (rho) stands for density. For this quantity I used the density of sludge 45.01 lbs./ft3 [15].

Weight “w” is equal to the average combined feces and urine per person per week multiplied by number of persons per household (n). For this project, I assumed five persons per household.

Optimization

The pilot design developed from the above estimate leaves room for optimization of the collection and storage process. The optimization of collection would depend on the amount of time waste can safely be stored at the household level, and the economic feasibility of pick-up frequency.

Development of Interview Guidelines

The qualitative analysis began with the development of an interview guide and a series of mock interviews. The mock interviews included two interviews with graduate students in the Department of City and Regional Planning recording feedback about the system and interview, and applying the feedback to the system design and interview guide (See APPENDIX 6: INTERVIEW G). These graduate students were chosen for given their familiarity with the planning process and infrastructure, and unfamiliarity with sanitation outside of personal experience. From their feedback I refined the interview guide for clarity of questions, and provided additional details in the presentation of the conceptualized alternative.

A deductive approach was used to create codes and develop the interview guide. The initial interview questions concerned the stakeholder’s role in their organization, their experience working with sanitation and understanding of conventional sanitation systems.

Community Scenarios

The community scenarios represent community-types interested in alternatives to sewer or septic connections. All are represented by real communities in North Carolina's Research Triangle Area in Chapel Hill, Chatham, and Durham Counties. Located outside of urban areas, these communities are near municipalities with high density and full municipal water and sewer services. They have similar geographic characteristics and climate conditions, making their sanitation options technically comparable. For the analysis I consulted existing master plans and studies when available.

For one community, their interest is the result of gaps in access to sanitation due to economic, social, and political factors. It is outside of urban areas and could be considered peri-urban and typically contain modest population density. In this study, I selected this community to be representative of communities with low resource access, and I categorize it as "low resource community. " The analysis for this community scenario was based on community-based reports along with Orange County Health Department documentation[16].

The second community I selected is motivated by environmental concerns, such as wanting to reduce their environmental footprint. I focus on a rural land cooperative that is intentionally exploring sanitation alternatives. They intend to growing produce and are interested in waste use. They have somewhat of a flexible budget, and I selected them as representative of communities with mid-level resource availability. I categorize this community as "middle resource community." The analysis for this community scenario was based on data from an interview with a land cooperative stakeholder.

The final community is a dense greenfield development that desires independent waste water utilities due to distance from sewer systems and the additional cost of connections. This community is being constructed by real-estate developers who work directly with local government. I selected this community as representative of communities with high-level resource availability. In my data, I categorize them as a "high resource community." The analysis for this scenario was based on data collected from the Chatham County 2017 Comprehensive Plan, and public connection cost data[17].

Financial Analysis

A financial feasibility study was conducted for the conceptual system described above. The capital costs, operation and maintenance, and monitoring costs were estimated and compared to either sewer or septic system costs depending on geographic factors. This analysis was conducted on the three scenarios ranging from low, middle, to high resource availability.

The first step of the cost analysis was the costing of the conceptual system.

Like conventional sanitation systems, its costs have two portions that determines the management and who is responsible for the costs. The system is privately managed at the household level, until the point of transport. The transportation off the property and the processing of the waste is managed by a third party which could be public, private, or a hybrid.

For the household expenses, I sourced materials for the first two components of the conceptualized alternative sanitation system, Commode & Collection and Storage. For the transport expense, I explored municipal solid waste costing. The monthly cost for bi-weekly pick was given a high value similar to that of Chapel Hill yard solid waste pick-up. This number was estimated high to allow for greater labor costs including safety and training of workers. The processing costs are tied to separate facilities and markets. For the scope of the study, I explored only the entry points into these systems. Therefore, the outputs, which allow for the possibility of resource recovery are not explored. Finally, the three cost scenarios were explored to determine the financial feasibility of the conceptualized alternative.

Qualitative Analysis

To address questions about the conceptualized design and the planning process around sanitation, I developed a questionnaire addressing both system design and planning concerns. Feedback on the design and interview questions was recorded and applied prior to the commencement of the stakeholder interviews.

The qualitative portion of the study included interviews with six professional working as either planners or engineers, and a farmer and a member of a land cooperative with interest in sanitation alternatives. Prior to conducting interviews, I submitted and IRB application to the UNC Office of Human Research Ethics where it was determined that no that the project did not require an IRB.

I audio recorded the interviews and took notes. From the notes and audio files key themes related to the perceptions, incentives, and barriers to the implementation of the conceptualized alternative sanitation system were extracted. From these data, a qualitative analysis of stakeholder interviews was conducted. To identify the validity of the stakeholder viewpoints I explored the following characteristics of each stakeholder: stakeholder role, experience working with sanitation, understanding of conventional sanitation systems, Interactions with conventional sanitation systems, household and personal use of conventional systems.

Using qualitative analysis software Dedoose, I coded the interview transcripts. The following parameters were used as codes for the qualitative analysis:

- Initial Responses to Conceptualized alternative sanitation System
  - Commode
  - Storage
  - Transport
  - Processing
- Possibility of general use
- Permits and Regulations
- How to discuss this with others (how would they describe it to colleagues)
- Planning aspects
- Marketability
- Overall Feasibility
- Comparison to conventional systems
- Cost to Household
- Cost to local governments and developers

The first four codes concerned the responses to the four components of the conceptualized alternative sanitation alternative: commodes and collection, storage, transport, and processing. The responses concerning each component were coded separately. The next six codes concerned overall feasibility, the possibility of general use of the conceptualized alternative, permits and regulations around sanitation alternatives, how the stakeholder would describe or discuss the system to others, planning aspects associated with sanitation, and the marketability of the conceptualized alternative.

Stakeholder Selection

The interviewed stakeholders were selected based on their professional capacity, and experience with sanitation or housing, and their familiarity to the scenario areas. Table 1 shows the range of stakeholders and the range of community scenarios discussed during the interviews. Note the PLAN2 interview included two planners working at the county level. All stakeholders had some experience working with conventional or alternative sanitation systems, except for the interviewee from the PLAN1 interview who primarily worked in affordable housing.

Table 1: Stakeholder Interviewed and community scenarios discussed

Stakeholder Interviews					
Community Scenarios discussed	**ENG1**	**PLAN1 (Private Sector)**	**Land Cooperative Member**	**ENG2 (Independent Water Authority)**	**PLAN2 (County) N = 2**
Low Resources	x	x		x	
Medium Resources	x	x	x	x	x
High Resources	x	x		x	x

CHAPTER 3: RESULTS

Conceptualized Design

Commode Design

To address concerns of cleanliness and odor, I incorporated a bagged design for collection at the commode level [18]. There were previous concerns about the impact of biodegradable bags on the waste processing, however high solids digestions can handle these items [14]. If co-composting were used without digestion however, the bags would need to be composting approved, which may increase cost.

Tank Capacity

Studies have shown the yearly average weight of feces and urine to be 47 kg, and 440 kg respectively [18]. The 487 kg per person per year was converted to 9.37 kg per person per week then the US standard of pounds giving me 20.6 lbs. per person per week. Assuming five persons per household I arrived at 103 lbs. per household per week, using a sludge density of 45.01 lbs. /ft3, and assuming a five person household. The weekly volume produced was 2.29 ft3, which I converted to 17.1 US gallons per week. To consider options for the frequency of collection transport I found the bi-weekly and monthly loads of 34.3 gallons and 68.6 gallons respectively. Based on these values I determined that a volume similar to standard 55-gallon drums would provide sufficient capacity for the pod system. For the actual design of the storage units I explored the centralized household composting designs available, specifically the Sun-Mar Composting Toilet of Figure 4.

Figure 4: Sun-Mar Composting Toilet with collection and storage infrastructure similar to the proposed system[19].

Financial Analysis

The conceptualized alternative capital cost include toilet installation, based on the average toilet installation for North Carolina [20]. The bags were priced based on commercial available biodegradable waste bags on Amazon.com. The concrete tank was estimated from a 500 gallon septic tank, and the pods from a standard 55 gallon drums [21]. These estimations, depicted in Table 2*,* were determine based on standard models of products using similar materials and of a similar size.

Table 2: Capital and Monthly Operation and Maintenance Costs for Conceptual Alternative, modeled from commercially available products [21]

Dry Sanitation Costs	
Capital Costs	
Toilet	$519
Storage	$810
Tank	$610
Pods	$200
Total	$1,329
Monthly Operation and Maintenance	
Monthly Disposal Fee	$40
Bi weekly Disposal	$20
Bags	$20
Total	$60

Table 3 shows the capital and connection costs of the conceptualized alternative and conventional systems for each of the community scenarios. The low resource community scenario required removal septic systems for water quality purposed and, thus I only considered the conceptualized alternative and the sewer option. The sewer option initial costs are less the conceptualized alternative option, however in the case of a retro-fit these costs would be much higher. The medium resource community's costs were highest for septic and lowest for the conceptualized alternative. The high resource community had the highest costs for the sewer system, and the lowest cost for the conceptualized alternative.

Table 3: Capital and Connection Cost Comparison for The Conceptualized Alternative Sewer and Septic for the Three Scenarios of low, medium, and high resource communities.

Initial Connection Costs			
Scenarios	Low Resource	Medium Resource	High Resource
Sewer	$4,425	$3,200	$4,500
Septic		$4,000	$2,000
Conceptualized Alternative	$1,329	$1,329	$ 1,329

Operation and maintenance costs are $720 yearly for Conceptualized Alternative and $160.50 for septic systems with similar capacity. Yearly septic costs were based on North Carolina State University's Septic Maintenance guidance [22].

Qualitative Analysis

Stakeholders

All stakeholders had some experience working with conventional or alternative sanitation systems, except for the interviewee from the PLAN1 interview who primarily worked in affordable housing. The engineers interviewed discussed their extensive experience (both more than 30 years) with sanitation, and limitations of conventional infrastructure. The county level planners provided extensive information about the permitted and regulations related to household sanitation.

This portion of the interviews also yielded responses about how respondents saw their individual and society's link to the environment. These statements set the stage for the interviewee's position on environmental conditions and was usually followed by approval for alternatives for sanitation. Example include:

> *"We just recently shifted? Our mission and it is now to reimagine, remember our relationship to ourselves and each other, to the land in pursuit and practice of collective liberation. And when we're talking about the land we're not just talking about soil and rock, we're talking about water and all the implication of what it means to be in a relationship with water in a way that is honoring us, honoring water itself as a resource, and understanding that we, in taking care of our resources like water, we are in fact taking care of ourselves, and taking care of each other." COOP1*
>
> *"We're told to be wise stewards of the resources that have been given globally. Unfortunately we fall far short of that." ENG2*

The goal questions related to the initial responses to the conceptual system was to determine which components of the system caught the attention of the interview and where they focused the majority of their attention. To provide a general overview of themes covered in the interview I extracted the frequency of code presence in interviews. Tables 2,

Table 5, and Table 6 show the number of times codes were mentioned during the respective stakeholder interview, based on the transcript analysis. Table 4 shows the commode and storage components received the majority of coded comments.

Table 4: Code Presence of Initial Responses to Conceptualize System

Initial Responses to Conceptualized System				
Stakeholder	Commode and Collection	Storage	Transport	Processing
Planner 1	3	7	2	0

Coop 1	3	3	1	2
Planners 2 (n=2)	7	5	3	2
Eng1	1	1	2	2
Eng2	0	0	2	4
Totals	**14**	**16**	**10**	**10**

The planners interviewed were particularly interested in construction at the household level, and how this would impact aesthetics, odor, home values, and ultimately marketability of the conceptualized alternative (See table 3). These comments primarily focused on the design of these system components.

Processing

As a farmer who grows and sells produce, the land cooperative member was interested in a system that would allow compost fertilizer to be used on crops.

Both engineers had concerns about mixing waste collected from multiple locations with the certified Class A bio solids in the OWASA Mason Farm plant.

Engineer 2 expressed general concern about land applying bio solids, based on his experience since the 1980's working with OWASA's wastewater bio solids in its Agricultural Nutrients Recycling Program (ANRP).

> *"We don't necessarily understand individual health effects or environmental effects. So how can we understand what the cumulative effects of these things? And those are questions that very well may never be answered. And so there always going to be those uncertainties. There's always going to be the uncertain risks. And then there's always going to be different levels of perceptions about those risks." ENG 2 OWASA*

Comparison to conventional systems

In comparison to conventional systems several of the interviewees brought up the importance of the cost comparison. As an example one of the county planners for the PLAN2 interview stated:

> *"I think this is this is a great idea. Implementation might be the hard part as far as cost and use in how people, because we've got somebody that approaches and says "I want to go with your most environmentally friendly septic system. I want a treat ahead of it I want a drip disposal. And then they find out the cost is $35000 compared to $12000 system. And they're not as interested but they were extremely interested to begin with that they knew was going to cost a bit more than just realized how much more and the cost of this I don't know if it's prohibitive. But I think the usefulness of why someone would use it over a flush toilet. We all know it's saving all that water. It's huge. It's our number one resource that I think is going to be jeopardized in the future. " PLAN2.*

Possibility of general use

Table 5: Code Prevalence of Interviews

Stakeholder	*Overall Feasibility*	Possibility of general use	Permits & Regulations	How to discuss this with others	Planning aspects	Marketa bility
Planner 1	8	6	2	4	1	3
Coop 1	1	1	1	0	0	0
Planners 2 (n=2)	3	1	4	0	10	6
Eng1	4	0	0	0	1	0
Eng2	2	2	1	2	2	3
Totals	18	10	8	6	14	12

On the feasibility of the Conceptualized Alternative, particularly for lower income or affordable housing Planner 1 expressed concern:

> *"…personally I would probably advocate for comparable services for people that have been excluded from those services. As oppose to, you have, I don't want to call them make shift solution, but this doesn't feel like it's going to increase the value of someone's home. Well it might increase their value, but in terms of the perception of others…*
>
> *If you're choosing, if you're looking for a new house. Are you going to go with one that's tapped into the traditional water and sewer infrastructure or something like this?*
>
> *…I think one thing that I think about in terms of just planning decisions in general. I think given the peoples for the vast majority of Americans any wealth they have, any wealth comes from their house. And I think sometimes that planners are not great about thinking about implications on household wealth, when they're making decisions. I think they are often, rightly so, people are thinking about the immediate needs of people, right people need of shelters. It's better to live in some kind of house instead of no house at all. I also think from a long term planning perspective and I'd like to think about*

what can we do to make sure that people's investments in their homes are advantageous. So I'd be worried because if it's the people in the ETJ [Extra Territorial Jurisdictions] that are given this the white people up the street that are tapped into infrastructure will not find it worth moving into this."

One of the planners from PLAN2 mentioned the possibilities for state regulations to support sanitation initiatives like the one proposed:

"And so not wasting water to flush toilets is a great plan. I love it. And mean that's I think this is where planning and environment health come into play where planning they can provide incentives for homes or for subdivisions that incorporate this type of plumbing or you'll have conservation subdivisions now that they can incorporate our state regulations are what we can do at that they can put on some additional requirements or incentives to communities to incorporate and I would guess you'd also have a dual system working here so this is just dealing with the toilet."

When asked if they ever participate in the design process the interviewees responded:

" Interviewee 2: We've got a couple of engineers that come in and say that they can answer all the problems of a subdivision with engineering and design but they are not brainstorming with us. "

"Interviewee 1: Well they brainstorming like in planning for our long range planning but not on things that are like to this level, this granular level. We're looking at the stuff that's got a bigger picture. Interesting concept. The regulatory piece is always the hurdle of work. If we could change the world here and everybody listened but what we always run up against us in our minds. I think sometimes it's always the regulatory framework and what it's going to take to get the legislature to do this to get the rules written. And this as well, the other piece of these types of activities this is more private sector. Because we're not making a product. We're inspecting or regulating a product. "

This was a primary deductive process with interview questions based on previously established themes, however during the stakeholder interviews the following additional themes naturally emerged: Concerns about management of non-toilet water waste; the challenges associated with constructing the chute system in the home; the possibility of retrofitting existing systems (particularly septic); and the carbon footprint associated with the transport of the dry waste.

Table 6: Code Prevalence of Additional Themes

Stakeholder	***Construction within home***	***Grey Water***	***Retrofitting***	***Transportation concerns***
Planner 1	2	0	0	1
Coop 1	1	0	0	0
Planners 2 (n=2)	1	3	0	3
Eng1	0	1	1	0
Eng2	1	5	0	1
Totals	5	9	0	5

Table 6 shows the code prevalence of additional themes. Questions about grey water and non-toilet wastewater was the most prevalent.

ENG2 in particular, stated the importance of addressing all wastewater in the home. He proposed the concept of planning water net zero communities that could manage waste near the site and use the energy bi-product to support potential economic development initiatives.

While PLAN1 was less optimistic about alternatives, and concerned about the perception of septic systems by real estate developers, and potential buyers of homes.

> *"It became more an issue of in a place like Chapel Hill where part of the town is on water and sewer and then across the street you may not be. It wasn't an issue for us but it was more about well is going to be an issue 10 years down the road if we go to sell the house. Do we have to do maintenance on the septic tank? What if the septic tank ruptures. Are we going to get stuck*

with a $15000 replacement cost. As opposed we can buy something across the street and be fully tapped in to water and sewer.

…it was more … our own sale, thinking about it. But that was one thing. It was mainly that this one real estate agent she was just scaring us, and didn't like the house and was trying to get us to move on."

CHAPTER 4: DISCUSSION

This study serves as an initial exploration of municipal-scaled sanitation systems that provide a alternative to the conventional septic and sewer systems. The study explored the following: design specifications of a feasible sanitation alternative in North Carolina; the economic feasibility of the conceptualized design for three community scenarios; as well as the incentives, barriers, and perceptions of this system among sanitation and housing professionals.

A Robust Sanitation Alternative

The conceptualized system diverges from the heavy, expensive infrastructure and introduces to a highly adaptive, more economically efficient solution. In addition to the providing high-level sanitation services, this system holds the possibility of value recovery through energy production and nutrient recovery as a product. With wide spread application of this approach, economies of scale and the establishment of component supply chains will aid in affordability.

This system could, in theory, be adapted to dense settings as well, however the focus of this study was on low-density communities. The Low-density areas such as small town and rural communities, would benefit from this low infrastructure solution.

Economic Feasibility in Community Scenarios

The conceptualized alternative connection cost appears to be cheaper based on the study estimates (Table 3: Capital and Connection Cost Comparison for The Conceptualized Alternative Sewer and Septic for the Three Scenarios Table 3). However, maintenance costs make it a less attractive alternative. This is particularly relevant for the low resource community or Rogers Road. Given the poor conditions for their septic systems, and the proximity of drinking water well, continued septic use is not an option [23]. If retrofitting the septic tanks for greywater treatment were possible, conceptualized alternative would be a more attractive option.

The middle resource community or, Land Cooperative, is in the unique position of having some flexibility with land use, and interest in sanitation alternatives. A larger scale conceptualized alternative program would likely benefit the Coop if they were able to meet regulations for approved bio solid application, like that of OWASA's bio solids program.

Finally, the high resource community, or Green-field development, may have the most reasons to consider conceptualized alternative. The connection costs are highest, and many Chatham County developments are connected to private independently managed sewage system (See APPENDIX 3) [17]. The biggest advantage of the conceptualized alternative over septic would be the decreased minimum lot size due to the elimination of a septic drain field. This would allow for smaller lost sizes, and thus more lots per development.

Perceptions of the Proposed Sanitation Alternative

Both the Planner 2 interviewees and Engineer 2 discussed the possibility of providing regulatory incentives for conceptualized alternative systems, particularly if they are connected to a processing system that provides productive outputs. These type of incentives could be explored in dense development with support from planning and regulatory agencies.

Additional design and planning work would also be required to explore a holistic wastewater approach. There is a need to address all of the water waste from households and commercial building, including toilets, sinks, and other appliances. Retrofitting septic tanks as an option and would require design, financial analysis, and pilot scale systems.

Barriers to Municipal Waste Services

I explored the possibility of expanding the municipal waste service to include transport of conceptualized alternative waste to facilities for compost and waste to energy facilities.

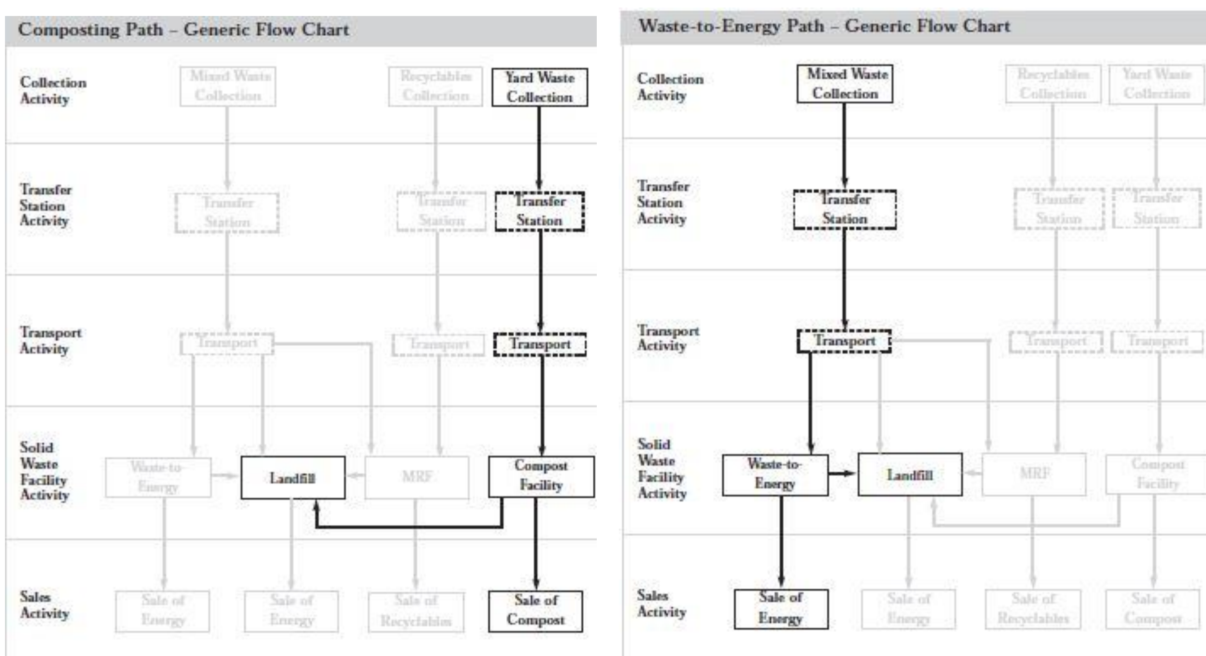


Figure 5: Municipal Solid Waste Compost and Waste to Energy Flow Charts [31]

These options include revenue streams from compost and energy. However, land application of bio solids is not currently a revenue generating exchange in North Carolina. The bio solids from wastewater treatment plants are typically given away to agricultural partners.

There are also concerns from the interviewed engineers about taking waste from multiple households and directly adding it to the OWASA bio solids without pretreatment.

Limitations

This project does not address the additional water waste from sinks, showers, and other household water sources. A holistic sanitation system would need to include grey water treatment. It would have been helpful during interviews to have compared existing alternative sanitation systems with the conceptualized alternative described above. This same comparison would have been useful in the quantitative analysis to explore, more broadly, if any other sanitation alternatives would be financially feasible for communities in North Carolina.

This study made use of a form of snowball sampling, which has limitations in the various and frequency of the results in a larger population, and thus the generalizability. For the purpose of this study, however, the snowball sampling allowed for identification of key stakeholders who provided useful insight into the topic of sanitation alternatives.

Finally, the initial cost analysis was limited in not addressing the potential resource recovery, and as a preliminary study, not addressing discounting of capital expenditures. Therefor the financial analysis, is more of an initial costing of a system that requires more exploration.

CHAPTER 5: CONCLUSION

The findings of the initial work serve to provide an introduction to the exploration of a conceptualized alternative. Its scope serves as a meaningful as a survey that will guide future research. These finding show a clear interest among stakeholders to explore sanitation alternatives, and specifically explore the removal water from the waste conveyance system. The capital and installation cost comparison shows promise for the use the conceptualized system, however higher operation and maintenance costs result in an overall higher cost for the conceptualized system. The potential benefits of resource recovery in the conceptualized, however, provide opportunity for the system to provide revenues that counter increased operation and maintenance costs. This resource recovery is particularly compelling due to the impact of essential nutrients found in human waste, on food production[8,24,25]. Pared with concerns about the scarcity of these resources, the study of new sources in low and high income countries is compelling[24]. Recent studies on phosphorus flows for major metropolitan areas confirm this interest[26].

Future Research

Future research should further explore the options for optimizing the return on end products. One potential line of research could explore the application of ecological sanitation alternatives on other wastes (ie animal). It would be additionally important explore the decision-making processes behind the placement of waste and energy sites, particularly given the environmental justice complaints and lawsuits against the pork industry for their waste management practices.

Some planning options include identifying the collaborative design process as a key stakeholder interaction in the early stages of development. This type of participatory design could help create more robust technical solutions that better fit within the regulatory framework and planning process.

It would be beneficial to do a survey of multiple regions to explore the geographic and climatological variations and how those impact the feasibility of sanitation alternatives. For example, the coastal areas of North Carolina would have distinct needs from North Carolina's western mountain region based on the soil and climate differences

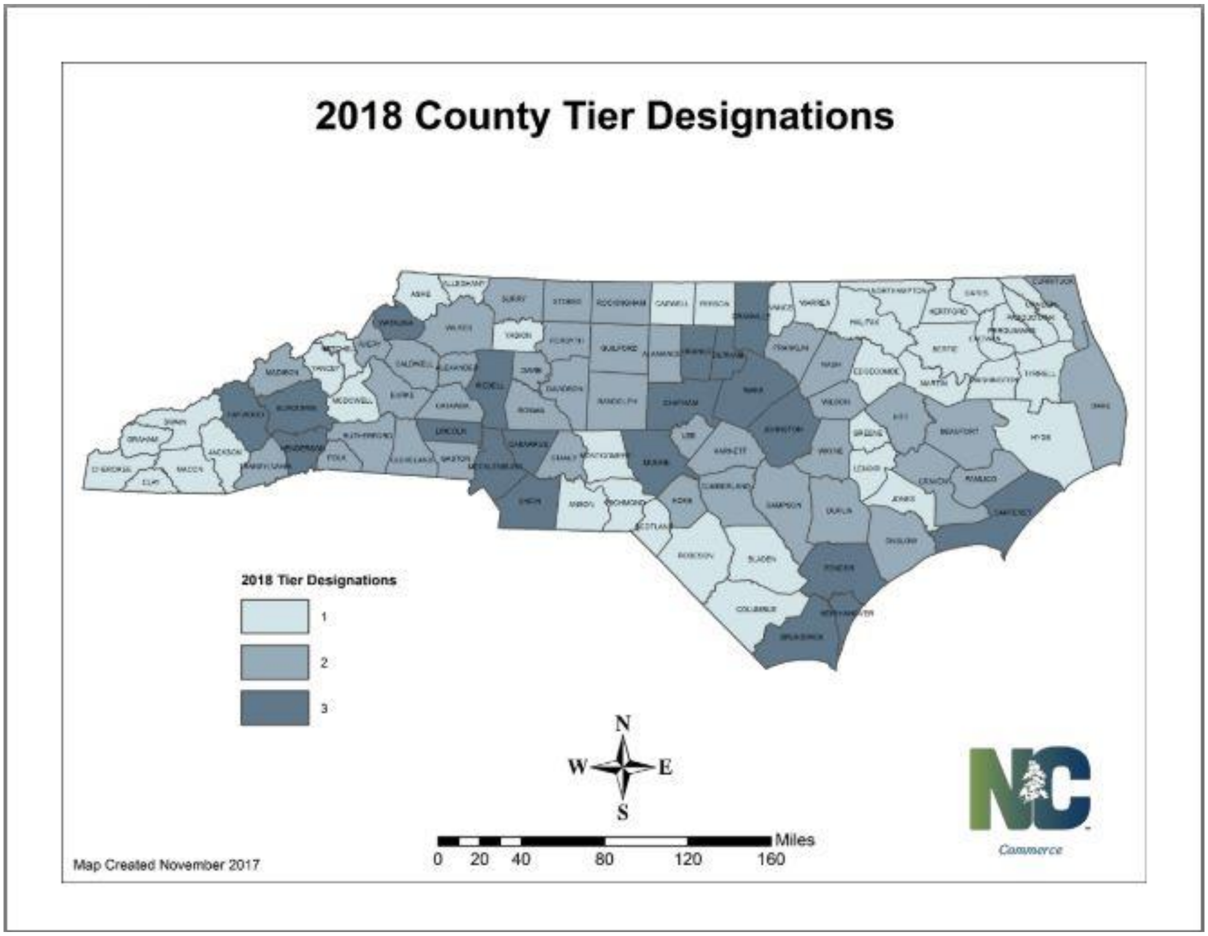
Concluding Thoughts

As previously mentioned, the technologies explored in this study are being used in some form throughout the world[27–29]. Although US cases exist, most studies are focused on sites outside of the United States. Given that the exploratory work shows interest, technical feasibility of a conceptualized alternative practitioners would benefit from further analysis of this option. The potential economic viability of also relies on research into the value chain capacities of the multiple uses of human waste. These potential benefits make the case for a more thorough exploration of sanitation alternatives in the US, and the initial study shows that a gap analysis and localized focus can help guide future research.

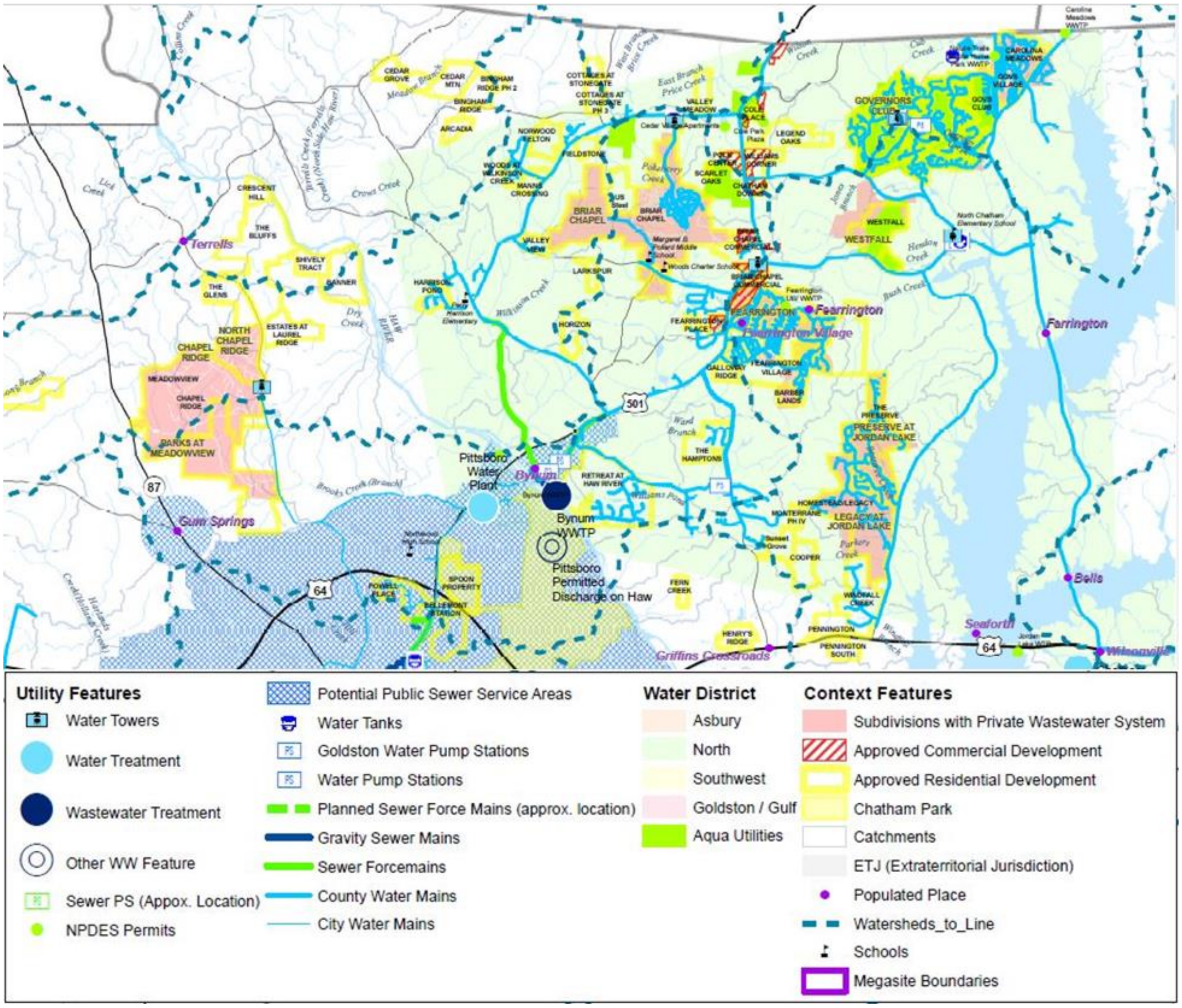
APPENDIX 1: JMP WASH DATA[1]

Year	Service Type	Service Level	Value	Country	Residence Type	Population
2015	Sanitation	Basic service	10.47	USA	total	33,689,948
2015	Sanitation	Limited service	0.00	USA	total	0
2015	Sanitation	Open defecation	0.00	USA	total	0
2015	Sanitation	Safely managed service	89.50	USA	total	287,985,707
2015	Sanitation	Unimproved	0.03	USA	total	97,977

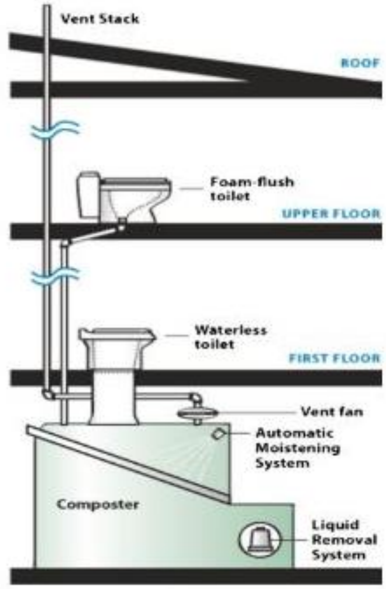
APPENDIX 2: 2018 NORTH CAROLINA DEVELOPMENT TIER DESIGNATIONS[12]



APPENDIX 3: MAP OF CHATHAM COUNTY SHOWING SUB DIVISIONS WITH INDEPENDENT SEWER WASTE WATER SYSTEMS[17]



APPENDIX 4: SUN-MAR COMPOSTING TOILET[30]



APPENDIX 5 EPA MUNICIPAL SOLID WASTE MANAGEMENT COSTS [31]

Types and Examples of MSW Management Costs

Up-Front Costs

- Public education and outreach
- Land acquisition
- Permitting
- Building construction/modification

Operating Costs

- Normal costs
  - Operation and maintenance (O&M)
  - Capital costs
  - Debt service
- Unexpected costs

Back-End Costs

- Site closure
- Building/equipment decommissioning
- Post-closure care
- Retirement/health benefits for current employees

Remediation Costs at Inactive Sites

- Investigation, containment, and cleanup of known releases
- Closure and post-closure care at inactive sites

Contingent Costs

- Remediation costs (undiscovered and/or future releases)
- Liability costs (e.g., property damage, personal injury, natural resources damage)

Environmental Costs

- Environmental degradation
- Use or waste of upstream resources
- Downstream impacts

Social Costs

- Effects on property values
- Community image
- Aesthetic impacts
- Quality of life

APPENDIX 6: INTERVIEW GUIDE

Part 1: Introductory

1. Can you tell me about your role in local/state government?
2. Do you have any experience working with sanitation systems?
   a. Can you tell me more about that?
   b. Can we talk about A first?
   c. Can you tell me about how it worked?
   d. Did you have any interactions with it?
   e. Did you play any role in making this work?
   f. Did you play a role in the design of it?
3. Can you talk about the current sanitation system you use at home?
4. Can you talk about the town's system

Part 2: The Interviewer will describe the system and shows the diagram.

Diagram:

Would you like to comment on this?

Part 3: Specific Questions

1. Are you a homeowner?
2. Would you want this to be in your home?
   a. Can you tell me more?
3. What, if anything, would it take for you to add this your property?
4. Compared to what's out there, how, if at all, is this better?
5. How is it worse?

6. Do you see this as something that could be used by people in general?
    a. Where?
7. If you were to talk about this with your colleagues, what kinds of things would you talk about?
8. Would you describe this system as "feasible"?
9. What, if anything, would you change about the system?
    a. Are there any parts or components that you see as problematic?
        i. Commode
        ii. Storage
        iii. Collection and transport
        iv. Processing
10. What do you think the planning phase would look like for a system like this?
    a. Do you think it would meet requirements?
    b. What problems do you think could arise?
11. Do you consider this a marketable system?
    a. Could you see other local government entities accepting this system?
12. What do you think the implementation phase would look like?
    a. Do you think it would meet permit/regulatory approval?
        i. Can you tell me more?
        ii. What, if anything, would need to change?
    b. What problems do you think could arise?
13. What do think about the financial viability?
    a. Would it be affordable at the government level?
    b. What about the household level?

c. If not, would be required for it to be so?

14. Is there anything else that would get in the way of it being implemented?

15. Is there something else you'd like to talk about that we haven't addressed?

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