Prospectus

Scale-up and Design of the Janicki Omniprocessor with Reverse Osmosis Technology
(Technical Topic)

The Negative Impacts of Wastewater Treatment Plant Operation on the Health and Quality of Life of Neighboring Communities
(STS Topic)

By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Background

In 2017, 1.6 million people died due to diarrheal diseases, among the leading causes of death worldwide (Dadonaite, Ritchie, & Roser, 2019). Unsafe drinking water, inadequate availability of water for hygiene, and lack of access to sanitation were attributed to around 88% of these deaths (Centers for Disease Control and Prevention, 2018). Cashman (2020) reported that in 2015, 1.2 million people in Dakar, Senegal alone had no flushing toilets and were not connected to a sewer line. Instead, they used tiny pit latrines in the middle of their streets, increasing the possibility of pathogens and other contaminants leaching into the surrounding environment and groundwater (Cashman, 2020). More than 2 billion people worldwide face living in such unsanitary conditions. This same number of people live in countries experiencing high water stress as it is (United Nations, 2018). The combination of inadequate sanitation, hygiene, and clean drinking water is a major cause of poor living standards, vulnerability to disease, and poverty.

The Janicki Omniprocessor (JOP), funded by the Bill & Melinda Gates Foundation and developed by Sedron Technologies, is the revolutionary solution. The JOP is a sanitation system that converts waste collected from pit latrines into three extremely valuable goods: potable water, electricity, and fertilizer (Cashman, 2020). This technology was initially implemented as a pilot project in Dakar, Senegal and currently serves potable water and electricity to 100,000-200,000 people in the city. The technical capstone encompasses scaling up this process to serve cities with a population of one million people as well as implementing reverse osmosis (RO) during the water filtration stage of the process. This technology will specifically be applied within wastewater treatment facilities (WWTFs), also known as wastewater treatment plants (WWTPs).

WWTPs intake water from homes, industries, and businesses to significantly reduce the amount of pollutants to a level that nature or humans can handle (Cressler, 2018). However, when wastewater is left untreated or inadequately treated to specific standards set by governments, this can have significant impacts on human health – especially to the communities that live in closest proximity to the facilities at fault. Harmful pollutants and organic material can seep into groundwater, polluting drinking water sources, such as wells. They can also enter surface water, such as lakes and rivers, posing a threat for human exposure to waterborne illnesses, such as hepatitis-A, typhoid, polio, cholera, and dysentery (Taylor, Yahner, Jones, & Dunn, 1997). WWTPs are also considered a major source of released harmful gases, called aerosols, which constitute a significant health risk to plant workers and surrounding inhabitants (Vantarakis et al., 2016). In addition to the health risks associated with WWTFs, people who live within a closer proximity to treatment plants can experience a lower overall satisfaction of life compared to communities located farther from them (Vantarakis et al., 2016).

The primary goal of wastewater treatment technology, such as the JOP, is to reinvent how human waste is dealt with. In doing so, it can transform some of the world's most undesired products into basic human necessities and better the living conditions of city populations. However, its implementation within WWTPs could counterproductively contribute to the marginalization and harm of neighboring communities. I will describe and assess the impacts of WWTPs on communities that live near them through the lens of Actor Network Theory (ANT) to understand how and why wastewater treatment operation has particularly effected human health and quality of life.

The Janicki Omniprocessor

Current Wastewater and Drinking Water Treatment Processes

In most cases today, public drinking water supplies do not come directly from a WWTP. That is, the majority of drinking water is not wastewater that has been treated and purified to a high quality. Instead, wastewater and drinking water treatment comprise different goals.

Typically, WWTPs remove contaminants from wastewater or sewage and convert it to an effluent that can be returned back to environmental waters (Wikimedia Foundation, 2020b). The influent for wastewater treatment mainly comes from sewers that collect water from homes, business, many industries, and storm runoff. Wastewater treatment, on its own, typically entails two main process steps: primary treatment and secondary treatment. The former uses gravity to allow suspended solids to settle and be removed from the wastewater. The latter involves biological processes, namely the introduction of bacteria, to remove around 85 percent of organic matter and other contaminants in sewage (United States Environmental Protection Agency, 1998). Additions of chlorine, UV light, or ozone are all disinfection methods that kill pathogenic bacteria (and reduce odor) in the treated water before it is discharged into receiving waters.

In most cases, municipal water treatment plants (MWTPs) intake surface waters, such as lakes, rivers, and oceans, and groundwater to purify them specifically for human consumption. Because the destination of this water is the human body rather than the environment, the steps of this process are more complex. Once this water arrives at the MWTP, there are five main steps in the treatment process: coagulation, flocculation, sedimentation, filtration, and disinfection (Tan, 2016). Various other chemicals can be added to adjust for water hardness and pH levels or prevent corrosion (Tan, 2016). Because treated wastewater is sent to natural waters and drinking water treatment receives influent from these natural waters, the environment is considered a “buffer” between the two processes to lessen the “yuck factor”. This term typically describes public perception regarding drinking water that was once contaminated with waste.

There are many facilities around the world that directly transform wastewater into drinking water, without the buffer of the environment. The largest of these “toilet-to-tap” facilities is located in Orange County, California, which will generate approximately 130 million gallons of drinking water per day by 2023. This is roughly enough water to serve one million people in the city’s population of 3.2 million. Despite the success of wastewater-to-drinking water plants, the process of recycling water can be extremely energy-intensive and expensive. While the most popular technology does address sanitation and clean water issues around the world, electricity is massively used rather than created. The JOP has a solution for this.

Expanding Beyond Current Technology: The Janicki Omniprocessor

The Janicki Omniprocessor, see Figure 1 below, operates as a steam power plant, incinerator, and water filtration system – with all three systems working harmoniously with one another (Cashman, 2020). To begin the entire process, wet biosolid waste, namely feces, is collected from pit latrines and transported to a WWTF. This wet biosolid waste is fairly complex. It is typically composed of 75% water (Britanica, 2020). Bacterial biomass is the major component (25-54% of dry solids) of the organic solids in feces (Rose, Parker, Jefferson, & Cartmell, 2015). The inorganic component of feces is primarily undigested dietary elements that depend on dietary supply (Rose et al., 2015). This feed is heated in a dryer to produce a dry biosolid waste and an unfiltered “sludge steam”. Sewage sludge is the solid, semisolid, or liquid residual material that is produced as a byproduct of wastewater treatment processes (United

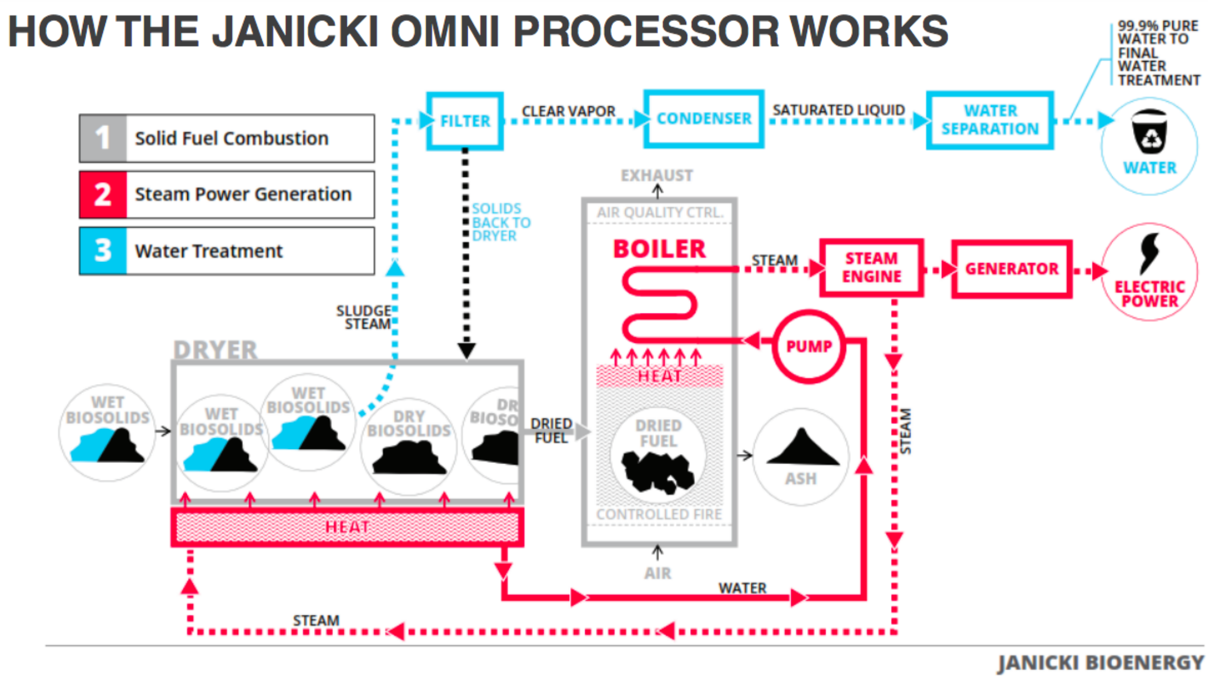

Figure 1. The Janicki Omniprocessor Flow Diagram (Cashman, 2020)

States Environmental Protection Agency, 2019). When heated, sewage sludge creates the aforementioned gaseous sludge steam, consisting of water vapor and particulate solids, that can be subjected to water treatment processes. From here, the sludge steam will go through a water treatment process while the dried biosolids will go through an electricity generation process.

In the water treatment process, (Figure 1, #3 in blue), the sludge steam is filtered to remove and recycle any large particulate solids from the vapor back into the dryer. The filtered vapor then enters a condenser and transforms into liquid water. The water then goes through a membrane separation process that will remove the remaining dissolved minerals and salts that were not removed from the filtration stage. At this point, the water will be sent for further disinfection steps and the addition of benign chemicals, such as fluoride, to create purified drinking water. This product water can be sent for direct human consumption.

For the power generation part of the system (Figure 1, #2 in red), the dry biosolids leave the dryer and enter a combustion chamber to heat a boiler (Figure 1, #1 in grey). Liquid water runs through this boiler and is converted into steam. Steam will then be run through a steam engine, at which it is divided into two different streams. High-pressure steam is run through a generator to create usable electric power while low-pressure steam is utilized to recycle heat into the initial dryer. The byproduct of solid fuel combustion, an ash, can also be used as a non-toxic fertilizer (Sedron Technologies, 2020).

The JOP expands beyond the initiative of wastewater-to-drinking water treatment technology because it creates two additional valuable products in addition to purified drinking water. It not only creates enough electricity to self-sustain the JOP process *and* distribute to surrounding communities but also non-toxic fertilizer for the purpose of agriculture. The JOP is the innovative technological solution to address inadequate sanitation, poor hygiene, and unequal access to clean water that are experienced by billions of people throughout the world. And, in addition, the JOP creates products, like electricity and fertilizer, that could also improve community living conditions.

The Proposed Janicki Omniprocessor Technical Design

The technical capstone project will be to design the entire process described above and scale it up beyond the original pilot project's goal of serving 100,000-200,000 people. The aim is to scale up the dimensions of each piece of equipment in the water purification, electricity generation, and incineration process so that enough products can be supplied to support 1,000,000 people. This single JOP design would disseminate access to adequate sanitation and basic human necessities to approximately 40% of the population in Dakar, Senegal, whose population is 2,476,400 people (World Population Prospects, 2020). This JOP design could also be applied to cities outside of the JOP's pilot project location.

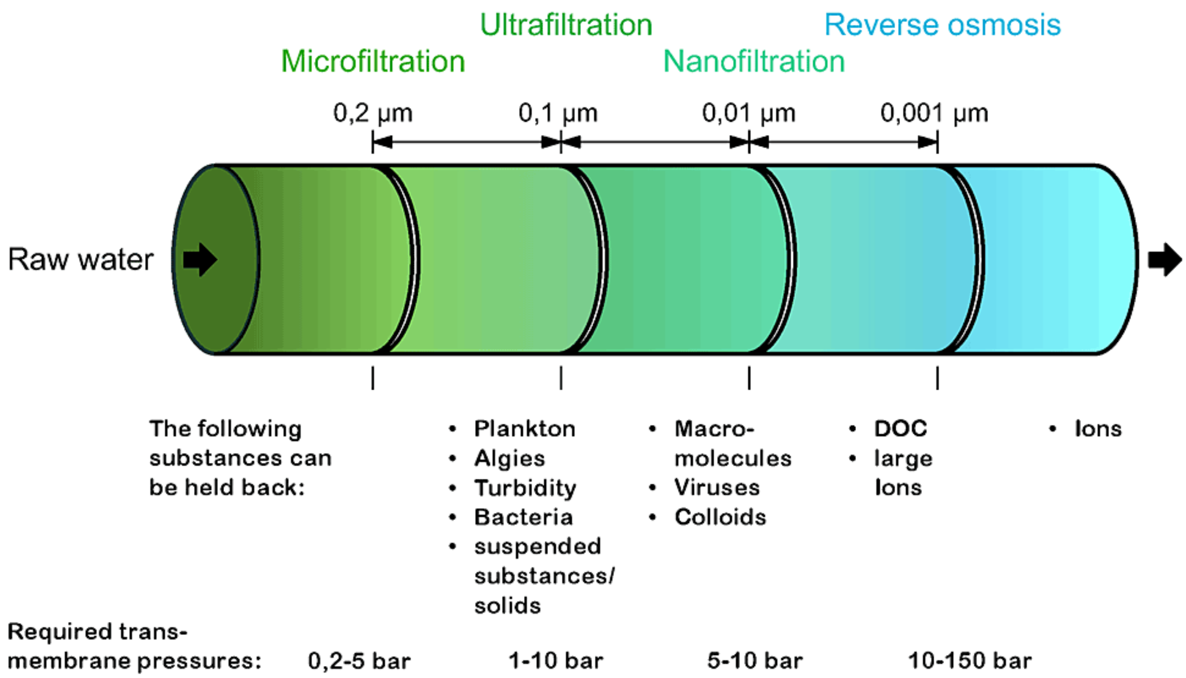

Figure 2. Membrane Filtration Systems (Ramamoorthy, 2015)

In addition to the scale-up of the JOP process, the proposed JOP design will specify the ill-defined "water separation" process of the drinking water treatment process to create extremely pure water, for both hygiene and drinking purposes. Specifically, reverse osmosis (RO) will be utilized (Figure 2 above, in blue). This process utilizes a large difference in applied pressure to force water through a semipermeable membrane filled with pores as small as 0.001 µm. The smallest membrane pore size makes it the most selective separation process, allowing only water molecules (without the addition of microscopic contaminants) to pass through the membrane. Because the feed stream is so complex, RO is an excellent choice to ensure that all microscopic solids (monovalent and multivalent ions, sugars, amino acids, proteins, polysaccharides, colloids, bacteria, viruses, and other particulates) are effectively separated from the water that will become purified drinking water.

Actor Network Theory (ANT) and Wastewater Treatment Processes

The technical project has a humanitarian aspect to its design by aiming to extend access to clean water and proper sanitation as well as provide other valuable communal goods. However, its implementation within wastewater facilities holds the ability to exploit certain communities, namely ones that live in closer proximity to them, over others (Vantarakis et al., 2016). Assessing the consequences that these communities face can be done through defining the human and nonhuman actors in the operational network of WWTFs and describing the relational ties between them (Nyakuengama, 2014). Latour’s (1992) Actor Network Theory (ANT), specifically the ideas of program of action (POA), delegation, and discrimination, will be utilized to understand how wastewater treatment operations have negative impacts on surrounding communities’ health and quality of life.

Actors in the Wastewater Treatment Network

The social and natural worlds exist in incessantly shifting networks of relationships (Wikimedia Foundation, 2020a). These networks are the sum of material and semiotic components, or actors, that interact to form relationships. ANT upholds the social constructivist claim that sociotechnical systems are developed through negotiations between people, institutions, and organizations (Latour, 1992). However, Latour (1992) opines that artifacts are an integral part of these negotiations as well. All of these entities in a network should be described in the same terms, allowing human and nonhuman actors to be treated equally (Wikimedia Foundation, 2020a). Therefore, each stakeholder, both human and nonhuman, are studied symmetrically in ANT (Latour, 1992).

Figure 3. Human and Nonhuman Actors of the Wastewater Treatment Network

The wastewater treatment network, see Figure 3 above, comprises multitudinous humans, organizations, technologies, materials, ideas, and customs that all equally work together to uphold the system. Each actor's defined role within the heterogenous network makes the wastewater treatment network functional. A variety of human (in green), tangible nonhuman (in blue), and nontangible nonhuman (in orange) actors, see Figure 3 above, shape wastewater treatment operation as it exists today. Defining all of the essential actors involved in the wastewater treatment network is required to utilize aspects of Latour's (1992) ANT to describe how specific communities are marginalized by WWTP operation.

Program of Action

Program of action (POA) denotes goal-directed behavior of both human actors and technological artifacts (Schulz-Schaeffer, 2006). It is the set of written instructions that can be substituted by the analyst of any artifact (Latour, 1992). A certain human strategy of goal attainment and an algorithm determining the behavior of a technological artifact are both programs of action (Schulz-Schaeffer, 2006). In the wastewater treatment system, the overarching POA is ensuring that incoming wastewater is treated to a certain quality before it is discharged to the surrounding environment or sent for human consumption. More broadly, the POA is protecting the health of the environment and humans from the risks that wastewater poses to both. However, each actor within the system has their own POAs that contribute to the overarching one. That is, parts of a program of action may be delegated to a human or nonhuman (Latour, 1992). For example, an environmental legislator's POA include goals for writing and passing environmental laws. For wastewater treatment technology, the POA is to function by its particular affordance and its scripted use or purpose (Foley, 2017). Understanding the specific programs of action for each actor within the wastewater treatment network is essential in identifying how wastewater treatment operation can impede on human health and quality of life.

Throughout the world, wastewater treatment operation has gone against the POA of wastewater treatment. Health-impairing contaminants contained in wastewater have returned to humans by way of surface or groundwater migration (Galke & SCS Engineers, 1979). This continues to create problems for farmers in surrounding communities who rely on irrigation to water their land and crops. In communities using treated wastewater for crop irrigation, the incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis has been two-to-four times higher than in control communities (Galke & SCS Engineers, 1979). Contaminants derived from WWTP operation may also be transmitted through the atmosphere (Galke & SCS Engineers, 1979). Biological pathogens present in wastewater aerosols may be inhaled by humans, especially those in closest proximity to wastewater treatment operations. These pollutants have serious consequences on human health, including typhoid, dysentery, and other intestinal disorders (Akpor & Muchie, 2011). It has also been shown that life satisfaction and quality of life have been impacted by WWTP operation. Those in closest proximity to operation have higher incidence of headaches, tiredness, and nausea because of their exposure to culturable bacteria in the air surrounding WWTPs (Vantarakis et al., 2016).

Delegation and Discrimination

Delegation describes the translation of an action into another expression (Stalph, 2019). Latour (1992) describes this as the transformation of a major effort into a minor one. Actors in the network, both human and nonhuman, can displace, translate, delegate, or shift the work they have been delegated to uphold the POA. In the wastewater treatment process, human actors (such as WWTP workers and operators) are removed from the task of directly removing contaminants from sewage. Instead, this task is delegated to specific technologies (such as the JOP), whose individual purpose is to do so. The technology permanently occupies the position of a human actor because the task of removing microscopic contaminants by hand would be impossible. Instead, plant workers and operators are delegated the many tasks of overseeing the day-to-day procedures and operating different types of machinery and equipment from a control room.

Understanding the roles delegated to each different actor in the wastewater treatment network establishes the problems that adjacent communities can face as a result of living near WWTPs. If the delegated role of a human actor (such as a WWTP operator) is totally ignored or mishandled in wastewater treatment, WWTPs could become negligent in their daily operations of decontaminating wastewater or releasing effluent at a certain purity into the environment. If a piece of technology during the treatment process defects, this delegated role must be shifted to another actor in the network so the POA can be upheld. The behavior imposed back onto the human by the nonhuman delegates prescription, or the moral and ethical dimension of mechanisms (Latour, 1992). Artifacts have certain inscribed programs of action by design and have the ability to prescribe certain programs of action to humans and other artifacts (Schulz-Schaeffer, 2006). In wastewater treatment, this would encompass a WWTP operator intervening in a control room when plant technology disrupts or delays normal WWTP operation. When a human or nonhuman actor does not uphold their delegated or prescribed POA, another actor in the network is discriminated against. Discriminated actors include the human user that has had to take an action to mitigate an escalating problem or resulting wastewater quality itself. Regardless, discrimination occurs because a network actor has not executed their delegated or prescribed purpose. Such issues can create deleterious effects on close communities.

The concepts of program of action, delegation, and discrimination in Latour's ANT illuminate that a single actor has the ability to invalidate the purpose of another and make an entire network nonfunctional. Whether a plant operator fails to maintain their purpose or a piece of technology within a WWTP fails, both events significantly contribute to the dismemberment of the original fabric of wastewater treatment. As a result, the goal of removing contaminants from sewage so that humans and/or the environment are not negatively impacted becomes null. Understanding both the programs of action and delegated roles of each actor within the network of the wastewater industry can highlight how and why wastewater treatment operation negatively impacts human health and quality of life of neighboring communities. One actor (whether nonhuman or human) has the capability to make the entire process of wastewater treatment not only counterproductive to the original intent of the process, but hypocritical.

Research Question and Methods

Humans have been known to develop various respiratory, gastrointestinal, and other illnesses through direct exposure to wastewater (Clark et al., 1981). Bioaerosols may also contain different types of microorganisms, such as viruses, pathogenic bacteria, and fungi, capable of causing skin, digestive system, respiratory, and nervous system diseases and human allergies (Vantarakis et al., 2016). In this same study, Vantarakis et al. found that inhabitants within 100-500 meters of WWTP operation had statistically different ($p < 0.05$) frequencies of experiencing bad mood, angriness, and sickness throughout the week than control participants.

The research question expounds upon these abovementioned statistics: How do the operation of wastewater treatment facilities impact the health and quality of life of communities that live near them? These health and other life impacts are not only a significant hazard for those that work within a WWTP, but for surrounding communities that could possibly come into contact with contaminated water or air. Globally, at least 2 billion people use a drinking water source contaminated with feces (World Health Organization, 2019). For communities who already do not have access to adequate sanitation or potable drinking water sources, the effects of WWTPs can be even more disastrous. While technologies, such as the JOP, have the ability to alleviate problems of inadequate sanitation, hygiene, and potable water, WWTP operation can impede on this initiative. Instead, it could continue to create problems for those living closest to the operation. This research question highlights how striving to alleviate large-scale issues can be unsuccessful and actually produce more problems during the process.

The research question will be analyzed using the ANT's central themes of program of action, delegation, and discrimination. Evidence of WWTP health impacts will be gathered using Environmental Protection Agency reports (1979, 1981), a case control study by Vantarakis (2016), and prior scientific literature by Choudri et al. (2018) and Ikehata et al. (2009). All of these sources have information detailing the specific health effects (symptoms and diagnoses) associated with wastewater treatment, reuse, and disposal. Vantarakis (2016) conducted a survey of 235 inhabitants living within a 500-meter radius of a WWTF and performed an evaluation of air microbiological quality. This study, and its cited ones, will be utilized to gather evidence about quality-of-life impacts for neighboring communities of WWTPs. Additionally, specific actors involved in the Flint, Michigan water crisis (Masten, Davies, & Mcelmurry, 2016) will be included to foster both reader familiarity and substance to the content of the thesis. All of these secondary sources will be examined through a descriptive analysis of several case studies. Vantarakis (2016) and Bauer (2002) present two specific communities that have been targeted in many ways by the establishment of wastewater processes in their communities. These, and additional case studies, will be analyzed to describe how surface waters, groundwater, and air quality can be negatively impacted by WWTPs. Therefore, neighboring communities suffer because of this. The descriptive analysis will aid in proving a connection between WWTF operation and real human impacts today, namely health and life satisfaction.

The timeline for conducting the work will begin approximately during winter break in December of 2020. I will begin the process of reading through and highlighting the vital information from the abovementioned case studies and specific communities that a descriptive analysis will be completed for. During this time, I will also collect other case studies and reports along the way that I believe can add substance to the analysis. Between January and February of 2021, case studies will be chosen and synthesized to begin answering the research question. This will also occur at around the same time as the preliminary technical design of the proposed Janicki Omniprocessor, which is innately connected with the STS thesis topic. Combining the agency reports, previous literature, and case studies all under the framework of ANT will likely last through March into April. At this point, the thesis will be reviewed by the STS and technical adviser for revisions and suggestions to be made. The final deliverable will be presented before graduation in May 2021.

Conclusion: This Affects All of Us

Every living person on Earth breathes air, drinks water, and creates sewage in one form or another. However, the operation of WWTPs allows some communities to do these daily activities more safely simply based on where they live. WWTFs have a strong contribution to diminishing human health and quality of life for neighboring communities regardless of their original intent to improve the lives of humans. As a result of the research, it is expected that I will use Latour's ANT to learn more about the specific individuals, technologies, and ideas involved in operating WWTPs. The research and analysis will illuminate the specific actors within the network that have orchestrated the deleterious effects that WWTPs have on neighboring communities.

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