PREVALENCE AND TREATMENT OF WASTEWATER-BORNE ANTIBIOTIC RESISTANCE

PUBLIC AWARENESS AND TRANSPARENCY OF WATER INFRASTRUCTURE IN CHARLOTTESVILLE, VIRGINIA

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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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Antibiotic resistance (AR) has become an increasingly prevalent issue in hospitals and water systems around the world. According to Ventola (2015), a medical researcher, antibiotic resistance is often “attributed to the overuse and misuse of antibiotics” (p. 1) and can be found in several bacteria, such as Carbapenem-Resistant Enterobacteria (CRE) which contain the *Klebsiella pneumoniae* cabapenmase (KPC) gene (CDC, 2019a, para. 1). These bacteria are resistant to almost all antibiotics, including Carbapenem, listed by the CDC as “antibiotic of last resort” (CDC, 2019b, para. 5). Antibiotic resistant bacteria (ARB) have been found by Mathers et al. (2011) in the University of Virginia (U. Va.) hospital system as well as the Moores Creek Wastewater Treatment Plant (WWTP) which handles the hospital’s wastewater. ARB contamination is a serious health risk for patients within the hospital as well as anyone in contact with hospital wastewater as illnesses contracted from the bacteria can be deadly (CDC, 2019a, para. 1). Further, antibiotic resistant bacteria may contaminate drinking water supplies downstream of wastewater treatment plants depending on their persistence in the environment.

Due to the constant increase of contaminants in our waterways, the US Environmental Protection Agency (EPA) has to periodically update drinking water regulations which dictate treatment standards for water treatment facilities. When these regulations are updated, community water authorities are required to assess the compliance of their water infrastructure and make updates where necessary. The success of these updates is largely dependent on both the existing water infrastructure as well as public participation in the process (Greenberg, 2016). In order to understand the role of transparency and community awareness on the successful implementation of water infrastructure, an Actor Network Theory analysis will be conducted on a controversy over water treatment that happened in Charlottesville, Virginia.

The topics presented for the Technical and Science, Technology, and Society (STS) papers are coupled through the prospect that as antibiotic resistance becomes a more prominent issue in water treatment, it will require water authorities to work with communities to update water treatment infrastructure. The presented timetable for both the Technical and STS project is as follows in Table 1, seen below.

Table 1: Timetable: Schedule for Technical and STS projects.

Proposed Duration	Technical	STS
October 1st-December 31st	Conduct wastewater sampling and write background, literature review and field methods	Research background on individual actors and history of the conflict
January 1st – February 15th	Plan and write methods for benchtop and point-of-use intervention experiments	Characteristic analysis on community and activist actors
February 16th – March 31st	Conduct benchtop and point of use experiments, analyze results	Collect news articles and write STS thesis
April 1st – May 1st	Write discussion and conclusion, revise Technical paper	Revise STS thesis

PREVALENCE AND TREATMENT OF WASTEWATER-BORNE ANTIBIOTIC RESISTANCE

Although antibiotic resistant bacteria containing the KPC gene have been found in both the U. Va. hospital system and the Moores Creek wastewater treatment plant, not much else is understood about its transport and fate within the Charlottesville wastewater system and surrounding environment. As contracting an infection from antibiotic resistant bacteria is potentially deadly, the lack in understanding about its movement is a potential health risk for both current patients in the hospital system as well as anyone in contact with the hospital wastewater and its byproducts.

The flow chart, shown in Figure 1, details the current expected path of bacteria containing KPC beginning in the hospital with an infected patient. The bacteria are then spread to the hospital internal plumbing where they are capable of growing on biofilms in the hospital

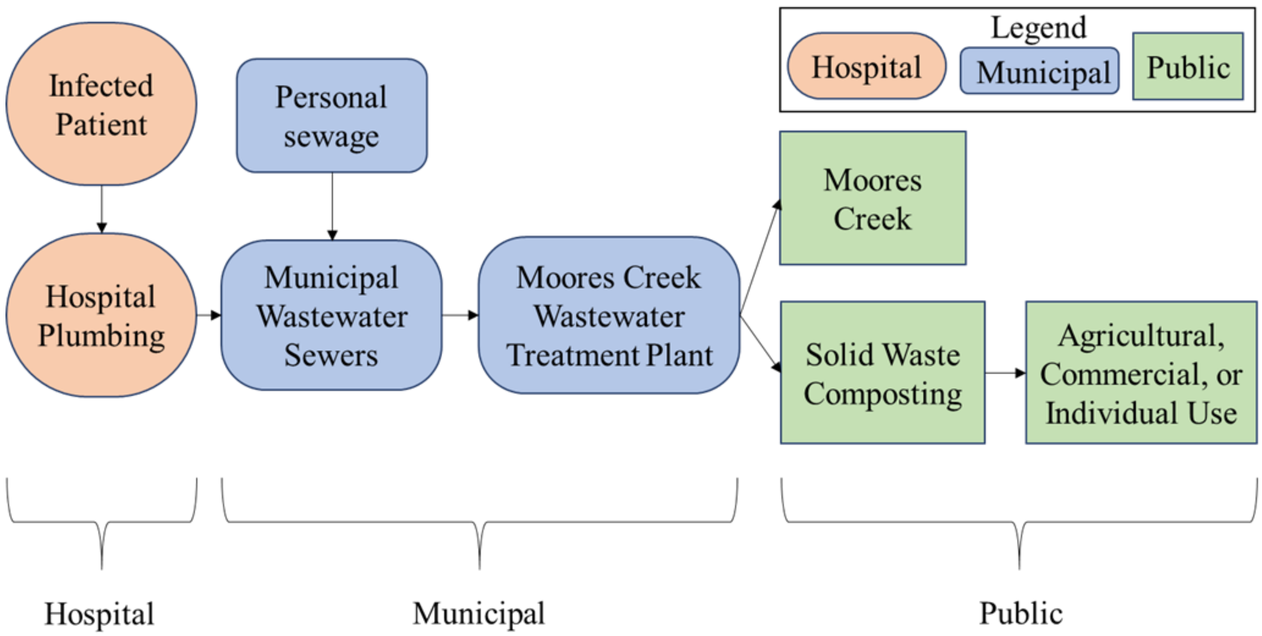

Figure 1: Flowchart of the Charlottesville Wastewater System: Antibiotic resistant bacteria, present in the hospital, are expected to be transported with wastewater through the municipal wastewater system and enter the public sphere with WWTP products (Sutton, 2019b).

plumbing. The bacteria may then be transported into municipal wastewater sewers where personal sewage joins the hospital wastewater and is transported to the Moores Creek facility for treatment. Finished products include treated wastewater, which is discharged into Moores Creek, and solid waste from the clarifiers and waste activated sludge, which is composted for reuse.

The Technical project plans to approach this issue in a two-step process. First, a study will be conducted to fully understand the transport and fate of bacteria containing the KPC gene in the municipal wastewater system. Once the scope of this bacteria is fully understood, a design process will be conducted to create a method to eliminate ARB either on a point source scale within the hospital system or on a municipal scale at the wastewater treatment plant. While the KPC gene was chosen as the focus for this study due to its presence in the U. Va hospital system, it is hoped that the results of this study can also be used to model the movement and persistence of other antibiotic resistant genes.

The first phase of the study will focus on tracking the movement of antibiotic resistant bacteria through the wastewater system. To do this, the study will sample multiple areas along the wastewater treatment process and test them for the KPC gene. Testing areas, some of which are shown in Figure 2, will include the U. Va. hospital outflow, Moores Creek WWTP, areas upstream and downstream of the treatment plant discharge outlet, solid byproducts, and compost made from the associated solid byproducts. Multiple areas within the WWTP will be sampled to understand the response of the bacteria to different wastewater treatment processes. With this information, a flow of ARB concentrations throughout the system will be constructed.

Figure 2: Map of Sampling Locations at the Moores Creek Wastewater Treatment Facility: Possible sampling locations include multiple areas within the wastewater treatment process (a-d) as well as along Moores Creek on both sides of final effluent outflow (e-f) (Google map adapted by Sutton, 2019c).

Once the scope of antibiotic resistance prevalence is fully understood within the system, a design process will be conducted to create a method to eliminate ARB either leaving the hospital or the wastewater treatment facility. As KPC has been reported numerous times within the U. Va. health system, it would be beneficial to prevent the spread of these bacteria before immunocompromised patients are exposed to it (Mathers et al., 2011). One proposed treatment is the use of UV radiation on a point source level within sink drains in order to deactivate the bacteria before it can multiply and spread the gene. In order to test this method, the Sink Lab, overseen by Dr. Amy Mathers and Dr. Shireen Kotay, in the U. Va. School of Medicine, will be used. For large scale disinfection in the WWTP, UV treatment, which is already used by the

Moores Creek facility, is also a possibility along with chlorination and ozone treatment. These possible solutions will be evaluated for disinfection efficacy through a series of benchtop experiments.

Much of the work for this project will be done in partnership with Dr. Amy Mather's lab in the U. Va. School of Medicine. This partnership will allow use of the U. Va. Sink Lab as well as lab equipment for conducting analyses such as quantitative polymerase chain reaction (qPCR) to identify bacteria potentially carrying antibiotic resistance. All phases will take place under the supervision of Professor Lisa Colosi Peterson and Ph.D. candidate Erica Loudermilk, in the U. Va. Department of Engineering Systems and Environment, with consultation from Dr. Amy Mathers and Dr. Shireen Kotay, in the U. Va. School of Medicine. Student team members, in addition to the author, include Anna Cerf and Dorian Nguyen. Results of this study will be presented in a scholarly article.

PUBLIC AWARENESS AND TRANSPARENCY OF WATER INFRASTRUCTURE IN CHARLOTTESVILLE, VIRGINIA

Throughout the United States, water infrastructure is quickly becoming insufficient at meeting water treatment requirements and will need to be either updated or replaced (ASCE, 2017a; ASCE, 2017b; Sedlak, 2019). Water infrastructure, which includes pipes, sanitary and stormwater sewers, and water and wastewater treatment facilities, is immensely important to the health and wellbeing of any community. Yet both the water and wastewater sections on the ASCE's 2017 Infrastructure Report Card (2017) have earned ratings of D or D+. These ratings highlight the dismal state of our water infrastructure, but does little in expanding on its effects on communities or how the issues it may cause are communicated to the public. Additionally, the US Environmental Protection Agency (EPA) periodically updates the drinking water standards in response to new information on contaminants. These updates prompt local water authorities to assess their water infrastructure and make updates to stay in compliance, often putting additional stress on already aged or damaged systems. Despite its importance, progress in updating these systems is often slow and with much debate due to the many stakeholders involved; such as national and local governments and their associated agencies, water and wastewater treatment facilities, and the communities they support.

CONTROVERSY OVER WATER IN CHARLOTTESVILLE

In 2012, the City of Charlottesville, Virginia experienced significant controversy over a water infrastructure decision. In response to US EPA updating a section of the disinfection byproduct regulations, the Rivanna Water and Sewer Authority (RWSA), in charge of both drinking and wastewater treatment in Charlottesville and the surrounding Albemarle County, was required to update their drinking water disinfection system (Frederick, 2012, p. 2). The water authority chose to switch from free chlorine to chloramines, a compound of chlorine and ammonia, for water treatment, a decision that was met with extreme community pushback (Frederick, 2012; Wheeler, 2012a; Wheeler & Beale, 2012). After months of discussion and community response, the less expensive chloramines were tabled and a combined method using activated carbon and chlorine was perused (Wheeler, 2012b). This Science, Technology, and Society (STS) research paper will conduct a network analysis on the actors surrounding the chloramines controversy in Charlottesville, Virginia to understand how transparency and public awareness can affect the implementation of water infrastructure in different communities.

WHY WAS THERE SO MUCH PUSHBACK IN CHARLOTTESVILLE?

The situation in Charlottesville, Virginia was not unique. According to Thomas Fredricks, the executive director of the RWSA board of directors, in a comment to NBC29, "approximately 40 percent of the US population, and 76 percent of the population of Virginians" drank water treated with chloramines in 2012 ("Debate Over Disinfecting Our Water," 2012, para. 15). So why was there so much pushback in the Charlottesville community about switching to chloramines? A combination of a highly educated population, a long history of community activism, local newspapers willing to closely follow the issue, public media, and local government's transparency on the issue may have all contributed to this controversy and its ultimate solution.

The controversy ultimately began when engineers from the Rivanna Water and Sewer Authority proposed the use of chloramines to replace chlorine as the secondary disinfectant as can be seen in the timeline in Figure 3 (Frederick, 2012). The decision to pursue chloramines over a combined activated carbon and chlorine treatment was both less expensive and easier to implement. Once plans of this entered the public forum, however, it was met by varied resistance

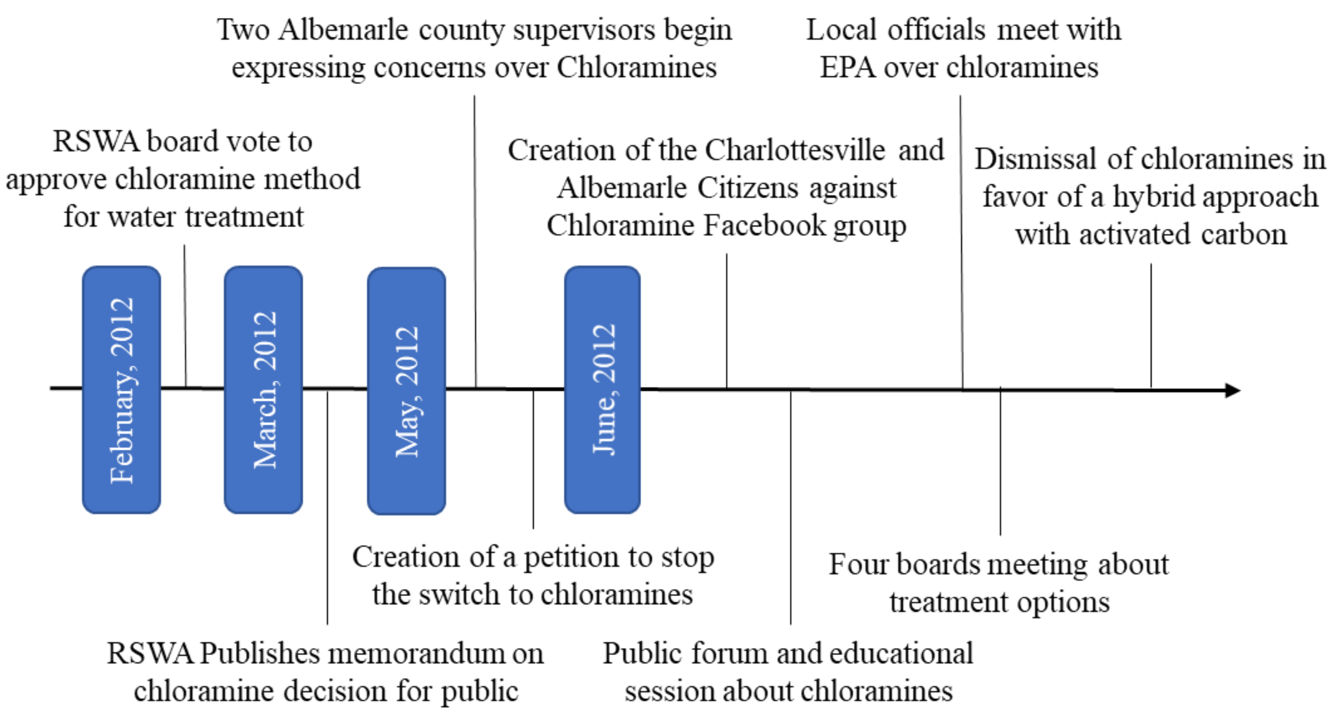

Figure 3: Timeline of Events during the Charlottesville Chloramine Debate: Events leading up to the decision to stop perusing chloramine treatment for water disinfection (Sutton, 2019d).

(Brashear, 2012; Tubbs, 2012). A local news source, Charlottesville Tomorrow, followed the situation avidly and publicized information on hearings and informational meetings which included activists against the adoption of chloramine (Wheeler, 2012a). Local officials, realizing a portion of residents were against the change, held public hearings and eventually decided to forgo the use of chloramines for other alternatives (Brashear, 2012; Wheeler, 2012b).

WHO IS PULLING THE STRINGS IN THIS CONFLICT OVER WATER?

In order to fully understand the effects of transparency and public awareness on this system, a network analysis will be conducted on relevant actors within the community. Actor Network Theory (ANT) is focused on studying a situation by looking at the interactions between different groups of actors (Law & Callon, 1988, p.285; Johnson, 2005, p.1792). Each of these actors is motived by their own interests and can have different levels of influence on a central issue (Jolivet & Heiskanen, 2010, p. 6748). A summary diagram of expected actors and their network for the Charlottesville water controversy is shown in Figure 4 on page 9, with the method of drinking water treatment as the central issue. Proposed actors include local authorities, such as the City of Charlottesville, Albemarle County, and the Rivanna Water and Sewer Authority, as well as community-based groups, such as activist groups and consumers of local water. Actants are also added to show influences that are very important to each actor and thus may affect their opinion on the central issue. The network analysis will be further explored by studying the actors themselves more in depth. In order to further develop a network analysis Barbara Wejnert (2002) proposed that the study of an actor's personal characteristics, such as education level and economic situation, could shed light on their willingness to adopt a technology (p.320). Analysis of individual traits will help to better characterize both the community consumer and activist actors.

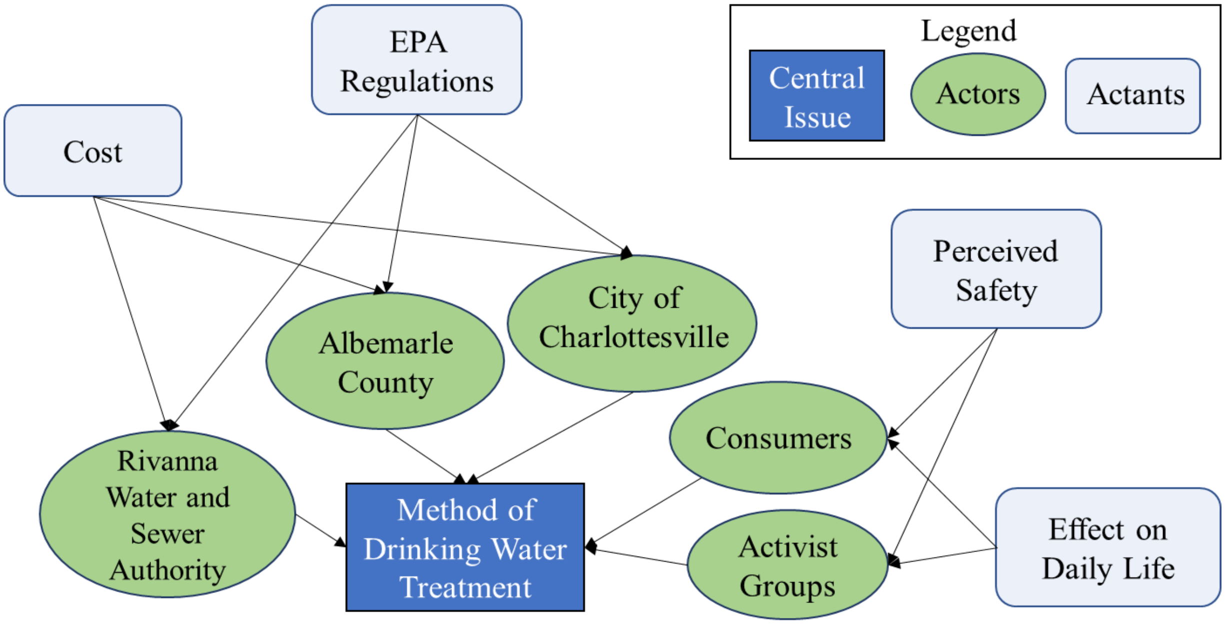

Figure 4: Charlottesville Chloramines Debate ANT Diagram: A diagram showing the main actors in the Charlottesville chloramines debate and the actants that influence each within their network (Sutton, 2019a).

This STS research project plans to examine the effects of transparency and public awareness on the implementation of water infrastructures through the use of an Actor Network Theory analysis. The City of Charlottesville and the surrounding Albemarle County will be used as a case study for this project. The results of this study can be used by engineers and policy makers to better understand how to communicate and discuss water infrastructure decisions with the public.

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