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Combating Climate Change: Saving American Wastewater Treatment Infrastructure

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Combating Climate Change:
Saving American Wastewater Treatment Infrastructure

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Abstract

Climate change is a significant issue currently facing the United States' wastewater treatment sector. It is becoming increasingly clear that its effects have the potential to damage and disrupt the operations of both treatment facilities and associated systems. This study aims to determine which effects of climate change contribute to this risk based on feedback from a combination of academic researchers and industry professionals. A case study of the city of Warwick, Rhode Island's wastewater treatment facility was used to supplement this information based on an evaluation of how this particular system has been impacted by the effects of climate change. The results show that changes in precipitation, increase in temperature, increase in storm intensity, sea level rise, and decrease in stream flows all threaten the functionality of American wastewater treatment infrastructure. Furthermore, it was found that changes in precipitation—specifically increase in rainfall intensity and decrease in rainfall frequency—have impacted the operations of Warwick's wastewater treatment facility. These findings make it apparent that necessary measures need to be taken to protect wastewater treatment infrastructure in the United States against the threat of climate change.

Keywords:

Wastewater treatment, climate change, adaptive solutions, case study, wastewater system flooding, wastewater intake, wastewater discharge

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Introduction

Climate change represents one of the greatest existential threats humanity has ever faced. Its effects are wide-ranging and now virtually every corner of 21^{st}-century American society is feeling its impact. This is immediately evident when studying weather trends across the country: in the Southwest, droughts are becoming more frequent and severe, creating the ideal conditions for forest fires; floods caused by erratic rain patterns are plaguing the Midwest on an annual basis; sea levels are rising along both the East and West Coasts, inundating coastal communities; extreme storm events such as hurricanes are growing ever more intense, causing greater destruction, especially in the Southeast. Even more concerning is the fact that climate projections predict that these phenomena will continue to worsen at an accelerating rate in the future.

One sector of American society that is particularly exposed to the effects of climate change is wastewater treatment. Several factors contribute to this being the case. Historically, wastewater treatment facilities have been constructed at low elevations adjacent to bodies of water based on certain design considerations (Hummel et al., 2018). This means that these facilities are also stuck in locations where they will be heavily impacted by severe weather events like flooding, storm surge, and hurricanes. Many of the processes involved in wastewater treatment are also directly influenced by climatic variables like precipitation and temperature (Zouboulis et al., 2014). In conclusion, climate change will profoundly impact wastewater treatment infrastructure in the United States if solutions designed to mitigate this risk are not implemented.

Review of Literature

Many previous research efforts have sought to provide a comprehensive overview of all the ways in which climate change is expected to impact wastewater treatment infrastructure in the United States. The broad scope of this type of study has been conducive to qualitative analysis, meaning that a wider variety of effects associated with climate change can be identified and explained without the use of data. There is some variability regarding which effects researchers identify but increases in temperature, changes in precipitation, and sea level rise are all consistently referenced as being significant (Singh et al., 2019; Zouboulis et al., 2014)**.** Changes in precipitation can further be divided into decreases in precipitation and increases in precipitation since these effects have very different impacts and should therefore be analyzed separately.

Rising temperatures across the United States are affecting many elements of wastewater treatment. The biological and chemical processes involved in treatment are climate-dependent, meaning that warmer temperatures enhance conversion processes and increase removal efficiencies**.** This can improve the feasibility of using certain treatment processes like anaerobic reactors since these systems are well-suited for operating in warmer climates (Zouboulis et al., 2014). However, decreases in the dissolved oxygen holding capacity of water and increased need for aeration and mixing both contribute to more volumetric direct energy consumption at treatment facilities (Khalkhali et al., 2020)**.** Members of the public served by municipal wastewater systems may also be negatively affected by increases in temperature because these changes can lead to sewer corrosion and odor problems (Singh et al., 2019).

Droughts are becoming more frequent and severe due to decreases in precipitation in arid regions. The lack of precipitation causes rivers and streams to experience lower flows, meaning that less wastewater effluent can be discharged if the water quality in these water bodies is to be maintained (Chappelle et al.). Water conservation policies designed to combat the effects of drought can further intensify issues in wastewater treatment since sudden drops in water use decrease the volume and quality of wastewater influent (Chappelle et al.). This has been observed to be the case in California during periods of drought. During the sustained period of drought that occurred between 2012 and 2016, messaging, social initiatives, and monetary incentives were created by the state's government to convince residents to limit their water use (Chappelle et al.). Consequently, per capita water consumption dramatically declined, leading to increases in the cost of treatment per volume for facility operators and the concentration of pollutants in influent and effluent flows (Chappelle et al.).

Increases in precipitation in wet climates are producing more frequent and severe flooding. This is a major concern since floodwaters can inundate wastewater treatment facilities, cutting off power, damaging equipment, and releasing untreated sewage in the process. An example of this phenomenon occurred in Seattle, Washington in 2017 when a single rainstorm caused 180 million gallons of wastewater to overflow into Puget Sound (Kirchhoff et al., 2019). Heavy rainfall events also threaten to cause combined sewer systems to overflow, especially since combined sewer overflow control programs have typically been designed based on historic hydrologic records and do not account for future projections (Zouboulis et al., 2014). These types of sewage overflows result in the contamination of natural ecosystems and residential areas and produce high concentrations of coliforms, Giardia, and Cryptosporidium (Zouboulis et al., 2014). This reduces the quality of influent and forces water suppliers to adapt treatment processes to meet regulatory standards.

Rising sea levels put wastewater treatment facilities in coastal communities at risk of flooding as well. The facilities in these communities have historically been located at low elevations adjacent to the ocean to increase the efficiency of effluent discharge and limit the need for pumping to the facility (Hummel et al., 2018). This means that these facilities are also at high risk of overflowing and being damaged during periodic storm surge events (Zouboulis et al., 2014). Moreso than for flooding caused by heavy precipitation, the risk of permanent inundation due to sea level rise may create the need for the permanent relocation of facilities in some cases (Hummel et al., 2018). Major cities along both coasts of the United States have already undertaken efforts to evaluate and quantify how exposed their wastewater treatment infrastructure is to these impacts. One risk assessment conducted by the New York City Department of Environmental Protection revealed that all 14 of the city's wastewater treatment plants and 58 of 96 pump stations—which contain a combined total of more than $1 billion worth of equipment—are considered at risk of flood damage due to sea level rise (Balci et al, 2014)

Research focused on quantifying the impacts of climate change on wastewater treatment has also been conducted. The process of creating a model capable of accurately assessing the predicted effects of climate change is very difficult due to the vast number of inputs that have to be considered. As a result, researchers typically select a limited number of climate change-related variables and outputs to include in their analysis. A noteworthy example of this type of research was focused on determining how drought conditions caused by changes in precipitation affect effluent water quality and how this impact can be mitigated. Significant findings that came out of this work included that drought and the water conservation measures that are often implemented to combat it both contribute to reductions in the quality and quantity of wastewater influent and effluent (Tran et al., 2017). These conclusions provide insight into the relationship between the variables of interest and could certainly influence public policy in drought-prone areas like the

Southwestern United States. However, this is still just a small piece of the much larger issue since drought is only one of a wide variety of effects associated with climate change and its impact is limited to certain regions.

Methodology

Climate change's impact on wastewater treatment infrastructure was evaluated using qualitative data collected from interviews with both academics and professional engineers. The interviewees all had a background in conducting research related to climate change's impact on American infrastructure or working in the field of wastewater engineering. Interviews consisted of a series of questions that were developed based on the respective expertise of each interviewee, but which generally covered what effects climate change has on wastewater treatment infrastructure, which of those effects are most significant, and what adaptive solutions can be implemented to combat those effects. Their responses were transcribed and the list of the effects of climate change that was compiled was then organized into categories based on whether these effects were related to wastewater intake or discharge.

A case study of flooding at the city of Warwick, Rhode Island's wastewater treatment facility was also conducted to supplement the qualitative data. The information used in this study was collected from Janine Burke-Wells in the form of interview responses and published articles that she authored. She was able to share first-hand information about this topic since she previously served as the Executive Director of the Warwick Sewer Authority from 2008 to 2019.

Results

Responses From Interviews

A list of the effects of climate change that impact wastewater treatment infrastructure in the United States was compiled using the responses from the interviews. This list is shown below in Table 1.

Table 1: Climate Change's Effects on Wastewater Treatment

Sea level rise
Increase in air temperature
Increase in depth of precipitation
Decrease in depth of precipitation
Increase in rainfall intensity
Decrease in frequency of rainfall
Increase in stream temperature
Decrease in stream flows
Increase in storm intensity

Of the effects of climate change included in Table 1, those that were most frequently mentioned in the interviews and identified as being of great significance are listed below in Table 2.

Table 2: Effects of Greatest Significance

Sea level rise
Increase in air temperature
Increase in depth of precipitation
Decrease in depth of precipitation
Increase in rainfall intensity

The effects of climate change included in Table 1 were also sorted based on how they affect wastewater treatment processes. Table 3 shows the list of effects separated into categories for those that affect wastewater intake and those that affect wastewater discharge.

Table 3: Climate Change's Effects on Wastewater Intake and Discharge

Intake	Discharge
Increase in depth of precipitation	Sea level rise
Decrease in depth of precipitation	Increase in depth of precipitation
Increase in rainfall intensity	Decrease in depth of precipitation
Decrease in frequency of rainfall	Increase in rainfall intensity
Increase in air temperature	Decrease in frequency of rainfall
Increase in storm intensity	Increase in stream temperature
	Decrease in stream flows
	Increase in storm intensity

Case Study of Warwick, Rhode Island's WWTF

The city of Warwick, Rhode Island's wastewater treatment facility has experienced several issues related to flooding since its construction in 1965. Flooding of the facility during the first few decades of its operation was primarily attributed to increased surface runoff from the surrounding area caused by further development and paving. In response, a levee designed to protect against a 100-year flood level with three feet of freeboard was constructed around the facility in the mid-1980s. This addition did limit the frequency of flooding. However, a series of heavy rainfall events in March 2010 still resulted in the complete inundation of the facility after the peak flow rating was exceeded and the adjacent Pawtuxet River flooded its banks. The collection system and basic treatment operations were restored less than a week after the floodwaters subsided, and the facility was in compliance with the standards for its pollutant discharge permits within three months.

Information collected on how the city of Warwick, Rhode Island's wastewater treatment facility has been impacted by climate change is summarized below in Table 4.

Table 4: Climate Change's Impact on Warwick, Rhode Island's WWTF

Change in Weather Patterns	Impact on WWTF
Increase in rainfall intensity	Increase in inflow during rainfall events resulting in flooding of the facility when peak flow rating is exceeded
	Rise in river levels during rainfall events resulting in flooding of the facility
Decrease in frequency of rainfall	Greater variation in inflow on a seasonal and annual basis

Discussion

The compiled responses from the interviews confirm that there are numerous effects of climate change that impact wastewater treatment infrastructure in the United States. These effects vary greatly but are all related to changes in temperature and precipitation, whether directly, as in the case of increase in air temperature and increase in depth of precipitation, or indirectly, for sea level rise and decrease in stream flows. Finding ways to categorize these effects is an important element of the discussion on what solutions should be implemented to limit their impact. For example, long-term trends such as increase in air temperature should be distinguished from acute short-term events like rainstorms that cause flooding since the respective time scales and impacts for these two groups are very different. Making such distinctions can be very difficult, however, since a cause and effect relationship often exists between these long-term trends and short-term events. Another characteristic that is significant in this context is whether an effect of climate change impacts wastewater intake or discharge. More often than not the impact is on both the intake and discharge sides of treatment but making this determination is still a key part of better understanding what specific elements of infrastructure and treatment processes are affected by climate change.

Changes in weather patterns have certainly had a dramatic impact on the operations of Warwick, Rhode Island's wastewater treatment facility. This is evident when considering how changes in rainfall intensity and frequency have resulted in highly variable influent flows and caused significant damage to the facility itself. However, a question that needs to be asked regarding this investigation is whether the weather events that caused these issues can be attributed to changes in climate or if they should be treated as isolated occurrences. On the one hand, no flooding event comparable in magnitude to that which occurred in March 2010 has since occurred in the

Warwick, Rhode Island area. Furthermore, the minor flooding events that the facility experienced between the start of operations in 1965 and the mid-1980s were stated to be the result of changes in the development of the surrounding area. On the other hand, climate data does indicate that long-term trends associated with changes in precipitation are contributing to more flooding events in wetter climates (Zouboulis et al., 2014). This suggests that climate change may still be contributing to disruptions of the facility's operations even if the magnitude of the March 2010 flooding event was an outlier.

Conclusions

Climate change is already having a profound impact on wastewater treatment infrastructure in the United States. The significant effects of climate change contributing to this impact include but are not limited to changes in precipitation, decrease in stream flows, increase in temperature, increase in storm intensity, and sea level rise. All of these phenomena tend to affect both the intake and discharge sides of wastewater treatment, with the notable exceptions being increase in air temperature—which primarily affects the collection and treatment of influent—and sea level rise, decrease in stream flows, and increase in stream temperature—which primarily affect the discharge of effluent. The risk of erratic weather patterns fueled by climate change damaging wastewater treatment infrastructure and disrupting facility operations is exemplified by the history of Warwick, Rhode Island's wastewater treatment facility. Furthermore, the results of this case study demonstrate that wastewater treatment systems are often among the infrastructure most exposed to the harm caused by extreme weather events, in part due to location and the very nature of their function.

Solutions designed to limit the impacts of climate change need to be implemented to maintain the functionality of our society's wastewater treatment sector. This is increasingly evident as climate projections continue to make it all the more clear that the effects of climate change already being observed are expected to worsen at an accelerating rate in the future. Therefore, it is now the responsibility of civil engineers to design and develop adaptive solutions that can mitigate the risk of damage in the event of the projected changes in climate occurring. Basic universal adaptions include installing new sensors and increasing the frequency of technical maintenance to ensure that facility operations are more closely monitored and maintained. Sources of backup power should always be available onsite as well so that facilities can maintain limited operations even in the event of power grid failure. On top of these recommendations, more drastic adaptations will be necessary in areas that frequently experience severe weather events. In areas like the Southwestern United States, diversifying the sources of water used in treatment facilities by drawing from multiple bodies of water or using desalinated seawater can help mitigate the risk of water demand exceeding supply. The recycling and reuse of treated wastewater can also dramatically decrease the amount of freshwater required for a treatment facility's operations. In wetter regions, like the East Coast of the United States, damage caused by flooding due to either sea level rise or changes in precipitation can be inhibited by the construction of barriers like seawalls or levees that block the flow of surface water into wastewater systems. This methodology has contributed to Warwick's wastewater treatment facility's protection against flooding since 2012 when the levee surrounding the facility was raised 5.5 feet.

Future research efforts in this field of study should focus on expanding the scope of quantitative modeling used for predicting the magnitude of climate change's impacts. Qualitative approaches to studying this issue have now enumerated which effects of climate change are significant in this context and introduced conceptual ideas for how their impacts can best be mitigated. This means that the limited quantitative work that has already been conducted should be expanded to generate more data and provide a more comprehensive picture of how acute these impacts are expected to be.

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Appendices

Interview Questions:

1. Can you share more information about your background in conducting research related to climate change's impact on American infrastructure or being employed in the field of wastewater engineering?
2. How is climate change affecting wastewater treatment infrastructure in the United States?
3. Which of climate change's effects on wastewater treatment infrastructure do you think are the most significant?
4. What adaptive solutions should be implemented to mitigate the impact of these effects of climate change?

Questions for the Case Study of Warwick, Rhode Island's WWTF:

1. Your article references the fact that the levee around the WWTF was constructed in the 1980s in response to damages caused by repetitive flooding events. Did the designers of the WWTF not properly account for flood risk or were these flooding events more severe than what the facility was expected to experience based on the predictions from the 1960s (perhaps due to changes in weather patterns including increased rainfall and more extreme storms)?
2. Is the drain system from Route 95 the only source of stormwater that gets treated at the WWTF or is Warwick's city-wide sewer system a combined system that treats both wastewater and stormwater?

3. How much does the inflow at the WWTF typically fluctuate during storm events due to increases in stormwater if the Big Flood resulted in flows five times the average?
4. Have any new adaptations designed to mitigate the risk of damage caused by flooding and other extreme weather events been made to Warwick's wastewater treatment system since your article was published in 2012? For instance, were any pump stations relocated, or are those plans at least still being considered?
5. Have there been any other major flooding events in the Warwick area since 2010? If so, how did these events impact Warwick's wastewater treatment system, and did the adaptive measures implemented in the aftermath of the Big Flood function as intended?
6. Do you think that the two flooding events that occurred in March 2010 are indicative of a greater trend related to changing weather patterns fueled by climate change? That is to say, did you observe that flooding events became more frequent and severe during your time at WSA?