Addressing Vulnerabilities and Emergency Power Capacities in the Wastewater Sector of Massachusetts

Faria Kader | ME | 20'
Michael Kirejczyk | BME | 20'
MaryLouise Ross | BME | 20'

Sponsor: Massachusetts Department of Environmental Protection
IQP Report - Fall 2018

Addressing Vulnerabilities and Emergency Power Capacities in the Wastewater Sector of Massachusetts

An Interactive Qualifying Project Report Submitted to the Faculty of the Worcester Polytechnic Institute In partial fulfillment of the requirements for the Degree of Bachelor of Science by:

Faria Kader | ME | 20’
Michael Kirejczyk | BME | 20’
MaryLouise Ross | BME | 20’

Project Advisor: Seth Tuler
Sponsor: Massachusetts Department of Environmental Protection

Fall 2018

Table of Contents

List of Figures

List of Tables

Authorship

1.0 - Introduction

Primary Author: MaryLouiseise Ross, Primary Editor: Faria Kader, Mike Kirejczyk

1.1 - Primary Author: Faria Kader, Primary Editor: MaryLouiseise Ross, Mike Kirejczyk

1.1.1 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

1.2 - Primary Author: Mike Kirejczyk, Primary Editor: MaryLouise Ross, Faria Kader

1.2.1 - Primary Author: MaryLouise Ross, Primary Editor: Faria Kader, Mike Kirejczyk

1.3 - Primary Author: MaryLouise Ross, Primary Editor: Faria Kader, Mike Kirejczyk

2.0 - Methodology

2.1 - Primary Author: Mike Kirejczyk, Primary Editor: MaryLouise Ross, Faria Kader

2.2 - Primary Author: Faria Kader, Primary Editor: MaryLouise Ross, Mike Kirejczyk

2.3 - Primary Author: MaryLouise Ross, Primary Editor: Faria Kader, Mike Kirejczyk

2.4 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

3.0 - Findings

Primary Author: Faria Kader, Primary Editor: MaryLouise Ross, Mike Kirejczyk

3.1 - Primary Author: Faria Kader, Primary Editor: MaryLouise Ross, Mike Kirejczyk

3.1.1 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

3.1.2 - Primary Author: Mike Kirejczyk, Primary Editor: MaryLouise Ross, Faria Kader

3.2 - Primary Author: Mike Kirejczyk, Primary Editor: MaryLouise Ross, Faria Kader

3.2.1 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

3.3 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

3.3.1 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

3.3.2 - Primary Author: Faria Kader, Primary Editor: MaryLouise Ross, Mike Kirejczyk

3.3.3 - Primary Author: Mike Kirejczyk, Primary Editor: MaryLouise Ross, Faria Kader

4.0 - Recommendations and Conclusion

Primary Author: Mike Kirejczyk, Primary Editor: Marylouise Ross, Faria Kader

4.1 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

4.1.1 - Primary Author: Faria Kader, Primary Editor: Mike Kirejczyk, MaryLouise Ross

4.1.2 - Primary Author: Mike Kirejczyk, Primary Editor: MaryLouise Ross, Faria Kader

4.1.3 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

4.2 - Primary Author: Faria Kader, Primary Editor: Mike Kirejczyk, MaryLouise Ross

4.2.1 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

4.2.2 - Primary Author: Faria Kader, Primary Editor: Marylouise Ross, Mike Kirejczyk

4.3 - Primary Author: MaryLouise Ross, Primary Editor: Mike Kirejczyk, Faria Kader

Abstract:

In the United States, more frequent and intense storms have been threatening vital water infrastructure, including wastewater and drinking water systems. We worked with MassDEP to improve back-up power capabilities to respond to power outages in wastewater facilities. Using data from MassDEP and EPA, we assessed risks and vulnerabilities associated with power loss. We concluded that the lack of data inhibits the ability to assess vulnerability. In addition, we found that facility managers could benefit from an interactive digital map of back-up power capabilities at wastewater facilities and information about opportunities to obtain funding to support upgrades. We recommend the MassDEP take further action to increase data quality and improve informational resources for facilities.

Executive summary

In the United States, more frequent and intense storms have been threatening vital water infrastructure, including wastewater and drinking water systems ("*Adapting to Climate Change*…", 2016). These storms, and subsequent flooding, can cause power outages that disrupt the functioning of these systems. One example is from the Greater Lawrence Sanitary District located in North Andover, Massachusetts. In 2017, a storm disrupted the power for 13 hours, and as a result, 8 million gallons of partially treated sewage water was spilled into the Merrimack River. The Massachusetts Department of Environmental Protection (MassDEP) has been attempting to investigate and record emergency backup plans for drinking and wastewater treatment facilities. This, however, has proven difficult due to the lack of consistency in the currently available data. We collaborated with the MassDEP to focus on gathering a more complete dataset on backup power in wastewater treatment facilities and gained a better understanding of current emergency capabilities.

The goal of this project was to assess backup power capacities and needs of wastewater facilities in Massachusetts, to develop informational resources for regulators and emergency planners.

Objectives and Methodology

We accomplished our goal by completing three objectives:

1. Characterizing wastewater facilities' emergency power capabilities and emergency resource knowledge
2. Determining facility vulnerability and risks associated with power loss
3. Create informational tools to improve emergency preparedness in wastewater facilities

For objective 1, we conducted semi-structured interviews with a Deputy Regional Director (DRD) of the Bureau of Water Resources, and 3 wastewater Section Chiefs. We gained a better understanding of how water systems work, what sort of plans are being used already, and past instances of power loss. We also gathered feedback on what information is useful to managers, regional directors and sections chiefs to plan for emergencies.

For objective 2, we assessed the risk of power outages, for which we considered risks of flooding which can contribute to power loss. We considered a facility's ability to cope with a power outage as a function of vulnerability. This includes, how long a facility can run on backup power, whether emergency power can operate the full system or only part of it, generator age, maintenance of equipment, and ability to get needed supplies from neighboring systems. Using the data from the US Environmental Protection Agency (EPA) showing Federal Emergency Management Association (FEMA) flood zones and self-reported flood risks, we determined that sites with high self-reported flood risk would be at greatest risk of a power outage. Survey data, obtained by employees at the MassDEP, included information about facilities that have their own form of backup power, their emergency power capacities, and those who partake in mutual aid sharing of resources. When we assessed the vulnerabilities in wastewater facilities, we focused on the sites without adequate emergency power and those who are not involved in mutual aid agreements.

For our final objective, we developed the best way to present information. We developed a prototype map to highlight Massachusetts' facility emergency power capabilities, flood zones, mutual aid participation, etc. The map can be used to identify which specific facilities are more vulnerable, allowing the MassDEP to target those facilities that could benefit from additional resource implementation. DEP staff suggested that information could be shared effectively with a pamphlet for the facility managers to increase awareness of resources available to them. We used multiple resources from EPA.gov, Mass.gov, and other outlets of information, to identify resources available to wastewater facilities regarding emergency preparation. The pamphlet contains explanations on WARN, grant aid options, and other ideas of backup power.

Findings

Our interviews and discussions with the MassDEP have helped us discover the reasonings behind the lack of efficient emergency backup power response within facilities.

1. **Data sets available to DEP are incomplete**

   We have recognized the need to improve the quality of compiled data in the MassDEP database since some of the information on wastewater facilities is incomplete. The data set show that 66% of facilities in the database have not reported whether they have backup power, or if the backup power is adequate enough to operate the facility. We were not able to completely assess which facilities are considered vulnerable throughout the entirety of Massachusetts and were limited only to facilities on which MassDEP has reported data.

2. **Findings related to future initiatives for emergency power**

   MassDEP is moving towards a green and sustainable energy initiative through the clean energy results program, which is why we looked into other forms of power that are more energy efficient. We have discovered some current options that include solar arrays and wind turbines to provide additional power, which proves more sustainable than diesel generators. These arrays and turbines can cut down electrical cost and usage for the facilities.

3. **What DRDs and Section Chiefs want to know about emergency planning**

   During our interviews, we asked the DRDs and Section Chiefs for feedback on what kind of information would be helpful to include in a digital map. As an example, we sent them the EPA map key that we referenced, which can be seen in Appendix E. Overall, they expressed that the EPA key was informative and easy to understand. As a result, we used the EPA map key as guidance for our deliverable. It was also found that a frequent concern that DRDs and Section Chiefs mentioned to us is a lack of funding for facilities to update or enhance their backup power capabilities. Another emergency response aid we decided to focus on WARN because it exclusively involves public systems, which is the main focus for MassDEP. Since WARN is a vital tool to increase cooperation between facilities, our sponsors emphasized the necessity of sharing information regarding the program with facility managers. This can be very useful to facility managers trying to recover from a power outage.

Recommendations

Based on our study we proposed five recommendations to the MassDEP. These recommendations are intended to help increase knowledge of vulnerable facilities in Massachusetts, and prompt actions to minimize their vulnerability.

1. **MassDEP should implement a system for more reliable and accurate data gathering**

   While analyzing and combining the data set, we concluded that the lack information can directly hinder effective emergency response plans. We recommend that reporting backup power capacity be made a requirement for every facility. It also would be useful to conduct another complete survey on emergency power because currently there are many gaps in the data on important information that could be useful to the MassDEP. Once the facilities are surveyed, it is recommended the MassDEP do a vulnerability assessment. This assessment can assist with comprehending the range of vulnerability from site to site.
2. **MassDEP should improve on informational resources to support emergency planning**

   A future project we recommend is to complete the digital map resource so that it includes all wastewater facilities in the Commonwealth. Our map prototype is not completed, and currently shows three locations and the categories on vulnerabilities we wanted to highlight:

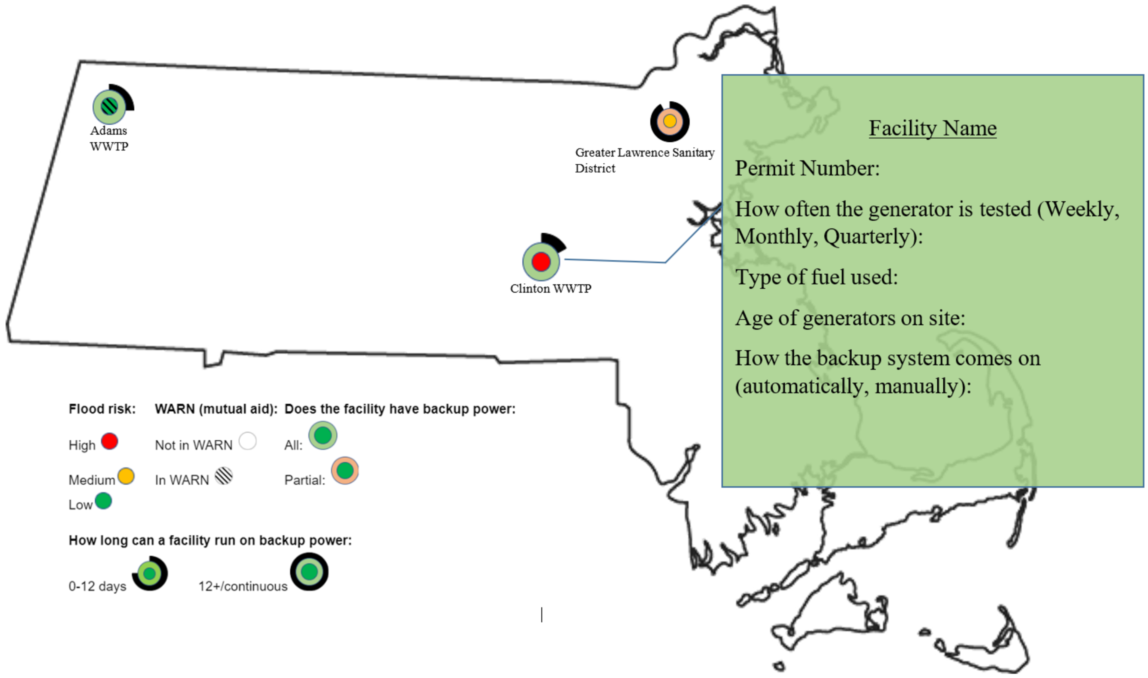


Figure 1: Prototype map

We believe it would be a useful tool in assessing and prioritizing facilities' vulnerabilities during an emergency or power outage. The map can be completed using the available survey data.

3. **The MassDEP should create a self-assessment tool for facility managers**

   Future projects should create a self-assessment tool that can aid facility managers track a site's information and gauge its vulnerability and identify areas or methods for improvement. We also found an apparent need for targeted funding to help wastewater facilities improve their backup power capabilities and reliability. We recommend that an increased focus on what grants are available to the facilities for backup power infrastructure should be prioritized. The pamphlet deliverable is one method of spreading information on the types of grants available, but it is recommended that other methods also be implemented.

4. **The MassDEP should create targeted funding for backup power through a website**

   Based on our project analysis and assessment of the existing resources available, interviews with MassDEP's DRDs, Section Chiefs and feedback from our sponsors, we see an apparent need for targeted funding to help wastewater facilities improve their backup power capabilities and reliability. The pamphlet deliverable is one method of spreading information on the types of grants available but it is recommended that other methods also be implemented. For example, by compiling grant or funding information and application links into one webpage could make access easier for site managers. It could be organized by factors like facility size requirements, public vs private grants, grants for renewable energy, etc.

5. **The MassDEP should conduct similar vulnerability assessments on the drinking water facilities in Massachusetts**

   While power outages in wastewater facilities are a large concern, it is also important to understand and address vulnerabilities in the drinking water facilities around Massachusetts. We recommend that the MassDEP do similar surveys and vulnerability assessments on drinking water facilities.

Conclusion

When power outages occur in wastewater treatment facilities, there can be very serious consequences. Any spills or leaks of untreated sewage water into the community can cause very serious health risks from parasites and harmful bacteria. This is why it is so vital to ensure that wastewater treatment facilities continue to operate even when the main electrical grid goes out. The MassDEP is taking the initiative to document the emergency power capabilities in the water sector of Massachusetts. Through this project we have concluded that the lack of data inhibits the MassDEP from understanding vulnerabilities and needs of municipal wastewater facilities. Further efforts need to be taken to improve data quality and increase focus on the needs of facilities.

Acknowledgements:

We are thankful for the information from EPA Region 1. The tours of Upper Blackstone Water Pollution Abatement District and Worcester Water Filtration Plant have also helped us with our data gathering. Ann Lowery, James Doucett, Michael DiBara and Kristin Divris have helped us with our data gathering. Deputy Regional Directors and Section Chiefs have also provided us with helpful information regarding this project.

1.0 Introduction

In the United States, more frequent and intense storms have been threatening vital water infrastructure, including wastewater and drinking water systems ("*Adapting to Climate Change*…", 2016). For example, in August of 2005, Hurricane Katrina caused catastrophic damage to states along the Gulf coast. Record breaking flooding destroyed cities and wiped out vital municipal infrastructure. The hurricane led to a disruption in power of more than 200 wastewater facilities (Copeland, 2005). Without power, treatment plants are no longer able to provide clean water to the communities around them, which can lead to more instances of disease and illness. Two weeks following the storm, only 40% of affected wastewater facilities were operational, and thus left millions without safe drinking water (Copeland, 2005). During hurricane Florence in 2018, there were generator failures at wastewater utilities (Wissbaum, 2018). The failures led to partially-treated wastewater to be released into the environment (Wissbaum, 2018).

Storms that are less severe than hurricanes can also profoundly impact water infrastructure. One example was in 2017, in the town of Lynn, Massachusetts, where heavy rain caused flash flooding that resulted in large amounts of property damage. Residents reported that sewage began overflowing in their sinks and toilets (Donnelly, 2018). One resident reported that the wastewater rose several feet in her basement, causing tens of thousands of dollars in damage (Donnelly, 2018). Older cities like Lynn have combined sewer systems that link storm water drainage and wastewater systems from homes or businesses (Donnelly, 2018). As a result, when flooding occurs, the water infrastructure cannot always cope with the influx of water.

Over the past decade, the number of storm systems has increased due to climate change (Extreme Weather, 2015). More extreme events will increase the amount of outside water inflow into sanitary and combined sewers ("Climate Impacts on Water Facilities", 2017). It would be ideal to move a facility to a better location or reconstruct certain facilities to be more adaptive to increased weather related instances. Unfortunately, this is not realistic due to the fact that reconstructing them could cost upwards of millions of dollars (Marshall, 2018). Thus, emergency planning is a critical strategy for protecting the water utilities in place ("Climate Impacts on Water Facilities", 2017). Because power is vital, understanding and improving a facility's emergency power plan can reduce the time the facility is inactive ("*Increased Power Resilience*…", 2017).

The Massachusetts Department of Environmental Protection (MassDEP) has been attempting to investigate and record emergency backup plans for drinking and wastewater treatment facilities. This, however, has proven difficult due to the lack of consistency in the currently available data. We collaborated with the MassDEP to focus on gathering a more complete dataset on backup power in wastewater treatment facilities, and gained a better understanding of current emergency capabilities. One issue that has been brought up to us by our sponsors is the inconsistent documentation of facility backup power, which is acting as a barrier in helping utilities during power loss (Divris, 2018). The goal of this project was to assess backup power capacities and needs of wastewater facilities in Massachusetts, to develop informational resources for regulators and emergency planners. Data of vulnerabilities and risks within the facilities helped us create a concept of a map to have a visual representation of which facilities need the most help from response agencies. We have also developed a pamphlet to present important information on mutual aid and backup power options currently available to wastewater facilities. The map will assist the MassDEP in providing aid to the wastewater utilities that are deemed vulnerable, and the pamphlet will outline helpful resources available to facility managers.

In the remainder of this report, we discuss a general overview of wastewater infrastructure, and the effects of power outages on them. Then, we define risks to facilities, vulnerabilities to long term outages, and introduce possible energy options for facilities to increase resiliency.

2.0 The critical role of Wastewater Infrastructure

There are around 16,000 wastewater treatment facilities around the United States and around 200 facilities in Massachusetts. Wastewater is water that been used in a home, business or industrial process. Harmful substances or chemical waste, such as pesticides, are sometimes disposed of in water systems, which is a threat to public water. There also can be other dangers such as animal waste or human attacks like bioterrorism that pose a threat in untreated water (*"Drinking Water Distribution…"*, 2017). Wastewater treatment plants are a vital component of municipalities because they ensure the removal of any harmful contaminants.

In wastewater treatment systems, water goes through a primary treatment, which involves the screening and removal of any solids as shown in Figure 1 (Loftus, 2018). The secondary treatment steps, which are different based on each facility, involve aeration, chemical, and/or bacterial remediation, to remove any harmful contaminants (Loftus, 2018). Then, the water goes onto multiple testing stages that verify that the water has been purified to a level where it can be discharged into the environment and poses no threat to human health.

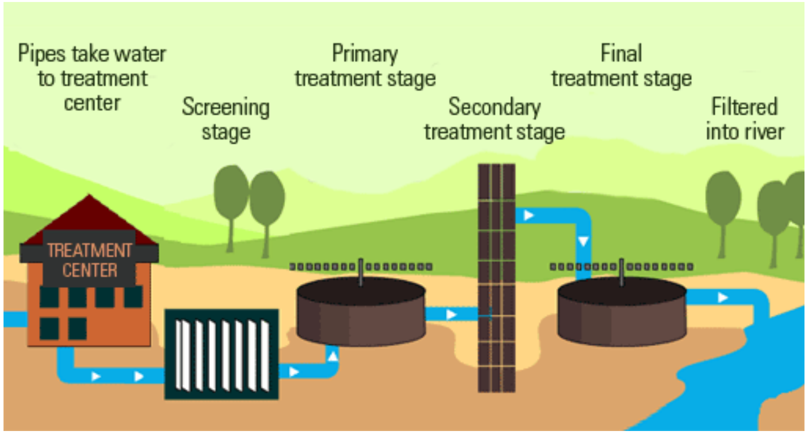


Figure 2: Wastewater Treatment Process[1]

2.0.1 Effects of power outages

Water contamination is a significant concern during power outages. For example, San Diego, CA, experienced an unexpected 12 hour electrical outage in 2011 which caused sites to be unable to filter and clean incoming water. Wastewater treatment facilities began spilling millions of gallons of sewage into local rivers because of backup and overflows (Miles, 2014). Samples from the rivers indicated elevated fecal bacteria levels, and reduced dissolved oxygen in the water (Miles, 2014). Even when the power was restored 12 hours after the initial shut down, the environmental effects were recorded up to two weeks after the event occurred (Miles, 2014). Being exposed to untreated water can lead to infectious bacteria such as E. Coli and salmonella entering the body. Symptoms of these bacterial infections include diarrhea, vomiting, dehydration and stomach cramps, which require antibiotic treatment (*"Water Treatment"*, 2015). Another result of contaminated water is parasites such as Cryptosporidium, which is a small parasite that lives in the host's intestines (*"Water Treatment"*, 2015). To minimize serious health risks and environmental pollution, the power must be restored as quickly as possible.

2.1 Risk and Vulnerability

A better understanding of risk to power outage, and how well a facility can cope, can help reduce the amount of time a facility is inoperable. Increasing information and data sharing between facilities and response agencies not only helps target sites with high risk, it also helps to reduce the vulnerabilities to long term power outages. A risk is something that exposes someone or something valued to danger, harm, or loss (Risk, n.d.). In this context, we defined risk as the potential of a power outage. A facility with a high likelihood and severity of an outage, in

[1] Environmental Protection Agency. (September, 2011). Primer for Municipal Wastewater Treatment Systems. Retrieved from https://www3.epa.gov/npdes/pubs/primer.pdf

weather related events, is at a higher risk. After addressing the risk to sites, it is important to examine vulnerabilities of how a facility might mitigate an outage if it were to occur.

Vulnerability is the "quality or state of being exposed to the possibility of being attacked or harmed" (Vulnerability, n.d.). A concern that wastewater facilities have is an extended power outage, which is considered to be any power loss that lasts longer than 4 hours (310 CMR 22.04, 2016). A facility's vulnerability to a long-term power outage is a function of its ability to cope with an electrical disruption. For example, if a facility has adequate emergency power to operate at full capacity, or how long a facility can run on emergency generators. Knowledge of these types of factors can help response agencies determine to what extent a wastewater site may be affected. If a particular site has higher likelihood of a power outage, or an outage of high severity, emergency preparations should be a top priority. Understanding how well the facility can mitigate the damage caused by an emergency after it has occurred can help determine if a facility can restore functionality on their own or if they need further assistance.

2.1.1 Emergency Power

An important approach to reducing vulnerability is the availability of emergency power sources Backup power ensures that wastewater utilities are able to continue providing their services even when there are outages ("*Increased Power Resiliency at Your…",* 2017). One option for emergency power is for the facility to run on its own microgrid. Microgrids allow facilities to isolate themselves from the main electrical grid either manually or automatically ("*Microgrids...*", 2014). This independence allows that facility to continually run critical equipment, while surrounding grids may experience power outages in the event of extreme weather or maintenance ("*Microgrids…*", 2014). One example of a microgrid being used was at Princeton University, where two microgrids were activated during Hurricane Sandy. Princeton was used as an emergency shelter for two days unaided by utility supplied power (*"Microgrids…"*, 2014). Microgrids allowed the facility to manage its critical electrical load until power on the macrogrid was restored and fully functional.

Currently, the most common backup power systems for wastewater utilities are generators. According to the EPA, when considering a proper generator system, the facility needs to determine equipment voltage, phase configuration, and other amperage needs ("*Is Your System Prepared?"*, 2011). Based on the amount of electrical needs, generator options include large stationary generators or smaller portable ones. Figure 2 shows the pros and cons of on-site versus off-site generators.

Generator	Pros	Cons
On-site (purchased)	• You know you have one • Reduced time to respond	• Could be costly • You perform the maintenance • The disaster that strikes your utility could also damage your generator
Off-site (rented or borrowed)	• Multiple sources to get one – EOC, WARN, vendor • Someone else performs the maintenance • Costs less than buying	• Travel delays to get it to your site • Your utility might not be high on the priority list to get a generator

Figure 3: Pros and cons of on-site vs off-site generators[2]

Having on-site electrical generators, as shown in figure 3, can have an immense impact on recovery time (Chang et al, 2013). In figure 3, initial time, ($\square_0$), shows where a disaster strikes water utilities and infrastructure. The graph shows the influence of pre-disaster mitigation (i.e *ex ante mitigation)* compared to post disaster mitigation (i.e *ex post action)*. For example, this shows how installing a generator in facilities can prevent a complete loss of function, compared to receiving a generator from an emergency response agency. When a storm hits, generators are able to turn on and stop the water facility from going non-operational.

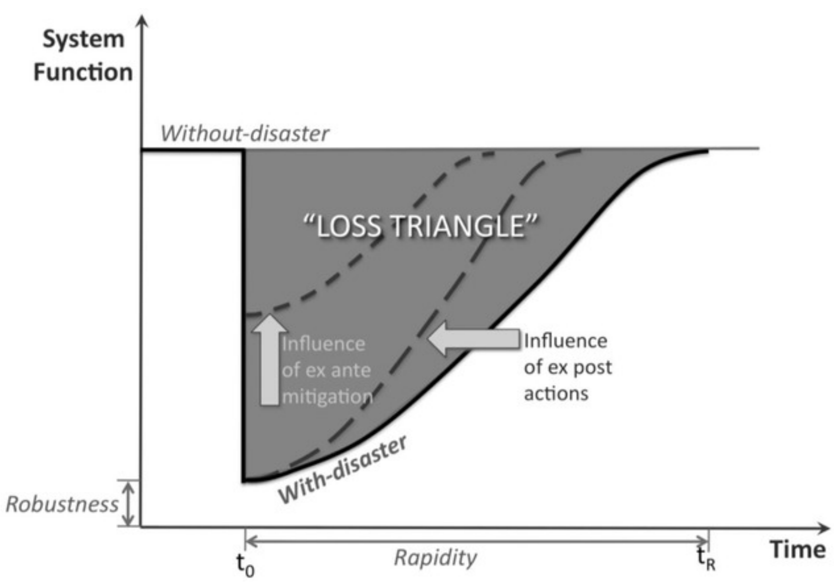


Figure 4: System function vs time during a disaster[3]

[2] Environmental Protection Agency. (2015). Power Resilience: Guide for Water and Wastewater Utilities. Retrieved March 27, 2018 from: https://www.epa.gov/sites/production/files/2016-03/documents/160212-powerresilienceguide508.pdf

[3] Chang, S. E., Mcdaniels, T., Fox, J., Dhariwal, R., & Longstaff, H. (2013). Toward Disaster-Resilient Cities: Characterizing Resilience of Infrastructure Systems with Expert Judgments. *Risk Analysis, 34*(3), 416-434. doi:10.1111/risa.12133

In addition to traditional generators that run off a fuel source like diesel or natural gas, solar energy is also an alternative on-site energy system. Photovoltaic (PV) solar energy is a solar panel that contains a semiconductor material which, when paired with an electric inverter, converts the sun's solar radiation into electricity. According to preliminary research, the Commonwealth of Massachusetts receives enough solar energy- 4 kilowatt-hours per square meter per day ($kWh/m^2/day$) - to justify the use of solar panels as a supplemental energy source (*"Commonwealth of Massachusetts Renewable Energy…"*, 2009). Solar panels can work in cold temperatures, and continually work when cleared of snow (*"Commonwealth of Massachusetts Renewable Energy…"*, 2009). A case study done at the University of Massachusetts in Lowell, looked at the viability of a wind-photovoltaic (wind-PV) hybrid power system. This case study can be seen in appendix A.

With multiple types of energy generation, facilities have many options when preparing for emergencies. In addition to electrical generation, working in conjunction with response agencies can decrease the time of power outage.

2.2 MassDEP's Current Emergency Initiative

The MassDEP has multiple ongoing projects that assist in preparing wastewater utilities for emergency situations, which are highlighted in table 1.

Program	What it does
Water Utility Resilience Program (WURP)	WURP works to compile previously collected data on wastewater and drinking water facilities, and uses that information to assess how vulnerable that facility may be in a storm or man-made disaster. WURP then prioritizes assistance to the facilities with high vulnerability based on where the facilities are located and infrastructure data (*Water Utility Resilience Program*, n.d.).
Water and Wastewater Agency Response Network (WARN)	WARN bridges communication between facilities during emergencies. The focus of WARN is the Mutual Aid Assistance Network. This program is a "utilities helping utilities" approach to recovering from a natural or man-made disaster by sharing equipment and personnel (WasteWater systems, 2010).

Table 1: Program names and description

In addition to programs like WURP and WARN, the MassDEP regulates emergency power plans for these facilities. The Code of Massachusetts Regulations (CMR) defines what is required in emergency plans. 314 CMR states that “All persons operating wastewater treatment facilities shall prepare, adopt, and keep current an operation and maintenance manual” (314 CMR 12.00, 2014.). This manual must include emergency operating and response programs, safety, and utilities and energy requirements (314 CMR 12.00, 2014).

While the MassDEP has programs and regulations about emergency backup power, there is still a need for more preparation in regard to emergencies. While Emergency planning is important, the MassDEP and other response agencies face obstacles in planning for outages because they lack knowledge of facilities’ needs. There has been an effort to record emergency power capability data, but this information is incomplete. In the following chapter we outline the processes used to address these problems.

3.0 Methodology

The goal of this project was to assess backup power capacities and needs of municipal wastewater facilities in Massachusetts and to develop informational resources for regulators and emergency planners. We accomplished this goal by achieving the following objectives:

1. Characterizing wastewater facilities’ emergency power capabilities and emergency resource knowledge
2. Determining facility vulnerability and risks associated with power loss
3. Create informational tools to improve emergency preparedness in wastewater facilities

Objective 1: Characterize wastewater facilities’ emergency power capabilities and emergency resource knowledge

We conducted semi-structured interviews with a Deputy Regional Director (DRD) of the Bureau of Water Resources, and 3 wastewater Section Chiefs. We ensured that all sensitive information was managed in excel sheets (or in pdf format) and given to MassDEP workers with correct security clearance in their secure data drive. To guarantee the privacy and well-being of participants, all questions have undergone review by the International Review Board, and all precautions have been taken to protect the interviewees’ name and identities. All interviews were voluntary and could be stopped at any time. We gained a better understanding of how water systems work, what sort of plans are being used already, and past instances of power loss. We also gathered feedback on what information is useful to managers, regional directors and sections chiefs during emergencies. Once we gathered all of the interview responses, we compared and contrasted the responses to each question. The interview questions used can be found in Appendix B.

When working towards this objective, we considered some practicalities that inhibited our data collection. We were unable to interview some DRDs and Section Chiefs due to time constraints. Originally, we had interviewed both drinking water and wastewater DRDs/section chiefs, but our focused changed to wastewater so we were unable to use information from the drinking water sector as evidence.

Objective 2: Determine facility vulnerability and risks associated with power loss

To assess risk of power outages, we considered risks of flooding which can contribute to power loss. Then, to assess vulnerability we considered several factors, as shown in Figure 6.

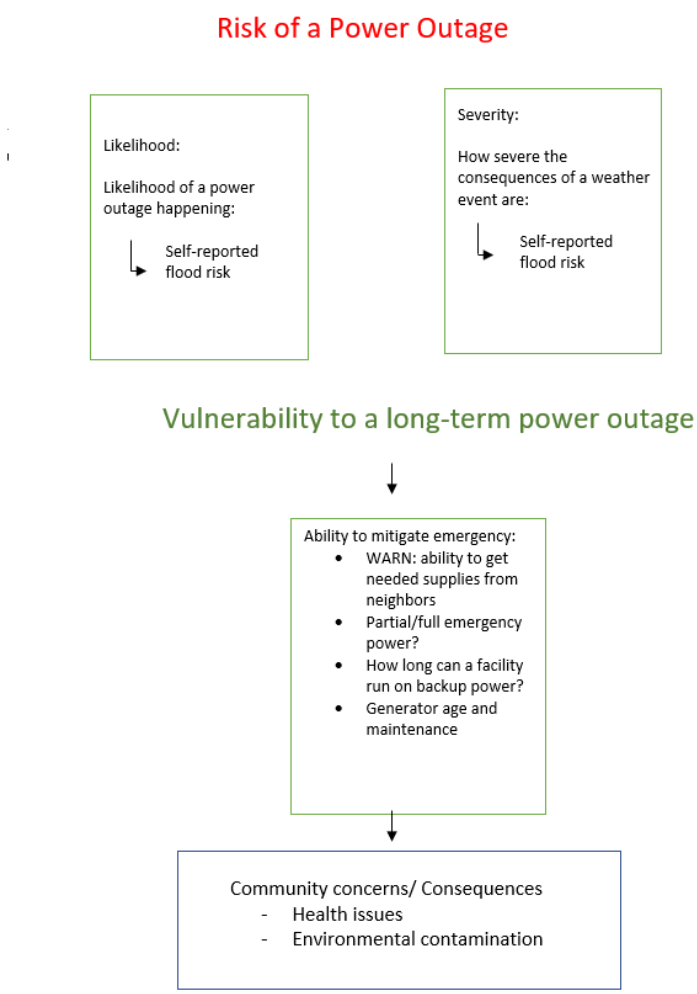


Figure 5: Risk and vulnerability categories

A map from the Environmental Protection Agency (EPA) shows Federal Emergency Management Association (FEMA) flood zones and self-reported flood risks. Using the data from the EPA map, we determined that sites with high self-reported flood risk would be at greatest risk of a power outage. Survey data, taken by employees at the MassDEP, included facilities that have their own form of backup power, emergency power capacities, and those who partake in mutual aid sharing of resources. When we assessed the vulnerabilities in wastewater facilities, we focused on the sites without adequate emergency power and those who are not involved in mutual aid agreements. To assess these vulnerabilities, we created a point system to give each facility a “vulnerability score”. The questions and point system can be seen in Table 2.

Are you in mutual aid?	How much of your facility can be run on backup power: (All, Partial, None)	How frequently is your backup system tested? (Weekly, Monthly, Quarterly)	How long can your facility run on backup power?	What is the age of generators in years?	Vulnerability score
Yes= 0 No= 1	All= 0 Partial= 1	Weekly= 0 Monthly= .5 Quarterly= 1	0-5 days= 1 5+ days= 0	0-30 years= 0 30+ years= 1	Column 1 + column 2+ …. = vuln. score

Table 2: Vulnerability scoring rules and criteria

A restriction that we encountered in the information available to us was that the data had not been updated for the facilities in some of the sources. Also, not every facility was represented in our dataset because facilities are not required to report all their information to the MassDEP.

Objective 3: Create informational tools to improve emergency preparedness in wastewater facilities

Emergency planners require accurate and complete information in order to deliver proper emergency response. For this objective, we developed the best way to present information. We intended to use GIS in order to create a map of Massachusetts that highlights facilities' emergency power capabilities, flood zones, mutual aid participation, etc. Displaying the compiled vulnerability data through the GIS program would make future research and analyses easier in case of emergencies because most vulnerable sites can be identified visually. During our interviews in objective 1 with the DEP employees and DRDs, we inquired on what they would like to see on the map. The GIS map can take an extended period of time to complete. We set up a meeting with a GIS specialist at the MassDEP to determine what can be shown on the map visually. After meeting with him, it became evident that we did not have enough time for the creation of it, which has only allowed us to develop a prototype/mockup of the map.

The map developed can be used to identify which specific facilities are more vulnerable, allowing the MassDEP to target those facilities that could benefit from additional resource implementation. DEP staff suggested that information could be shared effectively with a pamphlet for the facility managers to increase awareness of resources available to them. We used multiple resources from EPA.gov, Mass.gov, and other outlets of information, to identify resources available to wastewater facilities regarding emergency preparation. The pamphlet contains explanations on WARN, grant aid options, and other ideas of backup power. The pamphlet can be seen in Appendix C. In order to prioritize what information to include on the pamphlet, we corroborated with our sponsors to narrow down what programs could be most useful to site managers, and the best layout to organize information efficiently.

After, we presented our findings to the MassDEP, to broaden their options for technical assistance to drinking water and wastewater facilities and recommend our implementations to help improve emergency response for facilities. Through our objectives, the potential impact of the project will allow the MassDEP to further assist drinking water and wastewater facilities throughout Massachusetts.

4.0 Findings and discussion

This chapter highlights our findings for this project and the interpretations of those findings. Our interviews and discussions with the MassDEP have helped us discover the reasonings behind the lack of efficient emergency backup power response within facilities. We have recognized the need to improve the quality of compiled data in the MassDEP database since some of the information on wastewater facilities is incomplete. Our study also helped to identify vulnerabilities and needs for more assistance regarding mutual aid or grants.

4.1 Findings related to data quality

Qualitative data is essential in understanding the needs or risks to facilities responding to power outages. Our project description mentioned that sharing of data was a concern to the DEP (Divris, 2017). Our analysis suggests that a poor data quality presents significant challenges that hinder understanding the status of facility's emergency power efficiency or needs.

4.1.1. Data sets available to DEP are incomplete

In 2012, the EPA did a survey on emergency power in wastewater facilities. Another survey was taken in 2017, by Kristin Divris and John Murphy of the MassDEP. There are around 120 public wastewater treatment sites in Massachusetts, and with both surveys combined, we have data on about 169, implying that some privately-owned facilities were also surveyed. 56 responses were recorded for the MassDEP survey and 108 from the EPA survey. Since many facilities were not accounted for in the survey data, there is a lack of completeness in the data set. Also, some facilities only filled out one survey, or only had data that satisfies half of the columns.

Table 3 illustrates the lack of data by showing responses and non-responses to two questions in the surveys. These examples show that 66% of facilities in the database have not reported whether they have backup power, or if the backup power is adequate enough to operate the facility. Questions like these are a crucial part of determining how vulnerable a facility is and can affect the efficiency of emergency response.

Does the facility have emergency backup power?	Yes: 56/169 No: N/A No Information: 113/169
Does the facility have adequate backup power to run the facility during an outage?	Yes: 51/169 No: 5/169 No Information: 113/169

Table 3: Two questions from combined data set

Another problem was caused by differing categories between surveys, illustrated in table 4, which made combining results into one spreadsheet difficult.

EPA survey	MassDEP survey
Flood Risk	Does your facility have an emergency backup power system? (Yes/no)
Generator at critical locations in plant	How much of the facility can be run on the backup system? (All, partial, none)
Generator in collection system	Does the backup system come on automatically or is there a switch to turn it on? (Automatic/switch)
Pump stations operate under SCADA	Is the backup system adequate for facility needs? (Yes/no)
Generator for pump station	Would you be interested in acquiring a backup power system, or upgrading your existing system? (Acquire, update existing, neither)
% of plant that can operate on backup power (All, partial or none)	How frequently is the back-up system tested? (Weekly, monthly, quarterly)
How long they can operate on generator without refueling	Is the backup system tested under full load? (Yes/no)
Inundate or damage	What type of fuel is used for the generators? (Diesel, gasoline, liquid propane, natural gas)
Inundate or damage items	How many hours of fuel capacity are onsite to run the emergency backup system?
Inaccessible during flood	What are the age of your generators in years?
Cause of flooding	Are the generators fixed, portable, or towable units?
Money spent	Is the location of any fixed generators in the 100 year floodplain, or subject to any flooding? (Yes/no or unknown)

Table 4: Survey Categories. The categories marked in green were combined in final spreadsheet

In order to preserve relevant emergency power knowledge, we decided to combine the entirety of the data gathered from each survey into one data set. As a result, the spreadsheet has all the data categories from both surveys, and any that were similar were combined into one column (these are shown in Table 4 in green text). Another concern is that the data from the EPA survey is outdated because it was given back in 2012. In an interview with a Section Chief, the pointed out that one facility on the map was no longer active. Since lack of response lowers the quality of data that the MassDEP has gathered, there is an increased importance of consistent response rate from the facility managers.

4.1.2 Data on emergency backup power helps determine vulnerability, however incomplete data hinders vulnerability assessments

A facilities' ability to cope with a power outage, or how well a facility's emergency power restores operation, determines vulnerability. The data set that the MassDEP provided helped us categorize and rank the facilities vulnerabilities. Using this information, we found the following.

Categories from combined spreadsheet	Number of facilities / Total number of facilities
Facility's Self Reported Flood Risk	High: 15/169 Medium: 37/169 Low: 58/169 No Information: 59/169
Is the facility a part of mutual aid?	Yes: 98/169 No: 56/169 No Information: 15/169
How often does your generator get tested? How long can the facility run off emergency backup power?	Weekly: 23/169 Monthly: 23/169 Quarterly: 1/169 Annually: 2/169 No Information: 120/169
What is the age of your generator?	0-30 years old: 36/169 31+ years old: 19/169 No Information: 114/169
How long can the facility run off emergency backup power?	0-5 Days: 66/169 6-10 Days: 12/169 11+ days: 15/169 No Information: 76/169

Table 5: Data on vulnerability categories

We originally designed a vulnerability point system between all the categories of data and ranked the facilities based on that system. Due to the missing information, we could not determine whether that facility had a vulnerability within those categories. We were not able to completely assess which facilities are considered vulnerable throughout the entirety of Massachusetts and were limited only to facilities on which MassDEP has reported data. No accurate or complete vulnerability ranking can be created without significant additional data collection by agencies such as MassDEP. The ability to gather complete information will be a challenge. John Murphy and Kristin Divris commented that the 2017 survey they conducted was time consuming and took months to complete, leading us to believe that completing the list of facilities also would take a significant amount of time.

4.2 Findings related to future initiatives for emergency power

With increasing frequency of weather systems, proactive approaches to outage mitigation and prevention are critical. Understanding facilities' needs and ways they can improve energy efficiency is vital to planning for future projects. The following sections identify what we learned about different types of energy options being used.

4.2.1 Massachusetts is progressing from the use of diesel generators to cleaner energy options

According to our interviewees the most common type of backup power is in the form of diesel generators. Out of the 169 facilities we have data on, 56 documented what type of fuel they run on. Of 56 facilities recorded to have backup power, 51 are using diesel generators, as opposed to natural gas, gasoline, or liquid propane. Facilities relying on diesel depend on fuel deliveries, which increases vulnerability during long power outages. The occurrence of a large scale weather event could cause roads to be blocked by trees or ice, possibly affecting fuel delivery. If fuel cannot be delivered to a station, the facility may spend more time in an inoperable state. Another concern in regard to diesel use is that fuel that sits for too long in the tank becomes unusable, creating problems if an emergency need for that generator arises.

Since MassDEP is moving towards a green and sustainable energy initiative through the clean energy results program, we looked into other forms of power that are more energy efficient. Some current options include solar arrays and wind turbines to provide additional power, which proves more sustainable than diesel generators. These arrays and turbines can cut down electrical cost and usage for the facilities. For example, the Massachusetts Water Resources Authority (MWRA) uses solar arrays, wind turbines, and methane fueled combustion generators. This allows that site to run autonomously using their own clean energy. The Greater Lawrence Sanitary District (GLSD) wastewater facility is also making the switch to energy efficient generation. GLSD is switching to a combined heat and power system that will allow them to be on their own grid and be self-sufficient. Operating on their own power grid means that they will be able to continue functioning, even if electricity on the main grid has been lost.

4.3 What DRDs and Section Chiefs want to know about emergency planning

To increase the accuracy of emergency planning, the DRDs and Section Chiefs have expressed the necessity of knowing facilities' power abilities and possible needs. The following section relays feedback on what they and facility managers could find useful in an emergency situation. We also discuss facility needs to improve existing infrastructure through funding.

4.3.1 Creating a map works as a visual representation of risks and vulnerabilities of wastewater sites around Massachusetts

We used the combined data set to develop a graphic for a map which is specified in objective 3. Since there are facilities that did not respond or there is limited data on them, it affects the overall integrity of the map. During our interviews, we asked the DRDs and Section Chiefs for feedback on what kind of information would be helpful to include in a digital map. As an example, we sent them the EPA map key that we referenced, which can be seen in Appendix D. Overall, they expressed that the EPA key was informative and easy to understand. As a result, we used the EPA map key as guidance for our deliverable. The responses were as followed:

- Knowing how much of a facility can run on backup power should be represented in the map.
- What fuel a facility uses for generators, a "hot button" to show more data on each facility would also be very helpful, liked the key on the EPA map.
- Liked the EPA map setup.

We took all the feedback into consideration and developed a map prototype that can be seen in Figure 6.

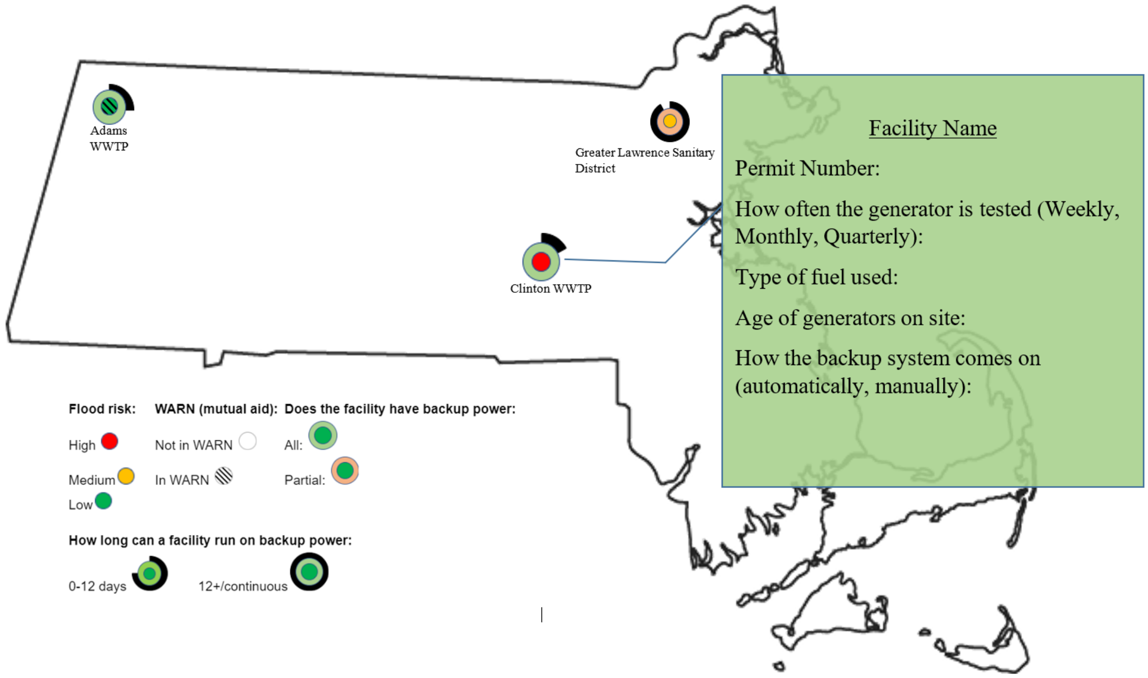


Figure 6: Map Protoype

4.3.2 Lack of funding impedes emergency preparation

A focus in this project was to figure out challenges that hinder wastewater facilities' response plan for power loss. A frequent concern that DRDs and Section Chiefs mentioned to us is a lack of funding for facilities to update or enhance their backup power capabilities. Most of the facilities that exist were also constructed in the 1980's, during which 75% of construction costs were covered by the federal government and an additional 15% by the government of Massachusetts (Brander, 2018). Grants such as the FEMA Hazard Mitigation Grant Program provide funds to prepare utilities for natural hazards ("Hazard Mitigation Program", n.d). The grant amount from FEMA varies from $9,000 to $25,000 per community ("Hazard Mitigation Program", n.d). These grants do not guarantee enough monetary assistance to enhance emergency backup power. Funding opportunities are also competitive and require a lot of effort to apply for.

4.3.3 Mutual aid enhances emergency response in wastewater facilities

Over 50% of the facilities completing the surveys reported that they were part of mutual aid agreements, which can be seen in figure 8. One type of mutual aid we wanted to feature was WARN. We decided to focus on WARN because it exclusively involves public systems, which is the main focus for MassDEP. Since WARN is a vital tool to increase cooperation between facilities, our sponsors emphasized the necessity of sharing information regarding the program with facility managers.

5.0 Recommendations and Conclusions

The work we have completed has led us to conclusions and recommendations for the MassDEP. These suggestions are intended to help increase knowledge of vulnerable facilities in Massachusetts, and prompt actions to minimize their vulnerability. In this section, we draw conclusions from our findings and make recommendations about data collection, vulnerability assessments, visual representations of data and making funding more accessible to facilities who need it.

5.1 MassDEP should implement a system for more reliable and accurate data gathering

While analyzing and combining the data set, we concluded that the lack information can directly hinder effective emergency response plans. With storm events occuring more often, the threat of complications in the water sector is becoming a concerning reality. We suggest that the MassDEP increase their available data on wastewater emergency backup power. There are several contributing factors that we have identified and recommended changes to increase readily available data.

5.1.1 Require information reporting to MassDEP through regulation

Currently, 314 CMR “Operation, Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Dischargers” states that all wastewater facilities are required to have some form of emergency backup power (314 CMR 12.00, 2014). However, they are not required to report the extent of their emergency backup power to MassDEP. The lack of responses to previous voluntary surveys contributes to the shortage of data in the DEP database, which obstructed our assessment of the data. We recommend that reporting backup power capacity be made a requirement for every facility. How often it needs to be reported, should be determined through conversations with wastewater managers and the MassDEP. Not only will reporting regulations increase facility response rate, it will ensure uniformity of responses in each category, and allow facilities to compare their “readiness” to other facilities.

5.1.2 Gather complete information about facility capacities in case of an emergency

We recommend conducting another complete survey on emergency power because currently there are many gaps in the data on important information that could be useful to the

MassDEP. With missing information, the MassDEP is unable to understand all of the facilities' needs when it comes to backup power. When resending the survey to facilities, we recommend that survey questions on backup power be prioritized. This suggested improved survey should include questions such as: how long can your facility run on backup power, what type of backup power do you use, and what fuel source do you use? However, questions having "yes or no" responses will gather a baseline of facility information. Example questions that can be changed include:

- Does the backup system come on automatically?
  - Original: Does the backup system come on automatically or is there a switch?
- Do you test your backup system?
  - Original: How frequently is the backup system tested?

As facilities respond to the new surveys, the MassDEP should then add their responses straight into the spreadsheet we created or a similar spreadsheet to ours. This assures that the MassDEP has current and up to date data in a singular source. We recommend that this data spreadsheet be available to be viewed by the MassDEP staff and facility managers with secure login access. Security issues should be resolved before deciding on access to facility managers and to the public.

5.1.3 Conduct vulnerability assessments of facilities to allow responding agencies to prioritize help

Understanding strengths and limitations of a wastewater system and location can allow the MassDEP and other responders to prioritize facilities that may need additional help in the event of an outage. We recommend the MassDEP do a vulnerability assessment, on facilities, using a similar point system described in the methodology chapter. This assessment can assist with comprehending the range of vulnerability from site to site. If a facility has a low vulnerability score, it does not have to be a top priority if an outage occurs. The point system can ensure a consistent evaluation of the necessary data.

While doing this, a set criterion for what makes a facility vulnerable to long term power outages needs to be established. For example, we categorized the age of a generator as a vulnerability. However, whether or not age affects the generators ability to run adequately is situational. This led us to conclude that data categories, that can be generalized for every facility, would be most useful in a vulnerability assessment.

We also recommend setting a vulnerability timeframe for how long a facility can run on backup power. A facility that can run on backup power for a longer time compared to other facilities is less vulnerable. To be precise, there needs to be a distinction on how long a facility can run on backup power before it becomes categorized as vulnerable.

5.2 Recommendations for informational resources to support emergency planning

An initiative we recommend is to complete the digital map resource so that it includes all wastewater facilities in the Commonwealth using the prototype. The map prototype that we have designed contains information such as flood risk, mutual aid options, whether or not the facility has backup power and for how long. Due to time constraints, we were unable to complete the map. However, it would be a useful tool in assessing and prioritizing facilities' vulnerabilities. Like the data set, the map should be accessible to both the MassDEP and facility managers to utilize for emergency response. Security issues will need to be considered and decided before general access is provided.

5.3 Recommendations for future projects

This project has given us important insight on wastewater facilities and the need to continue the research. Below we identify steps that can be taken in the future regarding improved emergency backup power knowledge in water infrastructure.

5.3.1 MassDEP should test and encourage facility self-assessment of backup power systems' capacities and needs

While we believe it is important for facilities to report their emergency backup power, it would also be beneficial to facility managers to have a general overview of their emergency power capacities in a visual diagram. We recommend creating a self-assessment tool for facilities to use. The self-assessment tool can aid facility managers with tracking a site's information, gauging its vulnerability and identifying areas or methods for improvement. A type of self-assessment tool that can encourage facilities to track their information, is the use of a "spider web" diagram that can be seen in Appendix E. One idea we recommend is to send this self-assessment out to facilities every year, so they can see what has improved, changed, or stayed the same from year to year. It could also be made available at conferences and events. This assessment should include quick and general questions to encourage facility managers to fill it out, and can get facility managers interested in updating or improving their backup power capabilities. This assessment should be voluntary to facility managers; however we believe an assessment like this would make reporting to the MassDEP easier because the facility would have information about their emergency power capacities readily available. We also recommend that for future projects, quantitative questions need to be created so that reasonable insight to facilities can be provided.

5.3.2 MassDEP should conduct similar studies on the drinking water sector of Massachusetts.

While power outages in wastewater facilities are a large concern, it is also important to understand and address vulnerabilities in the drinking water facilities around Massachusetts. We recommend that the MassDEP do similar surveys and vulnerability assessments on drinking water facilities. This will allow the MassDEP to better understand facility needs and increase emergency response to these facilities in the event of an emergency.

5.4 MassDEP should create targeted funding for backup power to facilities

Based on our project analysis and assessment of the existing resources available, interviews with MassDEP's DRDs, Section Chiefs and feedback from our sponsors, we see an apparent need for targeted funding to help wastewater facilities improve their backup power capabilities and reliability. These treatment facilities are critical public assets that are often overlooked when they are operating 24/7 behind the scenes, but quickly can become a public health and environmental threat during a prolonged power outage. We recommend that an increased focus on what grants are available to the facilities for backup power infrastructure should be prioritized. The pamphlet deliverable is one method of spreading information on the types of grants available but it is recommended that other methods also be implemented. For example, compiling grant or funding information and application links into one webpage could make access easier for site managers. It could be organized by factors like facility size requirements, public vs private grants, grants for renewable energy, etc.

Conclusion:

When power outages occur in wastewater treatment facilities, there can be very serious consequences. Any spills or leaks of untreated sewage water into the community can cause very serious health risks from parasites and harmful bacteria. This is why it is so vital to ensure that wastewater treatment facilities continue to operate even when the main electrical grid goes out. In response to this, the MassDEP is taking the initiative to document the emergency power capabilities in the water sector of Massachusetts.

During our project we combined emergency power survey data and conducted interviews, to help address vulnerabilities and emergency power capacities in the wastewater sector of Massachusetts. This led us do create a map prototype that visually represents facilities' vulnerabilities, and an informational resource pamphlet for facility managers. These tools can be used by response agencies and the facility managers to increase emergency preparation efforts in wastewater treatment plants. What we found throughout our research is that the data sets at the DEP are incomplete, Massachusetts is moving toward cleaner energy options, and what specific information Deputy Regional Directors would like to know in the event of an emergency power outage.

Through this project we have concluded that the lack of data inhibits the MassDEP from understanding vulnerabilities and needs of municipal wastewater facilities. Further efforts need to be taken to improve data quality and increase focus on the needs of facilities

Bibliography

Brander, K. (2018, September 21). Personal interview.

Brodeur, B. (2018, September 18). Personal interview.

Chang, S. E., Mcdaniels, T., Fox, J., Dhariwal, R., & Longstaff, H. (2013). Toward Disaster-Resilient Cities: Characterizing Resilience of Infrastructure Systems with Expert Judgments. *Risk Analysis, 34*(3), 416-434. doi:10.1111/risa.12133

Commonwealth of Massachusetts Renewable Energy and Energy Efficiency Potential at State-Owned Facilities and Lands. Massachusetts Executive office of Energy and Environmental Affairs. (2009) *Mass.gov.* Retrieved April 1st, 2018 from: http://www.mass.gov/eea/docs/eea/press/publications/022409-renew-potential-study.pdf

Construction, Operation and Maintenance of Public Water Systems, 310 CMR 22.04 (2016).

Copeland, C. (2005). Hurricane damaged drinking water and wastewater facilities: Impacts, needs, and response. CRS Report for Congress. Retrieved April 18, 2006 from http://www.ncseonline.org/nle/crsreports/05oct/RS22285.pdf

Divris, K. (2018, September 13). Personal interview.

Donnolly A., Moser D., (2018, January 6) Flood of Complaints in Lynn. *New England Cable News.* Retrieved from: https://www.necn.com/news/new-england/Flood-of-Complaints-in-Lynn-469089713.html

Dudley, B. (2018, September 20). Personal interview.

Environmental Protection Agency. (June, 2016) Adapting to Climate Change in the Northeast. [PDF] retrieved from https://www.epa.gov/sites/production/files/2016-07/documents/northeast_fact_sheet.pdf

Environmental Protection Agency. (2017) Drinking Water Distributions Systems. Retrieved from

https://www.epa.gov/dwsixyearreview/drinking-water-distribution-systems

Environmental Protection Agency. (2017, April 10). Increase Power Resilience at Your Water Utility. Retrieved April 03, 2018, from https://www.epa.gov/communitywaterresilience/increase-power-resilience-your-water-utility

Environmental Protection Agency. (September 2009). Is Your Water System Prepared? What You Need To Know About Generators [PDF]. Retrieved from: https://www.epa.gov/sites/production/files/2015-12/documents/waterwastewatersystemgeneratorpreparedness.pdf

(February, 2014). Microgrids- Benefits, Models, Barriers and Suggested Policy Initiative for the Commonwealth of Massachusetts. *KEMA.* Retrieved from: http://files.masscec.com/research/Microgrids.pdf

Giraud, F., Salameh, Z. (March, 2001). Steady-State Performance of a Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage. IEEE Transactions of Energy Conservation, 16(1), 1-7. Retrieved from: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=911395&tag=1

Gutro, R. (March 2013) Hurricane Sandy (Atlantic Ocean). *NASA* retrieved from

https://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html
Hazard Mitigation Grant Program. (n.d.). Retrieved September 29, 2018, from https://www.fema.gov/hazard-mitigation-grant-program
Leech, B. (2002). Asking Questions: Techniques for Semistructured Interviews. PS: Political & Politics, 35(4), 665-668. doi:10.1017/S1049096502001129
Loftus, T. (2018, September 14). Personal interview.
Lowery, A. (2018, September 13). Personal interview.
Marshall, K. (2018, January 16). How Much Does an Industrial Water Treatment System Cost? Retrieved from https://www.samcotech.com/how-much-does-an-industrial-water-treatment-system-cost/
MassEMA. (2018, March 13). "~218K outages at 5 PM Utilities report this will be a multi-day restoration effort. Those without power should stay with friends, family, at hotels or a nearby shelter - Call local public safety officials or 2-1-1 for shelter locations Safety tips: http://bit.ly/2j5qs8X **#MAsnow**" [Twitter Post]. Retrieved from https://twitter.com/MassEMA/status/973668885621813248
Metcalf & Eddy, Inc. (2003). Wastewater Engineering: Treatment and Reuse (4th ed.). New York: McGraw-Hill
Miles S., Gallagher H., Huxford C. (2014). Restoration and Impacts of the September 8, 2011, San Diego Power Outage. *J. Infrastruct. Syst*., 20(2): 05014002. Retrieved March 29, 2018 from: https://ascelibrary-org.ezproxy.wpi.edu/doi/pdf/10.1061/%28ASCE%29IS.1943-555X.0000176
Murphy, J. (2018, September 13). Personal interview.
N.a (2017, March 7). Climate Impacts on Water Facilities. Retrieved from https://www.epa.gov/arc-x/climate-impacts-water-utilities#impacts
NOAA-National Centers for Environmental Information (October, 2018) *National Climate Report - February 2017 Winter Snowfall Departure from Average*. Retrieved September 26, 2018 from: https://www.ncdc.noaa.gov/sotc/national/2017/02/supplemental/page-1
Operation, Maintenance and Pretreatment Standards for Wastewater Treatment Works and Indirect Dischargers, 314 CMR 12.00 (2014).
Risk | Definition of risk in English by Oxford Dictionaries. (n.d.). Retrieved from https://en.oxforddictionaries.com/definition/risk
Sandalow, D. *(November 2012). Hurricane Sandy and Our Energy Infrastructure. Department of Energy. Retrieved from https://www.energy.gov/articles/hurricane-sandy-and-our-energy-infrastructure*
Stone, M. (2018, September 7). Personal interview.
Vulnerability | Definition of vulnerability in English by Oxford Dictionaries. (n.d.). Retrieved from https://en.oxforddictionaries.com/definition/vulnerability
Water Treatment (2015). Center for Disease Control and Prevention. Retrieved from https://www.cdc.gov/healthywater/drinking/public/water_treatment.html
Wissbaum, B., Smart, B., Davis, E., & Bullock, C. (2018, September 14). Effects of Hurricane Florence: Utilities seeing damage, reporting issues after storm. Retrieved from http://www.wect.com/story/39093883/effects-of-hurricane-florence-utilities-seeing-damage-reporting-issues-after-storm/

Appendices

Appendix A: Princeton Case Study

In this study, data was collected over a two-year period and determined that the system satisfied its energy load requirements, with additional energy able to be stored in the batteries attached to the system (Giraud, 2001). It was found that energy gathered in a period of high-energy activity -ample sun- could make up for a period of deficit (Giraud, 2001). However, periods during the winter months affected the amount of energy able to be converted and stored. This backup system only accounts for power outages for one to two days. Even though this may not be a viable option for facilities that are at highly vulnerable to long term power outage, wind-PV is an option for facilities that may have less vulnerability and only experience short term power loss.

Appendix B: Interview questions

Preamble:

We are a group of students from Worcester Polytechnic Institute and we are working with the Massachusetts Department of Environmental Protection to gather information regarding emergency power in facilities. Currently, we are conducting interviews with regional directors regarding emergency power capacities. We are doing this to better understand what can be done to increase preparedness and information sharing. Your participation in this interview is completely voluntary and you may withdraw at any time. If you would like, we would be happy to include your comments as anonymous.

1. To start off, can you tell us your title, where your work, and what you do there.
2. What are some of the variations of the facilities in your region?
    a. For example do some use biological treatment? Chemical? Etc…
3. Have any of the facilities in your region experienced any power outages that have lasted more than 4 hours at a time? (examples:winter storms, hurricane sandy/irene, nor'easter, non-weather related incidents?)
    a. Have any of those outages resulted in problems at the facility? For example, release of untreated wastewater, inability to supply adequate drinking water or to treat it?
4. Have there been any facilities where power outages are becoming consistent?
5. What are some of the basic protocols that your office follows in preparation of an emergency situation (i.e hurricane)? What about after an incident (weather or non-weather related) has occurred?
    a. What are some of the priority actions to take? What types of difficulties follow the priority actions?
6. What are some types of backup power used in facilities? Which is most common? Why?
    a. Are there any facilities that run on other power sources such as a microgrid?
7. When power outages occur, what components of the system are most likely to go down?
    a. What happens when a components of a system fails.
    b. In general, what part of the system would have backup power? The whole system? Only parts of the system?
8. What challenges have you or specific facilities faced concerning emergency backup power?
    a. Money? Regulations? Accessibility?

We are creating a pamphlet that outlines information on emergency power options and also mutual aid programs such as WARN. Part of this project is understanding how to help facilities gain information to better prepare themselves incase of an emergency.

9. What information do you think would best benefit facilities in helping them understand options available to them regarding emergency power options/mutual aid?
    a. For example, mutual aid agreements, backup generators, solar power microgrids, or battery/energy storage.

We are also creating a map to display details about facility vulnerability and emergency power capacities. We have attached the map we are working on in the email sent.

10. Would this type of visual map be useful to you or facility managers?
    a. Is the information on the current map something that can be used incase of an emergency situation?
11. What other information is necessary to be displayed in the map?
    a. During an emergency situation what information is most valuable to you regarding these facilities?
    b. Is this information readily available to you

Appendix C: Pamphlet

Energy Options

Generators

There are many options for traditional generators. Since each facility is unique, one type of generator might be more suited than another type. Below is a chart giving general information on each type.

	Diesel[1]	Natural Gas[2]	Propane[3]	Gasoline
Fuel Storage	+	+	+	-
Fuel Delivery Method	-	+	-	-
Generator Availability	+	-	-	+
Generator Portability	-	-	-	+

Other things to consider for facilities that already have generators on-site are:

- How old is the generator?
- How often is the generator tested?
- Can my facility fully run on a backup power generator?
- Which is a better option: rent, borrow, or buy a generator?

For more in depth info on generator regulations and options, visit EPA.gov and Mass.gov
https://www.mass.gov/how-to/compliance-certification-stationary-engine-or-turbine

Solar Massachusetts Renewable Target Program (SMART).

The goal of SMART is to create a long-term solar incentive program that promotes cost-effective solar development. Have you thought about switching to solar energy and are interconnected with any of these companies?

- National Grid
- Eversource
- Unitil

If a facility fills the requirements, the tariff-based incentive will be provided directly from the utility company, to the system owner. Go to the following link to get more info on the program:
https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program#general-information-

Combined Heat and Power Generation (CHP)

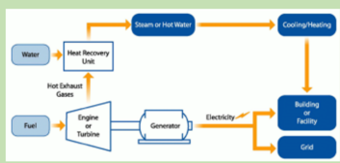
If you answer "yes" to these questions, you may qualify to be a good candidate for CHP!

- Are you concerned about the impact of current or future energy costs on your business?
- Is there a substantial financial impact to your business if the power goes out for 1 hour? For 5 minutes?
- Does your facility operate for more than 5,000 hours per year?
- Do you have thermal loads throughout the year (including steam, hot water, chilled water, hot air, etc.)?

Benefits of CHP:

- More cost-efficient;
- Uses heat given off by the generator to produce more electricity, meaning less energy lost as heat;
- Save up to two thirds saving in fuel costs
- Improved power quality and reliability; and
- Up to 50% reduced emissions

For more information on CHP, and for technical assistance go to http://www.northeastchptap.org/.



Combustion Turbine, or Reciprocating Engine, with Heat Recovery Unit

Resources to Ensure Uninterrupted Power for the Water Sector

MassDEP

Contact Information:
James Doucett (Clean Energy Results Program)
James.Doucett@state.ma.us

Mike DiBara (Clean Energy Results Program)
Michael.DiBara@state.ma.us

WPI

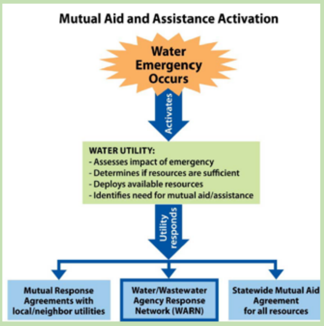
This Pamphlet was developed through an Interactive Qualifying Project with Worcester Polytechnic Institute and the MassDEP.
Fall 2018

In Massachusetts, an estimated 1.6 billion gallons of wastewater and drinking water is processed every day. With public health being a top priority, it is important to ensure that water utilities are prepared in case of an emergency. This pamphlet outlines grant opportunities, aid programs and power options that may be useful to facilities in preparation for possible power loss incidents.

Planning Assistance

Water and Wastewater Agency Response Network (WARN)

Power loss in utilities can prevent critical treatment of water, but neighboring facilities can provide support during power loss by supplying necessary backup generators. WARN was put in place to help connect facilities with each other. For more information on WARN and becoming a WARN member, please visit: https://www.epa.gov/waterutilityresponse/mutual-aid-and-assistance-drinking-water-and-wastewater-utilities



Response System for WARN

Emergency Power Facilities Assessment Tool

EPFAT is a web-based tool that contains emergency power assessment data that gets filled out by facility owners or operators or different water treatment plants. To learn more about EPFAT, please visit: https://www.usace.army.mil/Portals/2/docs/Emergency%20Ops/National%20Response%20Framework/power/EPFAT_Fa

Water Utility Resilience Program (WURP)

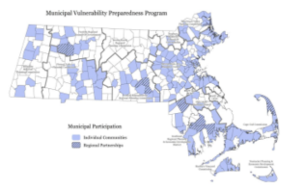
WURP works to ensure resiliency in water utilities during a major weather event. This program includes:

- Critical infrastructure mapping.
- Emergency and security preparedness.
    - Training support.
    - Drinking water program emergency response plan.
- Cyanobacteria support.
- Climate information and support.
    - National climate resource tools.

Technical assistance is prioritized through vulnerability and risk assessments. For greater detail on WURP's projects, please visit: https://www.mass.gov/guides/water-utility-resilience-program.

Municipal Vulnerability Preparedness Program (MVP)

The "MVP" program is a grant program in Massachusetts that provides help for communities in increasing resiliency against climate change related incidents. Different communities are awarded a grant for vulnerability assessments and for developing plans on adapting to hazards related to climate change. To learn more about how to become eligible for the MVP grant and other opportunities, go to: https://www.mass.gov/service-details/mvp-program-information



Participants in the MVP Program

Grant Programs

FEMA Hazard Mitigation Grant Program:

The FEMA Hazard Mitigation Grant Program (HMGP) works to provide funds that reduce future risk to the public in the event of a natural hazard. Projects covered by this grant are:

- Storm water upgrades
- Drainage and culvert improvements
- Property acquisition
- Slope stabilization
- Infrastructure protection
- Seismic and wind retrofits
- Structure evaluations.

The purpose of the program is to assist applicants in acquiring long-term, yet cost-effective ways to reduce the risks associated with natural disasters. Possible funding for a multi-community planning grant can range from **$9,000 - $25,000** per community. For more info go to: https://www.mass.gov/service-details/hazard-mitigation-grant-program-hmgp

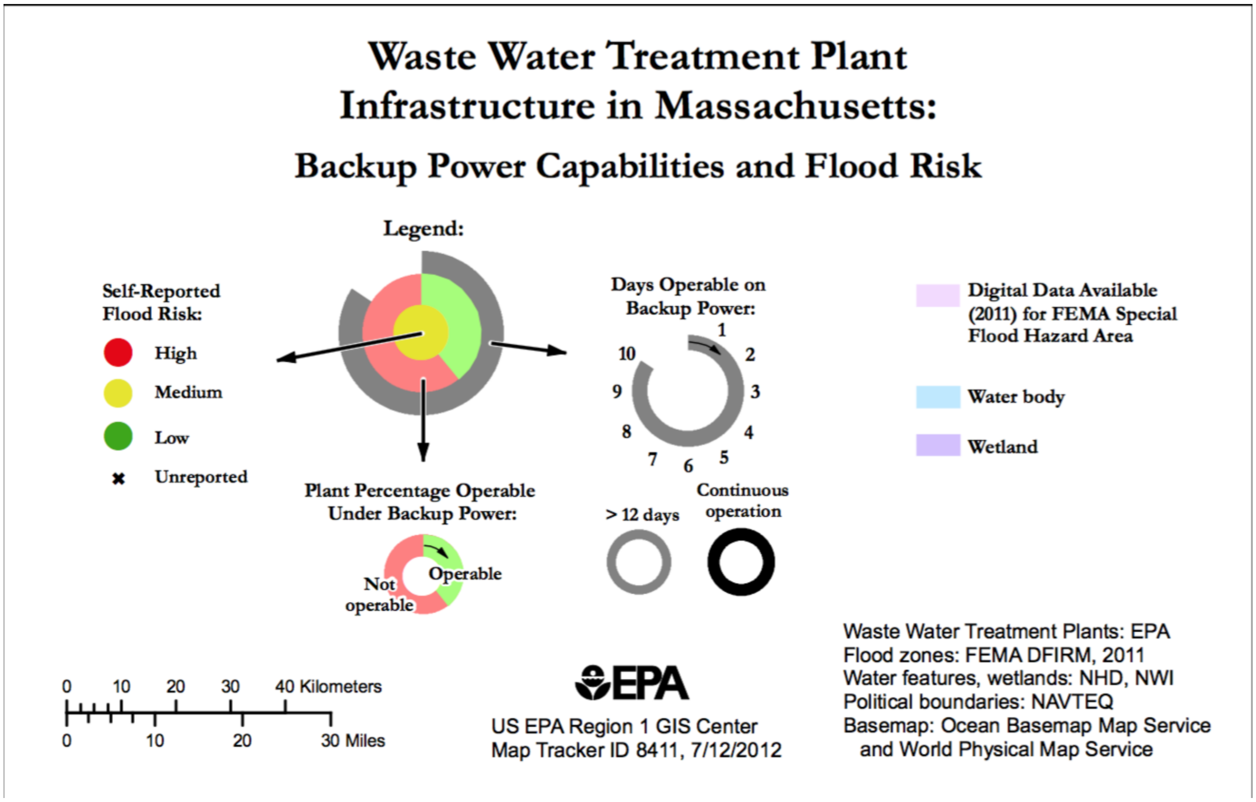
Rural Development Grants

The U.S Department of Agriculture and Rural Development has a water and waste disposal loan and grant program that services rural communities of **10,000 people or less**. These are long-term and low-interest loans, or there is an option for a grant combined with a loan. Funds can be used for the following:

- Drinking water sourcing, treatment, storage and distribution.
- Sewer collection, transmission, treatment, and disposal.
- Solid waste collection, disposal, and closure.

Storm water collection, transmission and disposal, etc. For more info visit: https://www.rd.usda.gov/programs-services/water-waste-disposal-loan-grant-program

Appendix D: Map key



Appendix E: "Spider web" Self-assessment tool