Creating a Comprehensive Survey and Preventative Maintenance Plan for Water Piping Infrastructure on a Historic College Campus*

Marla Rain Moock, Belle Williams, Professor Jonathan Bender

Abstract— **Many universities across the country are challenged with aging infrastructures, some of which are over a hundred years old and lack vital documentation. Among these, water dispersal systems are particularly susceptible to failures. Water inefficiencies, leaks, and flooding can negatively impact an operating college campus and those who inhabit it. This research project aims to examine the factors that contribute to leaks and bottlenecks in older universities' water dispersal systems, propose risk mitigation measures, and recommend preventative actions, while also providing a method for campuses to log their water distribution system if there are missing maps to easily isolate and locate valves and potential problem areas within the system. The formulation of this scientific methodology was centered on the premises of Sweet Briar College, serving as a case study and tailored in accordance with its distinct needs. The methodology focuses on three primary sections: a comprehensive GIS (Geographic Information System) overview of the current water distribution system of the campus, the identification of feasible preventative maintenance measures, and the development of a framework for the prompt detection of leaks in the foreseeable future. This scientific methodology provides a roadmap for universities to assess and address their aging water distribution systems, ensuring their efficient and safe operation for years to come.**

I. INTRODUCTION

The aging infrastructure of many universities across the country poses significant challenges, especially in regard to water dispersal systems. Water dispersal systems are responsible for delivering potable water to buildings, as well as removing and treating wastewater. These systems are critical to the day-to-day operations of a university, and any disruption can have serious consequences. Older universities' water dispersal systems often suffer from issues like leaks, bottlenecks, and inefficiencies that can negatively impact campus operations and the people who inhabit them. The lack of proper documentation and maps for these systems adds to the difficulties of identifying and resolving these issues. Therefore, this capstone project aims to examine the factors contributing to water dispersal system failures in older university infrastructures, propose mitigation measures to address these issues, and recommend preventative actions to reduce the likelihood of future failures.

Water dispersal systems consist of a complex network of pipes, valves, and fittings that transport water throughout a university campus. These systems are designed to ensure the reliable and efficient delivery of water to buildings and the safe and efficient removal of wastewater. people who inhabit them. The present study focuses on the development of a methodology that has been tailored to meet the unique needs of the Sweet Briar College campus.

*Research supported by the Sweet Briar College Margaret Wyllie Jones '45 Engineering Program.

All authors are with the Sweet Briar College Margaret Wyllie Jones '45 Engineering Program, Sweet Briar, VA 24595 USA

Despite their importance, water dispersal systems can be susceptible to a range of issues that can impact their performance, efficiency, and safety. Over time, pipes can corrode, crack, or break, valves can malfunction or fail, and joints can become loose or leaky. These problems can lead to water inefficiencies such as leaks and flooding, which can have serious consequences for campus operations and the

This methodology is centered on the Sweet Briar College campus as a case study, considering an in-depth examination of the campus's physical and environmental features, as well as its historical significance in order to provide individualized recommendations.

Established in 1901, Sweet Briar College is a small, prestigious women's college located in central Virginia. The campus spans a vast area of 2,840 acres, making it the fourth-largest campus among liberal arts colleges in the United States. The campus comprises twenty-one buildings that have been listed on the National Register of Historic Places, highlighting its cultural and architectural significance. Furthermore, Sweet Briar College boasts eight nature sanctuaries, two lakes, and 18 miles of trails, making it an ideal site for ecological and environmental research.

The intent of this capstone project is to offer Sweet Briar College a comprehensive proposal for maintaining and upgrading its existing water distribution system, with the aim of improving its operational efficiency and reliability. Moreover, this study endeavors to extend the benefits of the capstone team's findings to other aging colleges and historical municipalities facing similar challenges within outdated infrastructures.

II. LITERATURE REVIEW

There are four main focus areas to this project that require an in-depth analysis: other projects that aim to improve campus' water distribution systems, the approaches to locate and map water pipes, valves, and fire-hydrants through the use of geospatial information systems (GIS), preventative maintenance for water distribution systems, and strategies to isolate, locate, and address leaks promptly.

A. Case Study Analysis of Campus Responses

The mathematics and information science department of Guangxi College [1] sought to find the relations of leakage of water pipe networks and thus establish a mathematical model for campus supply systems. It analyzed the status of leaks in their campus water supply. This was found by using data from real-time water meters. It discusses the maintenance and management of the water supply network in a school, and how the replacement of water pipes should take into account the diameter, flow rate, material, and labor costs when prioritizing maintenance. The minimum maintenance cost model takes maintenance labor costs, material costs, and water loss of a corresponding pipe. This study also considered it necessary to take into account pipe replacements and related inspection equipment for an improvement of the school's leakage issues. In this study, the team built upon the concern of prioritizing pipe maintenance based on the rate of importance and collective budget of a campus.

B. Comprehensive Mapping Approaches

In *Towards an improvement of GPR-based detection of pipes and leaks in water distribution networks*[2], a study in the Journal of Geophysics, researchers aimed to improve ground penetrating radar to detect pipes and leaks. Ground penetrating radar (GPR) is a non-invasive geophysical method that can be used to detect the location of metal water pipes. GPR works by emitting electromagnetic waves into the ground and measuring the signals that are reflected back to the surface. The reflected signals are then processed to produce an image that can be used to identify the location and depth of buried metal pipes [3]. GPR was used as it reduces the area to dig and limits cost and collateral damages. This paper presents an ensemble approach aimed at improving GPR-based leak detection. Advanced radar data processing strategies were used to maximize qualitative and quantitative information to the end user. In this work, we built upon the work to visualize an interface for leak and pipe detection for the end user. However, the study was only conducted using one type of soil. It recognizes the variability of GPR due to soil and different types of pipes.

In the paper *Automatic Detection and Modeling of Underground Pipes Using a Portable 3D LiDAR System* [4], the authors describe a method for using a portable 3D Light Detection and Ranging (LiDAR) system to detect and model underground pipes.LiDAR is a remote sensing technology that uses laser pulses to create a 3D map of the environment. The portable 3D LiDAR system used in this study was mounted on a cart and moved along the surface above the pipes being detected. The LiDAR system emitted laser pulses that penetrated the ground and reflected off the underground pipes, creating a 3D point cloud of the pipes' location and dimensions. The researchers used signal processing techniques to detect the pipes within the point cloud data. They employed a Hough transform, an extraction technique for image analysis, to identify circular shapes that corresponded to pipes. The algorithm then estimated the location and dimensions of the pipes based on the detected circular shapes.Once the pipes were detected, the authors used a surface reconstruction technique to model the pipes' geometry and generate a 3D model of the pipes. Overall, this study demonstrates that a portable 3D LiDAR system, combined with signal processing and machine learning techniques, can be an effective tool for detecting and modeling underground pipes.This provided a good comparison for finding pipes not well-established.

These are just a few examples of the methodologies and technologies that can be used to locate and map water supply systems on college campuses. The effectiveness of each method will depend on various factors, including the type of soil and the depth and size of the pipes.

In *The management of water distribution network using GIS application case study: AL-Karada area* [5]presents the use of GIS technology to manage and optimize the water distribution network in Al-Karada, Iraq. The paper discusses the various components of the GIS-based water distribution system, including the spatial database, hydraulic modeling, and network analysis tools. The study highlights the benefits of using GIS technology for water management, including improved accuracy, efficiency, and cost-effectiveness. In particular, this study implements the use of ArcGis. The paper also discusses the challenges of implementing the system, such as data availability and user training. The findings of the study suggest that GIS-based water management systems can significantly improve the efficiency and sustainability of water distribution networks, particularly in areas facing water scarcity and limited resources. Overall, this paper provides valuable insights into the use of GIS technology in the management of water distribution networks, which can be incorporated into the literature review section of a research paper on water management and sustainability.

C. Preventative Maintenance Strategies for Water Networks

Many college campuses were built during a time when water distribution systems were not designed with the same level of longevity and durability as modern systems. As a result, these older systems are often made of materials that are more prone to corrosion and wear, such as cast iron or galvanized steel [6].

One of the most effective strategies for preventing corrosion in iron piping systems is the use of corrosion inhibitors. Corrosion inhibitors can be added to the water supply to form a protective layer on the inner surface of the pipes, reducing the rate of corrosion [7]. Additionally, the use of cathodic protection systems, such as sacrificial anodes or impressed current systems, can also prevent corrosion by supplying electrons to the pipes to neutralize the corrosion reaction [8].

Regular cleaning and flushing of the iron piping system are also important in preventative maintenance. This process involves removing sediment and debris from the pipes, which can contribute to corrosion and blockages in the system. Flushing can be done through the use of high-pressure water jets or specialized cleaning chemicals [9].

Finally, regular inspections of the iron piping system can help detect and address potential issues before they become major problems. Inspections can include visual inspections, ultrasonic testing, and magnetic flux leakage testing to identify areas of corrosion or damage [10].

In addition to the issues of aging infrastructure and corrosion, college campuses may also face unique challenges related to their water distribution systems. For example, campuses with large populations of students and faculty may experience significant fluctuations in water demand throughout the day, which can put stress on the system and increase the risk of leaks or other issues [1].

The frequency of exercising water valves can vary depending on several factors, including the age and type of valve, as well as the environment in which it is located. However, it is generally recommended to exercise water valves at least once a year to ensure that they function properly and to prevent them from becoming stuck or malfunctioning in an emergency [11].

D. Prompt Water Leak Detection

Leaks in water distribution systems can lead to significant water loss and increased maintenance costs. Therefore, it is essential to identify and repair leaks as soon as possible to prevent further damage. There are several methods to detect large leaks in water distribution systems, each with its benefits and drawbacks.

In *The State of Water Loss Control in Drinking Water Utilities* [12], a paper by the American Water Works Association, provides a review of the current state of water loss control in drinking water utilities. In terms of prompt water leak detection, the paper highlights the importance of detecting and repairing leaks quickly to minimize water loss and prevent damage to infrastructure. The paper discusses the various methods of leak detection, including visual inspections, acoustic leak detection, and advanced metering infrastructure. This paper looks into a small water authority that supplies water to 7,000 service connections through just over 320 miles of pipeline in a rural county near Nashville, TN. The authority has created a thorough system of district-metered areas (DMAs) that allow them to keep track of water flows and take action when there are indications of abnormal increases in demand, which are often indicative of potential leaks. By employing this method, the authority has been able to effectively manage water leakage. This paper will serve as the basis for recommending measures the campus should implement when evaluating potential leaks.

III. Methodology and Discussion

The formulation of this scientific methodology was centered on the premises of Sweet Briar College, founded in 1901, serving as a case study and tailored in accordance with its distinct needs. This methodology was focused on three primary sections, including a comprehensive GIS overview of the current water distribution system of the campus, the identification of preventative maintenance measures, and devising a framework for the prompt detection of leaks in the foreseeable future.

Step 1: Complete a Comprehensive Map of the Campus' Current Water Distribution System

A. Locate and Identify Historical Utility Documents

As the college's campus has a rich history dating back to 1901, it presented a unique challenge in terms of accessing documents from that era. Given the age of the campus, many modifications and additions have been made over the years, many of which were not well-documented and easily-accessible, thus requiring a meticulous search of archival prints to build a comprehensive survey. Sweet Briar's historical archives consist of thousands of documents, both categorized and some not. Ultimately, the team was able to unearth several documents that were vital in accomplishing this first step.

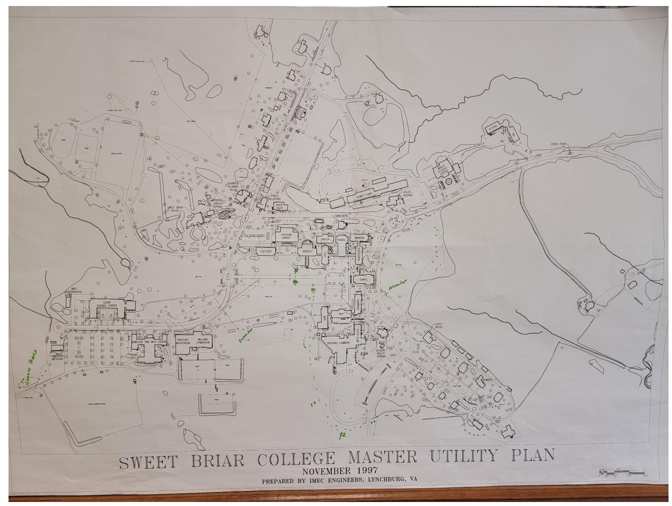

FIGURE 1. MASTER UTILITY PLAN OF 1997

The most useful of the documents was the Master Utility Plan of 1997 for Sweet Briar College, shown in Figure 1, which serves as the primary documentation of the institution's most recent comprehensive utility plans for its main campus. The Senior Director of Physical Plant and others at Sweet Briar College, from 1997 to the present, have maintained written updates to the plan as the campus has undergone growth and development. Two copies of Master Utility Plans have been manually updated, with one containing information on the length and diameter of pipes, while the other tracks the investigation of water lines and pipes. Utilizing the maps facilitates a collaborative approach for workers to update issues and incorporate new additions to the utility. The process of updating a physical map presents various limitations. Initially, physical maps are static and not easily modified or updated once they are printed or distributed. This condition complicates the incorporation of new information or changes in a timely and efficient manner and may not have the capacity to encompass all necessary details. This factor may result in critical information being excluded or not being displayed clearly, which could lead to potential inaccuracies or misinterpretations. In addition, physical maps are not readily available to all stakeholders who may require them. These consequences can lead to delays in accessing necessary information and hinder the decision-making process.

The Master Utility Plan of 1997 only includes lines on the main campus, leaving out many acres undocumented. The capstone team embarked on a collaboration with Clelie Steckle, the Director of Data Analytics and Development Communications at Sweet Briar College. Clelie Steckle and the team scoured the archives to uncover the historical utility data of the college, which served as a critical foundation for the comprehensive map.

B. Create A Map in ArcGIS

Once a foundation was established through the acquisition of maps and documents from the archives, the team utilized maps and documents from the archives to add known water lines to an ArcGIS map as a line layer. Four additional point layers (valves, pumps/hoses, fire hydrants, and water meters) were incorporated through on-site surveys using the ArcGIS Field Maps App. GPS coordinates obtained through the app were only accurate within a 20-meter range, thus images were attached to each point to reduce confusion. A basemap layer was incorporated to pinpoint locations more accurately, resulting in a comprehensive map of the college's water infrastructure. Disparities between data points and known waterlines led to the identification of four areas where alternative methodologies were required to locate missing water pipes.

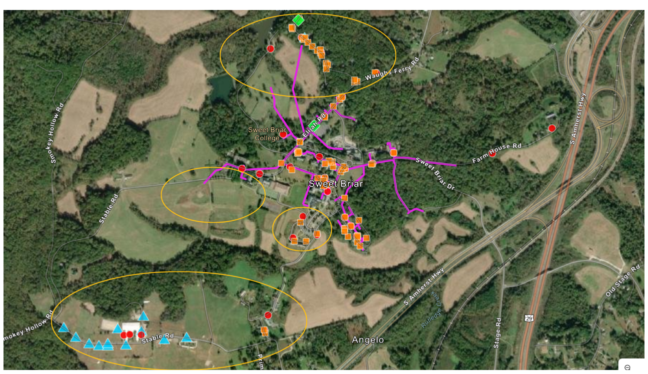

FIGURE 2. MAP OF WATER LINES AND CORRESPONDING WATER FEATURES

By integrating the four water distribution layers, the research team successfully identified disparities between the surveyed data points and the known water lines from archival documentation. As a result, the team identified four particular areas, as shown in Figure 2 above, where alternative methodologies were required to locate the elusive water pipes.

C. Use GPR to Locate Pipes Unaccounted For

The TerraSIRch SIR (Subsurface Interface Radar) System-3000 was utilized as the GPR for this project. It is difficult to detect PVC with this particular radar, thus can only detect metal pipes, so if any pipes are made of PVC, they will not be picked up on the radar. Since Sweet Briar was established in 1901, it is safe to assume that most of the water system consists of iron piping, as PVC was not common until the 70s. There is a potential that newer parts of the campus may have PVC pipes, which would necessitate the use of a more sensitive GPR system in the future. Additionally, the campus is located in central Virginia, thus much of the campus' soil is made of clay, potentially making it difficult to gather accurate readings from the GPR, which was a call for some concern beginning this phase of the project. Ultimately, the clay content did not interfere with the findings.

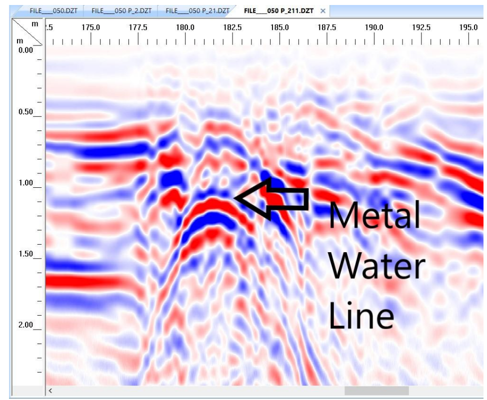

FIGURE 3. GPR READING OF METAL WATER LINES

The team initiated the use of GPR with assistance from J. David Harper and Alan Moore, regional representatives of the Natural Resources Conservation Service of the USDA, to scan the region between the water tower and the field where one of the water pipes trails off, based on the 1997 utility map, which only displays lines from the main campus. Figure 3 demonstrates the readings of a metal water line in proximity to the area. This methodology was applied throughout all areas where water lines were suspected to exist, owing to the presence of pumps, valves, and fire hydrants. However, no archived maps could be used to confirm these suspicions.

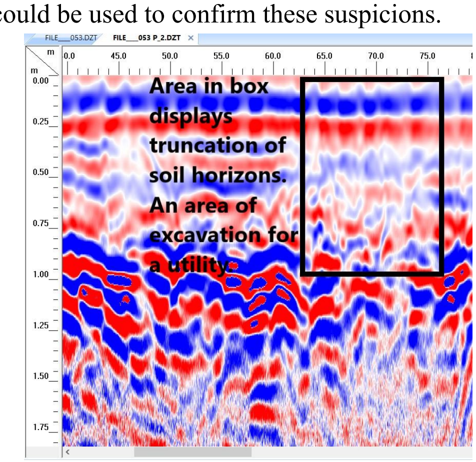

FIGURE 4. GPR FEATURES OF TRUNCATION OF SOIL

It is worth noting that GPR technology has proven to be effective in locating previously excavated areas, as evident in Figure 4 obtained from the team's fieldwork. Although the GPR model is incapable of detecting PVC, it can provide valuable information that suggests the possibility of a past excavation, potentially for installing PVC. Nevertheless, it is crucial to highlight that such evidence is not conclusive, and additional testing and monitoring are necessary to confirm any findings.

D. Combine All Data in Parts A-C to Create a Comprehensive Water Distribution Overview in ArcGIS

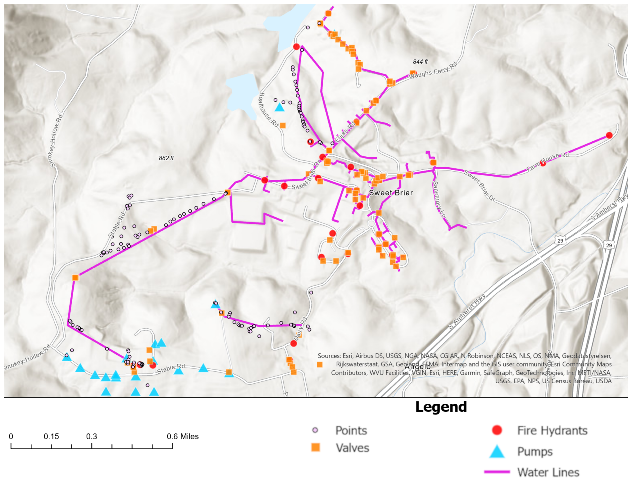

FIGURE 5. COMPLETED MAP OF CAMPUS

Upon analyzing the information from parts A-C, a thorough overview of the water distribution system was successfully completed using ArcGIS Pro, as demonstrated in Figure 5 above. To augment the existing map, GPR points discovered in part C were integrated to trace newly discovered water lines that were not previously recorded. Nevertheless, it is worth noting that the current GPR model cannot detect PVC pipes; thus, it is recommended that alternative methods be explored in the future to locate lines in areas where there is no record of pipes, but their existence is suspected due to the presence of valves, fire hydrants, and/or pumps/hoses.

Step 2: Develop a Recommended Maintenance Plan

After thorough consideration, the capstone team recommends the following preventative maintenance plan for Sweet Briar's water distribution system:

a. Conduct monthly site visits to the mapped water lines, during which document any atypical variations in soil moisture, formations, or other indications of system failure.

b. To ensure the ongoing accuracy of the map, periodically update it following the installation of new waterlines, pumps, valves, hydrants, and water meters.

c. Add an additional layer to this capstone's existing waterline map to report any leaks or damage. If the leaks continue to occur in the same area, it could be an indication of something else that needs to be addressed.

d. Exercise each valve annually to avoid future failure.

e. Use a shared file to track where, when, and solutions to water leaks when they occur. This can help track patterns of troubled pipes.

f. Track when water valves are opened and closed to prevent unnecessary or forgotten pipes from leaking. PDF files can be attached to valves individually within ArcGIS Field Maps to view the dates of when the valves were last exercised.

g. Place a water height monitor on the existing water reservoir on campus to ensure that there are no disparities between water meters and water usage.

Step 3: Method for Prompt Identification of Leaks

The extensive network of pipes across the vast fields of the campus presents a challenge in identifying the sources of leaks, particularly in less frequently visited areas that often go unnoticed. Past incidents of leaks on campus have taken several days to locate due to the lack of knowledge of certain pipe locations. However, with the recent incorporation of this map, Physical Plant personnel can now efficiently inspect all areas to detect any possible leaks, thereby improving response time and minimizing potential damage.

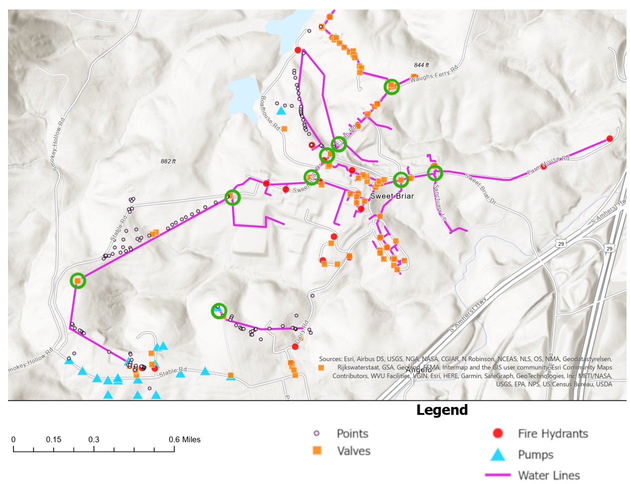

FIGURE 6. RECOMMENDED LOCATIONS FOR WATER METERS

Moreover, to improve the accuracy of leak detection and water usage monitoring, strategically placed "smart" water meters can be installed adjacent to valves along the main line, particularly in areas where pipes branch off and T-off into the fields. As illustrated by the green circles in Figure 6 above, these recommended locations would enable Physical Plant personnel to identify abnormal water consumption levels and detect potential leaks promptly.

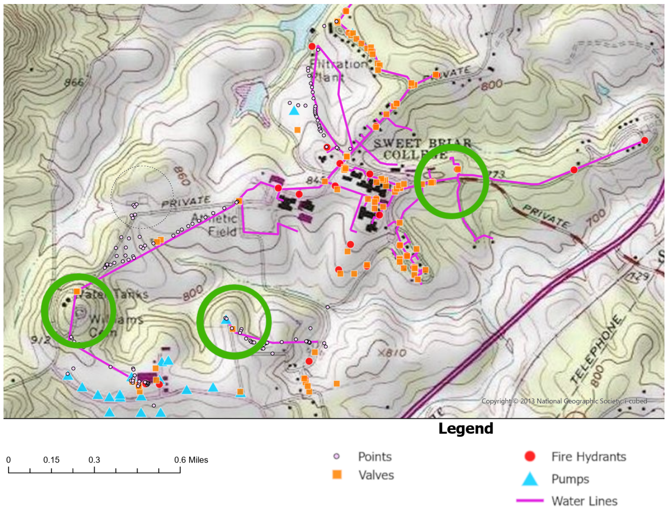

FIGURE 7. PRIORITY SPOTS BASED ON TOPOGRAPHY

Additionally, pipe fittings are a frequently observed source of leakage. Over years, the settling of soil can displace pipes, and when this occurs in conjunction with the installation of pipes in markedly dissimilar terrain, the probability of water leaks occurring is heightened. The prioritization of areas based on their topographical characteristics is depicted in Figure 7.

IV. Conclusion

This project used Sweet Briar College as a case study to serve as a valuable resource for scholars and researchers seeking to understand the unique features and needs of college campuses and other related municipalities, particularly those with a rich history and extensive ecological resources. Additionally, the findings of this study can inform the development of tailored methodologies, contributing to a better understanding of the physical, cultural, and environmental aspects of college campuses across the United States that may affect water distribution systems.

This project serves as just a stepping stone for the maintenance of the current system and integration of more modern infrastructure. Future surveying of the area can be performed to locate and add PVC lines to the ArcGIS map to aid in the future modernization of the waterline network.

Acknowledgments

The capstone team would like to thank soil scientists Alan Moore and J. David Harper of the USDA, Professors Jonathan Bender and Lili Lei of Sweet Briar College, Director of Physical Plant Rich Meyer of Sweet Briar College, Director of Grounds and Projects John Thomas of Sweet Briar College, and Director of Data Analytics and Development Communications Clelie Steckle of Sweet Briar College.

References

[1]Ruan, N., & Que, X. (2020). Research on the leakage problems of a campus water supply system. Proceedings of the 2020 9th International Conference on Applied Science, Engineering and Technology (ICASET 2020). https://doi.org/10.2991/aer.k.201203.010

[2]De Coster, A., Pérez Medina, J. L., Nottebaere, M., Alkhalifeh, K., Neyt, X., Vanderdonckt, J., & Lambot, S. (2019). Towards an improvement of GPR-based detection of pipes and leaks in Water Distribution Networks. Journal of Applied Geophysics, 162, 138–151. https://doi.org/10.1016/j.jappgeo.2019.02.001

[3]Ground penetrating radar (GPR) – an electromagnetic investigation method. Ground Penetrating Radar (GPR) – An Electromagnetic Investigation Method | GPRS. (n.d.). Retrieved April 5, 2023, from https://www.gp-radar.com/article/ground-penetrating-radar-gpr-an-electromagnetic-investigation-method

[4]Aijazi, A. K., Malaterre, L., Trassoudaine, L., Chateau, T., & Checchin, P. (2019). Automatic detection and modeling of underground pipes using a portable 3D lidar system. Sensors, 19(24), 5345. https://doi.org/10.3390/s19245345

[5]Kadhim, N. R., Abdulrazzaq, K. A., & Mohammed, A. H. (2021). The management of water distribution network using GIS Application Case Study: Al-Karada Area. Journal of Physics: Conference Series, 1895(1), 012038. https://doi.org/10.1088/1742-6596/1895/1/012038

[6]Uni-Bell PVC Pipe Association. (2012). Life cycle assessment of PVC water and sewer pipe and comparative sustainability analysis of pipe materials. https://www.uni-bell.org/files/Reports/Life_Cycle_Assessment_of_PVC_Water_and_Sewer_Pipe_and_Comparative_Sustainability_Analysis_of_Pipe_Materials.pdf

[7]]Palanisamy, G. (2019). Corrosion inhibitors. *Corrosion Inhibitors*. https://doi.org/10.5772/intechopen.80542

[8]Nanan, K. (2020, June 29). *The basics of cathodic protection*. Corrosionpedia. Retrieved April 5, 2023, from https://www.corrosionpedia.com/2/1368/prevention/cathodic-protection/cathodic-protection-101

[9]Hubbs, S. A. (2020, February 28). *Flush with success: Water Mains and fire hydrants*. Water Quality and Health Council. Retrieved April 5, 2023, from https://waterandhealth.org/safe-drinking-water/flush-with-success-water-mains-and-fire-hydrants/

[10]Ma, Q., Tian, G., Zeng, Y., Li, R., Song, H., Wang, Z., Gao, B., & Zeng, K. (2021). Pipeline in-line inspection method, instrumentation and data management. *Sensors*, *21*(11), 3862. https://doi.org/10.3390/s21113862

[11]Satterfield, Z. (2007). *Valve Exercising*. National Environmental Services Center . Retrieved April 5, 2023, from https://www.nesc.wvu.edu/files/d/1f62b334-8497-403e-bceb-f5116ac2c142/valve-exercising.pdf

[12]American Water Works Association. (2016). *Home | American Water Works Association*. The State of Water Loss Control in Drinking Water Utilities. Retrieved April 5, 2023, from https://www.awwa.org/Portals/0/AWWA/ETS/Resources/WLCWhitePaper.pdf?ver=2017-09-11-153507-487