Developing Best Management Practices for Water Utility Mobile Field Operations

An Internship Report

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Presented by

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Developing Best Management Practices for Water Utility Mobile Field Operations

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Abstract:

The utility sector has a crucial role in enabling and maintaining societal progress. To keep pace with a changing world the utility sector must embrace new technologies, a changing workforce, expanding energy sources, climate concerns and demands for system efficiency. However, the industry faces numerous challenges including increased demand, regulations, and rapid workforce turnover. These conditions place significant pressure on the sector to make meaningful and effective business decisions as mismanagement and lack of prioritization could have great consequences on the system, customer, and environment. Water utility disasters of the past exemplify the impacts of mismanagement and inappropriate prioritization. These events underscore the need for establish and implementing best management practices that align with regulations and the current work and management environment.

Advances in technology, in particular geographical information systems, offer an invaluable toolset for managing the workload and business processes of the utility sector. However, the rapid advancement of this technology and the utility sector has left gaps in the literature on the business decisions and employee roles associated with a GIS-centric approach to best management practices. This report will aim to address this knowledge gap by identifying best management practices using mobile field GIS applications for water infrastructure inspections. This work will be accomplished by first establishing the business processes of both traditional paper-based inspections and mobile GIS field application inspections and then providing an in-depth assessment and analysis of each business process to compare the effectiveness and efficiency to support asset management, regulatory compliance, and worker productivity. The findings will aid in deriving the best management practice for water utility inspections.

By promoting this approach and leveraging the power of mobile field applications the utility sector can enhance its system, meet regulations, and make informed business decisions. This research contributes to the ongoing efforts to improve the utility sector's reliability, efficiency, and environmental stewardship.

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To Taylor: Words cannot adequately convey the gratitude I feel for your unwavering support and belief in me. Your constant push to persevere, even in the face of challenges, has been a driving force behind my success. I am forever grateful for your love and encouragement.

To Mason: My dear daughter, you are a constant source of inspiration and strength. I hope that my achievements serve as a testament to the limitless possibilities that await you when you set your mind to something. Your unwavering love and belief in me have been my guiding light. I love you more than words can express, May.

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1. Introduction:

The utility sector in the United States has been the backbone of our society, driving forward momentum and making urbanization and larger-scale developments not only possible but also sustainable. With robust and reliable utility services, our cities have flourished, attracting businesses, fostering innovation, and accommodating the growing needs of a rapidly expanding population The continued growth and success of this sector is necessary to keep pace with the changing world. In recent years expanding energy sources, emerging technologies, climate change, and demands for more efficient systems has placed pressure on the industry to improve its business practices. However, altering business practices is made increasingly difficult by expanding service areas, increased regulations, and rapid workforce turnover resulting in a large degree of knowledge and skill loss (Mcleland, 2021).

The ever-increasing challenges and pressures faced by the utility industry have created an environment in which mismanagement and inappropriate prioritization can run rampant and result in catastrophic impacts on the customers, environment, and utility system. In just the past decade the headlines have been littered with stories highlighting a series of water utility disasters. One of the most notable occurrences was the Flint, Michigan water crisis, in which customers were exposed to lead contaminated water after an unchecked supply system was put into service. Others include the Atlanta, Georgia main break that resulted in a service stoppage leaving the city without drinking water and a Toledo, Ohio incident where a toxic algae bloom inundated the city's drinking water causing a water usage pause for three days (Missimer, Danser & Pankratz, 2014; Redfern, Daniels & Childers, 2018; Roy & Edwards, 2019). These examples represent a fraction of the water utility disasters that have occurred around the country but showcase how mismanagement and improper prioritization can lead to system deterioration and poor business choices, and socioeconomic distress.

These incidents, coupled with the challenges of expanding energy sources, advancing technologies, extreme weather events and climate change, and demands for more efficient and environmentally friendly systems, create a need for best management practices to be established and employed by the industry to ensure that proper and regulation-adhering work and management are being utilized. The advancement of technologies through the years has eased the burden of gathering the information necessary to align with these goals. The use of GIS is an effective strategy for managing utility asset data. In the context of water utility regulations, GIS has aided the utility industry in meeting standards for water infrastructure, quality, and supply. The ability to display real-time data on water distribution and collection networks, treatment facilities, and customer information has the potential to be instrumental in identifying at-risk areas and strategic planning for system rehabbing, lifecycle management, and expansion. Unfortunately, the documentation for a GIS centric approach to developing best management practices are lacking with limited literature published by individual utility companies or privatized industry sales companies outlining the business decisions behind their process. This leaves the workers in the dark as setup or workflows are rarely described.

Therefore, this report will attempt to identify best management practices, a term here which will refer to a workflow or set of practices that represents the most efficient and effective course of action for a particular task. This work will focus on using mobile field GIS applications for water infrastructure inspections, in particular measuring how they improve the efficiency and accuracy of data collection, analysis, and reporting. Inspections are an integral part of ensuring infrastructure health and system reliability. These inspections protect the environment and the community at large, therefore a focus and re-working of such an important part of the water utility system seemed pertinent.

The report will detail the project background, a review of both white and grey literature, required data, methodology, results, discussion and concluding thoughts and observations. This work was carried out at Greenville Utilities Commission (GUC), a local utility group that manages the water, sewer, gas, and electricity for the City of Greenville and surrounding communities operating under a charter issued by the North Carolina General Assembly and is governed for the citizens of Greenville by an eight-member Board of Commissioners. Through a workforce of roughly 500 office and field workers housed in two office branches, GUC develops, manages, and maintains an extensive utility network and a large customer base. Given its involvement with utilities, GUC is held to numerous federal and state regulations and adheres to a strict safety culture guided by Occupational Safety and Health Administration (OSHA)F guidelines. The GIS Data Services (GDS) group works in collaboration with three utility departments to carry out its roles and responsibilities and serves as a steward for all data collected by office and field personnel.

2. Literature Review:

To fully grasp the ideas being presented in this research it is necessary to understand the history of water utilities management in modern times. Best management practices are often heavily documented by the industry and give an insight to business operations and the key components to everyday work practices. By briefly examining the patterns of these best management practices of the past we can identify important and growing trends to establish a foundation for understanding where new best management practices are needed and understand the key components and ideas guiding this research.

Following the end of WWII, the United States witnessed a high rate of industrial growth, and as the urban areas swelled so did demand. The best management practices of the time guided the utility industry to rapidly expand water treatment plants and increase the distribution systems in these urbanizing areas to provide safe and reliable water to its growing populations (Burian et al., 2000). The following decades were marked by a focus on a concern for water pollution and environmental safety. The resultant legislation encouraged best management practices to be centered around the implementation of wastewater treatment and reduction of water pollution especially that occurring from non-point sources (Environmental Protection Agency, n.d.). This legislation is currently reflected in state level protections and encourages utilities to protect the public and environment from harmful pollutants (NC Department of Environmental Quality, n.d.)

The 1980s to the early 2000s marked a period of significant change for the U.S water utility industry. The 1980s were characterized by mounting pressure from aging infrastructure and increased demand which was only compounded by the looming environmental concerns that carried over from previous decades (UNDP, 2020). The industry struggled to maintain a maintenance schedule to remedy the failing system as they lacked the funding needed. However, the early 1990s witnessed momentum on this front as the increase of federal regulations provided the necessary funding to begin a practice of proactive management and investment, with the most prominent investment being the Safe Water Drinking Act in 1996 which assisted in financing state loans for improving drinking water systems (Copeland, 1999; Greer, 2020). The late 1990s and early 2000s was met with talks of climate change and sustainability. Thus, the green infrastructure movement was born, and most business practices focused on these green practices like stormwater management and rainwater collection (USGCRP, 2016). This period also witnessed a heavy focus on privatization and many public-private utility groups with an aim to improve service, which resulted in a technological transformation with automated meter reading and GIS becoming popular tools (Greer, 2020; Lassin & Frazier, 2010).

Today the rapid advancement of technology has pushed the industry to turn its focus to data-driven practices and decision making. The utility industry is attempting to convert its traditional pencil and paper systems to completely digital and data driven (Lassin & Frazier, 2010). This large shift has prompted an examination of the best management practices and a need to catalog the current system to identify the scale of the transition and the development of a prioritization method. Unfortunately, guidance and literature on these tasks is lacking given the stark change from decades of best management practices. This research will support the closing of this gap by aiding the establishment of best management practices for developing a mobile field application to aid in the management and support of a water utility system. To do this there will be a heavy focus on infrastructure, technology, and GIS, as these three areas represent the areas which the mobile field applications should be configured to address and utilize.

2. 1 Infrastructure:

Water infrastructure consists of many components, both man-made and natural, that contribute to the delivery and treatment of water. Typically, infrastructure is categorized by water, wastewater, and stormwater. For example, infrastructure can include pipes, valves, plants, catch basins, sewers, pump stations, manholes, and even land, reservoirs, and wells. A large percentage of the nation's infrastructure was built following World War II and the 2000 Community Water System Survey found that 30 percent of the water infrastructure for a community size of greater than 100,000 customers was between 40 and 80 years old and similarly 10 percent of that system was more than 80 years old (United States Environmental Protection Agency, n.d.).

Water has an integral place in the daily lives of communities around the country. The industries and people within these communities rely on water and wastewater to maintain daily operations and manufacture products and deliver services. This essential role of water and wastewater means that a community's economic sustainability is directly tied to the health and availability of its utility services. A 2020 study by the American Society of Civil Engineers on the economic role of water utilities found that underinvestment in water infrastructure rehab and repair could lead to a $2.9 trillion dollar decline in the gross domestic product (GDP) by 2039. This would be in addition to the loss of $732 billion dollars in sales by water reliant businesses and $14 billion to households in service disruptions in the same period (American Society of Civil Engineers, 2020). The economic benefits of investing in infrastructure are just as impactful, with studies estimating the creation of 800,000 jobs, $4.5 trillion in GDP by 2039, and a competitive edge for US exports (American Society of Civil Engineers, 2020). This benefit has been recognized by the current presidential administration and the bipartisan infrastructure bill aims to provide funding to support this growth (Department of Energy, 2021).

Infrastructure has an essential role in the utility system, and as described above plays an integral role in a community economic stability and growth. The utility industry is therefore tasked with establishing effective and efficient monitoring and management techniques for the infrastructure. In today's increasingly modern world the industry can turn to technology to assist in this often-daunting task.

2. 2 Technology:

Advancements in computer-based technologies, mobile applications, and larger information technology departments have allowed for an increased collaboration to develop an understanding of how to establish long-term management roadmaps for utilities. The development of utility-specific GIS, Supervision, Control and Data Acquisition (SCADA), and cloud-based portals and management systems have begun to emerge as viable options for utility management in years to come.

These software, applications, and business practices have brought asset management to the forefront of the business process. By modernizing the workflows of the past, the consensus in the industry is to move more systems from reactive maintenance to preventive maintenance and lifecycle-based management. An effective management system is powered by technology and focuses on building reliability, redundancy, and resiliency in the management process (NC Department of Environmental Quality, 2017). Technology serves to be the driving force for advancing infrastructure management and enables the business to understand their system to a point that they can accurately report their system condition and more readily meet regulation standards (Esri, n.d).

2. 3 GIS:

GIS has a unique role in storing, managing, and analyzing spatial and temporal information in various sectors including the utility sector. The use of GIS to support efficient utility resource management, planning and decision making has been vital to GIS maintaining a growing role in the utility sector. GIS has been implemented in the water sector in several uses and processes including data and asset management, distribution and infrastructure planning, emergency response and disaster management, monitoring and regulation compliance and stakeholder engagement.

Data & Asset management: GIS has allowed the water utility sector to collect, manage and organize data related to infrastructure, land use, customer information and attachments. This data management has been a key component of creating a repository for shared data that can be easily updated and analyzed (Schultz, 2012). GIS is useful not only for data storage and management but also for asset management. Water utilities have a large amount of assets and maintaining an accurate and complete record is necessary for reference and in many cases regulation. Additionally, the ability to locate and visualize these assets on a map can encourage a more efficient and effective work process. GIS empowers this record keeping and visualization which is a vital part of the business decision making process (Naimi et al., 2019; Shamsi, 2005).

Infrastructure and distribution planning: The vast amount of data and physical assets needed for a water system does not lend itself to an easy planning process. The organization and large storage capabilities of GIS aids in optimizing the distribution of water resources through the availability of tools and processes that can analyze demand pattens, service area expansion points, optimal routes of pipelines and many other spatial and temporal factors. These analyses assist in budgeting, planning and allocation of resources.

Emergency response: The need for accurate and on demand information is critical during emergency and disaster events. The data and information captured in GIS can provide support to both the workforce and management by assisting in the assessment of damage, outage information, and demand prioritization. By having this information on demand and available across many platforms the response and recovery efforts can begin seamlessly (Lassin & Frazier, 2010).

User functionality & engagement: As mentioned, GIS serves as an abundant information depository. This information highway from operations to management provides a unique interaction from many different viewpoints. The engagement with stakeholders including government bodies, management, field operations, and the public through maps, apps, and webpages can be integral to getting feedback and increasing investment in the system. This can promote transparency, foster community engagement, and builds trust between the stakeholders.

The clear role that GIS has in water utility points to its ability to drive business decisions. While it may appear that all facets of the water utility business practices have been fully explored and integrated into GIS the rapid and continuous advancement of technology coupled with gaining infrastructure, increased demand, changing environments, and increased business knowledge has created a gap that must be filled with best management practices.

GIS can be used to establish these best management practices as they require a comprehensive knowledge of the business flow and information, information already available in GIS.

Additionally, the best management practices for water utilities require an establish knowledge of the relationships between locations, assets, and customers. These factors allow for a utility to identify the proper asset, at an appropriate time, in an appropriate place and repair, replace or rehab it with the proper means at the most efficient cost possible (Sægrov, 2006).

Using GIS to establish best management practices: The suitability for using GIS to establish best management practices has been seen before in other research studies. As seen with other technologies the interest in automation and machine-driven workflows are becoming popular, this approach is also being experimented with in the GIS field in attempt to improve productivity. Venigalla and Baik (2007) identified this automation workflow in their work with Fairfax County Department of Public Works. The efforts here resulted in new workflows and an increase in performance statistics. This pattern of using GIS to improve efficiency and worker productivity was also identified by Luettinger and Clark (2005) who found that civil engineers could use GIS to identify least cost paths for construction routes and use this approach to avoid sensitive environments, right of ways, and land uses. This work continues to highlight the pattern of GIS improving business process, efficiency, and worker productivity. In addition to these accolades, GIS has been found to improve other components of the business process as shown by Wood et al. (2007), who used GIS to establish a method for recording water main breaks and this work helped identify customers at risk and increased the asset management. Similarly, Hahn and Cross (2014) worked to establish GIS based modeling for stormwater best management practices and found advanced visualization can be supported by a combination of GIS and civil engineering software. These works provide an expansive record showing the suitability of using GIS to establish sound business practices that can lead to a more efficient business workflow, cost reduction, and a more robust record keeping and asset management system.

The work described below will aim to add to this collection of research through the establishment of GIS-based best management practices by focusing on water utility-based inspections using mobile field applications. Inspections were chosen for this work for their ability to represent effective asset management and worker productivity; components that are central to the business process and provide meaningful metrics that can be used to identify improved efficiency and effectiveness. The inspections used for this work will consist of fire hydrants, pumpstations, and water and sewer system valves.

3. Project Background:

The successful management and delivery of water and sewer utilities to customers serve as the main goal of the water utility industry. The utility sector has committed itself to an abundance of planning for both the current and future states of the system to reach this goal. Advances in hardware and software over the past decade have opened the door to opportunities whereby the utility industry can revolutionize the operation and management of utility services. Geographic information systems (GIS) offer an unprecedented chance to optimize the utility industry of today. GIS technology catalyzes the advancement of the utility industry through several improvements. These improvements include but are not limited to increased compliance with regulations through prioritization of maintenance and construction, an increased understanding of system health and the associated risks, an integrated approach to management, and an allowance of amplified cooperation between office and field staff.

Greenville Utilities Commission, like many utility companies, had previously relied on paper maps, forms, and computer-aided design and drafting software applications like AutoCAD to track their utility assets. Technicians housed in each of the operating departments - Water Resources, Electric, and Gas - individually handled the manual input and AutoCAD tasks, a process of converting 2D drawings to 3D for visualization means using computer aided design software. By 2011, the Computer Aided Design (CAD) technicians had been restructured into the GIS Data Services group housed under Information Technology. Once formed, the GIS Data Services group (GDS) began to transition to a digital enterprise GIS system to improve the quality and reliability of the data to improve customer service and organizational business decisions including strategic planning to accommodate the growth of its service area. For the next decade, the GDS group worked tirelessly to begin the process of establishing spatial data flows, and standard operating procedures, and building the foundation to fully transition to a GIS-centric asset management system. At the time of this project, GDS had reached the end stages of the transition period and is now embarking on implementing and advancing the GIS system. This work will showcase the development of a mobile field application system to support the best management practices for the maintenance and management of water utilities.

The mobile field applications are all-in-one apps that use data-driven maps and forms to support common utility workflows. Using data-driven maps and forms the field crews can capture infrastructure data, edit the GIS system to correct or supply missing attribute information, find assets and pertinent information that supports their daily works and report real time business intelligence and location. The introduction of this system ties together infrastructure, technology, GIS and therefore has streamlined the daily work of the field crews. The support from this application allows for the utility to be efficiently supplied and maintained by GUC.

3. 1 GIS:

In the water utility world, the transition from traditional inspections to GIS-centric mobile field applications has revolutionized the way assessments and maintenance tasks are conducted. This shift has the potential to bring numerous benefits and efficiencies to the sector (Fenais et al., 2019.

Traditionally inspections for water utilities involved a manual process, where inspectors would physically visit various sites, carry out assessments, and record information using pen and paper. These conventional methods often resulted in data inconsistencies, delays in data collection, and difficulties in data management and analysis. Additionally, the processes were riddled with instances of human error and posed challenges in sharing information and receiving significant investment from stakeholders.

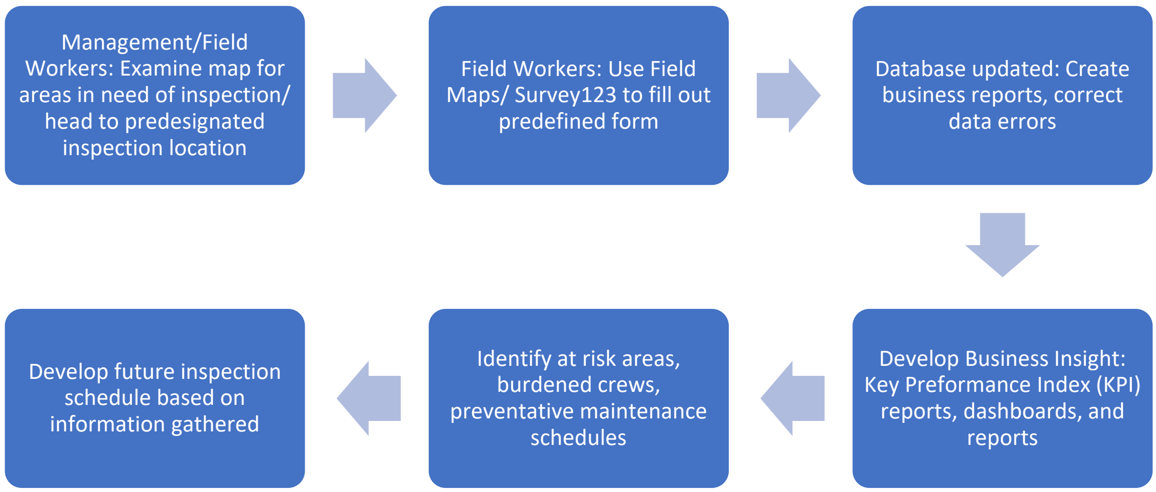

Figure 1: Proposed best management practices used in designing inspection practices. This workflow aimed to streamline the information pipeline from field to office and back

However, with the advent of GIS technology and the development of mobile field applications water utilities have been able to streamline their inspection process significantly as shown in Figure 1. The benefits to the system can be identified in several ways. Firstly, it has enhanced data accuracy and consistency. Inspectors can now collect data using mobile devices, often with predefined forms and templates, which has ensured a quick, consistent, and appropriate format that can be integrated into other business processes.

Secondly, the transition to mobile field applications has improved efficiency and productivity. Inspectors can access digital maps and real-time data directly on their devices, allowing them to plan their routes and prioritize inspections based on criticality and priority. The applications can provide the user with predefined instructions and guidance, ensuring that they gather all pertinent information. This improved business process eliminates paperwork, reduces duplication of efforts, saves time and results in more inspections in a shorter period.

Thirdly, the mobile field applications enable seamless data integration and sharing. The collected data is instantly synchronized with the database and portal environment so that it can be available for analysis, reporting and decision-making. This integration allows for company wide access to data, which fosters collaboration and improves overall operational efficiency. It also empowers data visualization. By adding inspection data to web maps, stakeholders can gain valuable insights into the condition and performance of assets. The spatial analysis helps identify trends, highlights potential issues, lends itself to prioritization, and enables preventative maintenance plans to be developed.

Additionally, the transition from traditional inspections to mobile field applications enhances data security and resilience. Traditional paper and pencil inspections are at risk of loss from human error or incident. Digitizing this data and storing it in a cloud platform and backed up database, data loss is minimized and consistently backed up securing years of data which once again highlighting the availability and protection of the gathered information.

4. Methodology:

Per the requirements set forth by the East Carolina University Masters of Geography degree, I have completed a period of work with Greenville Utilities Commission as a GIS Technician, averaging 40 hours a week from 2019 to present day in the GIS Data Services group. During this period, I was responsible for database editing, developing maps and apps for office and field use, cataloging, and updating standard operating procedures, familiarizing myself with the water system, attending department meetings, and increasing my GIS knowledge through conferences and course attendance.

The work described in this report was performed on a desktop computer with small support tasks requiring fieldwork, however, this accounts for less than 5% of the workload. The software used includes ESRI Desktop, Cloud, and Field suite, and Microsoft Office suite of applications. For the scope of this work, a focus on water system management was taken but the GIS Data Services group supports all utility departments at GUC and therefore simultaneously gathers skills from those areas as well that were applied to this work.

Objective: The primary objective of this work is to establish a set of best management practices for water utilities, focusing on optimizing their workflow. These practices aim to enhance both effectiveness and efficiency within the industry. To achieve this goal, we will pursue two specific objectives:

1. Thoroughly document the step-by-step process required for successfully implementing the conversion from paper-based inspections to mobile field applications. This documentation will serve as a comprehensive guide for water utilities seeking to adopt these modern practices.

2. Conduct a comparative analysis to evaluate the efficiency and effectiveness of mobile field applications in relation to the traditional approach. By employing a defined set of metrics, we will measure key performance indicators and compare the outcomes of both methods. This analysis will provide valuable insights into the benefits and potential areas of improvement when using mobile field applications for water utility inspections.

Through the achievement of these objectives, this work aims to establish a robust framework of best management practices that water utilities can adopt to optimize their workflows. By embracing technological advancements and implementing mobile field applications, the industry can improve its overall performance and deliver more efficient services to its stakeholders.

This work will extensively delve into the period spanning from 2019 to 2022. During this time frame, the initial phase (2019-2020) served as a development period in which the traditional methods were still used, while the subsequent phase (2021-2022) marked the implementation stage for the mobile field applications.

Objective 1 necessitates a comprehensive exploration of the necessary steps and procedures for the real-world application discussed herein. To effectively undertake this task and successfully meet the objective, a research method known as process tracing was employed. This approach entails tracing the causal mechanisms or sequential steps within a given case, thereby facilitating a profound understanding of the underlying dynamics at play. By utilizing process tracing, it becomes possible to gain valuable insights into the intricate workings of this methodology and achieve a more comprehensive outcome. Process tracing is a research method used in various fields, such as psychology, political science, and cognitive science, to understand and analyze how individuals or systems make decisions and perform tasks. It involves observing and recording the sequence of steps or events that occur during a specific process or task. When applied to a step-wise iteration, process tracing can be a valuable tool for gaining insights into the decision-making and problem-solving processes involved in each iteration.

Step-wise iteration refers to a process where a task or problem is broken down into smaller, manageable steps, and each step is executed sequentially to reach a solution or make progress. Process tracing can be used in this context to study the decision-making and cognitive processes at each step of the iteration (Tessem, 2018; Beach & Pedersen, 2019).

Achieving Objective 2 requires the necessary information be obtained through rigorous data collection, which includes conducting an extensive business process analysis. A business process analysis involves a detailed examination of the existing workflows and procedures in water utilities, aiming to gain a comprehensive understanding of their operations, challenges, and areas for improvement. This way a systematic examination of the entire workflow, from data gathering and management to field operations, collaboration, and emergency response will be completed. During this time key performance indicators (KPIs) will be developed, this will aid in later processes. This initial analysis will provide valuable insights into the effectiveness of the mobile field applications in streamlining processes, enhancing data management, improving field operations, and enabling efficient emergency response.

By conducting a comprehensive business process analysis, Greenville Utilities Commission will be able to gain a holistic view of the impact and effectiveness of the GIS mobile field applications. This analysis will provide valuable insights into the strengths, weaknesses, opportunities, and potential areas for improvement within the workflow, enabling informed decision-making and continuous enhancement of their inspection processes.

To conduct a comprehensive business process analysis the following steps will be taken:

I. Identify the traditional inspection process: Chart out the existing procedures followed by the water utility crew members. This may involve manual data collection, paper-based forms, and manual entry into the database. Each step will be documented including the collection, validation, integration, and stakeholder communication if any.

II. Define the KPIs: Determine the metrics that will be used to evaluate the effectiveness of the inspections. This includes inspection count, duration, accuracy, reporting abilities for the period of 2019-2022.

III. Describe the implementation and processes for the GIS mobile field application inspections. After implementation describe the relationship between the KPIs and the new practice.

IV. Observe and gather data by allowing field crews and staff to interact with new processes. Monitor the use of the applications and gathered inspections to collect data associated with the defined KPIs.

V. Analyze the collected data to identify pattens, trends and shortcomings. Compare the metrics from the mobile field application process to the traditional methods. Calculate the difference in inspection count, duration, system completeness, etc. to quantify difference in performance statistics.

VI. Identify the precise areas of improvement based on the ongoing analysis, identify benefits gained from the mobile applications. These benefits may include but are not limited to reduced inspection duration, improved data completeness and accuracy, streamlined integration, increased analysis, and improved stakeholder engagement and communication.

VII. Quantify the findings, identify statistics to show improvement or lack there of

VIII. Communicated findings and establish if process is eligible as best management practices. Make recommendations for future enhancements or changes.

This business process analysis approach serves as a valuable tool in establishing a comprehensive understanding of the business decisions, changes, and best management practices involved. Given the extensive nature of this process, it is beneficial to break it down into two distinct steps. The initial step, referred to as step one, encompasses processes one through six, while the subsequent step, step two, focuses on the remaining two processes.

The second step of the business process analysis will provide the results needed to achieve objective 2, as a comprehensive comparison between the traditional method and the proposed mobile field applications is conducted. To facilitate this comparison, metrics based on key performance indicators (KPIs) that were gathered during the initial step will be measured. These metrics are outlined in Table 1. In the results these metrics will be quantified as well as classified by their associated use as this lends itself to the holistic approach. These categories include but are not limited to:

Office and Field Use: Assessing how the traditional method and mobile field applications facilitate seamless collaboration between office-based personnel and field inspectors, examining the efficiency and effectiveness of information sharing, data collection, and communication.

Implementation: Analyzing the ease of implementation and integration of mobile field applications within existing water utility systems and processes. This evaluation considers factors such as training requirements, software compatibility, and potential disruptions during the transition period.

Technology: Examining the technological capabilities and features offered by mobile field applications, including data synchronization, real-time updates, GPS integration, offline accessibility, and other advanced functionalities that can streamline inspection processes.

Emergency Response: Evaluating the effectiveness of both methods in responding to emergencies and critical situations. This includes assessing the speed and accuracy of information dissemination, task allocation, and coordination during urgent scenarios.

Infrastructure and Planning: Considering how mobile field applications contribute to infrastructure management and long-term planning. This involves examining their ability to capture and store data related to asset conditions, maintenance schedules, and future development needs.

GIS: Exploring the integration of GIS functionalities within mobile field applications, which enables spatial data analysis, mapping, and visualization. This assessment determines the extent to which GIS enhances decision-making and efficiency in water utility inspections.

By considering these factors and categories in the comparative analysis, a comprehensive evaluation of the benefits and potential areas of improvement associated with adopting mobile field applications can be achieved. This evaluation will inform decision-making processes, identify best practices, and recommend strategies to optimize workflows and enhance overall performance within the water utility industry (McKibben & Pacatte, 2003).

To facilitate the analysis and comparison of the traditional process and the mobile field applications, several key metrics have been identified (Table 1). These metrics serve as objective indicators that enable a comprehensive evaluation of the capabilities and effectiveness of both approaches. By leveraging these metrics, the organization can make informed decisions and identify areas where improvements can be made to optimize workflows and enhance overall efficiency.

Table 1: Performance Statistics that will be used to measure the efficiency and effectiveness of the utilization of a mobile GIS field applications versus traditional methods.

Metric Type	Indicator	Description
Application Usage	Active user created content	Measure the total number of users created content for completing workflows
Application Usage	User engagement	Track User activity such as frequency and duration of app usage to assess, to assess engagement levels
Performance	Data Input Accuracy & Completion	Assess the accuracy of data input by field inspectors and compare it with the actual measurements or existing records
Efficiency/ Productivity	Inspection Completion Count	Analyze how many inspections completed using mobile GIS application compared to traditional methods

5. Results:

As previously stated, the central purpose of this research is to successfully accomplish the established objectives. In particular, with regard to objective 1, this section will offer an all-inclusive, meticulously outlined guide delineating the transition from conventional inspection approaches to the seamless integration of mobile field applications (Figure 2).

Furthermore, to fulfill objective 2, a concise yet comprehensive summary of the outcomes derived from the business process analysis will be presented. These results will play a pivotal role in providing valuable insights into the efficacy and efficiency of the adopted methodology.

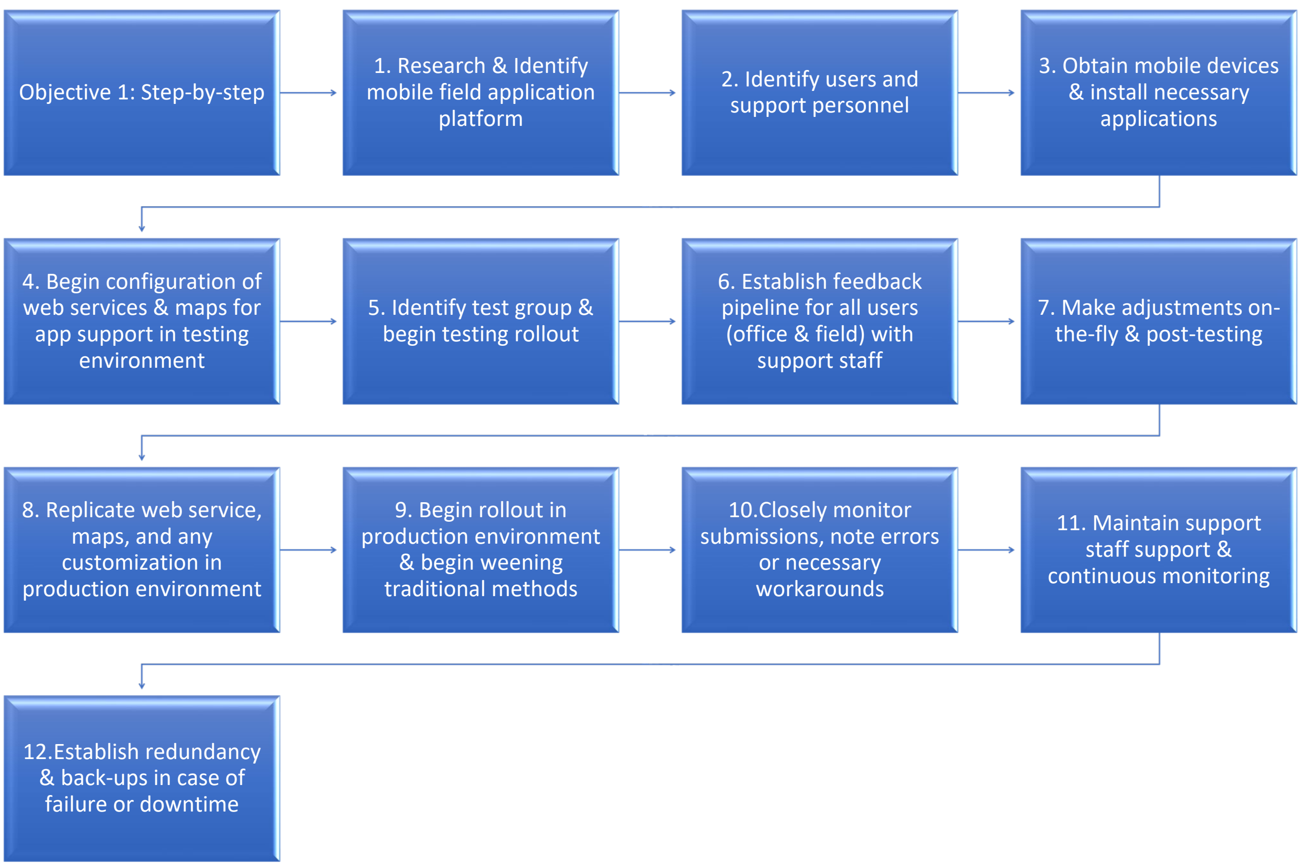

Figure 2: Detailed step-by-step process for implementing mobile field applications, the detailing of these steps aids to achieve objective 1.

5.1 Objective 1:

The findings will be structured within the categories of mobile field applications, technology, emergency response, infrastructure and planning, and GIS. This categorization ensures a systematic approach to organizing and analyzing the results. These results hold significant importance as they provide invaluable insights into the various areas explored in this research.

5.1.1 Technology:

Greenville Utilities Commission recognized the need to adapt to the increasingly technological world and sought to implement digital solutions to overcome challenges and create a more productive working environment. In their search for suitable tools, they identified Esri's suite of field applications as the ideal solution for their digital roadmap. These versatile mobile applications provided the necessary functionality and data synchronization capabilities.

Field Maps and Survey123 were selected as the preferred applications, aligning perfectly with Greenville Utilities Commission’s specific business requirements. These applications were licensed as part of the GUC enterprise system, and the technicians and GIS manager were assigned the task of setting them up.

In addition to the previously described tasks, several additional steps were taken to enable the field activities described here and ensure the effective use of the designed web maps and services (Appendix A).

The technicians collaborated with the Water Resource management and administrative staff to identify all crew members who would need access to the mobile applications. Once a list was established, the technicians and manager worked on adding named users with enterprise licenses that corresponded to their specific needs. In many cases, the field worker license type was assigned as it allows for geometry and attribute edits. After obtaining the licenses, the technicians worked directly with the crews to install the applications on the provided iPads, using either the company application manager or the Apple App Store.

Once the application was successfully downloaded on the device, the technicians assisted the field crew members with the sign-in process. Leveraging the already established enterprise system, the enterprise login option was utilized. To simplify the sign-in process, the technicians developed a QR code that could be scanned to automatically populate the necessary URL. Alternatively, the URL could be manually typed in. The users utilized their active directory (AD) username and password to log in. Upon successful login, the technicians provided support to the field crew members in familiarizing themselves with the application and setting up the specific maps they would be utilizing within the applications.

By following these steps, Greenville Utilities successfully implemented Esri Field Maps and Survey123, empowering their field crews with powerful digital tools and ensuring a smooth transition to a more efficient and technologically advanced workflow.

The successful transition to GIS-centric mobile field applications required the introduction of new technology to support users and enhance existing business processes. To facilitate the utilization of these applications, Greenville Utilities Commission provided field crews with a range of Apple iPads, ensuring compatibility with the selected mobile field applications, namely Field Maps and Survey123. Field Maps was specifically chosen for hydrant and system valve inspections, while Survey123 was utilized for pump station inspections.

Equipped with iPads, field crews were able to easily download and utilize the mobile field applications, empowering them to carry out inspections efficiently and effectively. These applications offered advanced features such as form styling, which streamlined data input and provided clear guidance to field workers regarding the required information for each inspection.

To consolidate and visualize the data collected through these mobile field applications, custom dashboards were developed. These dashboards served as a centralized hub for displaying a wide range of widgets, charts, and indicators, all sourced directly from the continuously updated database. Accessible both on-campus and from personal devices, these dashboards provided a convenient and comprehensive view of inspection data and KPIs.

5. 1.2 Mobile Field Applications:

The mobile field applications used in this project specifically refer to Esri Field Maps and Survey123. These applications have been customized and configured to meet the unique requirements of the office and field crew's everyday operations in the community. To provide a comprehensive understanding of their configuration and development, we will address the steps taken for each group separately.

5.1.2.1 Office Configuration:

To utilize the Esri mobile field applications, such as Field Maps and Survey123, licenses obtained from Esri are required. In this case, the licenses were obtained through an enterprise business package. These applications rely heavily on a substantial amount of data, and a well-developed map is essential for their effective functioning.

To meet the specific requirements of inspections, the assigned technician takes the necessary steps to organize all the required data layers within the map viewer. They make adjustments to symbology, visibility range, attribute fields, labels, base maps, and pop-ups to cater to the inspection needs and preferences of the field crews.

For optimal presentation and organization of the data, the technician has the ability to modify feature names, thumbnails, metadata notes, map descriptions, and adjust group sharing settings.

Following the configuration, the technicians enter a testing phase in which they assess the functionality of the application using the newly created map. This involves verifying proper sharing and visibility of the map within the mobile field application. The technician ensures the availability and functionality of all necessary mapping elements, including labels, base maps, text, and editing capabilities for the required data and fields. Subsequently, a testing group is selected in collaboration with management from the larger user population. Typically, these users are experienced crew members who are familiar with the inspection process and the specific assets required for inspection completion.

After the testing phase, any necessary minor adjustments, primarily aesthetic changes, are made to ensure optimal performance. The technicians then continuously monitor the data, applications, productivity, and functionality of the maps and apps for any disruptions or failures. Major functionality issues, if identified, are addressed and followed by restarting the testing process.

5.1.2.2 Field Use:

During their daily rounds, multiple crews collect data and complete inspections for hydrants, system valves, and pump stations. This data includes inspection information, as well as relevant attributes, attachments, or geometry associated with the assets. The data collected in the field is synchronized back to the GIS system, while updates made in the office are passed back to the field. The field crews actively provide feedback, noting any technical issues that occur, and often provide screenshots or detailed workarounds to the technicians and other field crew members.

5. 1.3 Implementation:

To ensure a smooth transition, the crews simultaneously used the newly implemented mobile field applications alongside traditional methods for several weeks. This approach prevented any data loss or disruption in workflow during the testing phase. Technicians closely monitored error logs for any technical issues and documented requested changes.

The initial round of work was completed in the GIS Portal TST, a testing environment that mirrors the production system. During this period, both Field Maps and Survey123 required the use of the testing URL. All services, web maps, custom attribute fields, symbology, and workflows were then recreated by the technicians in the GIS Portal PRD, the production environment. The field crews were provided with the production URL to access the production data.

Once the testing phase concluded, the paper and pencil tasks were encouraged to be abandoned but not forced, and the technicians closely monitored data entry and successful syncing with the system on a daily basis. Any issues that arose were immediately addressed by the technicians. Changes to the applications required management's permission to ensure that adjustments were made thoughtfully, allowing technicians and field crews to thoroughly adapt to the new workflow and portal components.

The implementation of the mobile field applications was executed successfully, thanks to the collaborative efforts of the technicians, GDS staff, and field crews. The process involved granting access through licensing, configuring web maps and services, and providing continuous support to field crews throughout the testing and implementation phases.

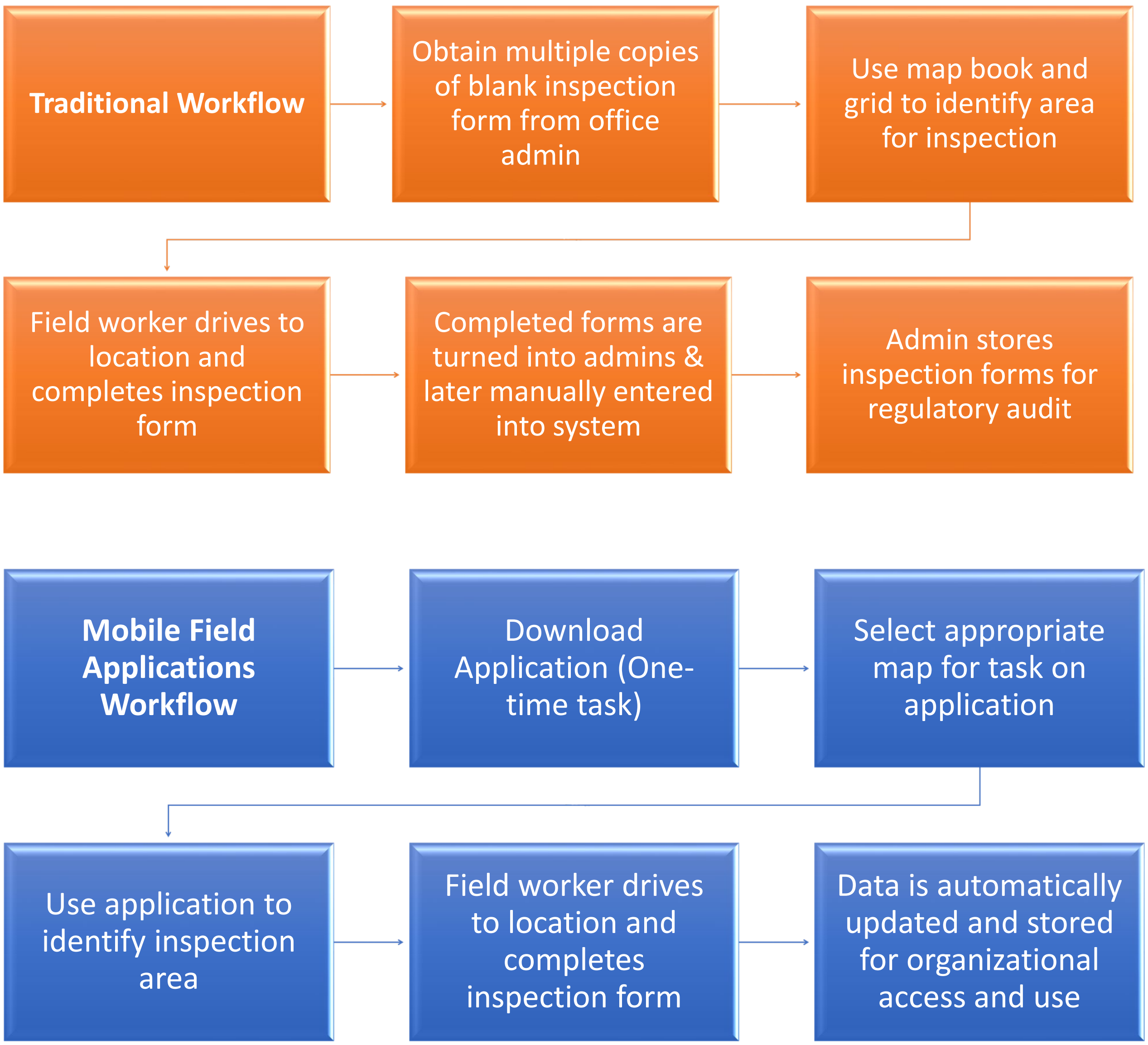

Figure 3: Comparison of the traditional water utility inspection workflow and the newly implemented water utility inspection workflow

5. 1.4 GIS:

The transition from paper-based water utility inspections to GIS-centric mobile field applications brought significant improvements to the inspection process (Figure 3). The paper forms used in the traditional approach were duplicated into smart form formats within the mobile field applications. Domains were set up within the GIS to facilitate pre-filled responses where appropriate. Inspectors gained access to the data and the ability to edit the organization's GIS database, with their edits instantly reflected across the entire organization. The gathered data served as the foundation for creating insightful dashboards and reports within the GIS system and applications. To ensure data redundancy and security, GUC implemented a dual server system (Appendix A).

5. 1.5 Infrastructure & Planning:

To ensure successful completion of field inspections, it is crucial for field staff to gather all necessary information about the assets. To fully leverage the functionality of the mobile applications and build on the traditional process several improvements were made during configuration.

One key improvement was the incorporation of established domain values into the customized forms within the mobile application. This allowed field workers to select from predefined lists of manufacturers, colors, sizes, and materials for the assets they were inspecting. By providing these options, the utility aimed to streamline data entry, improve consistency, and reduce the chances of errors resulting from manual input.

Furthermore, to expedite the process and eliminate repetitive tasks, the asset ID was pre-populated across forms and pop-ups in the applications. This eliminated the need for field staff to repeatedly enter the asset ID manually, saving time and reducing the risk of transcription errors. With this enhancement, inspectors could easily identify and associate the correct asset information without the burden of manual input.

5. 1.6 Emergency Response:

To enable effective emergency management through the mobile field applications and supporting systems, it was essential to gather and present the information in an Esri dashboard. Esri dashboards provide the ability to create dashboards from existing web maps. This approach was utilized, resulting in emergency response dashboard which leverages a widget system, allowing the addition of charts, maps, indicators, date selectors, and attachments. Technicians incorporated the required widgets to visualize various data points, such as total call count, call information, a map displaying all trouble calls, and charts highlighting values associated with the data. This dashboard was then accessed by administrative workers in the office, who added public and internal calls and relevant information. Subsequently, they contacted the appropriate field crew to address the emergency. The field crew utilized their iPads to access the dashboard, gather information, identify affected assets, and update the status of the issue as it was resolved.

The mobile field applications played a crucial role in recording emergency response situations and ensuring compliance with state and federal regulations. Real-time and on-demand data sharing capabilities across the organization during these high demand incidents (Appendix D).

Objective 1 has been addressed by providing a comprehensive and meticulous guide that facilitates the smooth transition from conventional inspection approaches to the seamless integration of mobile field applications. By adhering to this guide, organizations can effectively embrace the advantages offered by mobile technology in their inspection processes.

Table 2: Business process metrics with results from both the development and implementation periods

Metric Type	Indicator	Description	Results
Application Usage	Active user created content	Measure the total number of users created content for completing workflows	1,736 Items Total 610 (2019-2020) 670 (2021-2022)
Application Usage	User engagement	Track User activity such as frequency and duration of app usage to assess, to assess engagement levels	83,568 views 3,933 surveys (2021-2022)
Performance	Data Input Accuracy & Completion	Assess the accuracy of data input by field inspectors and compare it with the actual measurements or existing records	70.43% (2019-2020) 90.65% (2021-2022)
Efficiency/ Productivity	Inspection Completion Count	Analyze how many inspections completed using mobile GIS application compared to traditional methods	1,703 Pump Station 686 System valves 324 Hydrants (2019-2020) 1,867 Pump Station 1,003 System valves 340 Hydrants (2021-2022)

5.2 Objective 2:

The results discussed above have not only provided valuable insights but also laid a solid foundation for the accomplishment of objective 2, which focuses on evaluating the effectiveness of the newly implemented mobile field applications. This evaluation is conducted through a comparative analysis between the traditional inspection methods and the utilization of mobile field applications during the development period 2019-2020 and the implementation period 2021-2022, employing key performance indicators (KPIs), a typical business performance measurement as benchmarks for assessment (Asih,Purba & Sitorus, 2020).

The defined KPIs encompass crucial metrics such as the number of active users, adoption rate, data input accuracy/completeness, and inspection completion. By examining these KPIs a direct comparison with the conventional inspection methods can be made (Table 2). This comparative analysis provides an objective measure of the impact and benefits brought about by the integration of mobile technology into the inspection process.

5.2.1 Mobile Field applications:

To comprehensively gauge the adoption and usage of the mobile field applications, an exhaustive record of user content and usage was meticulously tracked from January to December for each respective year of the implementation phase. The results unequivocally showcase a substantial increase in users during the implementation period, clearly indicating the users' keen interest in the new system and their growing enthusiasm for adapting this methodology to other workflows (Figure 4).

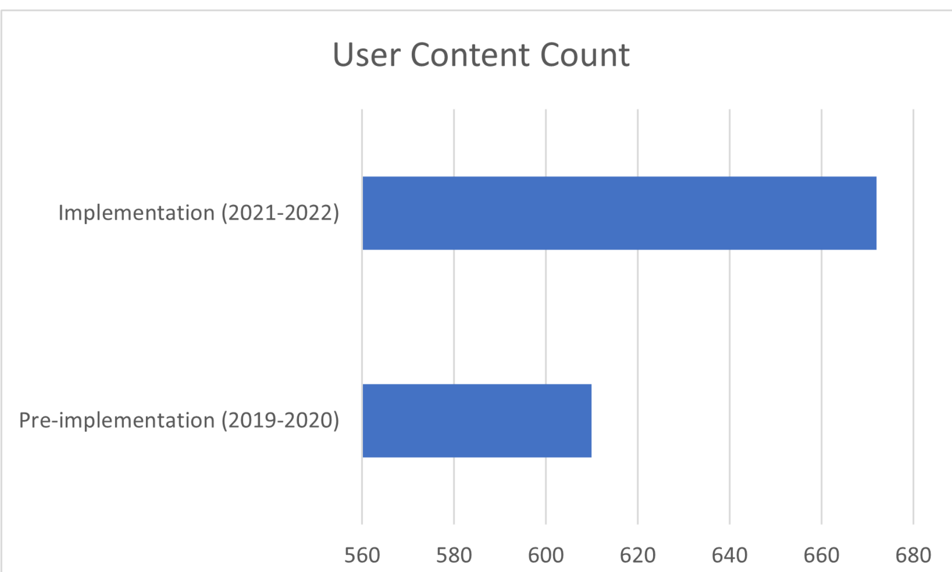

Figure 4:Comparison of user created content between both periods, the increase in content from the testing period to the implementation period showcases the eagerness to complete work with this new method.

Throughout the implementation period technicians continued to add users as they volunteered or asked to use the system, this was directly reflected in the user content that was available for work tasks. The rise in users over the implementation phase demonstrates the increasing integration of the mobile applications into the daily water utility inspections. It reflects the successful transition from traditional methods to a technology-driven approach, enabling field crews to leverage the benefits of real-time data, improved efficiency, and streamlined workflows.

The recorded user content and usage statistics serve as a testament to the effectiveness and positive reception of the mobile field applications within Greenville Utilities Commission. These figures provide valuable insights into the progress made during the implementation phase and serve as a foundation for continuous improvement and future enhancements to the mobile field applications.

5. 2.2 Technology:

In contrast to a more traditional approach which used desktop-based GIS software and internal storage, the use of GIS mobile field applications necessitated the use of ArcGIS Portal Enterprise, which facilitated data sharing, map distribution, and application deployment within the organization. The same data used in the inspection applications could be viewed on both mobile and desktop devices through the ArcGIS portal. The portal served as the licensing hub for the mobile field applications. Currently, the organization has 434 members, including 122 editors and 262 viewers. These consist of office and field workers of all capacities. Viewers can access all data in the portal but cannot make edits or changes, while editors have the ability to make changes to attributes and geometry. As of now, users have created 1,736 items for use on the Portal system, including maps, apps, experience pages, dashboards, and reports. The cloud-based data is seamlessly connected to on-premises databases, ensuring smooth data transfer between the two.

The introduction of new technology and the associated methodology described above resulted in significant improvements in inspection values, as demonstrated in Figures 4 through 7. The streamlined workflow, coupled with the form styling capabilities of the mobile applications, empowered field crews to efficiently gather and provide accurate information during inspections. Furthermore, the availability of real-time data and the centralized information pipeline created by the dashboards enhanced communication and decision-making at all levels of the organization.

By embracing these technological advancements, Greenville Utilities Commission experienced an increase in efficiency, data accuracy, and overall productivity in their field inspections as is shown through the performance statistics. The successful integration of iPads, mobile field applications, and custom dashboards has transformed the inspection process into a streamlined, data-driven system that supports informed decision-making and improves the overall effectiveness of water utility operations.

5. 2.3 Infrastructure and planning:

The data regarding infrastructure inspections highlights their critical role in ensuring the reliability and effectiveness of infrastructure systems. The recorded figures demonstrate the significant impact of implementing mobile field applications on the frequency and efficiency of inspections.

In terms of hydrant and valve inspections, a total of 83,568 views were recorded since the implementation period began (2021), this value represents each time a user uses the map. This showcases the increased interest in using this workflow. Furthermore, pump station surveys reached an impressive count of 3,933, reflecting the extensive monitoring and evaluation conducted on these crucial components.

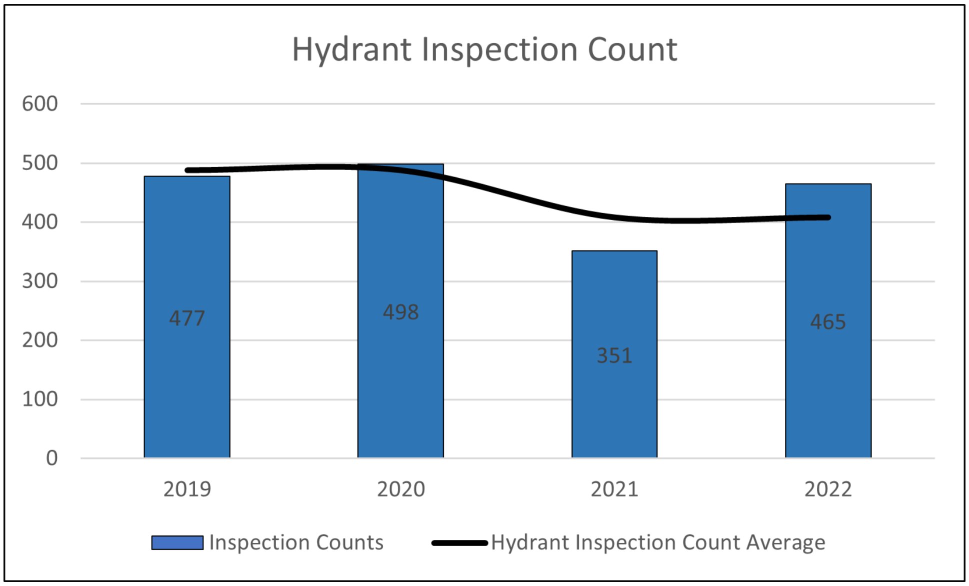

Figure 5:Hydrant inspections are a required and necessary process for maintaining and improving infrastructure. The trend revealed here show a dip in 2021 and rebounding in 2022.

Enhancing the analysis of hydrant inspections from 2019 to 2022, Figure 5 displays a compelling trend that emerges both before and after the implementation of the workflow change. Notably, prior to the new approach, the average number of annual inspections stood at approximately 488. However, following the implementation, this average experienced a slight decline, settling at around 408 inspections per year.

This intriguing shift in trend warrants further investigation in the upcoming discussion. By delving deeper into the factors that may have contributed to the change, we can gain valuable insights into the effectiveness of the new workflow and its impact on the frequency and efficiency of hydrant inspections.

In particular, we will explore potential reasons behind the decrease in inspections after the workflow change. Possible factors include a learning curve and personnel changes. Additionally, we will investigate whether the decrease in inspections correlates with a decrease in data accuracy and completeness.

By thoroughly examining these aspects, we aim to understand the implications of the workflow change. The analysis will provide valuable guidance for optimizing future inspection strategies and ensuring the reliable performance of hydrants.

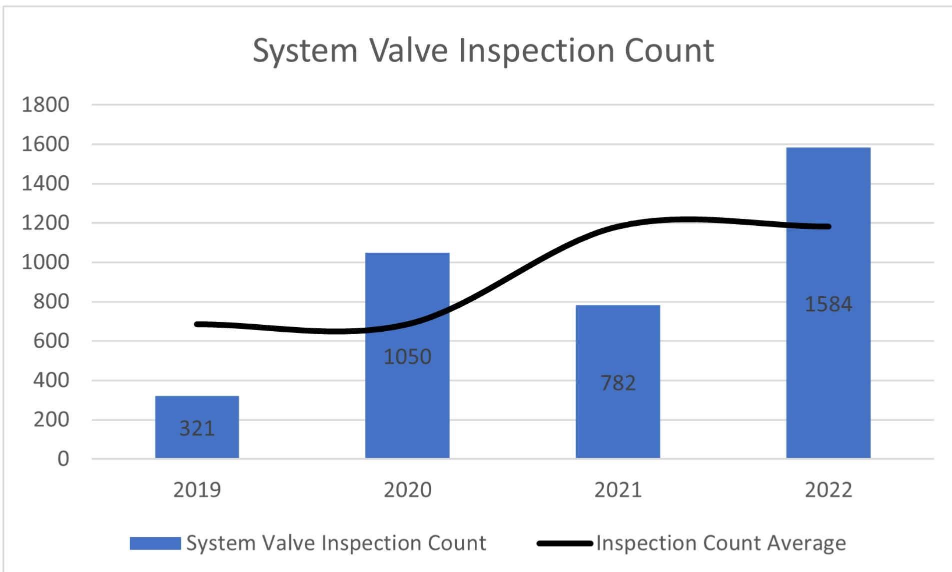

Figure 6:The figure highlights the trend of system valve inspection counts and uses the average for both the development and implementation period as a trendline.

Remarkable progress can be discerned in the realm of system valve inspections spanning the years 2019 to 2022 (Figure 6). Prior to the integration of mobile field applications, an average of 686 inspections per year were conducted, and following the implementation, this figure surged significantly, reaching an average of 1,183 inspections per year. This noteworthy escalation unequivocally demonstrates the profound impact and heightened efficiency brought about by the adoption of mobile technology.

Nonetheless, akin to the observation with hydrants, there appears to be a dip in inspection numbers during the year 2021. This temporary downturn, while noticeable, should not overshadow the overall pattern of improvement witnessed over the years.

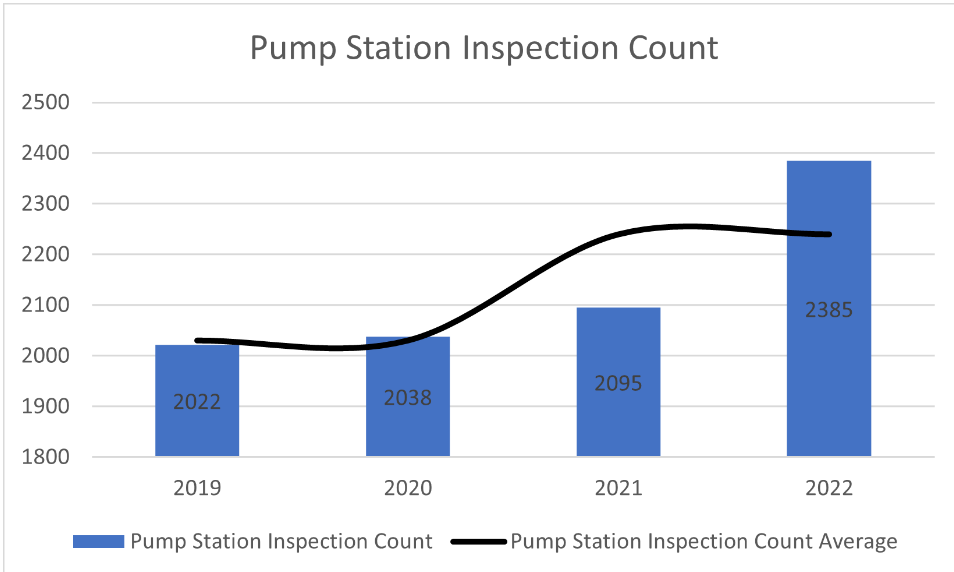

Figure 7:Use of the new technology-based workflow proved effective through the implementation period. The crews using this workflow did not experience as much of a learning curve as hydrants and system valves.

The count of pump station inspections from 2019 to 2022 further showcases the positive impact of mobile field applications (Figure 7). Prior to implementation, an average of 2,030 inspections per year were conducted, and this number increased to an average of 2,240 inspections per year following the implementation of the new technology. This indicates a consistent commitment to monitoring and maintaining the performance of pump stations, resulting in a more robust infrastructure network.

These statistics underscore the vital importance of infrastructure inspections in the context of planning and maintaining a sound infrastructure. The ability to conduct more frequent and comprehensive inspections, as enabled by mobile field applications, provides decision-makers with crucial information for effective planning, resource allocation, and ensuring the longevity and reliability of infrastructure systems. By embracing robust inspection practices, communities can achieve greater resilience, improved functionality, and a more sustainable infrastructure network.

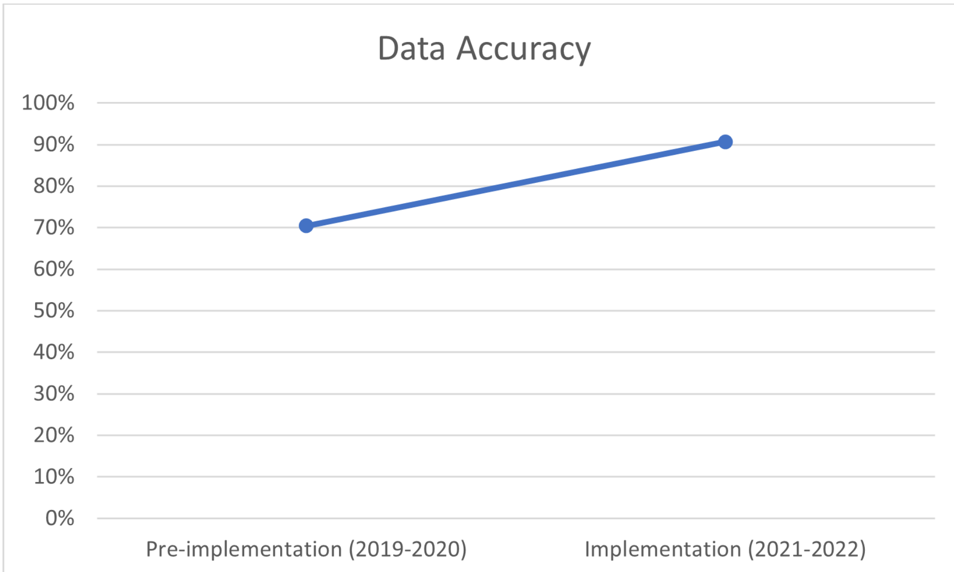

Figure 8:A system wide data review was conducted prior to implementation and after crews had been training and worked using the new workflow. The metrics used for data review focus on data completeness and accuracy, these metrics are maintained each review for standardization.

5. 2.4 GIS:

To ensure data accuracy and completeness, a data reviewer was conducted during each phase of the implementation (Figure 8). Data reviewer was run in each phase to gain an assessment of data accuracy and completeness. Data reviewer assessed various aspects, including the completion of required fields, the count of null values, and adherence to quality assurance standards. The results of these assessments provide valuable insights into the effectiveness of the mobile field applications in improving data quality.

During the development phase, the data reviewer yielded an average score of 70.43%. This score reflects the use of the traditional inspection’s workflow and data submission. As field crews familiarized themselves with the new tools and workflows, there was room for improvement in data accuracy and completeness.

As the implementation phase progressed, the average score from the data reviewer significantly increased to 90.65%. This substantial improvement demonstrates the effectiveness of the mobile field applications in enhancing data quality. Field workers became more proficient in using the applications, resulting in a higher level of accuracy and completeness in the data they collected.

The higher score achieved during the implementation phase indicates that the required fields were consistently filled in, and the count of null values decreased significantly. This improvement signifies the successful integration of the mobile field applications into the inspection workflow, enabling field workers to capture and record the necessary information with greater precision and reliability.

By continuously monitoring data accuracy and completeness through the data reviewer, Greenville Utilities Commission has been able to identify areas for improvement and implement corrective measures as needed. This iterative approach which can use the same measurement variables in each time period has not only enhanced the overall data quality but also instilled a culture of continuous improvement within the organization. The data reviewer scores provide a quantitative measure of the impact of the mobile field applications on data accuracy and completeness. They demonstrate the successful transition from traditional methods to the digital platform, resulting in more reliable and comprehensive data for decision-making and analysis purposes.

6. Discussion:

The results presented in the previous section demonstrate the successful implementation and adoption of mobile field applications by the Greenville Utilities Commission (GUC) for their water utility inspections. The discussion will now delve into the implications and significance of these results.

When interpreting the results, it is crucial to consider the factors contributing to and impacting the data. For example, the decline in work in 2021. The implementation of the workflow involved integrating the general workforce, which may not be as technologically inclined as the testing groups. Consequently, a steep learning curve was encountered during this period, leading to a temporary decrease in productivity. However, encouragingly, a notable rebound is evident in the 2022 data, with values showing significant improvement. Furthermore, the forecast for 2023 indicates even better performance, surpassing the levels achieved during the development phase. By incorporating these enhancements, the interpretation of the workforce integration and performance analysis becomes more informative and compelling. It ensures that readers gain a comprehensive understanding of the challenges faced, the efforts made to overcome them, and the positive outlook for future performance.

One of the key findings is the improvement in the inspection process achieved through the transition from paper-based methods to GIS-centric mobile field applications. As pointed out by Lassin and Frazier (2010), technology has served as a catalyst for improvement here. The use of smart form formats within the mobile applications streamlined data collection, eliminating the need for manual data entry, and reducing the potential for errors. The integration of the field crew's edits with the organization's GIS database in real-time ensured that the data was accurate and up to date across the entire organization. This enhanced data quality served as the foundation for creating insightful dashboards and reports within the GIS system and applications.

The analysis of application usage, performance, and efficiency/productivity revealed positive outcomes after the implementation of the mobile field applications. The increase in user content counts and usage over the years indicates a growing adoption rate and user engagement with the technology. The higher number of inspections conducted post-implementation compared to the pre-implementation period demonstrates the increased efficiency and productivity achieved using mobile field applications, a result that was mirrored in Luettinger and Clark (2005). Specifically, the average number of hydrant inspections, system valve inspections, and pump station inspections per year showed a consistent upward trend after the implementation, indicating improved operational effectiveness and therefore the necessary infrastructure management can occur (Sægrov, 2006).

The technology infrastructure played a crucial role in supporting the mobile field applications. The provision of Apple iPads to field crews enabled them to access and utilize the applications, enhancing their mobility and flexibility in data collection. The development of custom dashboards centralized data visualization and provided a convenient and centralized location for monitoring and analyzing inspection data. This technology integration allowed for seamless data synchronization and facilitated data redundancy and security through the implementation of a dual server system.

The mobile field applications also had significant implications for infrastructure planning and asset management. The collection of location and attribute data during inspections facilitated informed decision-making for repair and replacement work. The water main break map, which overlaid inspection data with soil types, helped identify vulnerable areas and prioritize maintenance efforts (Appendix D).

The mobile field applications proved invaluable in emergency response. As suggested by previous literature, this work was able to leverage real-time data sharing and monitoring capabilities enabled operations staff to promptly respond to emergency situations and address customer issues (Lassin & Frazier, 2010). Compliance with state and federal regulations was facilitated through inspections and the collection of relevant information such as identifying water service and main materials to ensure compliance with lead and copper service regulations (Naimi et al., 2019; Shamsi, 2005).

The business process analysis revealed the transformation of the traditional inspection process into a more efficient and streamlined workflow. The utilization of mobile field applications eliminated the need for paper forms and manual data entry, reducing administrative burdens and potential errors. The implementation of KPIs allowed for the evaluation of the applications' effectiveness and provided valuable insights into user adoption, data accuracy, and inspection completion.

While the implementation of the mobile field application approach offers numerous benefits, it is important to acknowledge and address some of the drawbacks associated with this methodology. One significant drawback is the increased requirement for time, manpower, and resources compared to the traditional paper and pencil approach. A robust GIS system necessitates ongoing monitoring, configuration, and continuous education to ensure its smooth operation. Unlike traditional methods that involve creating a form once and manually entering data into a GIS system if needed, the mobile field applications require regular maintenance and updates to keep the system running effectively.

Moreover, the adoption of mobile field applications entails additional costs, including equipment and licensing expenses. Companies considering this approach would need to make a substantial investment, especially if starting from scratch. It is crucial to carefully evaluate the financial implications and consider the long-term benefits before committing to this technology-driven approach.

Another important consideration is the potential impact of natural disasters, service interruptions, or other unforeseen events on the usability of the mobile field applications. If not adequately prepared, such incidents could disrupt the workflow and hinder data collection. To mitigate this risk, workarounds such as downloading and storing copies of essential data on devices can provide a backup option. However, these copies would require routine updating to ensure the availability of the latest information.

Despite these drawbacks, it is important to note that the benefits of the mobile field application approach, as highlighted throughout this analysis, outweigh the challenges associated with its implementation. By addressing the drawbacks proactively, such as dedicating resources to system maintenance and disaster preparedness, organizations can maximize the effectiveness of the mobile field applications while minimizing potential disruptions.

Ultimately, the decision to adopt a mobile field application approach should be based on a careful assessment of the organization's specific needs, resources, and readiness to embrace the required technological and operational changes.

7. Conclusion:

In conclusion, the results and discussion highlight the successful implementation and transformative impact of mobile field applications in the water utility inspections conducted by the Greenville Utilities Commission (GUC). The transition from paper-based methods to GIS-centric technologies has brought about significant improvements in various aspects of the inspection process.

The adoption of mobile field applications, such as Esri Field Maps and Survey123, has streamlined data collection, management, and analysis, eliminating the need for manual data entry and reducing errors. The integration of field crew edits with the organization's GIS database in real-time ensures data accuracy and consistency across the entire organization. This enhanced data quality serves as a foundation for generating insightful dashboards, reports, and visualizations that facilitate informed decision-making.

The analysis of application usage, performance, and efficiency/productivity indicates positive outcomes after the implementation of mobile field applications. The increased user content counts and usage demonstrate growing adoption rates and user engagement with the technology. The higher number of inspections conducted post-implementation reflects improved operational effectiveness, with consistent upward trends observed in the average number of inspections per year.

The technology infrastructure, including Apple iPads, custom dashboards, and dual server systems, has played a crucial role in supporting the mobile field applications (Appendix A). These technological advancements have enhanced mobility, data visualization, and synchronization, enabled seamless data transfer and ensuring redundancy and security.

The benefits extend beyond the inspection process itself. The integration of location and attribute data in planning and asset management processes has facilitated informed decision-making for repairs, replacements, and maintenance. The mobile field applications have improved emergency response capabilities, enabling prompt actions and issue resolutions.

The utilization of mobile GIS field applications described here plays a pivotal role in enhancing data management and integration. The seamless collaboration between these applications and the GIS database ensures data consistency and eliminates the existence of data silos. Real-time data, reports, and attributes can now be shared across the organization, office, and field crews simultaneously. Leveraging Esri dashboards, data can be disseminated efficiently among teams, departments, and employees, leading to improved business decisions and enabling the identification of areas in need of prioritization.

The methods and categories elucidated in this discussion are anticipated to yield a vast array of invaluable information, significantly contributing to the achievement of the defined objectives. Not only will they facilitate the development of a robust set of best management practices that will serve as a guiding framework for water utility infrastructure inspections at the Greenville Utilities Commission, but they will also establish an efficient and effective workflow and business decision network.

Furthermore, the resulting values are expected to alleviate the persistent challenges faced by utility companies, providing them with valuable guidance. The insights garnered from this research endeavor hold the potential to alleviate the burden and pressures encountered in the day-to-day operations of utility companies. Additionally, these findings have the capacity to offer invaluable assistance to other utility companies seeking to enhance their work, providing them with a roadmap for improvement and greater efficiency.

The successful transformation of the traditional inspection process into a more efficient workflow has been driven by the adoption of KPIs and the utilization of GIS-centric technologies. These advancements have reduced administrative burdens, and improved data accuracy and completeness. The positive outcomes observed in this study underscore the potential of mobile field applications in revolutionizing utility operations and paving the way for smarter and more sustainable water management practices.

Overall, the results demonstrate the significant benefits and improvements achieved through the adoption of mobile field applications for water utility inspections. The successful implementation of GIS-centric technologies, coupled with the integration of customized workflows, web maps, and dashboards, has transformed the inspection process, enhanced data quality and accessibility, improved operational efficiency, and facilitated informed decision-making for infrastructure management. The positive outcomes observed in this study serve as a testament to the potential of mobile field applications in improving utility operations and laying the foundation for best management practices for water utilities field inspections. The potential for future work here is plentiful, creating a foundation of technology driven, mobile field application powered utility management has the potential to optimize many workflows. Now that the approach is GIS-centric, an enhanced data store can inform business decisions and provide the support to transition from a reactive based workload to a preventative. Additionally, the information provided here could support another utility in making the transition and potentially create a community of collaboration for enhancements using a form of the outlined methodology.

In summary, the implementation of mobile field applications by the GUC has brought about significant improvements in data collection, management, and analysis for water utility inspections. The successful integration of technology infrastructure, coupled with customized workflows and dashboards, has enhanced operational efficiency, and decision-making capabilities. The results demonstrate the transformative impact of mobile field applications in driving efficiency, productivity, and sustainability in water utility operations and fulfil both project objectives.

Appendixes

Appendix A: Supplemental GIS Information

Supplemental GIS Information: It is crucial to emphasize that the successful attainment of both objectives critically relies on the utilization of the Geographic Information System (GIS) system, which serves as the cornerstone for all the research activities under discussion. Consequently, acquiring a comprehensive and profound comprehension of the specific GIS system employed at Greenville Utilities Commission becomes imperative. The data utilized by these applications is securely stored on the Greenville Utilities Commission GIS server, which operates on a robust federated system. This system not only ensures data integrity but also facilitates seamless sharing within the organization. The integration of stringent security measures guarantees the confidentiality and privacy of sensitive information.

The process of adding data to the server is efficiently accomplished through a publishing mechanism. This allows for the smooth integration of data into the server in real-time, enabling immediate availability for analysis and utilization.

Once the data is published, it becomes an item within GUC's enterprise portal, a powerful web-based component designed to facilitate the sharing of maps, apps, scenes, and various other data across the entire organization. These items are seamlessly incorporated into the map viewer on the portal site, providing users with easy access and a unified platform for data exploration.

The federation of these services with the main GIS system enables the synchronization of data, ensuring that the information remains consistent and up to date across all relevant applications and platforms. This synchronization process plays a vital role in completing significant data analysis, allowing for thorough business process analysis.

The robust GIS infrastructure, with its federated system and secure data management, provides a solid foundation for seamless data synchronization and comprehensive analysis. By utilizing these capabilities, the organization can gain valuable insights and drive data-informed decisions, ultimately leading to improved business processes and enhanced operational outcomes.

Appendix B: List of Figures

Appendix C: List of Tables

Appendix D: Mobile Field Applications

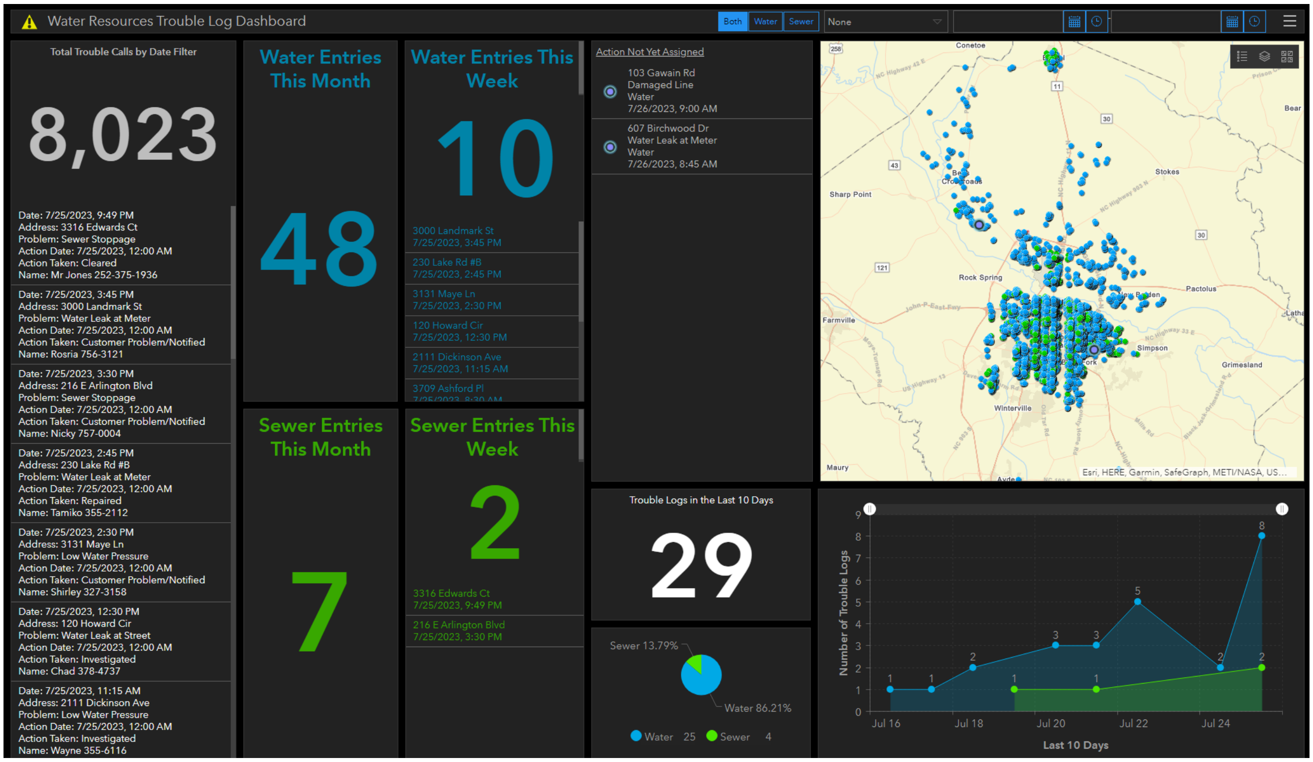

Figure 9: Trouble log dashboard created for monitoring emergency response indicators and data.

Emergency Response: The implementation of real-time data and continuous collaboration across the organization has significantly improved emergency response capabilities. The field crew, during their inspection rounds, can swiftly identify issues and promptly relay the information to the appropriate channels within the organization. This seamless process is mirrored with public calls, ensuring that emergency situations are addressed promptly and effectively. With a more comprehensive data collection process facilitated by the mobile field applications, the entire hierarchy of employees is equipped with the necessary data to address and resolve emergency situations. Furthermore, the data can be visualized and displayed in a centralized location to provide informative insights at all levels of the organization (Figure 9).

Figure 10: Water main break map illustrating the ability to used gathered information from the mobile field application to improve infrastructure planning and maintenance.

Water main breaks can have significant consequences for communities, leading to disruptions in water supply and potential infrastructure damage. To better understand these incidents and identify patterns, a comprehensive water main break map can be created (Figure 10). This map will not only showcase the locations of main breaks but also provide valuable insights into the correlation between pipe material and soil type with the occurrence of these incidents.

By creating a water main break map that incorporates incident locations, pipe material, and soil type data, stakeholders can gain a deeper understanding of the factors contributing to water main breaks. This knowledge will empower them to implement targeted strategies for mitigating risks and improving the overall resilience of water supply systems in the community.

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