INNOVATION AND COST EFFECTIVE APPROACH TO POTABLE WATER PIPE REPLACEMENT STRATEGICALLY FOCUSED ON DISTRIBUTION SYSTEM WATER QUALITY IMPROVEMENT

By

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ABSTRACT

The City of Sanford, Florida faces the challenge of expanding and maintaining its old potable water distribution system infrastructure to continue the high standard of service to its customers. The challenge includes meeting current and future distribution water quality regulations, reducing non-revenue water, minimizing pipe breaks and improving customer satisfaction. To help meet these distribution water quality challenges, the City received a Florida Department of Environmental Protection (FDEP) State Revolving Fund (SRF) Program low-interest loan and an *American Recovery and Reinvestment Act* (ARRA) grant in 2009. The proposed project included treatment improvement, pipeline replacements and looping to improve water quality and reduce pipe failures.

The City is currently upgrading one of two water treatment plants to ensure water quality compliance is maintained throughout the distribution system. With new treatment processes in place, the City endeavors to maximize the use of high quality water as it is distributed using improved distribution flow patterns, reducing distribution water age and replacing scaled and tuberculated pipes. Water age reduction would result in reduced flushing leading to water conservation and reduced operating costs (i.e. energy and chemicals), which was critical in the FDEP's inclusion of the project for SRF funding. This effort, using hydraulic and water quality modeling identified over 250,000 linear feet of pipe replacement and looping projects designed to maximize water quality throughout the system.

The City reviewed various pipe replacement options and selected pipe bursting as the construction method to replace existing distribution pipe. Implementing pipe bursting construction provided accelerated replacement schedule, no design requirements for replacements of same size up to 2 pipe diameter size increases, and delivered technically feasible and cost effective pipe replacements. As the project continues, it will be critical to ensure the strategic replacement plan is implemented during construction phase. Upon completion of the selected pipe replacement project, the City would realize water quality improvement of over 40% and financial benefits of over $500,000 for the City.

This paper presents a summary of the critical elements of this project applicable to other utilities, including acquiring grant and low-interest loans for planned projects, hydraulic and water quality strategic modeling, and pipe bursting construction lessons learned.

INTRODUCTION

Understanding the costs involved with infrastructure such as water pipe upgrades and operational costs to deliver safe water to customers' tap is very complex and not well understood. Public infrastructure investment protects public health as well as assures customers that this essential resource will be here for future generations. The April 2011 American Water Works Association (AWWA) Inside Insight "*Infrastructure: It's Not All About the "M" Word*" by Marcia Lacey estimates that the cost in the USA for replacing aged infrastructure range from triple-digit billions to more than $2 trillion. As a public servant, the City's Utility Department is responsible for providing its citizens safe drinking water at a feasible cost. For many years, the City tried to keep water services cost low by performing minor repairs and addressing pipes rehabilitation as needed. However, the water quality, water loss and operational limitations elevated the need to address the water system infrastructure to ensure our natural resources are maximized and public health is protected.

BACKGROUND

The City of Sanford (City) owns and operates two water treatment plants (WTPs) which produces approximately 7.3 million gallons per day (MGD) and serves over 57,000 customers via approximately 16,300 potable water meter connections throughout its distribution system. The Main Water Treatment Plant (WTP #1) provides approximately 73% of the City's supply. The Auxiliary Water Treatment Plant (WTP #2), which is the secondary water treatment plant serving the City's service area, provides, on average, approximately 27% of the City's supply of potable water. Both WTPs source is ground water which is aeration and chemical addition for treatment. Adequate disinfection is continuously provided throughout the distribution system. The distribution system comprises of water pipes of a variety of materials and sizes which were installed as early as the 1920s. Given the aging infrastructure, City staff with the assistance of Reiss Engineering, Inc. performed a water system infrastructure condition assessment using the City's hydraulic model that would maximize the benefit from pipe rehabilitation with respect to water loss and water quality improvement.

With the City's objective to cost effectively improve the distribution infrastructure and water quality, this paper presents a summary of the critical elements applicable to other utilities, including acquiring grant and low-interest loans for planned projects, hydraulic and water quality strategic modeling, and pipe bursting construction lessons learned.

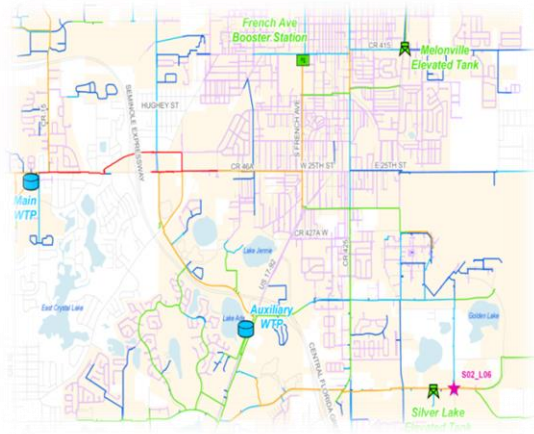
METHODOLOGY

To achieve the stated objectives a methodology was developed to identify water system projects that would provide improvement in water loss and water quality utilizing a potable water system updated hydraulic and water quality model (model). The City's model being structurally and operationally current was field calibrated to accurately simulate hydraulic and water quality conditions. Bulk disinfectant reaction rate coefficients were established through bench testing for the WTP #1 and WTP #2 finished waters. The resulting reaction rate coefficients were added to the model to simulate, evaluate, and maximize distribution water quality improvement by strategically selecting rehabilitation projects. Using the simulated hydraulic conditions and water quality improvements, the City was able to justify the need for grant and low rate loan funding. With the foresight of the hydraulic and water quality forecasting, the City concluded that the use of innovative trenchless technology, pipe bursting construction, would be the best approach given the financial and implementation benefits. The project methodology can be summarized into the size steps as listed below.

1. Hydraulic Model Development
2. Rehabilitation Projects Selection
3. Water Quality Forecasting
4. Rehabilitation Project Funding
5. Pipe Bursting Construction Lessons Learned

HYDRAULIC MODEL DEVELOPMENT

The City's model simulates the distribution system operation, including sources, booster stations and storage facilities. The model structure was built using a one-to-one approach with the City's GIS system. The key components of the distribution system which are incorporated into the model are discussed in the subsections below.



Facilities

The City's two WTPs, which were described previously, includes a high service pump station for supply and pressurization of flows to the distribution system. Calibrated manufacturer's curves for each pump within the respective WTP pump stations were incorporated into the hydraulic model to more accurately simulate field conditions. The City currently operates one booster station called the French Avenue Booster Station, which maintains adequate pressure in areas in the northern portion of the distribution system. There are two elevated tanks, the Mellonville Elevated Tank and the Silver Lake Elevated Tank, in operation. The Mellonville Tank was equipped with a pump to optimize the operation of the tank which will aid in reducing the storage age which was above 200 hours. The Mellonville pump operates based on time of day, system pressure and tank level in the northeastern portion of the City. The Silver Lake Elevated Tank operates on system pressure in the southeast portion of the City. The elevated tanks are required for providing fire flow storage for the distribution system.

Water Mains and Key Valves

Sanford's distribution system is comprised of approximately 340 miles of potable water pipe ranging in size from 3/4-inch to 24-inch in diameter. Typical information utilized in simulating distribution system water pipes in a hydraulic model are summarized in Table 1. The City has one 12-inch valve closed at the eastern end of the distribution system to help improve water quality in the area.

Table 1. Typical Hydraulic Model Water Pipes Input

Parameter	Background
Length (feet) / Diameter (inches)	The length assigned to a pipe represents the distance that water flows from one node to the next based on GIS information. A pipe's nominal diameter is used in combination with a roughness coefficient that is specific to the piping material.
Material	Pipe material data is currently incorporated into the hydraulic model. The City will continue to document pipe material and infrastructure age for existing and future installations. Material information was used for analyzing the distribution system for water quality and pipe breaks evaluations
Hazen-Williams Coefficient (Roughness)	Hazen-Williams Coefficient is used to calculate the pressure drop due to friction for a given pipe diameter and flow rate. The Hazen-Williams C factor depends on the type of the pipe material, age, and the internal condition of the pipe. Values in the City's model range from 100 to 150.
Minor Loss Coefficient	Minor Losses occur at valves, tees, bends, reducers, and other appurtenances within the piping system due to turbulence within the bulk flow as it moves through fittings and bends. Applicable minor losses are incorporated into the City's model.

Calibration

After model development and demand allocation using actual water billing data and GIS information to simulate the demands on the distribution system were incorporated, the model was calibrated to represent the system with over 90 percent accuracy.

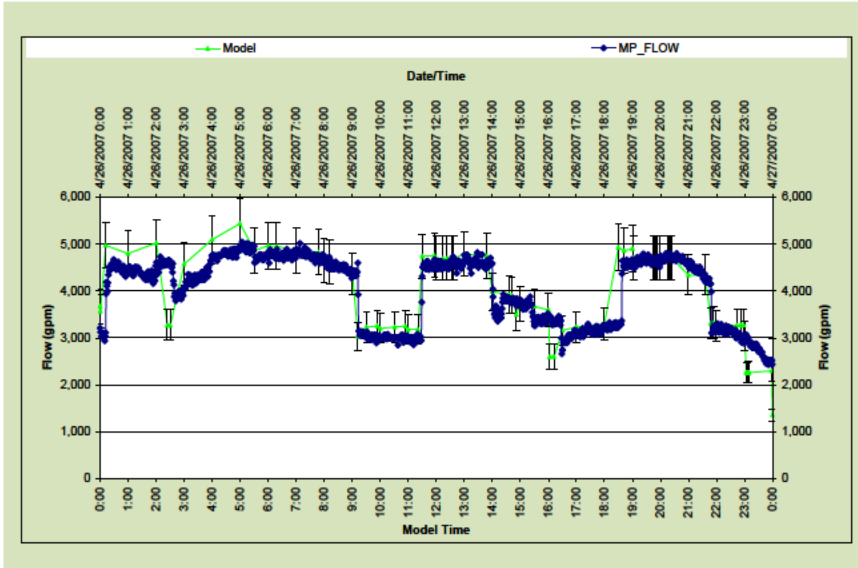


Figure 1. Actual versus Model Calibration Comparison

Figure 1 shows an example of field collected data collected using data loggers and the City's SCADA system versus model simulated data for the calibration period. Error bars representing 10% are included on the model data to demonstrate that the model consistently simulates hydraulic and water quality parameters over a 24-hour period using an extended period simulation (EPS) scenario. The model calibration approach illustrated in Figure 2, summaries the overall approach to a successful hydraulic and water quality model calibration.

Model Evaluations

The result of the model calibration is a fully working model of the water delivery system which can simulate many different conditions. The calibrated model was used for various evaluations to strategically determine rehabilitation projects that would yield the maximum water loss and water quality improvements. The model evaluations were critiqued using the City's water service criteria summarized in Table 2.

Table 2. Sanford Water Service Criteria

Category	Criteria
Average annual daily demand (AADD)	7.3 MGD
Maximum daily demand	1.3 x AADD
Peak hourly demand	2.5 x AADD
MDD plus Fire flow*	> 20 psi
AADD, MDD and PHD	> 40 psi
Fire Flow*	600 gpm (residential)/ 1250 gpm (commercial)
Maximum Water Age Goal	3 days
Maximum Pipe Velocity*	< 5 fps

*Based on City Utility Manual.

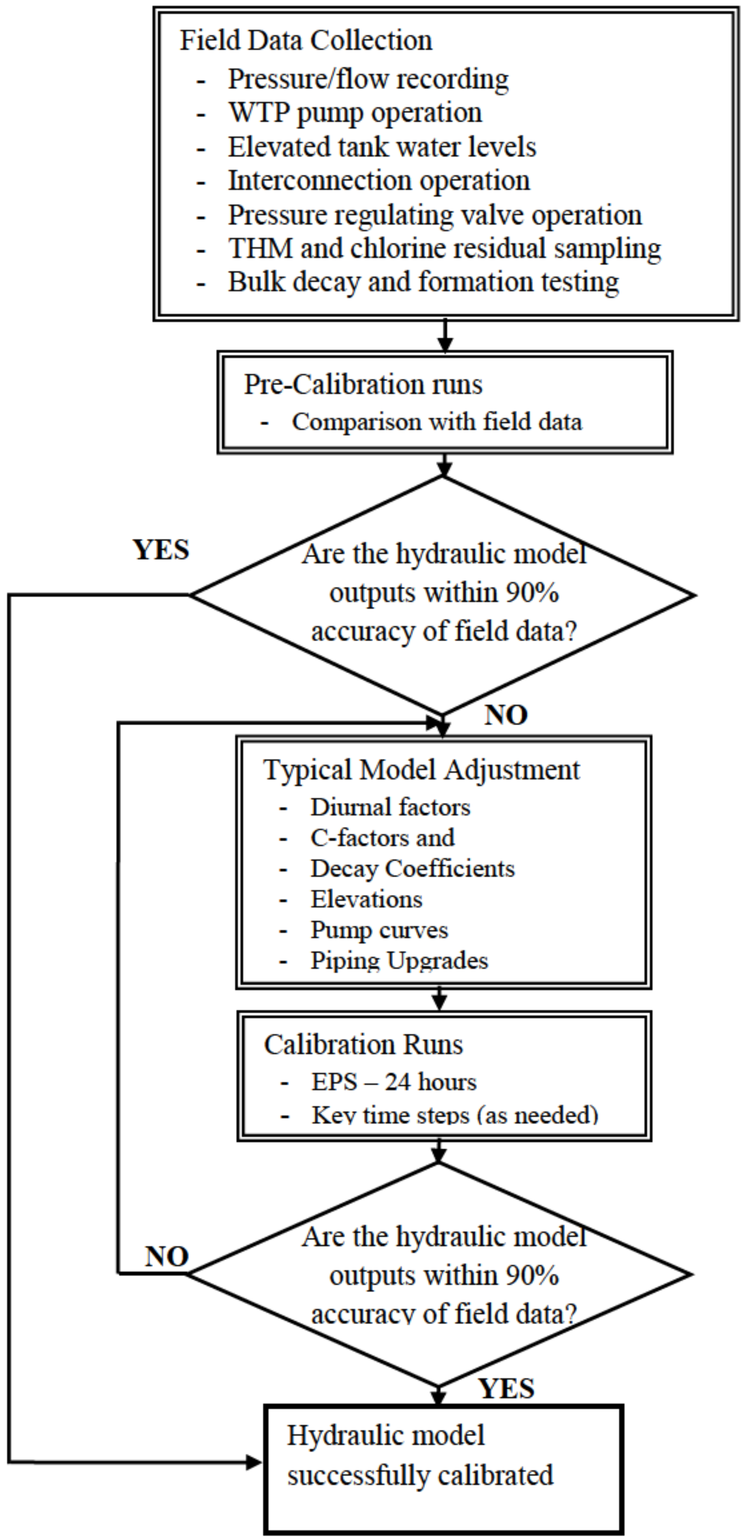


Figure 2. Calibration Methodology Diagram

REHABILITATION PROJECTS SELECTION

Using hydraulic modeling, the City identified 38 pipe replacements to improve water quality by strategically replacing iron-based water pipe with high density polyethylene pipe (HDPE) piping in key subdivisions throughout the distribution system. In addition, nine looping projects and other replacement projects were identified that enhanced the movement of water and significantly improved water quality in the water system.

In order to secure funds, the City showed water quality improvement due to completing the rehabilitation projects. The distribution water quality currently meets all required regulations. However, the City has recorded elevated THM at various locations throughout the distribution system and is proactively working to reduce THM concentrations. In addition to evaluating treatment options, the City is in the process of replacing and looping pipes throughout the distribution system. The first phase of pipe bursting and looping projects was completed in April 2011 and the second phase will be completed in December 2013.

Pipe Replacement and Looping Projects Evaluation

REI conducted a pipe replacement and looping projects evaluation in order to determine the pipe replacements and looping projects which would be technically and financially feasible, prioritize the projects and provide recommendations for implementation to the City. The phase 1 pipe replacement projects were selected based on pipe material, pipe condition (i.e. repeated main breaks); water age improvement (aesthetic and regulatory compliance), treatment facilities upgrades, customer complaints, and estimated cost. For the selection of the phase 2 pipe replacement projects the evaluation was expanded to include location and model water quality (THM and chlorine residual) results. Based on the evaluation, eight pipe replacement projects and six looping projects were selected for construction as shown in Figure 3.

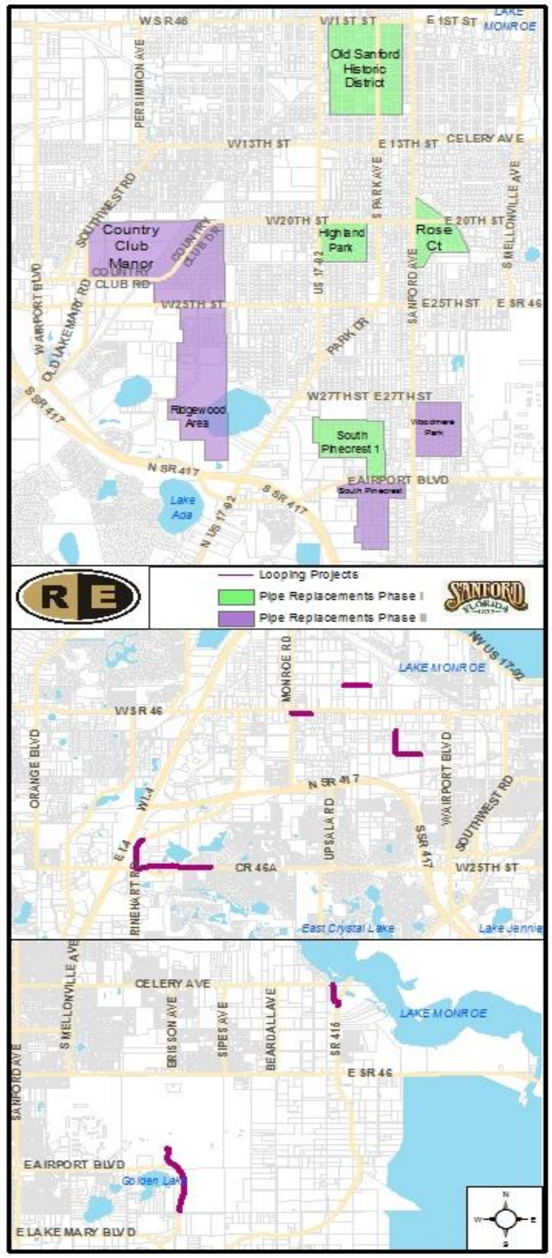


Figure 3. Pipe Replacement and Looping Projects

Other Replacement Projects

In addition to pipe replacement and looping projects the City identified several other key projects to address infrastructure conditions and water quality improvements. These projects included the following.

- **City-wide Meter Replacements** – Replacement old meters with a new "smart meters" technology. This technology is capable of detecting small leaks at the customers' service line allowing the City to notifying the customer about a possible leak which would reduce the City's water loss and minimize increases in the customers' utility bill. Currently approximately 99% of residential meters have been replaced.

- **Source Water Quality Management** – Review of groundwater well water quality and develop an operational matrix to maximize entry point water quality and ensure effective well usage on a daily basis.
- **Treatment Facility Modifications** – Modification WTP #2 with the addition of ozone and granular activated carbon (GAC) treatment processes. This facility is currently in construction with an anticipated completion date of April 2014.

WATER QUALITY FORECASTING

Trihalomethane (THM) concentrations simulated by the model were compared to field data which was collection from distribution system sites to verify that the model maintained acceptable accuracy in predictions. As shown in Figure 4, the model provided conservative THM concentration predictions when compared to actual field data. THMs were predicted at the future Stage 2 Disinfection/Disinfection By-Product (Stage 2) monitoring locations in the distribution system.

The various model runs were simulated for 600 hours to ensure output stabilization. Based on the model output stabilization occurred after approximately 4 days (100 hours). After the model output stabilized, the data was summarized as shown in Table 3. The model data indicates that GAC treatment at the Auxiliary WTP will reduce the THM formation potential throughout the distribution system. However, based on the existing operations, the improvement at the longest detention time compliance site would be close to or may exceed the 80 µg/L THM regulated maximum limit.

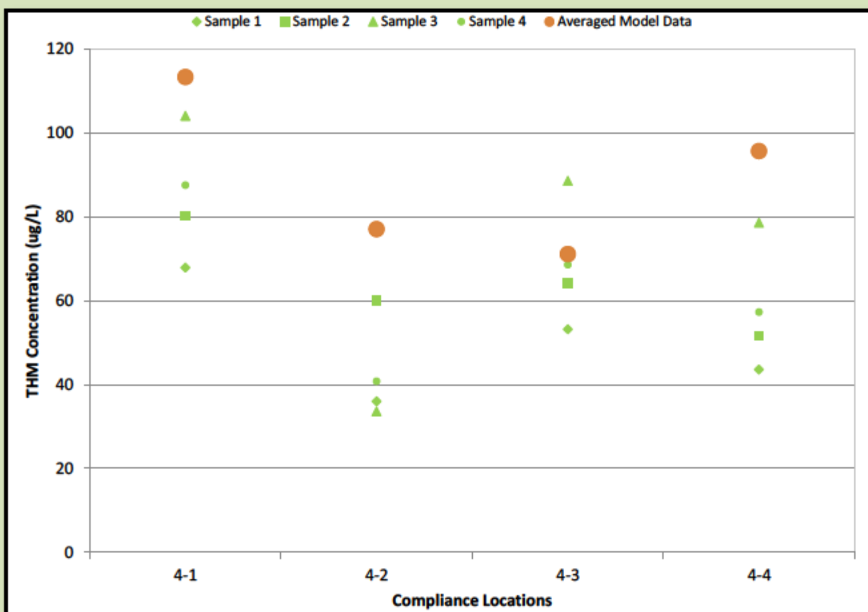


Figure 4. Model and Field THM Concentration Comparison

The ability to forecast the water quality of the distribution system provided the City with a decision making tool which assisted City managers and key staff members in selecting to use ozone and GAC at WTP #2. The City has the foresight that additional treatment may be required at WTP #1 to ensure Stage 2 compliance at long detention time (high water age) locations in the distribution system.

Table 3. Model THM Formation Predictions Based on Evaluated Treatment Regimes

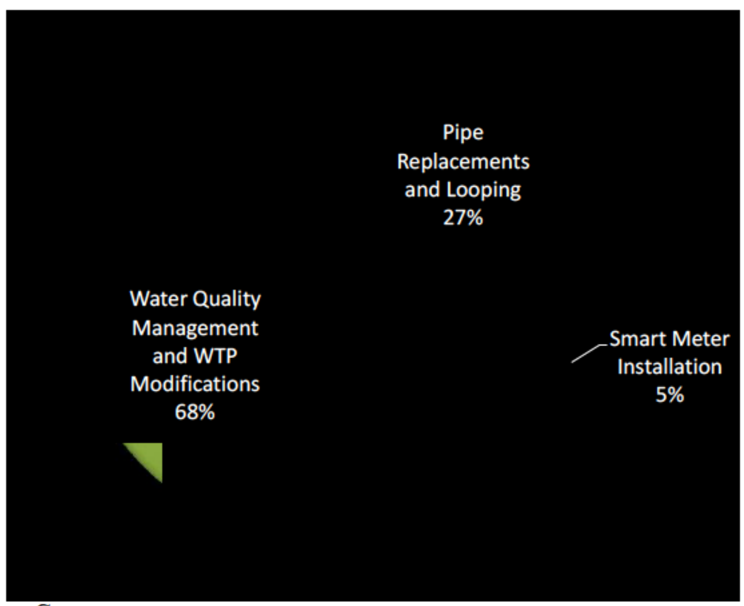
GAC Treatment Scenario Simulation with Pipe Replacements and Looping Projects	THM Concentration @ Water Age = 50 hours (ug/L)	THM Concentration @ Water Age = 70 hours (ug/L)	THM Concentration @ Water Age = 112 hours (ug/L)
WTP #2 Only (Full Breakthrough)	49	53	77
WTP #2 Only (Partial Breakthrough)	45	45	69
WTP #1 & WTP #2 (Full Breakthrough)	36	30	64
WTP #1 & WTP #2 (Partial Breakthrough)	25	19	36

Note: THM concentration compliance limit = 80 ug/L

REHABILITATION PROJECT FUNDING

Given the pipe rehabilitation and looping project selections, in addition to several other projects, the City was able to justify funding due to infrastructure conditions and water quality improvements under the *Safe Drinking Water Act* using model output. The following are the funding received from the *State Drinking Water State Revolving Funds* (SFR) and grants funds such as the American Recovery and Reinvestment Act (ARRA) having a grand total of $20 million (M):

- 2009 – 2010: $2.55 M ARRA funds and $450,000 SRF loan at a low rate
- 2011 – 2012: $4 M Grant funds and $13 M SRF loan at a low rate



Summary

Pipe replacement and looping funds, approximately $8 M, was used to complete approximately 120,000 linear feet of piping improvements which were ready to be executed. A portion of the grant funds, approximately $1.6 M, was used to replace residential meters and large (schools and commercial type) meters throughout the City. Given the potential for water conservation, this is considered by FDEP a "green project" which allowed the City to be considered a priority and listed in the top four (4) water providers funding list. This replacement program has assisted with reducing water loss from 22% to 11%. Further study in system water loss and conservation is been conducted under a separate grant with the St. Johns River Water Management District (SJRWMD) and those results will be available within the next year (2014). The source water quality management and treatment facility modification projects totaled approximately $20 M. Figure 5 demonstrates the funding allocation to the City's rehabilitation projects.

PIPE BURSTING CONSTRUCTION LESSONS LEARNED

Pipe bursting was determined to be the most viable method of construction for the pipe replacements. This method is well-established for installing new high density polyethylene (HDPE) pipe. In addition, molded couplings, centurion fire hydrants, and ball valves can then be installed without significant customer disruptions, as would occur with open trenching which would translate to significant cost savings to the City. Pipes were replaced to match the existing sizes or have a maximum increase of two pipe diameters to avoid design and permitting costs. An added benefit from water pipe replacements is the ability to increase fire protection for older areas of the City.

Lesson Learned

Successful implementation of the pipe replacement projects in the most efficient and cost effective manner require coordination among the project team members. One key step in project coordination is to identify construction team members and key personnel, and to define specific individual roles to avoid unnecessary delays during the construction process. As part of the coordination effort, the City developed construction project schedule goals and requirements. Planned quarterly meetings with the key project entities to discuss project status, budget, schedule, and address critical items such as customer complaints related to the field efforts. Some lessons learned and key tips to a successful pipe replacement project include the following.

1. **Conduct field verification prior to construction** – Locate and confirm pipe layout and sizes, number of apparatuses such as valves, and hydrants. This will confirm the infrastructure that is in the ground and assist in refinement of the project cost. In addition, this step help confirm City documents such as as-builts, GIS data, and hydraulic model inputs especially in older areas.

2. **Confirm pipe replacement method** – Determine locations where pre-chlorinated pipe bursting is not be feasible and select a replacement method that is cost effective for the location. Locations such as railroad crossings, water crossings, and other configurations may require open trench or directional drill replacement methods that require permitting.

3. **Document site before and after construction** – Use documentation methods such as pictures and or videos to ensure the site remains to acceptable appearance after construction is complete. Items such as customer connections and road, sod, and driveway replacement include issues that could arise during and after construction is complete.

4. **Communicate with the public** – Develop a low cost yet highly effective way to inform the public of the project status. Items such as website updates, newspaper articles, and department newsletters highlights are some ways to effectively interact with the public. In additional, methods such as project signs and onsite literature could assist in public communication.

5. **Implement timely team members meetings** – A project construction coordination meeting held between City department leaders and key project personnel to discuss pipe replacements construction tasks. These meetings ensure that project goals, requirements, required data were

being collected, and maintain inter-departmental communication.

6. **Manage data collection** – Determine the most feasible timing to collect global positioning system (GPS) mapping data of key items such as valve, hydrants, fittings, and water quality samples before and after construction to document improvements. Document the location, elevation, pipe size, material, installation year, and other pertinent data for the asset replacements using GPS loaded with Arc-Pad GIS or similar technology.

7. **Update distribution system hydraulic model (if applicable)** – Incorporate the updated pipe layout and field collected information. Determine and update hydraulic model the pipe roughness factor (C-factor) and system demands after construction is complete.

8. **Develop documentation** – Document and compare field water quality and water loss improvements after construction is complete. This will assist with quantifying the success of the project to managers, commissioners, and the general public. In addition, this information may be necessary for project reporting to satisfy funding requirements.

CONCLUSION

The benefits of pipe replacement include minimizing water loss, improving distribution water quality, and maintaining safe drinking water for the citizens of Sanford. The City utilized hydraulic and water quality modeling to select pipe replacement projects that would most benefit the City and a technical and financial basis. In addition, the City used model output to forecast water quality after system improvements. This forecast information was used to justify grant and low rate loan funding of approximately $20,000,000 to cost effectively improve the distribution system infrastructure. With the funding in place, the City implemented a cost effective pipe replacement method called pipe bursting which saved the City significant design and permitting fees. The lessons learned during this project will help Utilities successfully plan, manage, and implement similar construction projects.