CRITICALITY ANALYSIS AND INSPECTION METHODS FOR FORCE MAIN CONDITION ASSESSMENT

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ABSTRACT: This paper presents the results of the Cape Fear Public Utility Authority’s force main condition assessment program. The completion of this comprehensive program included the development of recommendations for force main re-inspection, repair, rehabilitation or replacement based on the findings of the condition assessment.

The Cape Fear Public Utility Authority (CFPUA) provides water and wastewater service in the City of Wilmington, NC and New Hanover County. Currently, CFPUA is working aggressively to continuously grow and enhance its asset management program into a critical decision-making process and tool for managing the life-cycle cost of assets. CFPUA retained the team of Highfill Infrastructure Engineering, PC and Brown and Caldwell to work with CFPUA staff to develop a comprehensive force main inspection and condition assessment program in support of the Authority’s asset management program for wastewater force mains. This paper will discuss the following portions of the CFPUA program:

Criticality Analysis: Development of an ESRI GIS-based criticality model to identify those force main segments that, based on current industry standards and CFPUA priorities, warrant the greatest consideration for field inspection. The criticality model was developed entirely within the ESRI GIS format and allows the user to change scoring and weighting factors for consequence of failure and likelihood of failure criteria to perform real-time sensitivity analysis of model outputs.

Condition Assessment: The evaluation and selection of applicable force main inspection technologies, and the design of a field inspection program to assess the condition of the high-priority DIP and PCCP force mains. The selected technologies included acoustic screening inspection and electromagnetic testing. The work included the planning and implementation of the acoustic screening and evaluation of four (4) critical force mains. The presence of VFD pumps and small wet-wells necessitated the development of detailed flow augmentation plans to maintain minimum velocities to ensure a successful inspection and accurate location data.

This paper will be of interest to those water and sewer utility staff that desire to plan, design, and implement an asset management program for wastewater force mains that includes an initial risk assessment, a prioritization of assets, an evaluation of alternative inspection technologies, the pre-planning required to implement alternative technologies, and interpretation of inspection data.


INTRODUCTION

The Cape Fear Public Utility Authority (CFPUA) provides water and wastewater service in New Hanover County, North Carolina, including the City of Wilmington. Formed in 2008 by the combination of the utilities departments of the City of Wilmington and New Hanover County, CFPUA inherited approximately 875 miles of gravity sewer, 145 pump stations and approximately 109 miles of force mains.

This project was focused specifically on CFPUA’s approximately 576,000 linear feet of wastewater force mains. In keeping with its approach of managing the life-cycle costs of key assets, CFPUA desired to develop a comprehensive program for force main inspection and condition assessment that would drive decisions regarding programming for re-inspection, repair, rehabilitation or replacement of force mains. Unlike gravity sewers, direct access to the interiors of force main pipelines for condition assessment is rarely
available. Gaining access for inspection can be expensive and disruptive, and attempting to assess all 109 miles at once is not viable. This program allows CFPUA to prioritize which mains warrant urgent action, and to determine what the most feasible course of action is for each. The ultimate goal of the program is to reduce the probability of force main failures in the future and reduce the life-cycle costs of long-term force main ownership, operation, and maintenance.

**METHODOLOGY – CRITICALITY ANALYSIS**

To establish priorities for force main inspection and maintenance, CFPUA performed a criticality analysis of their approximately 576,000 linear feet of force main. A criticality analysis is a form of risk analysis that assigns priorities to individual force main segments for field inspection. Criticality scores are calculated values that use criteria to estimate, i.e., score, the likelihood (i.e. probability) of failure and consequence (i.e. impact) of failure for a given force main segment.

Prior to conducting the criticality analysis, CFPUA subdivided each force main into shorter segments (segmentation). The vertical and horizontal alignment of a force main, the environmental conditions that a force main travels through and the physical characteristics of the force main, are not typically uniform along its entire length. For example, a segment of force main that crosses a creek as a submerged section of pipe (or as an aerial crossing) represents a higher risk (i.e. criticality) condition than a segment of the same force main that travels along a 30-ft dedicated sewer utility easement. The primary purpose of segmentation is to disaggregate a force main into smaller, more discrete segments that can be scored differently to better reflect the different risk potential along the entire force main alignment. The secondary purpose of segmentation is to assist in the planning of field inspection activities by identifying potential locations where inspection equipment can be inserted into the force main.

CFPUA segmented the force main system into 591 segments, and each segment was assigned a unique asset ID number for use with CFPUA’s computerized maintenance management system (CMMS). CFPUA utilizes Maximo for its CMMS. The criteria used to perform the segmentation process are as follows:

1) Changes in force main diameter
2) Changes in force main material
3) Locations of force main junction points (e.g. tee fittings)
4) Intersections with mainline valves
5) 2,500 linear feet or less per segment

**Weighting Factors**

Recognizing that each criterion is not of equal importance in determining criticality, weighting factors are used to prioritize the degree of importance. A higher weighting factor indicates that the criterion is of greater importance in the decision-making process. For both likelihood of failure and consequence of failure criteria, weighting factors were applied to the raw scores to arrive at a weighted score for each criterion.

CFPUA expressed a desire to place more importance on likelihood of failure criteria. For the initial criticality analysis, therefore, likelihood of failure scores were weighted with a factor ranging from 5 to 10, and consequence of failure scores were weighted with a factor ranging from 1 to 6. By applying greater overall weighting to likelihood of failure criteria, the criticality analysis resulted in a prioritization that places a greater emphasis on identifying force main segments with a higher likelihood, or probability, of failure. While consequence of failure is also recognized as important, the objective of this approach is to identify the force main segments that represent the highest likelihood of failure so that corrective action can be implemented prior to a failure event occurring.

**Likelihood of Failure Criteria**
Likelihood of failure scores are intended to represent the probability that a force main will fail based on the environmental conditions of where the force main is located and the physical characteristics of the force main. Likelihood of failure criteria typically include age, material of construction, soil type where the force main is buried, flow and pressure on the force main, work order history for the force main, and actual pipe condition (as observed and recorded through field inspections). Following is a brief description of the likelihood of failure criteria used by CFPUA for the criticality analysis.

**PIPE MATERIAL:** Pipe material is a critical factor in determining the most typical failure modes for a given force main segment. Most ferrous and cement-based force main failures are attributed to corrosion (internal or external), and most PVC and other plastic pipe force main failures are attributed to improper installation.

**AGE OF MATERIAL:** All pipe materials age and deteriorate over time due to abrasive, structural and mechanical forces, and corrosive agents. All pipelines, therefore, have a finite useful service life, but that service life is extremely difficult to predict because of the multitude of variables impacting it. 50 years is generally accepted as a reasonable design service life for a pressure pipeline, although many pipelines have provided a service life in excess of 100 years.

**STREAM CROSSINGS:** Force main segments that cross streams represent a special concern for CFPUA given the potential for accelerated rates of corrosion in the coastal environment and a history of failures at such locations. Deterioration of these pipe segments can be severe for ferrous and cement-based pipe materials, especially those segments that are exposed to such conditions over an extended period of time.

**RATES OF H₂S GENERATION:** Hydrogen sulfide (H₂S) is a known corrosive agent for ferrous and cement-based pipelines. CFPUA has implemented an Odor Control and Corrosion Program (OCCP), and data from this program was adapted for use in the criticality analysis.

**NUMBER OF FORCE MAIN JUNCTIONS (TAPS):** For the purposes of this analysis, a force main tap was defined as the location at which one force main is connected or joined to another force main by means of a structural or mechanical modification to the receiving force main segment. The location of the structural or mechanical modification is assumed to be a potential point of failure. Each segment may have 0, 1 or 2 taps associated with it. This criterion was scored based on the number of taps present on a force main segment.

**FORCE MAINS NOT SUBJECT TO CITY/COUNTY DESIGN STANDARDS OR INSPECTIONS:** According to CFPUA personnel, not all force mains in the CFPUA system were subject to City/County design standards or City/County inspection requirements. While it cannot be assumed that a force main has design, workmanship, or material deficiencies because it was not subject to City/County design standards or City/County inspection requirements, the criticality analysis factored in the potential for deficiencies to be present because system design, workmanship, and material quality cannot be confirmed. This criterion was scored based on CFPUA staff knowledge as to which force mains were not subject to City/County design standards and City/County inspection requirements.

**Consequence of Failure Criteria**

Consequence of failure scores are intended to represent the degree of impact of a force main failure on the service area located in close proximity to the force main. Consequence of failure criteria typically consider direct impacts, such as loss of service and cost for repair and cleanup, health and environmental impacts, such as public health risks and environmental resource impacts, and socioeconomic impacts, such as transportation and business disruptions (Thomson). Following is a brief description of the consequence of failure criteria used by CFPUA for the criticality analysis.

**QUANTITY OF FLOW:** This criterion is based on the potential quantity of flow discharged to the environment as a result of a force main segment failure. Average daily flow rates for each pumping station in the system was provided by CFPUA and incorporated into the criticality analysis.
**SURFACE WATERS:** This criterion is based on potential impacts to surface waters as a result of a force main segment failure. Force main segments located in closest proximity to surface waters were scored higher (greater consequence of failure) than force main segments located farthest from surface waters.

**GROUNDWATER WELLS:** This criterion is based on the potential impacts to public and private groundwater wells in the event of a force main segment failure. Force main segments located in closest proximity to groundwater wells were scored higher (greater consequence of failure) than force main segments located farthest from groundwater wells.

**HIGH QUALITY WATER AND OUTSTANDING RESOURCE WATER (HQW-ORW) MANAGEMENT ZONES:** This criterion is based on the potential impacts to high quality waters or outstanding resource waters as a result of a force main segment failure. Force main segments located in closest proximity to high quality waters or outstanding resource waters were scored higher (greater consequence of failure) than force main segments located farthest from high quality waters or outstanding resource waters.

**TRANSPORTATION SYSTEMS:** This criterion is based on the potential impacts to transportation systems in the event of a force main segment failure. This criterion was scored based on the number and type of transportation systems crossed by a force main segment.

**PRESENCE OR ABSENCE OF REDUNDANT FORCE MAIN:** This criterion is based on the presence or absence of a redundant force main in the event of a force main segment failure. Force main segments without a redundant force main were scored higher than force segments with a redundant force main.

**CULTURAL RESOURCE IMPACTS:** This criterion is based on the potential impacts to cultural resources in the event of a force main segment failure. Force main segments that crossed historic districts were scored higher than force main segments that did not cross historic districts.

**RESIDENTIAL IMPACTS:** This criterion is based on the potential impacts to residents in the event of a force main segment failure. This criterion was scored based on the estimated number of residential parcels located within an anticipated construction repair corridor for each force main segment. This corridor is initially set at 22 feet from either side of the segment. The number of residential parcels located within the corridor served as the score for a given segment.

**COMMERCIAL IMPACTS:** This criterion is based on the potential impacts to commerce in the event of a force main segment failure. This criterion was scored based on the estimated number of commercial parcels located within an anticipated construction repair corridor for each force main segment. This corridor is initially set at 22 feet from either side of the segment. The number of commercial parcels located within the corridor served as the score for a given segment.

**RESULTS – CRITICALITY ANALYSIS**

The ESRI GIS-based criticality analysis model was developed using the scoring criteria and weighting factors described in the previous section. The criticality model was developed entirely within the ESRI GIS environment and allows the user to change scoring and weighting factors for consequence of failure and likelihood of failure criteria to perform real-time sensitivity analysis of model outputs. The criticality analysis model was used to define likelihood of failure scores, consequence of failure scores, and total risk scores for each force main segment in the CFPUA force main system (591 segments, ~576,000 linear feet). Based on the findings of the criticality analysis model, CFPUA identified the force main segments for further investigation within the available budget. The PS 12, PS 14, PS 34, and PS 35 force mains included the highest rated segments and were scheduled for acoustic inspection. Additional individual force main segments were targeted for field reconnaissance where one or two segments scored high in criticality on an otherwise low scoring force main. An example is a PVC force main with an aerial stream crossing constructed of DIP.
METHODOLOGY – FORCE MAIN INSPECTIONS

With the completion of the criticality analysis model, and the identification of the highest risk force main segments, CFPUA then started the preparation and planning to conduct field inspection of these force main segments. The process started with a review of alternative force main inspection technologies.

Alternative Force Main Inspection Technologies

CFPUA considered alternative technologies for force main inspections. There are currently 43 technologies at various stages of development for the inspection of force mains. Of these, 17 are considered most reliable and appropriate for the inspection of wastewater force mains. The technologies vary in their reliability, in the sizes of pipelines for which they can be used, their ease of use, the degree of intervention required and the quality of the data. The level of intervention required is usually the major factor in the cost of deploying the technology, while the quality of the data produced is the major factor in the value of that technology. In general, the highest quality data is provided by those technologies requiring the most intervention.

Ductile Iron Force Mains

For ductile iron force mains the most critical condition parameter is the remaining wall thickness. There are several technologies which can test this parameter, to varying levels of confidence, including:

- Ultrasonic testing (UST)
- Magnetic flux leakage (MFL)
- Broadband electromagnetic (BEM)
- Remote field eddy current (RFEC) testing

The UST, MFL and BEM technologies can be deployed in either internal or external versions. Available internal versions require very close tolerances since the detection devices must be close to the pipe wall in order to function properly, although new versions are being developed which allow some standoff from the pipe wall. The UST technology in particular has very tight tolerances, the MFL and BEM only slightly less so. These very tight tolerances are acceptable in the steel gas pipeline industry due to the very tight construction tolerances. Their use in the wastewater force mains can be problematic and because wastewater force mains are often not equipped with insertion and retrieval stations, their internal use will require expensive and disruptive opening of the pipe. For these reasons internal UST, MFL and BEM technologies were not considered appropriate for this project. Specific internal RFEC tools have been modified for use in the water and wastewater industry and have been proven in the field. The internal RFEC tools were considered for this project.

The following discussions will focus on the external versions of UST, MFL and BEM. Since the external UST, MFL and BEM technologies are local tests, the test sites must be selected with some care. The ideal test sites are at the pipe crown at unvented high points in the line. In particular, high points which regularly contain pockets of trapped gases are the most likely sites for internal corrosion and therefore the preferred sites for wall thickness testing. The theory being that, if there is internal corrosion damage, it is most likely to occur at these sites. If no corrosion is found at unvented high points with trapped gas pockets, it can be assumed that the rest of the pipeline is in good condition. Obviously, this is only valid for internal corrosion.

The difficulty with this limited testing approach is that high points in the line, especially unvented high points, are often not known. This is particularly true when record drawings are incomplete, unreliable or when undocumented work has been done on the force main after construction. Pipelines have also been known to settle non-uniformly, creating intermediate high points. An inspection screening method using acoustic inspection technologies can be used to identify the unvented high points prior to local wall thickness testing.

PCCP Force Mains

There are two primary modes of failure for PCCP mains. For high pressure applications, the primary mode of failure for PCCP is loss of integrity of the
pre-stressing wires. For lower pressure applications, particularly in a wastewater system, internal corrosion of the concrete and external corrosion of the outer mortar layer can be the primary mode of failure.

The remote field eddy current with transformer coupled (RFEC/TC) tools provide information on the condition of the pre-stressed wire in the pipe. The wire is the primary structural element in the pipe and is vulnerable to corrosion and to hydrogen embrittlement. A second technology, the acoustically sensitive fiber optic (AFO) technology is installed within the pipeline to listen for ongoing wire breaks in the pipeline. Coupled with RFEC/TC data on existing wire breaks, the ongoing break data allows calculation of remaining useful life. The PipeScanner from Pure Technologies is an externally mounted tool which uses the same electromagnetic technology as PURE’s in-line inspection tools to check the integrity of the pre-stressed wires in PCCP. The top half of the pipe must be exposed so that the tool can be rolled along the crown of the pipe. The tool collects data on the pre-stressed wires with indications of where wire breaks have occurred and how extensive the wire break zone is. The tool will collect data over the entire length of exposed pipe, so the greater the length of exposed pipe, the more data is collected. Typically, at least one to three pipe sections are exposed.

For the lower pressure applications typical of wastewater force mains, the primary concern is internal and external corrosion. In order to assess internal corrosion in PCCP, an inline inspection must be conducted using man-entry visual and sounding inspection or technologies such as CCTV or sonar. For external corrosion, a soils evaluation is required.

**Inspection Technology Selection**

CFPUA evaluated the physical and economic feasibility of conducting a full, in-line inspection of each of the ferrous force mains using an internal RFEC tool. These tools provide a tremendous amount of quality data on the entire pipeline, which results in a high confidence in the resulting condition assessment of that pipe. The drawbacks to the use of the in-line tools are the cost of the inspection and the fact that the pipeline must be free of obstacles to the tools’ progress.

The potential obstacles in each pipeline were identified, including all the known valves, elbows, tees, diameter changes and material changes. The cost for replacing removable obstacles, such as 90 degree bends, inline plug valves, and tees, was included in the estimated cost of inspection. The cost of inspection was compared with the estimated cost of replacement. Generally, if the total cost of the inspection is less than 25 percent of the cost of replacement, then the inspection was considered economically feasible. PS 12 and PS 34 were found to not be technically or economically feasible for the in-line inspection. PS 35 was near the 25 percent threshold, but CFPUA has rehabilitated much of this pipeline already, with more slated for rehabilitation this year, so they have decided not to perform a full in-line inspection at this time.

Therefore, the selected approach for force main evaluation was to use one or a combination of the external tools (UST, BEM or MFL). The first step is to conduct acoustic screening and external corrosion screening to first identify the locations with the highest potential for internal and external corrosion. Where gas pockets are found or where external corrosive conditions are identified, a local, external electromagnetic tool can be used to verify remaining wall thickness.

**External Corrosion Investigation (Soils Evaluation)**

CFPUA performed an evaluation of external corrosion potential of ferrous and cementitious pipelines. While internal corrosion usually progresses more rapidly than external corrosion, external corrosion can be even more devastating over the life of a pipeline. Screening for indicators of potential external corrosion was conducted. The screening process included:

- Desktop analysis of soil data to identify areas of corrosive soils. While this data is very general in nature, it can provide an indication of where to look for corrosion impacts.
- Evaluation of other utilities near the force main to locate corrosion control systems in place, such as impressed current systems which could lead to stray currents.
In-situ analysis of soils and groundwater for pH and resistivity.

Close interval potential surveys (CIPS) to locate stray currents.

These inspections provide data on whether external corrosion could be present. Much like the acoustic systems, which identify gas pockets that could be sites for internal corrosion, these are screening tests. These inspections lead the inspection program to areas along the pipeline where external corrosion damage is most likely to occur.

Based on the results of the preliminary soil evaluation screening, detailed soil analysis locations can determined and samples taken at the pipe depth. The soil samples should be analyzed for the following soil corrosivity indicators:

- Type of Soil (i.e., gravel, sand, etc.)
- Soil Condition (i.e., groundwater presence, disturbed, undisturbed, stratified at pipe depths or uniform, etc.)
- Specific Soil Resistance (Resistivity)
- Water Content
- pH value
- Redox Potential
- Content of calcium and magnesium carbonate or total alkalinity to pH
- Presence of Sulfides
- Chloride Ion Concentration
- Sulfate Concentration

**Acoustic Testing**

Acoustic testing was selected as a screening tool to identify the location of unvented high points along the project force mains. Several technologies are available for acoustic testing, and the free-swimming acoustic tool, SmartBall®, provided by Pure Technologies (PURE), was selected for this project. The SmartBall system is inserted into the live force main and has been extensively used with success on wastewater force mains.

The tool is typically inserted into the live force main through small taps, pump inspection ports, or check valves, and the force of the flow carries the acoustic sensor through the main. The sensor can detect the characteristic sounds of leaks and, more importantly for this project, the sounds of gas pockets. The gas pockets are an indirect but effective indication of a high point. Once high points are located, the sites can be exposed and either the external UST, MFL or BEM technologies deployed to determine if there is internal corrosion.

Detailed inspection plans were developed based on review of existing information (i.e. record drawings, flow information, and previous studies) and initial field data collection for each force main. In general, the plan identified the proposed insertion and retrieval points for the tool, monitoring locations, flow augmentation requirements, traffic control issues, and any other work required in preparation of the inspection.

**Acoustic Inspection Monitoring Locations**

To track the SmartBall during the acoustic inspection, sensors are mounted on the pipe at strategic locations along the force main. Most of the proposed sensor locations utilize existing ARV manholes, which provide
the necessary direct access to the pipe. In portions of the force main where there is no existing means to access the pipe, it was necessary to temporarily expose the pipe so that a sensor can be attached. On this project, vacuum excavation was used to excavate a small (1 foot diameter) hole down to the force main pipe and the sensor was mounted from the ground surface. This method is less disruptive and less time consuming than traditional excavation.

High groundwater can sometimes be an issue when mounting sensors. The sensor will not adhere to the pipe wall while under water. Once adhered to the pipe wall, however, the sensor can be submerged and still function normally. Many of the proposed sensor locations at existing ARV manholes were in areas of high groundwater and standing water was observed in these structures during the field investigation. Due to the speed at which the groundwater enters these structures, it was necessary to pump the water from these manholes immediately prior to sensor mounting.

**Flow Augmentation**

The free-swimming SmartBall uses the flow in the force main to propel the ball through the system. Typically, a minimum velocity of approximately 1.5 feet per second is required to keep the ball moving through the upslope portions of the force main. A velocity of 2 feet per second is considered preferable.

All of the project pump stations have VFD pumps and relatively small wet wells. The variable speed pumps allowed CFPUA to fine tune the amount of flow, and therefore the velocity, in the force main during the inspection. However, the typical influent flows at the pump stations were not sufficient to maintain the desired flow velocity in the force main for the duration of the test. The wet wells were too small to store enough water without causing multiple extended stops and starts during the inspection. Therefore, flow augmentation was necessary at all of the inspection force mains. We determined the amount of additional flow required to maintain an approximate 2 fps velocity and developed a detailed flow augmentation plan using available hydrants to provide the additional flow to the pump stations.

**RESULTS – FORCE MAIN INSPECTIONS**

The flow augmentation was successfully performed on all the force mains, and the average SmartBall velocity during the inspections was between 1.3 and 2.0 FPS. The SmartBall was successfully inserted, tracked and retrieved at each of the inspection force mains.

The acoustic inspection data for PS 12, PS 14, PS 34, and PS 35 was collected and analyzed. No leaks were detected during the acoustic inspections, but a total of 25 gas pockets were identified.

The apparent gas pockets were located along the pipe profile using the record drawings provided by CFPUA. The intent of this exercise was to determine the apparent reasons for the pocket's presence at each site, if possible, and to identify an optimal location, or series of locations for conducting additional local testing of the force main pipe.

Many of the gas pockets identified, particularly on PS 34 and PS 35 force mains, are located in portions of the force main that were previously lined or replaced with PVC. There were two previous failures related to internal corrosion on PS 34 and approximately 2,700 feet of severely corroded DIP identified during adjacent construction work. Both areas have been subsequently replaced with PVC. All 8 gas pockets identified on PS 34 were in these areas. Although no additional testing for corrosion is necessary where the force main has been replaced with PVC or lined, the results provide confirmation that trapped gas was the likely cause of the internal corrosion found in this area and, more importantly, that the most likely locations for internal corrosion on PS 34 have been addressed.

**RECOMMENDATIONS**

Based on the findings of the acoustic testing, recommendations were presented to CFPUA to conduct local investigation at selected locations. Local testing sites were selected based on the gas pocket locations,
significance and accessibility. We recommended local wall thickness testing with an external BEM technology at 6 sites where gas pockets were identified. Soil sampling and analysis was also recommended at 3 of the BEM sites based on results of the external corrosion potential screening. Alternatively, CFPUA may decide that it is preferable to schedule the segment for rehabilitation or replacement rather than performing a local inspection either due to program costs or the age, history or criticality of the pipeline segment.

CONCLUSION

Without yet collecting extensive condition assessment data, the information provided by the criticality analysis, field inventory and acoustic inspections enables CFPUA to confidently proceed with three simultaneous courses of programming for force mains:

- Some critical segments of older force mains are being scheduled for replacement in lieu of additional expenditures on condition assessment for these mains.
- Several force mains have ongoing or planned projects for repairs or rehabilitation of previously identified deficiencies. In some cases, the projects are being expanded to address areas where anomalies were identified by acoustic inspection.
- Other force main segments are being programmed for additional investigation or future re-inspection.

CFPUA now has a GIS-based Criticality Assessment Model (CAM) that allows them to prioritize force mains for inspection at whatever frequency fulfills ongoing level of service objectives. The force main assessment program enables system managers to make informed decisions regarding force main re-inspection, repair, rehabilitation and replacement. Courses of action for the prioritized mains may proceed from acoustic inspection to external inspection to in-line inspection, if technically and economically feasible. The decision may be made, however, to proceed directly with programming for rehabilitation or replacement of a particular main or segment based on anticipated inspection costs and other factors such as age, criticality and failure history. The result is an integral program for making prudent decisions about how to most effectively invest inspection and rehabilitation funds into the force main system to support level of service objectives including protection of public health and the environment through reduced potential for wastewater spills.

REFERENCES