

APPLICATION OF ACOUSTIC INSPECTION TECHNOLOGY FOR TWO RIVERS UTILITIES' COLLECTION SYSTEMS

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ABSTRACT

Municipal wastewater utilities struggle to effectively manage the vast underground network of pipes that handle the conveyance of raw sewage through our nation's cities and towns. Operators must constantly balance a variety of challenges that negatively affect the success of the system including an aging infrastructure, high operation and maintenance costs, and sanitary sewer overflows (SSOs). Current maintenance operations target system cleaning based on a best guess approach using past performance and system knowledge. Excessive cleaning means cleaning pipe segments which do not need to be cleaned. This incurs both the immediate cost of wasted cleaning resources and the more subtle cost of future pipe maintenance due to over-cleaning.

A novel acoustic inspection device has been developed for rapidly assessing sewer line blockages in three minutes or less. Two Rivers Utilities (Gastonia, NC) has developed a research project with InfoSense, Inc. to make use of this inspection technology. The objective of the project is to develop a best practice approach for integrating the Sewer Line Rapid Assessment Tool (SL-RAT™) into the maintenance program to cost effectively enhance cleaning operations. The project will result in the development of best practice information on (1) how to effectively use the SL-RAT, and (2) how to adapt their current program in order to effectively use blockage assessment data for cleaning operations.

The project plan is based on a three stage process: Stage One - Acoustic Inspection Planning, Stage Two - Intensive Acoustic Inspection and Stage Three - Sustained Acoustic Inspection. This is a six month project, which will result in the initial inspection and characterization of the targeted sewer lines, followed by a sustained measurement campaign. Results of this work will be presented, along with discussion of the best practice approaches developed to help Two Rivers Utilities manage their collection system more efficiently and effectively through the use of acoustic inspection technology.

KEYWORDS

Sewer line inspection, wastewater operation management, pipe blockage assessment, collection system cleaning, condition based maintenance, acoustic pipe inspection.

INTRODUCTION

Motivation

Two Rivers Utilities was formed in July 2011 when the municipalities of Gastonia and Cramerton North Carolina combined their separate water and wastewater systems into one integrated entity. Two Rivers now serves almost 26,000 locations located primarily in the central part of Gaston County through a network of 550 miles of gravity fed sewer pipe. Much of the existing sewer pipe was installed during the region's textile heyday starting in the early 1900's and is composed of a variety of materials – approximately 75% VCP, but also including ductile iron, PVC, and asbestos cement.

Two Rivers employs approximately 120 employees with 55 people in wastewater collection services including one camera crew and three cleaning crews. Each year, approximately 150 miles of pipe is cleaned – all by water jetting. The camera crew inspects in the neighborhood of 10 miles per year and additional manhole inspections are conducted semi-annually during mowing operations on an additional

100 miles of pipe located off-road. Contractors are used rarely and typically only to provide specialized services.

Two Rivers has experienced a substantial reduction in collection system-related SSO's over the past six years. This improvement has been accomplished through a variety of activities including:

1. Developing a proactive maintenance culture and a preventive maintenance scheduling program based heavily on accurately tying work orders to specific assets.
2. Exploiting the use of the City of Gastonia's asset management system to institutionalize knowledge about collection system assets. The asset management system allows Two Rivers to document historical and operational details for scalable decision-making – rather than relying on “tribal knowledge”.
3. Embracing technology and exploiting its use – including the ability to widely share CCTV data after implementing a new digital video storage system in 2007.
4. Expansion of the FOG program to include plan reviews in the early 2000's.

Finally, good working partnerships across departments – including engineering and construction – have allowed the collection system maintenance crew to work together when identifying and prioritizing problem areas. Two Rivers collection system related SSO's/100 miles versus the percent of pipe cleaned since 2006 is graphed in Figure 1.

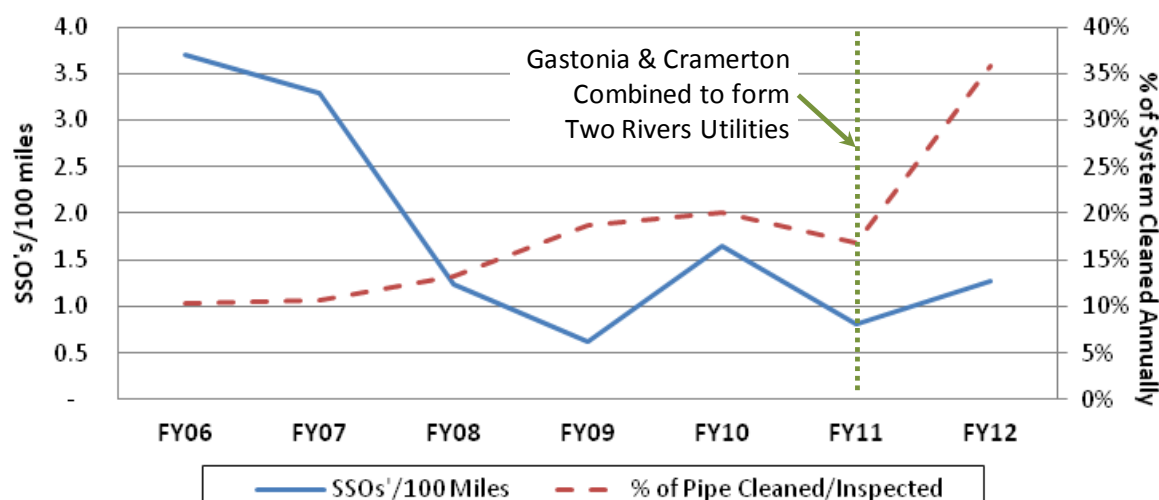


Figure 1 Two Rivers Utilities SSO incident rate and sewer pipe line cleaning history estimates for fiscal year 2006 to 2012.

In an effort to expand upon their excellent historical performance, in late 2011 Two Rivers began evaluating the possibility of using InfoSense's Sewer Line Rapid Assessment Tool in a pilot project. The utility maintenance team saw the technology as a good fit for Two Rivers. The SL-RAT's ability to quickly provide blockage assessments on hundreds of thousands of feet of pipe could act as a pre-cleaning assessment tool. And, ultimately as a force-multiplier to better focus their limited cleaning crews toward cleaning those pipes that were truly dirty.

Two Rivers Utility Pilot Project Objectives

The Two Rivers Utility pilot project was designed to address two questions: (1) how to effectively use the SL-RAT, and (2) how to adapt their current program in order to effectively use blockage assessment data for cleaning operations. To address these two questions – the objectives of the project where:

1. Assess the ability of the SL-RAT acoustical tool to
 - a. Reveal a state of partial obstruction in a pipe segment,
 - b. Define the progression of partial to complete obstruction for a pipe segment, through comparing historical acoustic inspection measurements.

2. Establish the suitability of the SL-RAT acoustical inspection tool for Two Rivers Utility to realize operational efficiency while maintaining or improving their operational performance, i.e., prevent system failures
 - a. Economically identify pipe segments requiring maintenance (prioritization aid, failure prevention method),
 - b. Establish optimal maintenance cycles (sustainable failure prevention).

METHODOLOGY

Acoustic Inspection – SL-RAT Operation

The sewer-line rapid assessment tool (SL-RAT™) exploits the similarities and differences between water and sound transmission through a sewer line segment in order to diagnose the extent of the pipe's blockage. This novel, patented methodology (Howitt 2009) is based on measuring the signal received from an active acoustic transmission through a segment. Figure 2 depicts the general configuration of the SL-RAT device. The acoustic transmitter generates sound waves just below the entrance to the manhole which naturally couple into the connecting sewer line segments, whether the depth of the manhole is 3 feet or greater than 20 feet. The sound wave propagates in the air gap above the wastewater flow from the speaker to the receiving microphone located at the adjacent manhole. Segment lengths exceeding 700 feet have been successfully evaluated. The acoustic receiver measures the acoustic plane wave from the transmitted signal in order to evaluate the condition of an entire segment and provides an onsite assessment in less than three minutes. An important practical aspect of the SL-RAT is that both the speaker and the microphone are placed just within the opening of the manhole and never come in contact with the wastewater flow and the operators have no requirement for confined space entry.

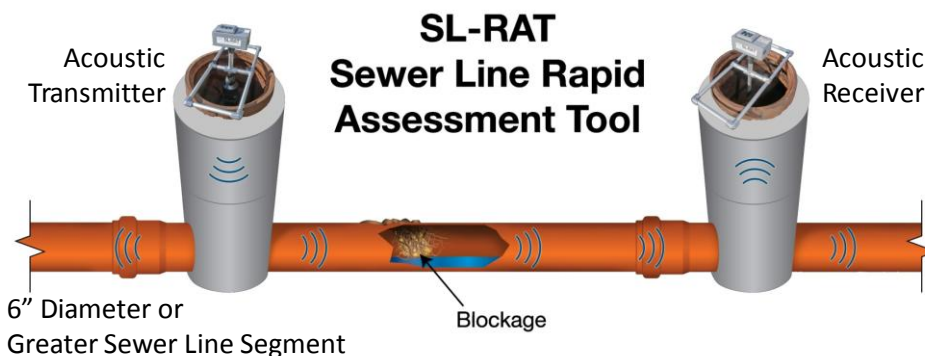


Figure 2 Concept and operation of the SL-RAT Acoustic Inspection System.

A pipe segment is a natural acoustic waveguide (Philip 1968). As illustrated in Figure 2, commonly encountered sanitary sewer defects, such as roots, grease, pipe sags and pipe breakages naturally absorb or reflect acoustic energy. These defects change a segment's acoustic properties and produce a measurable impact on the received signal at the microphone, i.e., the segment's acoustic fingerprint (SAF). Each segment has an individual SAF representative of its current state. The SAF changes over time as the condition of the segment varies. The SL-RAT uses the SAF to determine the SL-RAT Blockage Assessment, i.e., an estimate of the aggregate blockage within the pipe segment between the acoustic transmitter and acoustic receiver. The aggregate blockage assessment is provided to the operator at the end of each test on a scale from 0-10 with zero indicating complete blockage and ten indicating an essentially clean segment. Using the blockage assessment, the operator can determine whether or not maintenance is needed.

Condition Based Maintenance Program

Maintenance policies for wastewater collection systems' cleaning operations are currently a combination of fixed interval maintenance, i.e., Time-Based Maintenance (TBM) and reactive maintenance, i.e., Corrective Maintenance (CM). Figure 3(a) illustrates the optimal region of application for each strategy. The horizontal axes represents the remaining time to failure with values decreasing towards the right. The

vertical axis represents the relative risk and the cost associated with a pipe segment overflow. To illustrate, vandalism can lead to overflows, e.g., dumping leaves in a manhole. Since vandalism is an unlikely event and the time to failure is short, a CM program is the only option. A TBM program is appropriate in areas where periodic cleaning interval is required and can be reliably estimated, e.g., areas with high grease restaurants. In these areas there is a high risk and the time interval to failure can be predicted. A preponderance of grease and root blockages occur over a sufficiently long time interval, suggesting a CBM program is optimal. From Wiseman et. al.,

“Condition based monitoring is defined as: an identifiable physical condition which indicates that a functional failure is either about to occur or in the process of occurring. In this process, the items are inspected and left in service on the condition that they meet specified performance standards. The frequency of these inspections is determined by the potential failure (P-F) interval, which is the interval between the emergence of the potential failure and its decay in to a functional failure.”

Developing an overall maintenance policy that balances the maintenance strategies is the goal of Reliability Centered Maintenance (RCM) (Moubray 1997). RCM allocates cleaning resources based on optimizing the cost and risk associated with overflows.

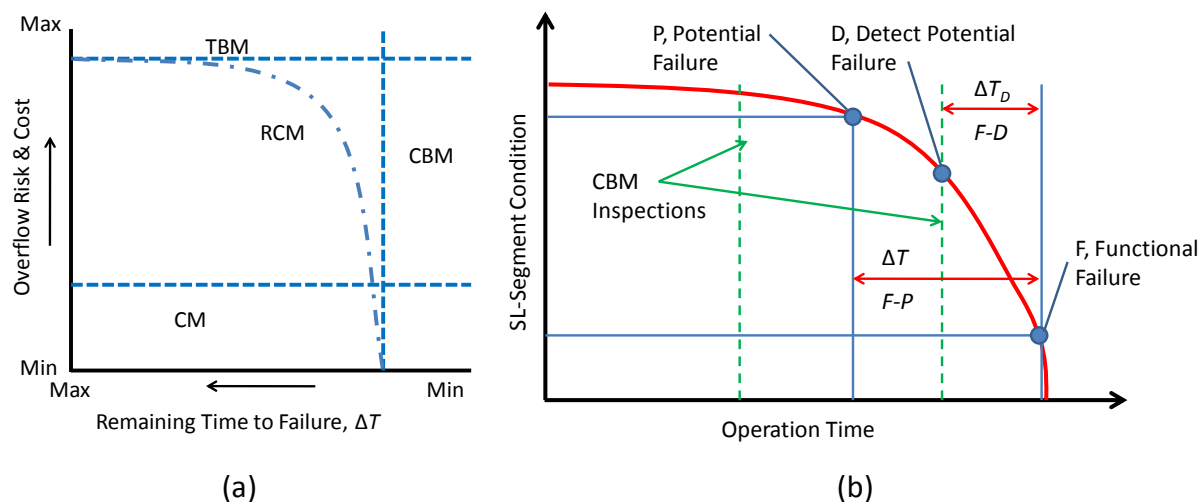


Figure 3 (a) Regions of optimal application for four maintenance strategies (Lehtonen 2006); (b) Relationship between inspection and P-F in a CBM based maintenance strategy (Moubray 1997 and Wiseman et. al.).

Historically, using condition based inspection to determine where and when to deploy collection system cleaning resources has not been economically feasible. The available inspection technologies are either cost prohibitive or provide inadequate information. The SL-RAT acoustic inspection equipment provides a clear condition assessment directly correlated with the cleaning requirements (Howitt 2010). Acoustic inspection requires significantly fewer resources compared to normal maintenance, i.e., SL-RAT acoustic inspection has been shown to be less than 1/10th the cost of cleaning (CMU 2011, CMU 2012). This provides the opportunity to rethink using condition based maintenance as a viable tool for deploying cleaning resources. This approach can improve maintenance quality, reduce unnecessary maintenance operations and, at the same time, reduce costs.

Approach

To meet the objectives of the project, selecting the target area within the Two River Utility's collection system for the pilot project was critical. The project team chose the heavily developed shopping center area to the east of downtown Gastonia called Franklin Square. This area was built primarily in the 1990's and is composed of a multitude of businesses including most major big box retailers and a variety of major chain restaurants and consumer product stores. Due to its highly visible nature and importance to the local community, the Franklin Square area is on a time based maintenance (TBM) schedule and has

been cleaned on a semi-annual basis since 2010, see Figure 4. The timing of the pilot project coincided with the next regular scheduled maintenance cycle for Franklin Square. In addition, based on operator feedback, there was an expectation that at least a portion of the approximately 12,000 feet of sewer pipe within Franklin Square was being over-cleaned based on the current six month preventative maintenance (PM) program.

The approach for the pilot project was the following:

1. Use the SL-RAT to acoustic inspect the sixty pipe segments within Franklin Square.
2. Based on the acoustic inspection blockage assessment, CCTV any segment indicating the pipe segment is significantly blocked. The blockage assessment threshold used to trigger CCTV was any score of five (5) or less.
3. Again, based on the acoustic inspection blockage assessment, only schedule cleaning maintenance on those segments within Franklin Square with scores of 5 or less.
4. Repeat acoustic inspection at regular time intervals as depicted in Figure 4. Note, these time intervals for acoustic inspection were intentionally selected to be very short in order to enhance characterizing each pipe segments P-F curve as illustrated in Figure 3(b).
5. Based on the repeat acoustic inspection, follow the same CCTV and cleaning protocol outlined in steps 2 and 3.

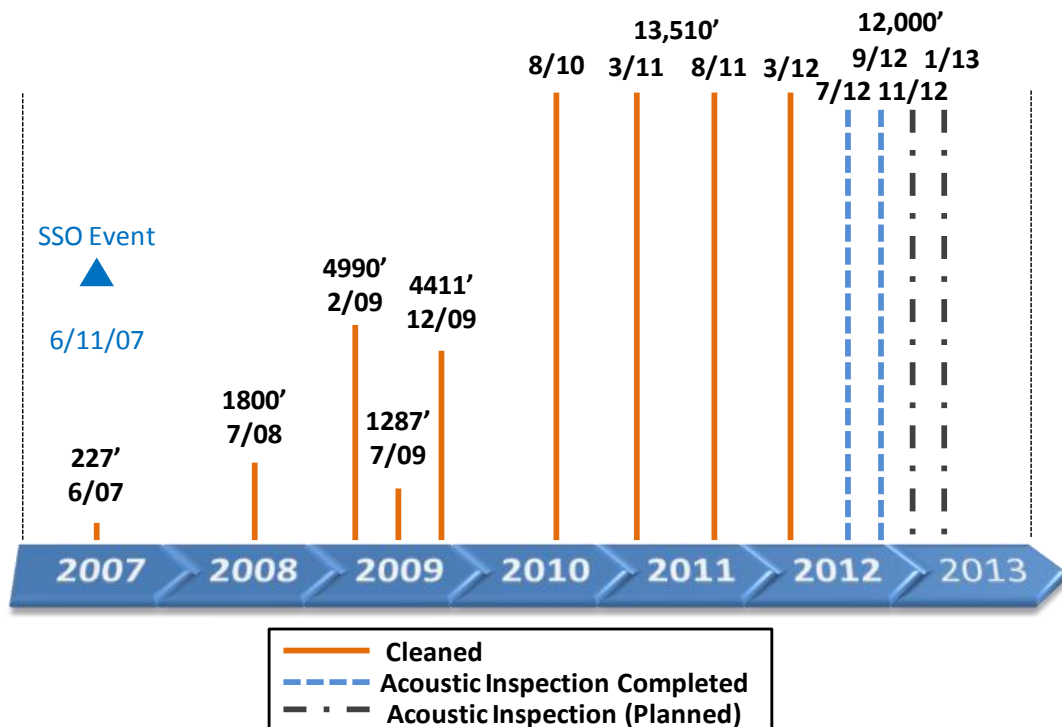


Figure 4 Two Rivers Utilities five year preventative maintenance schedule for the Franklin Square area - periodic maintenance schedule adopted in 2010 and SL-RAT acoustic inspection initiated in July 2012 to establish frequency and scope for periodic maintenance.

ACOUSTIC INSPECTION RESULTS

Preliminary results for the Two Rivers Utilities pilot project are presented in this section. To date, two of the four acoustic inspection measurement campaigns of Franklin Square have been conducted. Based on the preliminary SL-RAT blockage assessments collected, significant findings can be established as are evident from the results presented in this section and as further explored in the Discussion section.

The Franklin Square collection system was divided into three phases – Phase 1 through Phase 3. Blockage assessments, based on the acoustic inspection, are depicted in Figure 5 for Phase 1. The measurements are overlaid on to the Two Rivers Utility's GIS collection system map. The two measurement campaigns conducted are indicated for each segment with the value on the left indicating the assessment measured on July 11th and the one on the right measured approximately two months later on September 5th.

As discussed in the Approach section, segments with an acoustic blockage assessment of 5 or less would be investigated further using CCTV and if warranted would be cleaned. As can be observed from the results in Figure 5, all segments within the Phase I collection system registered above the predetermined CCTV/cleaning threshold, with the exception of one measurement with a blockage assessment of 3 on July 11th and 4 subsequently on September 5th. This measurement involved skipping over a buried manhole. Therefore, the measurement was due to the combined blockage assessment through two pipe segments. From the results, the system operator inferred that a blockage did not exist. The measurement of 3/4 was likely substantially lower than either segment might have individually measured if the buried manhole were not skipped. This lower result is typically caused by the additional coupling losses introduced by the acoustic signal passing through the intermediate manhole chamber. The Two Rivers Utility maintenance team made the determination to take no additional maintenance action, i.e., CCTV nor Cleaning, on these pipe segments.

One pipe segment within Phase 1 did stand out. During the planning stage for the pilot project, the Two River Utility maintenance team indicated the pipe segment tagged in Figure 5 was a known problem with its blockage captured on CCTV well before the start of the pilot project, Figure 6(a). The initial July 11th acoustic blockage assessment indicated the pipe segment was essentially clean (blockage assessment of 9). The reaction to this contradictory acoustic inspection was to reassess the blockage using CCTV. The CCTV conducted after the acoustic inspection confirmed the SL-RAT assessment and as depicted in Figure 6(b) the earlier blockage had cleared.

The results for the acoustic inspection blockage assessment for Franklin Square Phase 2 and Phase 3 are depicted in Figures 7 and 8, respectively. Within Phase 2 and 3 only a single pipe segment was measured with a blockage assessment of 5. All other pipe segments exceeded the CCTV/Cleaning threshold, indicating no additional maintenance was required. The Phase 2 pipe segment with blockage assessment of 5, Figure 7, was based on skipping an intermediate manhole. Therefore, the measurement was due to the combined blockage assessment through two pipe segments. One of the two segments was assessed at 6 and the combined pipe segments assessment was 5. From this, it was inferred that the second pipe segment was estimated to have an assessment greater than 5, if it had been measured directly. This estimate was confirmed during the September measurement campaign. Two additional manholes were skipped during the July measurement campaign, one each in Phase 2 and 3. The blockage assessment for these two measurements was 6 and 7, respectively.

Based on the July and September measurement campaign, the decision was made to delay the scheduled six month cleaning of the Franklin Square collection system until at least the results of the November acoustic measurement campaign are obtained.

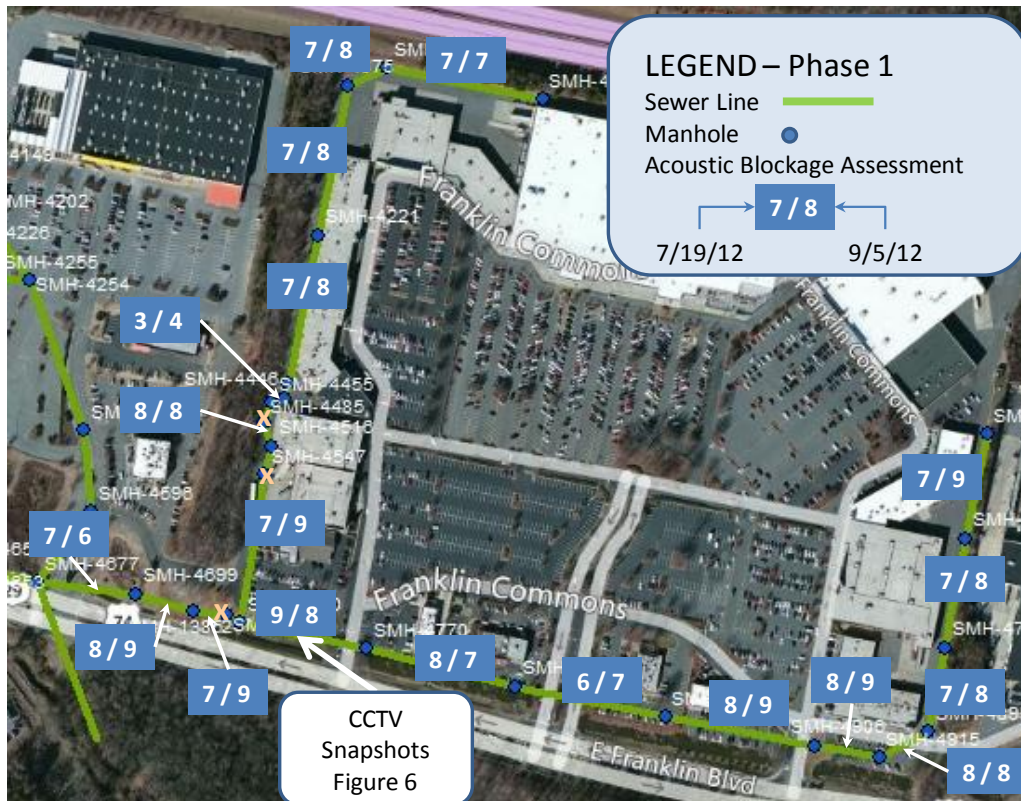


Figure 5 Acoustic inspection blockage assessment results for both the July 11, 2012 and the September 5, 2012 measurement campaign for the Franklin Square Phase 1 collection system.

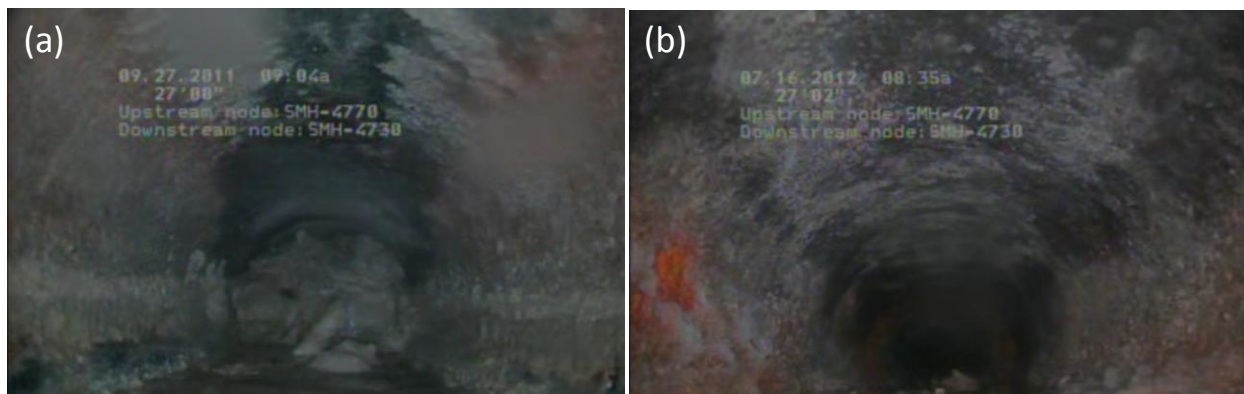
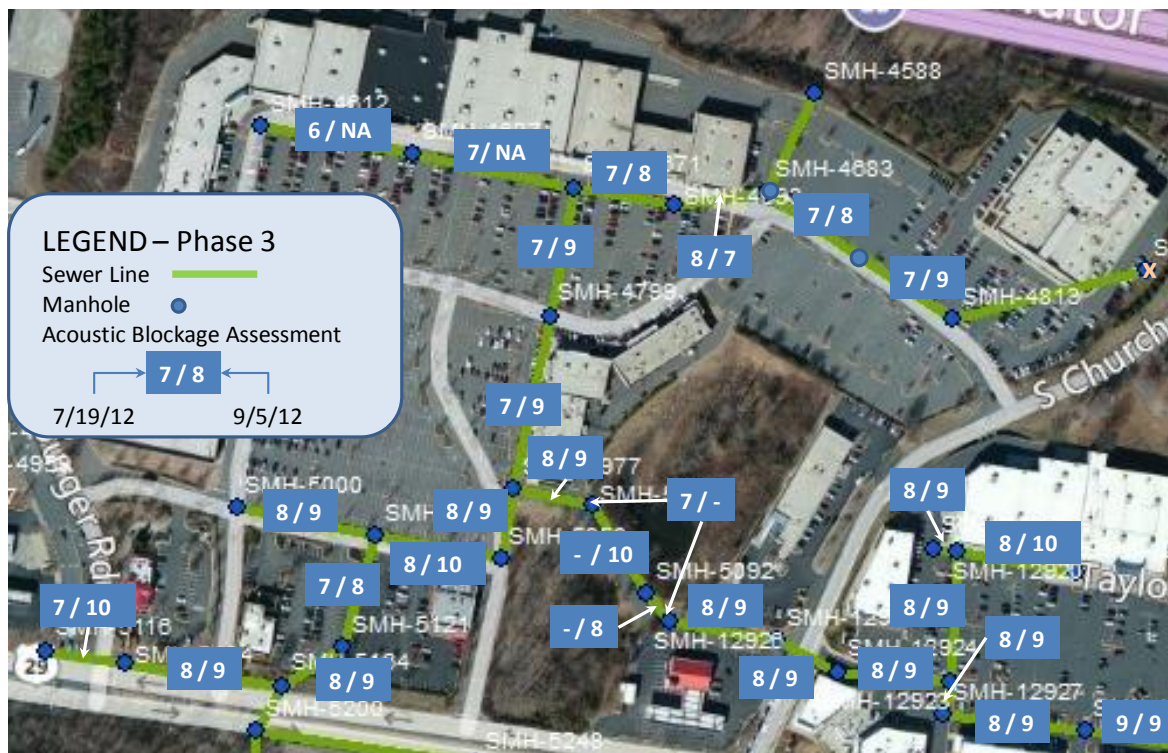
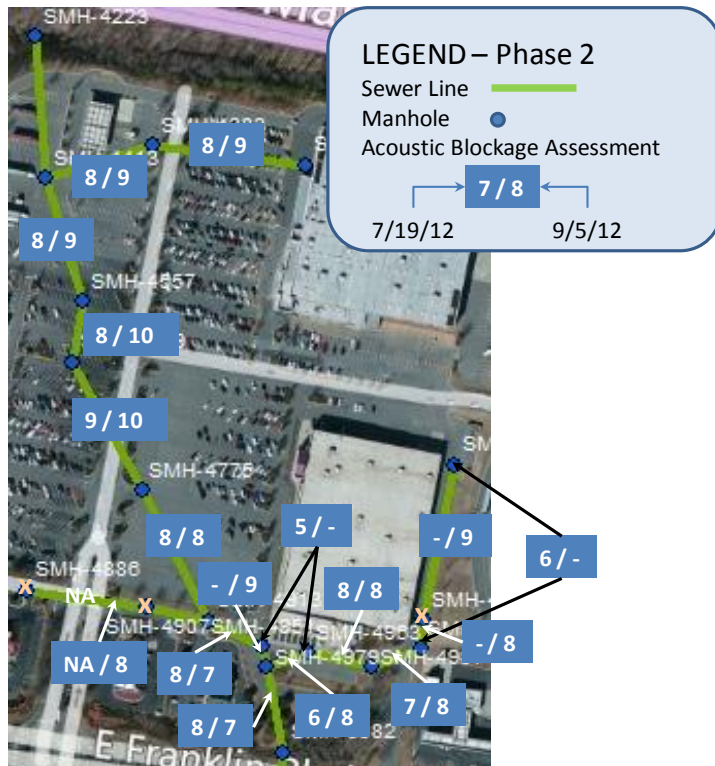


Figure 6 In (a), CCTV assessment prior to the pilot project indicated pipe segment acoustic inspection blockage assessment should be zero or near zero, due to significant pipe obstruction. Initial acoustic assessment indicated pipe was substantially unblocked based on assessment of 8. Subsequent CCTV, (b), revealed blockage had been cleared.



DISCUSSION

Evaluating Franklin Square Time Based Maintenance Cycle

Evaluating the effectiveness of using acoustic inspection to facilitate establishing maintenance schedules is under investigation as part of the pilot project. The current Franklin Square collection system PM incorporates a six month time based cleaning program. Based on the acoustic inspection to date, the scheduled PM cleaning program has been delayed by at least 4 months. In Figure 9(a), the distribution for the blockage assessment is graphed for both the July and September measurement campaigns. In Figure 9(b), the distribution for the change in individual pipe segments blockage assessment is graphed. It is clear that there is an overall general improvement in the acoustic blockage assessment from July to September. This improvement is likely due to variations in debris in the pipe segments due to variations in weather events and variations in the usage patterns for the Franklin Square collection system. As additional acoustic inspection data is collected, trends in the blockage assessment will be used to establish cleaning priorities within Franklin Square. As illustrated in Figure 3(b), the acoustic inspection data trends will be used to refine both the frequency for the cleaning cycle as well as the acoustic inspection. The current acoustic inspection trends suggest both the six month cleaning cycle and two month acoustic inspection cycle are excessive.

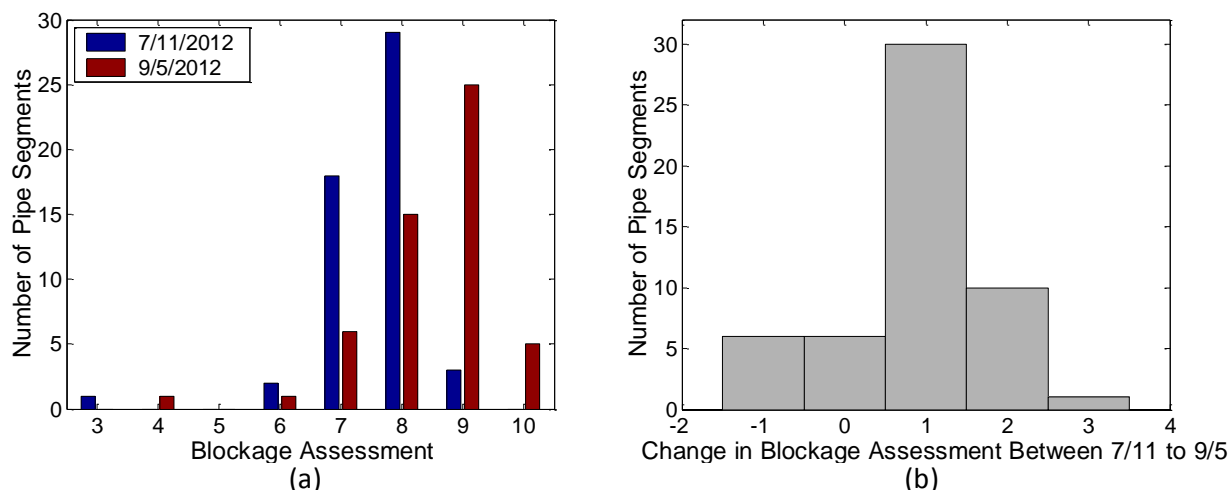


Figure 9 (a) Blockage assessment histogram. (b) Change in the acoustic inspection blockage assessment between the July and September measurement campaigns.

Acoustic Inspection Productivity Assessment

Economic feasibility of the SL-RAT acoustic inspection was evaluated based on measuring the productivity achieved during the Franklin Square pilot project. Each SL-RAT device has a GPS unit providing both map grade location information and date/time stamp for each measurement. The date/time stamp was used to evaluate the productivity and to estimate the time required for newly trained operators to achieve proficiency with using the SL-RAT. The total time required to conduct an acoustic inspection was evaluated where the total time includes: the measurement setup time, travel time between manhole locations and the actual time to conduct the measurement (1.5 to 3 minutes). Table 1 summarizes the productivity for the Franklin Square pilot project. The initial measurement campaign was conducted over the two mornings of July 11th and 17th. On July 11th, the Two Rivers field operators were trained to operate the SL-RAT. InfoSense conducted the Two Rivers operator training as they conducted the measurement campaign and the productivity times in Table 1 include the time required for training. Both the July and September measurement campaigns were conducted by the newly trained Two Rivers operators with minimal to no oversight by InfoSense. Figure 9 depicts the distribution of the total time required to conduct the acoustic inspections based on the combined July and September measurement campaigns. Two key observations are made:

1. With approximately 12,000ft of pipe inspected in 4 to 5 hours, the SL-RAT is an efficient tool for implementing condition based maintenance program, e.g., the cost of acoustic inspection is significantly less than the cost of alternative maintenance actions (CCTV or Cleaning).

2. With 80% of the total measurement times (setup/travel/inspection time) taking 5 minutes or less and with over 95% of the total measurement times taking 9 minutes or less to conduct, the newly trained Two Rivers operators achieved a high proficiency level in less than two days of using the SL-RAT.

Table 1 Summary of the Acoustic Inspection Productivity for the Franklin Square Pilot Project

	July 11 & 17	September 5
Approx. # Pipe Segments (# Feet)	60 segments (12,000 feet)	60 segments (12,000 feet)
Total Time Minutes (Hours)	311 min. (5.2 hours)	273 min. (4.5 hours)
Segments / Hour (Feet / Hour)	11.6 segments/hr (2319 ft/hr)	13.2 segments/hr (2639 ft/hr)

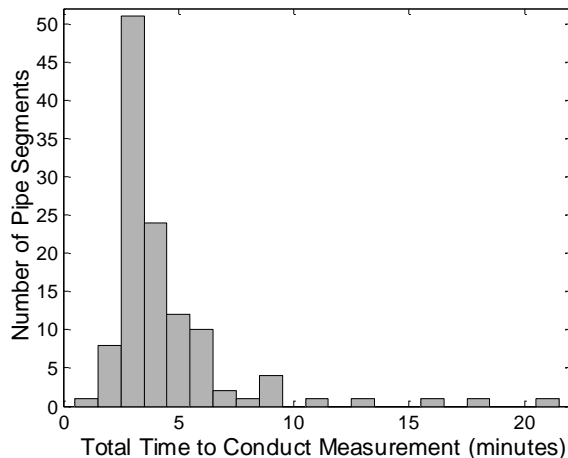


Figure 10 Distribution for the total time required to conduct an acoustic inspection including the setup time, travel time between manholes and the actual inspection time.

CONCLUSIONS

The SL-RAT is a novel acoustic inspection device developed to both effectively and efficiently assesses sewer line blockages, providing essential information for condition based maintenance planning. The preliminary results from the Franklin Square pilot project undertaken by Two Rivers Utilities in conjunction with InfoSense suggest:

1. For regions within a collection system requiring a periodic PM program, it is straight forward to incorporate acoustic inspection by substituting the more cost effective acoustic inspection for cleaning.
2. Acoustic inspection can cost effectively assists in establishing both the periodic PM cleaning maintenance cycles and the periodic acoustic inspection cycle.
3. Field operators can rapidly be trained to utilize the SL-RAT and achieve a high productivity level within a very short time interval. Training can be conducted while on the job.

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