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CASE STUDY

PILOT ACOUSTIC CONDITION ASSESSMENT OF WATER DISTRIBUTION SYSTEM, WASHINGTON SUBURBAN SANITARY

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CASE STUDY: CONDITION ASSESSMENT

PILOT ACOUSTIC CONDITION ASSESSMENT OF WATER DISTRIBUTION SYSTEM, WASHINGTON SUBURBAN SANITARY COMMISSION (WSSC), MARYLAND

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- Mr. John Marciszewski, Echologics LLC Division of Mueller Co., Atlanta, Georgia

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CASE STUDY SUMMARY

From March 12, 2012 to March 21, 2012, Echologics LLC, Division of Mueller Co, was contracted by GHD to survey approximately 17,500 feet of distribution mains for Washington Suburban Sanitary Commission (WSSC). This pilot project was initiated to fulfill three main objectives – 1) Calibrate the developed Asset Management (AM) desktop model, 2) Ascertain the criticality of the pipes scheduled for replacement based on the predictions of the asset management model, and 3) Evaluate the Echologics proprietary acoustic condition assessment technology. A comprehensive test protocol was established for this pilot project. The AM desktop model was first used to determine the worst condition pipelines and schedule replacements. The next step was to use Echologics' proprietary acoustic Pipe Integrity Testing (PIT) to survey selected segments of the pipelines scheduled for replacement followed by ultrasonic testing, in-field inspection, surrounding soil sampling and forensic analysis of randomly pulled pipe sections. Echologics' proprietary acoustic PIT predicted that almost 70% of the pipes being replaced based on asset management model predictions were not in need of replacement, including almost 40% that were at or near original condition. The results of other tests validated these predictions.

KEYWORDS

Break rate, condition rating, Asset Management (AM) model, remaining wall thickness, Pipe Integrity Testing (PIT) technology, coupon samples, condition assessment accuracy, cost-benefit analysis

LIST OF ACRONYMS

AM	Asset Management
CA	Condition Assessment
MGD	Millions Gallons per Day
NDT	Non Destructive Testing
PIP	Pipe Inspection Program
PIT	Pipe Integrity Testing
UT	Ultrasonic Testing
WSSC	Washington Suburban Sanitary Commission

UTILITY DETAILS

NAME

Washington Suburban Sanitary Commission

The WSSC logo and link can be found below.

Figure 1: WSSC logo

Link: http://www.wsscwater.com/home/jsp/home.faces

SERVICE AREA

WSSC serves Prince George and Montgomery counties of Maryland. The service area covers nearly 1,000 square miles.

SIZE AND BUDGET

The Washington Suburban Sanitary Commission is amongst the largest water and wastewater utilities in the United States. The utility services approximately 1.8 million residents and about 460,000 customer accounts. WSSC employs approximately 1,700 people. WSSC has an operating budget of approximately $1.4 billion for Fiscal year 2014; $742 million of the budget is being used in capital while $699 million is being used in operations. The pipeline replacement budget for Fiscal 2014 is approximately $70 million.

ASSETS

WSSC operates and maintains three reservoirs with a total holding capacity of 14 billion gallons, two water filtration plants with a combined average drinking water production of 167 million gallons per day (MGD), seven wastewater treatment plants with a total capacity to handle 74.1 MGD wastewater, nearly 5,500 miles of water main, and nearly 5,400 miles of sewer pipeline. The utility also has its own laboratory that performs approximately 500,000 tests to meet/ensure water safety and quality standards.

Mission Statement

"We are entrusted by our community to provide safe and reliable water, life's most precious resource, and return clean water to our environment, all in an ethically and financially responsible manner."

CASE STUDY FOCUS

This case study focuses on the pilot study, completed by WSSC, to evaluate the cost-benefit of using Echologics' proprietary acoustic-based condition assessment technology to validate and improve the pipe condition scores generated by the in-house asset management model. In addition, this case study also covers WSSC's comprehensive Pipe Inspection Program (PIP), used to establish the criticality of the distribution mains prior to making rehabilitation and/or replacement decisions

ASSETS CONSIDERED IN THE WORK

This case study concerns approximately 17,500 feet of water distribution pipes located within the control limits of WSSC. The pipes are made of cast iron and spun iron and range in diameter from 6 inches to 12 inches.

KEY DRIVERS

GHD developed an asset management plan for WSSC's water distribution system which established that WSSC should replace about 55 miles of bad pipe per year, for the next 40 years, to maintain its level of service. An AM desktop model was developed to assess the current condition of the pipes, and thereby determine critical pipes that need replacement or rehabilitation. The following pilot project was initiated to validate and calibrate the AM model, and to establish if Echologics' acoustic-based condition assessment technology is a cost effective option to validate the predictions of the model prior to all rehabilitation projects.

KEY FEATURES OF THE WORK

This project features the condition assessment pilot test procedure used by WSSC to calibrate their asset management model and the eventual analysis that led to the formation of a PIP for all future rehabilitation projects.

Technology Information

Echologics' LeakFinderRT™

LeakFinderRT, an Echologics' proprietary noise correlator technology, is used to detect leaks in pipes. Two sensors are generally mounted on fire hydrants, air valves, blow-offs or corporation stops to bracket a leak as shown in Figure 2. These sensors passively listen and record the noise created by the leak. The leak noise takes longer to arrive at point 1 than at point 2. The correlator measures this difference and determines the exact location of the leak.

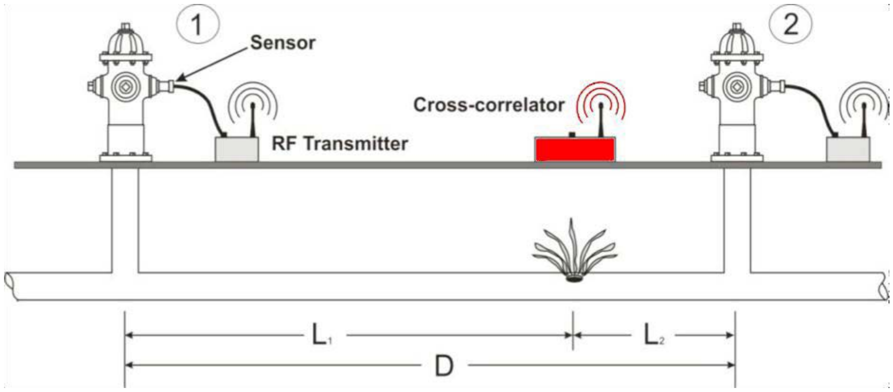

Figure 2: LeakFinderRT field set up

Echologics' Acoustic-Based Pipe Wall Integrity Testing

Echologics' proprietary acoustic PIT measures the remaining wall thickness of pipelines, which provides an accurate indication of their remaining life. When a low-frequency, non-dispersive, axi-symmetric acoustic pressure wave is induced in a pipeline, it causes the pipe wall to flex on a microscopic level. This facilitates the wave to travel through the pipe. The thicker the pipe wall the more resistant it is to this breathing and hence causes the wave to travel faster. By accurately measuring the velocities of these acoustic signals, the PIT technology calculates the remaining wall thickness.

To accurately measure the speed of sound, PIT introduces acoustic signals into the pipe. These signals are generated by physically tapping on fitting, flowing water from a fire hydrant, or using vibro - mechanical shakers which induce specific frequencies. Echologics' LeakFinderRT equipment is used to measure the time it takes for the acoustic signal to reach each sensor. The signal velocity is calculated using this measured time delay and the distance between sensors. Figure 3 shows the field set up for PIT.

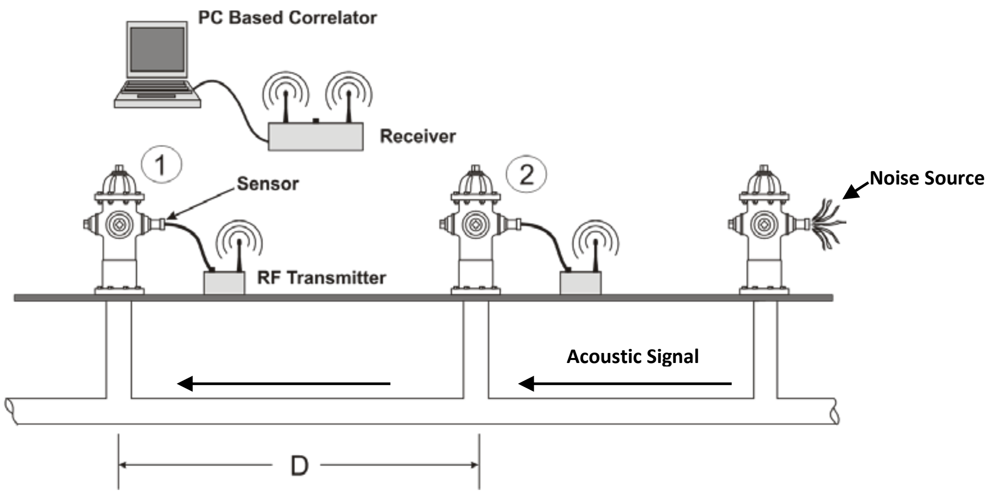

Figure 3: Pipe Integrity Testing field set up. The wave propagation velocity **(v) = D/ΔT where ΔT is the time delay between signals measured at sensor 1** and sensor 2.

The remaining wall thickness of the pipe section is calculated by using the measured velocity to solve the appropriate version of the water hammer equation (Figure 4).

$$v = v_o \sqrt{\frac{1}{[1 + (D/e)(K_{water}/E_{pipe})]}}$$

Figure 4: Water Hammer Equation in its simplified form

Where:
V = propagation velocity of leak noise in pipe
V_o = propagation velocity of sound in an infinite body of water
D = internal diameter of pipe
e = thickness of pipe wall
K_{water} = bulk modulus of elasticity of water
E_{pipe} = Young's modulus of elasticity of pipe material

Advantages

- Non-destructive, non-invasive and non-disruptive technology
- Low cost
- Provides minimum structural wall integrity over a segment length of pipe
- Good survey level accuracy but not high precision for localized corrosion
- Can cover up to 1 mile per day with one crew
- Leak detection can be performed simultaneously using the LeakFinderRT correlator
- The pipe needs to be pressurized to perform the velocity measurements, hence it need not be removed from service

- Can be included in engineering risk models to prioritize pipes for replacement or rehabilitation

Limitations

- The PIT method provides a minimum average value of the remaining wall thickness over the length of the pipe. Any of the following descriptions will hold true for a pipe with 10% measured loss:
    - Uniform loss of 10% throughout the entire length around the entire circumference
    - Uniform loss of 20% throughout half of the length around the entire circumference
    - Uniform loss of 10% throughout the top half of the entire length of pipe
- When dimensional, material or lining data of the pipeline are not available, PIT technology cannot provide an absolute thickness. However, reasonable pipe properties can be assumed based on historical data and the pipes can be ranked by their comparative thickness.
- Requires the section being tested to be fairly homogenous without any unknown transitions or plastic repairs. Pipes should all be the same diameter in the segment tested but up to 5% of the length in another diameter can be accounted for in the calculation. Pipes can also be tested with a concrete lining, i.e., non-homogeneous. Additionally, unknown valves and transitions will have a negligible impact on the end result as long as they are not closed.
- Recognition of high levels of localized degradation in pipes might be missed, as PIT calculates minimum average remaining thickness values over defined lengths
- In case of composite pipes, the PIT technology does not indicate if the thickness loss is in the pipe or the lining. The concept of effective thickness is used to perform measurements on composite pipes. Effective thickness of the pipe is the additional host material that should be added to the pipe to restore its stiffness on removing the lining.

Asset Management Model

In the past, WSSC used pipe break rate trends along with the information of pipe age and material to select the worst performing pipes for replacement. Presently, WSSC uses an AM model to predict the current condition of the pipelines.

The AM model uses the following methodology to prioritize pipelines for replacement:

- AM model calculates mathematical decay curves for pipes using the following factors:
    - Construction year
    - Rehabilitation date
    - 15 year break history
    - 5 year break history
    - Lining presence
    - Lining installation year
    - Fire flow results

- Aggressive soil conditions
- Stray currents
- Cathodic protection system
- Poly wrap
- Enhancements
- Initial wall thickness
- Corrosion rate of material
- External soil corrosion and cut off thickness.

- The AM model also assigns a condition rating to pipes based on the pipe age, material, installation characteristics, work order history and inspection history.
- The decay curve along with this condition rating is used to determine the probability of failure of the pipeline as shown in Figure 5.
- The determined probability of failure combined with the consequence of failure of the pipeline are used to prioritize pipes for replacement.

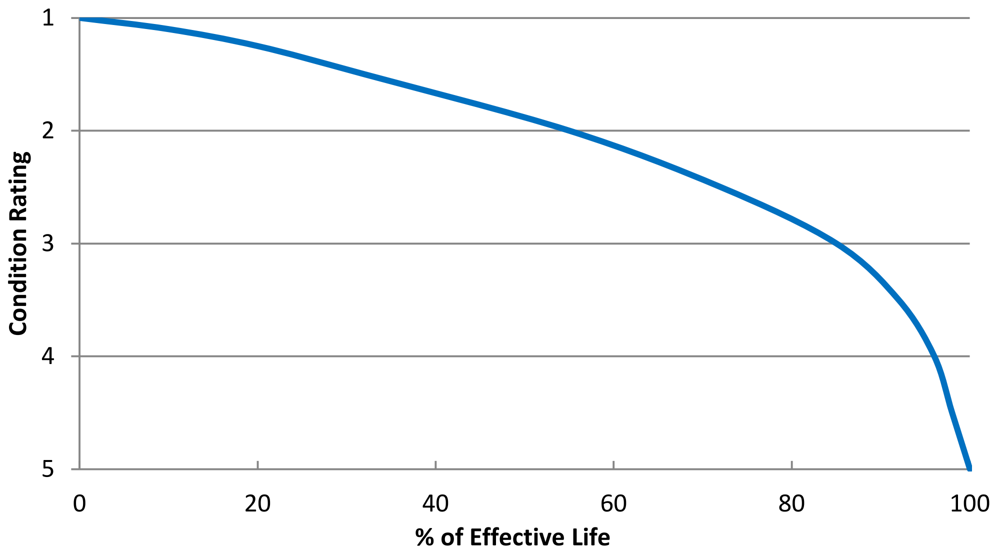

Figure 5: Example of a Decay Curve generated by AM model

WSSC decided to use the AM model as a screening tool to select pipes in poor structural condition, and perform selective inspection and testing on them to determine the pipelines that need rehabilitation or replacement. This would not only enable better prioritization of the pipes but would provide adequate data to calibrate the desktop model and hence improve the accuracy of the model predictions. WSSC explored various condition assessment technologies and finally selected Echologics' PIT technology to conduct a business case pilot.

Pilot Test

The pilot test was conducted on 32 cast iron pipeline segments (average 200 feet) scheduled for replacement. The segments were selected based on the asset management model predictions. These pipelines were tested using the Echologics' LeakFinderRT platform and Echologics' proprietary acoustic PIT technology prior to dewatering. Echologics generally provides only the remaining wall thickness[1], and it is the responsibility of the utility to interpret the remaining life. On the request of the utility personnel, Echologics LLC custom engineered a pipe scoring system for WSSC, a ranking scale from 1.0 to 5.0, that relates to the pipe's current progress from new pipe (Rating = 1.0) to reaching its failure thickness (Rating = 5.0). This ranking procedure is based on wall thickness only.

The Echologics tests indicated that approximately 70 percent of the pipes were not in need of replacement, because they still had sufficient levels of remaining wall thickness, including segments that were at or near their original condition. To validate these results, WSSC performed field investigations and forensic analysis. Visual testing and ultrasonic testing were performed at several sites to measure the thickness of the pipe. Soil samples next to the pipe segments were obtained to conduct corrosivity testing. Pipe coupons were collected from the sites for destructive forensic testing. Figure 6 illustrates the pipe sample preparation for forensic analysis. The degree of corrosion, graphitization, tuberculation, cracks and lining degradation were noted for each coupon.

(a) (b) (c) (d)

Figure 6: Pipe Sample Preparation for Forensic Analysis (a) Cleaning and marking the sample with the date of forensic analysis (b) Wall thickness measurements made with ultrasonic thickness gauge (c) Pit depths measured with Pit gauge (d) Graphitization within the pipe walls measured with micrometer

Sampling Methodology

The sampling process for this pilot test was vital because it was essential to get random data that could be used to make an inference for the entire population. A stratified random sampling method was applied in this test. The strata (locations) in this project was classified into two regions. The North-West region (Montgomery County) represents an area with low soil corrosivity, while the

[1] Echologics does offer Remaining Service Life calculations for cast iron and asbestos cement mains.

South-East region (Prince George's County) represents an area with relatively high soil corrosivity. An illustration of a sampling site is shown in Figure 7.

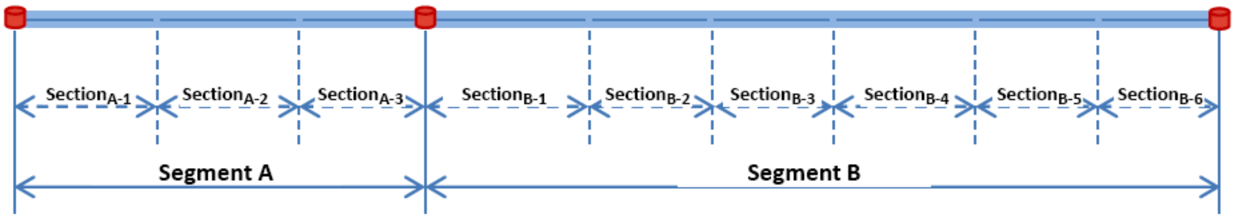

Figure 7: Example of a Sampling Site

The Echologics' acoustic measurements were conducted on all pipe segments (segment A, Segment B, etc.) that were under construction during spring 2012 and their strata was documented. The field measurements were conducted by section (Section A-1, Section A-2, Section A-3, etc.) and the number of sections that could be selected from each segment was based on the length of the segment (Table 1). For forensic analysis about 30 sections were randomly selected from each stratum (Section A-1, Section B-2, Section B-6, etc.).

Table 1: Maximum Number of Pipe Sections per Segment

Segment Length	Maximum number of sections
Length < 200 ft.	2
200 ft. ≤ Length ≤ 500 ft.	3
Length > 500 ft.	4

Pilot Test Results

The following inferences were drawn from the pilot test:

- The data regarding the size, diameter, lining status, installation and rehabilitation year of pipelines being used in the AM model had multiple errors and did not match with the data obtained from field measurements. About 22 percent (9 of 32 in segments) of mismatch was observed.
- All but 2 of 32 sections that were being replaced in actual had a greater average minimum wall thickness (0.56 inch - 0.28 inch) than the new pipes replacing it (0.25 inch).
- There was little correlation between soil corrosivity and external corrosion rate.
- The decay rates used in the AM model were too aggressive and were revised to align with the forensic test results.

The results of the pilot study were used to establish the pipe condition prediction accuracy of the AM model and the condition assessment (CA) technologies. The forensic analysis results were considered as the basis to make these predictions. The AM model was 33 percent accurate in predicting the bad pipes and should be used in identifying large populations of test segment targets. Figure 8 below illustrates that the original AM model was too aggressive and that there was better correlation between the condition assessment technologies than the model.

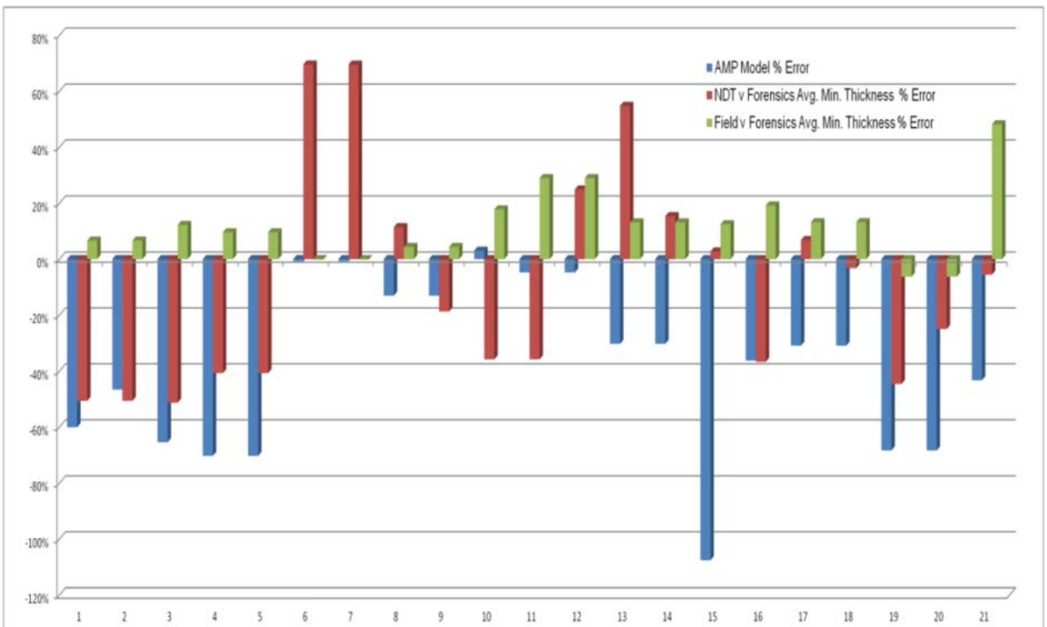

Figure 8: Condition Assessment Technologies Percent Error in detecting the worst condition pipelines. A positive percentage error implies that the model or test predicted a higher pipe thickness at that test location than the forensic test. Likewise a negative percentage error signifies that the model or test predicted a lower thickness than the forensic analysis.

The Echologics' acoustic testing was an improvement on the AM model. The Echologics' acoustic testing predicted the overall condition of the pipeline similar to the AM model. However, the field measurements conducted using ultrasonic and visual inspection were conducted at only a few locations. The field measurements were 86 percent accurate at identifying the condition of the pipeline at these few locations. However, it would take an impossibly large number of ultrasonic samples on a pipeline to derive the overall condition. Figure 9 and 10 demonstrate the accuracy loss in interpreting overall pipe condition using a limited number of ultrasonic samples and coupons, at two test locations on the same street. This limited coupon sampling was considered to be a reason for the poor correlation of field investigation results with PIT results.

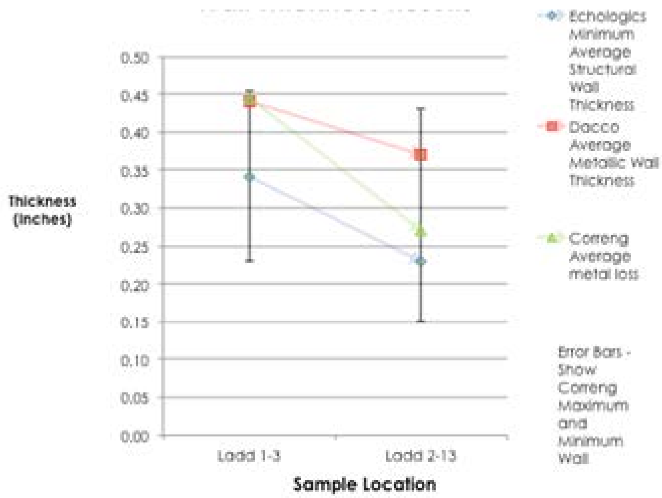

Figure 9: Variations in the remaining wall thickness measurements made by acoustic testing and forensic analysis of two 12 inch samples prepared from a pipe segment during the pilot study. There is a variation of approximately 0.1 inch between the pipe samples prepared from the same pipe segment and analyzed by different forensic labs. The acoustic test indicates a lower remaining wall thickness as compared to both the forensic tests.

Ladd 1-3			
	Echologics	Correng	Dacco
% loss	31.5		
Average wall thickness (inch)	0.34	0.44	0.44

Ladd 2-13			
	Echologics	Correng	Dacco
% loss	53.6		
Average wall thickness (inch)	0.23	0.27	0.37

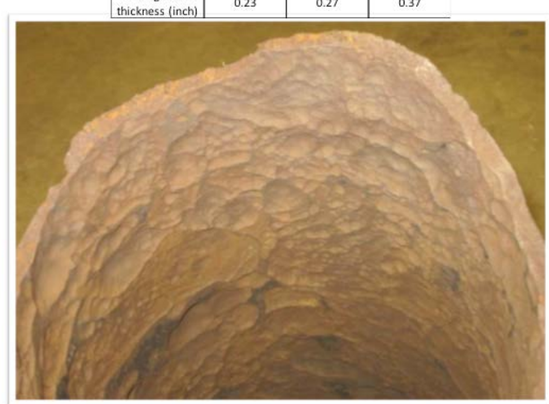

Figure 10: The remaining wall thickness measurements of adjacent pipe segments made using acoustic testing and two forensic analysis. The acoustic test rightly tracked which pipe had a lower remaining wall thickness.

Cost Comparison of Condition Assessment (CA) Technologies

The cost of conducting an Echologics' acoustic test was approximately \$3 - \$5 per linear foot for the pilot study. The Ultrasonic Testing (UT) costs about \$2500 - \$3,500 per test pit. The coupon testing was done in-house and was not very expensive. After the pilot test, it was realized that for acoustic PIT test to give accurate results, the pipe diameter, presence of lining and tuberculation must be known. Vendors offered special favorable costs to the utility for the pilot study.

Cost Benefit Analysis

Base on the pilot test results, WSSC conducted multiple evaluations to study the cost benefits of using CA technologies in determining pipe conditions.

The relative costs that would have been incurred, if 3 miles of the tested pipes were replaced based on each of CA test results was calculated and is shown in the Table 2 below. These costs clearly show that use of condition assessment technologies results in total rehabilitation cost savings.

Table 2: Rehabilitation Costs of the 3 miles of pipe in Sample Set based on results of Selection Method

Selection Method	Pipe Replacement Cost	Clean and Line Cost	Cathodic Protection Test	Total
Break Rate Method	\$ 3,090,417	\$0	\$0	\$3,090,417
AM Model	\$1,006,458	\$10,994	\$258,333	\$1,275,786
Acoustic Testing	\$37,500	\$256,901	\$0	\$294,401

WSSC also developed a financial model, to determine the breakeven point of the CA program, i.e., when exactly the program would be worth the cost and effort. This analysis was done to justify the cost of condition assessment. The model inputs were the base year in which decisions were made as to when the pipe replacements should be made, the initial cost of pipe replacement, the interest rate on the borrowed capital, the yearly inflation factor for pipe replacement projects and the NDT cost. The model calculated the annual net revenue value of the pipeline and thereby the percentage rate of return on the cost invested. Figure 11 shows the rate of return values per each deferred replacement year for four assumed NDT costs. From market analysis the present cost to conduct all the non-destructive tests that were performed in the pilot test was estimated as \$5 per linear foot. From Figure 11 it can be inferred that WSSC would reach its break event point in the third year, if the replacement decisions were made in the same year as the pilot test.

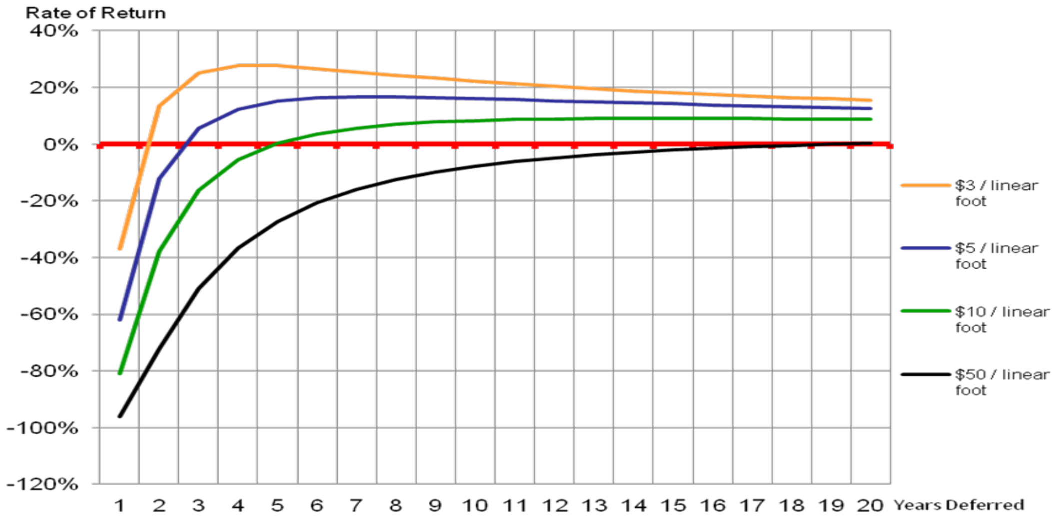

Figure 11: Rate of Return values per each deferred replacement year indicating that the higher the initial test cost the longer is the replacement deferment required.

PROPOSED PIPE TESTING RATIOS FOR FUTURE CONDITION ASSESSMENTS

After a detailed accuracy comparison, cost comparison and benefit analysis of the condition assessment options, a PIP was designed to better prioritize pipes in future replacement projects. The PIP was proposed based on the assumption that all pipelines can be grouped into cohorts based on their time, material, class and lining status and hence their 100 percent testing will not be required. Figure 12 shows the proposed test ratios of the PIP. The updated AM model revised using the pilot test results is being used to recommend pipes for subsequent NDT testing. Figure 13 depicts the recommended selection procedure for future water main replacement projects.

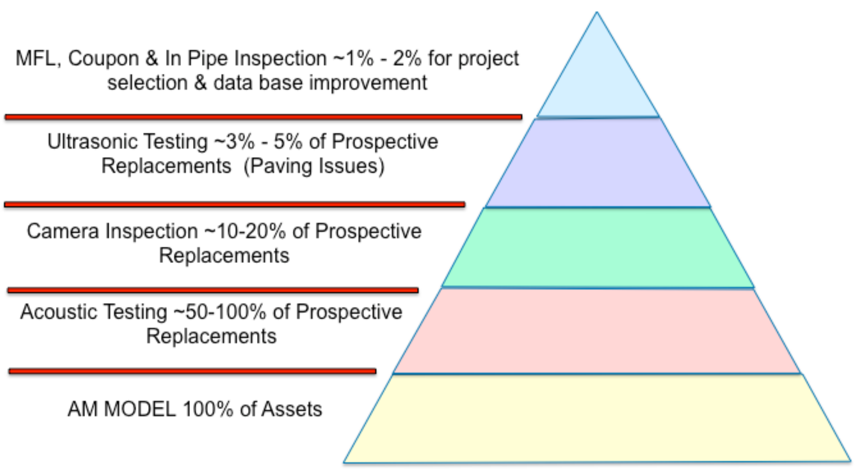

Figure 12: Proposed Pipe Inspection Program

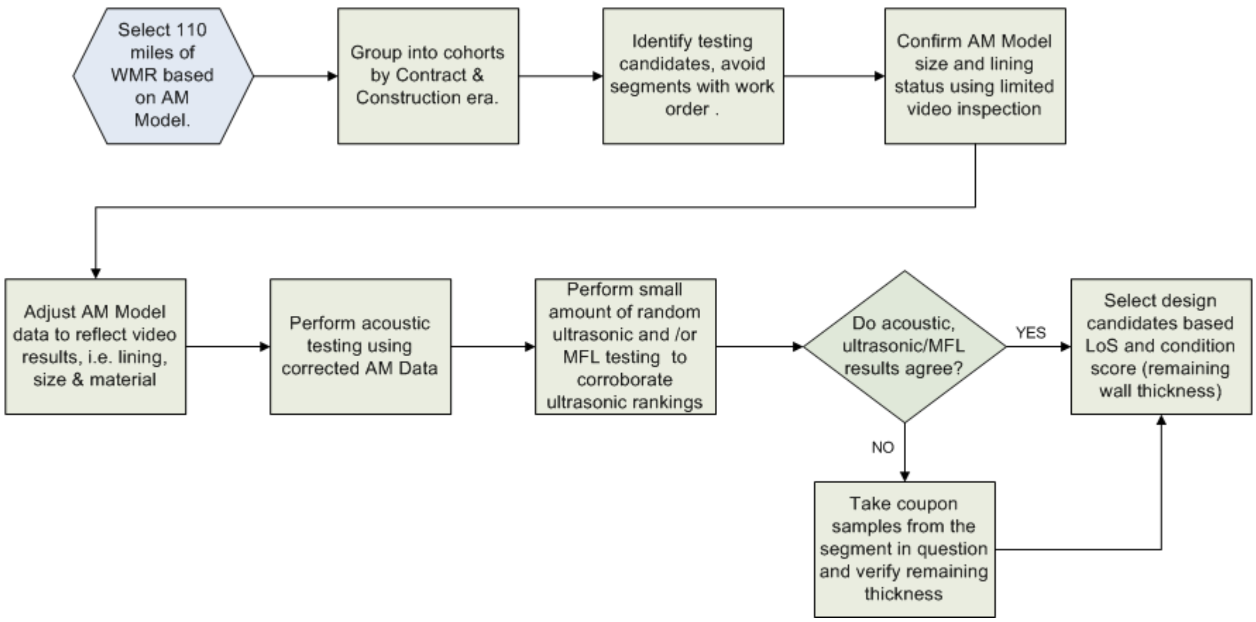

Figure 13: Flow chart showing the selection procedure recommended for future water main replacement projects

COST INFORMATION OF PILOT TEST

The total cost of the pilot test was $100,000. The cost of conducting Echologics' acoustic test was approximately $3 - $5 per linear foot for the pilot test. Vendors offered special favorable costs to the utility for the pilot study. The cost of the UT testing was about $2500 - $3,500 per test pit.

KEY LESSONS LEARNED

The following observations and lessons learned from the pilot test were provided by WSSC.

- The PIT wall thickness results may differ from spot readings obtained by other NDT technologies. This is because the PIT technology presents the weakest structural line of the pipeline by averaging the minimum circumferential thickness along a defined length (300 feet to 500 feet). However the ultrasonic and coupon testing evaluate a single location on the pipe segment.
- PIT test results reflect structural thickness of mortar lining as roughly one-third of the observed thickness in case of factory lined pipes. For example, a mortar lining of 0.25 inch is shown as 0.08 inch in test results.
- Having reliable information on material, diameter, lining and initial wall thickness enables accurate calculation of the percent degradation of the pipe section using PIT technology. During the pilot test, an error in the input data fed into the Acoustic PIT test regarding the pipe material resulted in wrong prediction about the pipe condition.

- Field lined and unlined pipelines revealed the worst Acoustic PIT test results.
- Factory-lined pipes showed the best Acoustic PIT test results.
- Echologics does offer Remaining Service Life calculations for cast iron pipe and asbestos cement pipe.
- Acoustic PIT test and forensic testing results showed a good match.
- The cost of any NDT test can be justified by comparing it against the level of accuracy and benefit provided by the test.

TIPS FOR SUCCESS

- Acoustic PIT test accuracy depends on knowing the correct dimensions, material class & lining status in advance. It is advised to have a camera test prior to the acoustic PIT test to verify the data especially the presence of lining in neighborhoods of the same vintage.
- To reduce interference from old repairs in pipelines with work order history, confine acoustic test lengths to approximately 200 feet or less.
- Establish cut off thickness for each pipe material in the system to avoid removal of any thick pipelines due to errors in predictions. A 50% wall loss has a different impact when comparing 0.625" cast iron to 0.25" ductile.
- Conduct pilot tests before choosing the appropriate NDT method for a situation.

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