Pressure Pipe Condition Assessment Technology Evaluation

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Municipalities across the United States are struggling to effectively manage aging infrastructure within their utility systems. As these systems age and approach the end of their expected useful life, municipalities end up with pressure mains of unknown condition, which could fail at any moment. Once utility staff decides to take action, the challenge becomes how to systematically prioritize the various portions of the system, and what technologies to employ to effectively and efficiently assess them.

The City of Largo (city), the fourth largest city in the Tampa Bay area, services more than 80,000 residents through over 236,600 lin ft of wastewater force mains and 227,100 lin ft of reclaimed water pressure pipes. To help protect its aging pressure systems, the city decided to implement an assessment program that would allow it to prioritize critical areas of the respective systems and determine remaining service life and renewal needs. Subsequent to this prioritization, various testing methods and technologies were applied to evaluate the condition of the assets. Technologies were recommended based on the quality and reliability of the results, as well as the invasiveness of the testing methodologies (technologies with minimal system downtime and minimal impact to the community were preferred).

The assessment program included detailed review of existing data, hydraulic modeling, a criticality assessment, and asset prioritization to identify problem areas within the pressure systems. The criticality ranking system considered risk and prioritization, and consisted of the likelihood of failure and consequence of failure, which were combined to provide a prioritization score, or ranking, for each asset. The assets with the highest score (those with the highest likelihood of failure, highest consequence of failure, or both) were identified as candidates for the assessment technology pilot.

Prior to the implementation of the field assessment pilot, four types of nondestructive inspections were evaluated, including external thickness, external defects, internal dewatered (dry) inspections, and internal pressurized (wet) inspections. Assessment technologies associated with these methods were evaluated to assess their efficacy in determining the condition of the city's sanitary force main and reclaimed water pipe network. A total of 17 assessment technologies were evaluated as part of the study, five of which were selected for the field assessment pilot study, which was completed in mid-2018.

Following the successful completion of the pilot program, the city plans to perform similar assessments on other prioritized mains within its system using the technologies that provided the best results during this pilot study.

This article will detail the criticality assessment, prioritization ranking, testing technologies assessment, and field assessment pilot testing results.

Table 1. Criticality Ranking System

Category	Criteria	Weighting	Low Probability				High Probability
			1	2	3	4	5
Likelihood of Failure	Past Failures	30%	No Historical Failures	Isolated and corrected	Unknown or minor issues	Multiple Failures	Major Failures
	Condition Assessment	25%	New Pipe < 5 years old	Minimal Corrosion	Some Corrosion and/or Minor Issues or Unknown	Mild Corrosion or 50% to 70% pipe remain	Major Corrosion and/or less than 50% pipe wall
	Pipe Material	15%	PVC or HDPE	--	Unknown or DIP	--	VCP, CIP
	Installation Date	15%	2007 or later	1997-2006	1987-1996, Unknown	1977-1986	Earlier than 1976
	LOS Requirements	15%	Velocity < 4 fps	Velocity 4-5 fps	Velocity 5-6 fps	Velocity 6-7 fps	Velocity ≥7 fps
Consequence of Failure	Pipe Diameter	45%	≥6"	8"	10"-14" & Unknown	16"-20"	≥24"
	Redundancy	30%	Full Redundancy	--	Partial Redundancy	--	No backup/ redundancy
	Key Crossing (Environmental)	25%	No crossings	--	Adjacent to Water Body	Water Body	Significant Water Body or Airport Crossing

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Data Collection and Analysis

Data collection involved the gathering of information, including hydraulic models, geographic information system (GIS) data, record drawings, flow data, equipment locations, reports, and institutional knowledge from city staff for both the reclaimed water and wastewater systems. With assistance from the city, the collected data were used to update its existing hydraulic models, assess and prioritize critical areas using a criticality ranking system, and evaluate inspection technologies to determine which ones would best suit its pressure systems. Some data and system information were not available at the time; therefore, reasonable and diligent assumptions were made for this assessment report.

Criticality Ranking System

To prioritize repair, rehabilitation, and replacement activities, the city's reclaimed water and wastewater pressure systems were assessed. Asset records were compiled and a criticality ranking system was developed and applied to each asset. The criticality ranking system consisted of likelihood of failure and consequence of failure, and when combined, provide a prioritization score for each asset. Table 1 presents the criticality ranking system categories and criteria, as presented in this section.

The criticality ranking system analysis involved the collection, processing, and inventory of several sets of data. To facilitate breaking the systems into distinct assets, pipelines were split up into small segments based on the location/neighborhood, pipe diameter, length, and material. Using this approach, the reclaimed water system was broken up into 198 reclaimed water main segments, two outfall segments, and two reclaimed water plant main segments.

Likewise, the wastewater system was split into 109 wastewater public force main segments and 112 wastewater private force main segments. Al-

Figure 1. Ultrasonic Thickness Testing Implementation

Figure 2. Ultrasonic Thickness Testing Transducer

Figure 3. Typical Pulsed Eddy Currents Setup

though the private segments were identified, no analysis was completed per city direction for this project.

Once the criteria for each category were determined, a weighting score was also allocated based on applicability and significance to the city's system. Each criterion was assigned a weighting factor, with sums equaling 100 percent for each category. For example, within the likelihood of failure category, a past failure criterion was identified as the most important; therefore, it was assigned the highest weighting factor of 30 percent. Condition assessment criterion was considered the second most important and was assigned a weighting factor of 25 percent. Pipe material, installation date, and level of service requirements were each considered of equal impact and were given a 15 percent weighting factor. The sum of these criteria totals 100 percent.

Additionally, each segment was assigned a rank score ranging from low (1) to high (5) chance of failure, which equates to ranking from best to worst condition. In order to calculate the prioritization score for each pipe segment, the percent weighting factor was multiplied by its associated rank score, then each result was added up, taking the sum for each category. After the individual scores for likelihood of failure and consequence of failure categories were determined, they were multiplied together to generate a risk or prioritization score for each pipe segment.

Condition Assessment Technologies

In order to obtain a more complete understanding of the physical condition of the city's reclaimed water pipes and wastewater force mains, field investigations utilizing nondestructive testing (NDT) methods were performed on the recommended pipe segments based on the criticality assessment. The NDT allows for the evaluation and inspection of a pipe's condition with minimal to no interruption to service during testing.

Four types of NDT inspections were evaluated, including external thickness, external defects, internal dewatered (dry), and internal pressurized (wet) inspections. Assessment technologies associated with these methods were evaluated to assess their anticipated efficacy in determining the condition of the city's reclaimed water pressure and wastewater force main network, and its compliance with National Association of Sewer Service Companies (NASSCO) pipeline assessment certification program (PACP) inspection requirements. A total of 17 assessment technologies were evaluated as part of the study and are explained. Five of these technologies were selected for incorporation into the field assessment pilot study.

External Thickness Inspection

Ultrasonic Thickness Testing

Ultrasonic thickness testing (UTT) is used to measure the wall thickness and corrosion in metallic pipes by measuring the transit time of sound waves through the pipe wall. The UTT can be used in all pipe sizes and provides current wall thickness. The measured thickness is then compared to the original wall thickness to determine the percentage of material remaining.

The subject pipe does not have to be cut or exposed to damaging chemicals during the test, and the pipeline can remain in service during testing, which is typically performed at fixed angles on the top half of the pipe. The portability of the testing equipment allows for a relatively quick onsite inspection and results are instantaneous. Figure 1 shows a typical UTT setup; the instrument used is handheld and relatively inexpensive. When the test is properly set up, results are repeatable and reliable. The UTT is typically completed at system high points, as determined through review of record drawings or subsurface utility engineering.

The UTT uses high-frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more. A typical UTT inspection system consists of several functional units, such as the pulser/receiver and transducer, as shown in Figure 2, and display devices. A pulser/receiver is an electronic device that can produce high-voltage electrical pulses. Driven by the pulser, the transducer generates high-frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. Signal travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, and orientation can be gained.

Figure 4. Phased Array

Pulsed Eddy Currents

Pulsed eddy currents (PEC) were used to detect corrosion and general wall loss in ferrous materials. This technology can be used without direct contact with the surface of the material and, therefore, does not require surface preparation. This technology can be useful where the pipe surface is rough or inaccessible. Similar to the UTT, the equipment is portable and the

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pipeline can remain in service while the test is performed.

The PEC works using the principle of electromagnetic induction. A magnetic field is created by an electrical current in the coil of a probe. When the probe is first placed on or near the pipe, the field penetrates through all the layers and stabilizes in the component thickness. The electrical current in the transmission coil is then switched off, causing a sudden drop in the magnetic field. This sudden change in the magnetic field strength generates eddy currents, which diffuse inward and decrease in strength as they propagate. The decrease in eddy currents is monitored by a set of receiver coils in the probe and used to determine the wall thickness; the thicker the wall of the pipe, the longer it takes for the eddy currents to decay to zero. Figure 3 shows the typical PEC setup.

Phased Array

Phased array ultrasonic testing (PAUT) measures the wall thickness of ferrous pipes and detects defects or discontinuities, such as cracks. This type of testing is commonly used on pipes between 2 and 36 in. in diameter. The PAUT is more expensive than UTT (the typical configuration is shown in Figure 4) and is typically used to determine the integrity of steel pipe welds.

Figure 5. Radiography

Figure 6. Pit Gauge

The PAUT consists of computer-based agitation to elements in a probe. The timing of the agitation can be varied to obtain a clearer picture of the internal characteristic of the pipeline. The PAUT uses multi-element probes, each of which can pulse individually, and the beam can be steered electronically through the test piece. As the beam is swept through the inspection subject, the data gathered from the multiple beams is compiled and results in a visual image, presenting a "slice" through the object. The speed with which these results are gathered, interpreted, and presented is far faster than the more traditional UTT inspection methods and radiography.

Radiography

Radiography testing (RT) utilizes radiation to detect damage or thickness changes in ferrous and nonferrous pipelines. This technology can reveal both internal and external defects and can be performed in pipes up to 36 in. in diameter. The process can be relatively more time-consuming and expensive than other technologies and is typically used on pipes with a solid-free internal fluid.

This testing method is based on the same principle as medical radiography. The pipe material is exposed to X-ray or gamma-ray radiation, with either film or reusable phosphorus plates used to capture the image on the other side. The film or plate is placed on the remote side of the pipe and radiation is then transmitted through from one side of the material to the remote side where the radiographic plate is located, as shown in Figure 5.

The radiographic plate detects the radiation and measures the various quantities of radiation received over the entire surface of the plate. This plate is then processed, and the different degrees of radiation received by the film are imaged and represented in different degrees of black and white.

The amount of energy absorbed by the object depends on its thickness and density. Energy not absorbed by the object causes exposure of the radiographic film, which shows up dark, and areas of the film exposed to less energy remain lighter; therefore, areas of the object where the thickness has been changed by discontinuities, such as cracks, will appear as dark outlines. Inclusions of low density, such as slag, will appear as dark areas on the film, while inclusions of high density, such as tungsten, will appear as light areas. Results require interpretation by experienced, qualified inspectors.

Figure 7. Alternating Current Field Measurement ACFM

Pit Gauge

Pit gauge technology measures the depth of pitting along the pipe wall of all sizes of pipes to determine the degree of corrosion. Typically, pit gauge is used on pits already identified from alternative inspection technologies. Any damage or deviation from normal measurements indicates a corrosion issue. This technology is limited to use in cast iron pipe material and is relatively inexpensive.

A typical pit gauge consists of a simple lever and a pointer, as shown in Figure 6. This method could bring variable results as it's dependent on the inspector's skills; therefore, results may vary.

External Defect Inspection

Electromagnetic Testing

Electromagnetic testing is commonly used to determine the extent of deterioration of concrete pipes. Pipe sections are dewatered and equipment is set up that generates an electromagnetic field. The electromagnetic field is used to determine the pipe quality and tests for breaks and other damage in the pipe. This type of testing is performed in concrete pipes, but since none were found in the wastewater or reclaimed systems, this technology was not evaluated further.

Alternating Current Field Measurement

Alternating current field measurement (ACFM) testing is an electromagnetic technique developed to detect the surface cracks and record the location and characteristics of the crack working through paint and other pipe coatings, as shown in Figure 7. An ACFM inspection can be used in metallic pipes of all sizes.

An ACFM probe introduces an electric current locally into the part and measures the associated electromagnetic fields close to the surface. The presence of a discontinuity disturbs the associated fields and the information is graphically presented to the system operator. The ends of a defect are easily identified to provide information on defect location and length. The depth of the flaw (through the pipe wall) plays an important role in determining structural integrity and is calculated using mathematical computations, thus allowing an immediate evaluation of the implication of the indication.

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Figure 8. Liquid Penetrant

Figure 9. Magnetic Particle

Figure 10. Closed-circuit tellevisiion

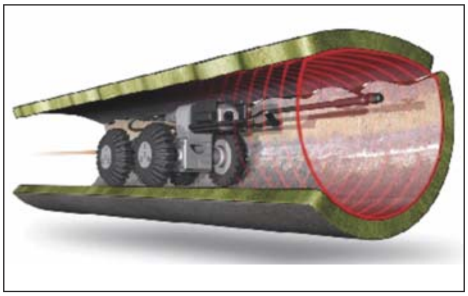

Figure 11. Laser Profiling

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Liquid Penetrant

Liquid penetrant inspection, also known as dye penetrant inspection, is widely used to locate surface breaking defects in pipes. The penetrant can be applied to metallic and plastic pipes; however, test materials must be relatively nonporous and the testing surface must be free of all contaminants, including dirt, oil, grease, paint, rust, etc. The dye reveals cracks and other imperfections of pipe surface, as shown in Figure 8.

The dye is applied to the surface of the pipe for a certain predetermined time, after which the excess penetrant is removed. The dye penetrates into pipe surface at discontinuities by capillary action. Penetrants typically used include visible or fluorescent dye penetrant. The inspection for the presence of visible dye indications is made under white light and inspection of presence of indications by fluorescent dye penetrant is made under ultraviolet (or black) light under darkened conditions. Evaluations are based on code requirements.

Magnetic Particle

Magnetic particle testing is commonly used for the testing of materials that can be easily magnetized, such as ferrous metals. This technology detects defects that are open to the surface and just below it, including cracks, seams, and laps in ferromagnetic pipelines.

The most commonly used method for magnetic particle testing is the yoke technique, which is portable and can operate in alternating current (AC) or direct current (DC) modes. The yoke has an electric coil in the unit creating a longitudinal magnetic field that transfers through the legs to the examined area. In this technology, the test material is first magnetized; any object that is magnetized will be surrounded by an invisible magnetic field. When the ferromagnetic material is defect-free, it will transfer lines of magnetic flux through the material without interruption; when a discontinuity is present, the magnetic flux leaks out of the material, typically if the discontinuity is perpendicular to its flow. As the flux leaks out, the magnetic field will collect ferromagnetic particles, making the size and shape of the discontinuity easily visible. If the defect is parallel to the lines of the magnetic flux, there will be no leakage; therefore, no indication will be observed. A typical configuration is shown in Figure 9.

Internal Dewatered Inspection

Closed-Circuit Television

Closed-circuit television (CCTV) technology is widely used to identify corrosion, leaks, and other internal issues, including cracks and fractures in plastic and ferrous pipelines between 6 in. and larger in diameter, as shown in Figure 10. A CCTV inspection can be done in gravity wastewater and reclaimed water pipelines during low-flow conditions. Force mains must be dewatered prior to inspection. Ideally, the line inspection needs to take place during low-flow conditions.

A CCTV inspection typically consists of a remotely operated camera that is mounted on a self-propelled robotic crawler connected to a video monitor at the surface. The CCTV camera is typically inserted through a manhole and, once in the pipe, must be assembled to keep the lens as close as possible to the center of the pipe. The vehicle is tethered to a fiber optic cable that is operated remotely. Inspections produce a video record that can be used for future reference. The CCTV identifies visible defects up to 1,000 ft away from the point of insertion.

Laser Profiling

Laser profiling technology provides accurate empirical data on ovality, capacity, and other conditions of pipelines using a projected laser light, as shown in Figure 11. This technology allows the detection of wall thickness, if the original internal diameter is known, and defects in plastic and ferrous pipes. The laser profiler can operate in pipe sizes 8 in. and larger in diameter under pressure, or in dewatered reclaimed and wastewater pipelines.

The profiler projects a ring of laser light on the internal pipe surface, which is in the field of view of the camera while it's moving through the pipe. Lasers are used in the atmosphere, above the waterline; these can be either two dimensional (2D) or three dimensional (3D), depending on the level of detail required. A typical 2D laser profile provides an indication of the pipe ovality above the waterline, as well as general defects in the pipe wall; fine defects, such as cracks, may not be apparent. The value of laser profiling is that it provides clear evidence of pipe ovality, while the human eye is easily fooled using CCTV alone. Software excerpts the profile from the camera video and trends it over the length of the pipe to build a geometric profile.

Magnetic Flux Leakage

Magnetic flux leakage (MFL) is a method used to detect corrosion and pitting in metallic pipes. This technology scans pipe through linings to measure remaining wall thickness, scans the length and circumference of a pipeline, and provides depth and location of metal wall loss caused by corrosion, pitting, or other deterioration mechanisms. The minimum testing pipe diameter is 24 in. and is used in nonpressurized pipelines, as shown in Figure 12. The cost associated with this technology is significantly high.

The problem with the MFL testing technique is that it contains permanent magnets that are utilized to form a magnetic flux field in the pipe wall. Defects will influence the path of the magnetic field and will cause some of the flux to leak out of the tube wall. This leakage field will be picked up by the coils and the sensors in the probe. Size of the leakage field is determined by pull speed of the probe and by the shape, dimensions, and location of defects. Signals that represent the size of the leakage field, and thus the condition of the tube, are presented on a computer screen. The tool requires contact with the pipe wall.

Internal Pressurized Inspection

SmartBall Leak and Gas Detection

The SmartBall® by Pure Technology leak detection platform is a free-swimming, nontethered foam ball that can accurately identify and locate leaks, gas pockets, and defects in pipelines over 4 in. in diameter. This technology is used in metallic, pressurized pipelines, including force mains and reclaimed water pipelines. A typical configuration is shown in Figure 13.

This tool is comprised of a 2-in.-diameter aluminum ball that includes an acoustic sensor at the center. The tool is manually inserted into the system through a minimum 4-in.-diameter tap using a claw and is extracted at a second point in the system with a net. During an inspection, the tool is inserted into a pipeline and travels with the product flow for up to 17 hours, while collecting information about leaks, gas pockets, and defects. It requires only two access points—one for insertion and one for extraction—and is tracked throughout the inspection at predetermined fixed locations on the pipeline. The tool can complete long surveys in a single deployment without disruption to regular pipeline service. The SmartBall needs at least 1 ft per second (fps) for simple runs, but a velocity of 2 fps is preferred for more complex pipe configurations. Higher velocities can potentially reduce data accuracy.

PipeDiver Electromagnetic Inspection

The PipeDiver® (Figure 14) is a free-swimming, electromagnetic tool used to detect leaks, variances in wall thickness, and defects in ductile iron pipes. This electromagnetic inspection procedure provides a nondestructive method of evaluating the baseline condition of the pipe wall to gather data for each pipe and identify anomalies produced by areas of wall loss and property changes. The PipeDiver is used inside active large-diameter pipes ranging from 16 to 48 in. It's used in pressurized water, wastewater, and reclaimed water pipelines and the cost can be high.

The sensors collect information about the condition of the pipe walls in the system as it travels through active pipes. Petals allow the PipeDiver to navigate through butterfly valves and different pipe configurations, with CCVT data available during testing. Data are collected and analyzed after the test to locate irregularities.

Acoustic/Closed-Circuit Television

This system comprises a CCTV and leak detection system for pressurized mains. The acoustic/CCTV is a tethered system that can be used in pipelines of ferrous and plastic pipe materials, such as ductile iron, polyvinyl chloride (PVC), and high-density polyethylene (HDPE). This technology allows for the detection of leaks, gas pockets, and defects in pipes greater than 6 in. The system can visually and acoustically detect air pockets in pipelines during inspections and can navigate bends totaling up to 270 degrees, as well as small pressure fittings, air valves, and gate valves. Most common acoustic/CCTV technologies include LDS-1000 by JD7 and Sahara by Pure Technologies (Figure 15). The equipment can be inserted through fire hydrants or small pressure fittings or valves (greater than 2 in.) and is used for inspection in water and reclaimed water pipelines, with lengths between 2,000 and 3,200 lin ft.

The acoustic/CCTV system consists of a sensor head and a hydrophone, which is an electrical instrument used to detect or monitor sound underwater. The sensor head is inserted into a pipe through any access point greater than 2 in. in diameter. As the sensor is conveyed through the pipeline by product flow, acoustic signals are picked up at the surface by the hydrophone. The signal is fed through a cable and then to the processing equipment. The system operator is able to hear signals from the system directly, as well as view the signal on a computer with spectrogram software. The system locates leaks by identifying acoustic signals; the size of leaks can be estimated based on the acoustic signal recorded by the de-

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Figure 12. Magnetic Flux Leakage

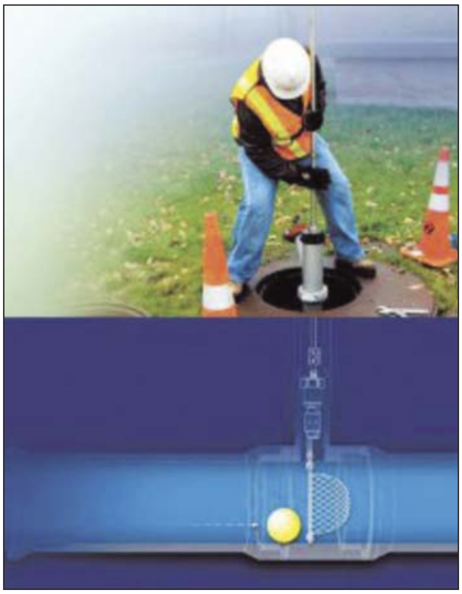

Figure 13. SmartBall

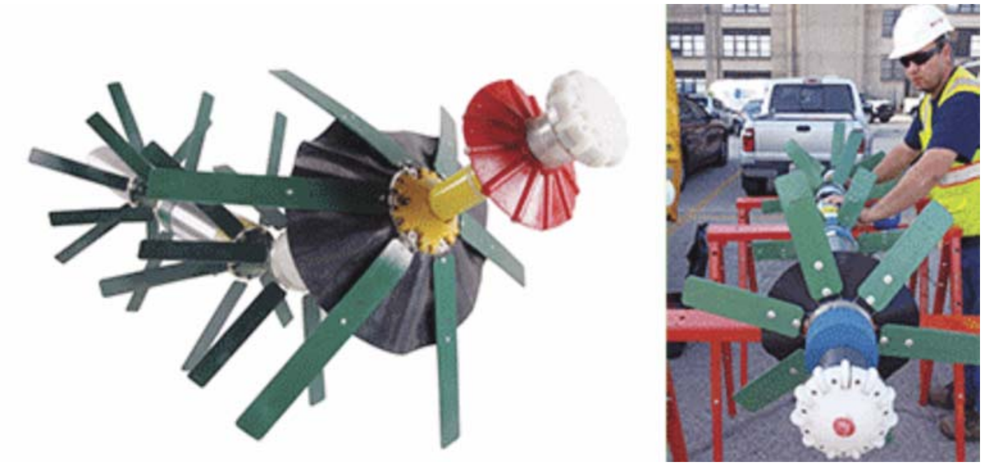

Figure 14. PipeDiver

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vice. Typically, the system requires a minimum of 1 fps of flow for simple pipe runs and up to 2 fps for multiple bends and fittings. Higher velocities can potentially reduce data accuracy.

SeeSnake and HydraSnake

The SeeSnake™ and HydraSnake™ by Pika measure changes in wall thickness every tenth of an in. along the entire pipe segment to be tested. This technology also detects corrosion defects in 4-in.- to 78-in.-diameter ferrous pipe sizes under pressure or in dewatered reclaimed and wastewater pipelines (Figure 16). The cost associated with this technology is high.

As the tool travels through the pipe, it records the wall thickness and stores the information onboard; the data is then sent to a computer in real time during deployment. The SeeSnake does not require contact with the pipe wall and can measure through scale, wax, and nonmagnetic liners. The tool has a small diameter and is flexible, which allows the tool to travel through tees and short-radius elbows. The tool does not have external movable parts, so they can't break off or get caught at tees and branches. The tool can be pumped through the pipeline with the flow or with compressed air.

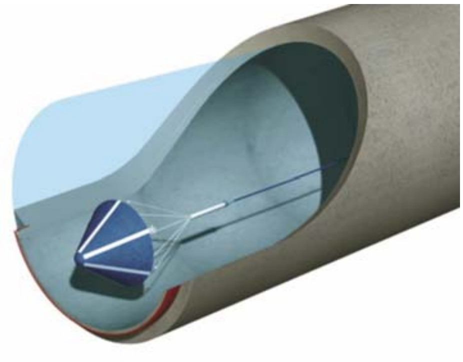

Figure 15. Acoustic/Closed-Circuit Television

Figure 16. SeeSnake and HydraSnake

Ground Penetrating Radar, Survey, and Air Lancing

Ground penetrating radar (GPR) is a nondestructive geophysical method that uses radar pulses to identify underground objects. Data collected with GPR can be used to evaluate the field conditions that may affect pipeline condition assessment. The surveyed field data can be used to identify high points or high segments of the pipe that could be subject to a higher risk of internal crown corrosion due to the accumulation of sewer gases.

This field data will also identify locations where the pipe could be relatively easily excavated and exposed for inspection. The implementation of these services will not require the pipelines to be removed from normal service. The data collected during each inspection shall be recorded using a data management system compatible with city databases and GIS, and modified as appropriate for the criteria and parameters being assessed with each technology.

Condition Assessment Technology Summary

Table 2 summarizes each of the assessment technologies characteristics, relative cost, and recommendations for the city's systems.

Table 2. Technology Assessment Comparison

Inspection Type	Technology	Testing Location		Material			Pipe Diameter	Pressure		Results Identified				Data Collected		Cost	Recommended Technology
		Interior	Exterior	CI	DI	PVC	inches	No Pressure	Pressure	Leaks	Wall Thickness	Gas Pockets	Defects	Specific Point	Full Pipe Length	Dollar	
External Thickness Inspection	**Ultrasonic Testing**		X	X	X		All	X	X		X			X		$	X
	Pulsed Eddy Currents		X	X	X		All	X	X		X			X		$$	X
	Phased Array		X	X	X		2-36	X	X		X		X	X		$$$	
	Radiography		X	X	X	X	2-36	X	X		X		X	X		$$$	
	Pit Gage		X	X			All	X	X		X			X		$$	
External Defects Inspection	Electromagnetic Testing (Concrete)	X		X	X		24-60	X					X		X	$$$$$	
	Alternating Current Measurement		X	X	X		All	X	X				X	X		$$$$	
	Liquid Penetrant		X	X	X	X	All	X	X				X	X		$$	
	Magnetic Particle		X		X		All	X	X				X	X		$$$	
Internal Dewatered Inspection	CCTV	X		X	X	X	6 ≤	X		X			X		X	$$	
	Laser Profiling	X		X	X	X	8 ≤	X			X		X		X	$$	
	Magnetic Flux Leakage	X			X		24-102	X			X		X		X	$$$$$	
Internal Pressurized Inspection	**SmartBall**	X		X	X		4 ≤		X	X		X	X		X	$$$$	X
	PipeDiver - Electromagnetic	X			X		16-48		X	X	X		X		X	$$$$$	
	CCTV/Acoustic Sahara and LDS 1000	X		X	X	X	16 ≤		X	X		X	X		X	$$$$	X
	SeeSnake and HydraSnake	X		X	X		4-78	X	X	X	X		X		X	$$$$$	

Technologies associated with the identification of external defects were not given further consideration, as these technologies provide very limited information on the condition of the pipelines, and performing such investigations will be relatively expensive since the pipeline will have to be excavated and exposed. Additionally, leaks, wall thickness, and gas pockets cannot be determined through these types of inspections, and these criteria are relevant to understand the condition of the pipe. Technologies that require dewatering of the pipelines, including CCTV, laser profiling, and MFL, were initially evaluated, but due to the effort involved in the dewatering of the pipelines to perform the testing, were discounted.

Among the external thickness inspection technologies, radiography, phased array, and pit gauge were not considered further. Radiography can present a potential health hazard, and requires licensed technical personnel due to the radiation associated with the test, multiple shots, access to both sides of the pipe, and a dark area to develop the film, making it time-consuming. Phased array inspection is typically used to assess the integrity of steel welds, primarily in the oil and gas industries. The pit gauge inspection method is limited to cast iron pipe materials and is subject to human error.

Ultrasonic testing and pulsed eddy currents are preferred for ferrous pipes due to their versatility, ability to precisely size defects at a relatively small number of points (less human error), immediate availability of test results, relatively low cost, and inherent lack of hazards for those working around the inspection site. Ultrasonic testing and pulsed eddy currents were recommended for external inspection of both wastewater and reclaimed water pipelines.

Among the internal pressurized inspection technologies, PipeDiver, SeeSnake, and HydraSnake were not considered further. These technologies were too expensive for this pilot and may be used for detailed analysis, once a need is determined following initial inspections by other less costly means. The internal pressurized CCTV inspection alone cannot identify the thickness of the pipe, nor can it be used to estimate the anticipated life expectancy of the pipe; therefore, using a combination acoustic/CCTV, such a Sahara or LDS-1000, for the reclaimed water mains, was recommended. This combination of technologies will provide detection of leaks, gas pockets, and defects in live mains, and record sounds directly.

Conclusions and Recommendations

In summary, the following technologies will be used during the pilot and will likely be viable options for future testing:

- Reclaimed pressure pipe inspections, including acoustic/CCTV technologies via LDS-1000.
- Sahara and external nondestructive thickness technologies via ultrasonic testing, along with a surge analysis.
- Force main inspections, including acoustic technology via SmartBall and external nondestructive thickness technologies via ultrasonic and pulsed eddy currents.

In addition to physical pipe assessment, additional assessments may be completed on the pressure piping, including hydraulic modeling, surge analyses, and pressure monitoring. A surge analysis simulates sudden changes in flow and velocity, which can cause overpressurization or underpressurization of pipe work. These changes could include sudden valve closures, pumping changes, and power loss. Pressure monitoring in the system may be used to monitor the effects of surge within the system or determine if existing operating practices are causing sudden changes in flow and velocity.

Following the successful completion of the pilot program, the city plans to perform similar assessments on other prioritized mains within its system using the selected technologies.