



MANAGING AGING INFRASTRUCTURE AND EXTENDING ASSET LIFE

Condition Assessment and Rehabilitation Guide



Infrastructure in the U.S. is in need of replacement and rehabilitation.

The American Society of Civil Engineers (ASCE) Infrastructure Report Card graded our pipelines a D or less. According to the U.S. Environmental Protection Agency (EPA), there are over 80,000 miles of public sewers and between 23,000 to 75,000 sanitary sewer overflows every year; in drinking water, over 240,000 water main breaks occur each year, wasting six billion gallons of treated water every day.

The EPA estimates \$271 billion is needed for wastewater infrastructure over the next 25 years and the American Water Works Association (AWWA) estimates that upgrading existing water systems to meet the drinking water needs of a growing population will require at least \$1 trillion.

Replacement is not the only option to address aging infrastructure.

There are several methods of pipeline rehabilitation methods. The chosen method will depend on the pipe design, size and material, available access, surrounding soils and whatever issue is prompting the work. Available rehabilitation and life extension methods can protect pipelines from corrosion, restore structural integrity, reduce infiltration, eliminate leaking joints, improve water quality and increase pipeline flow capacity.

For owners of storage and treatment facilities, balancing the rehabilitation required to maintain regulatory compliance and provide reliable and safe operations is an effort that calls for careful evaluation, planning and budgeting to meet today's financial constraints. Condition assessments allow owners to integrate infrastructure improvements with regulatory compliance-driven projects. Condition assessments may also identify maintenance and operations adjustments that can extend facility life.

Special thanks to these organizations for sharing photographs:

AP/M Permaform

Avanti International

FloWav

Genesis Pipe Rehabilitation

Hydromax USA

Logiball

Murphy Pipeline Contractors

NASSCO

NorCal Pipeline Services

Pro-Pipe

Pure Technologies

RedZone Robotics

Rocky Capehart

SEKISUI SPR Americas

SewerVUE

The Water Research Foundation

TT Technologies

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Pipelines

Pressure Pipes

The pressure pipeline condition assessment industry has made major strides in methodologies and technologies. However, whether it is a sewer force main or a water transmission main, older pipeline designs seldom considered the need for access for inspection or

assessment purposes. Removing a pipeline from service to assess its condition is a challenge and the costs associated with accessing the pipeline to employ new technologies can be daunting.

Gravity Pipes

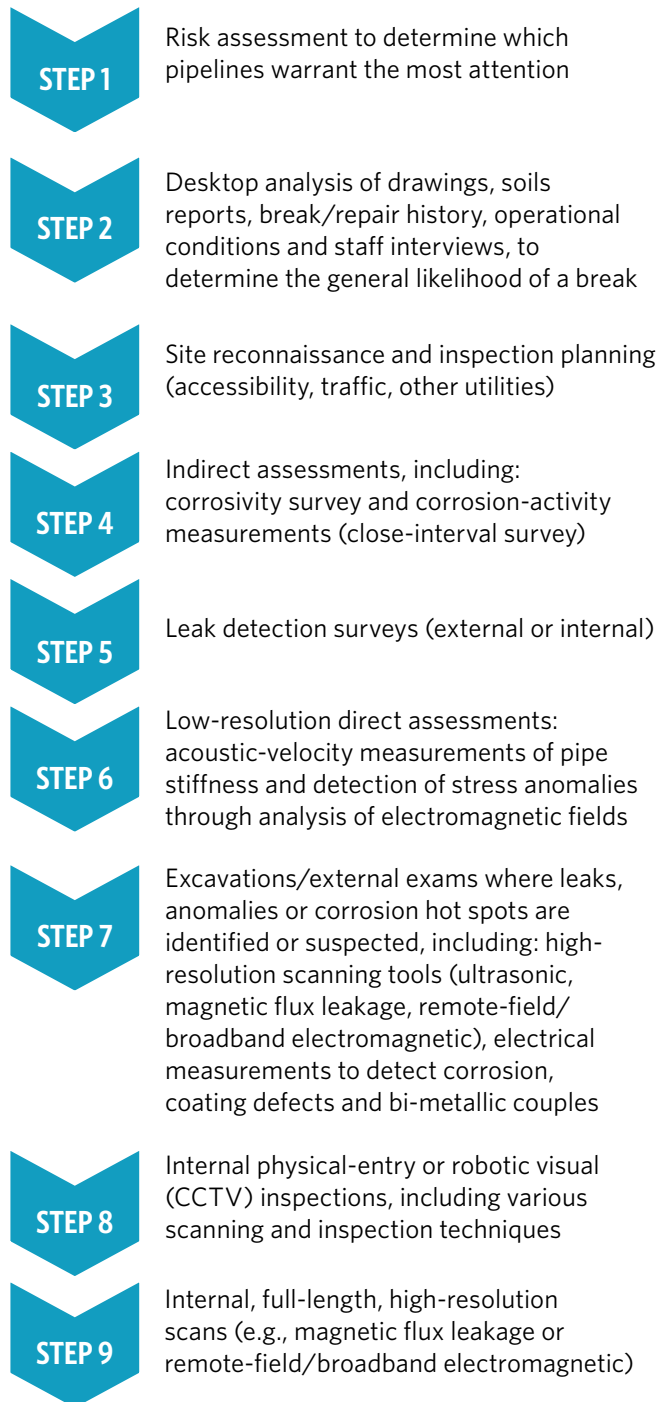
Current methods of gravity pipeline inspection use sophisticated and robust CCTV equipment with high-definition digital capabilities. Laser, sonar and additional sensors can be added to identify debris and measure vertical and horizontal deflections, hydrogen sulfide and many more parameters. On the low technology side, observations and debris from pipe cleaning have always been a primary source of condition assessment information for maintenance optimization and a secondary source for capacity and structural decisions. Federal and State regulations are in place for CSOs and SSOs in sanitary sewers.

Storm sewers are probably the infrastructure asset most taken for granted. Yet, if they fail to perform, the resultant flooding can threaten public health and safety as well as cause significant property damage. Storm sewers have a greater opportunity to collect surface debris that can cause clogs, backups and failures. Since storm sewer construction methods and materials are similar to sanitary sewers, condition assessment methods also are also similar.

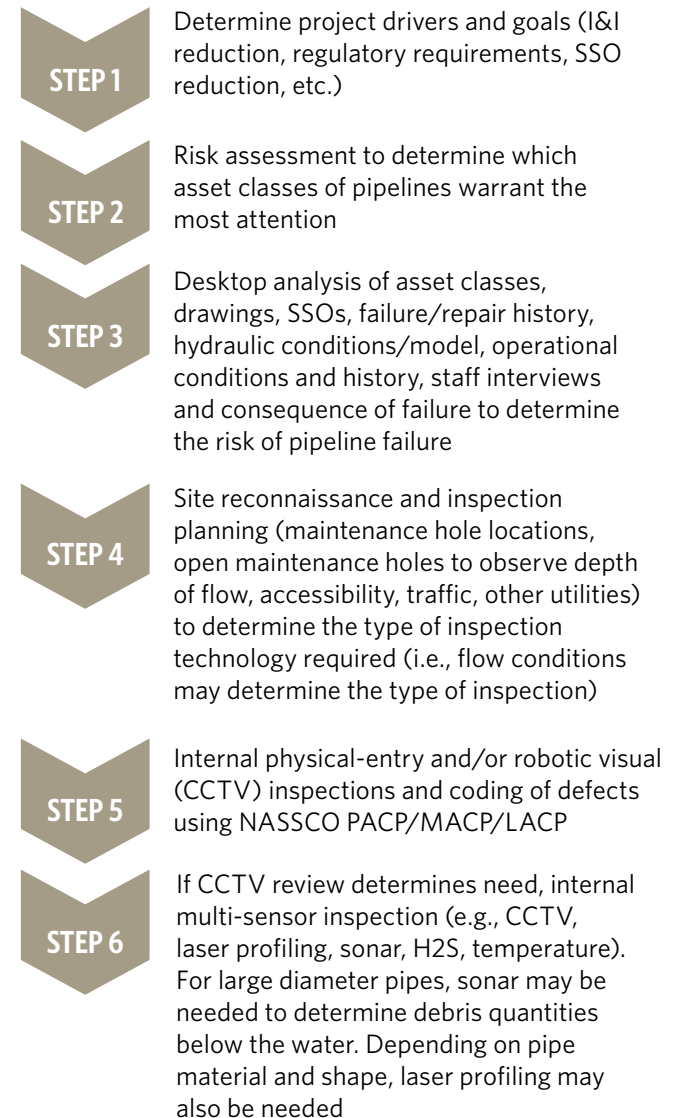
Assessment Process

The general progression for pipeline condition assessments are shown below. Using multiple methods to find all defects is necessary to provide a more complete understanding of pipe condition. However, some steps can be omitted and/or modified for each specific situation.

Pressure Pipe Condition Assessment Process



Gravity Pipe Condition Assessment Process



Pressure Pipes (Water Mains and Force Mains)

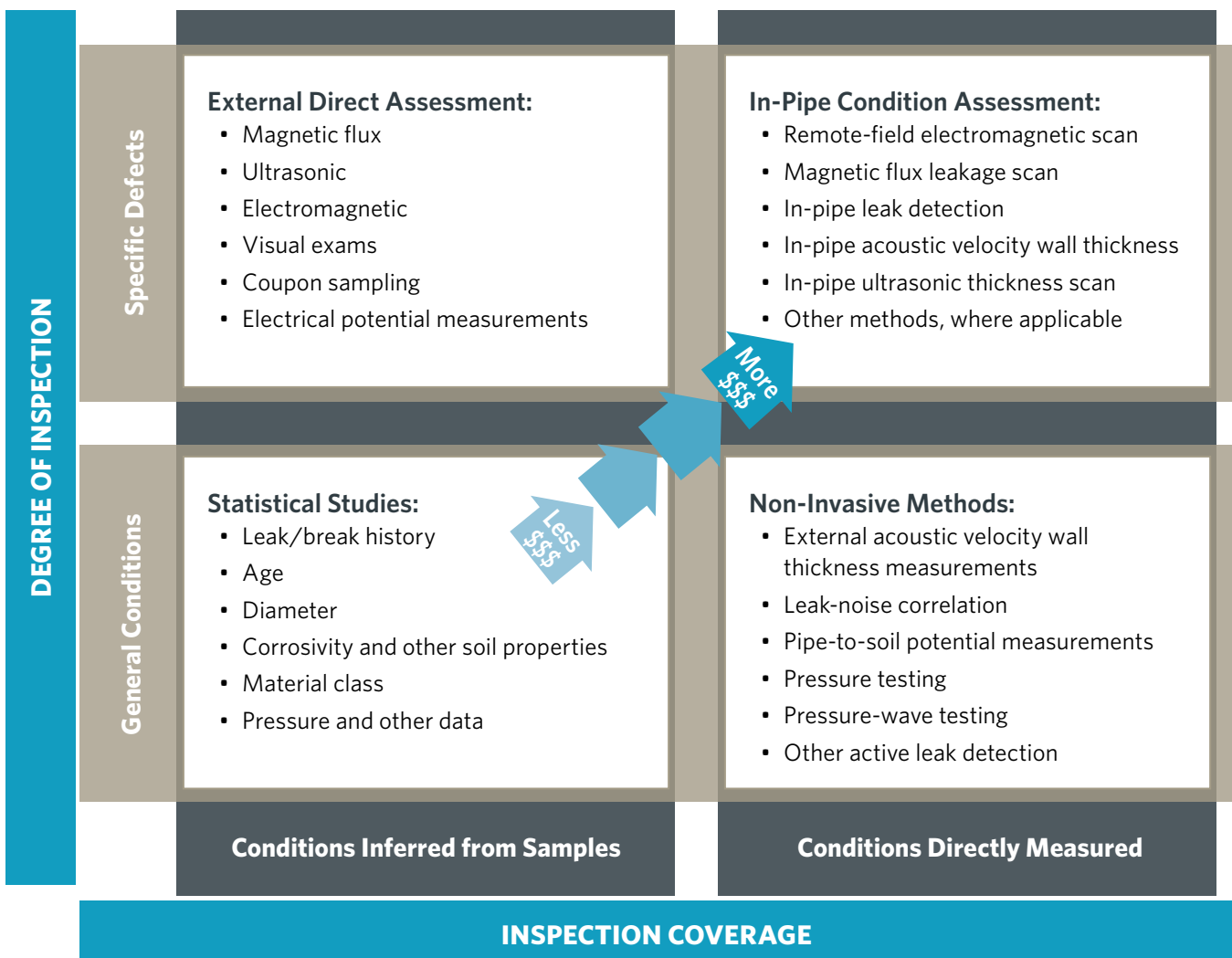
Choosing an Assessment Method

1. Degree of inspection. Are you ascertaining the general condition of the pipe, or do you want to find small defects?

2. Inspection coverage. How much of the pipe is to be assessed?

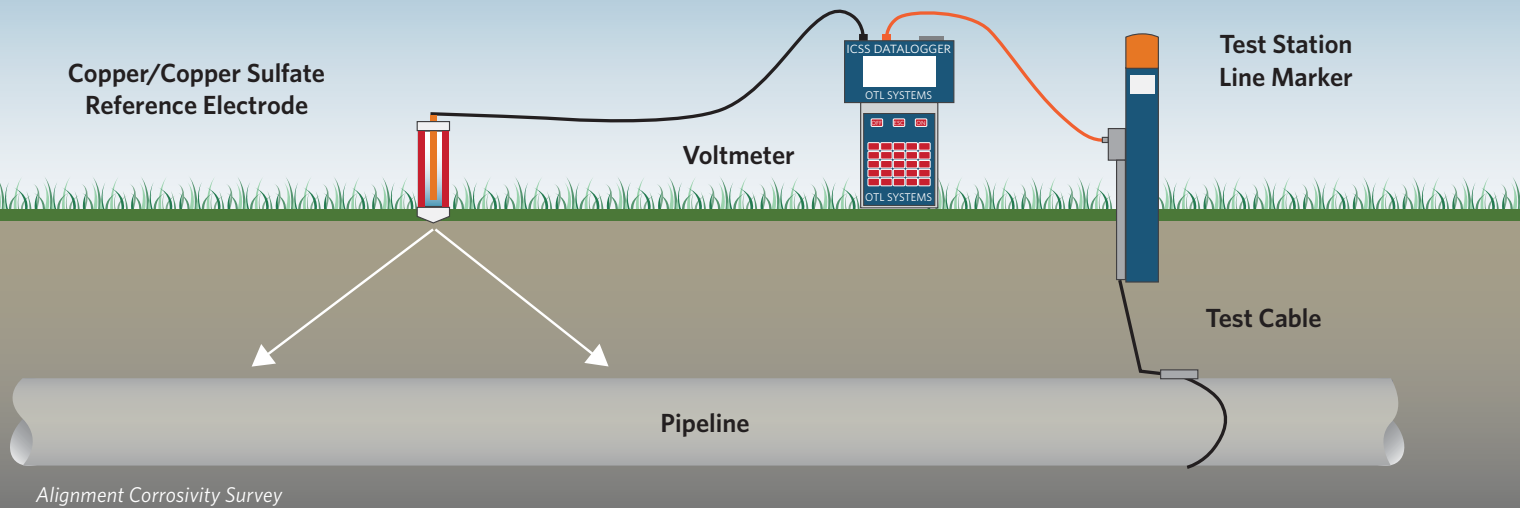
3. Pipeline access. How easy is it to get near or in the pipe with various tools? Can the pipe be shut down and dewatered? How long can it be out of service?

4. Cost of the assessment. What is the perceived risk and the overall value of the asset? An expensive assessment is harder to justify for assets where the replacement cost is relatively inexpensive.

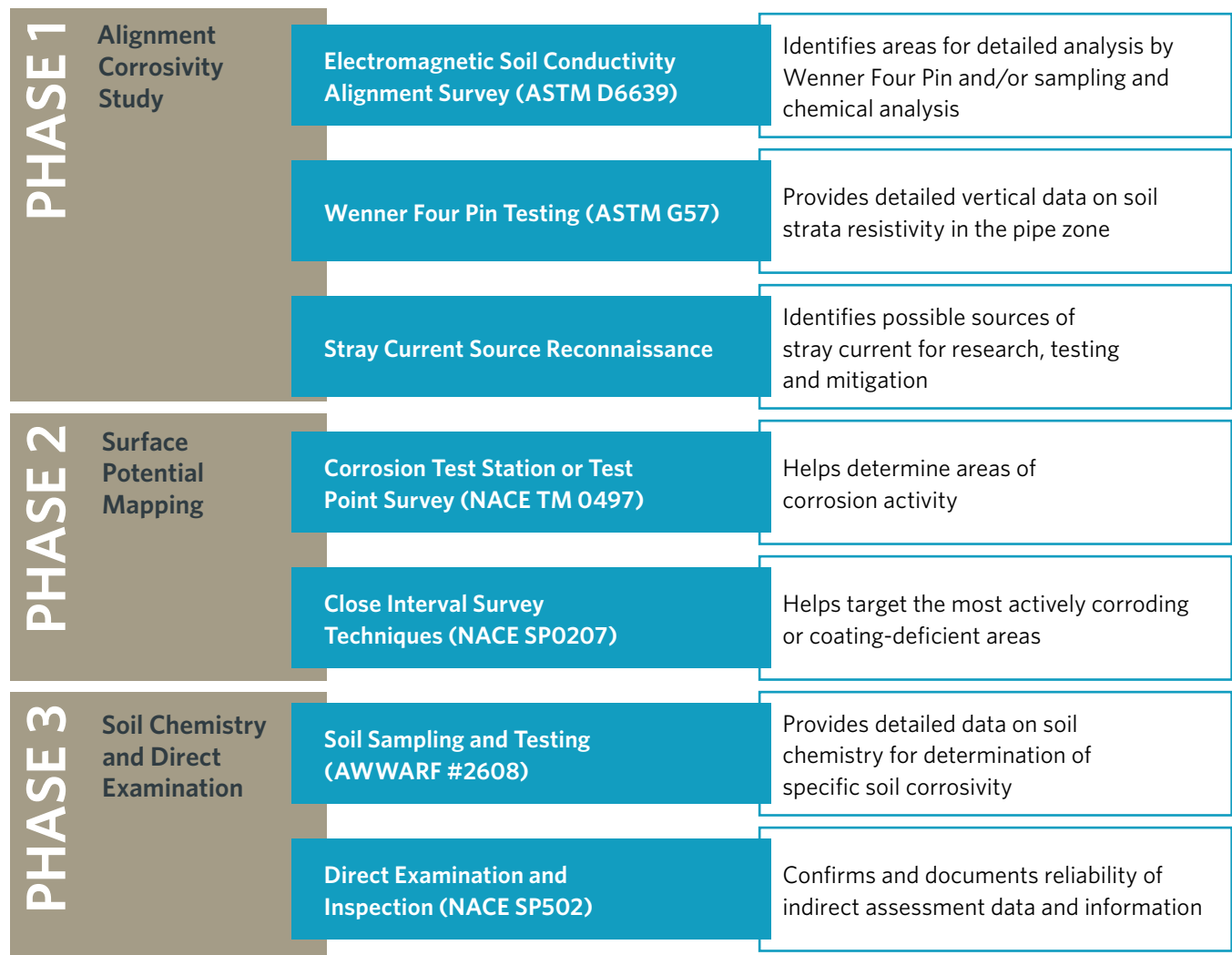


Risk assessments determine which assets merit detailed assessments. The degree of inspection and the inspection coverage influence the cost. Some methods may not be practical due to access limitations.

[Graphic modified from Laven, et al. (2011)]



Assessing Corrosion Risk With Corrosivity Surveys



Selecting Condition Assessment Technologies for Pressure Pipes Based on Pipe Material

METHOD	CORROSION SURVEY	ACOUSTIC	REMOTE FIELD ELECTROMAGNETIC	ULTRASONIC
	Various electromagnetic, electrical and laboratory methods characterize the corrosivity of soils, detect/measure corrosion activity and assess effectiveness of corrosion protection and cathodic protection.	<ul style="list-style-type: none"> Acoustic velocity: pipe wall stiffness is calculated from the speed of sound transmission. Acoustic monitoring: alerts and pinpoints the location of wire breaks. 	Changes in electromagnetic signals indicate broken wires, corrosion pits and changes in wall thickness and stress anomalies.	Reflection of sound waves is used to measure the thickness of various types of materials. Tool must have direct contact with material being measured.
ASBESTOS CEMENT (AWWA C402)	Assess potential for concrete deterioration (pH and sulfates).	Acoustic velocity has been used with moderate success.	N/A	N/A
PRESTRESSED CONCRETE CYLINDER PRESSURE PIPE (AWWA C301 AND C304 - PCCP)	<ul style="list-style-type: none"> Assess potential for metal and concrete deterioration. Detect active corrosion. 	Acoustic monitoring for detection of wire breaks. Acoustic velocity can be used for prioritization of other assessments.	Used to detect broken wires.	N/A
NON-PRESTRESSED CONCRETE PRESSURE PIPE (AWWA C300, C302 AND C303)*	<ul style="list-style-type: none"> Assess potential for metal and concrete deterioration. Detect active corrosion. 	N/A	Used to detect broken bars and cylinder corrosion.	N/A
DUCTILE IRON CAST IRON (AWWA C150 AND C153)	<ul style="list-style-type: none"> Assess corrosivity to iron. Monitor corrosion activity. 	Acoustic velocity may be able to detect gross deterioration.	Used for detailed internal scan of pipes and external spot assessment. Works with cement mortar and tuberculation.	Used for external spot assessments.
STEEL (AWWA C200)	Assess potential for metal and concrete deterioration. Monitor corrosion activity.	Acoustic velocity may be able to detect gross deterioration.	Used for detailed internal scan of pipes. Works with cement mortar and tuberculation.	Used for external spot assessments.
COPPER	Assess potential for metal and concrete deterioration.	N/A	Used for detailed internal scan of pipes.	N/A
PLASTIC PIPES HDPE (AWWA C906) PVC (AWWA C900)	N/A	N/A	N/A	N/A

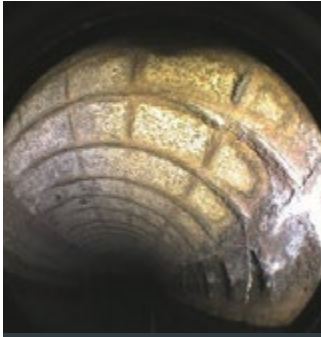
* AWWA C300 - Reinforced Concrete Pressure Pipe, Steel-Cylinder Type (CCP)
 AWWA C302 - Reinforced Concrete Pressure Pipe, Noncylinder Type (RCP)
 AWWA C303 - Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type (BWP)

MAGNETIC FLUX LEAKAGE	BROADBAND ELECTROMAGNETIC	OTHER	TYPICAL RECOMMENDED APPROACH
Changes in magnetic fields are used to detect corrosion pits and other defects. Tool must be at constant, close distance from pipe wall.	Changes in electromagnetic signals indicate corrosion pits and changes in thickness. Scanner held near pipe, but works through coatings, linings and scale.	<ul style="list-style-type: none"> • Sampling of pipes for various physical tests. • Manned entry for visual and sounding (delamination testing). • Petrographic (microscopic) examinations of concretes and mortars. 	<p>GENERAL APPROACH (all pipe types):</p> <ol style="list-style-type: none"> 1. Statistical analysis of available data 2. Risk prioritization (likelihood and consequence of failure) 3. Records review (leak/break repairs, drawings, specs, reports, soil info) 4. Site reconnaissance (accessibility, traffic conditions, other utilities) 5. Inspection planning (shutdowns, bypass, permits, alternatives) 6. Leak detection and/or field condition assessment inspection
N/A	N/A	<p>Testing of samples:</p> <ul style="list-style-type: none"> • Phenolphthalein stain • SEM/EDS • Petrography 	<ol style="list-style-type: none"> 1. Tests of opportunity samples from repairs and service taps 2. GIS mapping of soil data, breaks and condition assessment data 3. Targeted condition assessment of high-consequence pipes
N/A	External and internal spot assessments.	<ul style="list-style-type: none"> • Internal sounding to detect delamination. • Internal visual (manned entry or CCTV). • External direct assessment • Petrographic analysis of mortar/concrete. 	<ol style="list-style-type: none"> 1. Risk analysis based on pipe type, manufacturer, wire type, year of manufacturer, corrosivity 2. Manned entry/sounding (if feasible) 3. Electromagnetic scanning 4. Acoustic monitoring
N/A	External spot assessments. Emerging method for internal scanning.		<ol style="list-style-type: none"> 1. Corrosivity survey 2. External direct assessment where corrosion risk is highest 3. Manned entry examination 4. Electromagnetic scanning
Internal scanning of non-CML lined pipes. External spot assessments.	External spot assessments. Emerging method for internal scanning.	Petrographic analysis of mortar.	<ol style="list-style-type: none"> 1. Corrosivity survey 2. Remote field electromagnetic
Internal and external scanning of both CML and non-CML pipes.	External spot assessments. Emerging method for internal scanning.	Petrographic analysis of mortar.	<ol style="list-style-type: none"> 1. Corrosivity survey 2. Pipe-to-soil potential; cathodic protection assessment 3. Remote field electromagnetic or magnetic flux leakage
N/A	Potential for detailed scan of pipes.	<ul style="list-style-type: none"> • Forensic examinations of failed pipes. • Electrochemical noise monitoring. 	<ol style="list-style-type: none"> 1. Evaluate construction methods and standards. 2. Evaluate soil corrosivity. 3. Forensic exams of failures
N/A	N/A	Forensic examinations of failed pipes using laboratory and mechanical tests.	<ol style="list-style-type: none"> 1. Review of drawings, specs and inspection records 2. Forensic examination, if early or frequent failures have occurred

LEAK DETECTION METHODS apply to all pipes. **Leak noise correlation** is most effective on small diameter, metallic pipes. **Internal leak detection** tools apply on large diameter pipes with few appurtenances. Leak detection methods can also **detect gas/air pockets**.

Condition Assessment Technologies and Tests for Pressure Pipes

CLOSED-CIRCUIT TELEVISION INSPECTION (CCTV)



DESCRIPTION/MATERIALS: Remotely operated vehicles with digital cameras provide the ability to quantify and code pipeline defects and perform virtual zoom, pan and tilt to focus inspection on any potential defect.

- All materials

TECHNOLOGY PROVIDERS:

- RedZone Robotics
- Hydromax USA
- Pro-Pipe
- Aquam
- Carylton Corp.
- Others

COST:

\$

ADVANTAGES:

- Simple and relatively inexpensive.
- New side-scan technologies can provide high-definition imaging and ability to “unfold” the pipe and take measurements.

SIZE:

6" to 240"
(depending on the flow)

LIMITATIONS:

- Provides limited data (only visible defects).
- Little to no data on extent of internal corrosion.
- No data on external corrosion.
- Requires insertion of equipment into pipe.
- Ineffective when pipe is full of water.

MULTI-SENSOR INSPECTION (MSI)



DESCRIPTION/MATERIALS: Ability to provide concurrent inspection using high-definition CCTV, sonar and 2D or 3D LIDAR.

- All materials

TECHNOLOGY PROVIDERS:

- RedZone Robotics
- Hydromax USA
- PureRobotics
- Aquam
- Carylton Corp.
- Others

COST:

\$\$

ADVANTAGES:

- Customizable for specific pipe materials.
- Obtains detailed imaging of interior wall.
- Provides information on shape, wall loss and ovality.

SIZE:

24" to 240"

LIMITATIONS:

- Provides limited data (only visible defects).
- Little to no data on extent of internal corrosion.
- No data on external corrosion.
- Requires insertion of equipment into pipe.

MAGNETIC FLUX LEAKAGE (MFL)



DESCRIPTION/MATERIALS: Changes in magnetic fields are used to detect corrosion pits and other defects. Widely used in oil and gas industry.

- Ductile Iron Pipe (DIP)
- Steel Pipe (WSP)

TECHNOLOGY PROVIDERS:

- Cypress ETI

COST:

\$\$\$\$

ADVANTAGES:

- Provides high-resolution wall loss data of entire pipe circumference.
- Detects individual corrosion defect locations.

SIZE:

48" and up

LIMITATIONS:

- Cannot provide information on linings or coatings.
- Requires insertion of equipment into pipe.
- Few tools are currently available.
- Dry pipe is generally required.
- Scaling and/or linings may cause interference.
- Tool must be at constant, close distance to pipe wall.

BROADBAND ELECTROMAGNETIC TECHNOLOGY (BEM)



DESCRIPTION/MATERIALS: Changes in electromagnetic signals indicate corrosion pits and changes in thickness. Scanner held near pipe, so direct contact with pipe wall is not required.

- All metallic pipe

TECHNOLOGY PROVIDERS:

- Rock Solid

COST:

\$\$\$ to \$\$\$\$

ADVANTAGES:

- Detects internal and external flaws, inclusions, graphitization and fractures.
- Scan through linings, coatings and scale.
- Applied with “keyhole” tools in vacuum excavated holes.

SIZE:

- BEM™ Internal (6" and up)
- BEM™ External (2" and up)




LIMITATIONS:

- Spot assessments may not reflect pipe condition.
- External scan requires excavation to expose pipe.
- Internal scan requires insertion of equipment into clean, empty, straight pipe.
- In-pipe tool is prototype; cannot negotiate bends.

Condition Assessment Technologies and Tests for Pressure Pipes

<p>REMOTE FIELD TESTING (RFT)</p> 	<p>DESCRIPTION/MATERIALS: Used for detailed internal scan of pipes. Changes in electromagnetic signals indicate broken wires, corrosion pits and changes in wall thickness and stress anomalies. Also referred to as Remote Field Eddy Current (RFEC) or Remote Field Electromagnetic (RFET).</p> <ul style="list-style-type: none"> • Cast Iron Pipe (CIP) • Ductile Iron Pipe (DIP) • Steel Pipe (WSP) • Bar Wrapped Concrete Cylinder Pipe (BWP) • Prestressed Concrete Cylinder Pipe (PCCP) <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • PICA • Pure 	<p>COST:</p> <p>\$\$\$\$</p> <p>SIZE:</p> <p>3" to 26"</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Accurately measures wall thickness. • Detects individual corrosion defects. • Scans through linings and coatings. • In use on water pipelines for nearly 20 years. • Detects broken bars and cylinder corrosion in PCCP. <p>LIMITATIONS:</p> <ul style="list-style-type: none"> • Requires insertion of equipment into pipe. • Must run through pipeline slowly (5 to 10 ft/min). • Cannot provide information on linings or coatings. • In some cases, pipe must be drained.
<p>ACOUSTIC VELOCITY WALL THICKNESS TESTING (AWT)</p> 	<p>DESCRIPTION/MATERIALS: The speed of sound transmission calculates pipe wall stiffness while acoustic monitoring alerts and pinpoints the location of wire breaks in PCCP.</p> <ul style="list-style-type: none"> • All metallic pipe • Asbestos Cement Pipe • Prestressed Concrete Cylinder Pipe <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • PICA • Pure • Hydromax USA 	<p>COST:</p> <p>\$\$</p> <p>SIZE:</p> <p>All sizes</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Does not require insertion of equipment into pipe. • Leaks identified immediately. • Finds gas pockets in force mains. • Detects gross deterioration. • Acoustic monitoring detects wire breaks in PCCP. <p>LIMITATIONS:</p> <ul style="list-style-type: none"> • Measures average wall thickness over segment scanned (not individual defects). • Validation tests have yielded mixed results. • May need to pothole to attach accelerometers.
<p>ACOUSTIC LEAK AND GAS POCKET DETECTION</p> 	<p>DESCRIPTION/MATERIALS: Devices that use a combination of acoustic data and hydrophones.</p> <ul style="list-style-type: none"> • All materials <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • PICA • Pure • Hydromax USA • Others 	<p>COST:</p> <p>\$\$</p> <p>SIZE:</p> <ul style="list-style-type: none"> • Sahara (10" and up) • SmartBall (8" and up) • Fiber optics (all sizes) • p-CAT (6" to 36") metallic and AC pipes • Nautilus (10" and up) 	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Relatively non-disruptive. • Pipe can stay in operation. • Tool can be tethered or free-swimming. • External (non-invasive) methods are also available. • Competitive market for services. <p>LIMITATIONS:</p> <ul style="list-style-type: none"> • Measures average wall thickness over segment scanned (not individual defects). • Validation tests have yielded mixed results. • May need to pothole to attach accelerometers.

Condition Assessment Technologies and Tests for Pressure Pipes






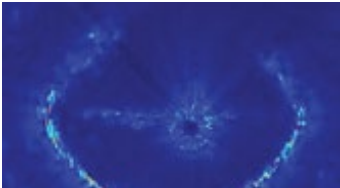
<p>ULTRASONIC (FOR WALL THICKNESS)</p> 	<p>DESCRIPTION/MATERIALS: Reflection of sound waves measures the thickness of various types of materials.</p> <ul style="list-style-type: none"> • All ferrous pipe <ul style="list-style-type: none"> ◦ Cast Iron Pipe (CIP) ◦ Ductile Iron Pipe (DIP) ◦ Steel Pipe (WSP) 	<p>COST: \$</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Quick and easy to use. • Effective for external spot assessments and measuring wall thickness.
<p>SOIL CORROSION AND RESISTIVITY SURVEY</p> 	<p>DESCRIPTION/MATERIALS: Various electromagnetic, electrical and laboratory methods characterize the corrosivity of soils, measure corrosion activity and assess corrosion protection and cathodic protection.</p> <ul style="list-style-type: none"> • All metallic pipe • Asbestos Cement Pipe (AWWA C402) • Prestressed Concrete Cylinder Pressure Pipe (AWWA C301 and C304) • Non-Prestressed Concrete Pressure Pipe (AWWA C300, C302 and C303) 	<p>COST: \$</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Non-disruptive. • Finds areas with high risk of external corrosion.
<p>PIPELINE CURRENT MAPPER (PCM)</p> 	<p>DESCRIPTION/MATERIALS: This tool measures leakage of electrical current on a pipeline and is used to detect coating defects and determine pipeline electrical continuity.</p> <ul style="list-style-type: none"> • All metallic pipe 	<p>COST: \$\$</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Identifies and quantifies corrosion potential. • Detects pipeline coating defects. • Locates electrical discontinuities in the pipeline. • Integrates with GPS. • Accurate in congested areas. • Doesn't require a connection to the pipe.
<p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • HDR • Others 	<p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • HDR • Others 	<p>SIZE: All sizes</p>	<p>LIMITATIONS:</p> <ul style="list-style-type: none"> • Provides limited information on pipe condition.

Condition Assessment Technologies and Tests for Pressure Pipes






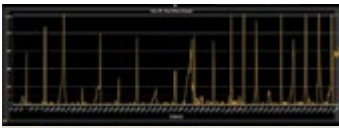


<p>BASELINE POTENTIAL SURVEY (BPS)</p> 	<p>DESCRIPTION/MATERIALS: Survey conducted along the pipeline to measure its existing condition. It provides a quick overview of the system, identifies areas where further assessment is warranted and determines the level of protection once the cathodic protection system is put into effect.</p> <ul style="list-style-type: none"> • All metallic pipe <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • HDR • Others 	<p>COST:</p> <p>\$</p> <p>SIZE:</p> <p>All sizes</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Indicates trends over time that can indicate problems. • Useful for recurring surveys to monitor changes in effectiveness in cathodic protection system. <p>LIMITATIONS:</p> <p>Provides limited information on pipe conditions.</p>
<p>CLOSE-INTERVAL POTENTIAL SURVEY (CIS)</p> 	<p>DESCRIPTION/MATERIALS: Like a Baseline Potential Survey, but conducted at numerous locations (every 5-10 feet) along the pipeline.</p> <ul style="list-style-type: none"> • All metallic pipe <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • HDR • Others 	<p>COST:</p> <p>\$\$</p> <p>SIZE:</p> <p>All sizes</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Determines the efficiency of the cathodic protection system. • Finds electrical discontinuity in a pipeline. • Identifies areas of active external corrosion. • Quantifies corrosion that is occurring. <p>LIMITATIONS:</p> <ul style="list-style-type: none"> • Cannot identify internal corrosion. • Performed over pipeline centerline which adds cost if alignment is in the street. • Requires pipe to be electrically continuous.
<p>ELECTRICAL CONTINUITY SURVEY (ECS)</p> 	<p>DESCRIPTION/MATERIALS: Test of the state of electrical continuity along the pipeline is performed at test station spans to validate the installed condition.</p> <ul style="list-style-type: none"> • All metallic pipe <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • HDR • Others 	<p>COST:</p> <p>\$</p> <p>SIZE:</p> <p>All sizes</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Identifies open joints (non-welded, rubber gasket or push-on joints without bond cables). • Gauges effectiveness of existing cathodic protection system, or suitability for addition of new system. <p>LIMITATIONS:</p> <p>Provides limited information on pipe condition.</p>
<p>DIRECT CURRENT VOLTAGE GRADIENT (DCVG) SURVEY</p> 	<p>DESCRIPTION/MATERIALS: Pipe coating evaluation technique that detects cathodic protection current pickup at coating holidays. (NACE defines a holiday as a protective coating discontinuity that exposes unprotected surface to the environment).</p> <ul style="list-style-type: none"> • All dielectrically coated metallic pipe <p>TECHNOLOGY PROVIDERS:</p> <ul style="list-style-type: none"> • HDR • Others 	<p>COST:</p> <p>\$\$</p> <p>SIZE:</p> <p>All sizes</p>	<p>ADVANTAGES:</p> <ul style="list-style-type: none"> • Locates voids in pipe coating. • Quantifies defects in real-time. • Provides indication of defect size. <p>LIMITATIONS:</p> <ul style="list-style-type: none"> • Cannot identify internal corrosion. • Does not quantify corrosion damage. • Requires a connection to the pipe and electrical continuity. • Less suited for urban areas.

Gravity Pipes (Storm and Sanitary Sewers)

Condition Assessment Technologies for Gravity Pipes


	SIZE	DESCRIPTION	EXPECTED INFORMATION
FLOW MONITORING 	6" and up	Sensors to measure depth of flow, or depth of flow and velocity, installed in hydraulically suitable manholes. Advanced methods include data storage and wireless transfer.	Wastewater flows used to determine dry weather diurnal flows, wet weather I/I flows for master planning, projection of capacity requirements and identification of deteriorated pipelines on a mass scale.
SMOKE TESTING (RAINFALL SIMULATION) 	4" and up	Introduction of harmless, non-toxic chemical smoke into isolated regions of the collection system and distributed through test section by large blowers. Defects photographed and cataloged by crew. Requires public notification.	Identifies inflow points. Escaping smoke helps identify uncapped cleanouts, storm drain interconnections, poorly fitting manhole covers, roof leaders and—under certain conditions—broken main sewer and house lateral pipe.
DYED WATER TESTING 	4" and up	Introduction of dyed-water to verify leaks, voids and cross-connections between the sanitary sewer and the storm sewer. Often performed in tandem with a CCTV inspection.	Correlates estimated flow rates from storm sewer system to sanitary sewer. Can also identify locations where flow is transferred from the sanitary sewer to the storm sewer and determine the presence and location of leaks in, or voids around, the pipeline.
FLOW ISOLATION (NIGHT RAIDS) 	4" to 24" (practical), but could be used at any size	Between midnight and 6 a.m., measure flow rate in each influent sewer in the manhole at the most downstream location of the test basin; flow in the sewer at this time is attributable to infiltration through leaking joints and broken sewer pipes. Continue working upstream along each pipeline branch where significant flows are measured until flow becomes minimal.	Identifies high rates of groundwater infiltration. Reaches with significant flow changes to be further evaluated.
CLOSED-CIRCUIT TELEVISION (CCTV) INSPECTION 	4" to 120"	Digital cameras provide ability to quantify pipeline defects and perform "virtual" pan and tilt to focus inspection on any potential defect.	Longitudinal pipeline cracks, circumferential cracks, fractured pipe, offset joints, roots, vertical and horizontal misalignments, broken lateral connections, protruding taps, rodents and vermin, etc.
LASER PROFILING (LIDAR) 	18" to 144"	Above water inspection in pipelines, typically collected at a rate of 12x/second.	Identifies loss of pipe wall due to corrosion. Quantifies ovality of pipe. Compares deflection versus design in horizontal and vertical directions.
SONAR PROFILING 	18" to 144"	Assess pipelines that continuously operate in a high flow condition, such as siphons and force mains. Typical collection rate of 1x/second.	Calculates debris levels and volumes in pipe for quantification of subsequent removal costs. Helps determine whether pipe capacity issues can be addressed by cleaning, or if pipe upsizing is needed. Identifies major structural anomalies.

Condition Assessment Technologies for Gravity Pipes

	SIZE	DESCRIPTION	EXPECTED INFORMATION
MULTI-SENSOR DATA COLLECTION 	18" to 144"	Common to provide concurrent high-definition CCTV, LIDAR and sonar inspection. Typical collection rate of 6x/second. Consider completing all three inspections concurrently, even if only one is specified, to allow subsequent recovery of additional data if determined valuable.	High-definition cross-section images and measurements at every 50 feet and at significant defects, as determined by the CCTV operator. Also can measure hydrogen sulfide, temperature and other data.
PIPE PENETRATING RADAR 	18" and up	This in-pipe inspection tool applies the same principals of ground-penetrating radar and can be combined with concurrent CCTV and laser profiling. Radar signals are directed toward the pipe wall, then reflections and refractions are measured to identify material interfaces. Can extend to 5 feet beyond the pipe wall and measure to an accuracy of $\pm 1/8$ inch.	Pipe wall thickness, variation in pipe wall thickness (indicative of corrosion), voids outside the pipe. For non-metallic pipe only.
MANHOLE INSPECTION 	N/A	Visual inspection can be completed without entering manholes to determine moderate to significant manhole defects. Tools such as remote CCTV cameras can be used to enhance inspection without requiring manhole entry. Manhole entry can be performed to provide more detailed inspection and testing.	Reveals structural integrity of manholes, signs of historic surcharge and signs of I/I (root intrusion, stains and active water flow). May also help identify blockages that can be cleared to reduce SSOs.
LATERAL INSPECTION (LIDAR) 	4" to 6"	Specialized CCTV camera equipment allows inspection of laterals where cleanouts are provided. Mainline CCTV equipment can inspect areas around each lateral connection with good results.	Identifies lateral defects similar to mainline CCTV.
JOINT PRESSURE TESTING 	6" to 42"	Tests pipe joints for integrity as part of I/I reduction.	Determines the extent of joint leakage and helps prioritize rehabilitation. Often done in conjunction with a chemical grouting operation.
FOCUSED ELECTRODE LEAK LOCATOR (FELL) 	6" to 60"	Uses electrical currents to determine if leakage or infiltration potential exists. Requires flow interruption to fill the pipe with water for testing.	Indicates joints and other portions of pipe where water is electrically connected to the ground.
MANHOLE VACUUM TESTING 	N/A	Determines I/I leakage potential through use of vacuum. Requires interruption of sewer flows.	Indicates which manholes are not completely sealed and might be sources of I/I.
MANHOLE HOLIDAY (SPARK) TESTING 	N/A	Uses high voltage instruments to determine integrity of manhole linings. Technique requires manned entry and flow interruption.	Provides information regarding lining integrity.

Pipeline Rehabilitation

Pipeline Rehabilitation Technologies

METHOD	DESCRIPTION	ADVANTAGES
<p>OPEN CUT REMOVE AND REPLACE</p> 	<p>Traditional method of excavating trench, installing bedding, laying pipe, backfilling and replacing pavement.</p>	<ul style="list-style-type: none"> • Proven approach for thousands of years. • Built to current standards. • Sequencing work may avoid bypass. • Numerous experienced contractors result in competitive pricing.
<p>CURED-IN-PLACE PIPE (CIPP)</p> 	<p>Inserting a felt liner impregnated with a thermosetting resin inside an existing pipe to form a new structural pipe inside the old pipe. Fiberglass reinforcement may be used to reduce thickness of liner in gravity pipes. Fiberglass, polyester or carbon fibers can be used for pressure pipe applications.</p>	<ul style="list-style-type: none"> • Provides a fully structural replacement pipe with proper design. • Small reduction in cross-sectional area. • Smooth interior with no joints typically improves flow capacity. • Installed from maintenance holes, therefore no entrance or exit pits are needed. • Liners can be cured with hot water, steam or ultraviolet light (which may also provide strength and environmental advantages). • Grouting not required due to tight fit or very small annulus. • Accommodates bends, deformations in existing pipe and non-circular conduits. • Lateral connections reinstated robotically. • Numerous experienced contractors result in competitive pricing.
<p>SLIPLINING</p> 	<p>Placement of a solid continuous or segmented pipe inside an existing pipeline. Typical materials include HDPE, PVC, FRP, steel and VCP.</p>	<ul style="list-style-type: none"> • Used for non-structural and fully structural rehabilitation. • If butt fusion pipe is used, the number of joints is minimized or eliminated. • Typically, only one pit is required (to pull pipe into the line). • If segmented pipe is used, sewer flows may not require interruption. • Less costly than installing a new pipe, particularly as burial depth increases.
<p>PIPE BURSTING PIPE REAMING</p> 	<p>Technology that replaces an existing pipe by breaking the old pipe and replacing it by inserting a new pipe of equal or large diameter.</p>	<ul style="list-style-type: none"> • Allows existing pipe to be upsized. • Up to 25% less expensive than open cut. • Maintains existing pipe alignment. • No disposal needed, as existing pipe fragments are left underground. • Reduces surface and community disruption.
<p>CLOSE-FIT LINING DIE-DRAW LINING ROLL-DOWN LINING FOLD-AND-FORM LINING</p> 	<p>Inserting a plastic pipe (HDPE or PVC) inside an existing pipe, either by folding the new pipe (U-shape) or by pulling the new pipe through a reduction die to temporarily reduce the diameter of the new pipe.</p>	<ul style="list-style-type: none"> • Provides a fully structural replacement pipe. • Small reduction in cross-sectional area (can install thin wall liners). • Excavation pit may not be required for smaller diameters. • Liner remains in tight contact with the inside of the host pipe; no grouting needed. • Adds more competition among lining methods. • Requires less downtime than CIPP. • Accommodates large radius bends.


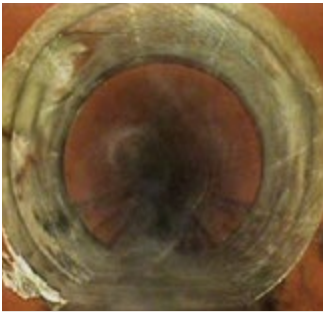



LIMITATIONS	SIZE	MAXIMUM INSTALLATION LENGTH	CONSTRUCTION TIME	CONSUMER DISRUPTION	OVERALL COST
<ul style="list-style-type: none"> Significant surface, socioeconomic and environmental costs. Potential community disruptions, including traffic, noise and dust. Significant geotechnical requirements. Often requires new alignment. Parallel pipes are difficult to add in congested corridors and increase O&M costs. 	All sizes	No limitation	High	Extreme	\$\$\$
<ul style="list-style-type: none"> Requires flow bypass. Relatively high unit costs. Obstruction can inhibit the installation process. Failures may occur due to improper wet-out, delays in transport, equipment failure during curing operations, poor design, lack of cleaning and hydrostatic forces. Styrene may be a byproduct of some liners; can be potential issue for odor complaints and has been identified as potential to interfere with wastewater treatment biological processes. Certified inspectors are highly recommended to monitor and inspect materials, installation and curing operations. 	<ul style="list-style-type: none"> 4" to 120" for gravity pipes 6" to 54" for pressure pipes 	<1,500' between access holes	Moderate	Moderate	\$\$
<ul style="list-style-type: none"> Significant reduction in cross-sectional area of pipe; large annulus. Insertion and reception pits may be needed. Bypassing may be required. Lay down area for butt-fused pipe is required. Generally can't pass through inflection points. Laterals must be reinstated externally (open excavation). Grouting of annular space may be required. Failures may include separation of pulling head from pipe, joint failure, excessive pulling loads leading to pipe failure and missed laterals. 	<ul style="list-style-type: none"> Up to 60" for HDPE and PVC Up to 120" for FRP/GRP Up to 144" for steel 	Varies with site conditions and material	Moderate	Moderate	\$\$
<ul style="list-style-type: none"> Needs geotechnical information in pipe zone and trench over the pipe. Insertion and reception pits may be needed. Potential for heaving or settlement depending on soils. Lateral reconnection by open cut is required. Failures may be caused by equipment breakdown, insufficient ground cover, curved pipes, narrow previous trench and rocky soils. Bursting system components undersized or not compatible with the application. 	2" to 54"	<1,000'	Moderate	Moderate	\$\$
<ul style="list-style-type: none"> Bypass required. Pit excavation may be required for installation. Lay down area for butt-fused pipe is required. May not be suitable for existing pipes with bends more than 22.5° (pits must be excavated for larger bends). Relatively higher cost compared to other lining methods. Infiltration may follow annular space. Failures can result from operator error, equipment failure, improperly sized pipe and liner slippage in service. 	3" to 60"	3,000'	Moderate	Moderate	\$\$

Pipeline Rehabilitation Technologies

METHOD	DESCRIPTION	ADVANTAGES
<p>SPIRAL WOUND LINING</p> 	<p>Strips of ribbed PVC are spun inside an existing gravity pipe to create a new pipe within the old pipe.</p>	<ul style="list-style-type: none"> • Adds more competition among lining methods. • Can be used for non-circular conduits. • Accessible through existing manholes. • Can negotiate bends between access points. • Improves flow coefficient. • Relatively long installation lengths are possible.
<p>CENTRIFUGALLY CAST CONCRETE PIPE LINING (CCCLP)</p> 	<p>Mechanical cleaning followed by centrifugally applied Portland cement-based binder with a complex formulation of pozzolans, admixtures, crystalline forming mineral, rheological admixtures and reinforcing fibers. The binder is mixed with carefully graded select silica sands.</p>	<ul style="list-style-type: none"> • Provides a fully structural replacement pipe with proper design. • Small reduction in cross-sectional area. • No joints and smooth interior. • Accommodates non-circular pipes, bends and deformations in existing pipe. • Short curing time shortening bypass time. • Can be fortified against MIC with an antimicrobial admixture. • Crack healing assisted by crystalline forming mineral admixtures. • Great short term mechanical properties, including compressive and flexural strengths. • Proven method since 1996.
<p>GEOPOLYMER LINING</p> 	<p>Cleaning followed by a spin- or spray-applied fly ash based binder with aluminosilicate, other lime containing minerals, alkalies and other admixtures along with fine-grained aggregates. Some are fiber-reinforced.</p>	<ul style="list-style-type: none"> • True alumina silicate condensations in the lab where highly refined raw materials are used along with high curing temperatures. • Accommodates non-circular pipes, bends and deformations in existing pipe. • Short curing time shortening bypass time. • Products have evolved over the past few years and their short term mechanical properties approach those of the industry standards. • More resistance to direct acid contact than Portland cement-bonded products. • Potential use in mild acidic industrial applications where pH <5.
<p>MANUFACTURED IN-PLACE COMPOSITE PIPE (MICP)</p> 	<p>Robotically installed composite system comprised of a closed-cell elastomer, high tensile carbon fiber filament and a high tensile rigid layer. Installed using autonomous navigation and control as well as a synergetic matrix of sensor feedback for real-time design validation.</p>	<ul style="list-style-type: none"> • Reduces long term creep effect and material fatigue. • Fills and seals any annular space or other discontinuities. • Absorbs and shields rigid layer from strain caused by seismic events. • Reports exact liner thickness and fiber pitch, 360 degrees in real-time during installation. • Structurally independent (AWWA Class IV) renewal solution. • Radial and axial carbon fiber reinforcement. • Lining of 0 to 90 degree bends without excavation. • Unlimited internal pressure rating. • Zero annulus – minimal diameter loss. • Autonomous control with auto correct platform eliminates 'applicator error.' • Significantly reduced environmental and public disruption. • Reduced installation times. • Utilizes excavated or manway accesses. • Does not require confined space entry.

LIMITATIONS	SIZE	MAXIMUM INSTALLATION LENGTH	CONSTRUCTION TIME	CONSUMER DISRUPTION	OVERALL COST
<ul style="list-style-type: none"> Relatively high cost compared to other lining methods. Specialized personnel required to operate winding equipment. Continuous fusion, solvent-welded or mechanical joints are required. Annular space must be grouted. Potential failures caused by equipment breakdown and unexpected obstructions. 	6" to 200"	<3,000'	Moderate	Moderate	\$\$ to \$\$\$
<ul style="list-style-type: none"> Surface cleaning and preparation needed. Products are not for use against direct acidic conditions. Bypass may be needed. Active infiltration needs to be addressed prior to application. May require confined space entry. Some materials may be costly. Not for certain industrial processes or structures where upstream acidic production occurs in significant quantities. 	36" to 120"	600'	Moderate	Moderate	\$\$
<ul style="list-style-type: none"> Bypass may be needed. Active infiltration needs to be addressed prior to application. May require confined space entry. Current products offered are hybrids; may compare their properties to simple Portland and sand mortars. Difficult to determine where it is resistant enough for typical municipal applications. One manufacturer suggests corrosion rates of 3" in ten years. Areas with severe MIC can produce acid concentrations nearing 7% with pH near 0. Autogenous crack healing not well studied. 	36" to 120"	500'	Moderate	Moderate	\$\$
<ul style="list-style-type: none"> Bypass required. Pit excavation may be required for installations without existing access points. Limited applications to date. 	48" and up	2,000'	Moderate	Low	\$\$

Pipeline Rehabilitation Technologies

METHOD	DESCRIPTION	ADVANTAGES
<p>SPRAY-APPLIED POLYMER LINING</p> 	<p>Mechanical cleaning followed by spray-applied product, epoxy, polyurethane or polyurea.</p>	<ul style="list-style-type: none"> ▪ Proven method. ▪ Relatively low cost. ▪ Stops internal corrosion; provides internal corrosion protection. ▪ Improves water quality and hydraulics.
<p>SPOT REPAIRS</p> 	<p>Methods for repairing short sections of pipe. Common methods include internally or externally applied fiber-reinforced polymer and internal seals.</p>	<ul style="list-style-type: none"> ▪ Minimal surface disruptions. ▪ Small reduction in cross-sectional area with internal repairs.
<p>CHEMICAL GROUTING</p> 	<p>Uses a packer and grouter to stop infiltration, close small voids and/or test the seal of individual gravity pipeline joints. Special shape and size packers can be designed and constructed.</p>	<ul style="list-style-type: none"> ▪ Proven method. ▪ Relatively low cost. ▪ Does not require bypassing. ▪ Not affected by active infiltration.
<p>CEMENT MORTAR LINING</p> 	<p>Mechanical cleaning followed by spray-applied mortar, per ANSI/AWWA Standard C602. Oldest pipeline rehabilitation method, introduced in the 1960s.</p>	<ul style="list-style-type: none"> ▪ Proven method. ▪ Relatively low cost. ▪ Stops internal corrosion; provides internal corrosion protection. ▪ Improves water quality and hydraulics. ▪ No work needed to restore services.
<p>CROWN SPRAYING</p> 	<p>Application of magnesium hydroxide to protect concrete gravity sewers and retard corrosion.</p>	<ul style="list-style-type: none"> ▪ Low unit cost. ▪ Protects corroded concrete pipes. ▪ Can be applied quickly.

LIMITATIONS	SIZE	MAXIMUM INSTALLATION LENGTH	CONSTRUCTION TIME	CONSUMER DISRUPTION	OVERALL COST
<ul style="list-style-type: none"> Thick linings are not proven to serve as fully-structural rehabilitation. ANSI/AWWA Standard C620 exists for 1 mm epoxy lining only. 	4" to 96"	Depends on equipment.	Moderate	Moderate	\$ to \$\$
<ul style="list-style-type: none"> Requires excavation for external repairs. High unit cost due to limited length of pipe repair. 	6" to 36"	3' to 20'	Moderate	Moderate	\$ to \$\$
<ul style="list-style-type: none"> Not a structural rehabilitation. Subject to failure when used in areas with fluctuating groundwater levels. Failures can result from operator error, equipment failure and improper mixing. Use of grout materials may be restricted in the future. 	6" to 144"	Depending on packer length space.	Low to Moderate	Low	\$ to \$\$
<ul style="list-style-type: none"> Minimal structural improvement. Only applicable to unlined cast iron and steel water mains. Not recommended for soft water. 	4" to 144"	Varies	Low	Moderate	\$
<ul style="list-style-type: none"> Temporary (1-2 year expected life). Only protects the pipe above the flow zone. 	27" and up	Depends on pipe size and equipment capacity.	Low	Low	\$



Treatment Facilities and Pump Stations





Facility conditions impact maintenance levels, power consumption and system performance.




Condition assessments for water and wastewater treatment facilities require a complete evaluation by a multi-disciplined team to define needed facility improvements, prioritize or schedule the improvement projects and estimate their costs. The best approach

includes a trained and experienced team working interactively with utility management and operations and maintenance staff.

Performing a condition assessment on a pump station helps identify components that may need to be repaired or replaced to ensure continued service and reliable operation.

Common Reasons to Assess Conditions at Facilities and Pump Stations

-  "I need to develop a Capital Improvement Program."
-  "I don't have enough budget to replace all of the aging or failing equipment."
-  "Which projects do I focus on first?"
-  "I want to extend the life of my equipment."

-  "Which breakdowns are most likely to shut down my entire facility?"
-  "I don't have much information on my equipment."
-  "I need an asset management program but don't know where to start."

Maintain or Replace... or Upgrade

Utilities routinely face the dilemma of repairing versus replacing a broken piece of equipment. When the equipment breaks, there is very little time to evaluate a third option: should it be upgraded to meet performance requirements?

A condition assessment can proactively help to resolve this three-dimensional dilemma. It can look at asset and system performance, in addition to the more traditional condition and reliability parameters while immediately addressing major deficiencies.

Prioritizing Projects

(Likelihood of Failure) x (Consequence of Failure)

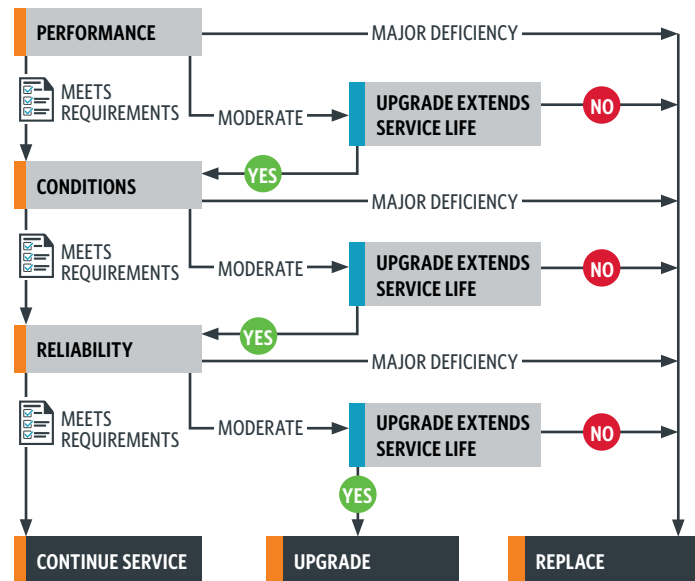
Almost all condition assessments at treatment plants and pump stations use some version of this formula.

Likelihood of Failure

Think of this as the condition of the asset. What is the chance that it will break down? It is a combination of many factors, including age, maintenance history and working environment. A condition assessment can provide a numerical rating to better understand this risk.

Consequence of Failure

What happens if an asset breaks? It may not only impact plant performance, but also seriously impact customers, businesses and the environment. One breakdown might not have an impact because of redundancy, but another may cause a citywide water outage. These must be evaluated and prioritized.



CONSEQUENCE OF FAILURE	Severe	10	20	30	40	50	60	70	80	90	100
		9	18	27	36	45	54	63	72	81	90
	Moderate	8	16	24	32	40	48	56	64	72	80
		7	14	21	28	35	42	49	56	63	70
		6	12	18	24	30	36	42	48	54	60
	Low	5	10	15	20	25	30	35	40	45	50
		4	8	12	16	20	24	28	32	36	40
		3	6	9	12	15	18	21	24	27	30
		2	4	6	8	10	12	14	16	18	20
	Negligible	1	2	3	4	5	6	7	8	9	10
		Negligible	Possible			Likely			Very Likely		
		LIKELIHOOD OF FAILURE									

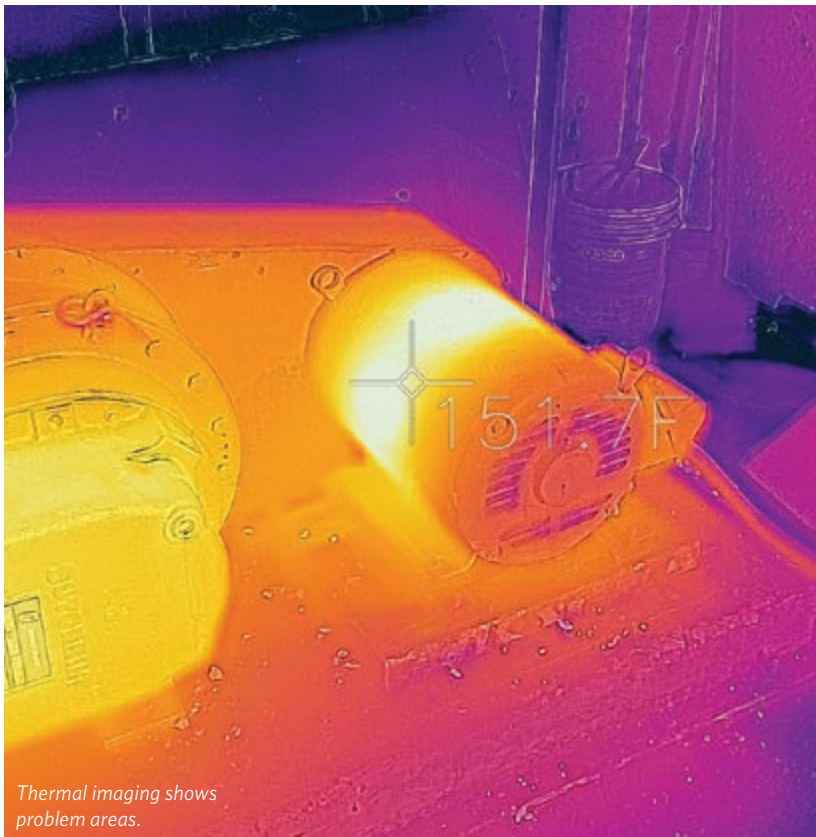
Combining Likelihood of Failure and Consequence of Failure



Use of an accelerometer to measure vibration



A standing nickel generally means that vibration is < 0.1 in/sec.



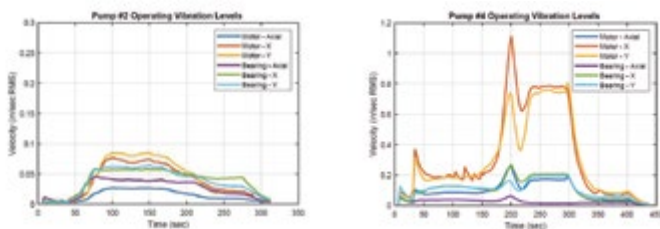
Thermal imaging shows problem areas.

Tools for Above Ground Infrastructure

Vibration Analysis

Maximum recommended vibration for most pumps is between 0.17 and 0.34 in/sec and will vary depending on pipe size and style. Vibration analysis techniques can vary from "rule of thumb" to highly complex.

Is your pump RPM at the critical speed? If so, you may get resonance and excess vibration. Use specialized equipment to test this, especially if you use a variable speed drive.

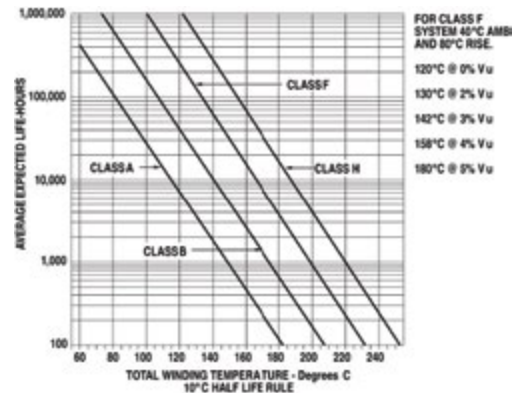


Vibration graphs of two identical pumps in series. Only one is below the required 0.34 in/sec

Thermal Imaging

Measuring temperatures of motors and electrical equipment provides important information about their condition.

Did you know that for every 10° C (18° F) increase in motor temperature, the life of the winding insulation is reduced by 50%?



Winding Temperature vs. Motor Life



Electrical Testing

While technically still thermal imaging, high resistance electrical connections in switchgear, starters, etc. can become major problems if left unchecked. Thermal imaging can be utilized to detect such "hot spots."

Additionally, ground fault monitoring can also provide insight as to the condition of the electrical distribution system. Phase to ground faults can cause uneven phase voltages leading to reduce motor and equipment life expectancies.



Acoustic Testing

Cavitation of pumps can cause serious impacts to impellers and overall pump performance. The sounds associated with cavitation are not always obvious. Experienced operations and maintenance staff using a stethoscope on the pump volute are able to detect cavitation.

Condition Assessment for Treatment Facilities and Pump Stations

	ARCHITECTURAL	STRUCTURAL	MECHANICAL (HVAC AND PLUMBING)
COMPONENTS	<ul style="list-style-type: none"> • Building conditions • Masonry and exterior walls • Insulation • Sealants • Doors and windows • Roofing systems • Floors and ceiling • Paint systems and finishes • Occupancy and life safety • Accessibility • Means of egress 	<ul style="list-style-type: none"> • Process structures • Building structures • Cast-in-place concrete • Precast/prestressed concrete • Structural steel • Concrete masonry • Miscellaneous metals, including aluminum and stainless steel • Equipment foundations and supports • Piping support systems 	<ul style="list-style-type: none"> • Air handling equipment • Make-up air units • Heating equipment • Cooling equipment • Ductwork • Boilers • Chillers • Cooling towers • HVAC controls • Hot/chilled water systems • Plant water systems • Plumbing fixtures and piping systems • Supply and exhaust fans
SUGGESTED ELEMENTS TO ASSESS	<ul style="list-style-type: none"> • Asset ID and age • Maintenance history • Type of construction • Roof type and condition • Exterior walls and insulation condition • Interior walls condition • Doors, windows and hardware condition • Stairs, ladders and guardrail condition • Coatings condition and corrosion issues • Accessibility compliance 	<ul style="list-style-type: none"> • Asset ID and age • Maintenance staff assessment • Previous evaluations/inspections • Exposure and loading conditions • Overall condition – structural distress or movement • Surface condition – cracking, spalling, corrosion conditions • Strength of concrete or grout per ASTM • Petrographic examination of concrete • Concrete sounding and other non-destructive testing methods • Half-cell corrosion testing per ASTM • Phenolphthalein testing • Microstructural analysis per ASTM 	<ul style="list-style-type: none"> • Equipment ID, age and nameplate • Historical maintenance information • Overall condition and reliability • Spare parts • Previous reports/inspections • Control cabinets and controls • Fan and heating system performance • Ventilation issues • Plumbing issues
STANDARDS/CODES	<ul style="list-style-type: none"> • International Building Code • International Existing Building Code • International Fire Code • International Energy Conservation Code • NFPA • ANSI • ASTM • FM Global • Underwriters Laboratory (UL) 	<ul style="list-style-type: none"> • International Building Code • International Existing Building Code • American Concrete Institute (ACI) • American Institute of Steel Construction (AISC) • American Welding Society (AWS) • ASTM/ANSI • SEI/ASCE 11 for Existing Buildings • SEI/ASCE 7 Minimum Design Loads for Buildings and Other Structures 	<ul style="list-style-type: none"> • NFPA • IBC Codes • Underwriter Laboratory (UL) • ANSI/AWWA • ASME/ASTM • ASHRAE • NEMA

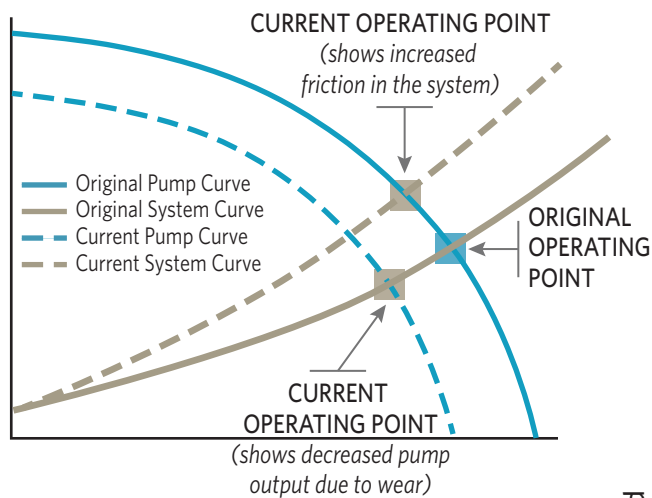
PROCESS	ELECTRICAL AND I&C	SITE CIVIL
<ul style="list-style-type: none"> ▪ Process equipment ▪ Process basins ▪ Pumping equipment ▪ Chemical feed systems ▪ Valves, piping and pipe supports ▪ Flow control and gates ▪ Process efficiency issues ▪ Ancillary equipment 	<ul style="list-style-type: none"> ▪ Switchgear and switchboards ▪ Site power distribution and transformers cables ▪ Standby power and transfer switches, UPS systems ▪ MCCs and VFDs ▪ Panelboards and disconnects ▪ Major motors ▪ Conduits, raceways and conductors ▪ Lighting systems and emergency lighting ▪ Grounding and surge protection ▪ I&C equipment – field devices, primary elements, control panels, PLC's ▪ Control approach and SCADA system ▪ Security systems 	<ul style="list-style-type: none"> ▪ Overall site review ▪ Site access ▪ Site roads, parking and fencing ▪ Exterior lighting ▪ Landscaping ▪ Storm water management ▪ Neighborhood concerns
<ul style="list-style-type: none"> ▪ Equipment ID and nameplate data ▪ Historical maintenance records and operational history ▪ Asset management information ▪ Equipment age/normal asset life ▪ Equipment reliability and impact of failure ▪ Performance rating and condition ▪ Spare parts availability ▪ Previous facility evaluations ▪ Performance tests – pumps, blowers, etc. ▪ Ancillary systems – air, seal water, priming, etc. 	<ul style="list-style-type: none"> ▪ Asset/equipment ID, age and nameplate ▪ Visual inspection ▪ Maintenance history ▪ Equipment condition and reliability ▪ Conduit/wire condition ▪ Equipment suitability for environment ▪ UPS requirements ▪ Lighting level ▪ Primary elements condition ▪ Data communication ▪ SCADA controls performance ▪ Interview plant operating staff ▪ NEC/NFPA compliance review 	<ul style="list-style-type: none"> ▪ Site paving ▪ Site drainage issues ▪ Site lighting condition and levels ▪ Landscaping condition ▪ Site access/control ▪ Noise/neighborhood issues ▪ Storm drainage system
<ul style="list-style-type: none"> ▪ State regulatory requirements ▪ IO state standards ▪ Hydraulic Institute ▪ AWWA standards ▪ NSF ratings ▪ ASTM/ANSI 	<ul style="list-style-type: none"> ▪ National Electric Code (NEC) ▪ IBC Codes ▪ NFPA ▪ IEEE ▪ Underwriters Laboratory (UL) ▪ NEMA/ANSI ▪ ISA 	<ul style="list-style-type: none"> ▪ Applicable local standards ▪ AASHTO ▪ ASTM ▪ U.S. Army Corps of Engineers



Pump Performance Testing

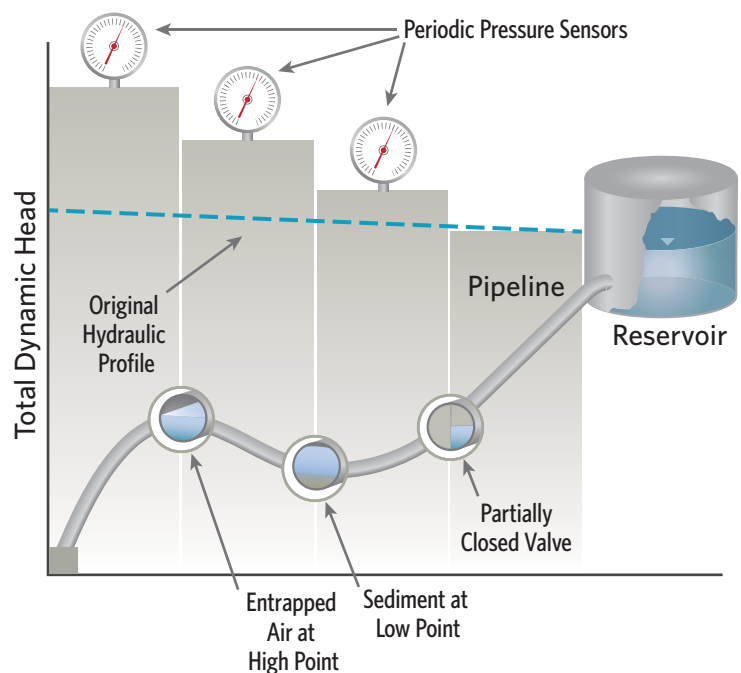
Determine Causes for Loss of Pump Output

Pump performance testing helps a utility determine the cause of decreased pump performance. Though decreased performance is often attributed to premature pump wear, in many cases the cause is a constriction — either upstream (clogged intake screen) or downstream (sediment accumulation, entrapped air) — that can be addressed through maintenance.



In the figure to the left, comparison of the current operating point to the original operating point may indicate either impeller wear (reduced pump curve) or increased headloss in the system (increased system curve).

There are many potential causes of increased headloss in the system, as shown in the figure to the right. Pressure sensors and portable flow meters at strategic locations can be used to pinpoint specific issues, such as reduced cross-sectional area due to entrapped air (air valve failure) or accumulated sediment.



Rapid Condition Assessment

If a utility has limited budget or is short on information, it may be appropriate to perform a rapid condition assessment. Facilities can be evaluated at a high level to get an initial idea of the improvements that will be needed. This approach is ideal for smaller utilities or when performing due diligence acquiring new assets.

TASK	ADVANTAGES	DISADVANTAGES
Evaluation done at system level, not at asset level	Do not need detailed information on each asset	Less granularity on issues
One rating for each of six categories: Architectural, Structural, Mechanical, Electrical, Process, Civil	Simplified and standardized approach to compare dissimilar systems	Inability to evaluate issues with individual assets
Evaluation by experienced operator or engineer	Benefit by from personal, hands-on experience	No advanced diagnostic tools used
Class 4 or 5 Cost Estimates	Immediate range of costs	Potentially -20% to +100% of actual cost

IMMEDIATE RECOMMENDED IMPROVEMENTS	FACILITY/PROCESS NAME	CRITICALITY	OVERALL RATING	WEIGHTED RATING
Polymer Usage Evaluation	Dewatering Centrifuge	5.00	2.80	14.00
Odor Control Evaluation/Rehabilitation	Equipment Building Common Facilities	5.00	2.56	12.81
Effluent Pump Evaluation	Effluent Pumping	0.00	2.50	0.00
Odor Control Evaluation	Biofilter 1	5.00	2.00	10.00
Secondary Process Modeling	Aeration Basins and Splitter Box	4.00	2.29	9.14
Drive Chain Replacement	Headworks Fine Screening	3.00	2.81	8.44
Odor Control Evaluation/Rehabilitation	Digester Building Common Facilities	5.00	1.56	7.78
Water Cross Connection Evaluation	Digester Building Common Facilities	5.00	1.56	7.78
Polymer Usage Evaluation	Rotary Screen Thickener	5.00	1.33	6.67
Odor Control Evaluation	Biofilter 2	5.00	1.00	5.00

6 YEAR RECOMMENDED IMPROVEMENTS	FACILITY/PROCESS NAME	CRITICALITY	OVERALL RATING	WEIGHTED RATING
Rehabilitate/Replace Gravity Thickener	Gravity Thickener	5.00	3.31	16.56
Rehabilitate/Replace Alkalinity Control System	Alkalinity Control System	5.00	3.20	16.00
Replace/Upgrade Dewatering System	Dewatering Centrifuge	5.00	2.80	14.00
Miscellaneous Building Improvements	Effluent Building Common Facilities	5.00	2.64	13.21
Replace Plant Effluent pH and DO Analyzers	Effluent Building Common Facilities	5.00	2.64	13.21
Replace VFDs (Square D Altivar)	Effluent Building Common Facilities	5.00	2.64	13.21

AACE INTERNATIONAL'S COST ESTIMATE CLASSIFICATION MATRIX FOR THE PROCESS INDUSTRIES				
	PRIMARY CHARACTERISTIC	SECONDARY CHARACTERISTIC		
	MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES Expressed as % of complete definition	END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY Typical variation in low and high ranges (*)
CLASS 5	0% to 20%	Concept screening	Capacity factored, parametric models, judgement or analogy	L: -20% to -50% H: +30% to +100%
CLASS 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
CLASS 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
CLASS 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
CLASS 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

(*) The state of process technology, availability of applicable reference cost data and many other risks affect the range. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.



Tanks and Reservoirs

Condition assessment of tanks and reservoirs should be scalable to the utility's available budget and adaptable to shifting priorities. Whether for concrete reservoirs or steel water tanks, an assessment program establishes program goals, prioritizes reservoirs based on triage-level assessments and then provides comprehensive physical and performance evaluations.

Rehabilitation of water storage reservoirs is an important part of a complete facility management and maintenance

plan. Rehabilitation may include sandblasting, repair/ replacement of roof, shell, columns and floor, leak repair, interior and exterior re-coating, cathodic protection and safety and building code upgrades. For reservoirs, rehabilitation focuses on repairing the core of the structure and protecting it from future deterioration. Properly rehabilitated reservoirs will minimize leakage, protect the health and safety of consumers and provide a safe working environment for operators.



1 Inspection Recommendations

INSPECTION TYPE	DESCRIPTION	STAFF REQUIREMENTS
Routine (daily to weekly)	Exterior inspection to detect acute changes such as storm damage and vandalism.	One staff member.
Periodic (quarterly to annually)	Exterior inspection and limited internal visual inspection from hatch to monitor areas of concern.	Two to three staff members. Requires safety procedures and coordination.
Comprehensive (every five years)	Internal and external physical evaluation, review of operations and maintenance records and performance evaluation.	Multi-disciplined team, including staff familiar with operations, maintenance, water quality, reservoir design and structural engineering.

2 Triage

Typically conducted in the first few months of a program, a triage assessment is carried out with the tank in service.

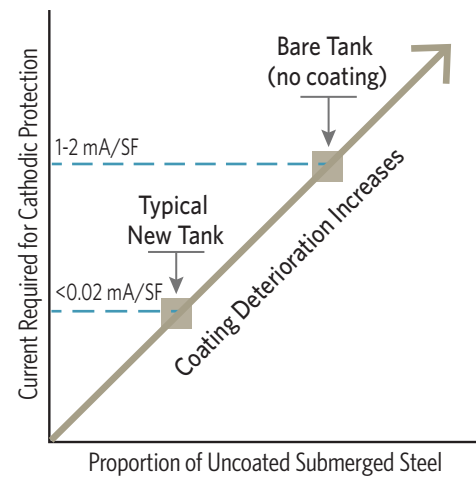
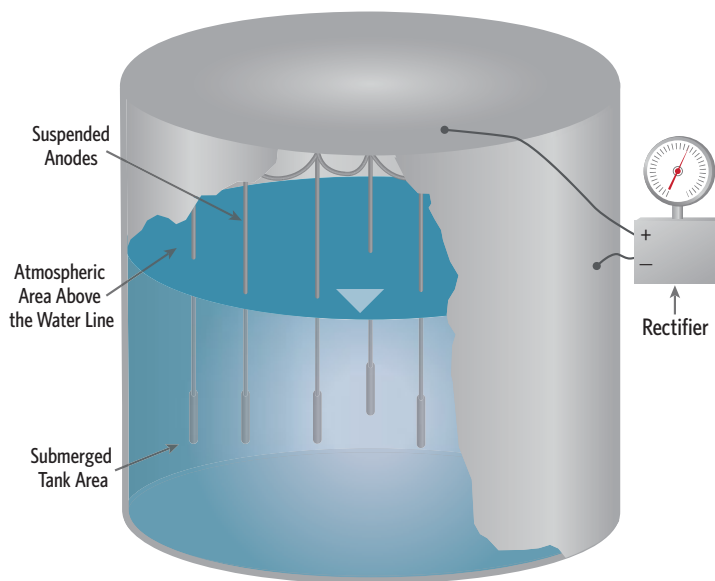
- ✓ Perimeter and site walk
- ✓ Exterior roof assessment
- ✓ Interior visual assessment from the hatch
- ✓ Review of historical O&M data
- ✓ Cathodic protection coatings assessment (steel tanks only)

1 Water Quality Challenges

CHALLENGE	CAUSATIVE FACTORS
MICROBIAL	
Proliferation of bacteria/bacterial regrowth	Detention time, temperature, food sources, bacterial sources, lack of residual
Biodegradation of tank coatings and materials	Exposure time, surface area, material properties
Nitrification	Temperature, presence of ammonia, detention time, lack of residual
CHEMICAL/PHYSICAL	
Short-circuiting/dead zones	Detention time, common inlets and outlets, insufficient baffles or mixing
Disinfection by-product formation	Detention time, presence of precursors, presence of excess sediment

2 Leveraging a Cathodic Protection System for Rapid Condition Assessment

Condition of steel tank coatings can be efficiently assessed using either a permanent current cathodic protection (CP) system, or a temporary system specifically installed for condition assessment. The current applied through an impressed current CP system can be adjusted to the total area of exposed submerged steel below the water level in a steel tank. As the coating degrades over time, the CP current increases.



AWWA D102 recommends complete removal and recoating at 25% bare (current of 0.25 to 0.5 milliamps per square foot [mA/SF]), or when the atmospheric area above the water line requires recoating. As CP systems do not protect the atmospheric area, recoating of tanks with CP systems is often targeted at protecting this more vulnerable area.

3 Common Steel and Coatings Tests

- Ultrasonic thickness testing of exterior shell, bottom and roof
- Interior and exterior weld inspections
- Pit-depth measurements
- Visual coating inspection per SSPC-VIS2
- Dry-film thickness measurements
- Adhesion testing per ASTM 3359 Method X-Cut
- Qualitative lead testing

3 Comprehensive Inspections

Based on triage assessment, tanks are prioritized for comprehensive assessment

	CONCRETE	STEEL
Visual Inspection Internal raft inspection for concrete tanks or dry inspection for steel tanks.	✓	✓
Code Conformance Analytical evaluation comparing the tank's condition to design and prevailing codes. <ul style="list-style-type: none"> • Concrete – International Building Code references ASCE 7-05 for minimum loads • Steel – Per AWWA D-100 and SEI/ASCE 11-99 	✓	✓
1 Water Quality Challenges (See adjacent table)	✓	✓
Ventilation Calculated per ASHRAE Fundamentals Handbook. Requirements depend on the tank and ambient conditions. Ventilation affects long-term reservoir performance.	✓	✓
Deck Movement Decks are frequently found to be improperly constrained or not performing as designed. Deck movement can compromise the roof and expose metals to corrosion.	✓	
Cracking ACI 350, Code Requirements for Environmental Engineering Concrete Structures and Commentary, has replaced ACI 318. ACI 350 calls for a higher reinforcement ratio to minimize crack widths and produce water-tight structures.	✓	
Leakage Perform leak tests per ACI 350. Evaluation should also consider liner type and condition, if applicable.	✓	✓
2 Cathodic Protection Assessment (See adjacent section)		✓
3 Steel and Coatings Testing Will vary according to the tank and level of assessment. Common tests include those shown to the left.		✓

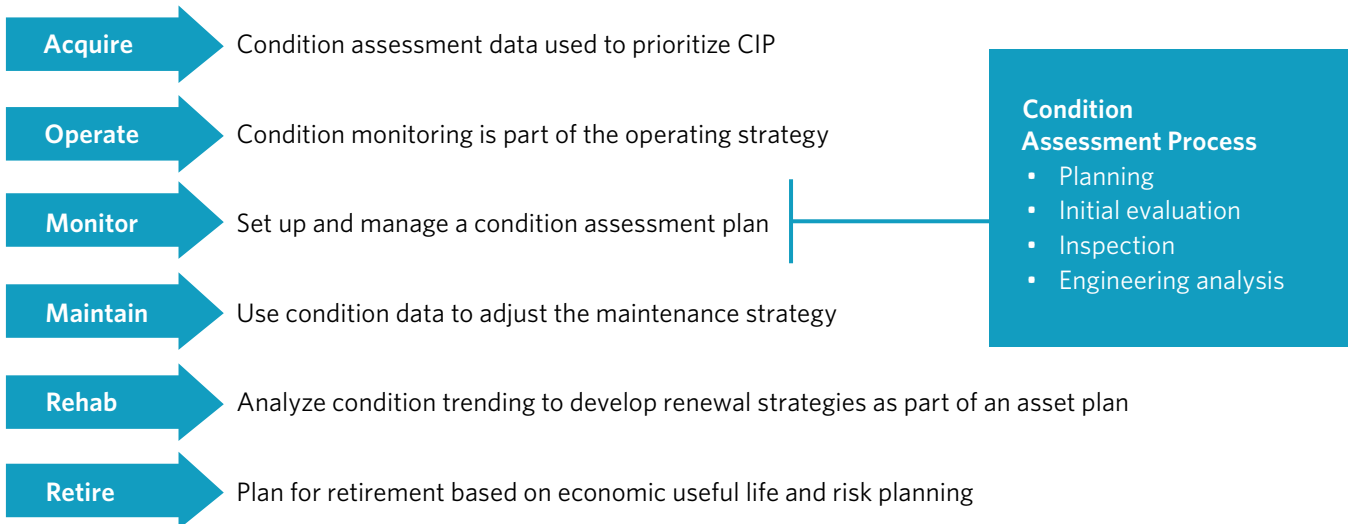
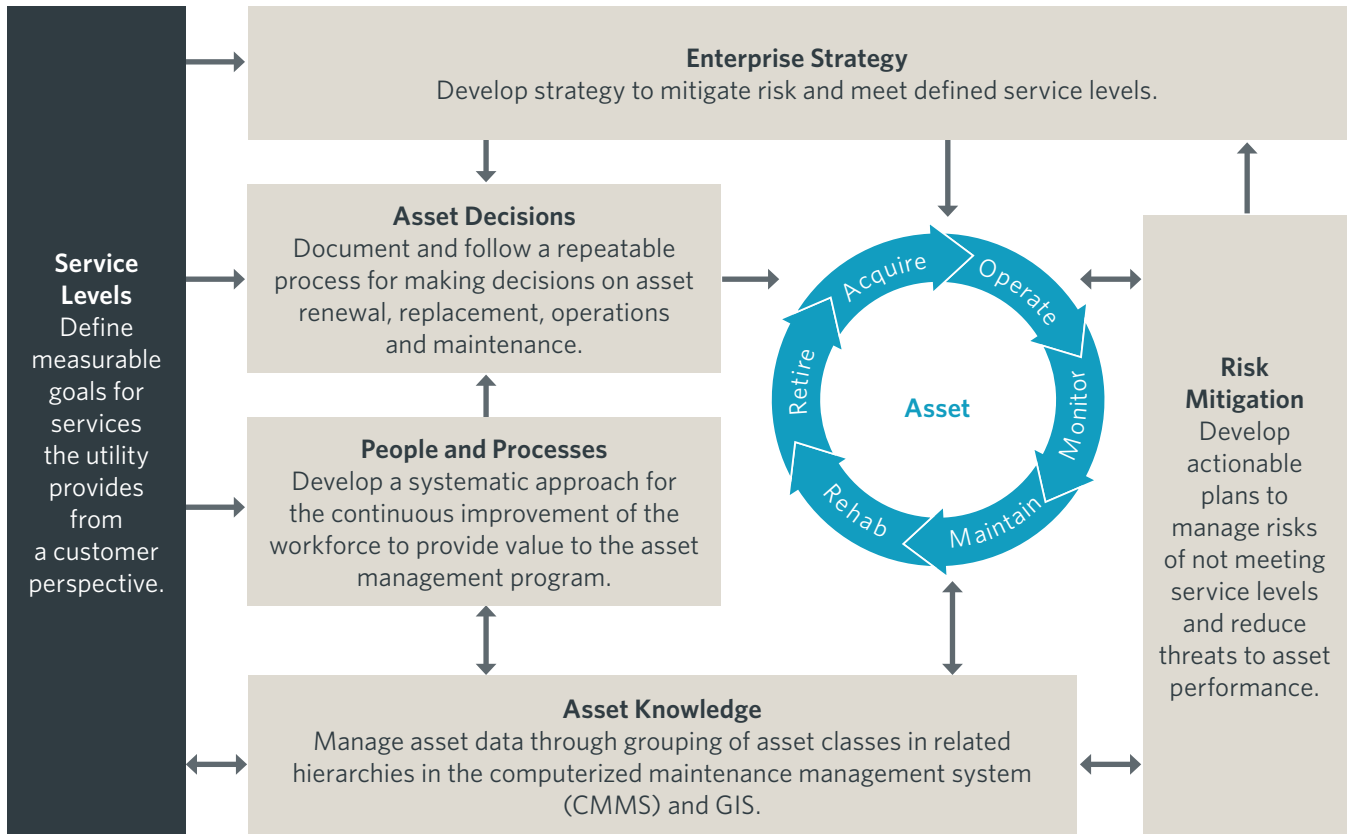


Asset Management

Managing assets is a process that requires a structured approach, defined resources and an ability to adapt to the changing needs of the system. HDR's approach is flexible and tailored to fit your needs. We succeed when you can make confident and defensible decisions based on your data.

Integrating Condition Assessment into Your Overall Asset Management Program

Asset management is a structured, data-driven approach to optimizing the lifecycle cost of asset ownership and focuses on providing reliable and dependable levels of customer service. Condition assessment is an integral part of the asset management process.





Asset Management = Smart Investment

Successful asset management enables the efficient, strategic allocation of limited resources toward sustainable capital and operational programs.

Asset management is not just about a single project. It is about developing the right tools to leverage data about the condition of your assets to achieve organizational objectives.

The Asset Management Process Ask Yourself:

What is the current state of my assets?

What is my required level of service?

What assets are critical to performance?

What are my best investment strategies?

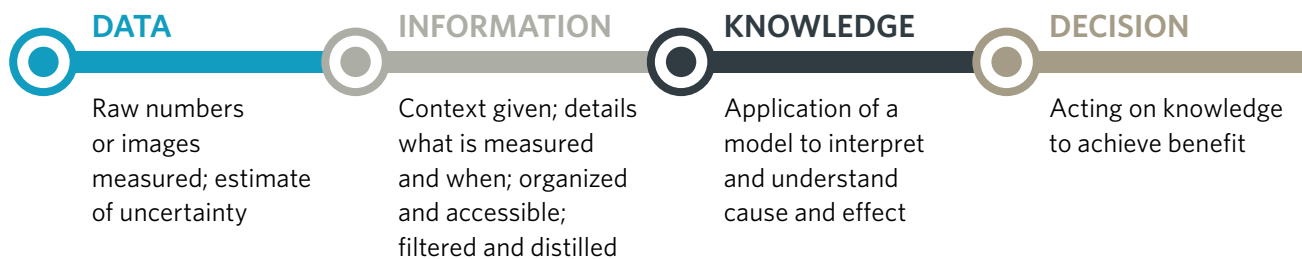
What is my best long-term funding strategy?

Reasons to Create an Asset Management Strategy

RISK MANAGEMENT	DESIRED OUTCOMES
<ul style="list-style-type: none"> • Aging infrastructure • Uncertainty about when and where to invest • Loss of knowledge from an aging workforce 	<ul style="list-style-type: none"> • Informed decision-making process • Predictable, prioritized investment level • Predictable infrastructure performance • Regulatory compliance • Thriving community • Improved ability to engage stakeholders • Sustainable infrastructure

Transforming Condition Data into Actionable Decisions

HDR develops asset management decision support tools by building a practical and structured process for transforming data into actionable decisions. Our tools store data in an analyzable format to streamline development of reporting dashboards.





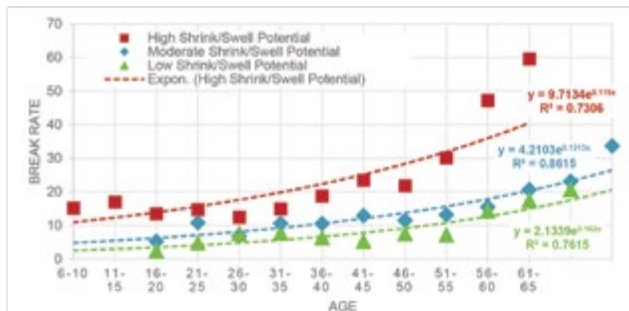
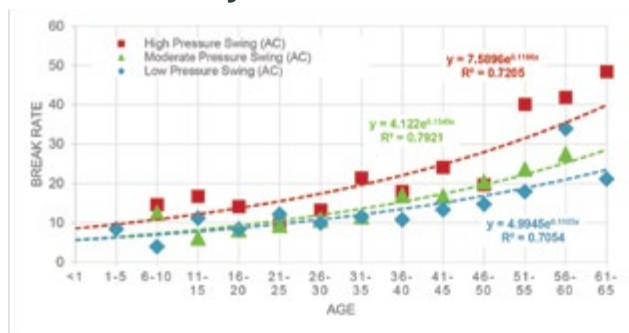
Collect the right data. When a pipe is exposed (e.g. break response, new tap installation, pipe renewal, appurtenance renewal), it provides a unique opportunity to cost-effectively gather condition assessment data (e.g. pipe samples, photos, soil samples) that can be crucial in making effective pipe management decisions.

Asset Management and Water Distribution Systems

Extending asset life varies among utilities and depends upon factors such as system performance, size and effectiveness of a utility's historic renewal program and physical characteristics such as material quality, construction quality, system age, strength of deterioration sources and stresses (internal and external). These characteristics and condition assessment data can be evaluated to identify priorities and cost-saving alternatives to replacement such as pressure reduction and corrosion protection.

Recent advances in analytical techniques can support utilities to better understand and communicate investment scenarios by forecasting level of service several decades into the future including breaks per year, break response staff needs, customer outages and flow not delivered.

As utilities evolve, implementation of utility-wide condition assessment and renewal strategy is appropriate to cost-effectively sustain desired service levels while avoiding future rate shock when addressing aging infrastructure.



Variation in deterioration rates can be measured using historic break data to quantify which factors drive some pipes to deteriorate faster than others. At this utility, pipes exposed to excessive ground movement (high shrink/swell) and pressure variations (high pressure swing) deteriorate faster and will have a shorter life.

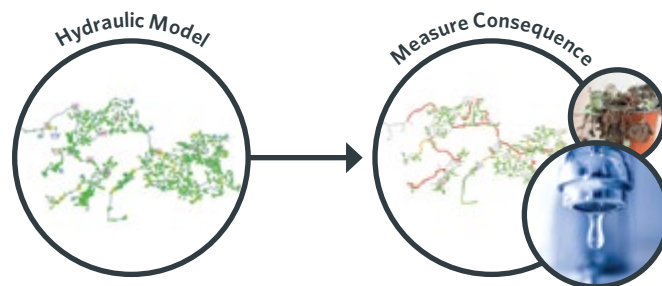
Water utilities in the U.S. replace approximately

0.37%
of their pipelines each year.*

*AWWA 2003, AWWA 2011

At this pace, it would take roughly

270 years
to replace an entire system.



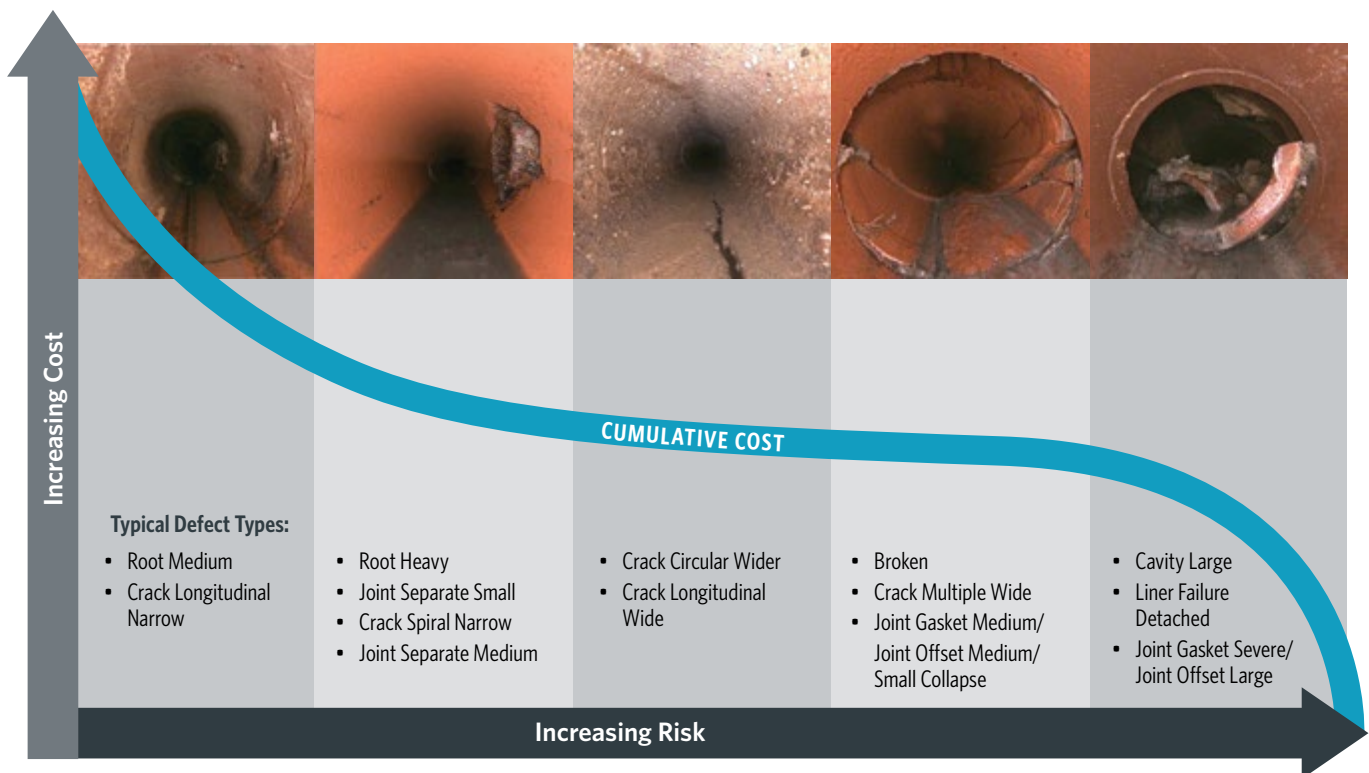
Not all failures are created equal. By fully leveraging an existing hydraulic model, utilities can cost-effectively quantify the consequence of failure for each pipe in the systems in terms of customer outages, critical customer outages, water lost and demand not delivered.



Asset Management and Wastewater Collection Systems

The true renewal need for wastewater systems varies widely from utility to utility and depends on system performance, regulatory drivers and system characteristics. Age alone is not a good indicator of investment needs for replacement or extending asset life. Analytical tools and decision logic can be applied to wastewater condition assessment data to support improved decision making for managing assets by balancing cost, risk and level of service.

Effective programs incorporate condition assessment data and risk to optimize operations and maintenance. Condition data can be applied to increase or reduce the frequency and type of preventative maintenance programs to manage risk, extend asset life and save resources.



With competing goals, asset management helps manage complexity and use resources efficiently.



Looking for More Guidance?

We've conducted research, served on committees and translated manuals. More than any other consultant, HDR has advanced the practice of water main condition assessment. If you want more guidance on condition assessment and rehabilitation, please contact us at water@hdrinc.com, or access our recommended reference documents at hdrinc.com/AssetLife



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The Water Research Foundation

- *Acoustic Signal Processing for Pipe Condition Assessment (Report #4360)*
- *An Assessment of Water Distribution Systems and Associated Research Needs (Report #706)*
- *Answers to Challenging Infrastructure Management Questions (Report #4367)*
- *The Assess-and-Fix Approach: Using Non-Destructive Evaluations to Help Select Pipe Renewal Methods (Report #4473)*
- *Asset Management Research Needs Roadmap (Report #4002)*
- *Criteria for Optimized Distribution Systems (Report #4109)*
- *Development of an Effective Management Strategy for Asbestos Cement Pipe (Report #4480)*
- *Distribution Infrastructure Management - Answers to Common Questions (Report #2629)*
- *Distribution System Security Primer for Water Utilities (Report #2931)*
- *Effects of Electrical Grounding on Pipe Integrity and Shock Hazard (Report #913)*
- *External Corrosion and Corrosion Control of Buried Water Mains (Report #2608)*
- *Failure of Prestressed Concrete Cylinder Pipe (Report #4034)*
- *Global Review of Spray-On Structural Lining Technologies (Report #4095)*
- *Investigation of Pipe Cleaning Methods (Report #2688)*
- *Leveraging Data from Non-Destructive Examinations to Help Select Ferrous Water Mains for Renewal (Report #4471)*
- *Managing Infrastructure Risk: The Consequence of Failure for Buried Assets (Report #4451)*
- *No-Dig and Low-Dig Service Connections Following Water Main Rehabilitation (Report #2872)*
- *Optimizing Corrosion Control in Water Distribution Systems (Report #2648)*
- *Retrofit and Management of Metallic Pipe with Cathodic Protection (Report #4618)*

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- *AWWA Manual M77: Condition Assessment of Water Mains*
 - *AWWA Manual M28: Rehabilitation of Water Mains, Fourth Edition*
 - *NASSCO and WEF's Trenchless Technologies and Asset Management Manual of Practice*
 - *NASSCO's Pipeline Assessment Certification Program Reference Manual*