MAY 8, 2026

Extending the Useful Life of Water Mains Through Condition Assessment and Rehabilitation

SCOTT JAUCH
EMPLOYEE OWNER
CONDITION ASSESSMENT REGIONAL PRACTICE LEAD

BLACK & VEATCH

© Black & Veatch Corporation, 2026. All Rights Reserved. The Black & Veatch name and logo are registered trademarks of Black & Veatch Corporation.



Agenda

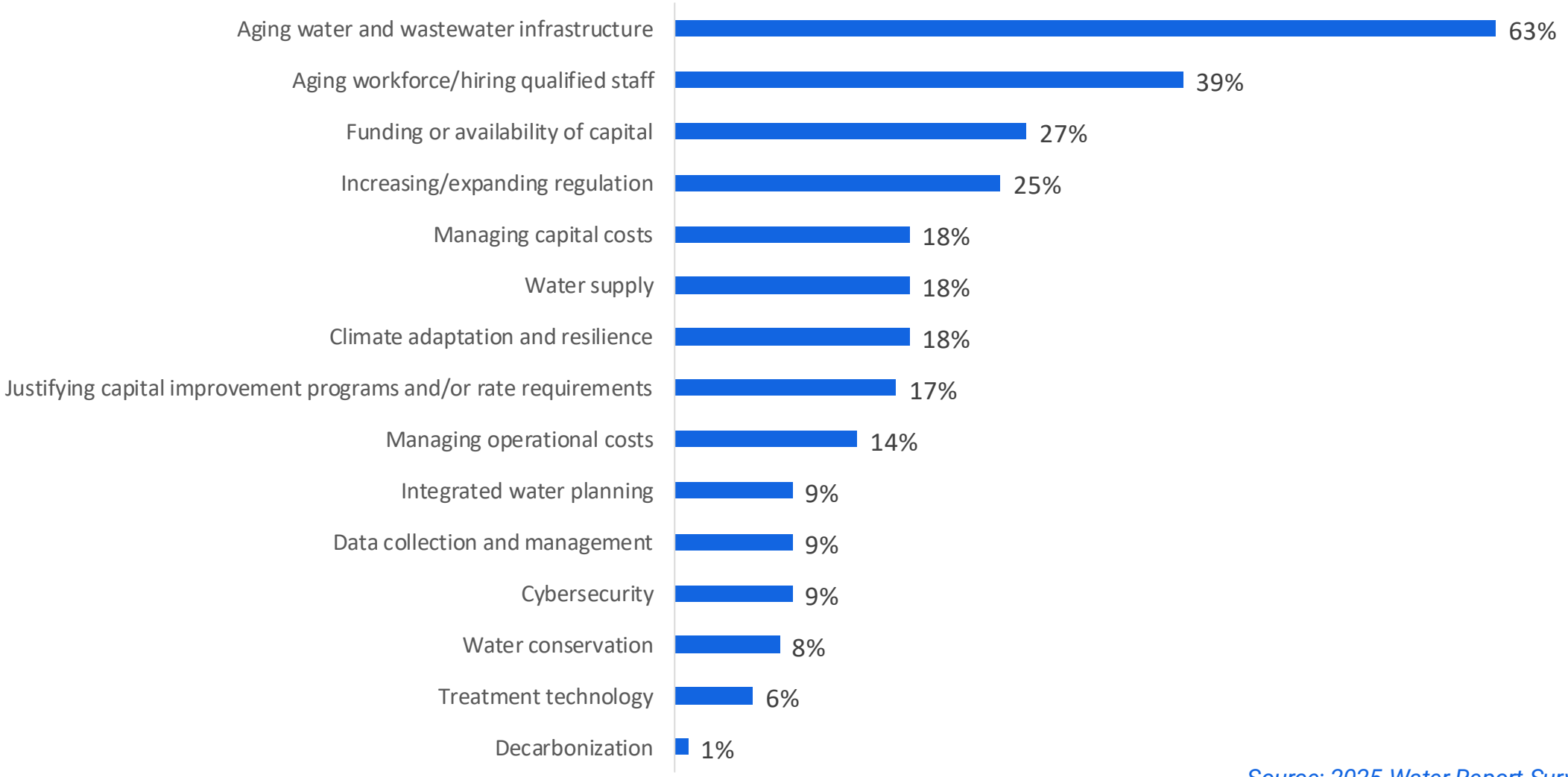
01	02	03	04
Common Water Main Materials and Failure Modes	Available Technologies	Available Rehabilitation Methods	Case Studies

BLACK & VEATCH

1

What are the Main Challenges Facing Utilities?

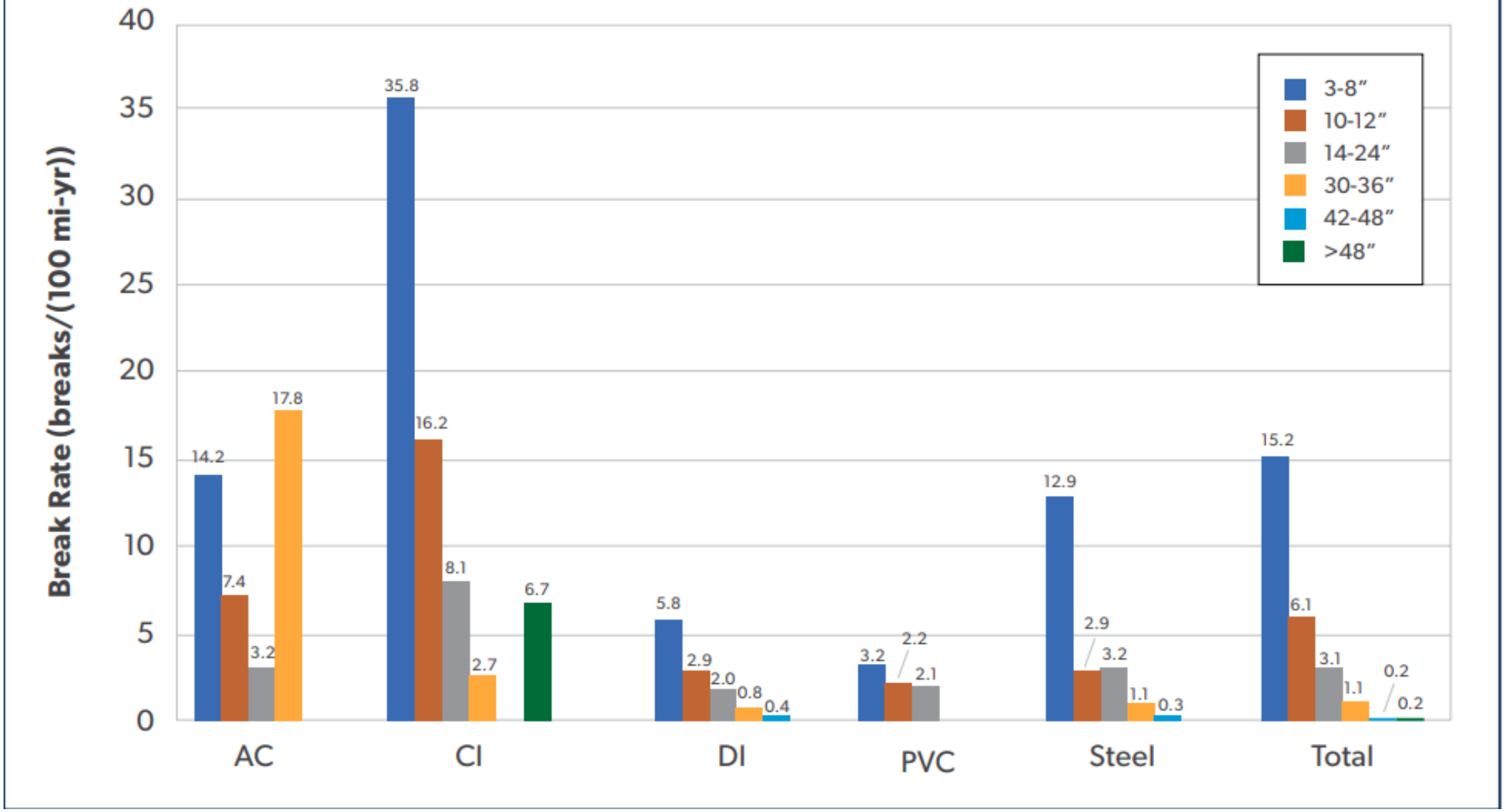
Most Challenging Issues Facing the Water Industry Today



Source: 2025 Water Report Survey

BLACK & VEATCH

FIGURE 37: BREAK RATE BY DIAMETER OF PIPE MATERIAL (DETAILED SURVEY)

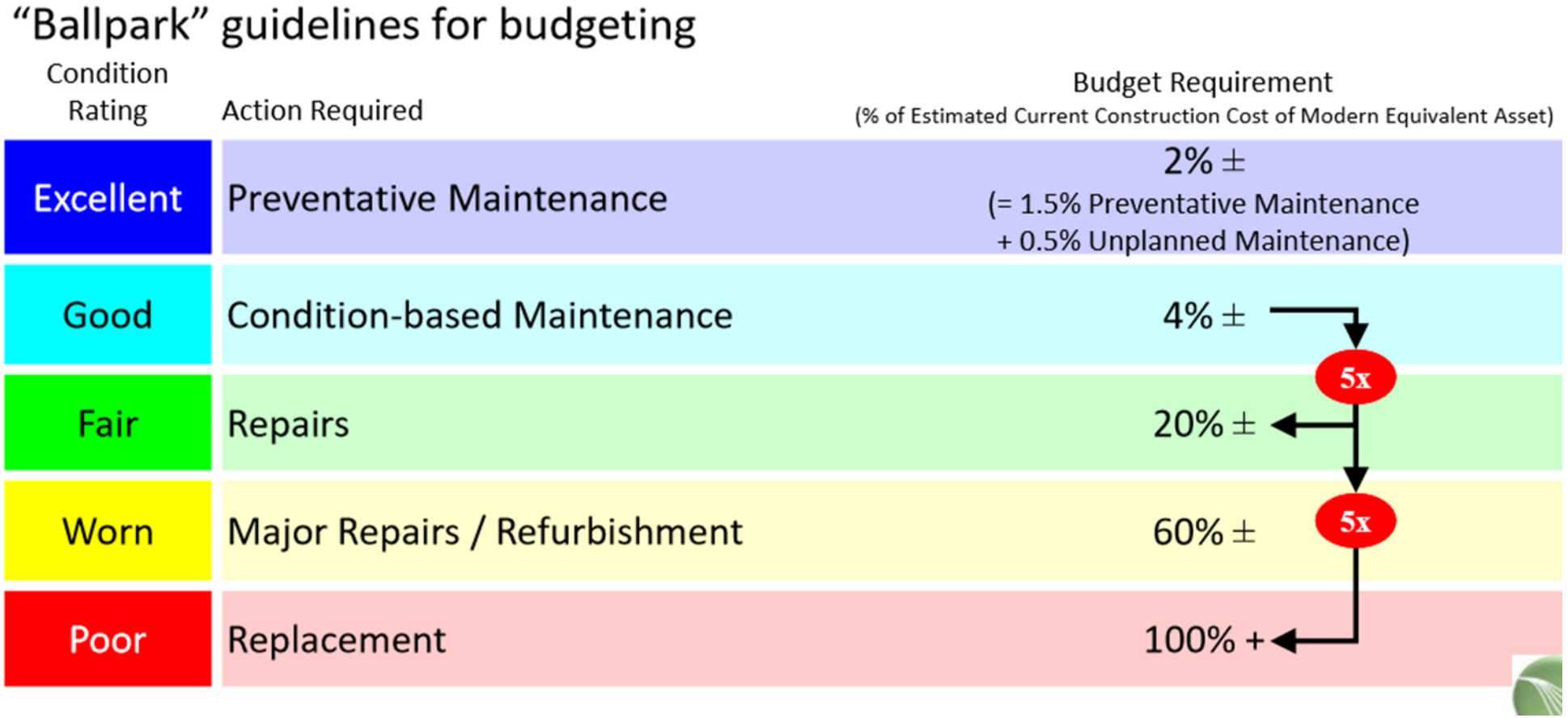


BLACK & VEATCH

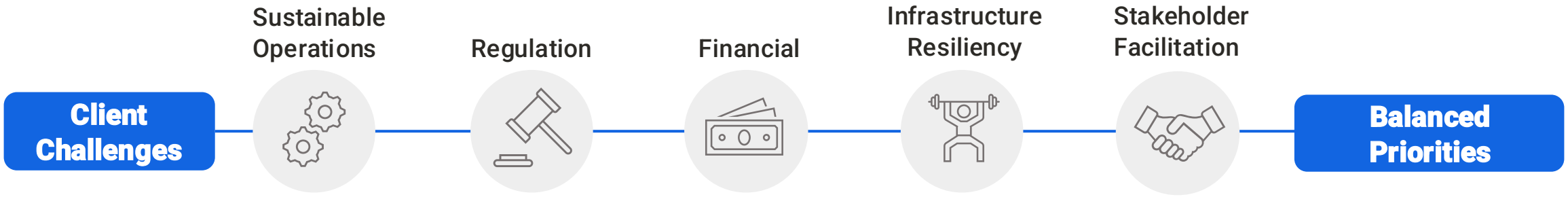
© Black & Veatch Corporation, 2023. All Rights Reserved. The Black & Veatch name and logo are registered trademarks of Black & Veatch Corporation.

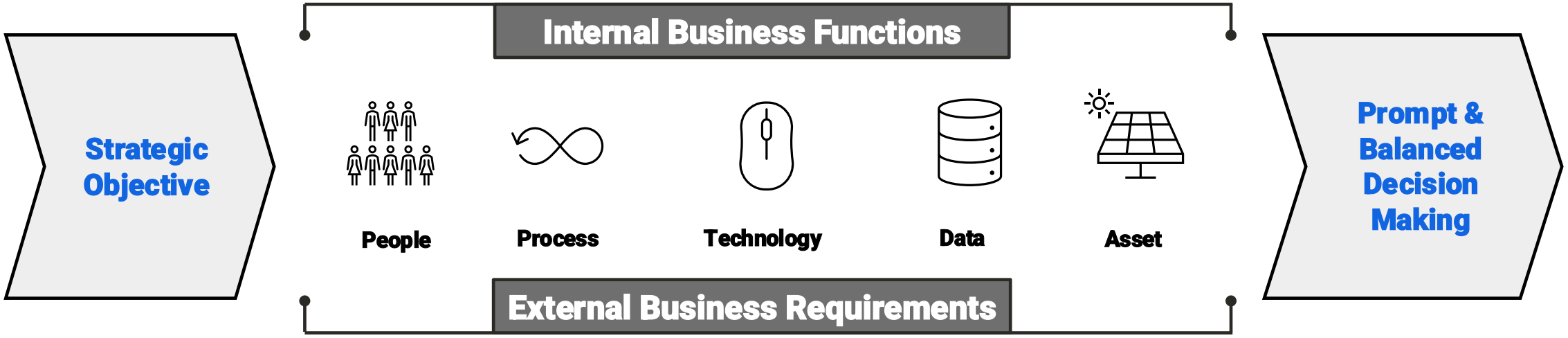
The Law of Fives

- If maintenance is not performed, then repairs equaling five times the maintenance costs are required.
- If repairs are not made, then renewal costs can reach five times the repair costs.



The Need for Robust, Balanced Decision Making







Common Water Main Materials and Failure Modes

BLACK & VEATCH

Pipe Materials and Failure Modes

Pipe Type	Typical Material Aging Processes	Common Failure Modes
PCCP	Broken prestressing wires as a result of: ▪ External corrosion ▪ Hydrogen embrittlement ▪ Cathodic protection	Pipe rupture Joint leaks
CCP	External corrosion of reinforcement or steel cylinder	Bursts or blowouts Pipe barrel leaks Joint leaks
CIP	External and internal corrosion Bell cracks (leadite) Slow crack growth / rapid crack propagation	Longitudinal bursts Split bell Circumferential beam breaks Pipe barrel leaks Joint leaks
DIP / Steel	External and internal corrosion	Longitudinal bursts Pipe barrel leaks Joint leaks
ACP	Internal and external calcium leaching Slow crack growth / rapid crack propagation External sulfate corrosion	Longitudinal bursts Circumferential breaks Joint leaks
HDPE	Chemical degradation Slow crack growth	Poor welds Brittle fractures
PVC	Slow crack growth Cyclic loading	Brittle fractures Split bells Joint leaks

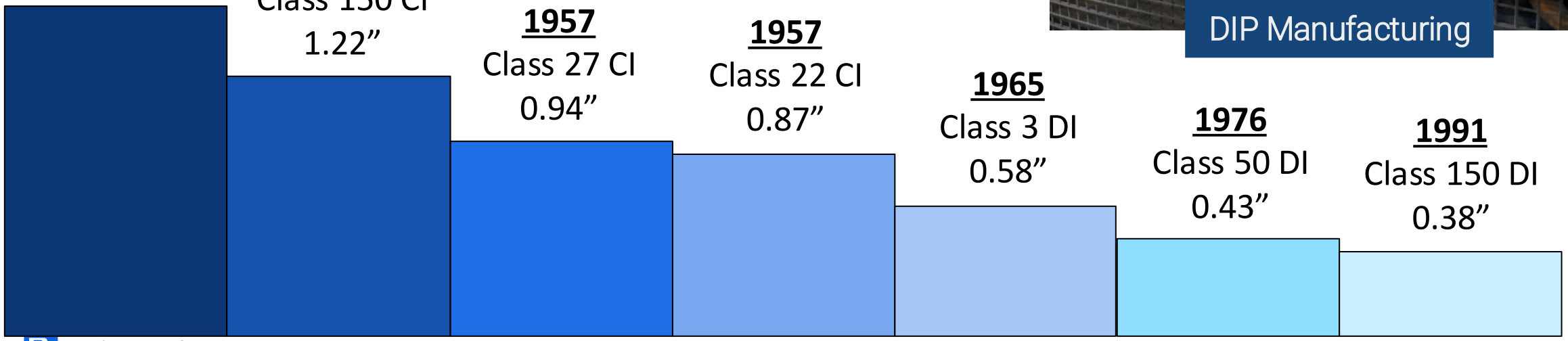


PCCP rupture



CIP Barrel Corrosion

Typical Pipe Materials - Metallic

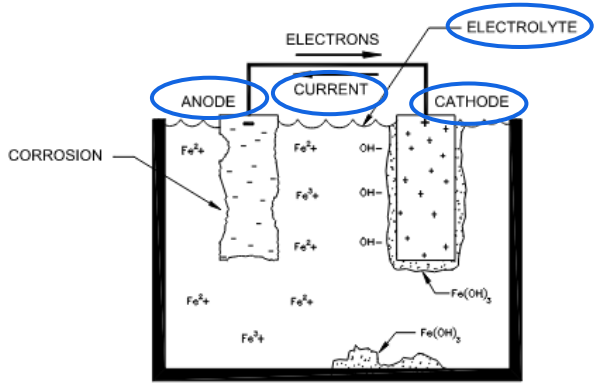




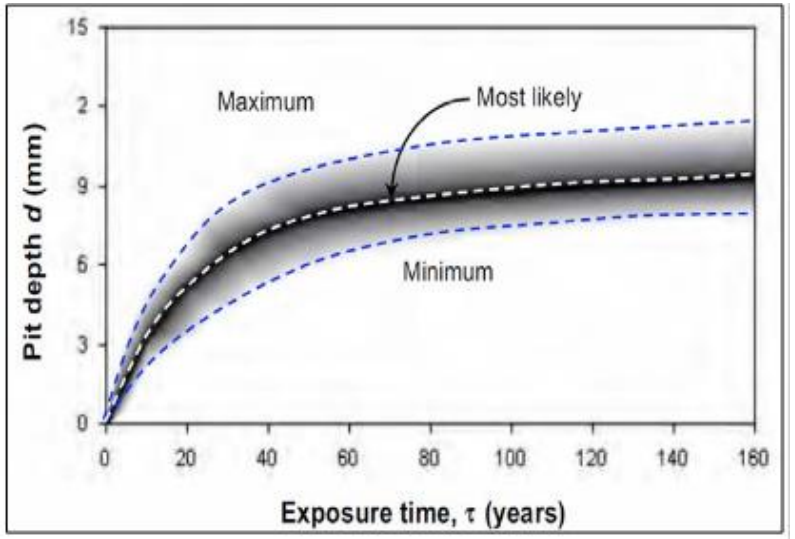
DIP Manufacturing

Electrochemical Corrosion

- Four elements for corrosion to occur?
  - Anode = oxidation and metal loss
  - Cathode = reduction
  - Electrolyte = water or moisture in soil
- Current path
- Galvanic corrosion between two metals; greater the dissimilarity, the greater the corrosion.
- In iron pipes, as pits deepen, they can become shielded with scale, rust, or graphite slowing corrosion



AWWA (American Water Works Association). "Manual of Water Supply Practices—M77, Condition Assessment of Water Mains." (2019).



Rajani, Balvant and Yehuda Kleiner. 2001. Comprehensive Review of Structural Deterioration Of Water Mains: Physically Based Models.

Metal	Volts[2]
Commercially Pure Magnesium	-1.75
Magnesium Alloy (6% Al, 3% Zn, 0.15% Mn)	-1.60
Zinc	-1.10
Aluminum Alloy (5% Zinc)	-1.05
Commercially Pure Aluminum	-0.80
Mild Steel (clean and shiny)	-0.50 to -0.80
Mild Steel (rusted)	-020 to -0.50
Cast Iron (non-graphitized)	-0.50
Lead	-0.50
Mild Steel in Concrete	-0.20
Copper, Brass, Bronze	-0.20
High Silicon Cast Iron	-0.20
Carbon, Graphite, Coke	+0.30

Helgeson, D. R. 1985. Basic Corrosion and How it Affects Utility Operations. AWWA Seminar Proceedings. Distribution System Symposium.

Metallic Pipe / CCP Failure Modes

Generalized Corrosion

Corrosive Soils
Stray Current

External Corrosion



WALL LOSS

PIPE FAILURE

Joint Leakage

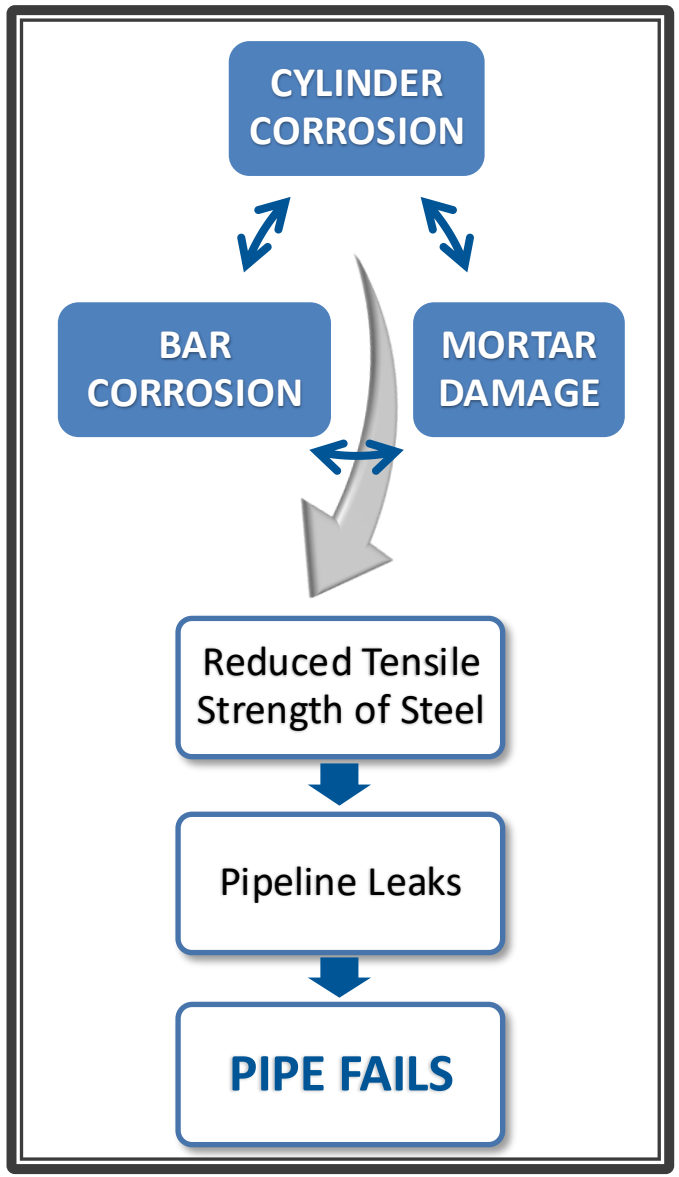
Insufficient Thrust Design
Transient Pressure
Pipe Bedding Disruption

Joint Separation



LEAKAGE

PIPE FAILURE



BLACK & VEATCH

Failure Modes: CIP

- CIP fails from cylinder corrosion, bell cracks, and joint leakage
- Corrosion pitting often leads to cracks.
- Small cracks expand with corrosion within the cracks until pried open.
  - Graphite is typically distributed throughout the material which provide a plane for cracking to propagate.
  - DIP carbon is formed in nodules, making it more resistant to cracking

Cylinder Corrosion



Leadite Joints



Split Bell



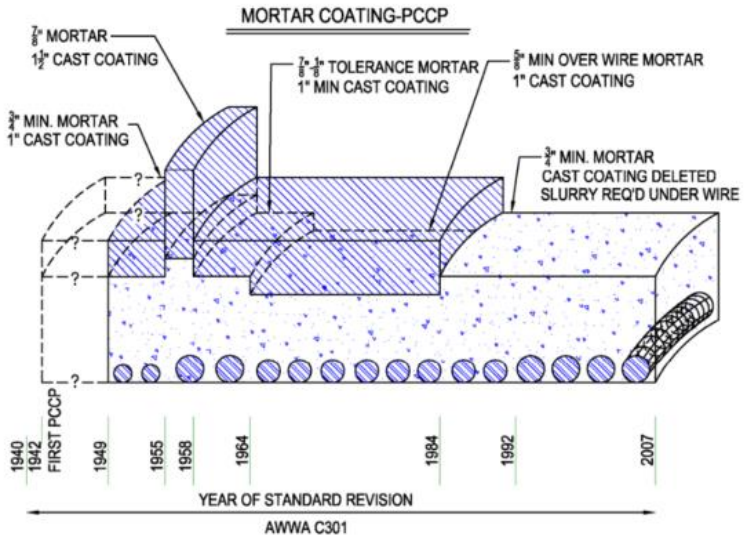
Crack Propagation

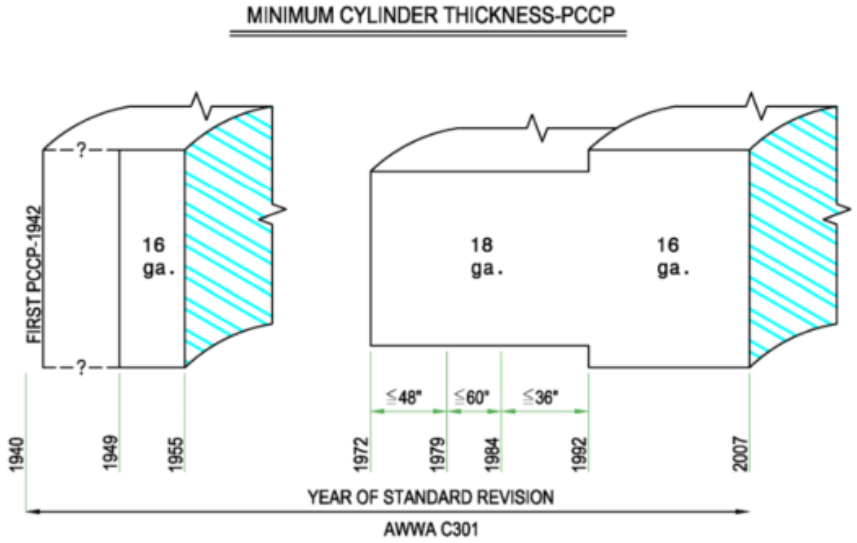


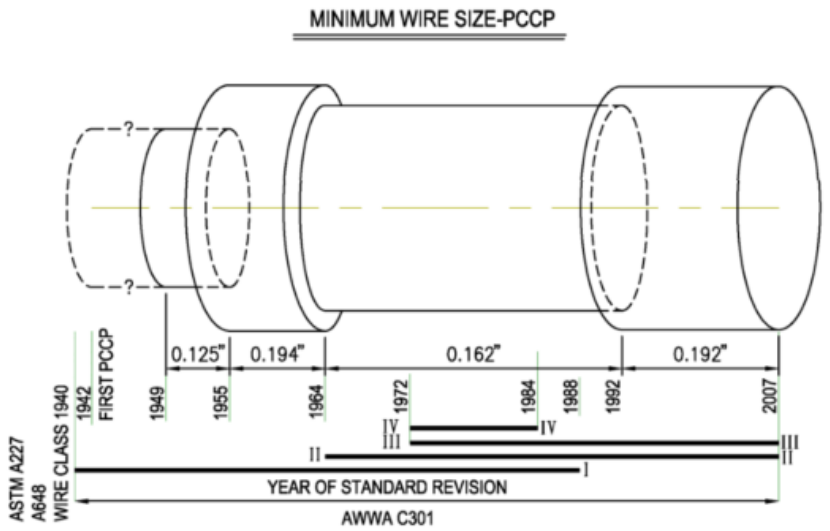
Grigg, N. S., and D. Ballantyne. "Visual guidance for common pipe failures." Water Research Foundation, Denver (2017).

Typical Pipe Materials - Concrete

Pipe Type	Characteristics
Reinforced concrete cylinder pipe	Low pressure and gravity mains
Bar-wrapped steel cylinder pipe	Thin steel cylinder with mild steel reinforcement
Prestressed concrete cylinder pipe (1942 – 1964)	Class I wire, <75% ultimate strength wire stress, moderate failure rate
Prestressed concrete cylinder pipe (1964 – 1984)	Class III/IV wire, increased failure rate
Prestressed concrete cylinder pipe (1984 – present)	Reduced failure rate







Romer, Andrew E., Graham EC Bell, and R. Dan Ellison. "Failure of prestressed concrete cylinder pipe." Pipelines 2007: Advances and Experiences with Trenchless Pipeline Projects. 2007. 1-17.

BLACK & VEATCH

Failure Modes - CCP

MORTAR DAMAGE



CYLINDER/BAR CORROSION



PIPE LEAKS/BREAKS



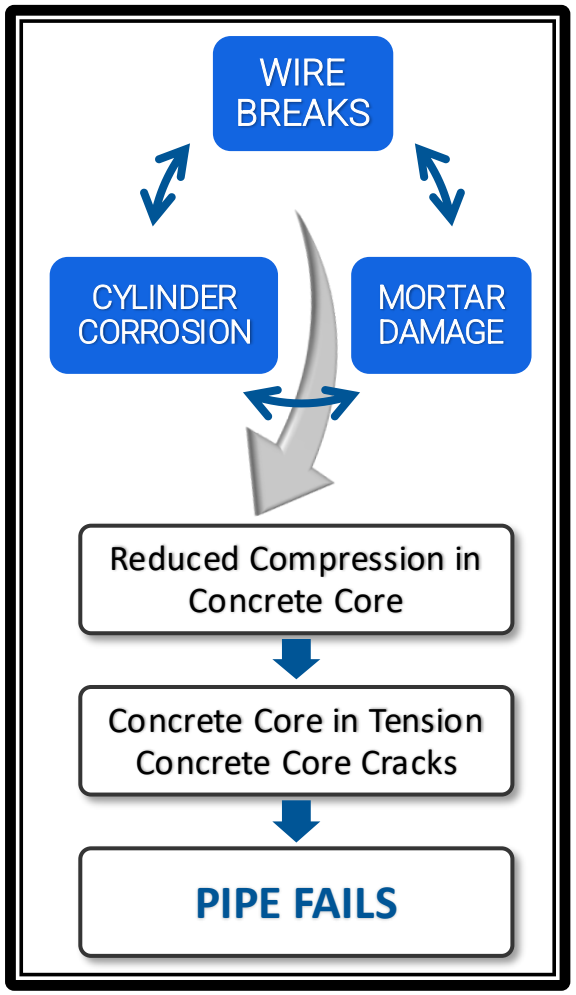
JOINT FAILURE





BLACK & VEATCH

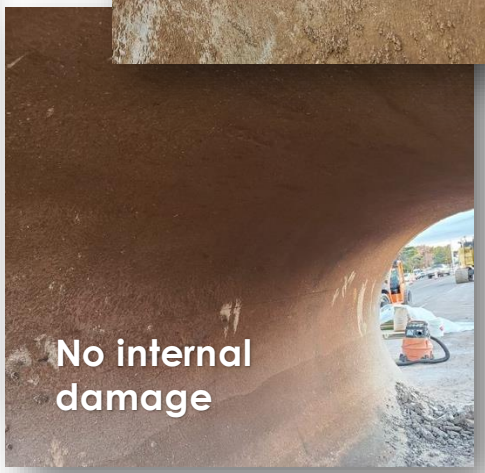
PCCP Failure Modes













PCCP failures begin with wire breaks

BLACK & VEATCH

Failure Modes - PCCP

- PCCP fails primarily from wire breakage due to varying causes.
- Sensitivity of PCCP to wire breaks depends on pipe properties and pressure













Asbestos Cement Pipe

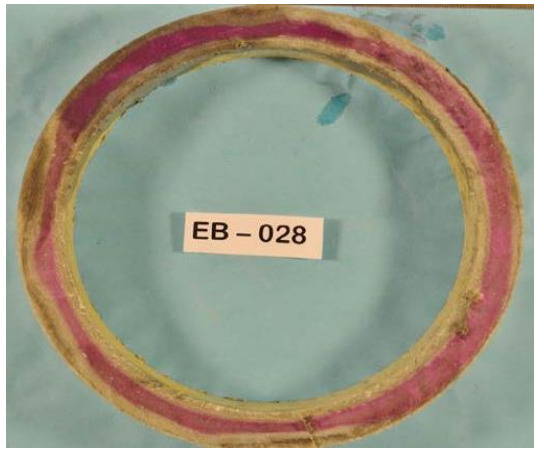
Pipe Type	Characteristics
Asbestos cement – Type 1 (1930s – 1950s)	Less resistant to calcium leeching, sulfate, and other salts
Asbestos cement – Type 2 (1950s – 1980s)	More resistant to calcium leeching, sulfate, and other salts

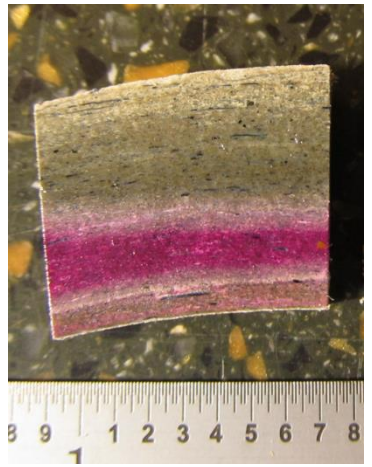
CONTRIBUTING FACTORS

- Specifications (manufacturer, type, age, diameter)
- Water chemistry (internal/external, lime leaching)
- Soil properties (sulfate attack, movement)
- Biodegradation
- Operating or transient pressures
- Climate









- ACP degrades by loss of cement binder integrity & softening matrix

HDPE Pipeline Deterioration and Failure Modes

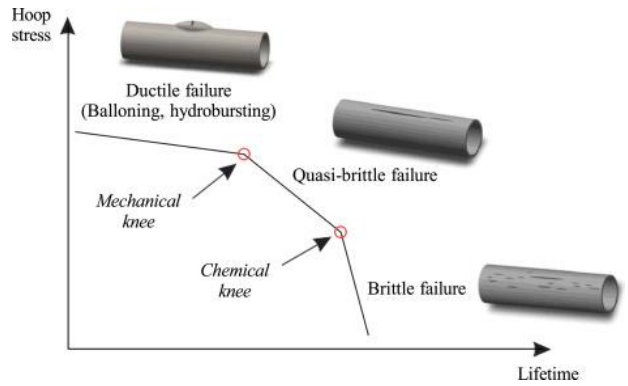
Ductile and Brittle Failures

Geometrical Discontinuities

Chemical Degradation

Crack Propagation

Micro - Cracking



SLOW CRACK GROWTH

PIPE FAILURE

Joint Failure

Poorly Fused Joints
Welding Procedure QA/QC

Joint Cracking



LEAKAGE

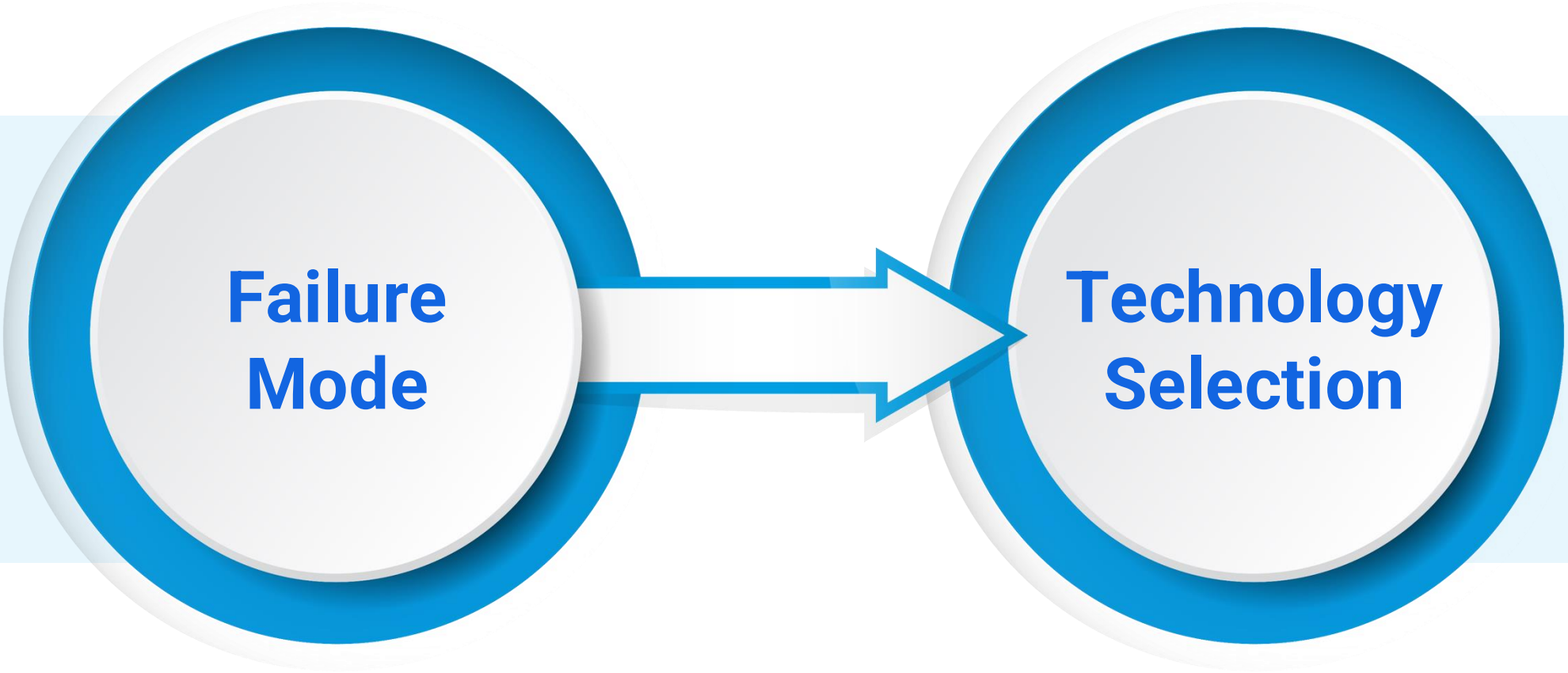
PIPE FAILURE

BLACK & VEATCH

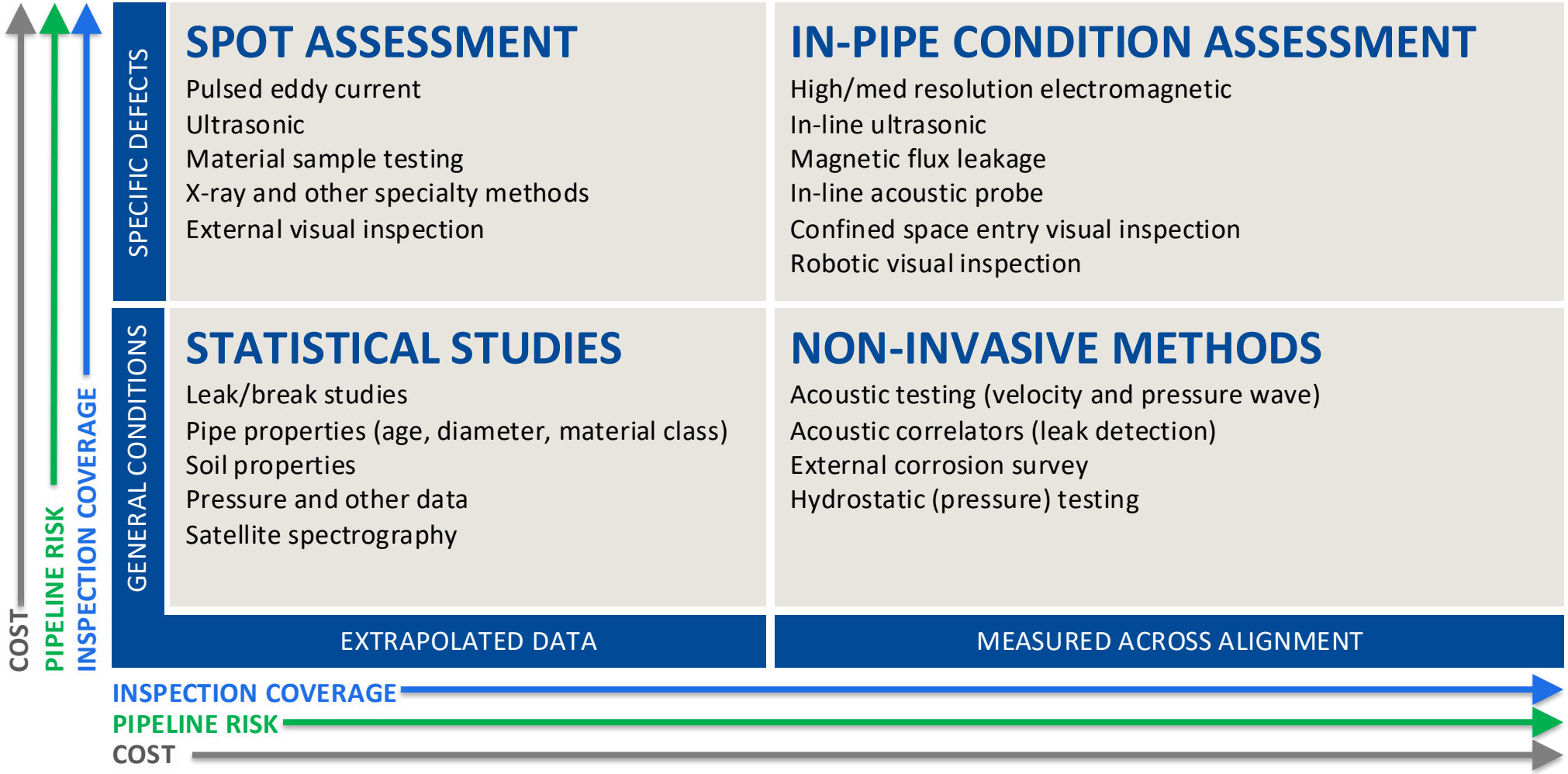


Available Technologies

BLACK & VEATCH

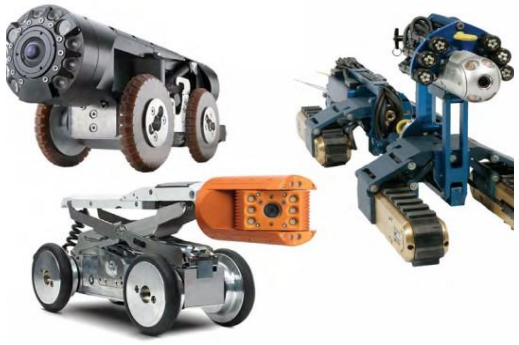

Failure Mode
Technology Selection

Tailoring Technology Application to Pipeline Risk



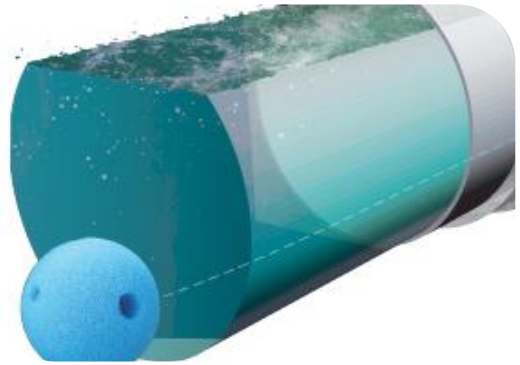
BLACK & VEATCH

Technology Options



Internal/External Visual Inspection

All Materials



Leak Detection

All Materials



Corrosion Survey/Lab Testing

DIP | Steel | CIP | PCCP | CCP



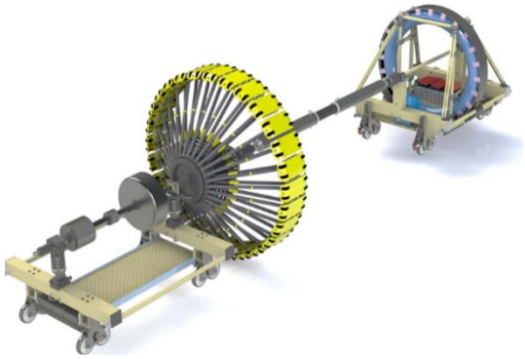
Wall Integrity Testing

DIP | CIP | ACP



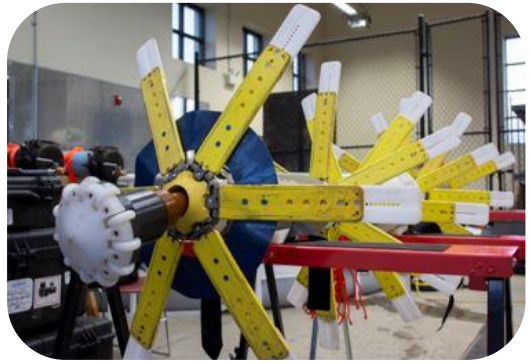
Magnetic Flux Leakage

Steel



Electromagnetic Testing

DIP | Steel | CIP | PCCP | CCP



Ultrasonic

DIP | CIP | Steel



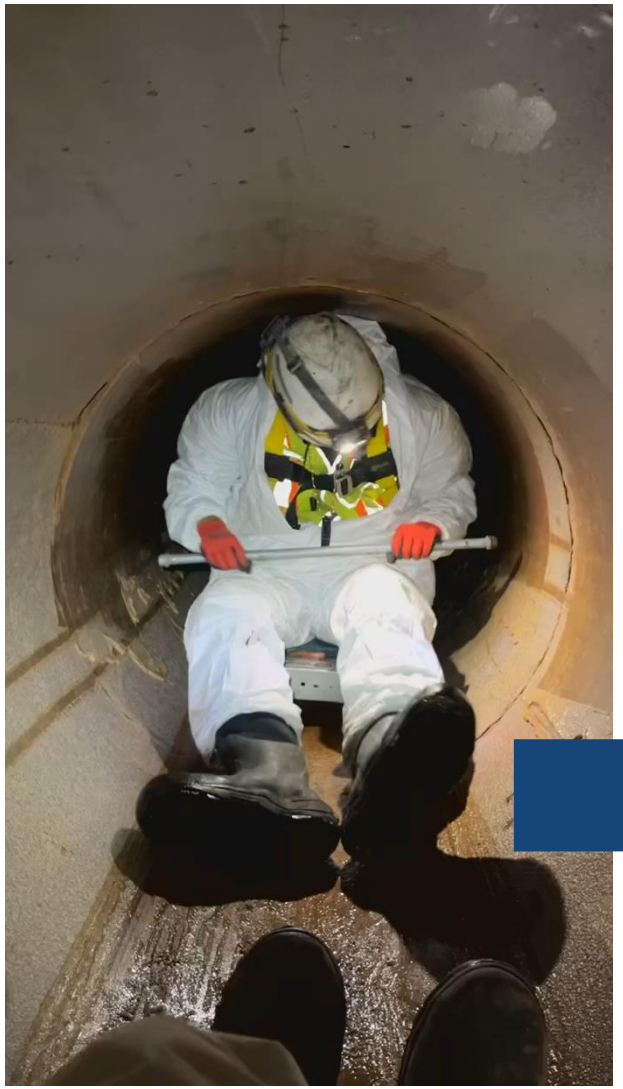
Transient Pressure Monitoring

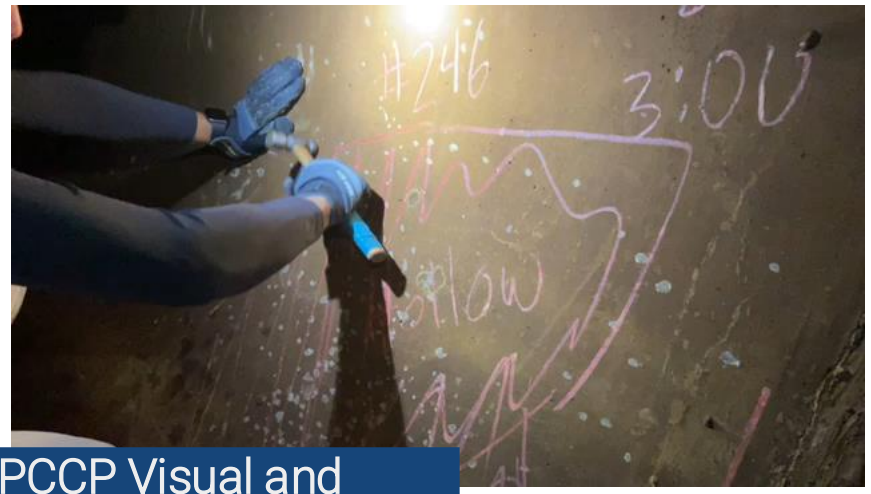
All Materials

BLACK & VEATCH

Internal Visual Inspection

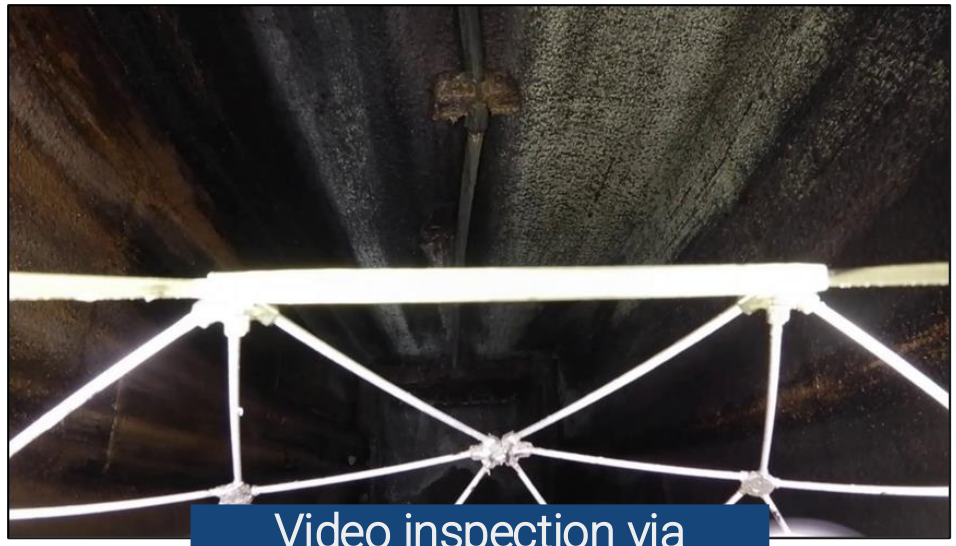
All Materials





PCCP Visual and Sounding

Visual assessment for deterioration or damage. For different materials, may include use of metallic rods or hammers for voids.



Video inspection via drone and crawler



BLACK & VEATCH

Visual Inspection

Circumferential Cracking



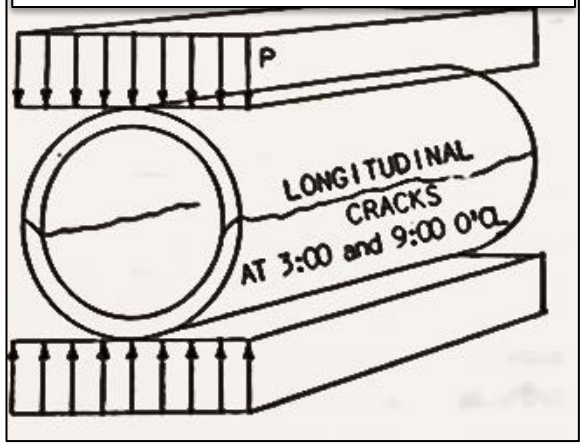
Joint Separation



Joint Spalling



Longitudinal Cracking



Hollow & Longitudinal Cracking



Outlet Corrosion



External Visual Assessment

All Materials





Continuity Testing



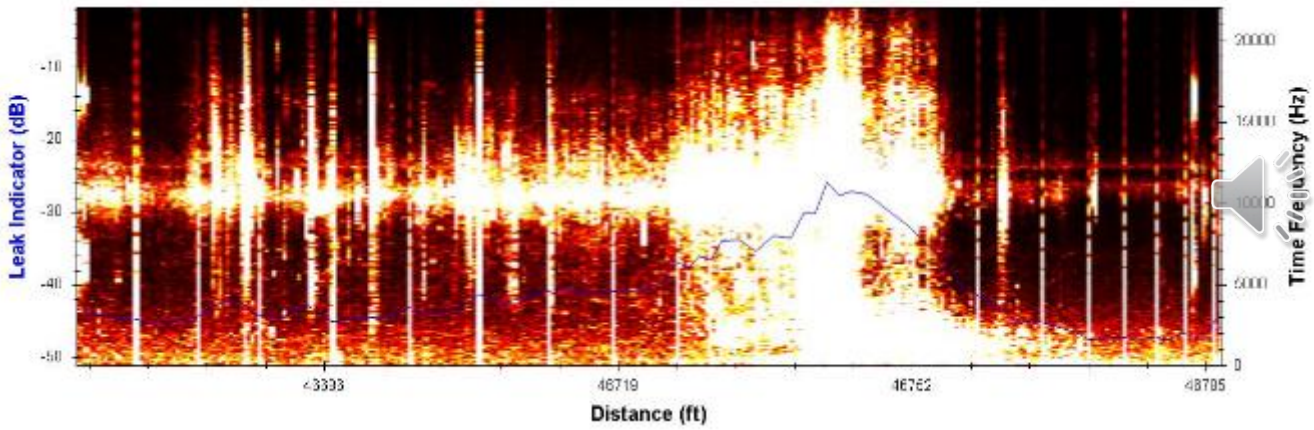
Verification with UT

BLACK & VEATCH

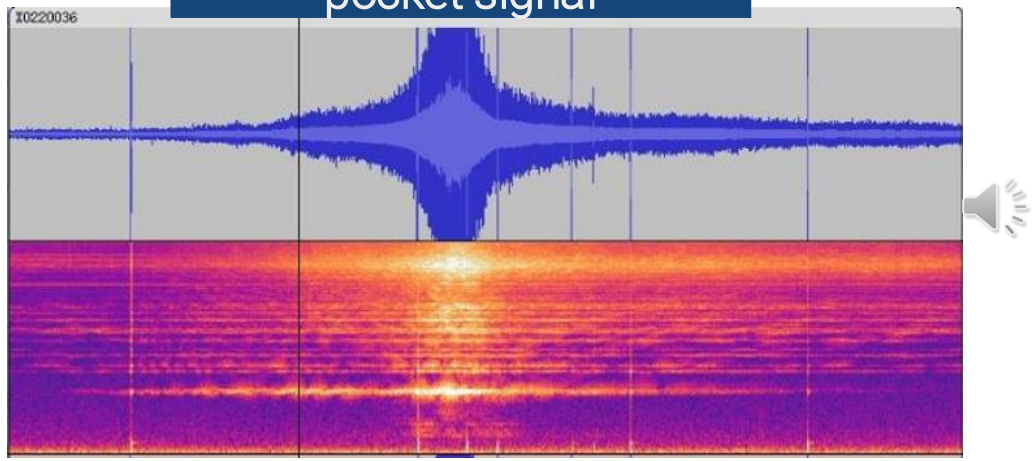
Exposing a pipe to verify other testing results or to investigate damage mode.

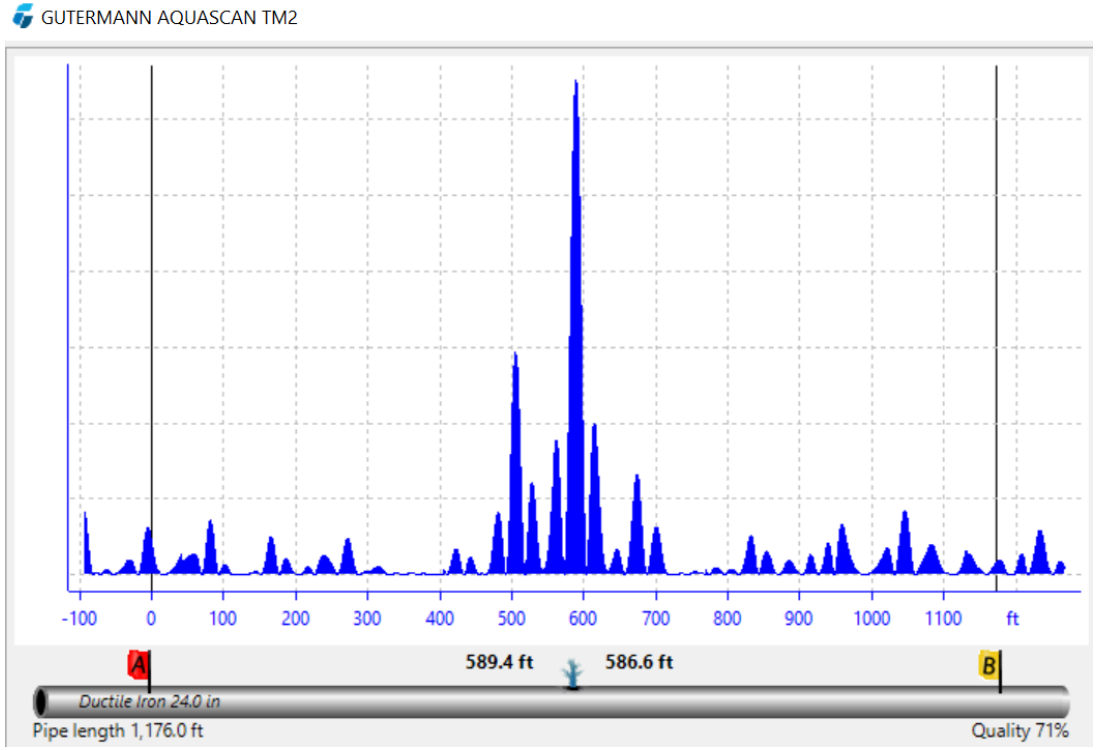
Leak Detection

All Materials



In-line acoustic leak / gas pocket signal





Acoustic correlator signal

Deploy acoustic sensors either in the pipe or externally to listen for leak signatures and other acoustic anomalies.

BLACK & VEATCH

Corrosion Survey

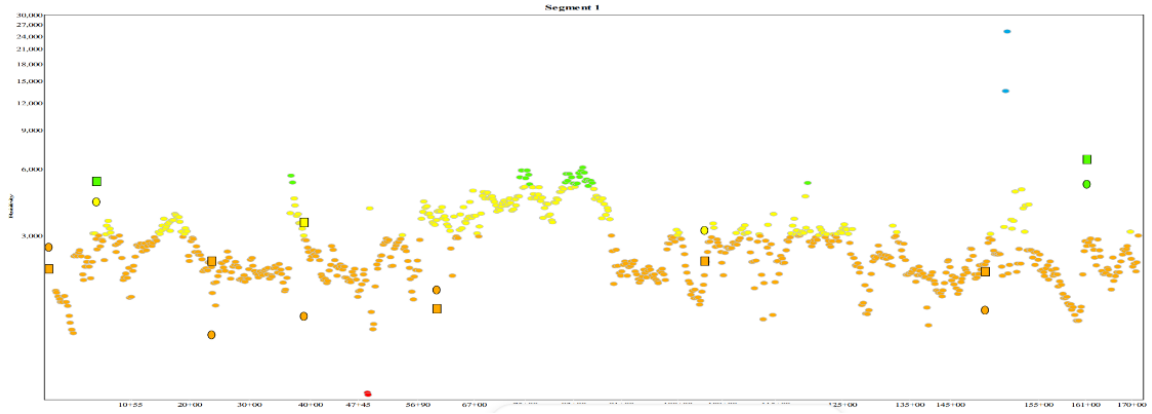
DIP | Steel | CIP | PCCP | CCP

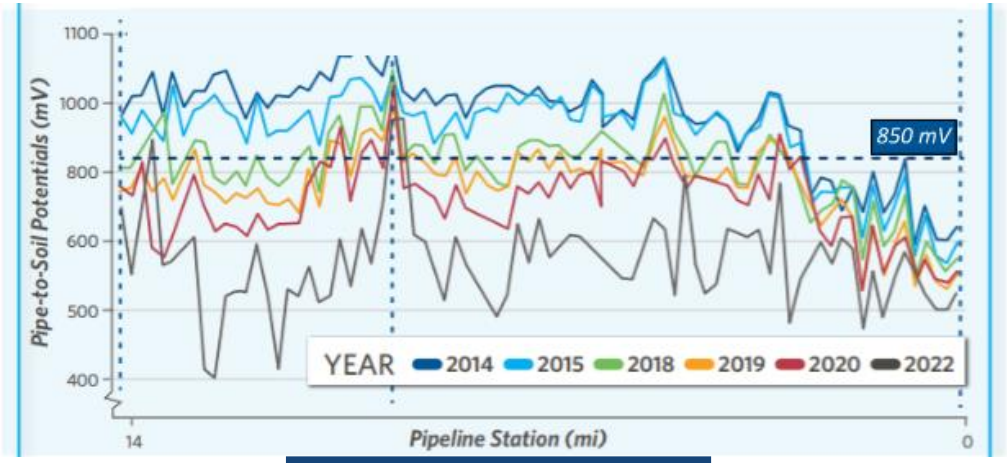


Wenner 4-pin



Electromagnetic Conductivity (EMAG)





Pipe to Soil Potential Survey

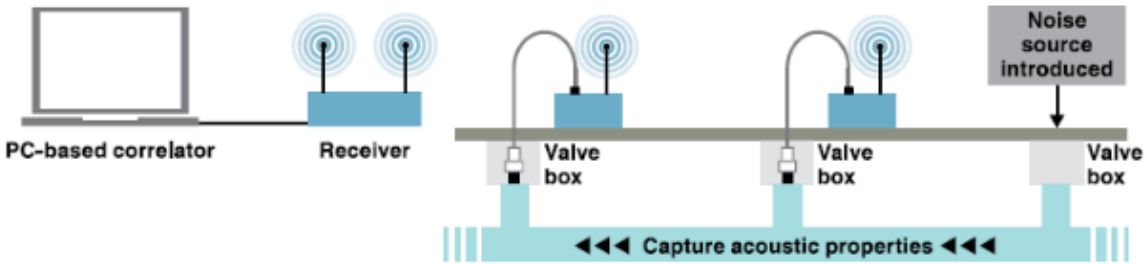
Soil resistivity (ohm cm)	Corrosivity Rating
>20,000	Essentially non-corrosive
10,000 to 20,000	Mildly corrosive
5,000 to 10,000	Moderately corrosive
3,000 to 5,000	Corrosive
1,000 to 3,000	Highly corrosive
<1,000	Extremely corrosive

Surveying pipe installation environment to establish if the pipe is in a corrosive environment.

Wall Integrity Testing

DIP | CIP | ACP

Vibroacoustic / Acoustic velocity method

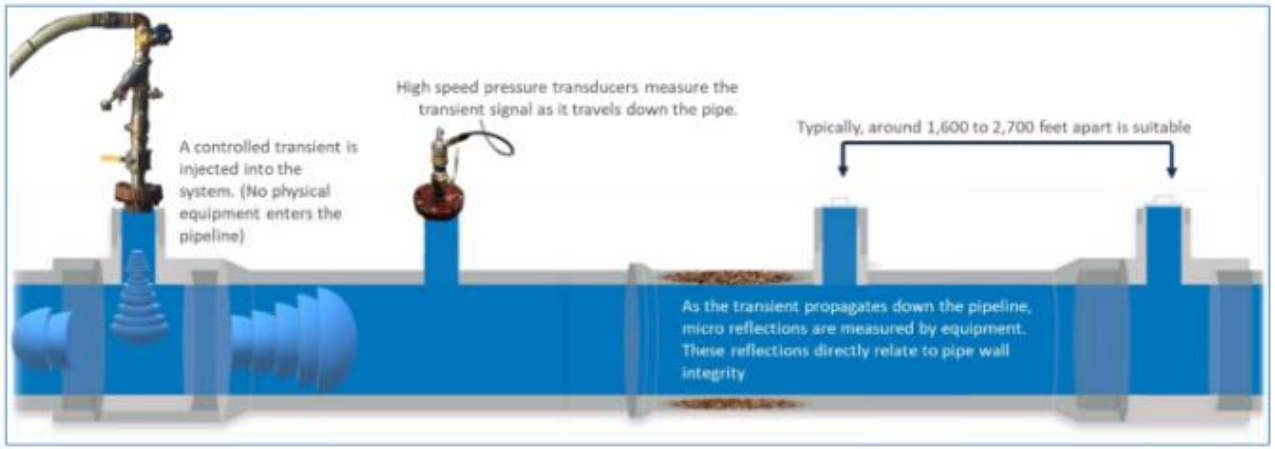


AWWA (American Water Works Association). "Manual of Water Supply Practices—M77, Condition Assessment of Water Mains." (2019).

$$c = \frac{c_0}{\sqrt{1 + \frac{D}{e}\frac{K_{water}}{E_{pipe}}}}$$

Wave speed formula

Pressure wave method



AWWA (American Water Works Association). "Manual of Water Supply Practices—M77, Condition Assessment of Water Mains." (2019).

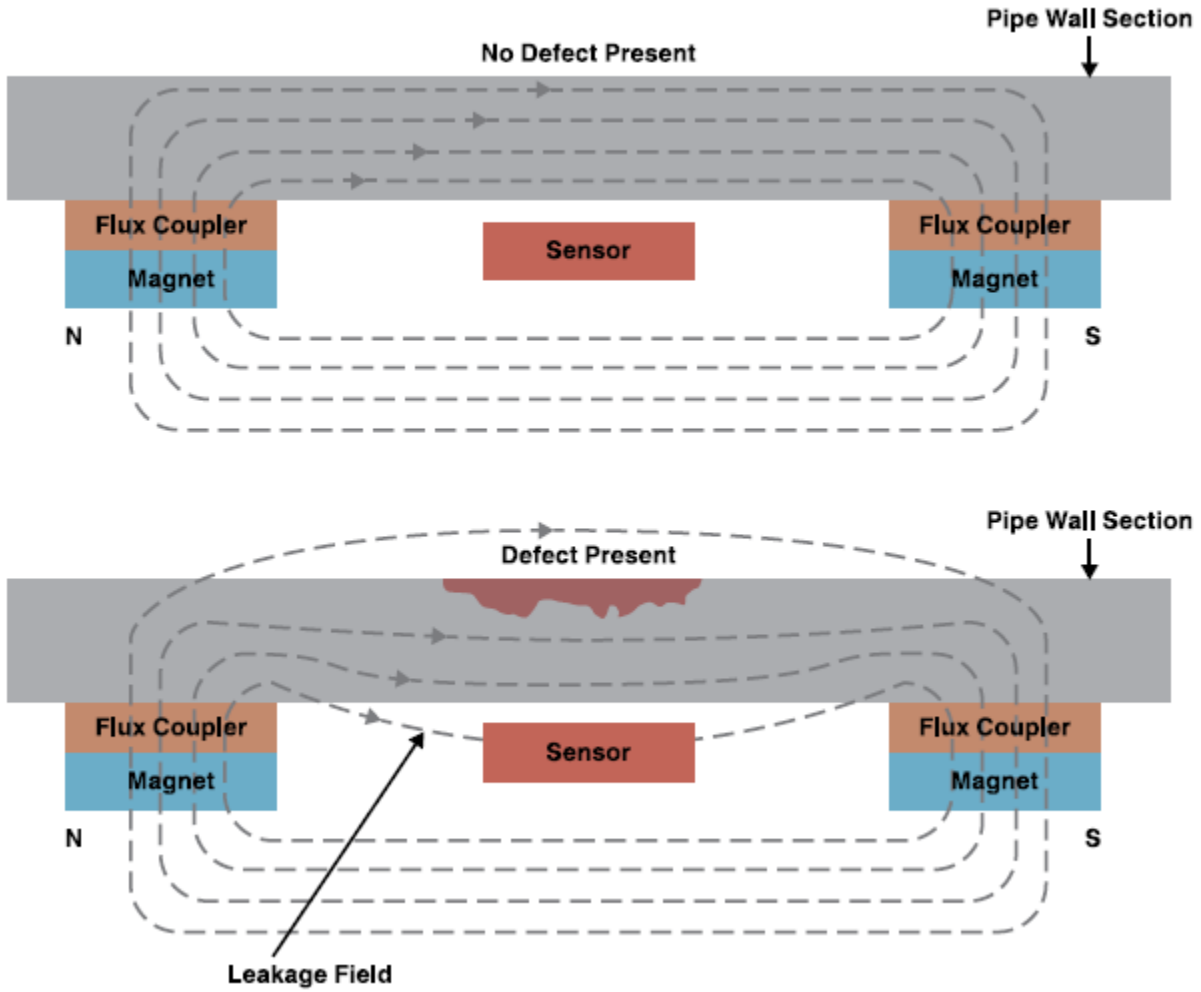
Apply impulse to pipe wall to indirectly measure wall stiffness. Wall stiffness can be an indicator of wall thickness or integrity, depending on pipe type

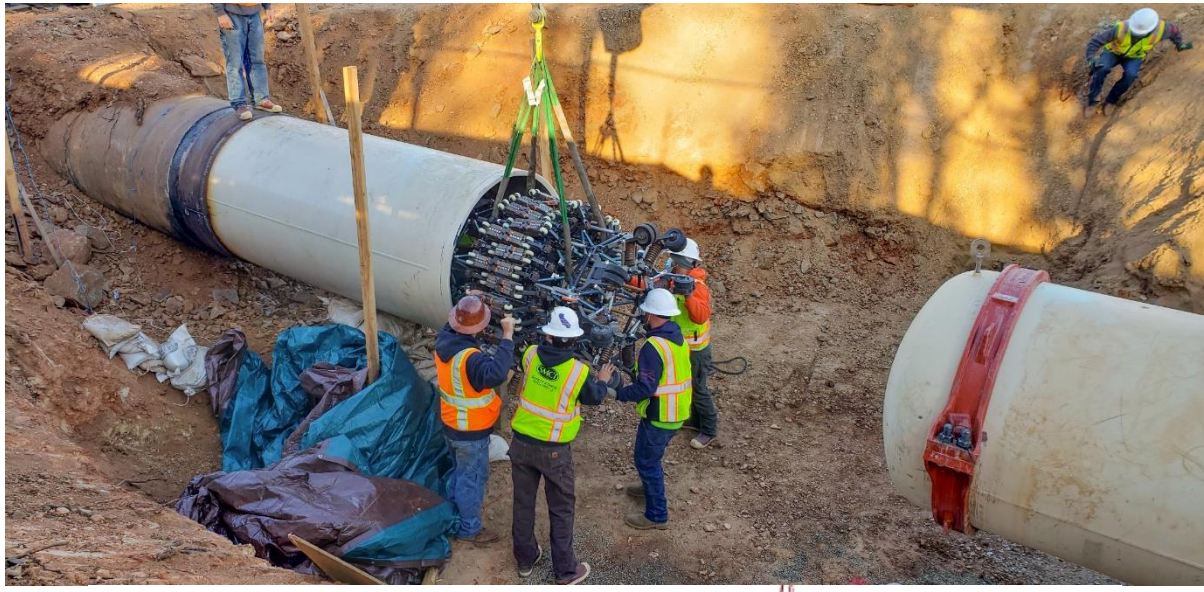
BLACK & VEATCH

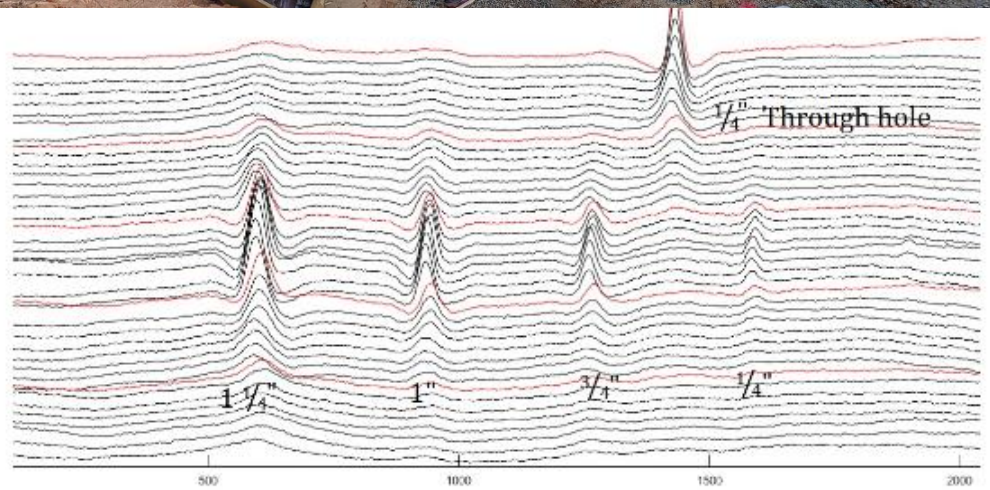
Magnetic Flux Leakage

Steel

Apply magnetic field to the steel cylinder. Changes in the magnetic field picked up by the sensor represent cylinder defects.





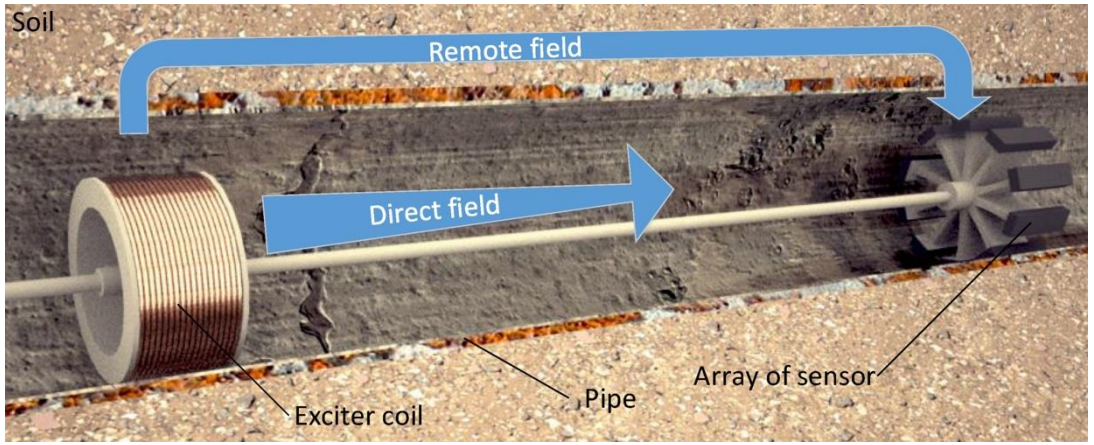


AWWA (American Water Works Association). "Manual of Water Supply Practices—M77, Condition Assessment of Water Mains." (2019).

BLACK & VEATCH

Electromagnetic Testing – Frequency Domain

DIP | Steel | CIP | PCCP | CCP



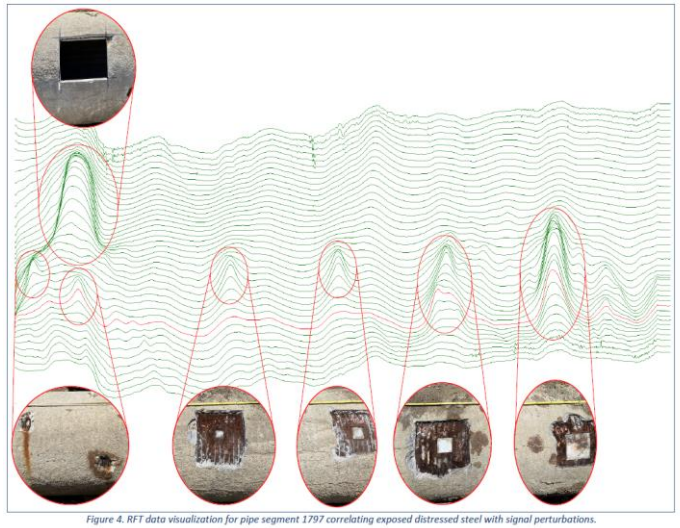
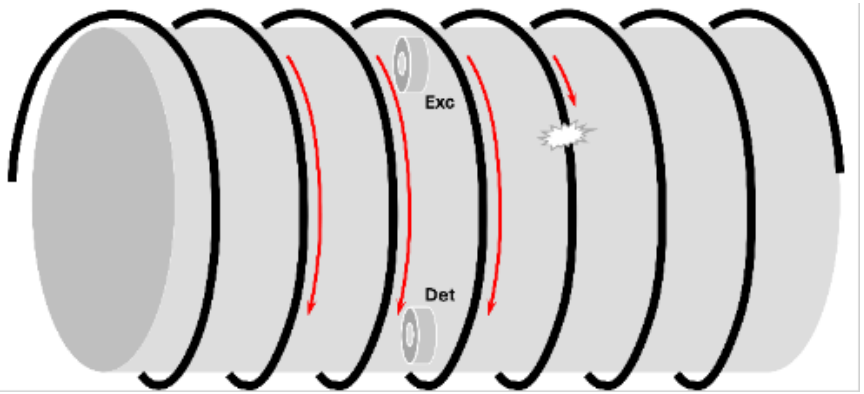


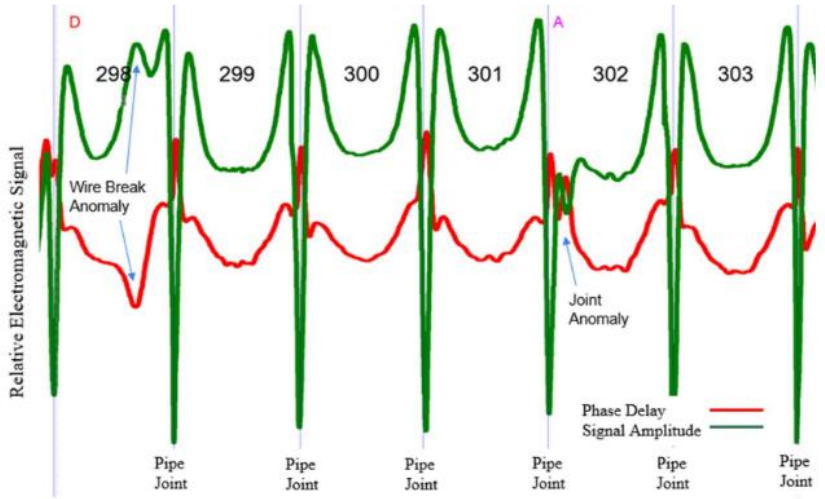
Figure 4. RFT data visualization for pipe segment 1797 correlating exposed distressed steel with signal perturbations.

Remote Field Electromagnetic Data



AWWA (American Water Works Association). "Manual of Water Supply Practices—M77, Condition Assessment of Water Mains." (2019).

INSIGHT WATER TECHNOLOGIES



Near Field Electromagnetic Data

BLACK & VEATCH

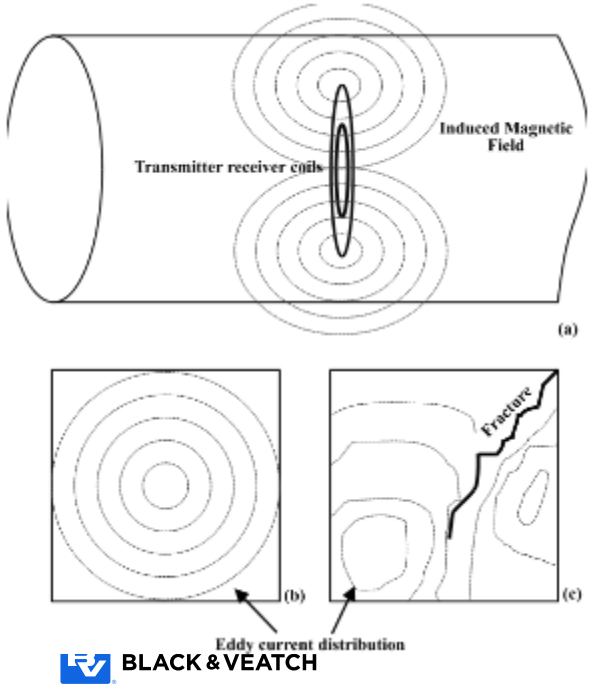
Apply eddy currents to the embedded metallic components to measure cylinder loss (Steel, DIP, CIP, CCP) or wire/bar breaks (CCP, PCCP).

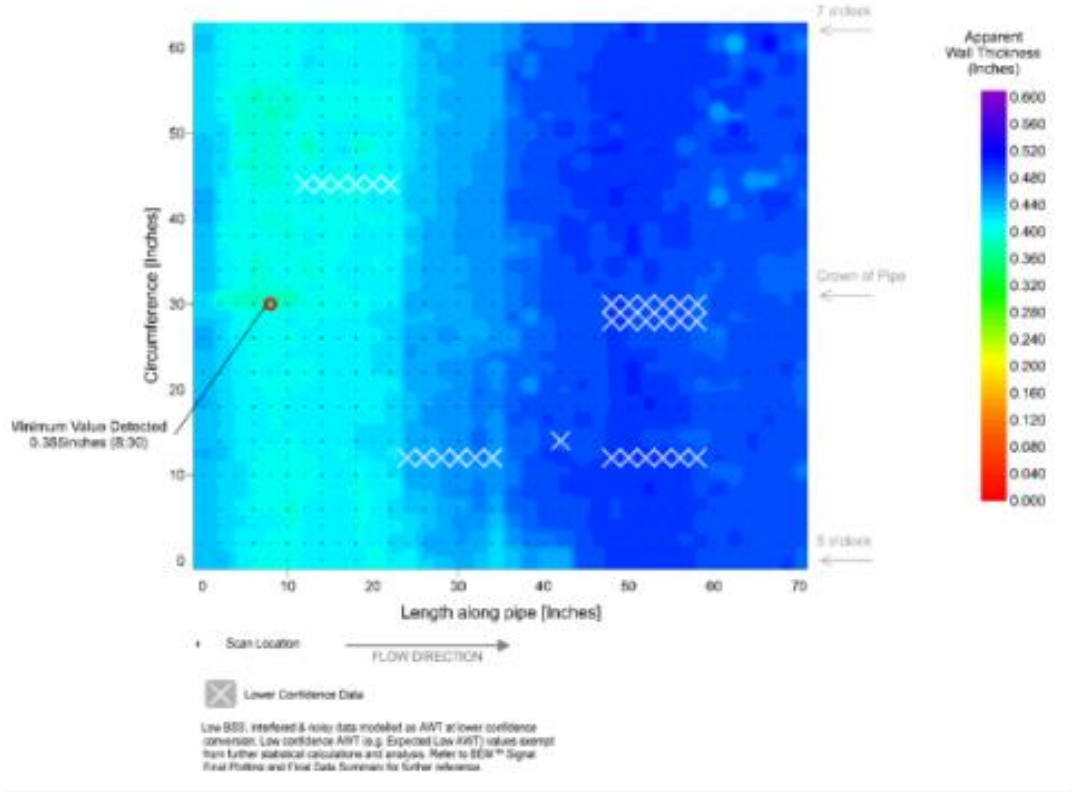
Electromagnetic Testing – Time Domain

DIP | Steel | CIP | PCCP | CCP

Broadband Electromagnetics







Induced magnetic field to distribute eddy currents to measure the decay rate to calculate an average and apparent wall thickness.

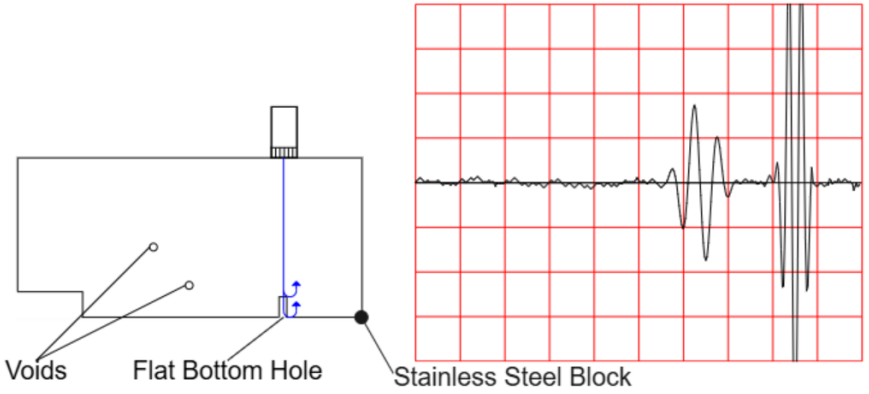
BLACK & VEATCH

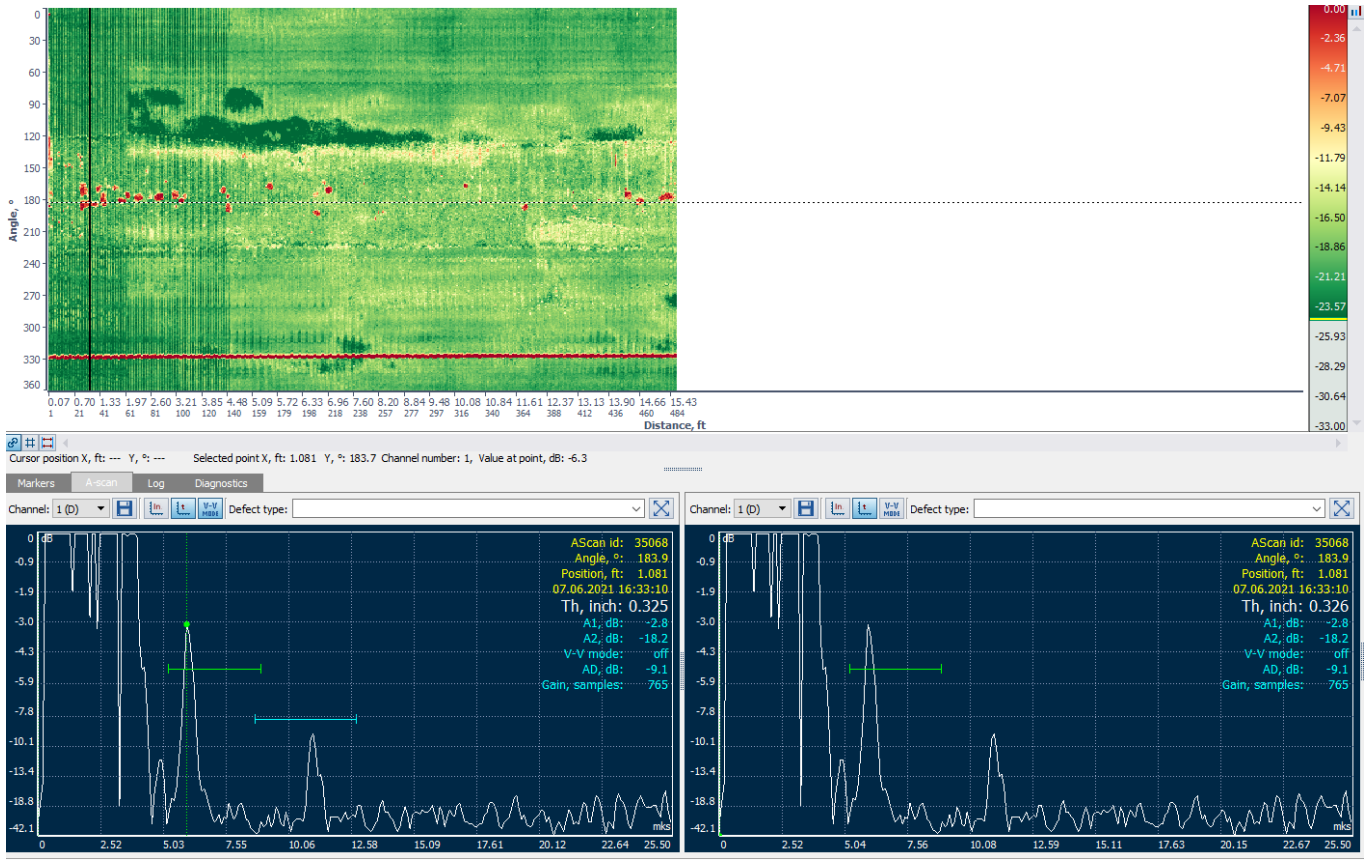
AWWA (American Water Works Association). "Manual of Water Supply Practices—M77, Condition Assessment of Water Mains." (2019).

Ultrasonic Thickness Testing

DIP | Steel | CIP







Apply ultrasonic sound waves to the cylinder to **directly** measure thickness of the cylinder.

Transient Pressure Monitoring

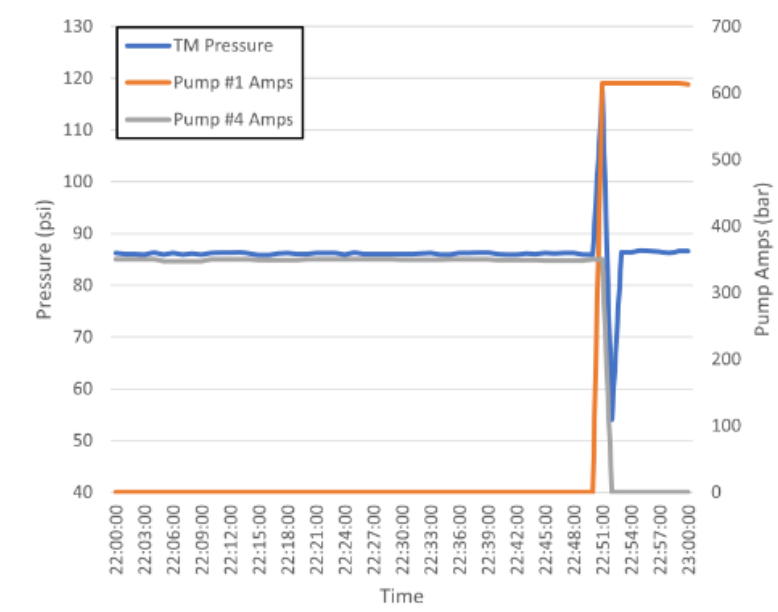
All Materials



Hydrant Mounted Transient Monitor



Recorded transient data

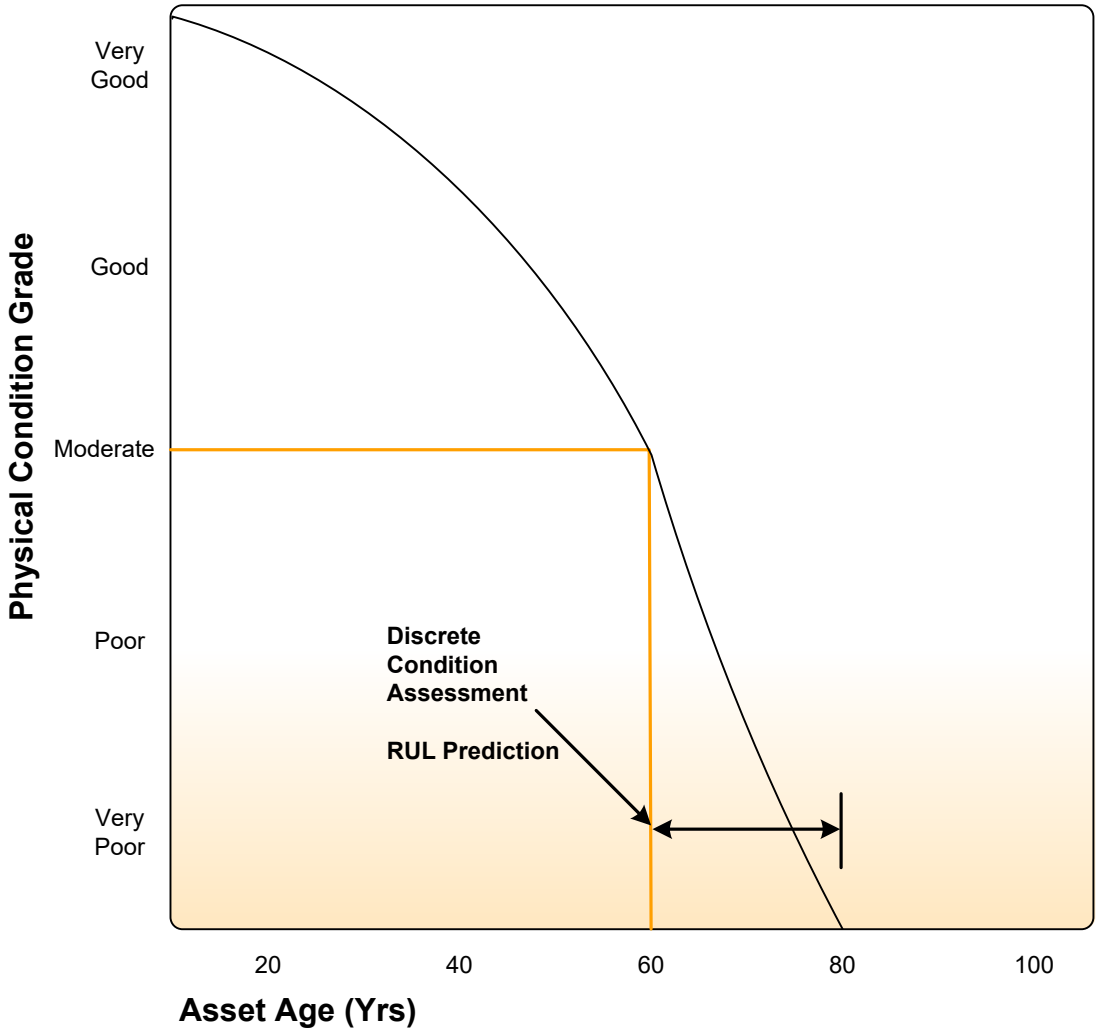


Corresponding SCADA pump data

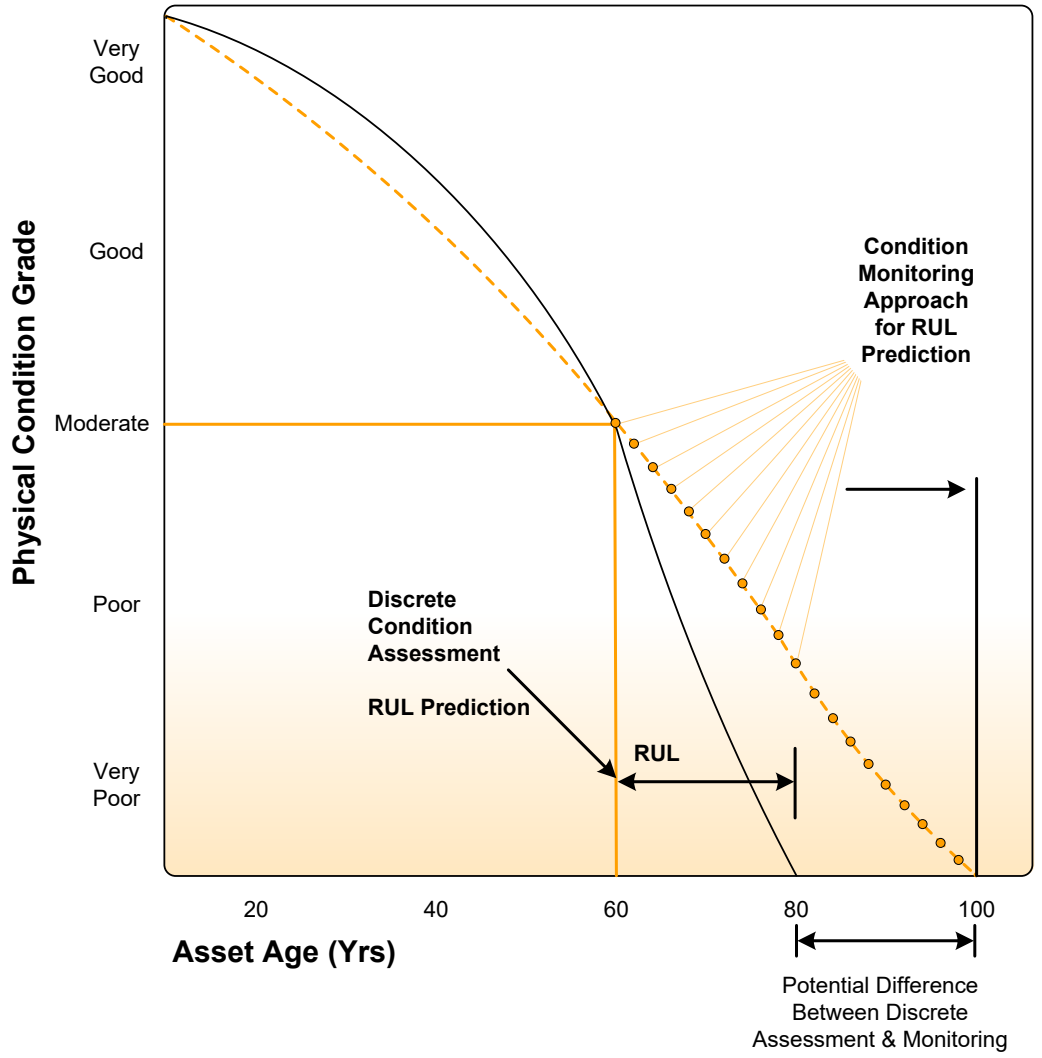
Pressure transducer in contact with the water column to measure rapid changes in water pressure as frequently as 100 Hz.

BLACK & VEATCH

Assessing Useful Remaining Life



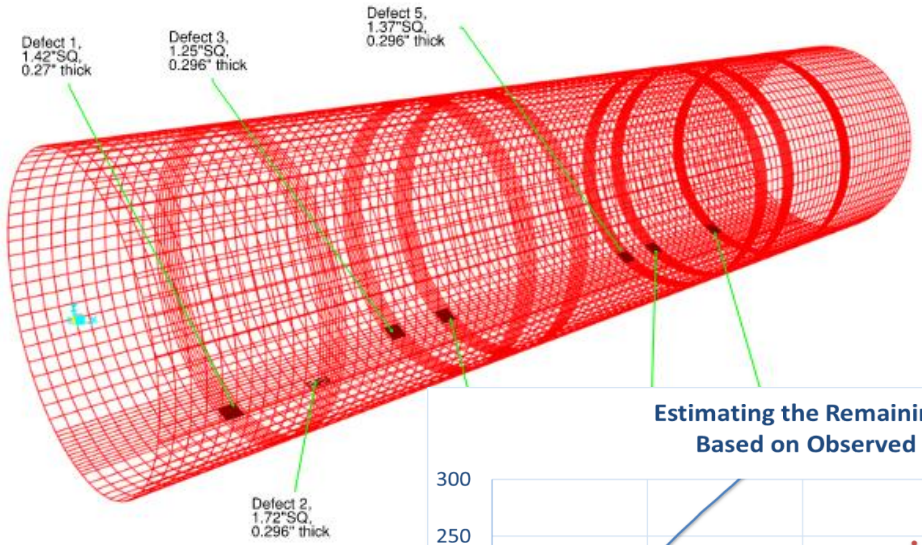
Using Condition to Extend Useful Remaining Life

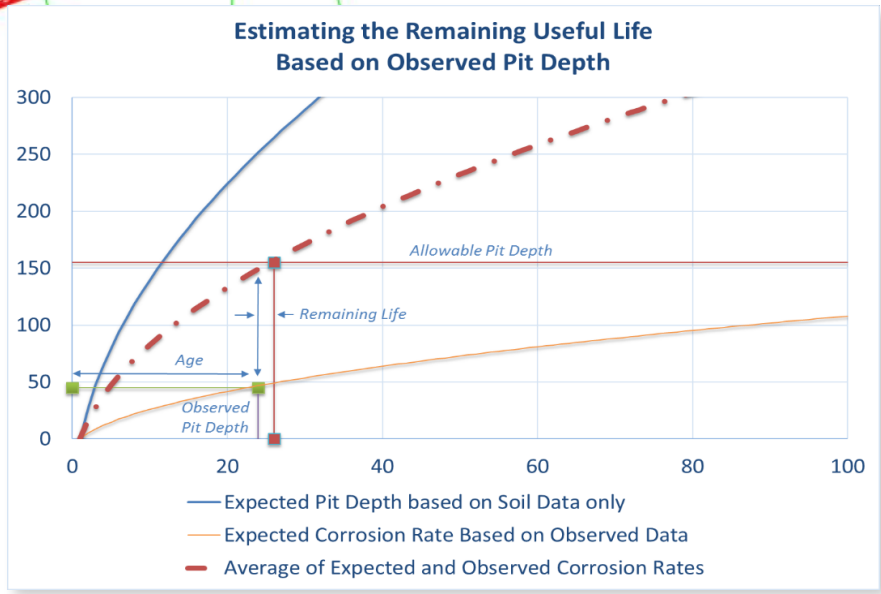


Condition assessment may allow deferral of replacement

Remaining Useful Life Estimation

- **Advanced Structural Analysis**
  - Actual defect combinations
  - Internal and external loads
  - Encasement represented (where present)
- **Remaining Useful Estimation**
  - Quantitative data
  - Engineering judgement





BLACK & VEATCH



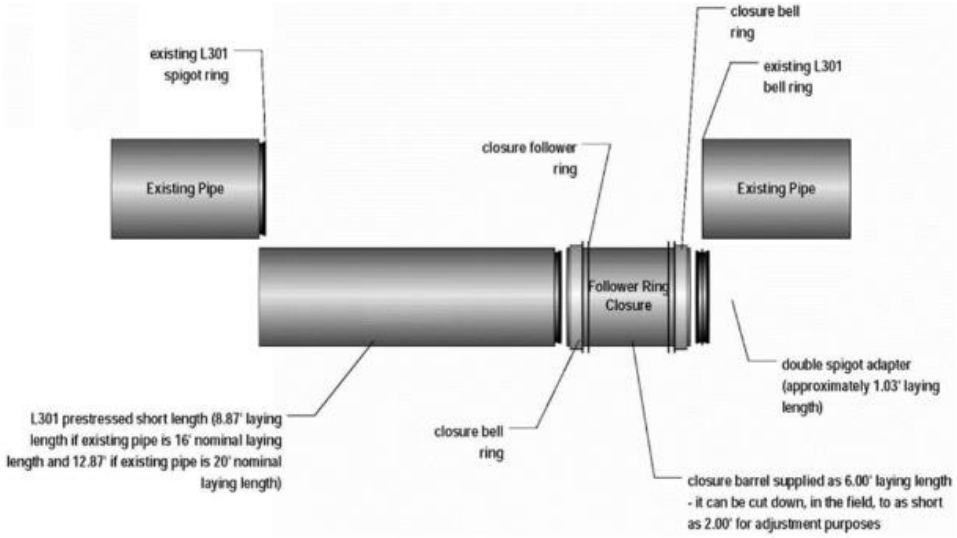
Available Rehabilitation Methods

BLACK & VEATCH

External Spot Repairs

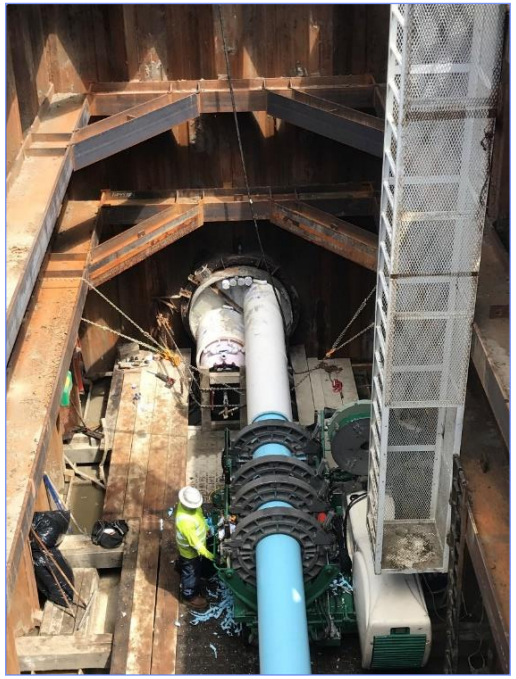
- Allows local repair depending on cause and extent of distress
- Clamps
- Welded saddles
- FRP
- Local replacement

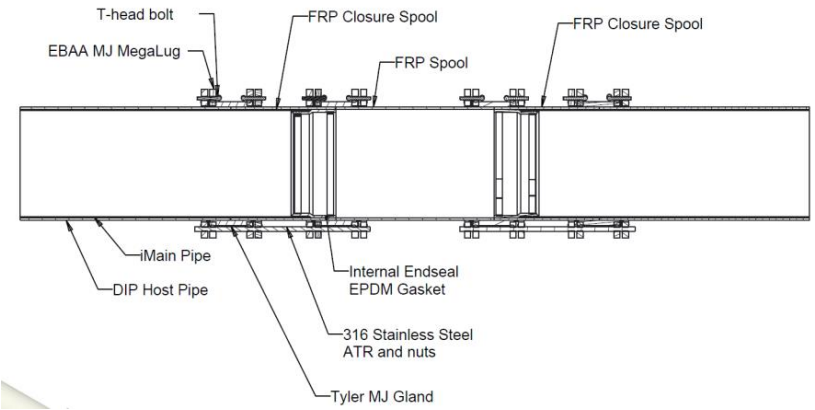




Sliplining

- Multiple options
  - HDPE (AWWA C906, M55)
  - PVC (AWWA C900, M23)
  - FRP (AWWA C950, M45)
  - DIP (AWWA C150, M41)
- Designed per their corresponding manuals/standards, subject to each material's limitations
- Grouted vs sealed annulus
- Diameter reduction (varies)
- Requires access pits





Polymeric Linings

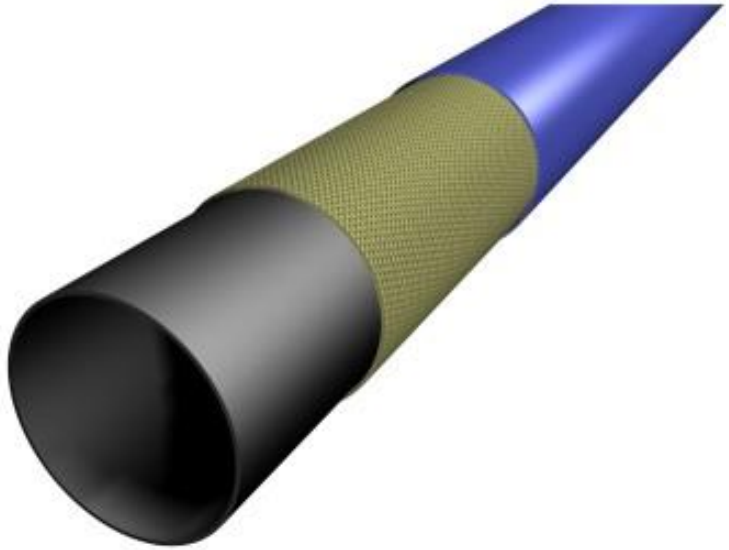
- Non-structural to semi-structural per AWWA C620
  - Depends on thickness, engineer's evaluation
  - Research continues
- Epoxies, polyurethanes, polyuera
- Manual or robotic application
- Rapid cure
- Several challenges in large-diameter pipes (e.g., distance, thickness, uniformity)



Cured-in-Place Lining

- Textile tube saturated with thermosetting resin
  - Inversion (ASTM F1216) or pull-in-place (ASTM F1743)
- Close-fitting in existing pipe
- Used in sewers since 1980s, expanding to water mains
- Applicability to water mains depends on
  - Diameter (up to 72 in. felt-based, 48 in. fiberglass)
  - Pressure (low to medium pressure)
  - Host pipe condition and loads
- AWWA C623 covers materials and procedures, not design
  - Typically designed per ASTM F1216 Appendix
  - New non-mandatory design appendix is in development



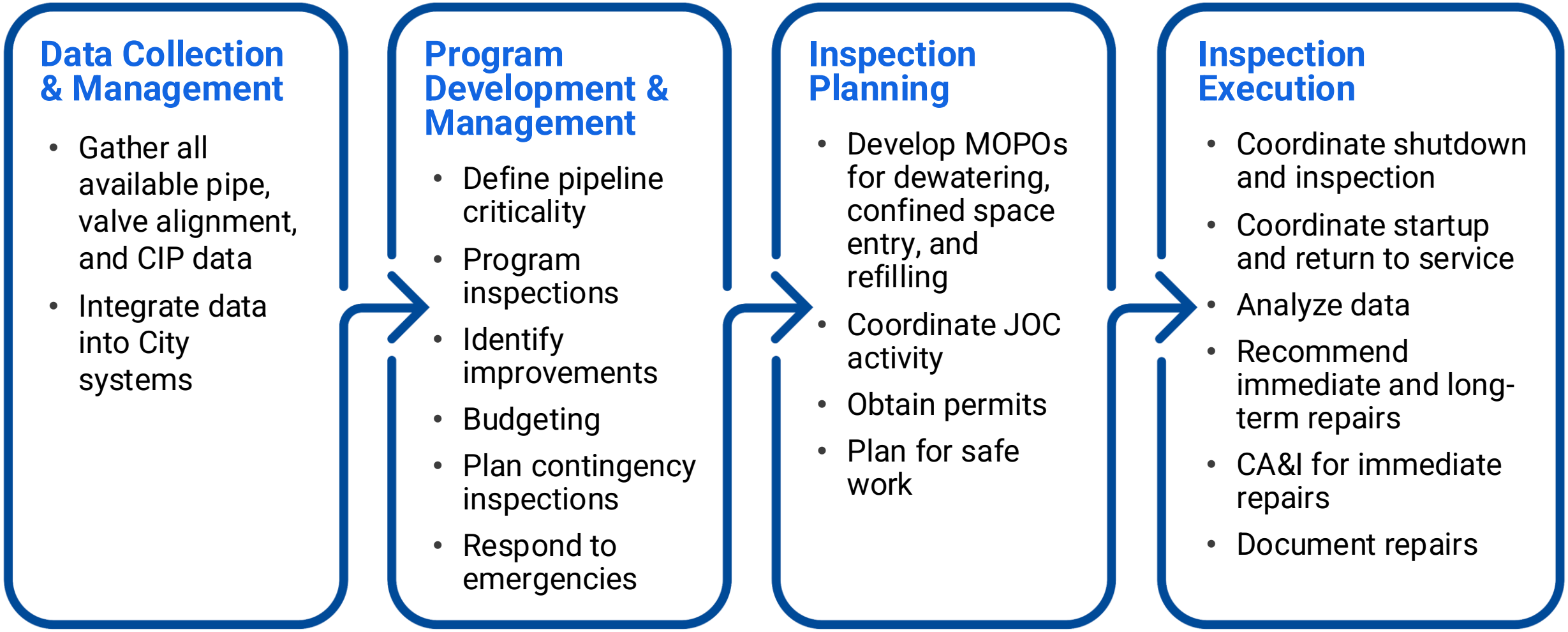




Case Studies

BLACK & VEATCH

Transmission Main Program Major Components

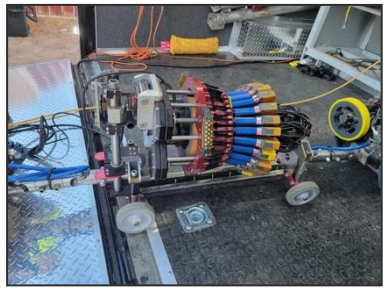


Condition Assessment

WHAT WAS DONE?

- Electromagnetic testing, leak detection, visual assessments, thrust restraint review, corrosion and pressure assessments



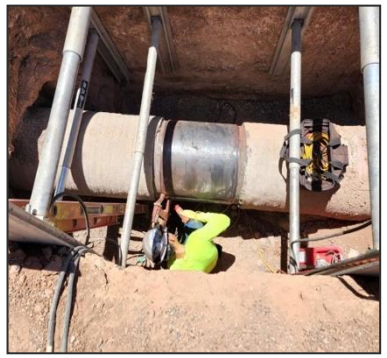




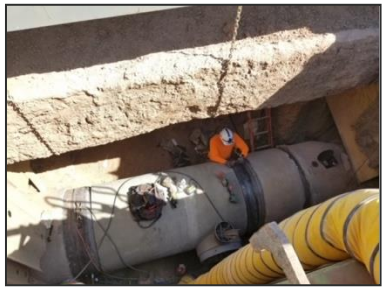
Rehabilitation

WHAT WAS DONE?

- Pipe replacement, butt straps, internal/external joint welds, joint mortar repairs







Design/Construction

WHAT WAS DONE?

- Valve replacement, appurtenance upgrades, pipeline design, cathodic protection





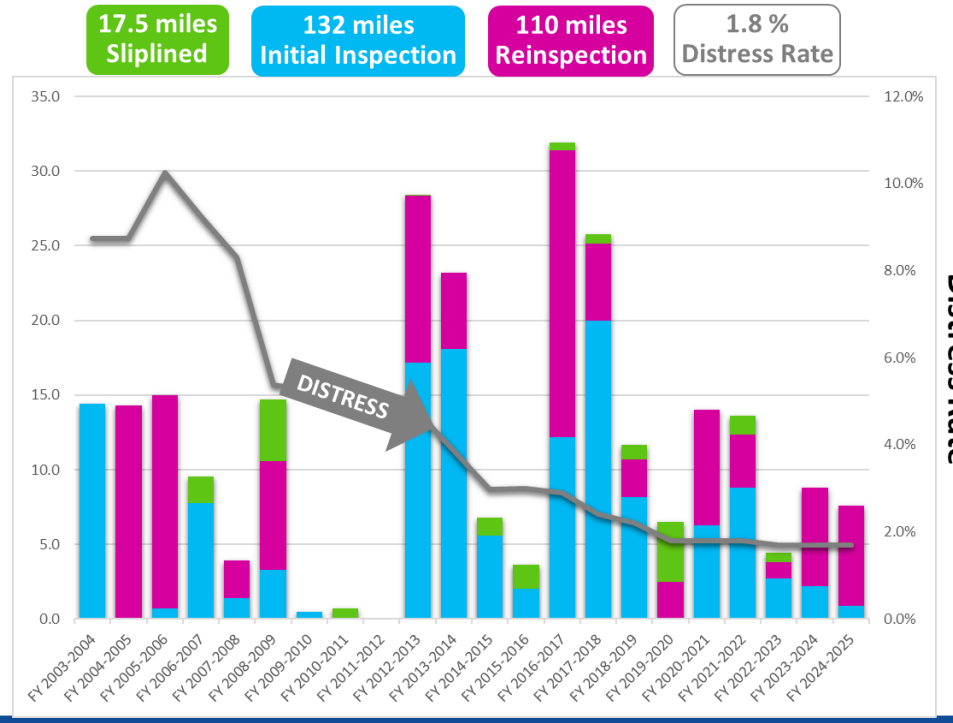


Inspection Program by Year

Pipeline	FY 2016-2017	FY 2017-2018	FY 2018-2019	FY 2019-2020	FY 2020-2021	FY 2021-2022	FY 2022-2023	FY 2023-2024	FY 2024-2025	FY 2025-2026	FY 2026-2027	Recommended Interval From 2011 - 2015 & 2016 - 2019 Programs
4a	3.1										3.1	10 years
4b							0.1					—
5a					4.5							7 years
5b		2.7	0.5									10 years
7b			0.5				2.1					10 years
8									3.0			10 years
9		3.5	1.0			0.5	4.0					5 years
13			2.5			5.2						10 years
14							3.0					—
28							1.5					—
30									6.4			—
38										0.5		—
39											1.3	—
40											0.2	—
Contingency Pipeline	5b	13	14	23b	24b	28						
Reinspection Placeholder	--	--	--	--	--	--	--	--	--	--	5.0	
Totals	31.5	25.2	10.2	2.5	22.1	15.5	19.4	15.7	15.5	16.4	16.5	
Initial Inspection	12.3	19.4	7.6	0.0	14.3	7.3	7.8	3.1	7.1	4.0	8.4	
Reinspection	19.2	5.8	2.55	2.5	7.8	8.2	11.6	12.59	8.4	12.35	8.1	
Sliplined	0.5	0.6	1.0	4.0	1.1	1.3	0.8	0.5	0	0	0	
# of Pipelines	7	11	8	2	7	5	7	4	3	6	6	
Distress Rate	2.9%	2.4%	2.2%	1.8%								

Consistent Planning Criteria

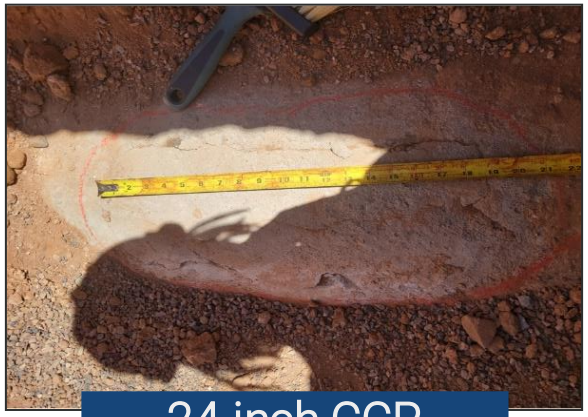
- ✓ Consider multiple other WSD and non-WSD projects
- ✓ ~45 miles/3 years
- ✓ Maintain inspection interval for each pipeline
- ✓ Identify contingency pipelines



Clear Multi-year Plans

Risk Reduction

Electromagnetic – Field Validation



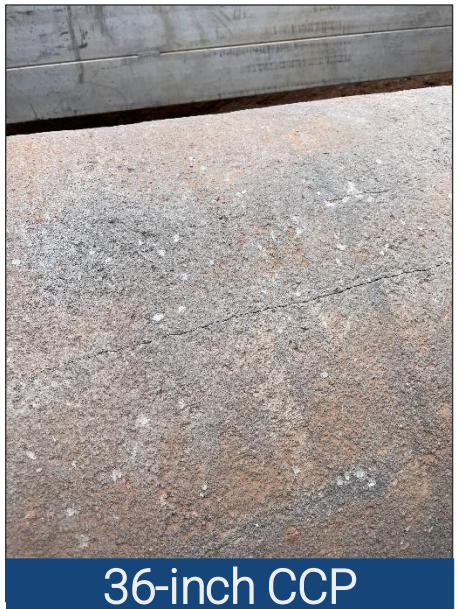


24-inch CCP
Pinhole leak





24-inch CCP
Wall loss / broken bars





36-inch CCP
Corrosion pitting



36-inch CCP
CP Test Station



BLACK & VEATCH

Scott Jauch
jauchs@bv.com

© Black & Veatch Corporation, 2026. All Rights Reserved.
The Black & Veatch name and logo are registered trademarks of Black & Veatch Corporation.

Building a World of Difference.®

© Black & Veatch Corporation, 2026. All Rights Reserved. The Black & Veatch name and logo are registered trademarks of Black & Veatch Corporation.