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Understanding Cathodic Protection and Its Applications

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Topics to be Covered

1. **Corrosion Problems Facing Water Utilities**
2. **Asset Management**
3. **Corrosion Chemistry with Specific Examples**
4. **Pipe Materials and Coatings**
5. **Basic Cathodic Protection**
6. **CP for Existing WMs using an Anode Retrofit Program**
7. **Cathodic Protection for New Water Mains**
8. **Cathodic Protection Performance Verification**
9. **Stray DC Current Interference**

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Section 1

Corrosion Problems Facing Water Utilities

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What's the Rest of the (Unexcavated) Pipe Look Like?

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State of the Water Industry Report – Year 2016

The Top 3 Issues Facing the Water Industry by All Respondents

1. Renewal & replacement of aging water and wastewater infrastructure.
2. Financing for capital improvements.
3. Public understanding of the value of water systems and services.

Source: "2016 State of the Water Industry: The Cornerstone Needs Support", *Journal AWWA*, 108:7, Jul-2016, pp. 63-73.

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What is the leading cause of many water main breaks?

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What Are the Consequences of Pipeline Failures?

Energy Pipeline "Incidents"

Water Main Breaks

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Section 2

Asset Management

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Asset Management: A Real-World Definition

"A water utility's asset management plan is an optimization process that attempts to meet the competing objectives of cost minimization and reliability maximization."

Source: Rubin, S.J., A Call for Reliability Standards, *Journal AWWA*, (Jan-2011)

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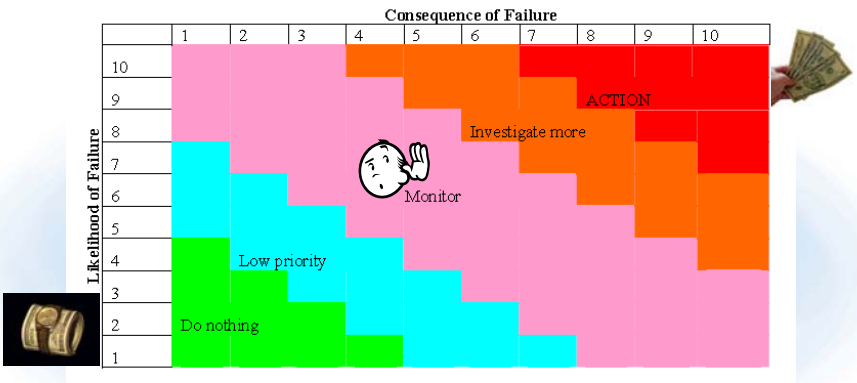
Evaluating Failure Risk: Probability vs. Consequences

Risk = (Likelihood of Failure) x (Consequence of Failure)



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Section 3

Corrosion Chemistry with Specific Examples

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Corrosion: Practical and Scientific Definitions

Practical Definition	The Tendency of a Metal to Revert to its Native State
Scientific Definition	Electrochemical Degradation of Metal as a Result of a Reaction with its Environment

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Four Components of a Basic Corrosion Cell

- **Anode** – A metal electrode in contact with the electrolyte which corrodes.
- **Cathode** - A metal electrode in contact with the electrolyte which is protected against corrosion.
- **Electrolyte** – A solution or conducting medium such as soil, water or concrete which contains oxygen and dissolved chemicals.
- **Metal Path** – An external circuit that connects the anode and the cathode.

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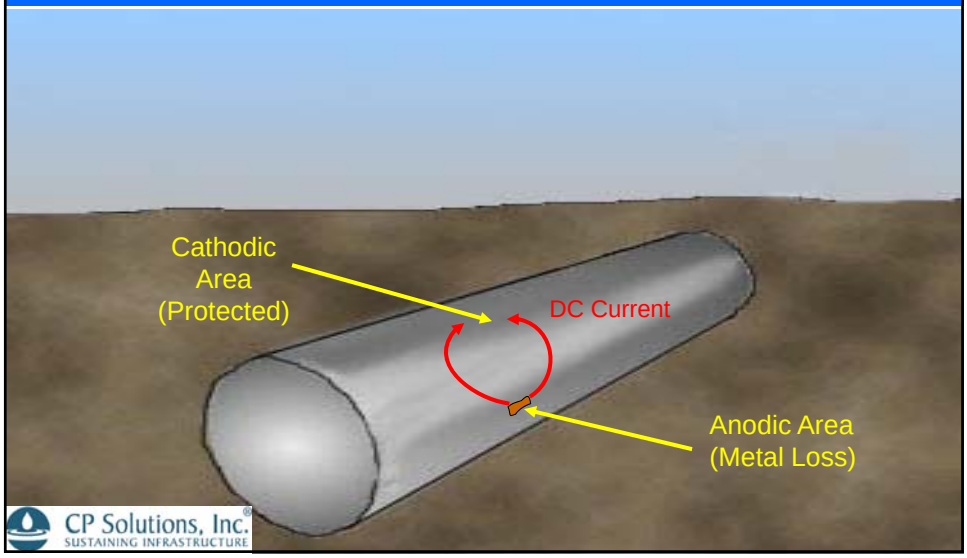
Anodes & Cathodes on a Buried Metallic Pipe



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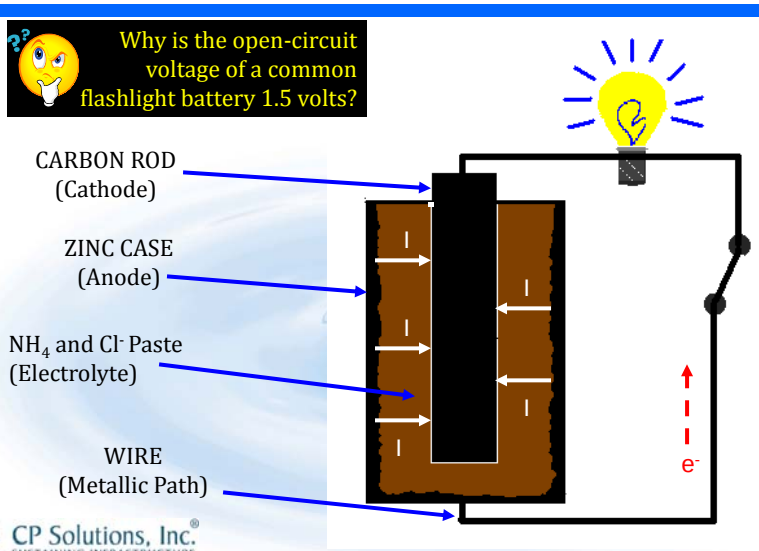
Components of a Familiar Corrosion Cell



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Practical Galvanic Series

Less Active More

Material	Potential*
Pure Magnesium	-1.75
Magnesium Alloy	-1.60
Zinc	-1.10
Aluminum Alloy	-1.00
Mild Steel (New)	-0.70
Mild Steel (Old)	-0.50
Cast / Ductile Iron	-0.50
Stainless Steel	-0.50 to + 0.10
Copper, Brass, Bronze	-0.20
Gold	0.20
Carbon, Graphite, Coke	0.40

*Measured in Volts versus a Cu-$CuSO_4$ Reference Electrode

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Hey! Give me less theory and more examples!

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Galvanic Corrosion at Bi-Metallic Pipe Connection

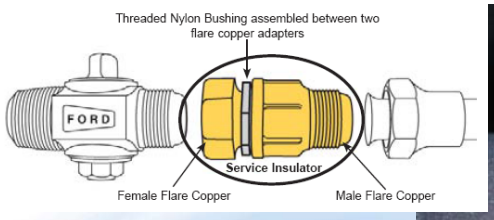

Photo Credit: Drinking Water Services, City of Ottawa, Canada

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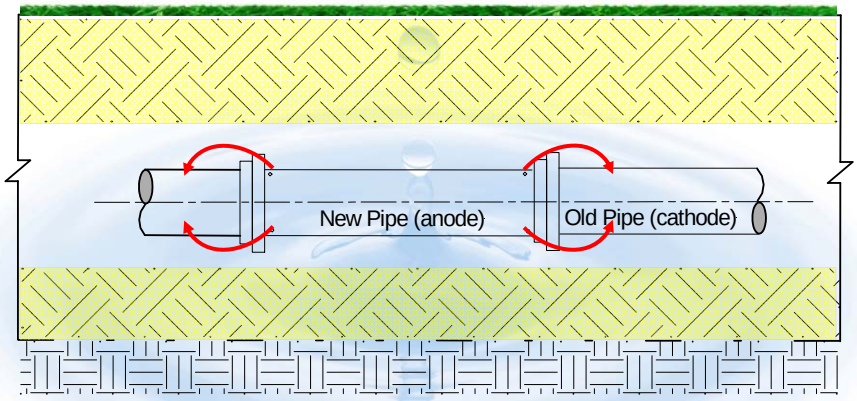
Old-New Pipe Connection Corrosion Cell



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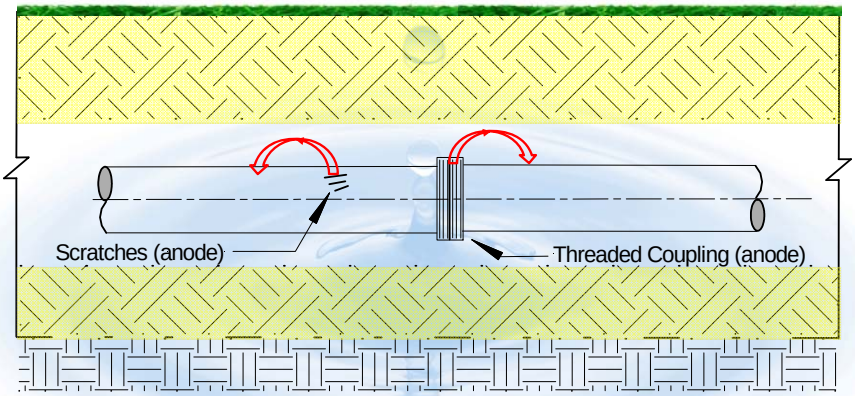
Corrosion Caused by Dissimilar Surface Conditions



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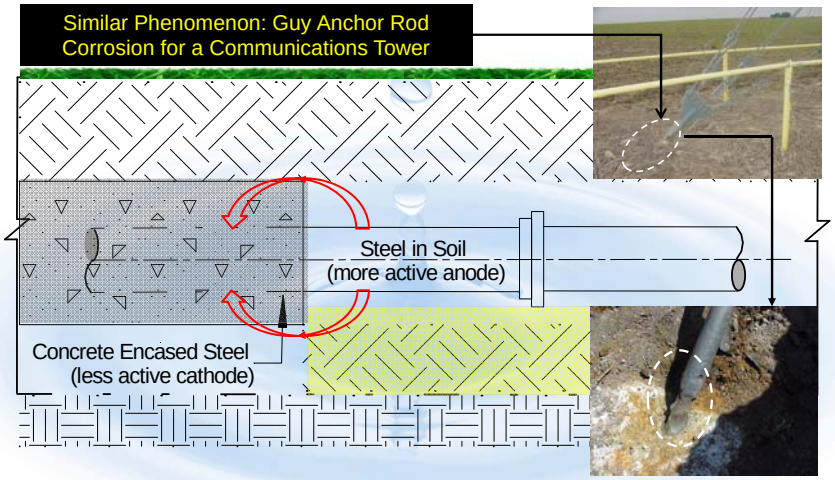
Galvanic Cell – Same Metals in a Non-Uniform Electrolyte



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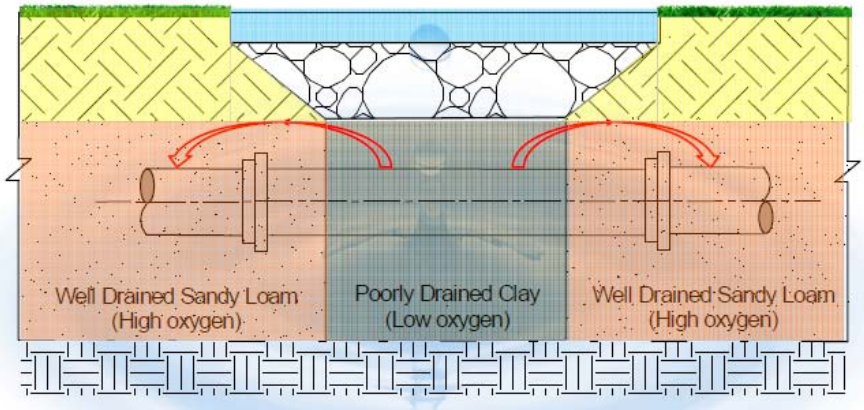
Galvanic Cell – Same Metals in a Non-Uniform Electrolyte



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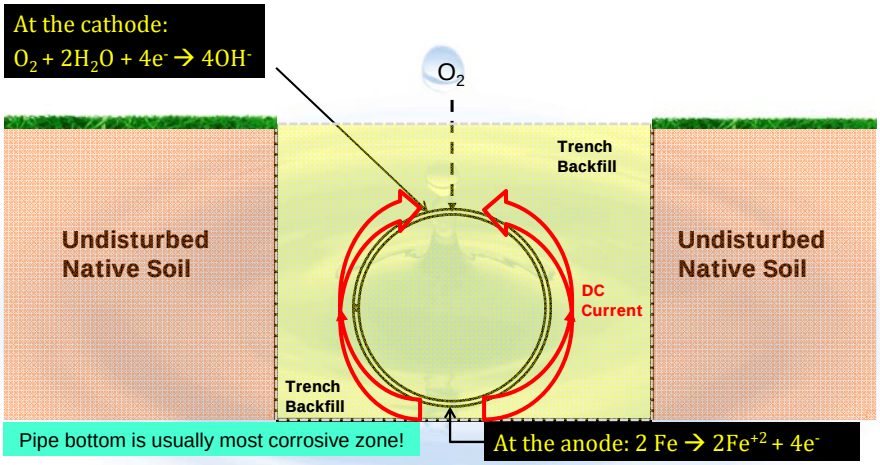
Specific Types of Corrosion – Differential Oxygen



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Differential Oxygen Corrosion: A Specific Example

Photos courtesy of CP Solutions, Inc.

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Specific Types of Corrosion - Pitting

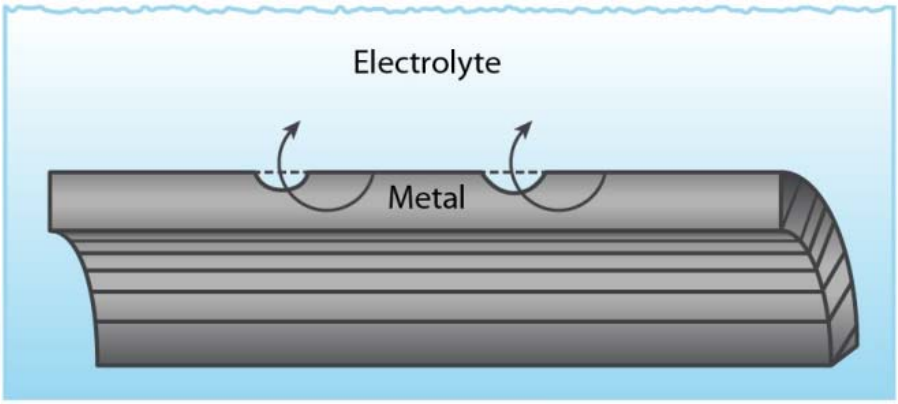

Figure courtesy of **NACE International**

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Pitting Corrosion: Ductile Iron

Photo Credit: CP Solutions, Inc.

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Pitting Corrosion: Carbon Steel

Photos courtesy of CP Solutions, Inc.

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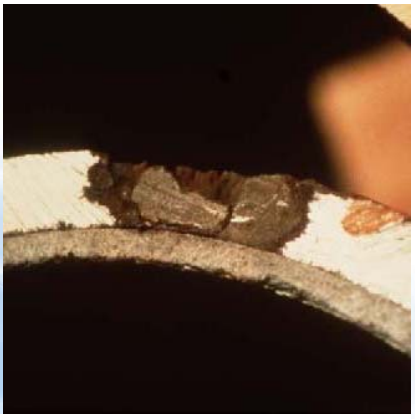
Selective Metal Corrosion - Cast Iron Graphitization



Photos courtesy of CP Solutions, Inc.

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Section 4

Pipe Materials and Coatings

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Basic Electrochemistry – Combined Reactions

Note: The electrons just facilitate the reaction!

- At the anode: $2Fe \rightarrow 2Fe^{+2} + 4e^-$ (iron oxidation-corrosion)
- At the cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (reduction of oxygen)
- Combined Reaction (electrochemical dissolution of iron)

  $2Fe + O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4OH^-$
- Convert Ferrous Iron to Ferric Iron (Rust is the Result)

  $2Fe^{+2} + 3OH^- \rightarrow Fe_2(OH)_3$

If water and oxygen cannot reach the metal surface, will corrosion be stopped?

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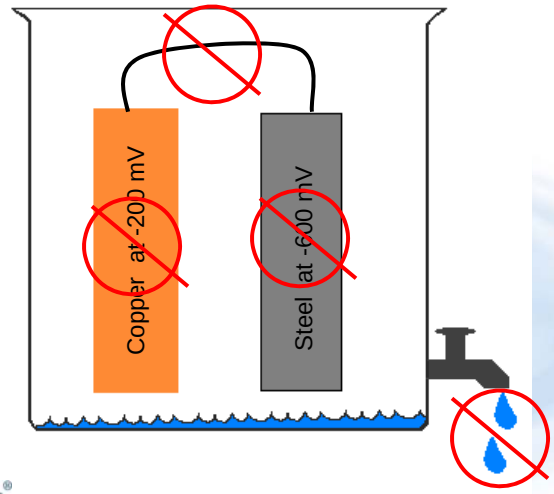
Eliminating the Corrosion Cell



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Prestressed Concrete Cylinder Pipe – Cylinder Forming

Photo Credits: Forterra, Inc.

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Prestressed Concrete Cylinder Pipe - Wire Wrapping

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Prestressed Concrete Cylinder Pipe – Concrete Jacket

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Mortar Integrity on Reinforced Concrete Pipe

New installation looks good…

Photo Credits: CP Solutions, Inc.

…but is there latent damage?

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Prestressed Concrete Cylinder Pipe – Corrosion Failures

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Coated Steel Pipe - Factory-Applied Coating Systems

AWWA C-214 Standard Tape Wrap

Photo Credits: Northwest Pipe

AWWA Standard C-222 Polyurethane

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Large Diameter Coated Steel Pipe – Installation Photos

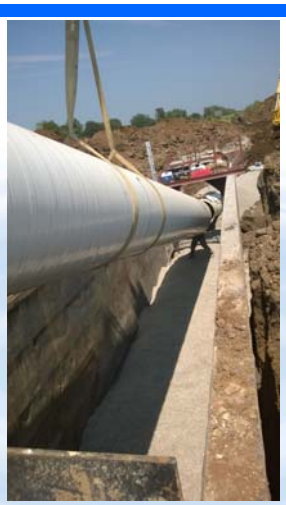

Photo Credits: CP Solutions, Inc.

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Coating Integrity on Coated Steel Pipe

New installation looks good…

…but is there latent damage?

Photo Credits: CP Solutions, Inc.

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Consider Long Term Pipe Coating Damage

Does it adequately resist soil stress?

Photo Credits: CP Solutions, Inc.

Will my pipe coating resist damage from third-party “hits” after burial?

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Pipe Coating/Tape Wrapping– Long-Term Effectiveness

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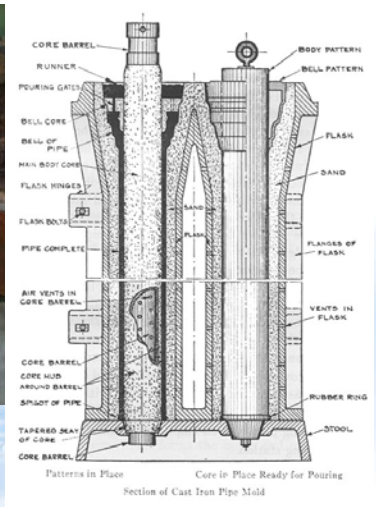
Pit-Cast Iron Water Pipe (Circa 1915)

Left Photo Credit: CP Solutions, Inc.

Right Photo Credit: Ductile Iron Pipe Research Association



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Ductile Iron Water Pipe (Contemporary)

Photo Credit: CP Solutions, Inc.

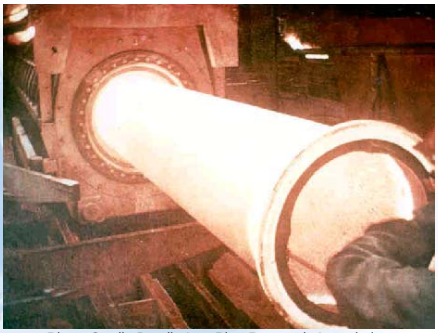

Photo Credit: Ductile Iron Pipe Research Association

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Poly-Wrap Integrity on Ductile Iron Pipe

New installation looks good…

Photo courtesy of CP Solutions, Inc.

…but is there latent damage?

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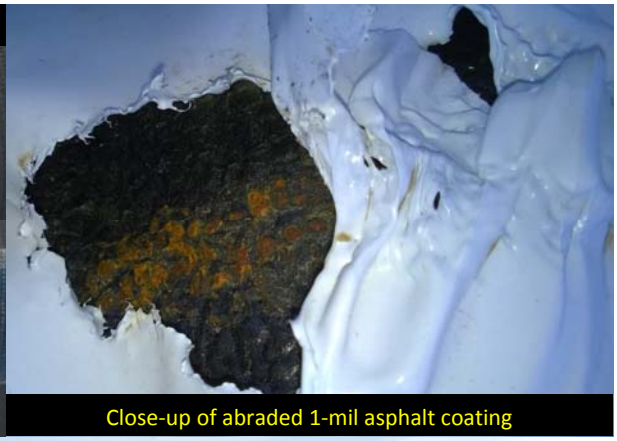
DIP Asphalt Coating – A True Corrosion Barrier?



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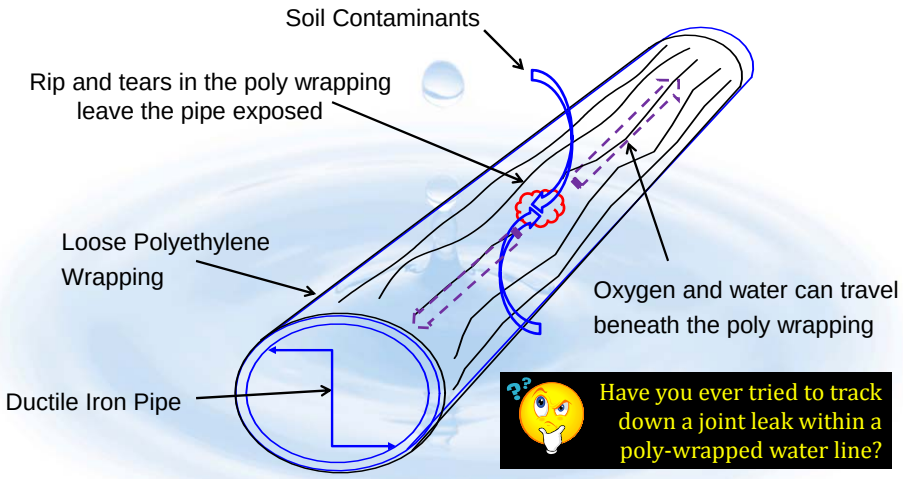
Loose Poly Wrapping – An Effective Corrosion Barrier?



Have you ever tried to track down a joint leak within a poly-wrapped water line?

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Section 5

Basic Cathodic Protection

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How Cathodic Protection Works

- **Basic Corrosion:** Corrosion occurs where DC current discharges from the metal to the electrolyte.
- **CP Objective:** To allow your structure to receive DC current (be cathodic) from an expendable anode placed in the soil.

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Practical Galvanic Series

More Active
Less

Material	Potential*
Pure Magnesium	-1.75
Magnesium Alloy	-1.60
Zinc	-1.10
Aluminum Alloy	-1.00
Mild Steel (New)	-0.70
Mild Steel (Old)	-0.50
Cast / Ductile Iron	-0.50
Stainless Steel	-0.50 to + 0.10
Copper, Brass, Bronze	-0.20
Gold	0.20
Carbon, Graphite, Coke	0.40

*Measured in Volts versus a Cu-$CuSO_4$ Reference Electrode

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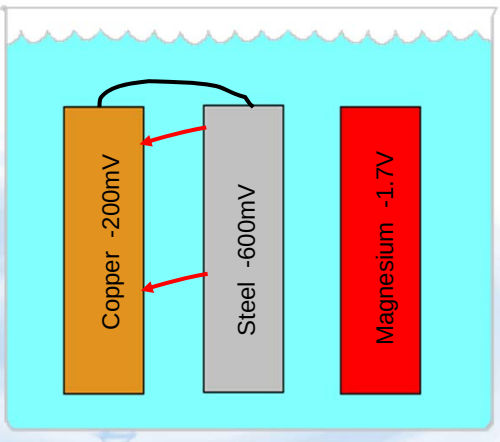
Galvanic Corrosion – No Cathodic Protection Benefit

1. Anode
2. Cathode
3. Electrolyte
4. Metal Path



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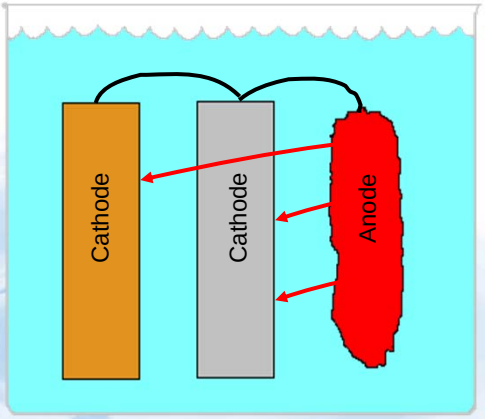
Galvanic Corrosion Mitigated w/Cathodic Protection

1. Anode
2. Cathode
3. Electrolyte
4. Metal Path



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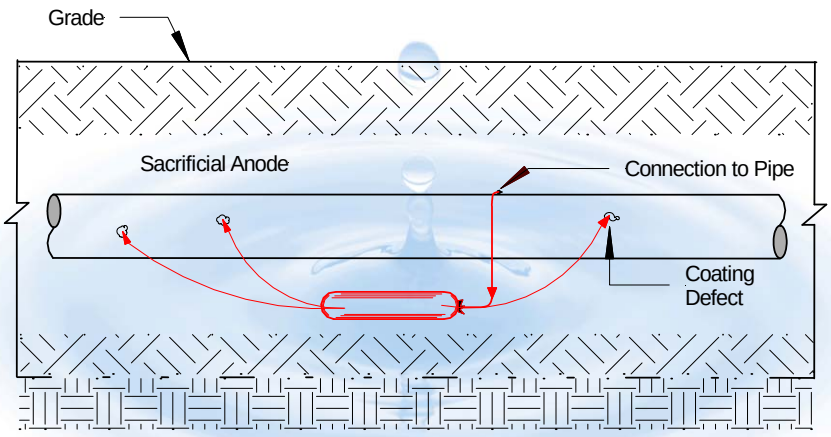
Typical Horizontal Sacrificial Anode Installation



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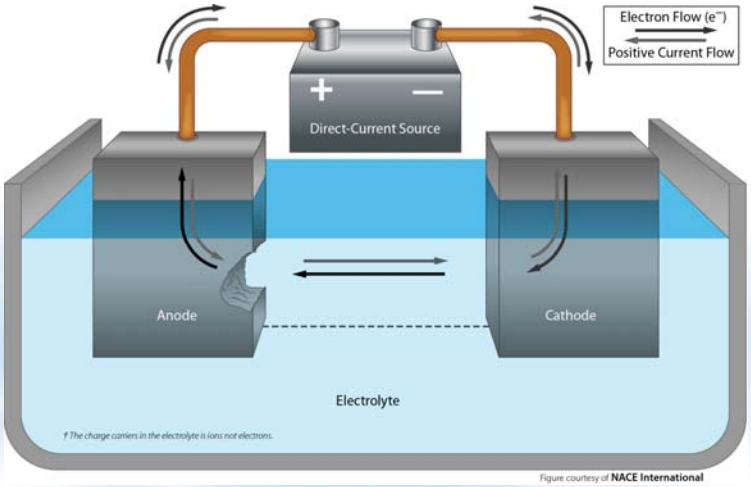
Rectified Anode Cathodic Protection Schematic



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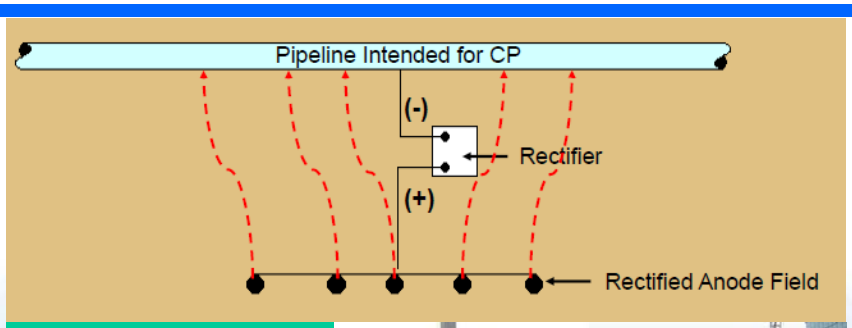
Rectified Anode Cathodic Protection on a Pipeline



DC current is obtained from more noble (inert) metal anodes powered by a transformer/rectifier

Photo Credits: CP Solutions, Inc.

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15’ SVAC – Open Flight Augur Installation




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25’ SVAC - Hollow Stem Augur Installation





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100’ DVAC - Rotary Mud Drill Installation

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Section 6

Cathodic Protection for Existing Water Mains using an Anode Retrofit Program

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Anode Retrofit Programs – An Overview

Anode **R**etrofit **P**rogram (ARP) - A method to install sacrificial anodes to buried water mains.

- Since 2003 – Louisville (KY) Water Company
- Since 2004 – Des Moines (IA) Water Works
- Since 1980's – Many Ontario (Canada) Water Utilities
- More Recently – Several California Water Utilities

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Anode Retrofit Program - Purpose

- Reduce the Number of Broken Water Mains
- Extend Service Life of Water Mains
- Reduce Operating Costs of Water Mains

Photo Credits: CP Solutions, Inc.

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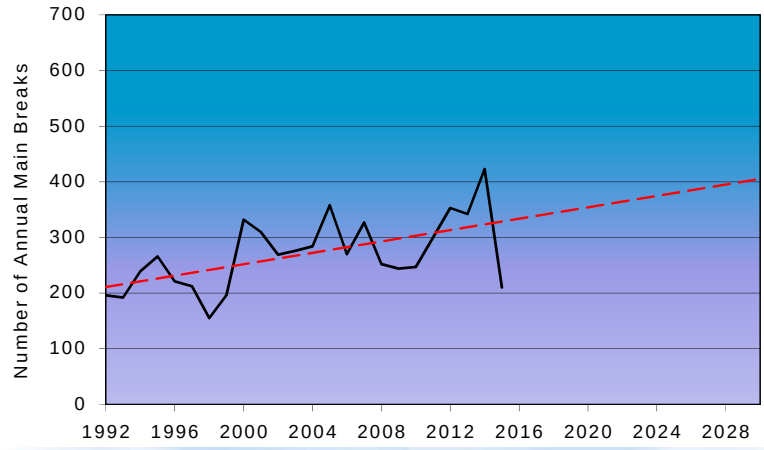
DMWW's Long-Term Main Break Data (1992-2015)



Data courtesy of Des Moines Water Works – Des Moines, IA

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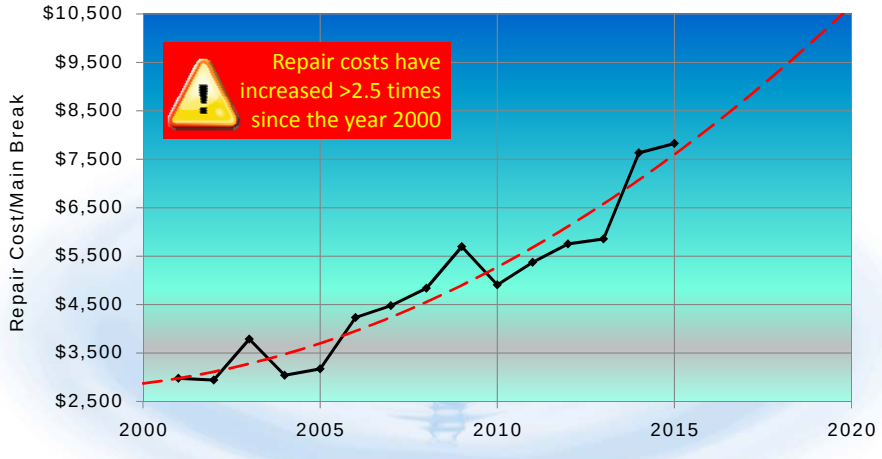
DMWW's Main Break Repair Costs (2001-2015…)



Data courtesy of Des Moines Water Works – Des Moines, IA

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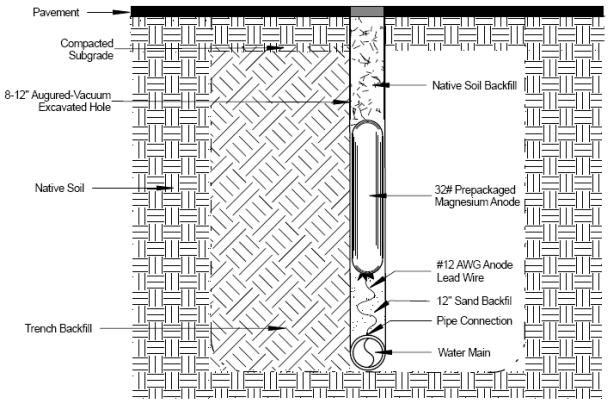
Typical Anode Retrofit Installation Method



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Keyhole to Pipe & Wire Connection

Exothermic Welding Tool Down the Hole

Photo Credits: CP Solutions, Inc.

Testing the Wire Connection

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Alternative (Non-Keyhole) Installation Methods

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Technical Evaluation of the DMMW's ARP

How does one verify that the anodes are working and can one make an estimate of the anodes' effective service life?

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Evaluating the Effectiveness of the CP Installation

Test Station between Sidewalk and Curb

Measuring CP Effectiveness at Buffalo Box Test Station

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Main Break Reduction Evaluation of the DMMW's ARP

Does the data show that retrofitting CP anodes on water mains actually reduces the main break rates?

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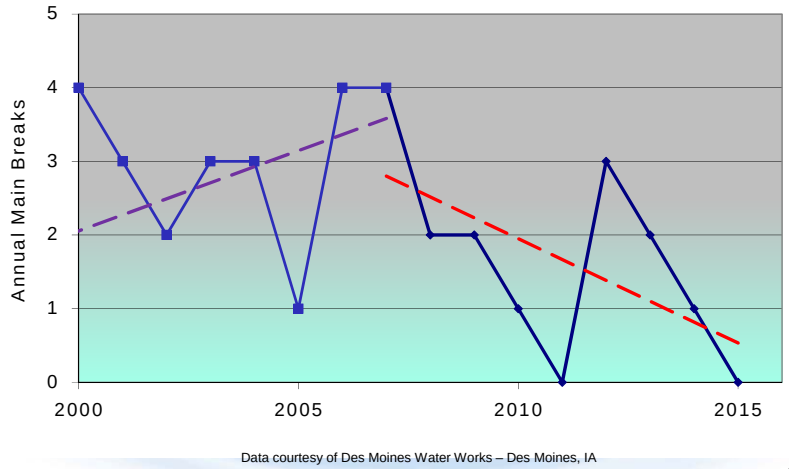
Example: Main Breaks on 2007 Anode Retrofit Project



Data courtesy of Des Moines Water Works – Des Moines, IA

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Economic Evaluation of the DMMW's ARP

But does the economic data show that retrofitting CP anodes on water mains <u>is actually cost-effective</u>?

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DMWW Anode Retrofit Program: 2004-2011 Summary

- ARP installed on ~82,000 feet of 6" - 16" cast iron mains
- ARP costs are $9 to $15/ft. pipe
- ARP cost ~10-15% of break repairs/pipe replacement
- ARP resulted in average reduction of 85% in main breaks
- ARP adds a ~25-year service life extension to water mains

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Section 7

Cathodic Protection for New Large Diameter (>16") Water Feeder Mains

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Corrosion Control Criteria: New Water Mains

A water utility must consider corrosion protection as part of its design analysis for the following types of pipe materials used for new water mains:

- Prestressed Concrete Cylinder Pipe (AWWA C301)
- Ductile Iron Pipe (AWWA C110)
- Welded Steel Pipe (AWWA C200)

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Cathodic Protection System – Keys to Success

1. Integrity of the pipe's coating/wrapping system
2. Pipe is electrically isolated from foreign structures
3. Pipe must be an electrically continuous structure
4. Pipe connections must be electrically secure
5. Install accessible test points to verify effectiveness
6. Install anodes simultaneously with the pipe

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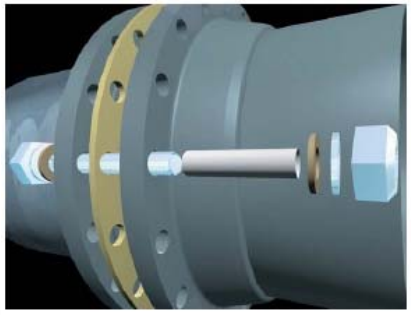
Flange Isolation Kit Components



FIK components should always meet NSF-61 requirements

Photos courtesy of Garlock Pipeline Technologies, Inc. – Wheat Ridge, CO

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Isolation Corporation Stop

Photo Credit: CP Solutions, Inc.

Photo courtesy of James Jones Company – Decatur, IL

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Pipe Sleeve Isolation Spacers

Photo Credits: CP Solutions, Inc. (left) and
Des Moines Water Works (right)

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Casing Sleeve – Typical Pipe End Seals

Link-Style End Seal

A suitable end seal prevents pipe-to-casing contact and also keeps soil/water from entering into the casing annulus!

Boot-Style End Seal

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Wall Penetrations on Pipe With Cathodic Protection

Link-Style End Seal


Thru-Wall Pipe w/Anchor

Pipe welded to rebar of concrete wall!


No isolation of pipe-rebar

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Continuity Bonds at Mechanical Pipe Joints


Ductile Iron Pipe w/Mechanical Joints


Steel Pipe w/Rubber Gasketed Joints

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Exothermic Welds and Connection Devices

Proper surface preparation will allow good welds

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Proper Coating of Exothermic Welds Connections

Raw Connections before Coating

Photo Credits: CP Solutions, Inc.

Restore poly wrap over test station wires

Finished Connections Ready to Backfill

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A Suitable Post-Type CP Test Station Installation

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Suitable Flush-Type CP Test Station Installation

Terminal board is mounted to PE Pipe

Concrete pad is optional per owner

Crushed gravel provides drainage

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Anodes Installed in an Open Pipe Trench

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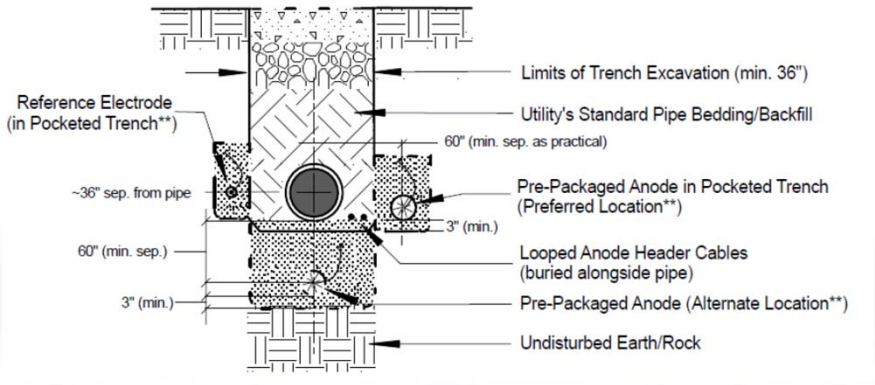
Anode Test Station – Section View



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Section 8

Cathodic Protection Performance Verification

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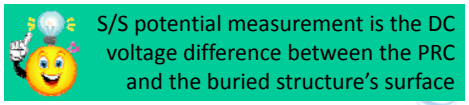
Structure-to-Soil Potential w/Portable Reference Cell



S/S potential measurement is the DC voltage difference between the PRC and the buried structure's surface

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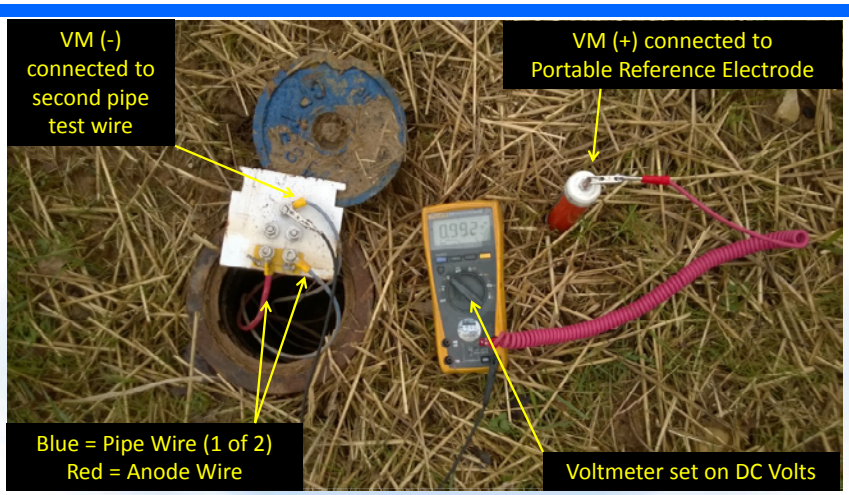
CP Performance Validation – S/S Potential Data



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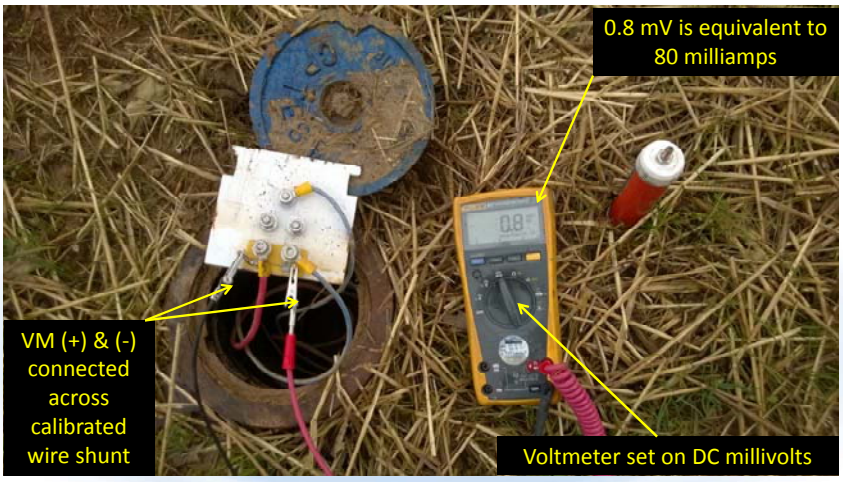
CP Performance Validation – Anode Current Output Data



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The "True" Cathodic Protection Criterion

- Corrosion is the degradation of a material due to a reaction with its environment
- CP is achieved when the cathodic sites are polarized in the electronegative direction to the potential of the most anodic sites.
- Only practical method to determine this is by measuring structure-to-soil potential data using a standard reference electrode.

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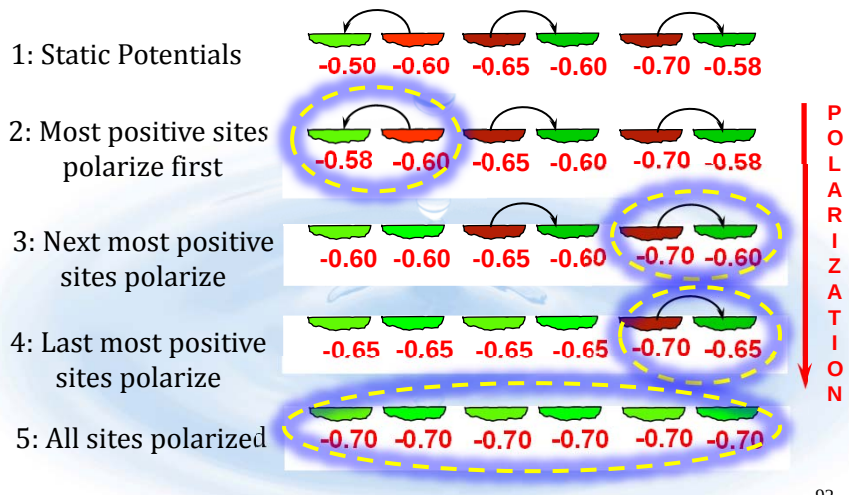
Polarization reduces the ΔV along the structure



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Summary: The Real Benefits of Corrosion Mitigation

Water Main Life Extension of least 25 years at a cost that is much less than…

- Direct costs of pipe repairs and/or water main replacement.
- Indirect costs resulting from water loss/service disruptions.

Cathodic protection **saves $5 to $10** for every $1 spent resulting in…

- Increased water main service life
- Increased level of reliable water service to customers
- Increased health and security of the municipal water supply

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Section 9

Stray DC Current Interference

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DC Transit System Causing Electrolytic Corrosion

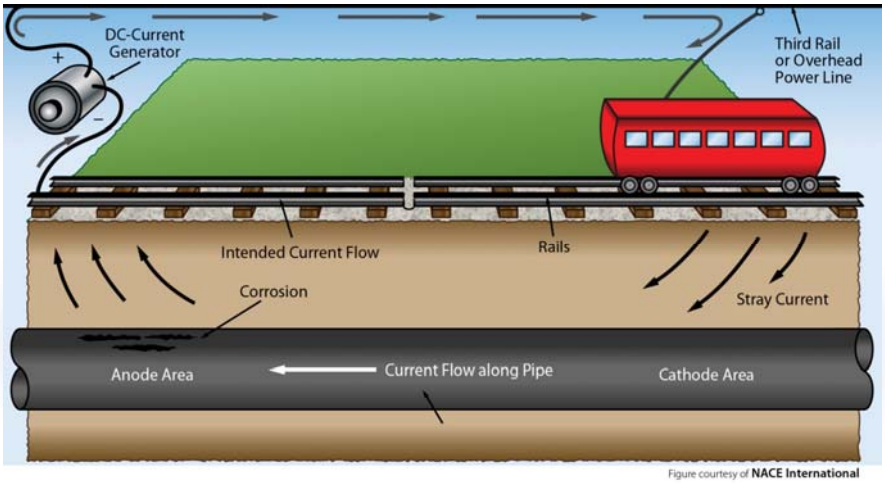

Figure courtesy of NACE International

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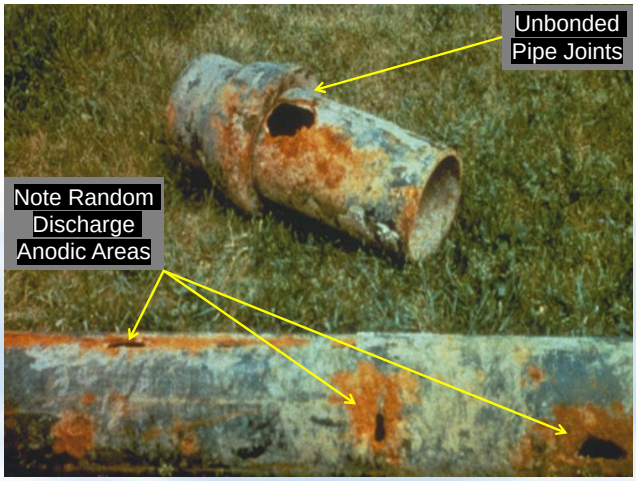
Effects of Stray DC Current from DC Transit System



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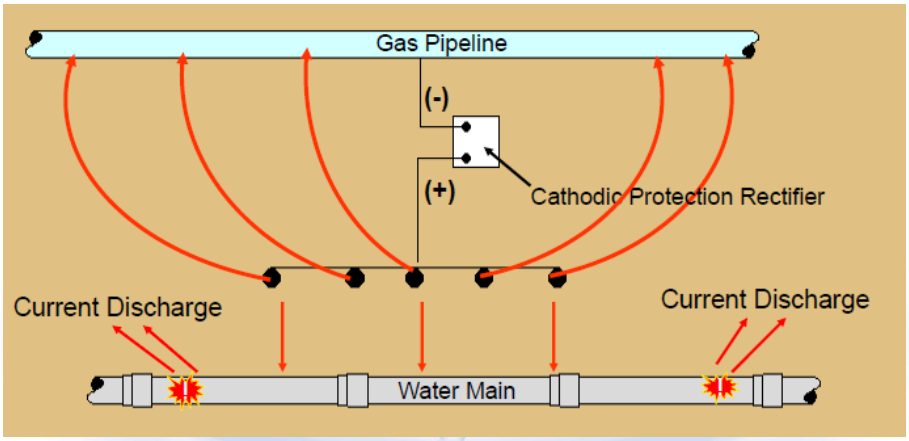
Stray DC Interference from an Rectified-Anode CP System



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Effects of Foreign CP System at Pipe Joint

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Observing and Testing for DC Interference

Observations: Look for changes in S/S potentials along the buried structure at

- Discrete test points (discrete test stations)
- Close-interval potential survey (CIPS)

Methodology

- Interrupt foreign all CP rectifiers and note S/S during both ON and OFF cycles

Recognition: Abnormal Operating Conditions

- Positive S/S shifts with the foreign rectifier ON require additional investigation/mitigation

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IEEE-IAS/IES Dinner Presentation: 5/24/2017

Do You Have Any Questions?

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