Practical Solutions to External Corrosion Problems on Buried Water Mains

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Topics to be Covered

1. **Corrosion Problems Facing Water Utilities**
2. **Asset Management**
3. **The Chemistry of Corrosion and Real World Examples**
4. **Pipe Materials and Coatings**
5. **Basic Cathodic Protection**
6. **CP for Existing WMs using an Anode Retrofit Program**
7. **Solving Corrosion Problems at WM Breaks**
8. **Solving Corrosion Problems on Trans & Dist WMs**
9. **Cathodic Protection Performance Verification**

Module 1
Corrosion Problems Facing Water Utilities

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

State of the Water Industry Report – Year 2014

Top 3 Issues Facing the Water Industry As Ranked by All 2014 SOTWI Respondents

Rank	Issue	Average Score*	Critically Important† %
1	State of water and sewer infrastructure	4.57	63
2	Long-term water supply availability	4.51	64
3	Financing for capital improvements	4.41	53

*Average rating of issue importance on a scale of 1 (unimportant to 5 (critically important)

†Percentage of respondents who scored the issue as critically important (i.e., 5 on the scale of 1 to 5)

Source: "2014 State of the Water Industry: Ongoing Challenges and No Easy Solutions", *Journal AWWA,* 106:6, Jun-2014, pp. 30-41.

What is the leading cause of many water main breaks?

Corrosion!

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What Are the Consequences of Pipeline Failures?

Energy Pipeline "Incidents"

Water Main Breaks

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Module 2
Asset Management

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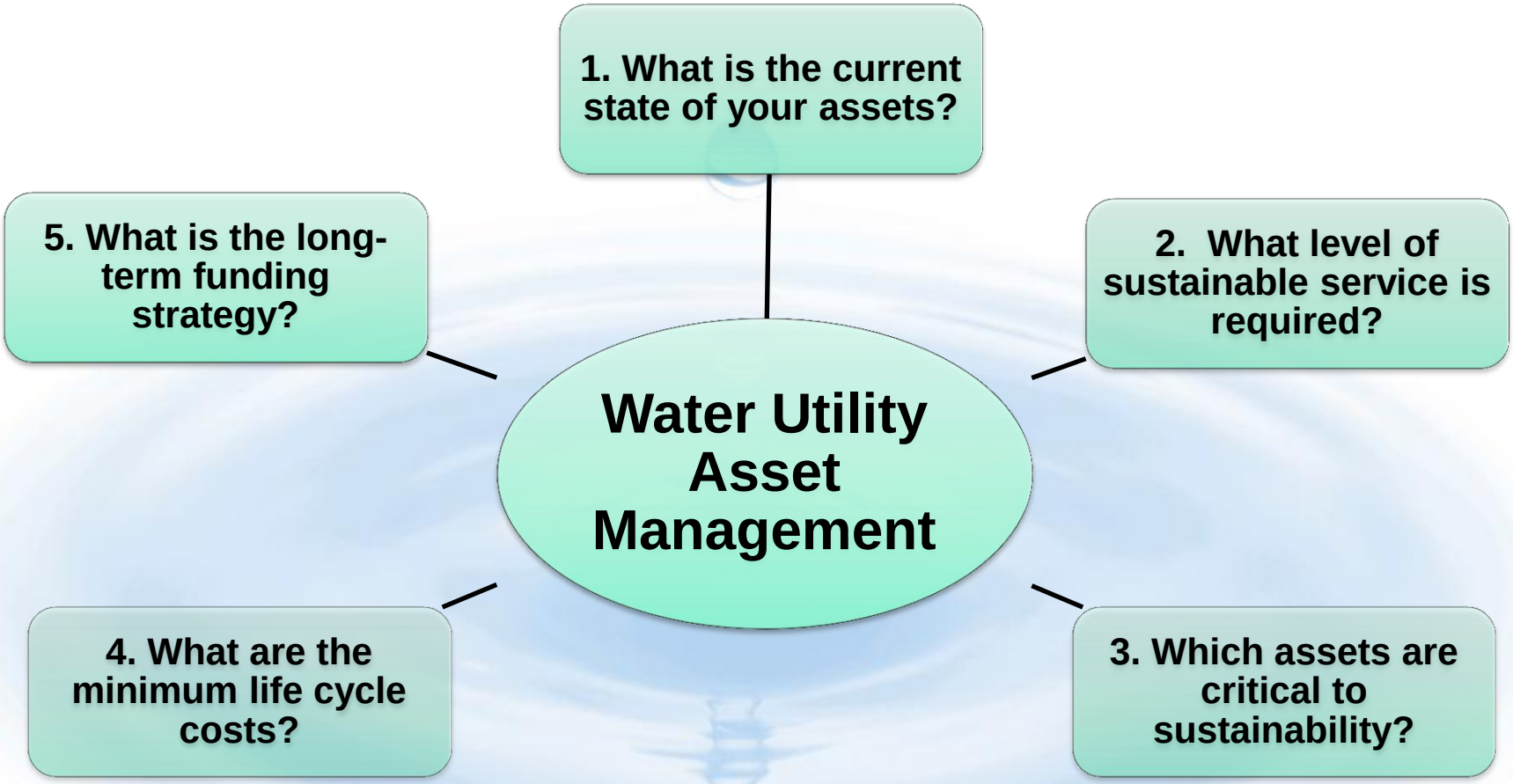
Asset Management: A Real-World Definition

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

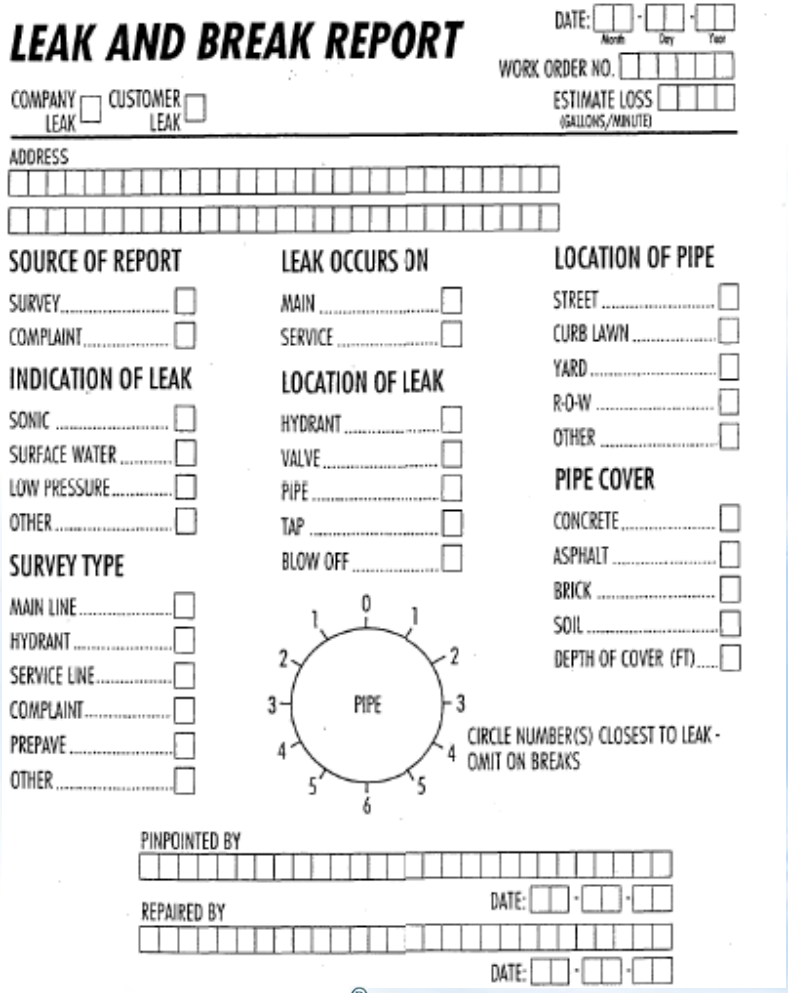
Source: Rubin, S.J., A Call for Reliability Standards, *Journal AWWA*, (Jan-2011)

Asset Management – The Core Framework



Source: U.S. EPA. Asset Management: A Best Practices Guide. EPA 816-F-08-014, (Apr-2008)

Data Collection for Water Main Breaks



LEAK AND BREAK REPORT

DATE: ☐☐-☐☐-☐☐ (Month Day Year)

WORK ORDER NO. ☐☐☐☐☐

ESTIMATE LOSS (GALLONS/MINUTE) ☐☐☐☐

COMPANY LEAK ☐ CUSTOMER LEAK ☐

ADDRESS

SOURCE OF REPORT
- SURVEY ☐
- COMPLAINT ☐

INDICATION OF LEAK
- SONIC ☐
- SURFACE WATER ☐
- LOW PRESSURE ☐
- OTHER ☐

SURVEY TYPE
- MAIN LINE ☐
- HYDRANT ☐
- SERVICE LINE ☐
- COMPLAINT ☐
- PREPAVE ☐
- OTHER ☐

LEAK OCCURS ON
- MAIN ☐
- SERVICE ☐

LOCATION OF LEAK
- HYDRANT ☐
- VALVE ☐
- PIPE ☐
- TAP ☐
- BLOW OFF ☐

CIRCLE NUMBER(S) CLOSEST TO LEAK - OMIT ON BREAKS

LOCATION OF PIPE
- STREET ☐
- CURB LAWN ☐
- YARD ☐
- R-O-W ☐
- OTHER ☐

PIPE COVER
- CONCRETE ☐
- ASPHALT ☐
- BRICK ☐
- SOIL ☐
- DEPTH OF COVER (FT) ☐

PINPOINTED BY

REPAIRED BY DATE: ☐☐-☐☐-☐☐

DATE: ☐☐-☐☐-☐☐

A "reasonable goal" for water system main breaks is 25 to 30 breaks per 100 miles of main per year*

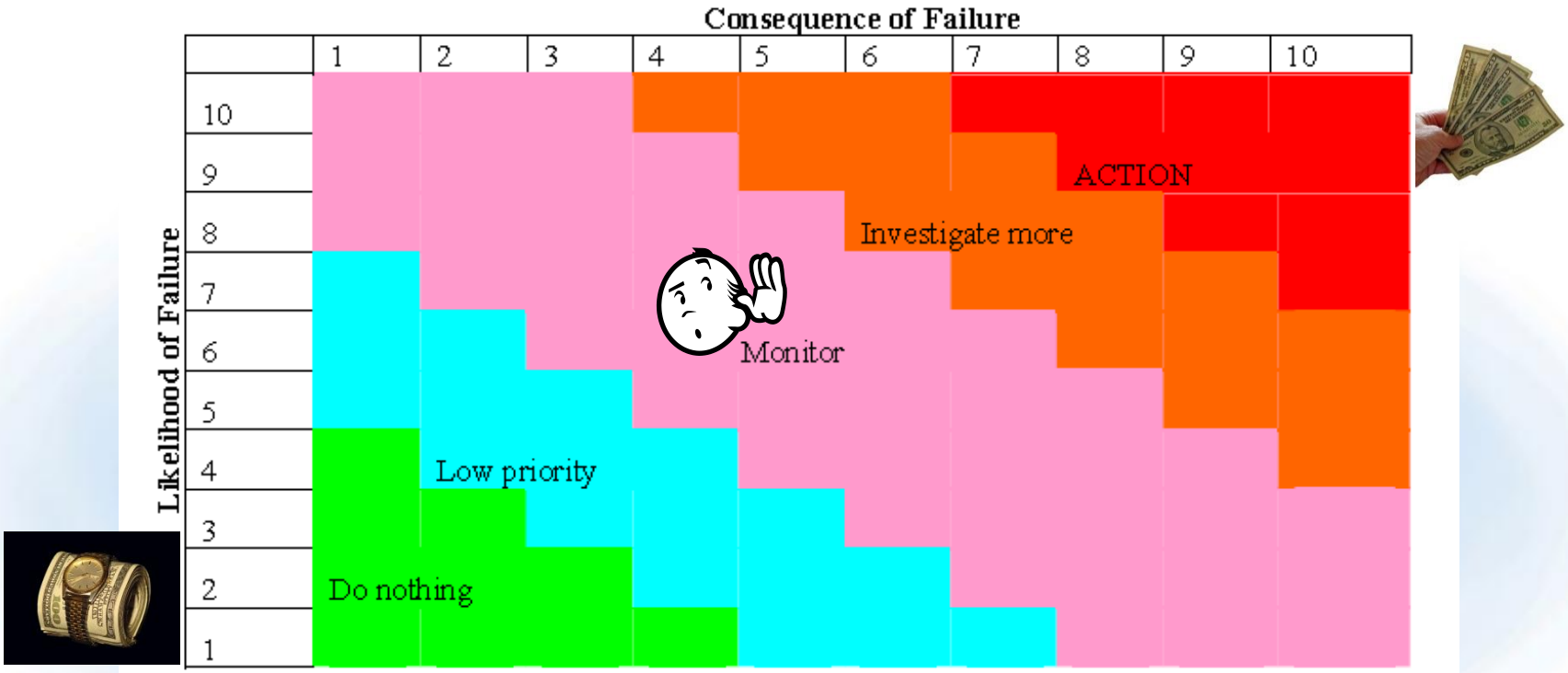
Source: AWWARF, *Distribution System Performance Evaluation*, AWWA, Denver, CO, 1995

"We produce about 20 million gallons a day, and we lose about 30 percent through leaks and breaks."

Source: "Answer Man," *Ashville Citizen-Times*, 7/13/2014

Evaluating Failure Risk: Probability vs. Consequences

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



Module 3
The Chemistry of Corrosion
and
Real World 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

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.

Components of a Familiar Corrosion Cell

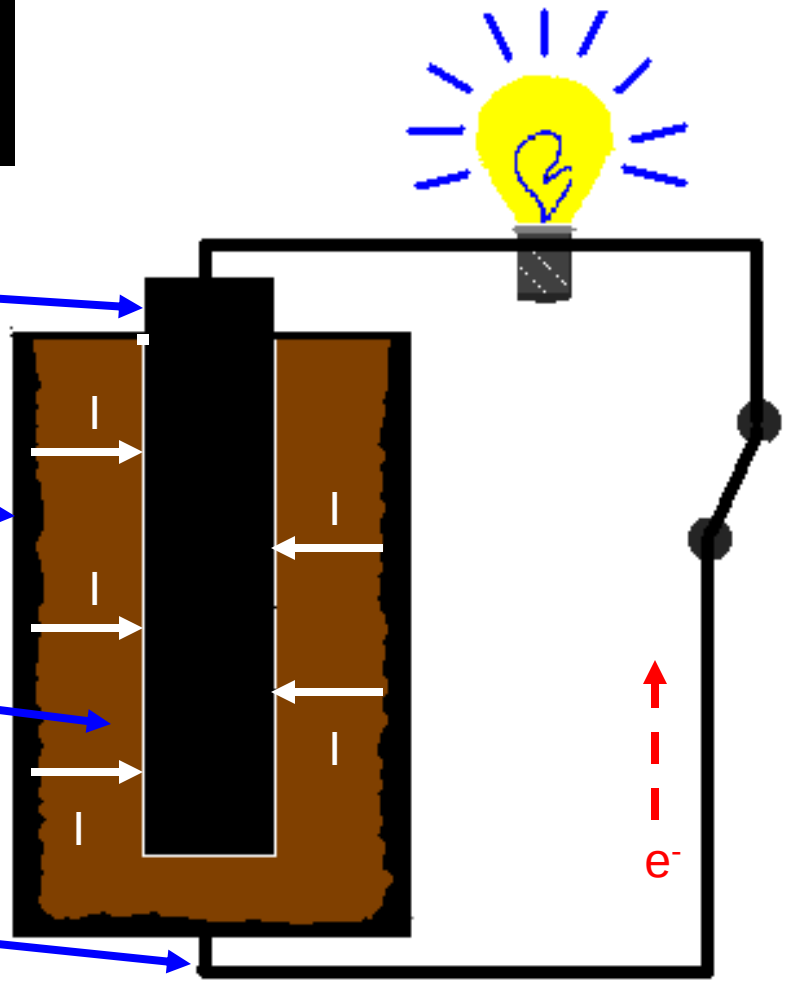
Why is the open-circuit voltage of a common flashlight battery 1.5 volts?

CARBON ROD
(Cathode)

ZINC CASE
(Anode)

NH_4 and Cl^- Paste
(Electrolyte)

WIRE
(Metallic Path)



Practical Galvanic Series

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

Galvanic Corrosion at Bi-Metallic Pipe Connection

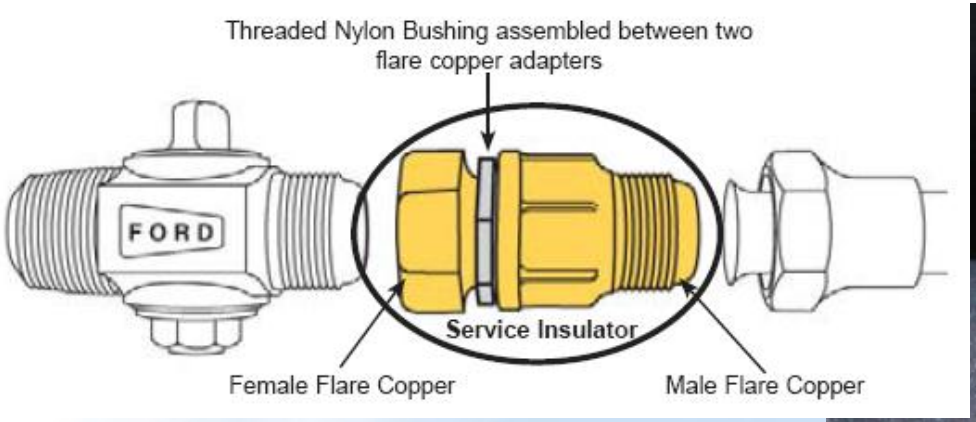
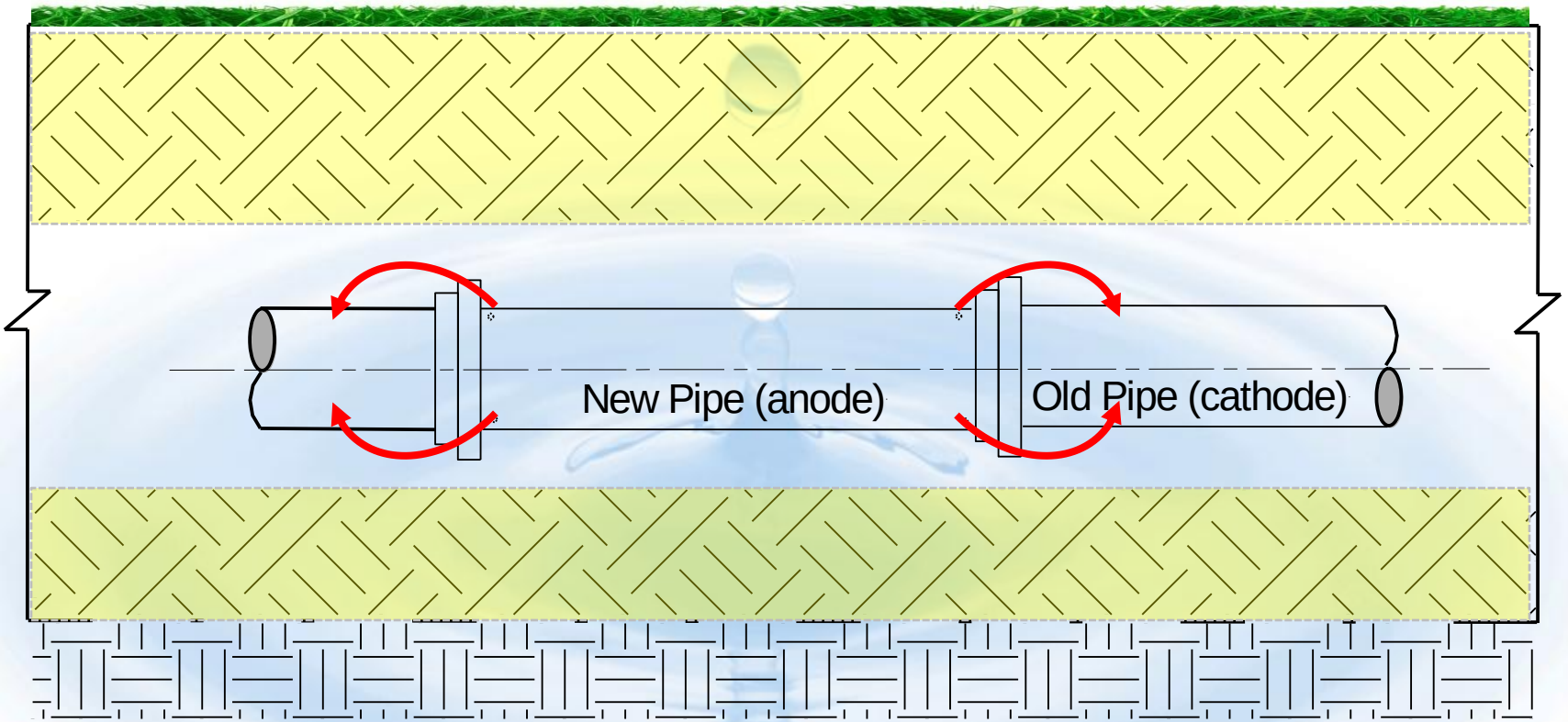


Photo Credit: Drinking Water Services, City of Ottawa, Canada

Old-New Pipe Connection Corrosion Cell



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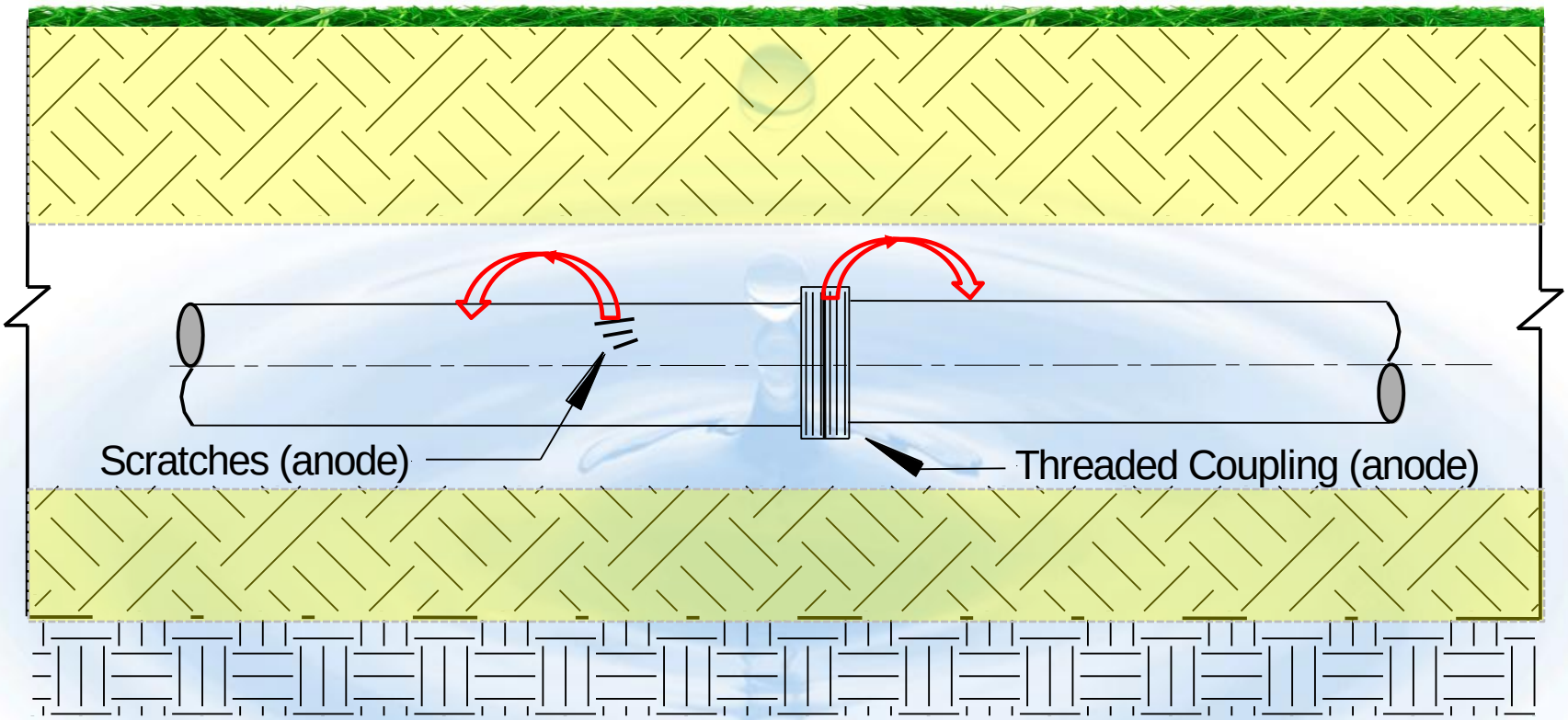
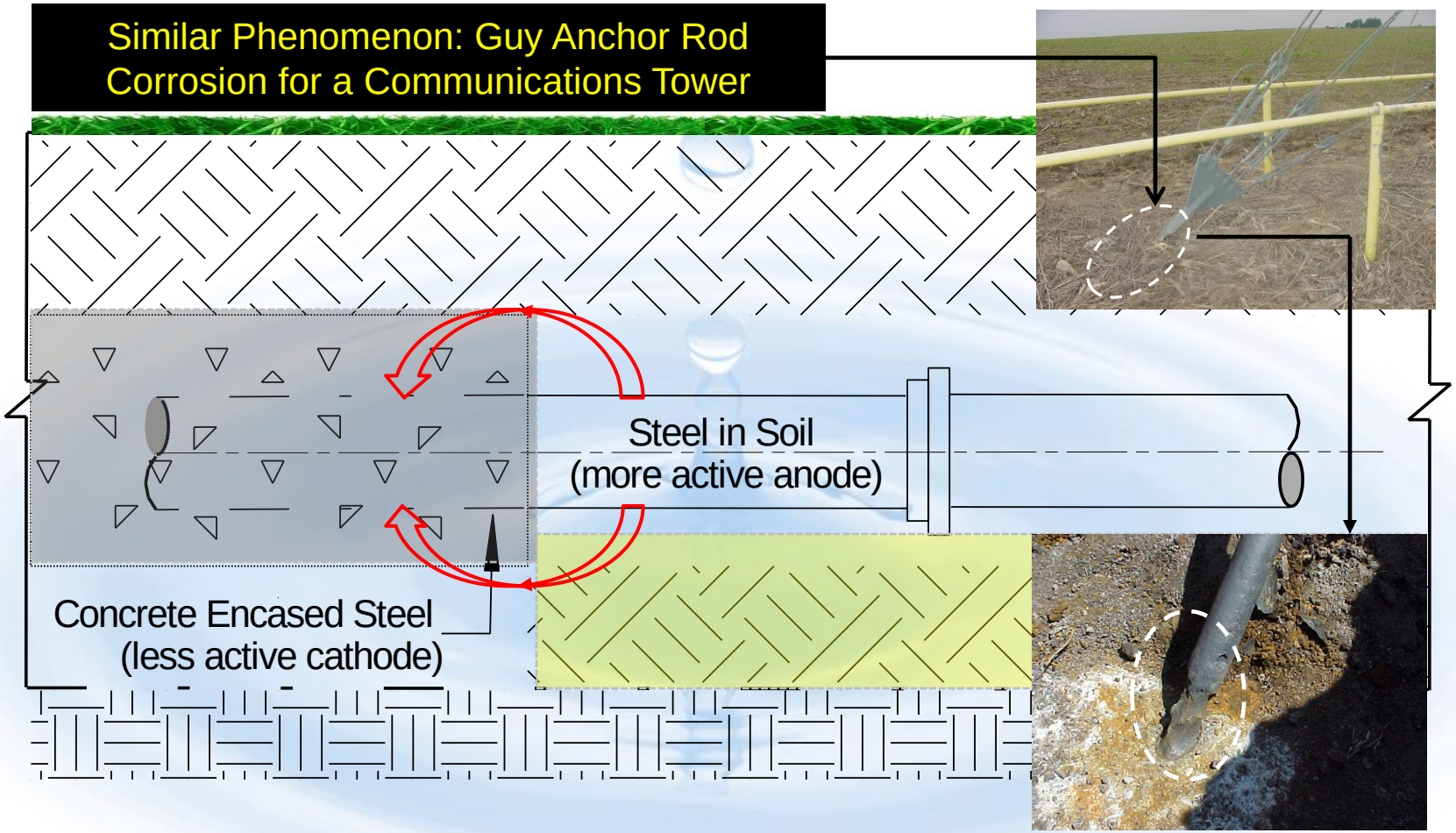
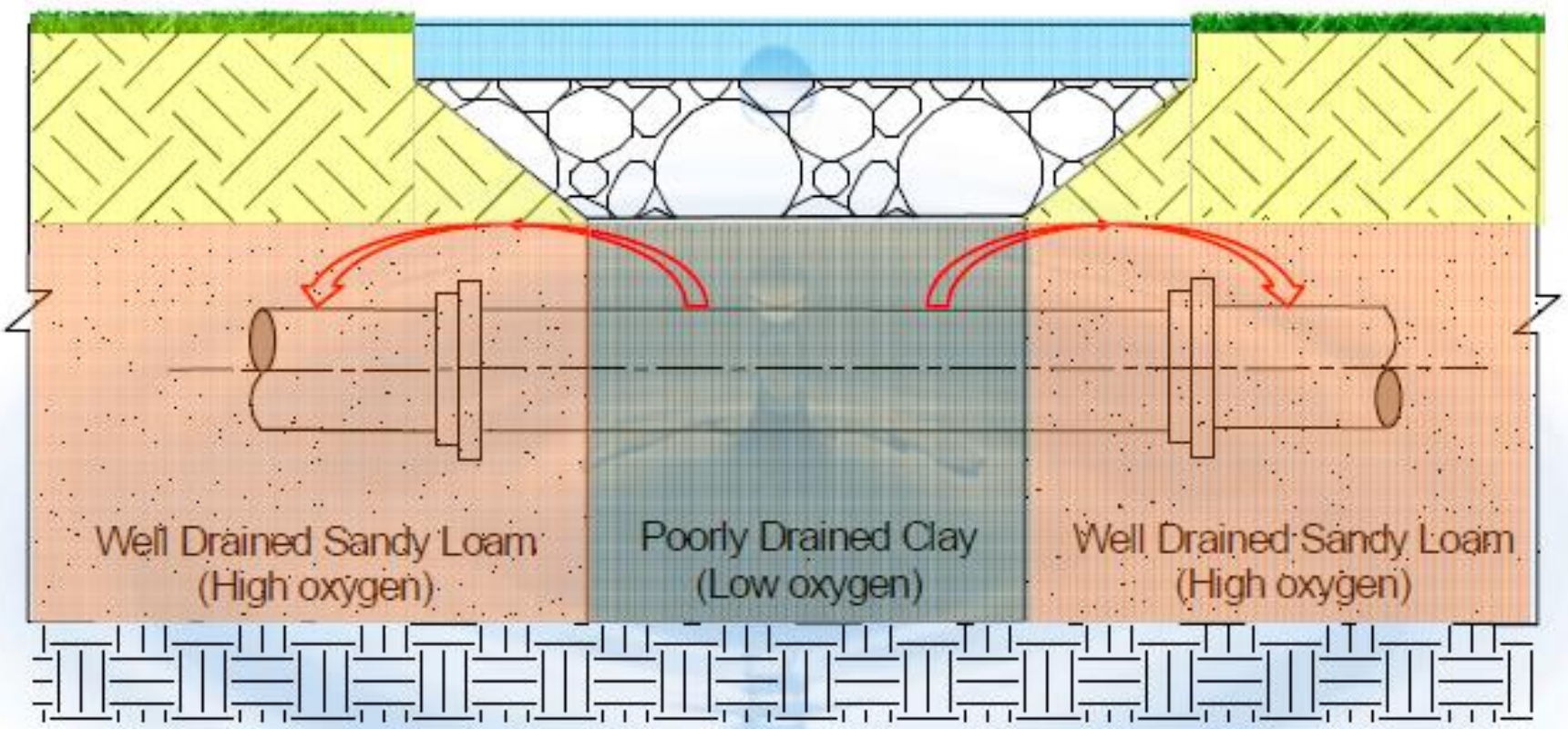
Corrosion Caused by Dissimilar Surface Conditions



Galvanic Cell – Same Metals in a Non-Uniform Electrolyte



Galvanic Cell – Same Metals in a Non-Uniform Electrolyte



Corrosion Reactions: Passivation

Photo courtesy of Hanson Pipe

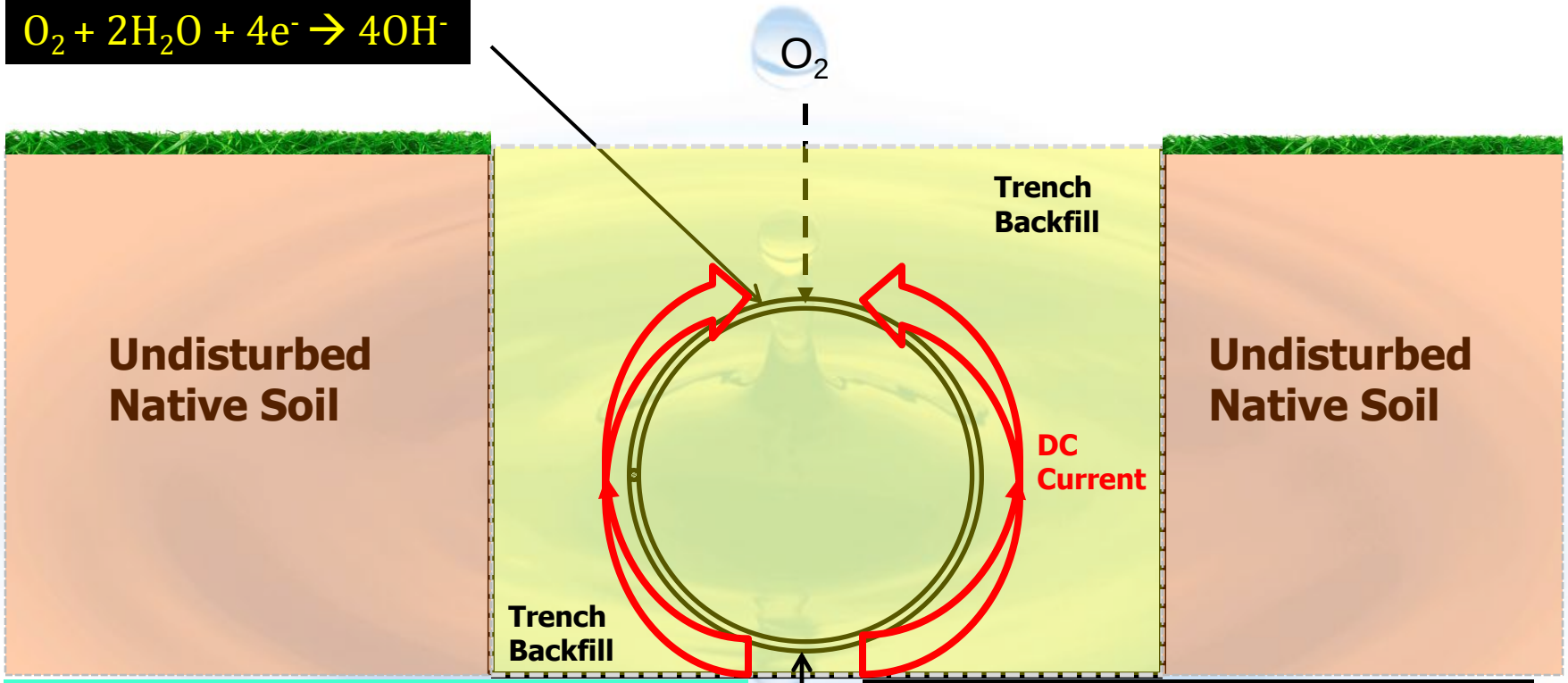
Photo courtesy of Detroit Free Press

The high pH (>12) of the cement mortar coating on the prestressing wires and embedded steel cylinder passivates the steel and provides corrosion resistance. However, if the mortar coating fails due to defects in the pipe's fabrication, installation, or during its operation, the wires could be subjected to an accelerated

Specific Types of Corrosion – Differential Oxygen

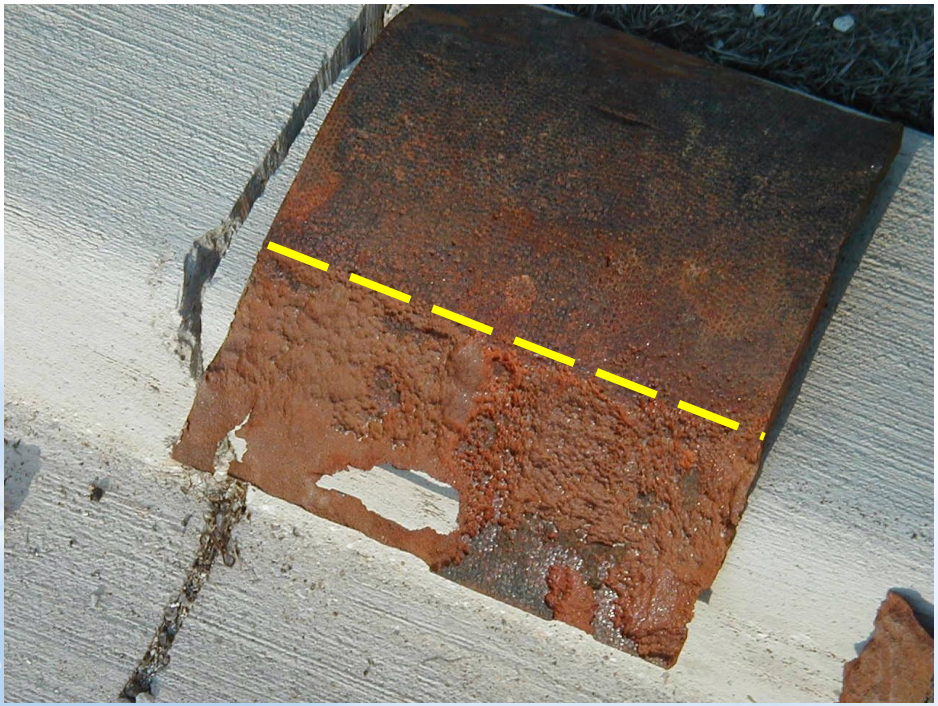
At the cathode:

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$



Pipe bottom is usually most corrosive zone!

Differential Oxygen Corrosion: A Specific Example



Photos courtesy of CP Solutions, Inc. – Bartlett, IL

Pitting Corrosion: Specific Examples

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

Module 4
Pipe Materials and Coatings

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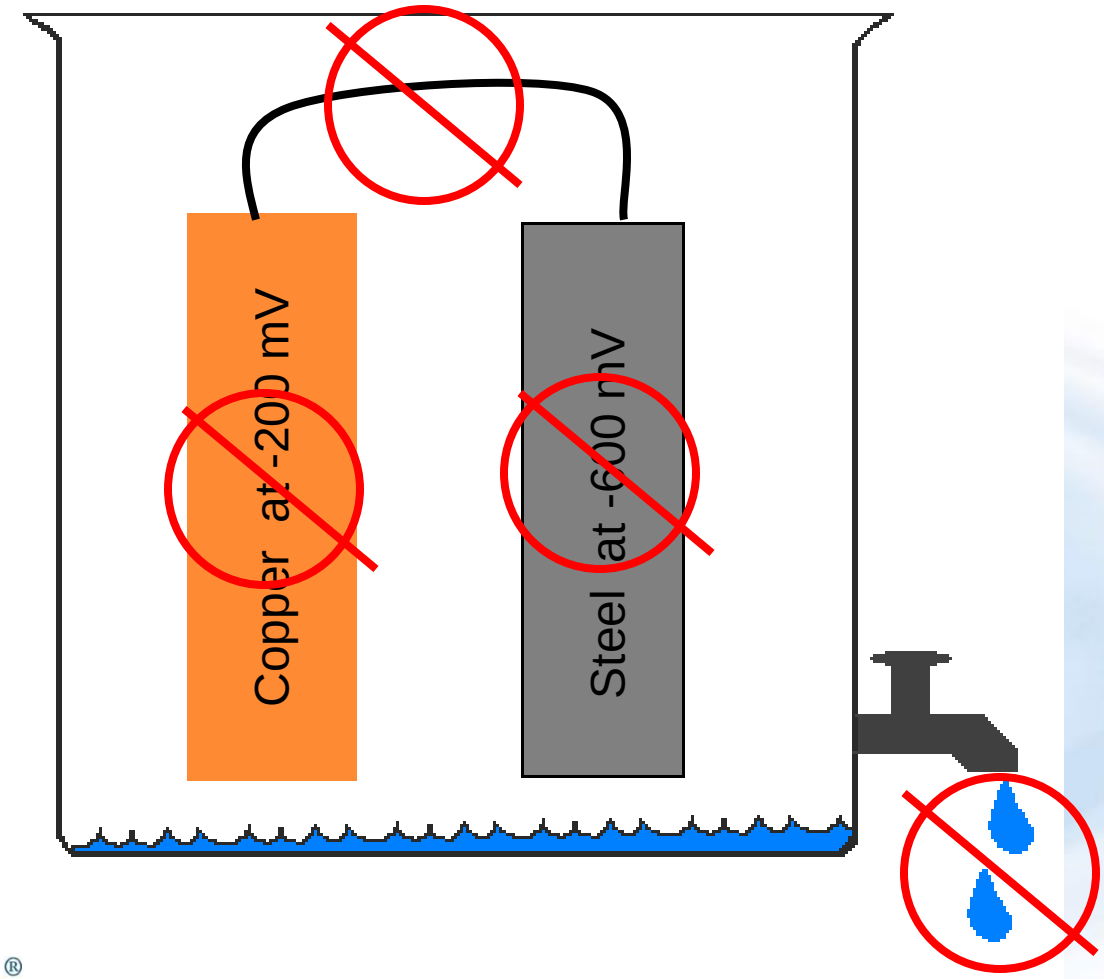
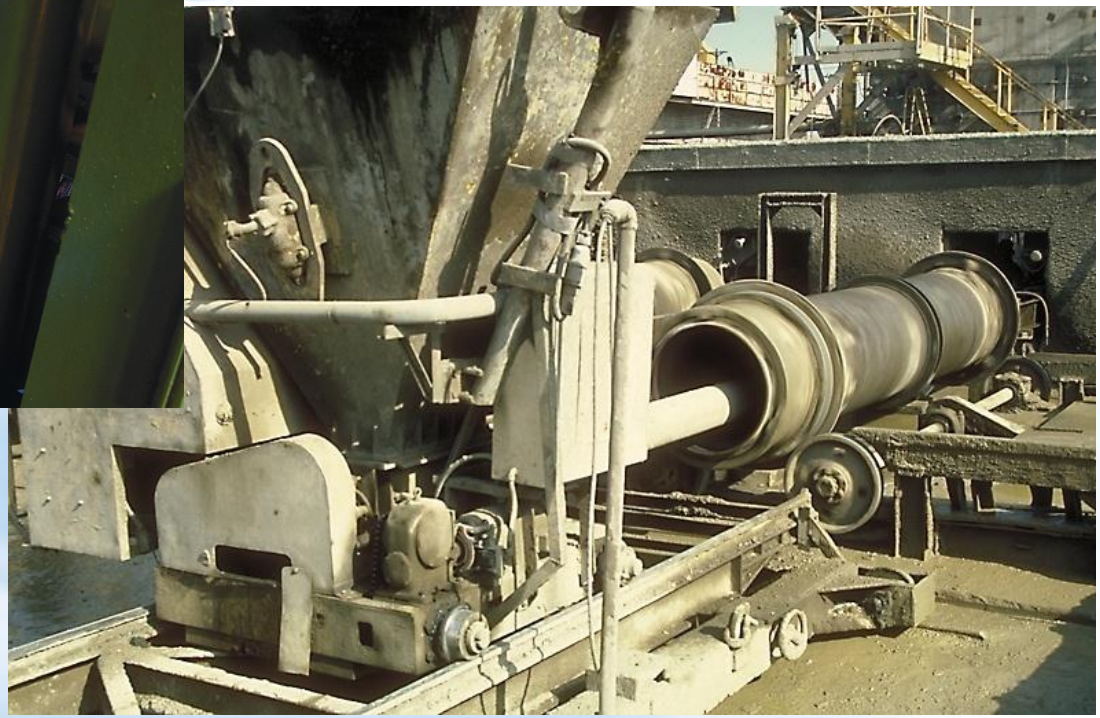
Eliminating the Corrosion Cell



Prestressed Concrete Cylinder Pipe – Cylinder Forming

Photo Credits: Hanson Pipe



Prestressed Concrete Cylinder Pipe - Wire Wrapping

Photo Credits: Hanson Pipe

Prestressed Concrete Cylinder Pipe – Concrete Jacket

Photo Credits: Hanson Pipe

Prestressed Concrete Cylinder Pipe – Corrosion Failures

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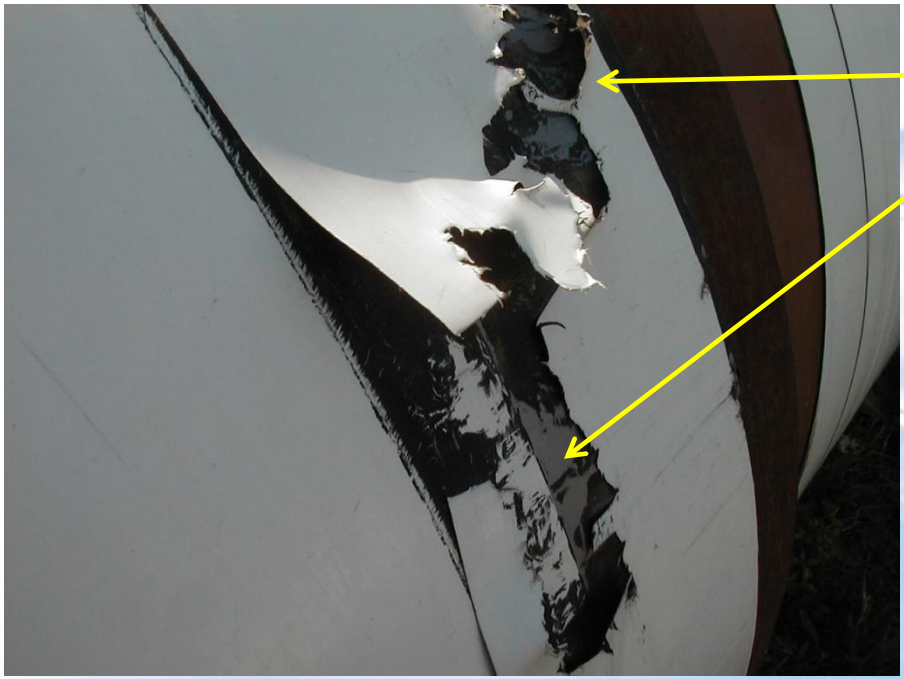
Coated Steel Pipe - Factory-Applied Coating Systems

AWWA C-214 Standard Tape Wrap

Photo Credits: Northwest Pipe

AWWA Standard C-222 Polyurethane

Coated Steel Pipe – AWWA C214 Field Damage



Third-party pipe “hit” damages outer tape wrapping

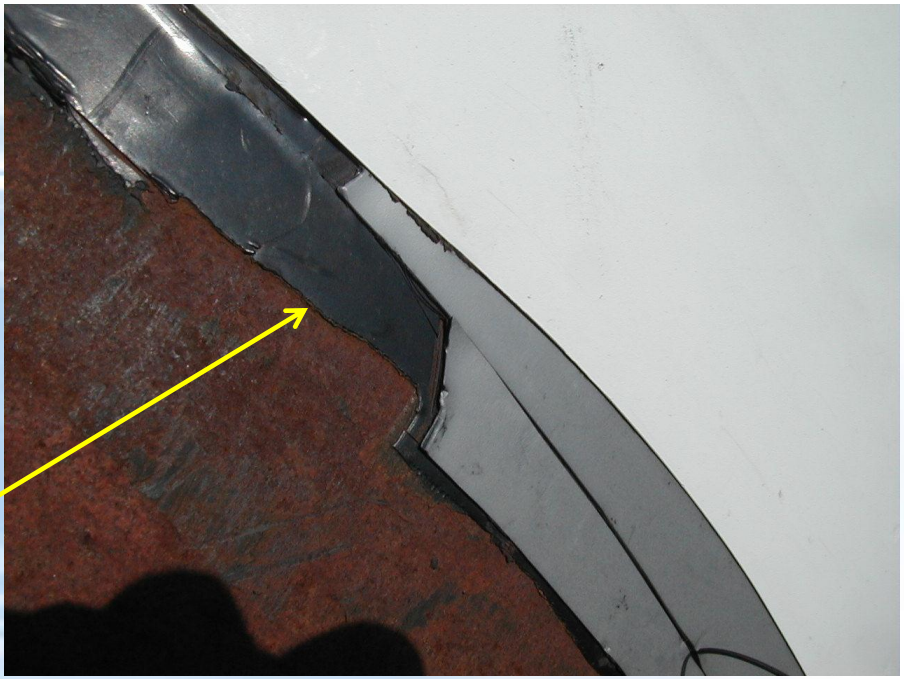


Photo Credits: CP Solutions, Inc.

Inner tape wrapping layer remains bonded to pipe

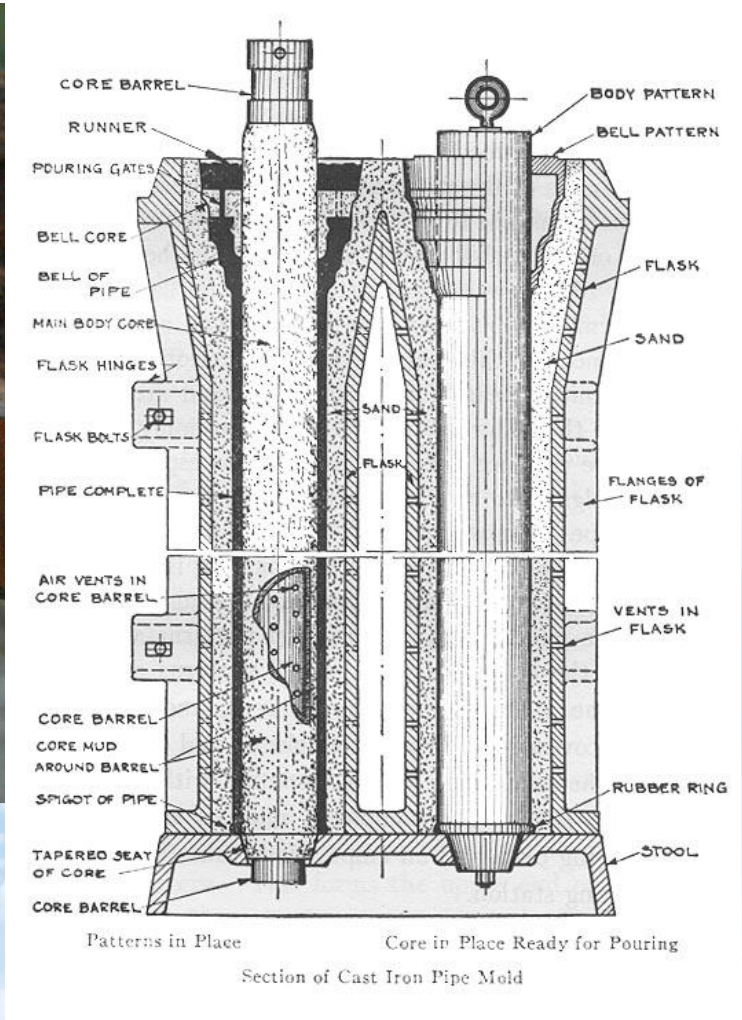
Pipe Coating/Tape Wrapping– Long-Term Effectiveness

Photo Credits: CP Solutions, Inc.

History of Grey Iron & Ductile Cast Iron Pipe

- Grey iron was first cast in the U.S. using vertical pits (sand molds) beginning in about 1830 and was installed until the 1940's.
- Spin cast iron pipe was first manufactured in the 1920's and installed up to the 1970's.
- Ductile cast iron pipe was commercially introduced in the 1950's and replaced spin-cast pipe by the late 1960's.

Pit-Cast Iron Water Pipe (Circa 1915)



Left Photo Credit: CP Solutions, Inc.

Right Photo Credit: Ductile Iron Pipe Research Association

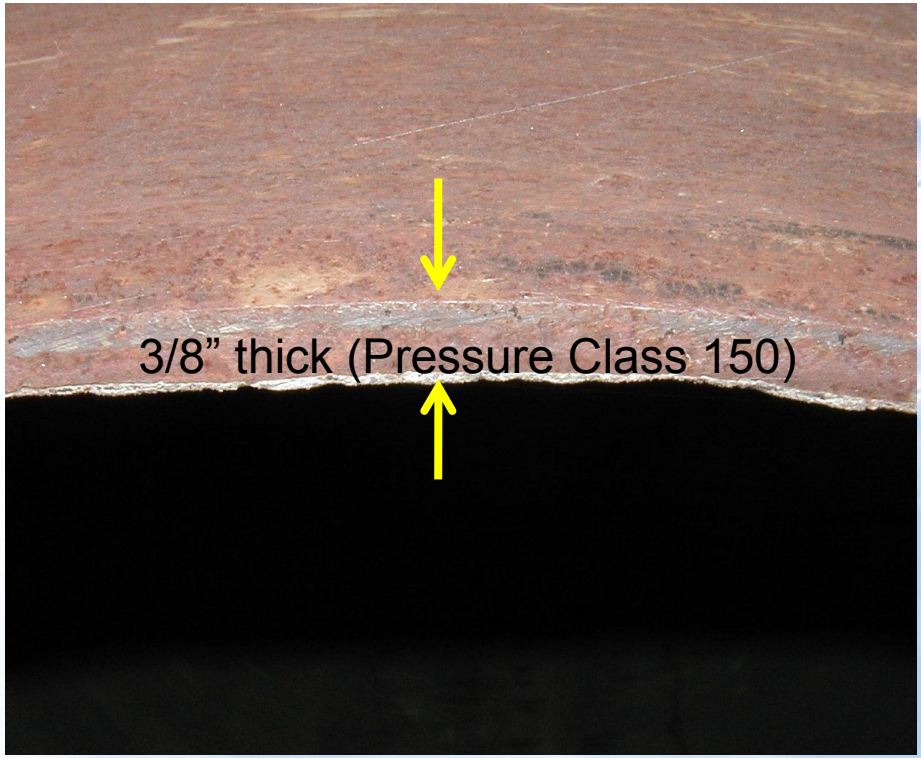
Graphitization of Gray Cast Iron Pipe

Graphitization weakens the cast iron pipe wall

Corrosion continues until the pipe fails

Photo Credits: CP Solutions, Inc.

Ductile Iron Water Pipe (Contemporary)



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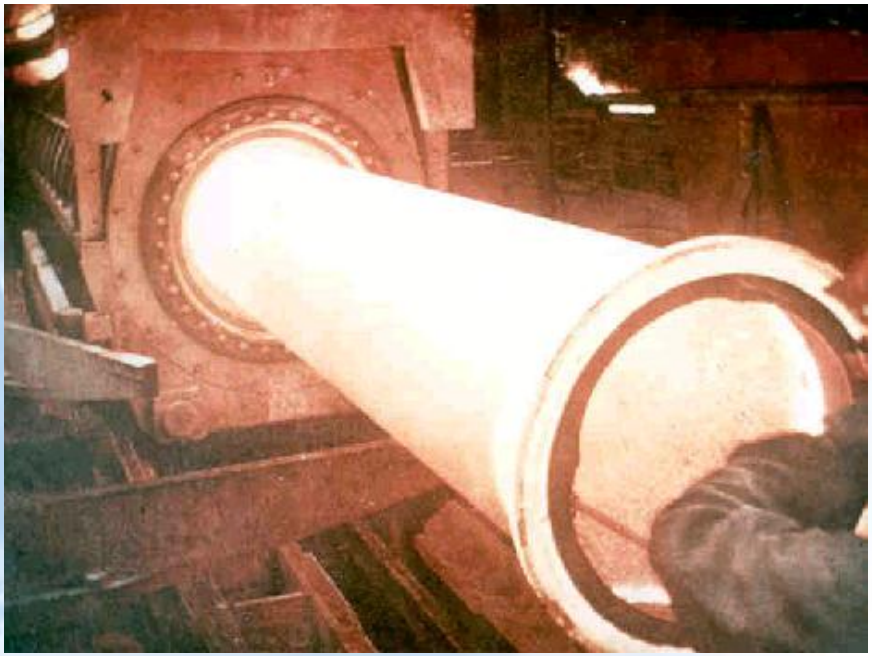
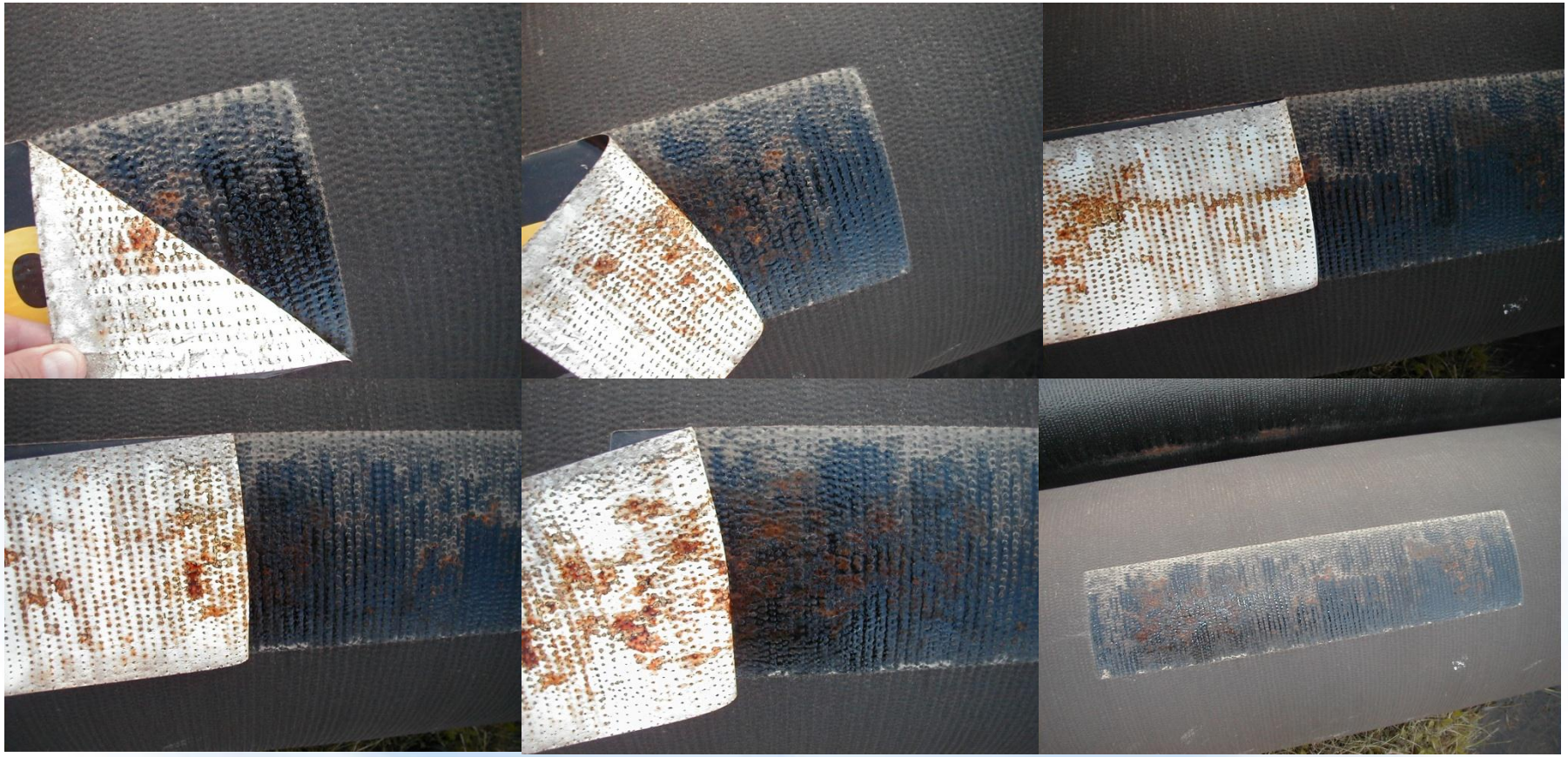


Photo Credit: Ductile Iron Pipe Research Association

Ductile Iron Pipe – Specific Example of Soil Pitting

Photo Credit: CP Solutions, Inc.

DIP Asphalt Coating – A Corrosion Barrier?



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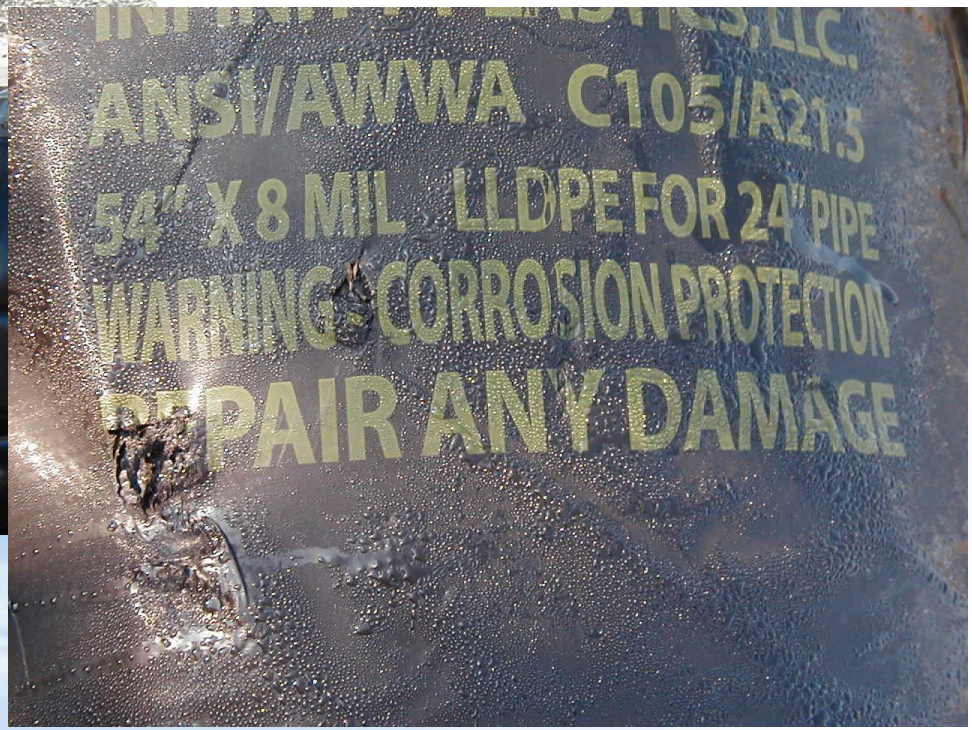
Loose Polyethylene Wrapping – A Corrosion Barrier?



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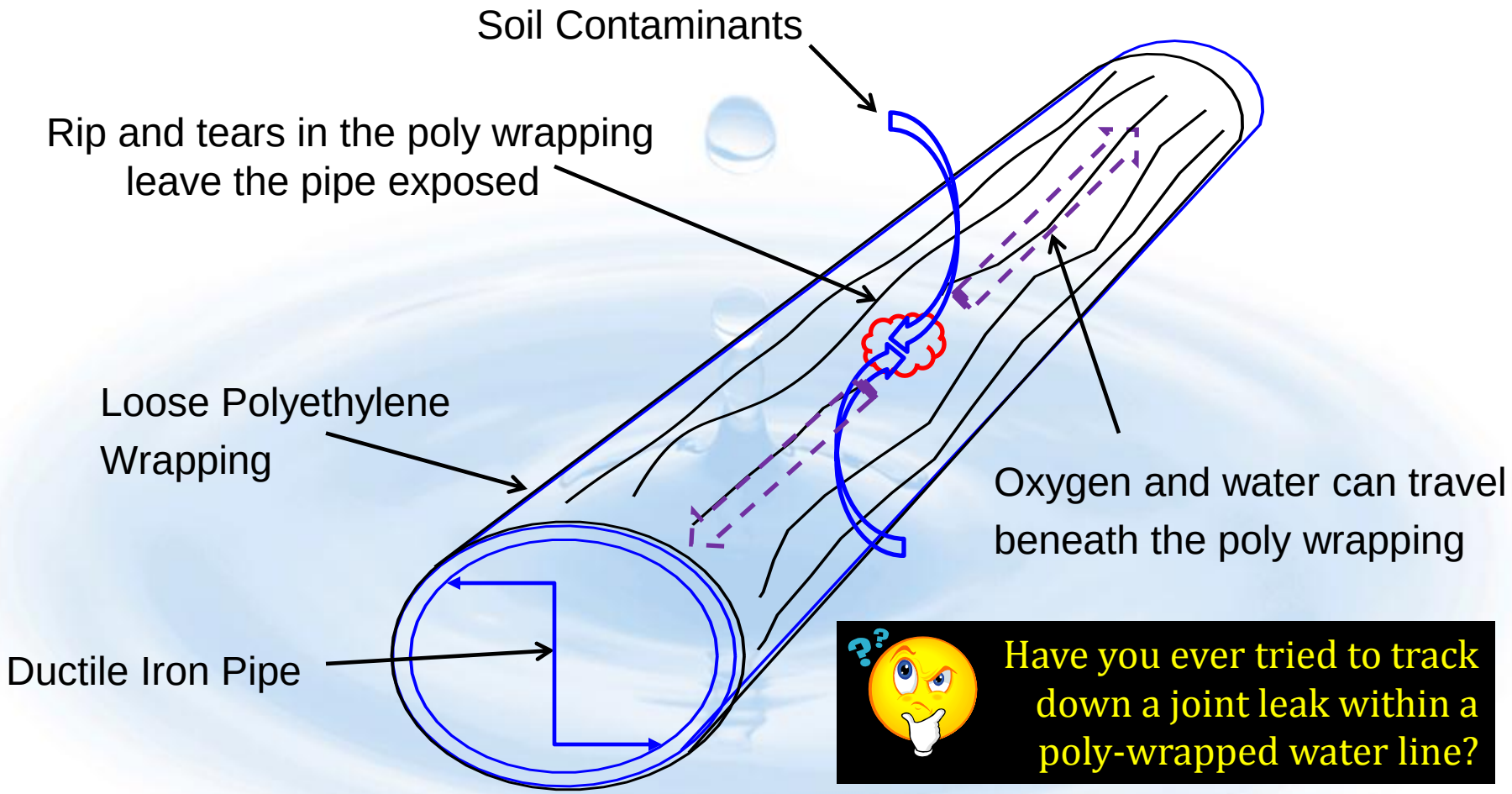
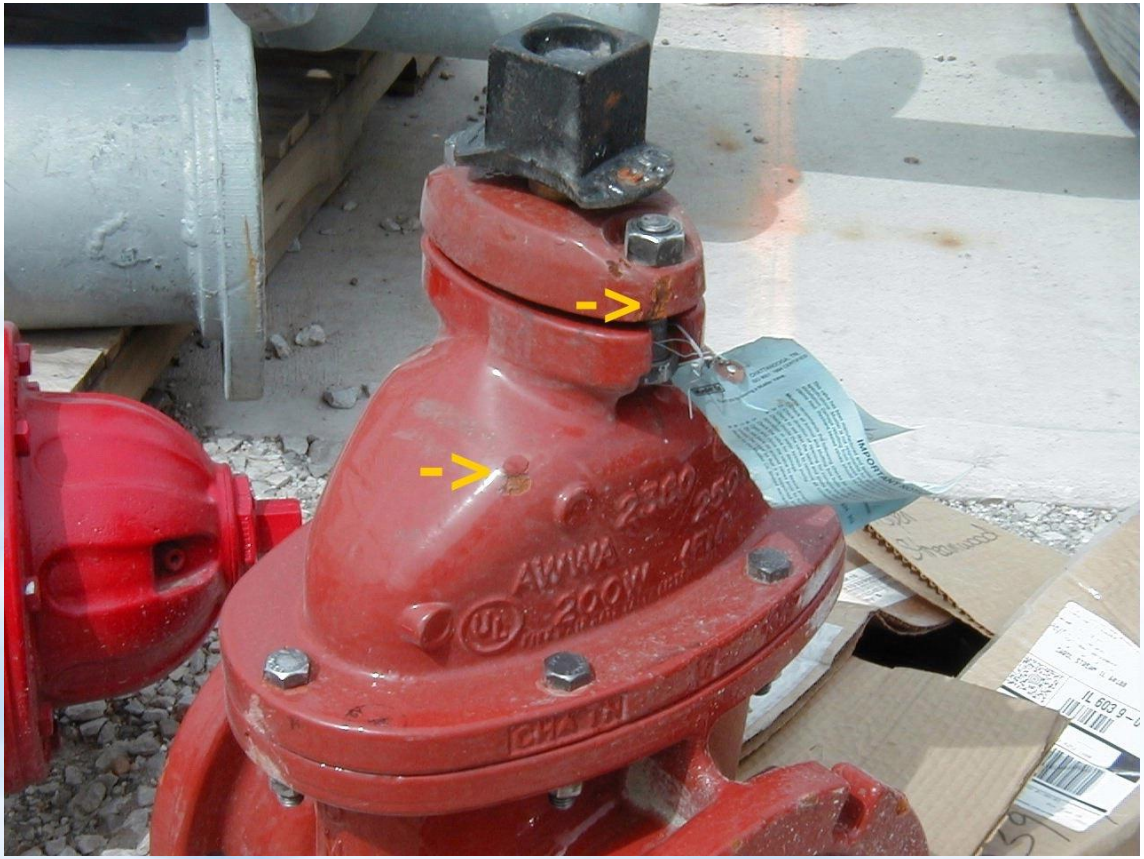
Loose Poly Wrapping – An Effective Corrosion Barrier?



Epoxy Coated Valves & Fittings – Before Burial



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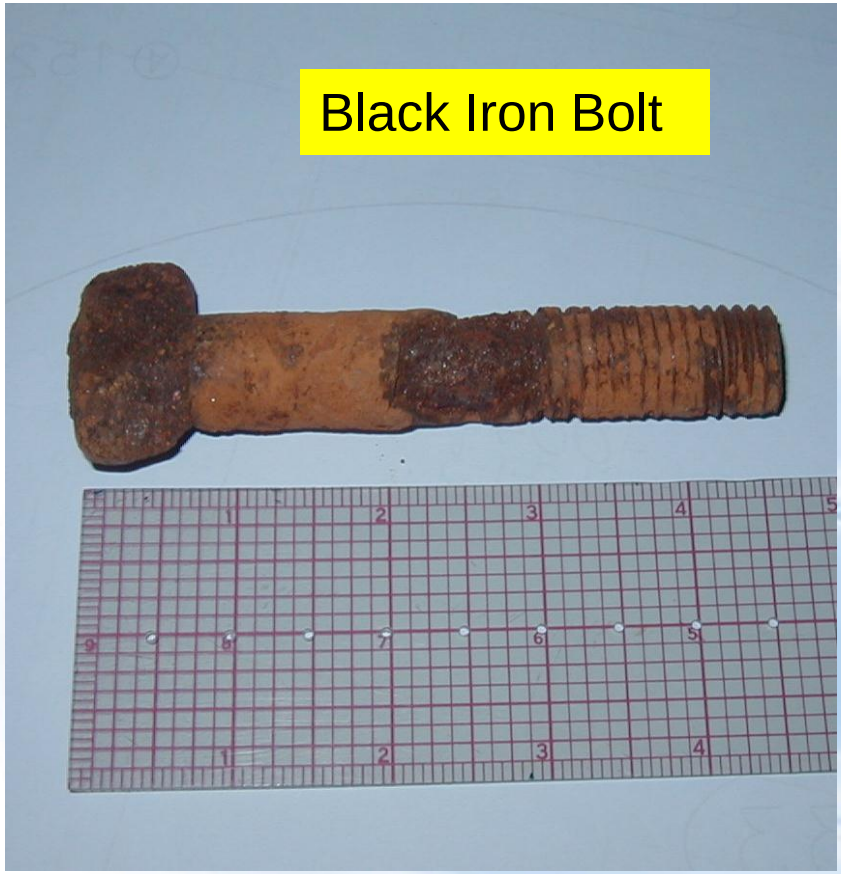
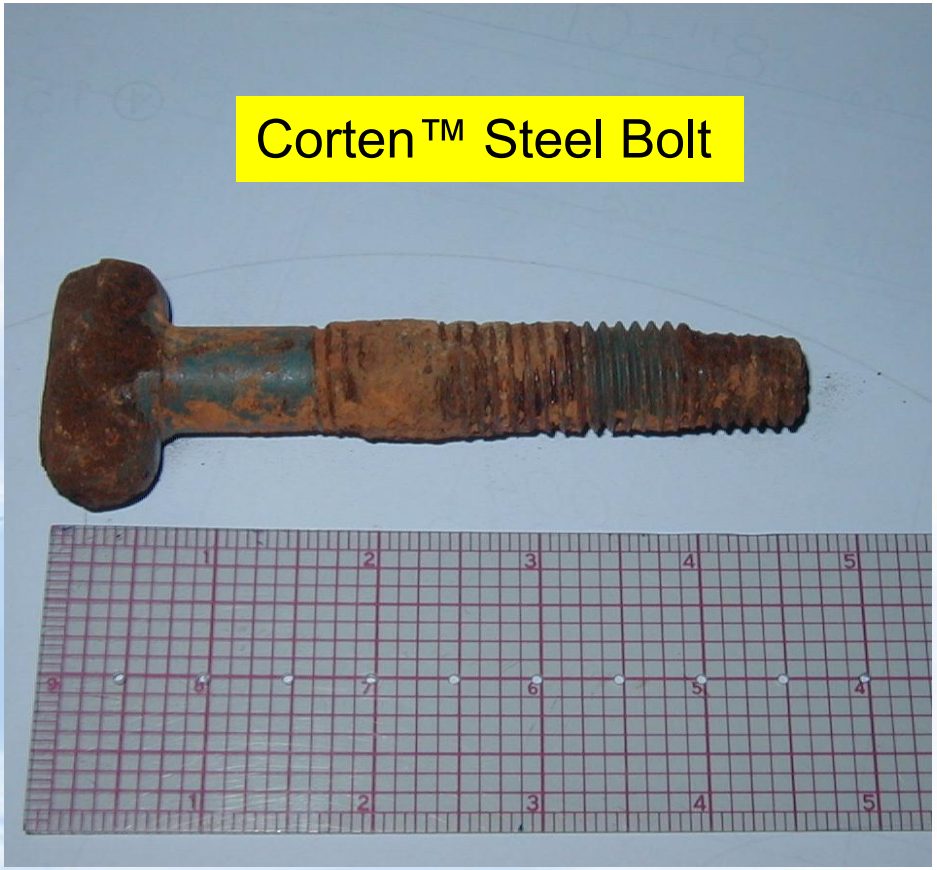
Epoxy Coated Valve – After Burial

Photo Credit: CP Solutions, Inc.

Carbon Steel Valve Bolts – Corrosion Examples





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Module 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.

Two Types of Cathodic Protection Systems

- **Sacrificial Anode:** DC current is obtained from more active metal anodes that are connected directly to the structure.
- **Rectified Anode**: DC current is obtained from more noble (inert) metal anodes that are powered by a rectifier/transformer.

Cathodic Protection System Types – Sacrificial Anodes

Sacrificial Anode: DC current is obtained from more active metal anodes connected directly to the structure

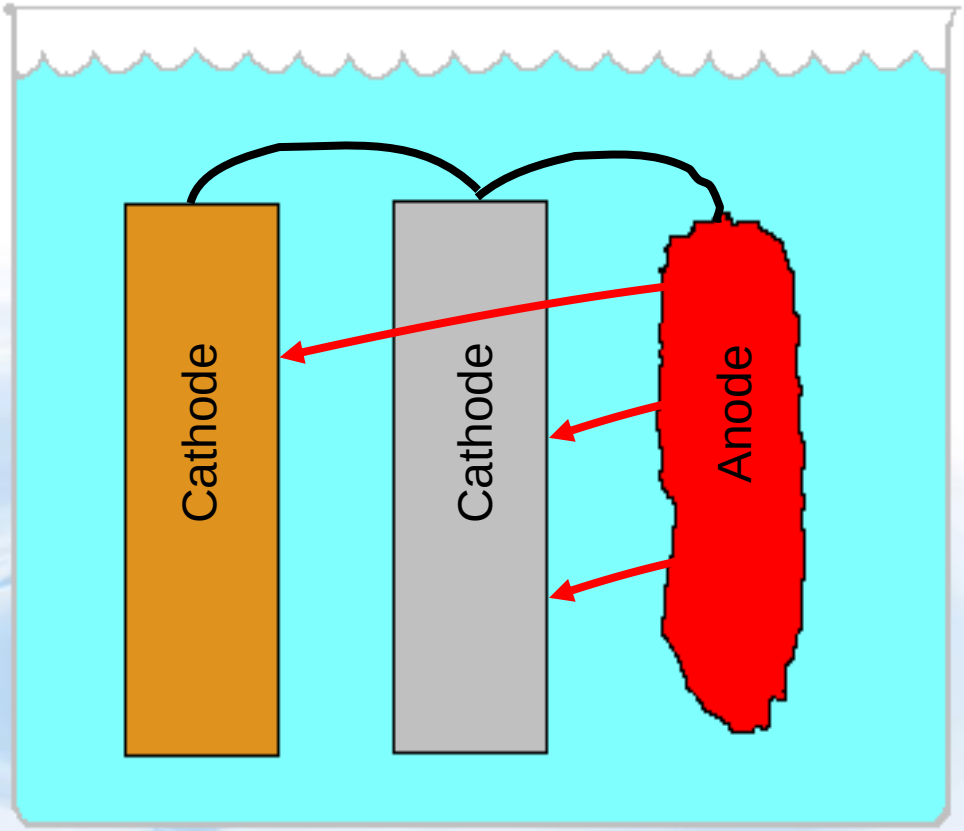
Practical Galvanic Series

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

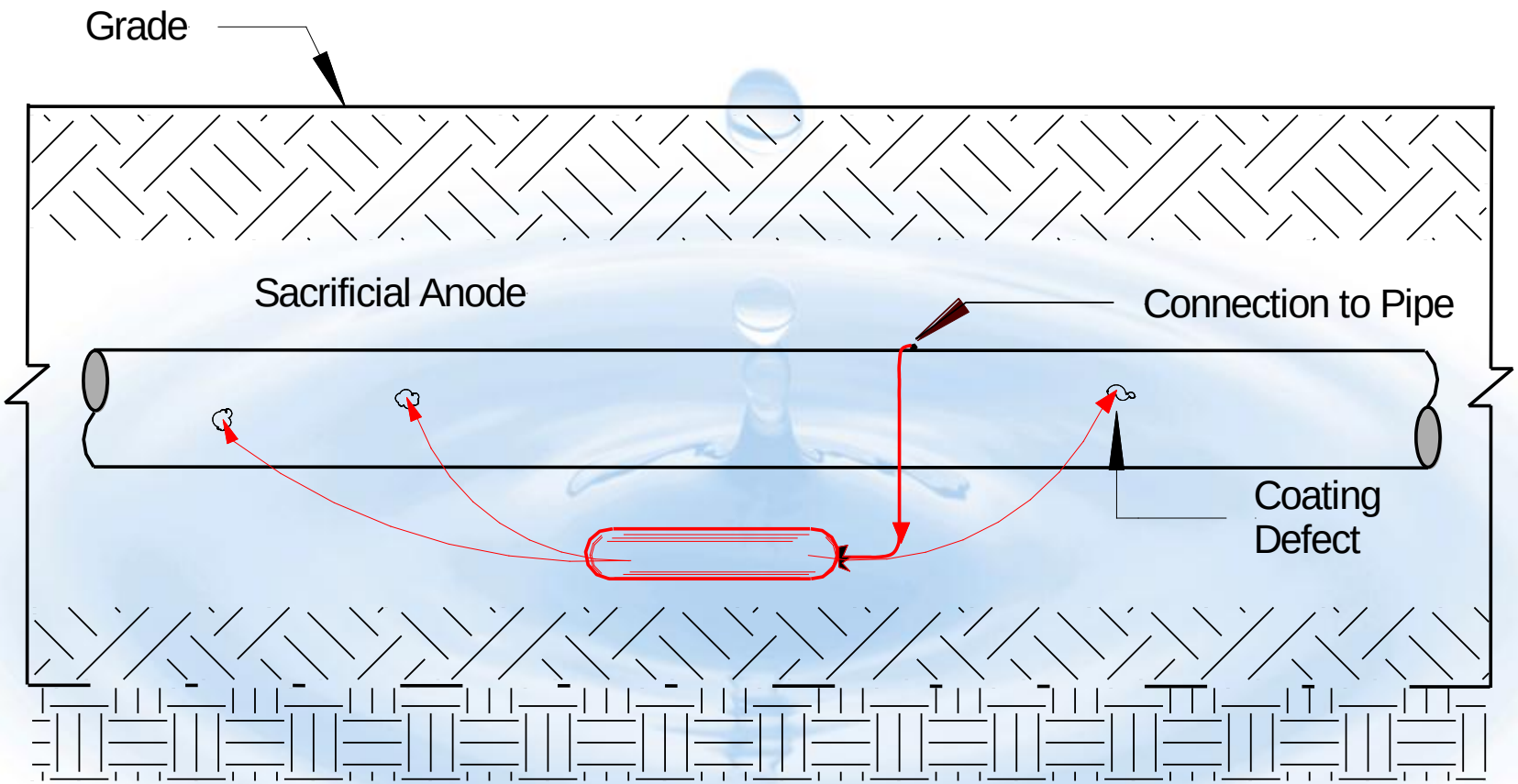
*Measured in Volts versus a Cu-$CuSO_4$ Reference Electrode

Galvanic Corrosion Mitigated w/Cathodic Protection

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

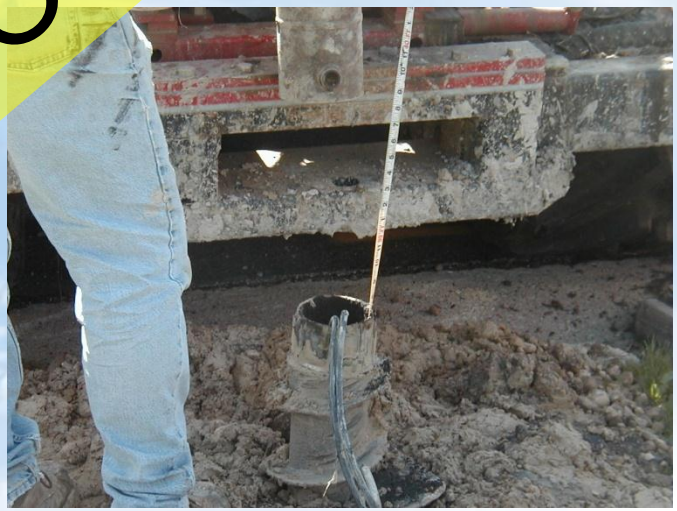


Typical Horizontal Sacrificial Anode Installation



Rectified Anode Cathodic Protection

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



Beyond Our Scope

Module 6
Cathodic Protection for Existing Water Mains using an Anode Retrofit Program

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Anode Retrofit Programs in the U.S. – An Overview

The Des Moines (IA) Water Works

~10K feet of ARP annually

The Louisville (KY) Water Company

~65,000 feet of ARP annually

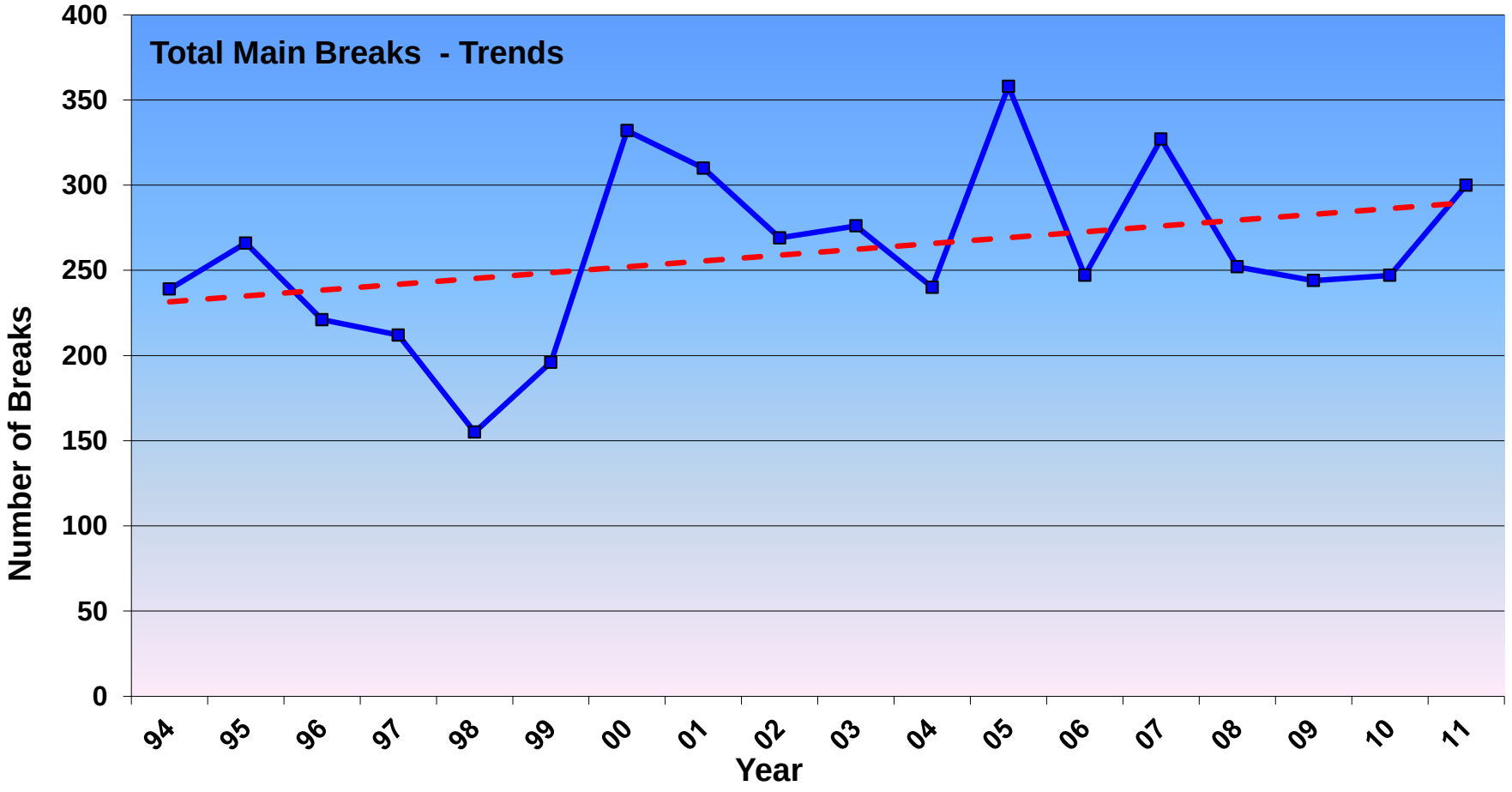
Did you know that many Canadian Water Utilities have successfully used the ARP for more than 25 Years?

Des Moines Water Works – Water Main Life Status

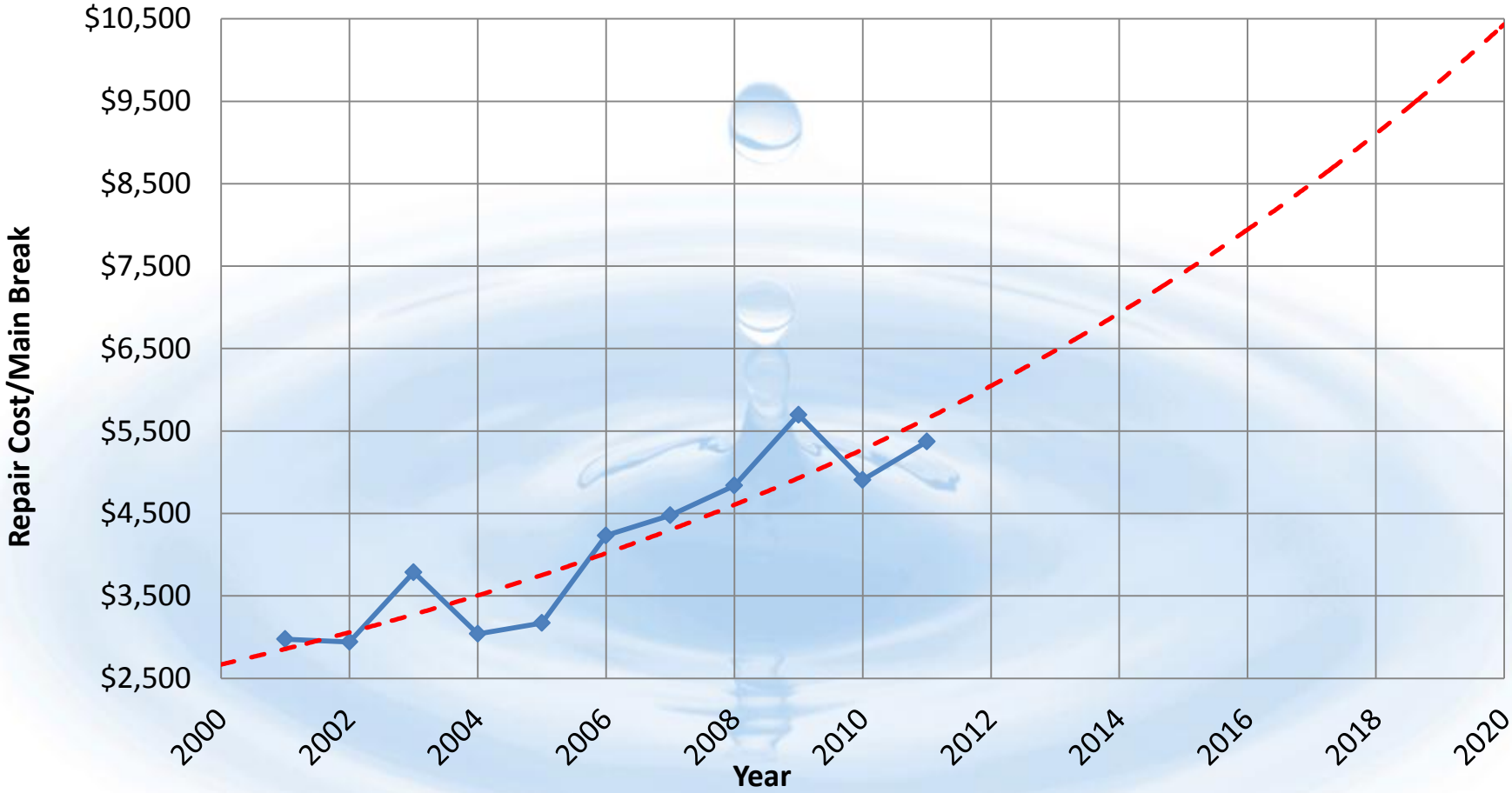
- 521 miles out of 1380 miles* has reached its life expectancy
- 92 miles will reach life expectancy in the next decade

*includes approximately 380 miles of non-metallic pipe used for a rural water distribution system

DMWW's Long-Term Main Break Data (1994-2011)



DMWW's Main Break Repair Costs (2000-2011…)



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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

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

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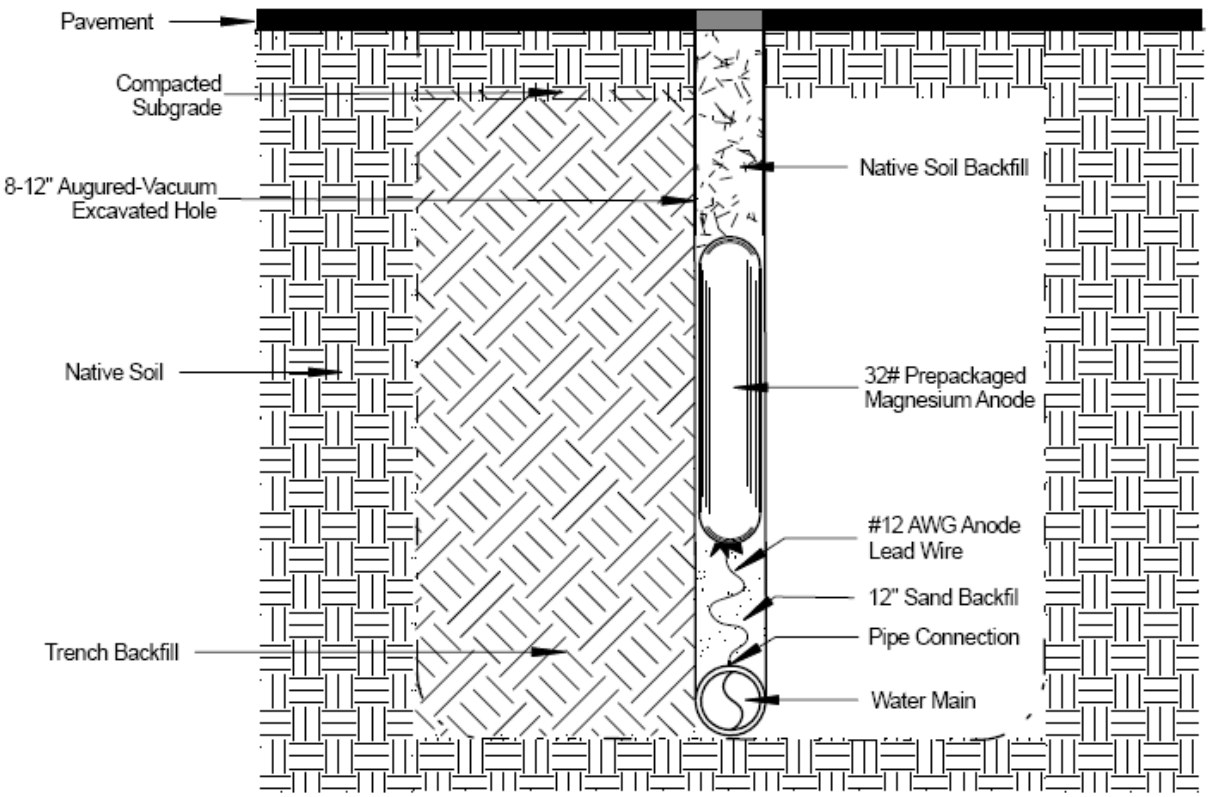
Implementing an Anode Retrofit Program

The ARP Objective Selection Model

- Pipe material/age/diameter
- Number of pipe failures
- Pipe condition
- Ease of anode installation
- Soil characteristics
- Traffic disruption
- Excavation/restoration costs

Typical Anode Retrofit Installation Method



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Installation in Paved Roadways – Asphalt or Concrete

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

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Exothermic Weld Connection and Hardware

Exothermic Weld to Pit Cast Iron

Exothermic Welds Can Be Used On:

- Pit-Cast Iron Pipe
- Spin-Cast Iron Pipe
- Ductile Iron Pipe

Anode Lead Wire into Welding Tool

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

Keyhole to Pipe & Wire Connection

Exothermic Welding Tool Down the Hole

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

Testing the Wire Connection

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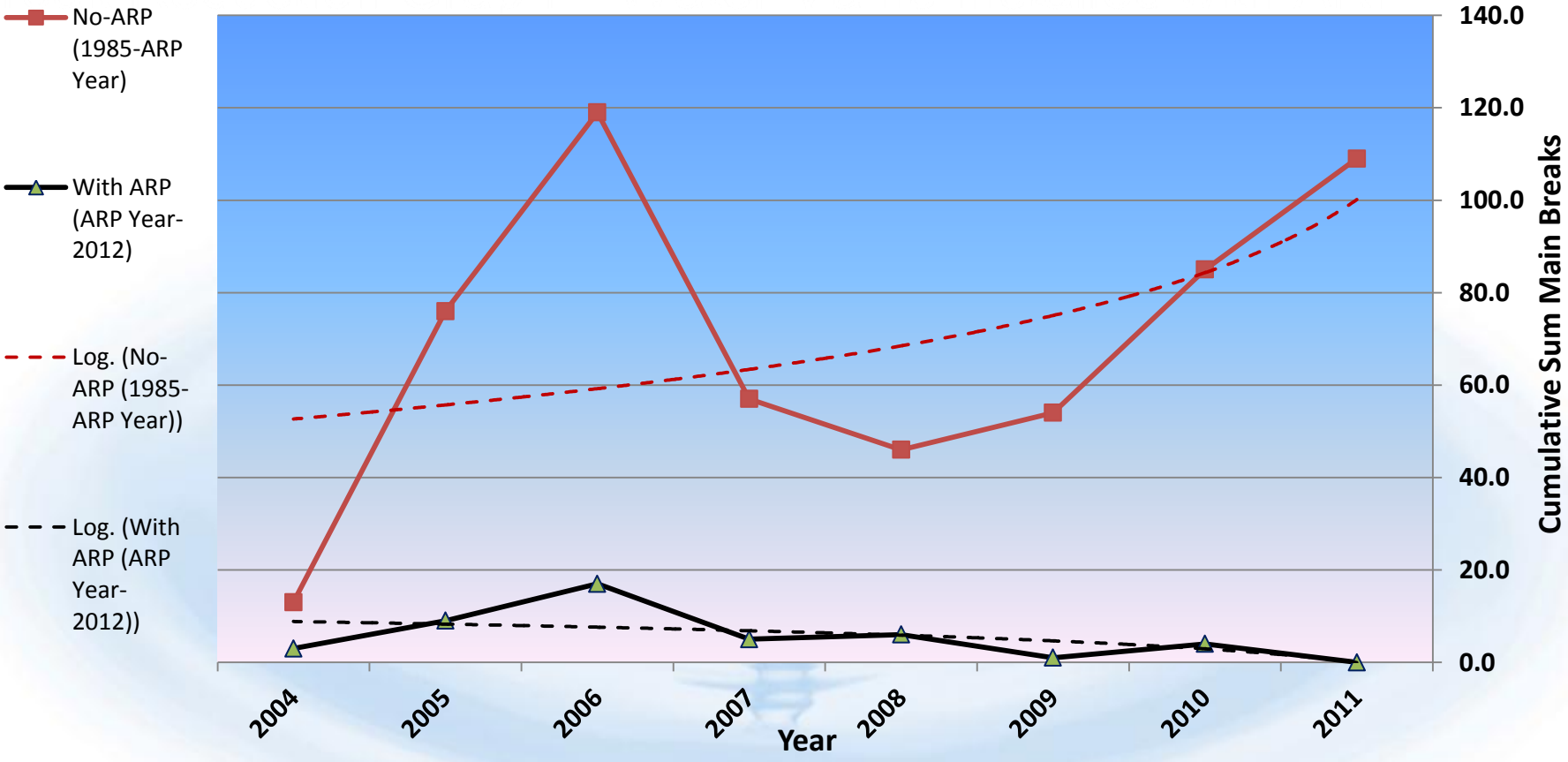
Main Break Reduction Evaluation of the DMMW's ARP

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

DMWW Main Break Comparison – ARP vs. No-ARP



Economic Evaluation of the DMMW's ARP

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

DMWW Anode Retrofit Program: 2004-2011 Summary

- ARP installed on 82,370 feet of 6” to 16” water mains
- Total ARP Installation Cost = $1,028,838
- Main Break Cost (over 25 years) w/o ARP = $4,700,833
- Cost of New Mains would have been >$10 Million
- A 25-year service life extension is expected
- An average reduction of 85% in water main breaks

Module 7
Solving Corrosion Problems at Water Main Breaks

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What's Your Biggest Cost to Repair a Main Break?

“Hot-Spotting”: CP Anodes at Water Main Breaks

Do I really want to re-excavate this hole for another water main break?

Install a sacrificial CP anode while the water main repair excavation is already open!

Cathodic Protection Is Proactively Inexpensive

Cost of repairing a water main break

versus

installing a sacrificial anode during a pipe repair…

Average Cost of a Main Break

$3,500 to $5,000

Cost of a CP Anode and a Connection Device

Less than $150!

Use a Secure Connection to Attach Sacrificial Anodes

Module 8
Solving Corrosion Problems on Transmission and Distribution Water 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)

Why Install CP on a Water Transmission Main?

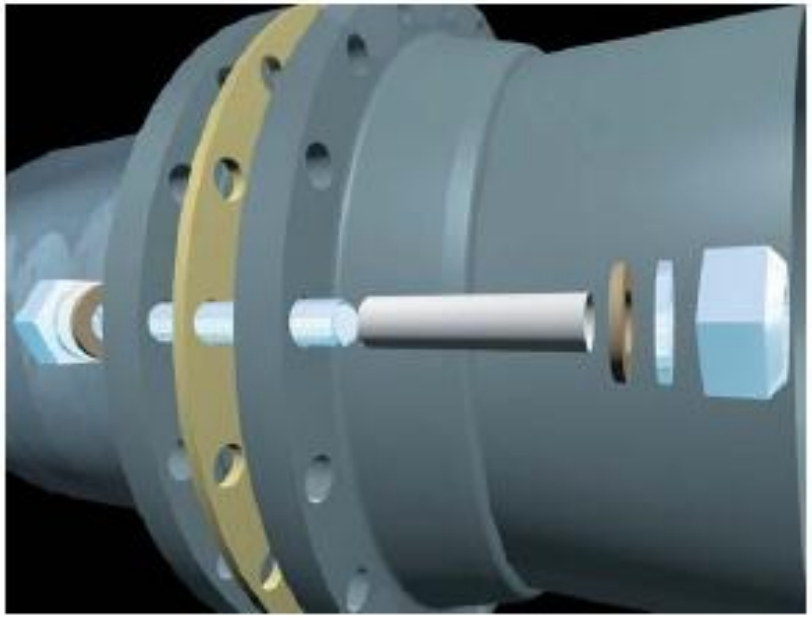
The CP system will extend the life of the new water transmission main by at least 25 years at a cost that is much less than…

- Pipe repairs or,
- Main replacement or,
- The potentially more significant (but incalculable) indirect costs that could occur as a result of a service disruption to a key facility that the water main serves.

CP System Summary – Electrical Isolation Requirements

- Isolation at all connections to existing water mains, service laterals, and steel casing sleeves:
  - Flange isolation kits (FIK)
  - Pipe Isolation Couplings (PIC)
  - Isolation Corporation Stop (ICS)
  - Casing isolation pipe support skids/cradles
  - Casing isolation end-seal boots
  - Wall penetration pipe sleeve seals

Flange Isolation Kit Components



FIK components should always meet NSF-61 requirements

NSF/ANSI Standard 61 establishes minimum health effects requirements for the chemical contaminants and impurities that may be indirectly imparted to drinking water.

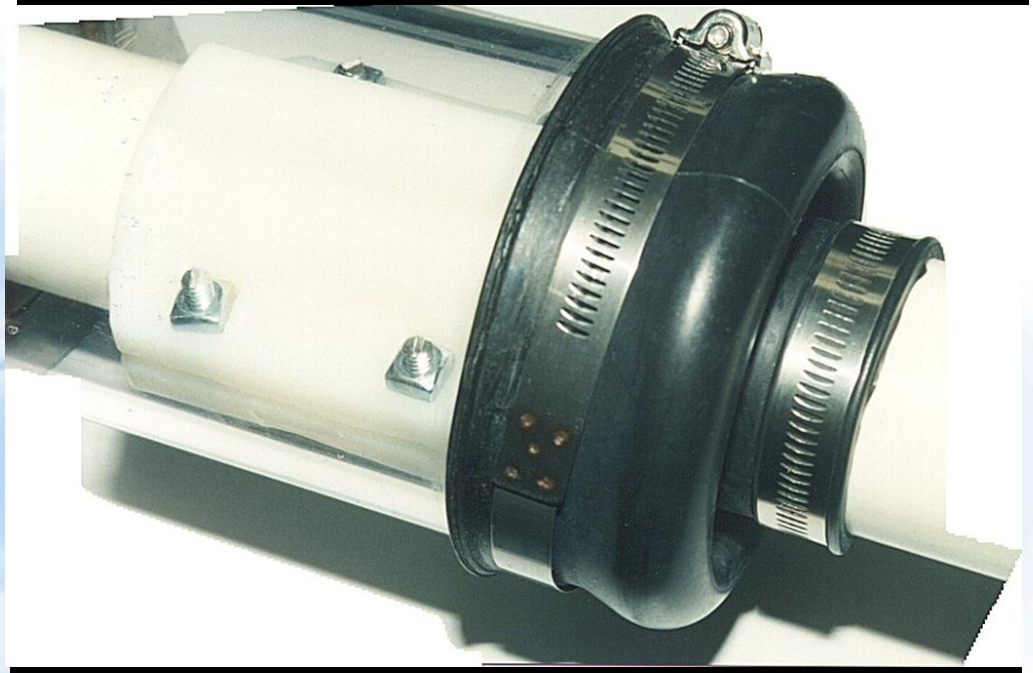
Casing Sleeve – Typical Pipe Isolation Skids

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

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

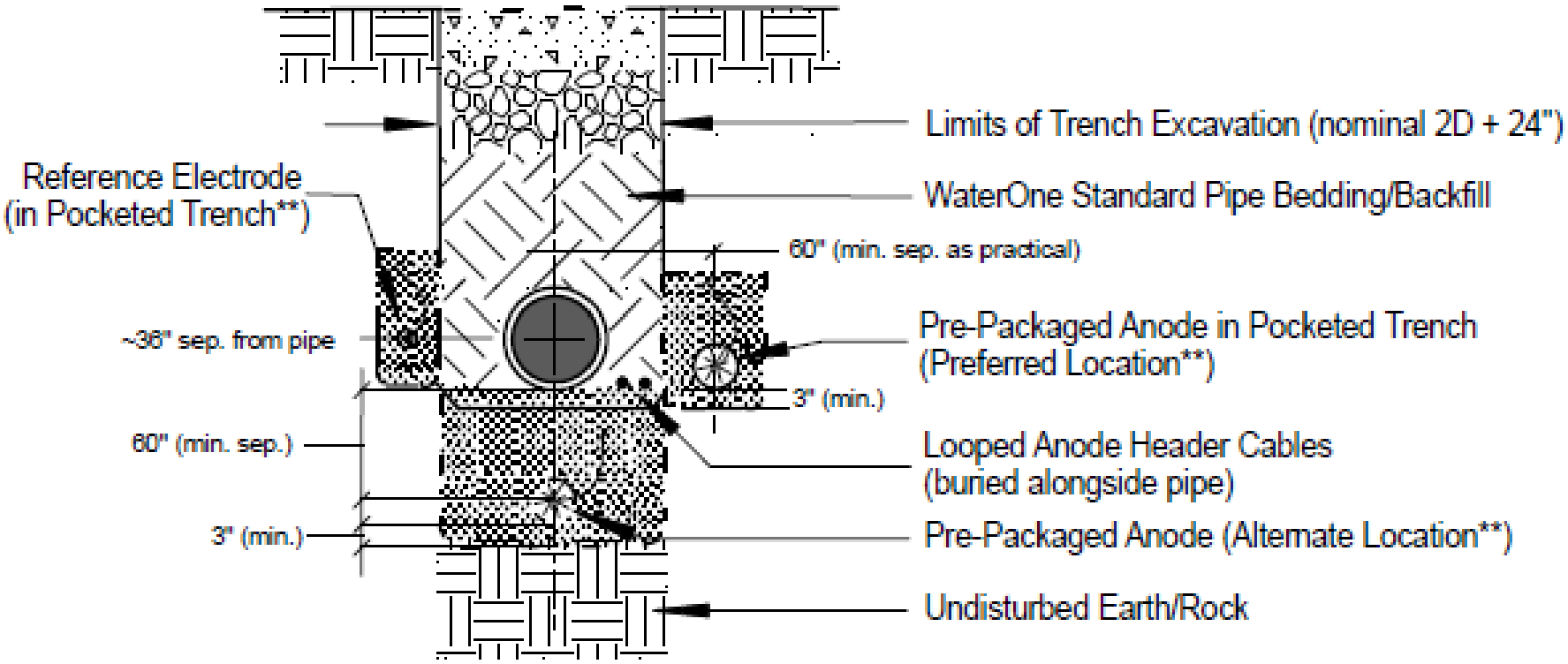
Photos courtesy of CP Solutions, Inc. – Bartlett, IL

CP System Summary – Anode System

- Prepackaged anodes installed in multiple clusters along the water main.
- Each anode connected to an insulated copper cable using a mechanical splice.
- Anode header cable runs into a test station and is connected to a separate cable that connects back to the pipe.

Magnesium Anode used for Cathodic Protection

Anode Test Station – Section View



Anodes Installed in the Pipe Trench

Photo courtesy of CP Solutions, Inc. – Bartlett, IL

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CP System Summary – Corrosion Monitoring System

- Test stations types installed at:
  - All buried isolation devices,
  - Steel casing sleeves,
  - All anode installations,
  - At foreign pipeline crossings w/rectified CP systems,
  - At other unspecified intervals to allow for structure-to-soil potentials to be measured.

Installing Continuity Bond Cables across Pipe Joints

Photo courtesy of CP Solutions, Inc. – Bartlett, IL

Running Test Wires through Poly Wrapping

Photo courtesy of CP Solutions, Inc. – Bartlett, IL

Exothermic Welds and Connection Devices

Proper surface preparation will allow good welds

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

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Proper Coating of Exothermic Welds Connections

Raw Connections before Coating

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

Restore poly wrap over test station wires

Finished Connections Ready to Backfill

A Suitable Post-Type CP Test Station Installation

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

Polymer Concrete Flush Test Station Enclosure

TS enclosure set adjacent to road and suitable for incidental traffic loads

Photos courtesy of CP Solutions, Inc. – Bartlett, IL

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Economics of the CP Installation

What is the additional cost of installing cathodic protection on a new water transmission main?

Economics of CP Installations on New Water Mains

- On small projects, the total initial cost of a CP system should be less than 3-5% of the capitalized construction cost (CCC).
- On larger projects, the CP could be only 1 to 2% of the CCC.
- Over the typical 25-year life expectancy of a CP system, the annualized cost can be less than 0.10% of the CCC.

The effectiveness of any CP system is highly dependent upon the quality of any coating and or wrapping system applied to the external pipe surface.

Higher quality pipe coatings will reduce the cost of the cathodic protection.

Module 9
Cathodic Protection Performance Verification

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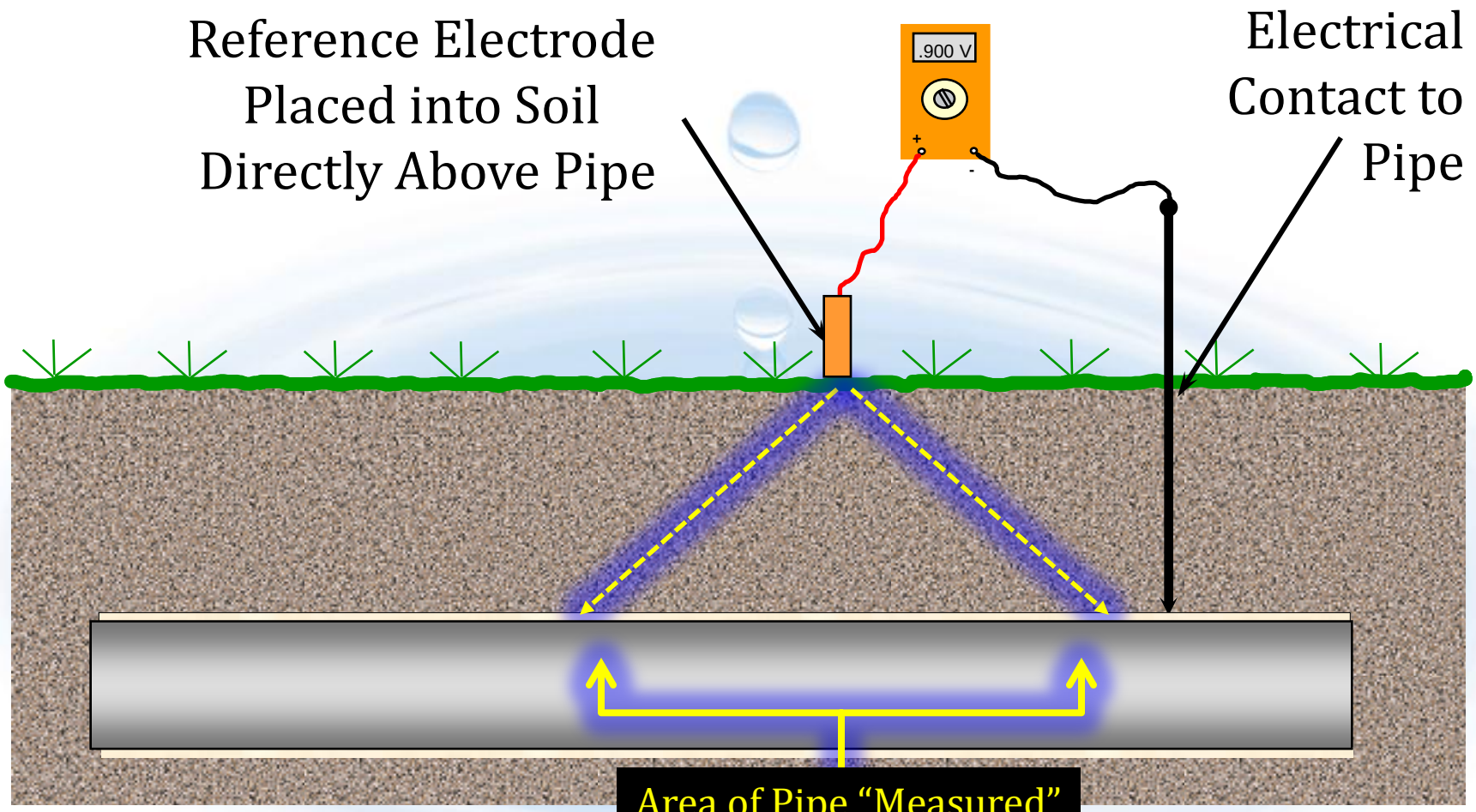
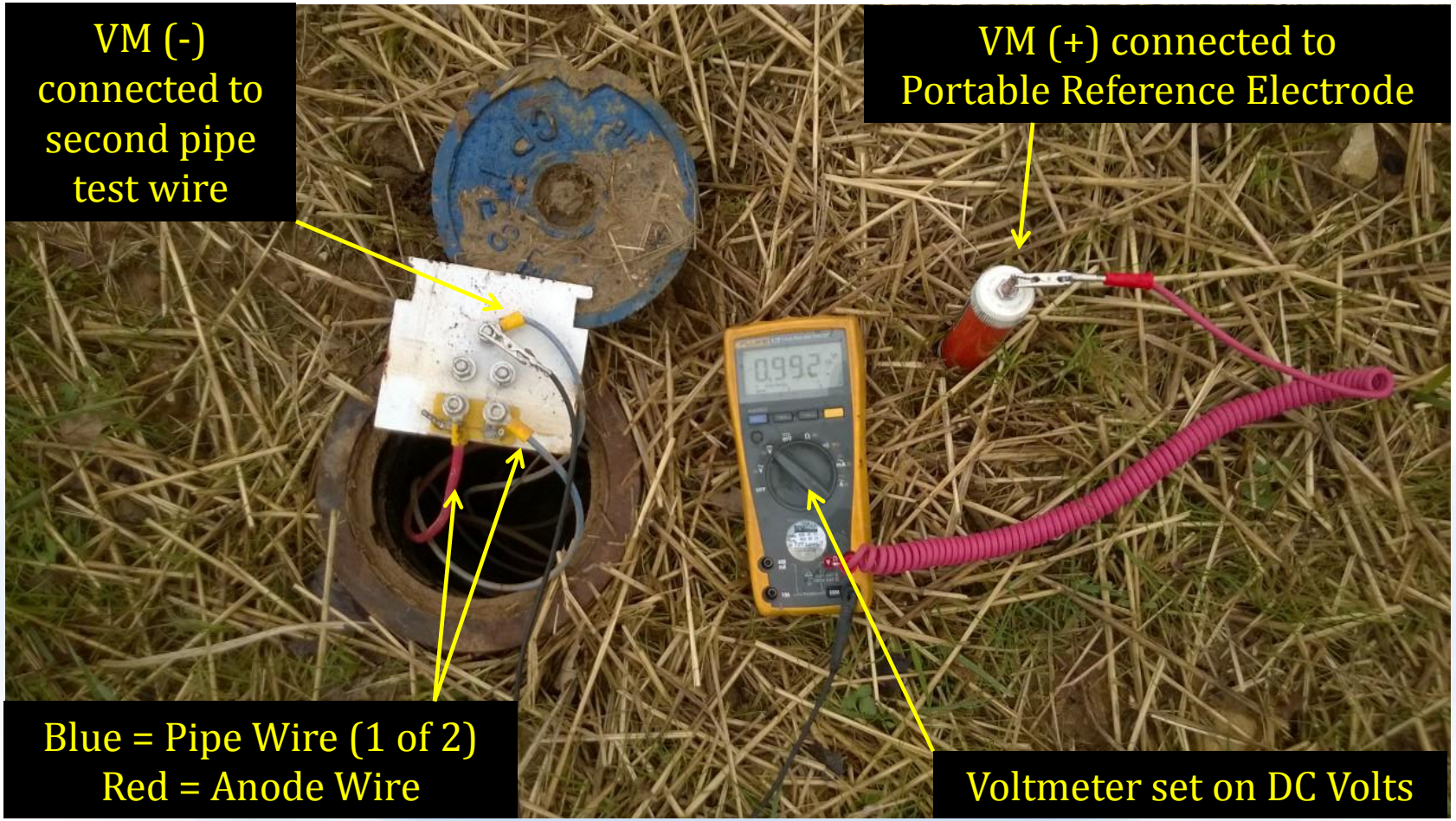
CP Measurements – A Standard Process

- Measurements are typically made from grade
- High-input impedance multi-meter
- Standard reference electrode (stable baseline)
- Compare the measured potentials versus a recognized standard recommended practice

Structure-to-Soil Potential w/Portable Reference Electrode



CP Performance Validation – S/S Potential Data



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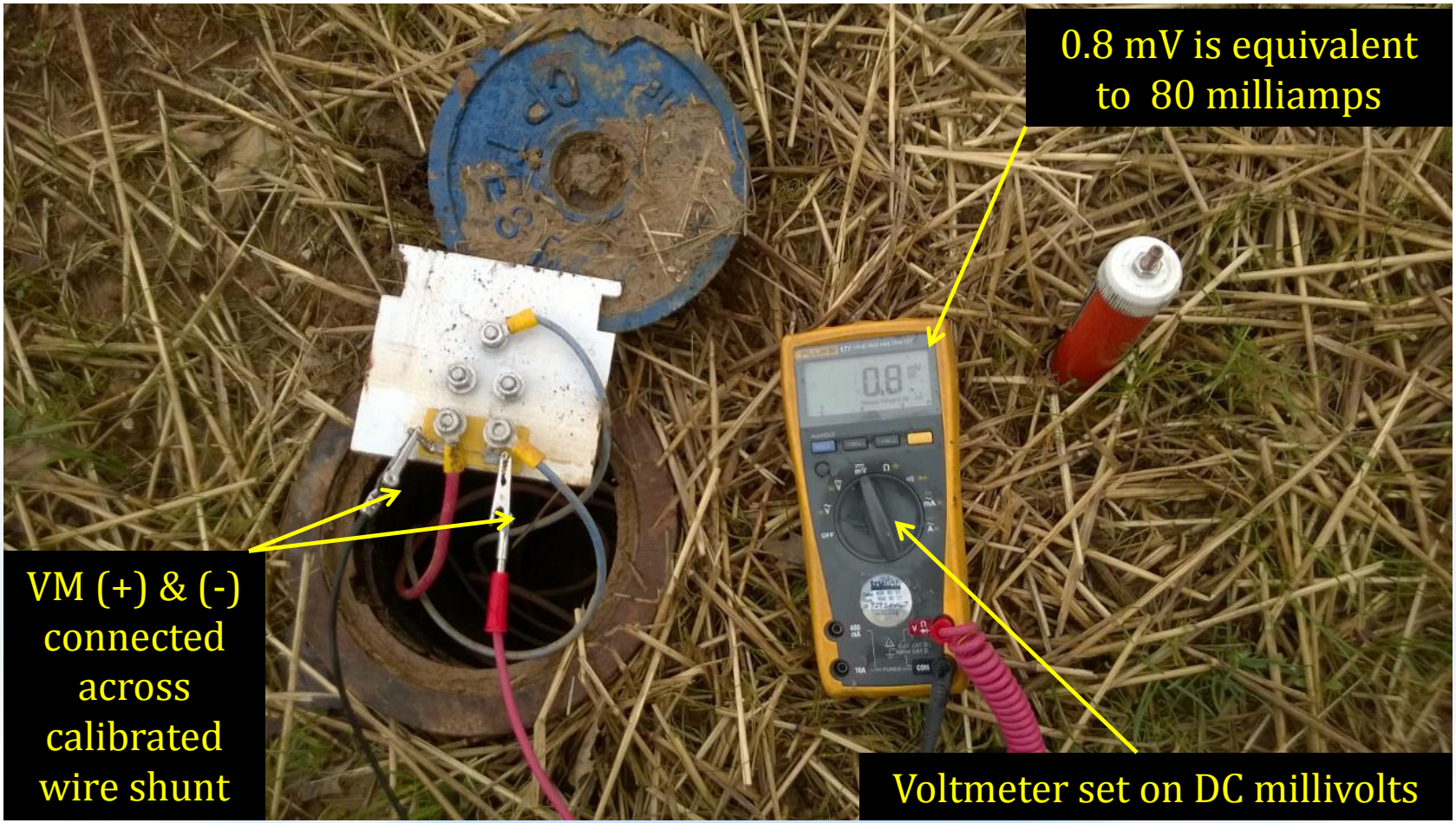
CP Performance Validation – Anode Current Output Data



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Summary: The Real Benefits of Corrosion Mitigation

- Reduction in the corrosion to the water infrastructure
- Reduction in water main breaks
- Reduction in non-metered water loss
- Reduction in costs for emergency repairs
- Increased water main service life
- Increased level of reliable water service to customers
- Increased health and security of the municipal water supply

Studies have shown that implementing a corrosion mitigation program using cathodic protection for water and waste water infrastructure will commonly save between $5 and $10 for every $1 spent.

Do You Have Any Questions?

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