A Tale of A Corroded Pipe: Failures, Analysis and Mitigation

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June 26, 2019

Agenda

- LCDU and The Far Hills Force Main
- Pipe Corrosion – Contributing Factors and Assessment Techniques
- Far Hills Condition Assessment
- Recommendations for Future Mitigation
- Engineering – Operational Ability
- Other Anode Installation
- One Year Later
- Proactive Measures

LCDU and
The Far Hills Force Main

Lake County Department of Utilities (LCDU)

- Gary L. Kron (GLK) Water Reclamation Facility
- 20 MGD design flow / 55 MGD peak hydraulic capacity
- Began operation in 1963
- Discharges to Lake Erie

Lake County, Ohio

Number of Pump Stations	32
Number of Grinder Pumps	55
Total Length of Gravity Lines (miles)	463
Total Length of Force Main (miles)	35
Service Area (square miles)	58
Population Serviced	90,000

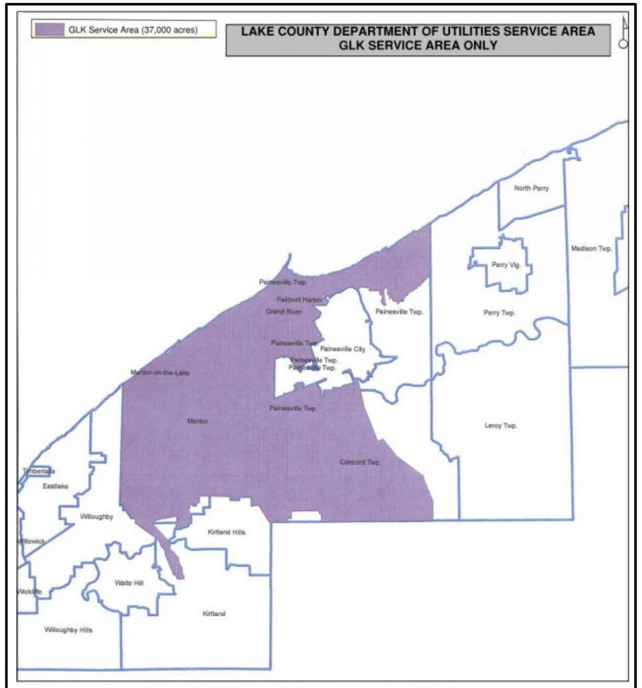


Figure 1-1. LCDU Sewer Collection System for GLK Service Area

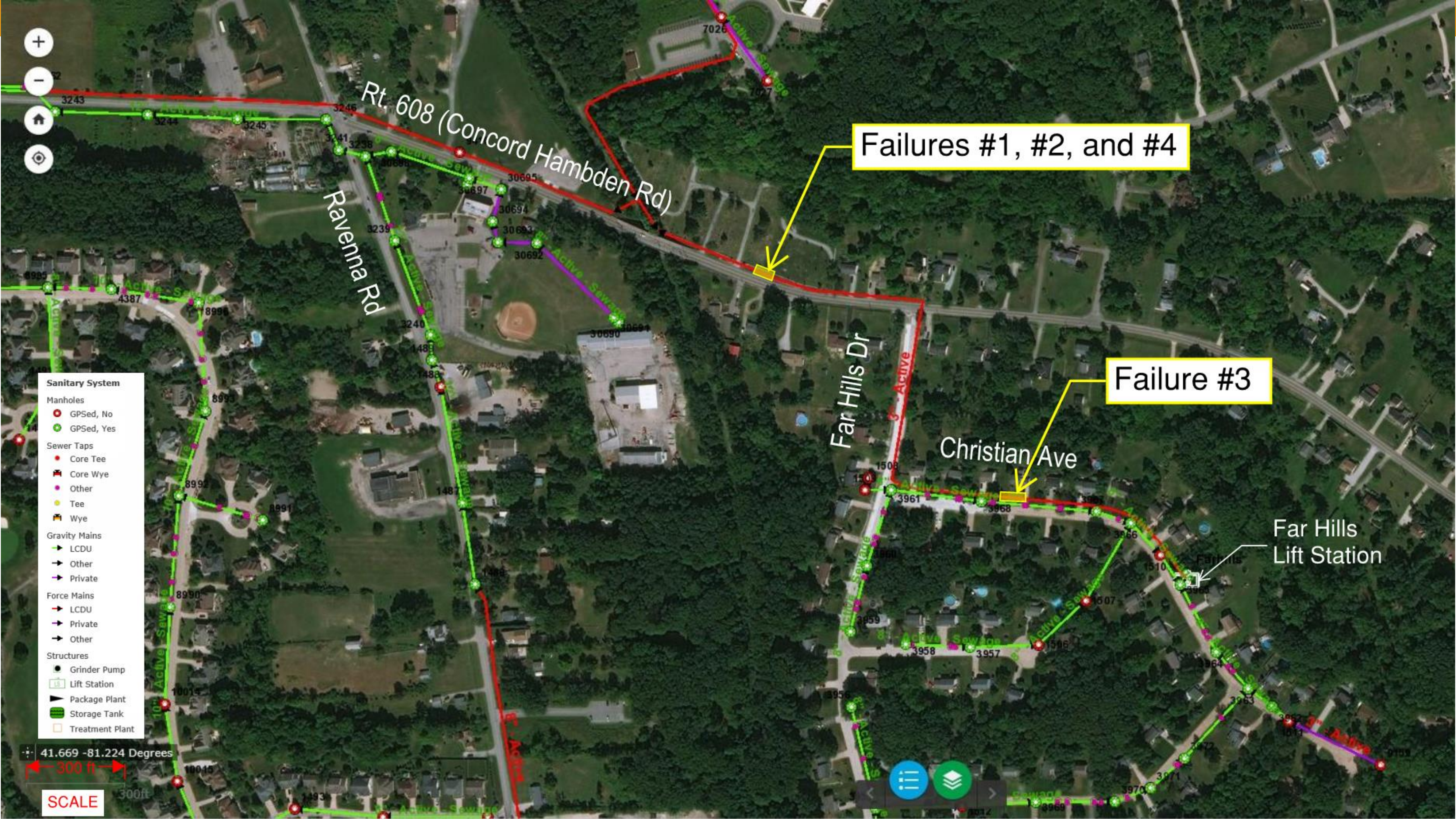
GLK Service Area

The Far Hills Force Main

- Located in Concord Township (Lake County)
- ~4,500 LF of 3”/4” ductile iron sanitary force main
- Begins at the Far Hills Pump Station
- Installed in 1993 (25 years old)
- Lake County hired Brown and Caldwell (BC) in Spring/Summer 2018 to investigate the Far Hills force main and its recent failures

4 Separate Failures in February 2018

- All within ¼ mile radius of one another
- No apparent changes in weather or flow characteristics
- Failed segments removed and retained, existing pipe repaired, trenches backfilled
- Failures resulted in sanitary sewer overflows (SSOs)
- Pipeline not historically failure-prone



Failures #1, #2, and #4
Failure #3
Rt. 608 (Concord Hambden Rd)
Ravenna Rd
Far Hills Dr
Christian Ave
Far Hills Lift Station
Sanitary System
Manholes
GPSed, No
GPSed, Yes
Sewer Taps
Core Tee
Core Wye
Other
Tee
Wye
Gravity Mains
LCDU
Other
Private
Force Mains
LCDU
Private
Other
Structures
Grinder Pump
Lift Station
Package Plant
Storage Tank
Treatment Plant
41.669 -81.224 Degrees
300 ft
SCALE

Apparent Cause: Exterior Corrosion (“Differential Aeration Cell”)

All failures occurred at the pipe invert

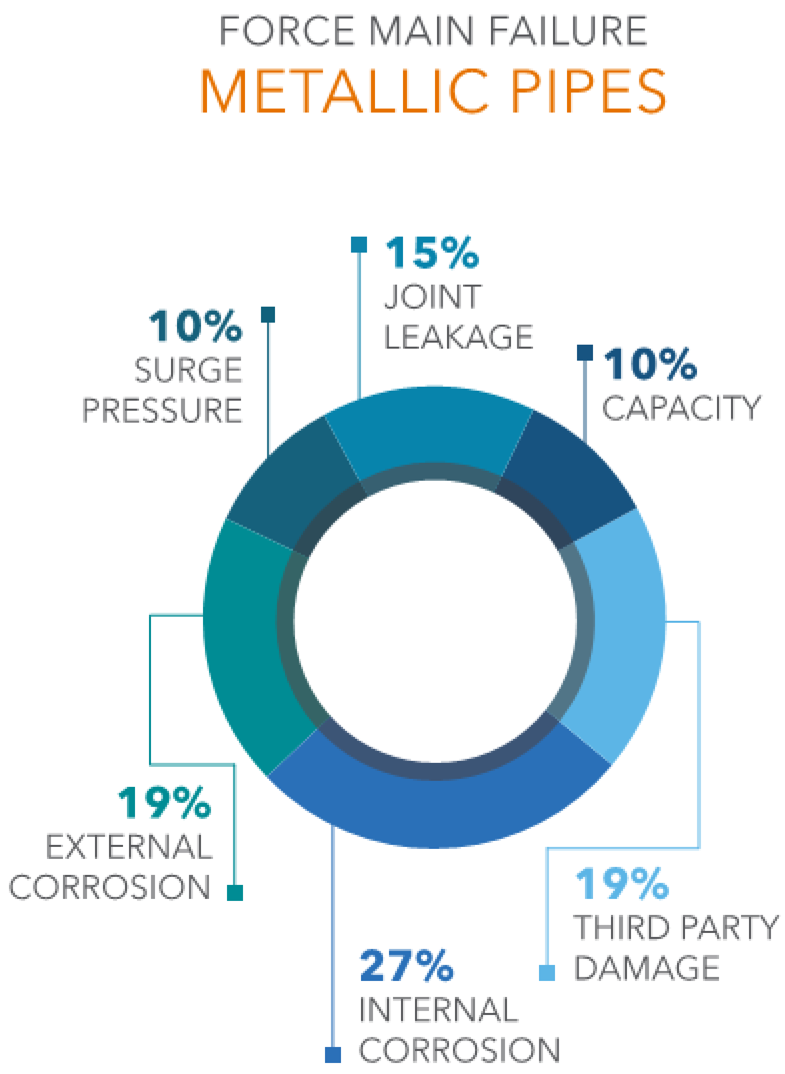
Pipe Corrosion – Contributing Factors and Assessment Techniques

Force Main Failures – By The Numbers

- 63% of force mains in the U.S. are metallic pipe (cast iron, ductile iron, or steel)

- About half of force main failures are due to external or internal corrosion
- A quarter of force main failures are due to surge pressure and joint leakage

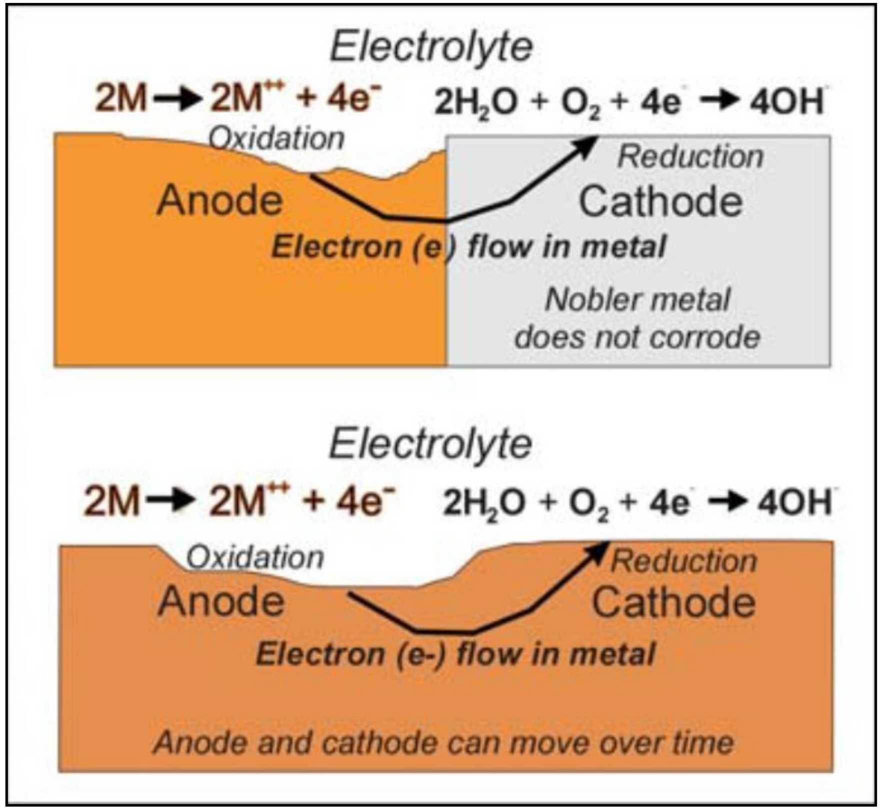
→ **Nearly 75% of force main failures are preventable**



Source: *Implementing A Proactive Approach to Force Main Asset Management*, Xylem.

General Exterior Corrosion Factors

- Aggressive electrolyte (soil, water)
- Lack of or ineffective cathodic protection
- Stray current interference
- Potential for increased rate of corrosion at or near repair sites
- Poor or lack of a corrosion resistant coating



Differential Aeration Cell

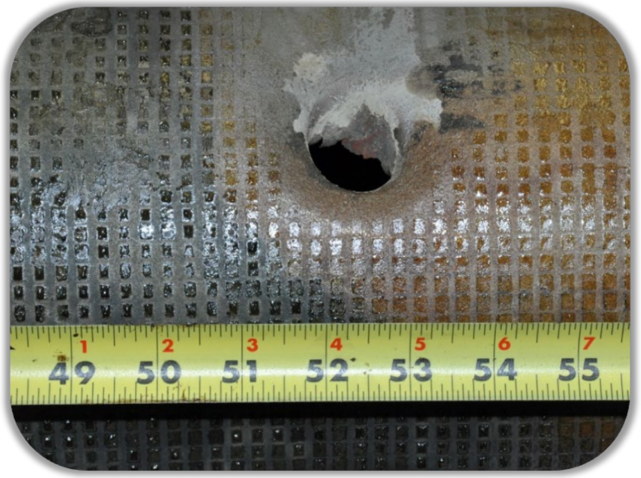
- Highly aerated environments influence the corrosion of iron and other metals
- An uneven supply of air on the metal surface creates anodic (oxygen-rich) and cathodic (oxygen-starved) sites
- Can be caused by crevices, lap joints, dirt and debris, moist insulation

Cast and Ductile Iron Corrosion

- **Electrolytic** – perforation, localized pitting

- **Graphitic** – preferential loss of strength

- **Stray current** – pipe becomes part of an electrical circuit involving a foreign direct current source



Corrosion Assessment Techniques

Soil Testing

- Soil chemistry, Wenner 4-Pin method (soil resistivity)

Acoustic Systems

- Acoustic leak detection, free swimming leak detection

Electromagnetic Systems

- Remote field eddy current, pipe penetrating radar

Ultrasonic Systems

- Ultrasonic testing, long range guided wave

Visual Systems

- Sonar, laser profiling, CCTV

Far Hills
Corrosion Assessment

Why Perform a Corrosion Assessment?

- Understand cause of pipe failures
- Identify areas requiring immediate attention
- Mitigate risk
  - Improve rehab, repair, and replacement strategies / develop proactive planning
- Reduce occurrence of failures
- Reduce capital costs
  - Condition assessment programs can be implemented at about 5-15% of the cost of replacement
- Increase confidence / ensure safety in the overall operations of force mains for both LDCU and the public

Field Study, May - June 2018

Phase 1

- Environmental assessment along select points of the force main
- Goal
  - Gather data to evaluate whether or not the conditions which led to recent failures were present throughout the alignment

Phase 2

- Direct assessment of the force main
- Goals
  - Determine the remaining wall thickness
  - Facilitate the installation of cathodic protection (sacrificial anodes) at the most vulnerable sites

Project Team

Brown and Caldwell

- Management
- Coordination
- Direct pipe assessment
- Reporting
- Instruction on sacrificial anode installation

Corrosion Probe, Inc.

- Soil testing
- Direct pipe assessment
- Reporting
- Instruction on sacrificial anode installation

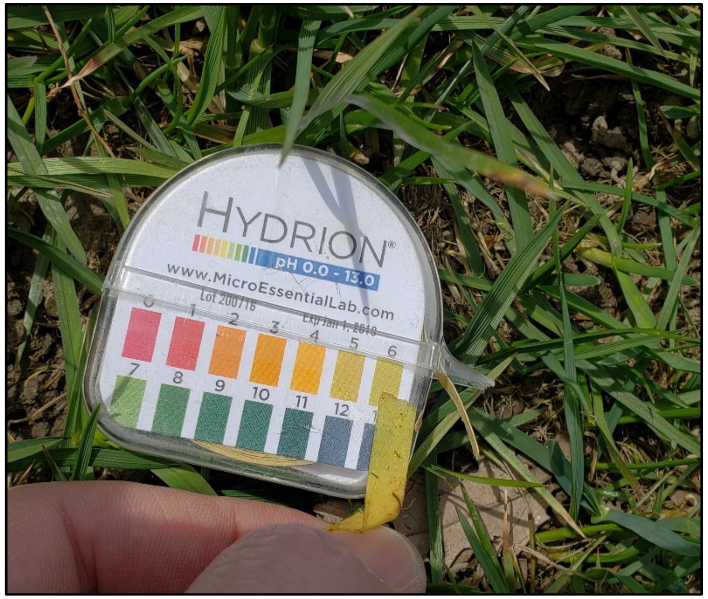
Lake County

- Coordination
- Traffic control
- Safe excavation
- Materials for anode installation (via this project)

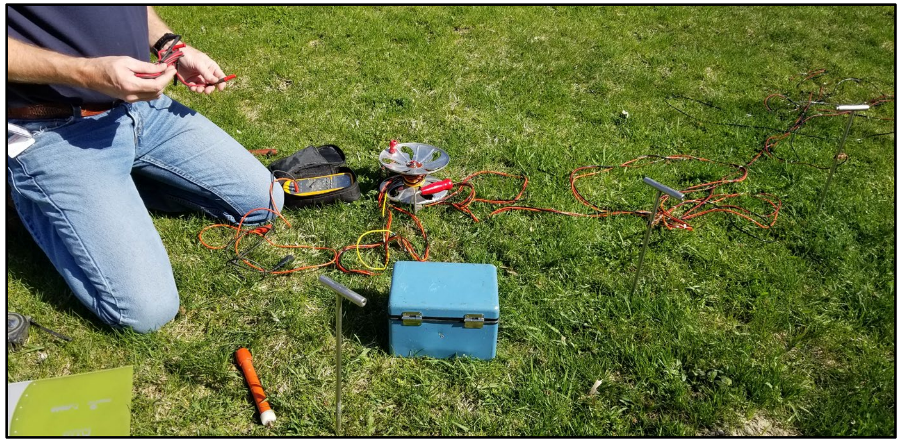
Phase 1 – Environmental Assessment

11 ground surface tests

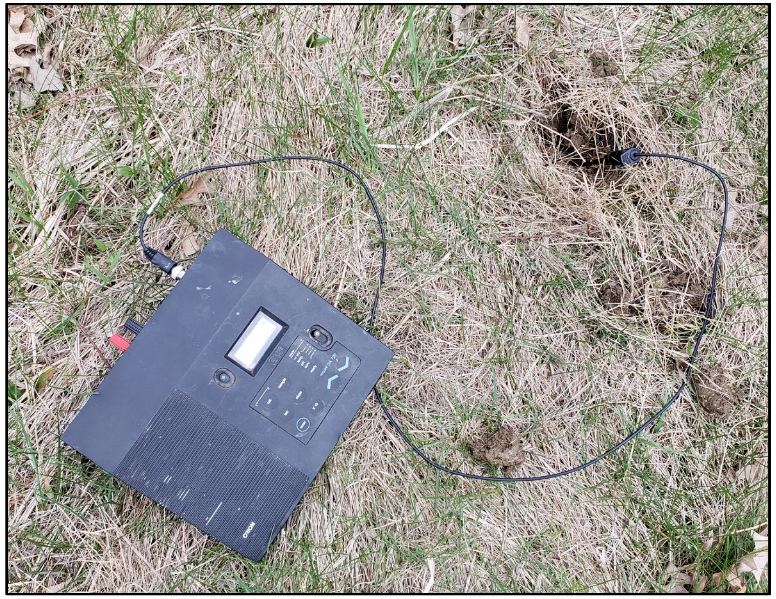
Surface pH



Soil resistivity averaged over
2.5 FT, 5.0 FT and 7.5 FT depths



Surface oxidation and
reduction (REDOX) potential



Ductile iron typically corrodes
faster in these soil conditions:

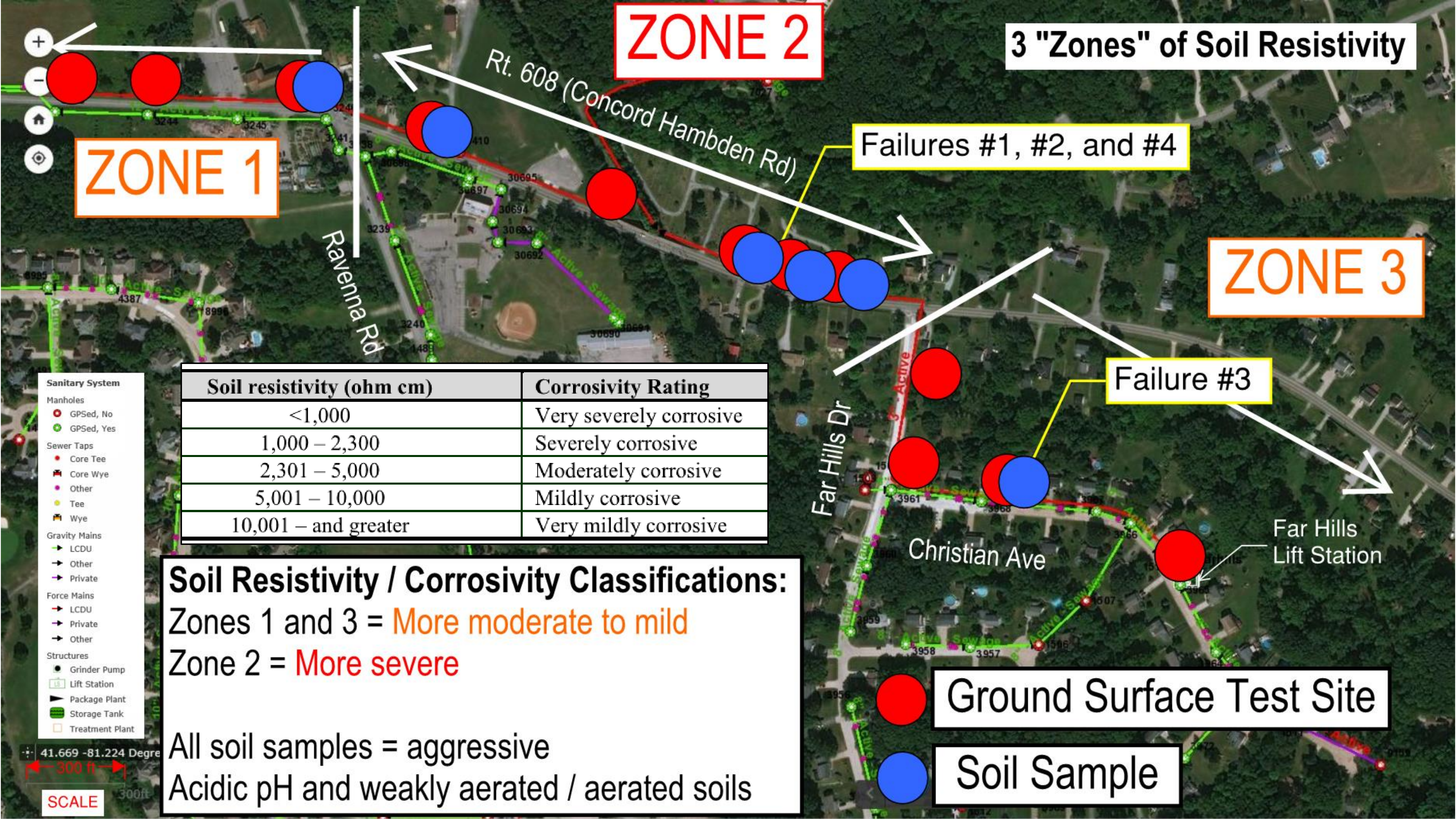
- Acidic pH
- Low resistivity
- Negative REDOX potential

Phase 1 – Environmental Assessment (Contd.)

6 soil samples

- Soil type and condition
- Specific soil resistivity
- Water content
- pH
- REDOX potential
- Calcium and magnesium carbonate content
- Presence of sulfides
- Chloride and sulfate ion concentrations

3 "Zones" of Soil Resistivity



Soil resistivity (ohm cm)	Corrosivity Rating
<1,000	Very severely corrosive
1,000 – 2,300	Severely corrosive
2,301 – 5,000	Moderately corrosive
5,001 – 10,000	Mildly corrosive
10,001 – and greater	Very mildly corrosive

Soil Resistivity / Corrosivity Classifications:

Zones 1 and 3 = More moderate to mild

Zone 2 = More severe

All soil samples = aggressive

Acidic pH and weakly aerated / aerated soils

Other Phase 1 Findings

- Pipeline is not electrically continuous
- 2 natural gas pipelines in area (1 confirmed protected by anodes, other unknown)

Exterior Corrosion Prediction Holds True

- Field and lab analysis from Phase 1 suggested the mechanism of pipe deterioration was exterior corrosion (differential aeration cell) as predicted
  - Graphitic and/or electrolytic corrosion

Phase 2 – Direct Assessment

3 direct assessments of the pipe (one in each “Zone”)

- Visual observations
- Wall thickness measurement using an ultrasonic gauge (UT Testing)

Phase 2 – Direct Assessment (Contd.)

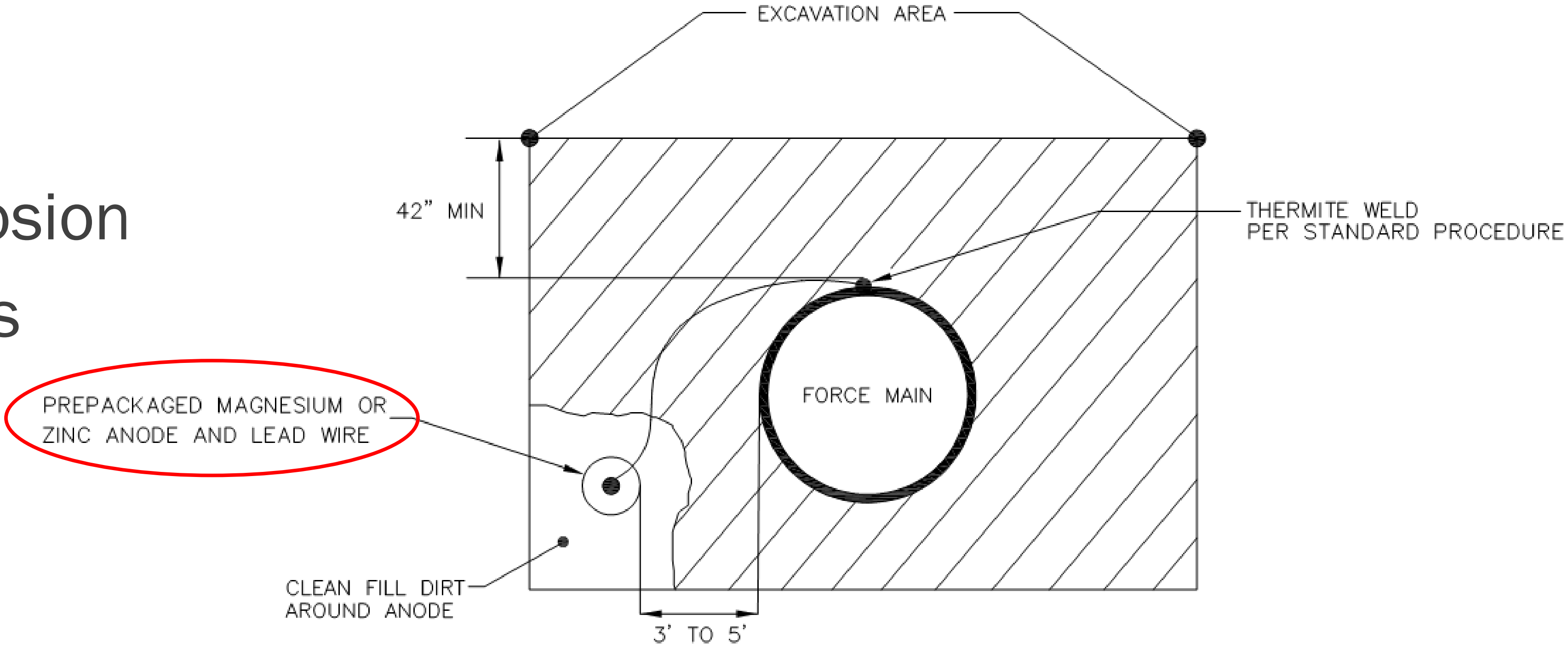
- The original surface texture of the pipe was still visible in most areas, but some pitting corrosion was found at the pipe invert
- The pitting was observed to be very deep and soft
- A repair clamp was installed over top of a pipe area nearing failure

Phase 2 – Direct Assessment (Contd.)

3 sacrificial magnesium anodes (32 lbs.) were provided and installed on the force main to provide cathodic protection

Purpose of anodes:

- Slow the rate of corrosion
- Prevent future breaks
- Prolong service life



Phase 2 – Direct Assessment (Contd.)

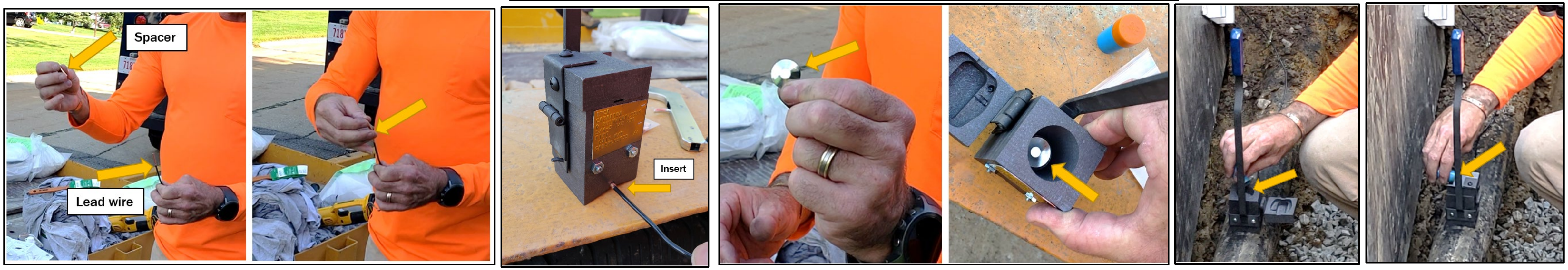
Why 32 lbs.?

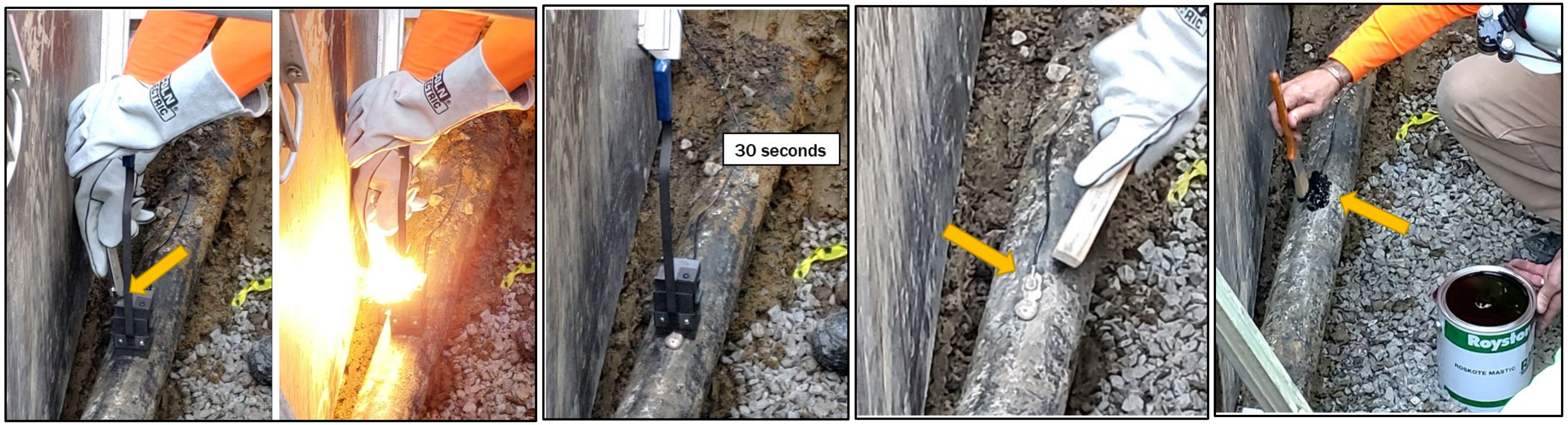
- Expected to provide sufficient protection for ~10 years under normal conditions
- Inexpensive (~$200 with welding supplies)
- Easy to handle

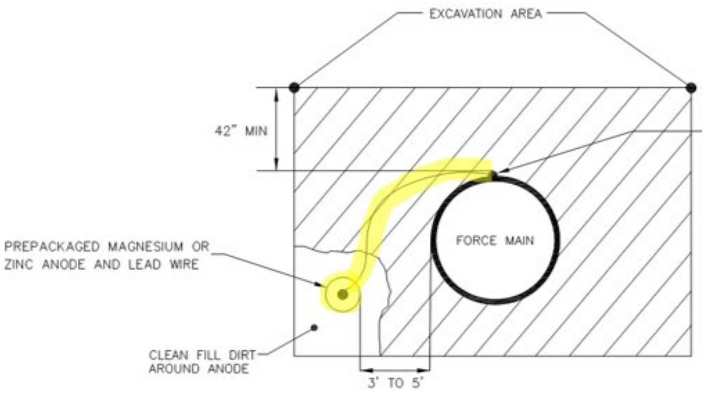
Heavier anodes = more Mg^{2+} = longer lasting

(but are more costly and difficult to handle)

Anode Installation







Remaining Factor of Safety (FOS)

- UT readings were used to calculate the remaining FOS of the pipe wall thickness
- Determined in accordance with AWWA C150 Thickness Design of Ductile Iron Pipe
- A safety factor of 2.0 is typically used in design calculations
- All found to be well above (>10)
- Far Hills FM appears to have provided a generous corrosion/material defect allowance

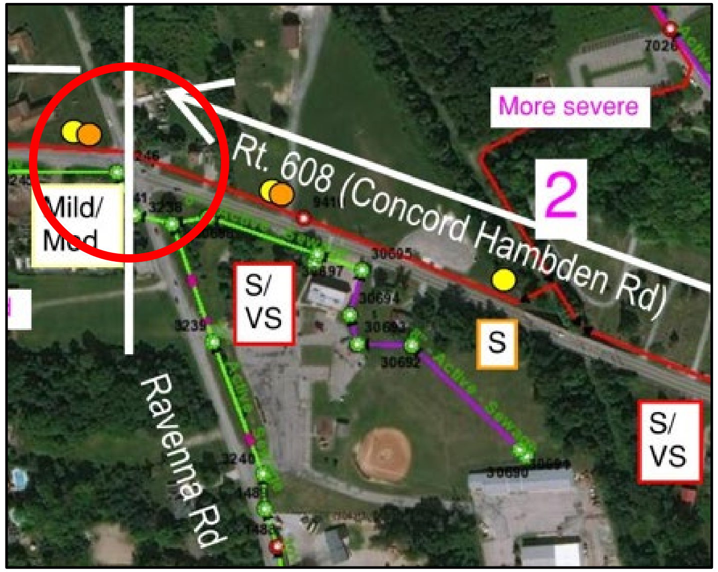
→ Un-pitted and areas with limited pitting have sufficient strength to remain in service

Ultrasonic Wall Thickness Testing Factors of Safety			
Force Main Location	Minimum Wall Thickness Reading (inches)	Average Wall Thickness Reading (inches)	Limiting Factor of Safety
Location #1	0.315	0.351	> 10
Location #2	0.258	0.310	> 10
Location #3	0.225	0.270	> 10

Other Phase 2 Findings

- Microbiological influenced corrosion (MIC) may also be occurring on some sections of the pipe exterior
  - Black scale/slime (possibly iron sulfide) on pipe exterior
  - UT measurements suggested general pipe thinning

- De-icing salt is heavily applied at the intersection of Rt. 608 and Ravenna Rd ("Zone 2")
  - De-icing salt can lead to corrosion as it leaches into the soil and increase chloride and sulfide content, reduce resistivity
  - Observations were consistent



Assessment Conclusions – Field Findings

- Potentially corrosive environmental conditions exist throughout the pipe alignment
- “Zone 2” had the most corrosive conditions
- Conditions that appeared to contribute to the corrosion include:
  - Moist soil
  - Possible different soil strata/layers
  - Bare pipe exposed to the corrosive soils
  - Low pH
  - No external corrosion protection
  - Low soil resistivity
- Widespread pitting was not found – the pipeline does not appear to be experiencing universal corrosion
- Wall thickness tests showed areas with limited or no corrosion had more than adequate wall strength to continue service

Assessment Conclusions – Summary

- Corrosion has occurred in localized areas
- Additional failures may occur
- Sacrificial anode installation is feasible when excavations occur
- The 4 recent failures do not presently appear to be indicative of a larger trend that would indicate the entire pipeline is beyond its useful life

Engineering – Operational Ability

Other Anode Applications – “A Tale of Corroded Pipe<u>s</u>"

- Timeline of Events
  - 5/13/19
  - 5/14/19
    - What can go wrong, will go wrong!
- Williams Pump Station Force Main
  - Located in Grand River, Ohio
  - Similar pipe, soil characteristics, and number of breaks as the Far Hills FM
- Photos: What we found?

Williams Force Main Break – May 2019

Williams Force Main Break Photo Gallery

One Year Later

- All 10 anodes have been used within the GLK Collection System
- A new order of 10 anodes on order
- Employee Training
  - All Collections Personnel have been trained
  - We were also able to extend an invite to LCDU Water Distribution

Continued Above Ground Force Main Inspections

- Original commitment – annual inspections
- With the increased likelihood of breaks, LCDU is now conducting inspections quarterly at the Far Hills and Williams force mains

Proactive Measures – Sanitary Sewer Overflow Reporting

- "Steps taken or planned to eliminate and/or reduce the overflow – include schedule of major milestones"
- "Steps taken or planned to prevent reoccurrence of the overflow(s) - include schedule of major milestones"

OhioEPA

State of Ohio Environmental Protection Agency

Ohio EPA Form 4237
Issued 08/04

Sanitary Sewer Overflow 5-Day Follow Up Report

Report Submitted by:	
Date	
Facility Name	
Ohio NPDES Permit No.	
Period Covered by Report	
Contact Person Name	
Contact PersonTitle	
Mailing Address	
City, State, Zip	
County	
Telephone No.	
E-mail Address	

Signature required at end of form

Overflow Information	
Event start date and time – if multiple locations, include information for each	
Event end date and time	
Location(s) the SSO – include unique ID number if one exists	
Destination(s) of overflow	☐ Basement or building ☐ Ground ☐ Storm sewer to receiving water ☐ Directly to receiving water
Specific receiving water(s) (if applicable)	
Estimated volume (million gallons) – if multiple locations, include volume for each	
Sewer system component(s) from which release occurred	☐ Manhole ☐ Constructed overflow ☐ Pipe crack ☐ Pump station ☐ Other (explain)
Cause(s) of overflow	☐ Extreme weather ☐ Equipment failure ☐ Power failure ☐ Debris in line ☐ Roots ☐ Grease ☐ Other blockages ☐ Line deterioration ☐ Vandalism ☐ Other (explain)

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Click to clear all entered information (on both pages of this form) CLEAR

Steps taken or planned to eliminate and/or reduce the overflow – include schedule of major milestones	
Steps taken or planned to prevent reoccurrence of the overflow(s) – include schedule of major milestones	
Steps taken or planned to mitigate the impact(s) of the overflow(s) – include schedule of major milestones	
Additional information (attach additional pages, maps, etc. as needed)	

I CERTIFY THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION IN THIS REPORT AND ALL ATTACHMENTS. I BELIEVE THAT THE INFORMATION IS TRUE, ACCURATE, AND COMPLETE.

Signature Date

Title

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Far Hills Force Main Break – June 2019

The Design Decision Model

- DIPRA and Corrpro's risk-based model for corrosion control of ductile iron pipe
- Balances the likelihood of a corrosion-related concern against the consequences of such an occurrence

TABLE 1

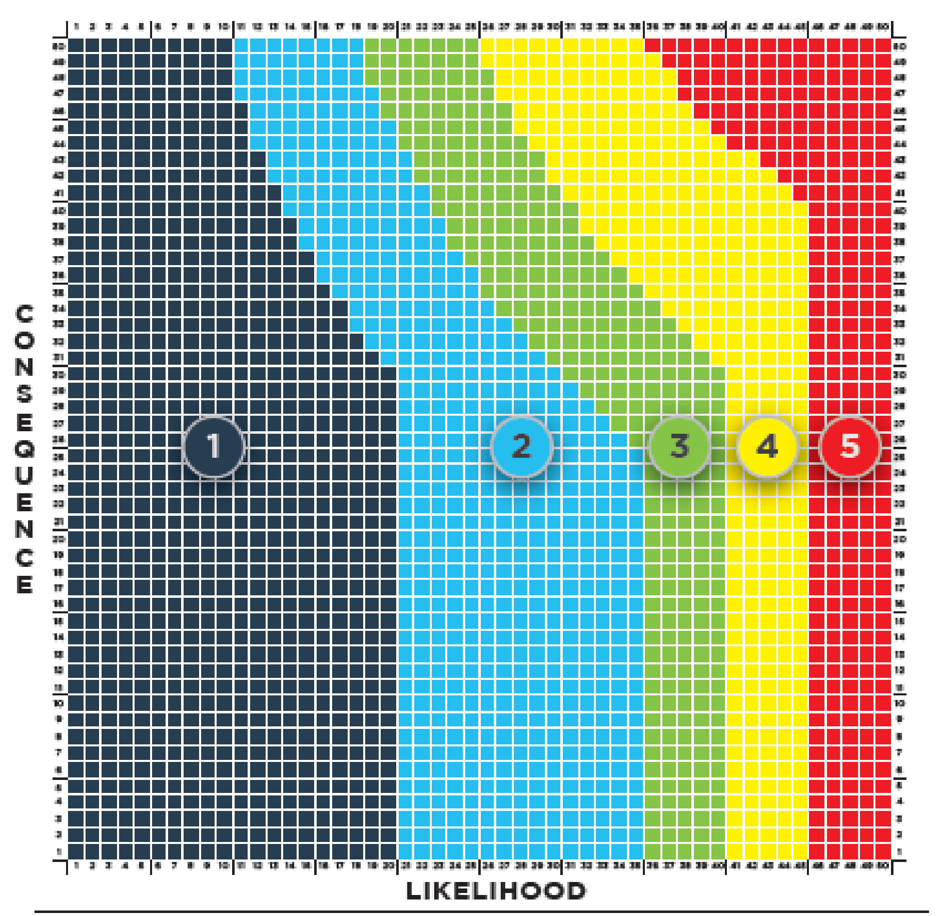
Design Decision Model® (DDM®)

Recommendations	
1	As manufactured with shop coat
2	V-Bio® Enhanced Polyethylene Encasement
3	V-Bio® Enhanced Polyethylene Encasement, or V-Bio® Enhanced Polyethylene Encasement with Joint Bonds
4	V-Bio® Enhanced Polyethylene Encasement with Metallized Zinc Coating, or V-Bio® Enhanced Polyethylene Encasement with Life Extension Cathodic Protection
5	V-Bio® Enhanced Polyethylene Encasement with Metallized Zinc Coating, or V-Bio® Enhanced Polyethylene Encasement with Cathodic Protection

* Recommendations in Zones 4 and 5 recognize a practical difference between distribution and transmission mains. Distribution mains are generally smaller sized pipes, with the final classification to be defined by the pipeline owner. Cathodic protection should be considered where external corrosion is a significant risk or where pipe repairs/replacements would be cost prohibitive.

FIGURE 1

DDM® Two-Dimensional Matrix



The Design Decision Model (Contd.)

Far Hills Force Main

TABLE 2

Likelihood Score Sheet

LIKELIHOOD FACTOR		POINTS	MAXIMUM POSSIBLE POINTS
RESISTIVITY	< 500 ohm-cm ≥ 500 - 1000 ohm-cm > 1000 - 1500 ohm-cm > 1500 - 2000 ohm-cm > 2000 - 3000 ohm-cm > 3000 - 5000 ohm-cm > 5000 ohm-cm	30 25 22 19 10 5 0	30
CHLORIDES	> 100 ppm = positive 50 - 100 ppm = trace < 50 ppm = negative	8 3 0	8
MOISTURE CONTENT	> 15% = Wet 5 - 15% = Moist < 5% = Dry	5 2.5 0	5
GROUND WATER INFLUENCE	Pipe below the water table at any time	5	5
pH	pH 0 - 4 pH > 4 - 6 pH 6 - 8, with sulfides and low or negative redox pH > 6	4 1 4 0	4
SULFIDE IONS	positive (≥1 ppm) trace (> 0 and < 1 ppm) negative (0 ppm)	4 1.5 0	4
REDOX POTENTIAL	= negative = positive 0 - 100 mv = positive > 100 mv	2 1 0	2
BI-METALLIC CONSIDERATIONS	Connected to noble metals (e.g. copper) - yes Connected to noble metals (e.g. copper) - no	2 0	2
	TOTAL POSSIBLE POINTS		60
Known Corrosive Environments	Cinders, Mine Waste, Peat Bog, Landfill, Fly Ash, Coal		21

* Soils with Known Corrosive Environments shall be assigned 21 points or the total of points for Likelihood Factors, whichever is greater.

TABLE 3

Consequence Score Sheet

CONSEQUENCE FACTOR		POINTS	MAXIMUM POSSIBLE POINTS
PIPE SERVICE	3" to 24" 30" to 36" 42" to 48" 54" to 64"	0 8 12 22	22
LOCATION: Construction-Repair Considerations	Routine (Fair to good access, minimal traffic/other utility consideration, etc.)	0	20
	Moderate (Typical business/ residential areas, some right of way limitations, etc.)	8	
	Difficult (Subaqueous crossings, downtown metropolitan business areas, multiple utilities congestion, swamps, etc.)	20	
DEPTH OF COVER CONSIDERATIONS	0 to 10 feet depth > 10 to 20 feet depth > 20 feet depth	0 3 5	5
ALTERNATE WATER SUPPLY	Alternate supply available - no Alternate supply available - yes	3 0	3
	TOTAL POSSIBLE POINTS		50

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FIGURE 1

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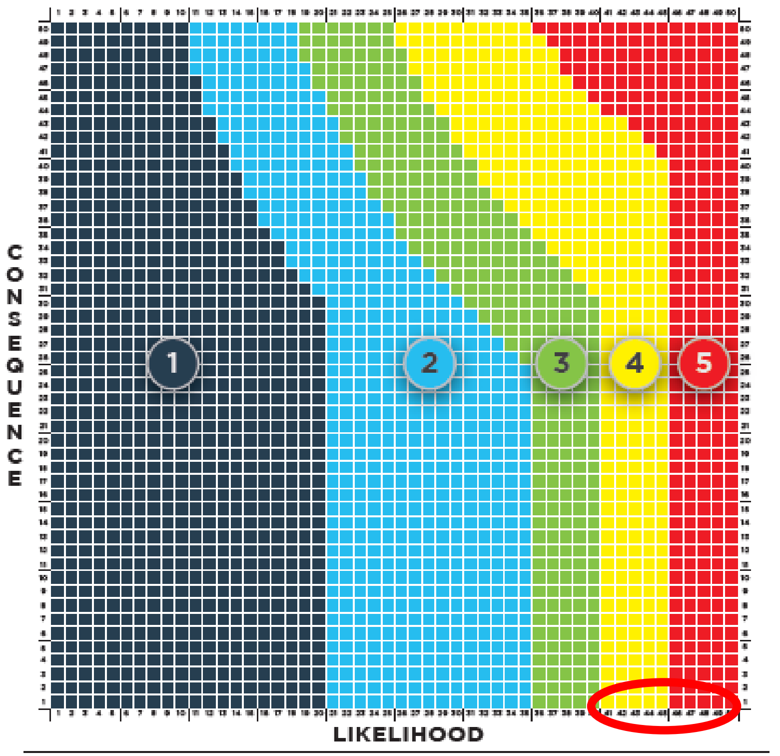


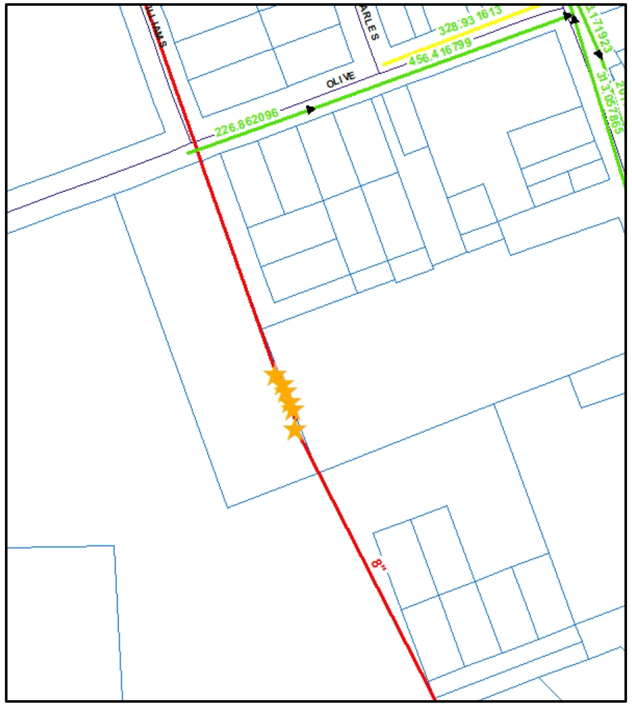
GIS Layer for Break/Anode Site Monitoring

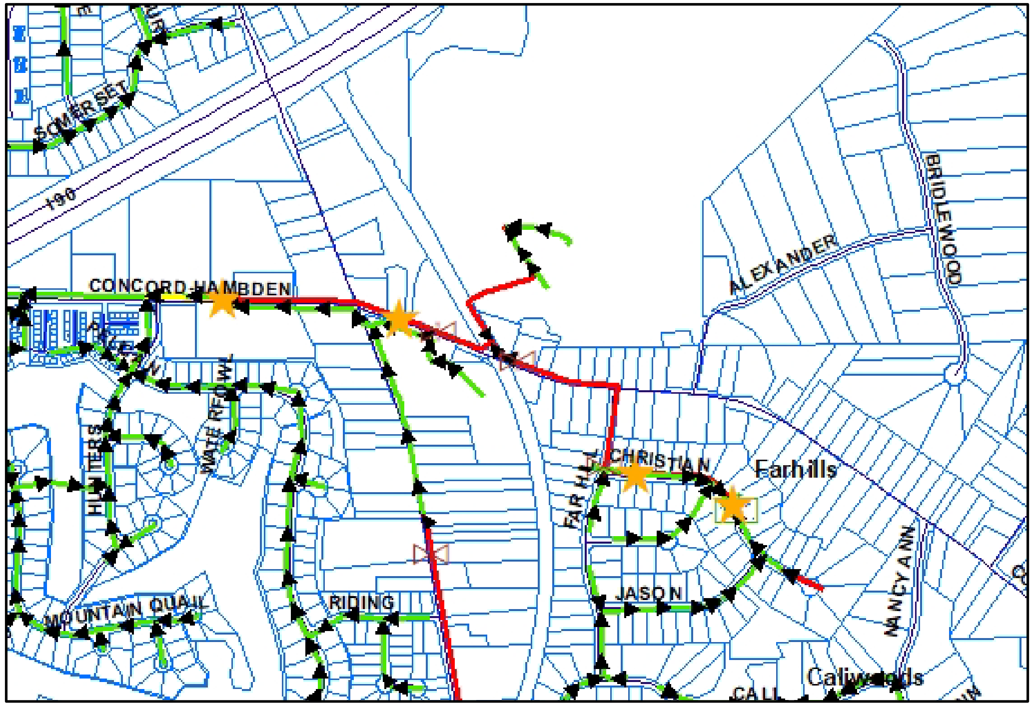
- Lake County created a GIS layer to assist pipe monitoring efforts
  - Easily identify break sites and anode install locations
  - Collect and store data on anode and repaired pipe conditions

Control Valves: Anode

Facility ID	1271
Valve Type	Anode
Install Date	
Location Description	
Diameter	
Owned By	LCDU
Managed By	GLK-LCDU
Enabled	True
Condition Score	
Condition	

...





Thank you.
Questions?

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