Chapman Engineering

30 PLUS YEARS

THANKS TO
SOUTHERN IDAHO/
EASTERN OREGON
SUN VALLEY, IDAHO
NACE/SSPC/AMPP

AC Power Involvement with Pipelines: Safety Risks, Corrosion Risks, Measuring, Modeling, and Mitigation, Part 2

January 12, 2024

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(With Thanks to Mike Ames)

FURTHER AC INTERACTION DISCUSSION

- Does a particular pipeline build power? If so, it has very good coating quality. Poor coating means the pipe is “grounded out” effectively to soils.
- Large electric towers with big power loads cause big power induction on a pipeline. **Pipe/soil/interaction characteristics vary,** meaning **field measurements are vital for accurate modeling.**
- It’s typical that WELL-COATED pipeline approaching at shallow angle, and/or running parallel to an HVAC system will suffer large induced power loads.
- There are “end effects” to find and control, where current tries to preferentially leave the pipeline **beyond** pipeline deviations away from parallel and close-approach segments.

BASIC DC OR AC ELECTRICITY

Ohm's Law: Voltage = Current x Resistance

(or Impedance for AC)

V = I x R – if we can measure DC or AC voltage and current, we can determine resistance of a circuit by simply "doing the math." In AC power, two other factors also are involved (capacitance and inductance), but not usually major compared to R, in this type of work.

Or measure voltage and resistance – then you determine the current flowing.

BASIC DC OR AC ELECTRICITY

Power Law: **Power (watts) =**

Voltage (volts) x Current (amps)

or P = V x A – if we measure the induced voltage on pipe, do we learn current flow?

Nope – have to build a temporary "discharge"/ drain circuit and measure the current. Also must do this at multiple locations. One drain almost never fixes the problem.

In AC power world,

P = V * A * power factor (PF ≈ 0.95).

HOW MIGHT ONE FIGURE OUT AN AC-INDUCED CORROSION PATTERN?

- As Pipeline Integrity Management (PIM) procedures mature, more surveys are required to detect AC safety and corrosion issues, especially in HCA’s and now, MCA’s;
- Review AC voltage readings on annual CP surveys and ECDA reports. Compare with ILI pig runs showing wall loss. If they line up together? **A BIG SIGN;**
- Evaluate AC-induced corrosion risks by estimating current drain from a “worst case” one-sq-cm area, soil resistivity measured in field, and AC pipe-to-soil voltages. Do this at how many locations? How to get power loads overhead?
- Request AC corrosion modeling (SES CDEGS-ROW, Elsyca IRIS, Technical Toolbox AC Mitigation Toolbox (ACTB), other qualified parties/softwares).

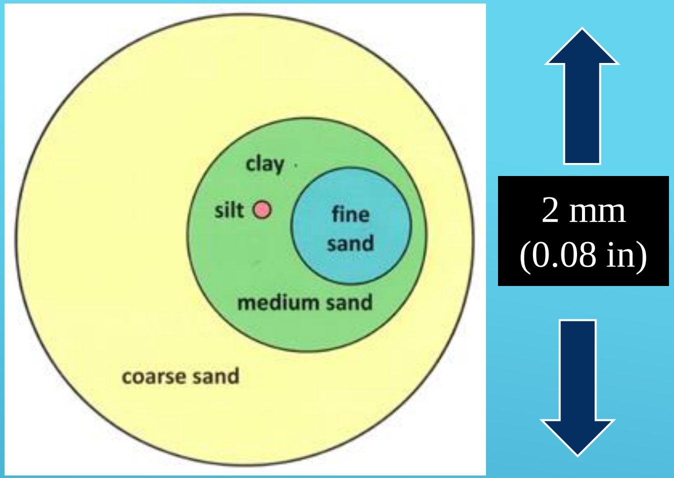
DATA FROM CONSTRUCTION RECORDS, SMART PIG RUNS, CP SURVEYS & ECDA INSPECTION(S)

Line	12" Diam	43.60	Miles								
HCA		41.80	Miles								
								Confidence			
Station	**Depth**	**Length In.**	**Dug**	**ACVolts**	**Comments**	**Meas 090709**		**Ratio**			
465+53	21%	1.89									
465+53	47%	3.25	2008	10.23	Installed 10 mag anodes and decoupler.	0.5VAC @0.5A		0.4468			
674+91	19%	1.85									
674+91	31%	1.28	2009					0.6129			
675+01	10%	1.18									
675+01	17%	1.00	2009	15.22				1.7000			
2311+71	27%	1.30									
2311+71	51%	0.88	2008	1.3	High concern area			1.8889			
								Scatter indicates good calibration ILI.			
	Wall thicknesses					Loss Rate Per Year Depth Inches					MPY Per
	2001	**2008**	**2009**		**Evaluating the wall loss rates**	**2008**	**2009**	**2008 MPY**	**2009 MPY**	**VAC**	AC Volt
465+53	0.312	0.246	0.165		Loss rate 100% between 2008 and 2009	0.0094	0.0183	9.36	18.33	10.23	1.792
674+91	0.312	0.253	0.215		Loss rate 43% between 2008 and 2009	0.0085	0.0121	8.47	12.09		
675+01	0.312	0.281	0.259		Loss rate 49% between 2008 and 2009	0.0045	0.0066	4.46	6.63	15.22	0.436
2311+71	0.312	0.228	0.153		Loss rate 65% between 2008 and 2009	0.0120	0.0199	12.03	19.89	1.3	15.300
							AVG	8.58	14.24	8.92	5.84

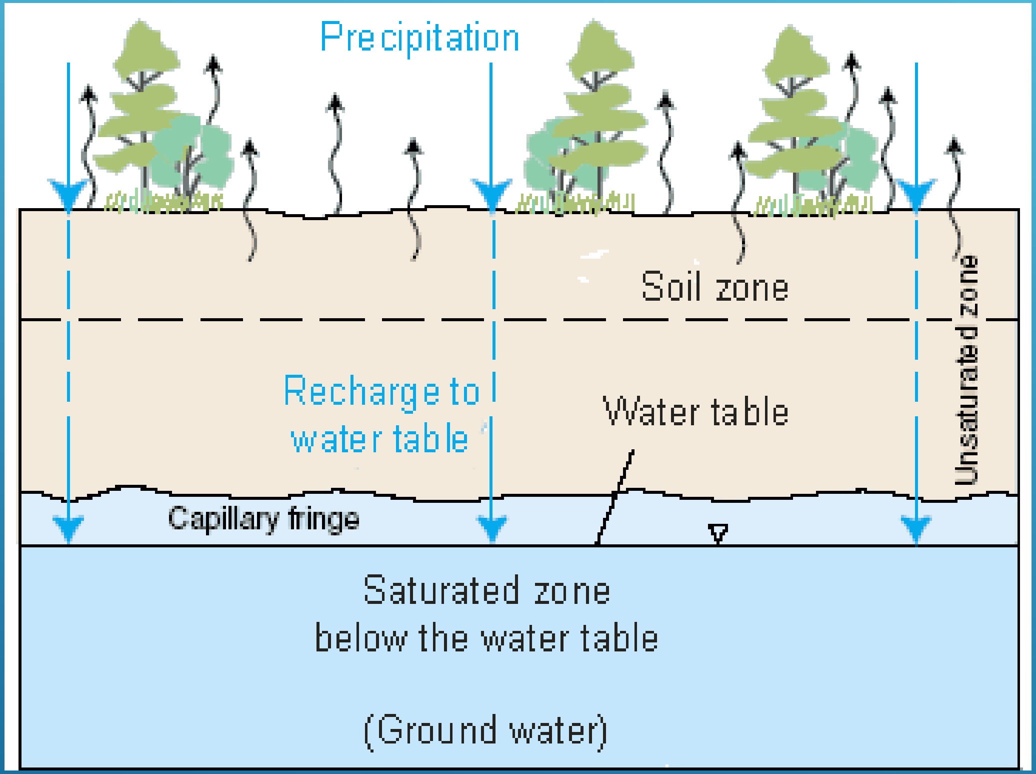
SOIL RESISTIVITY

- Soil resistivity can be obtained by several means and sources (old single-point resistivity bar, soil box analysis, Wenner Four-Pin (Megger and others) all possible);
- A resistivity profile is needed that includes pipe depth and both shallower and deeper intervals;
- Samples for lab analysis can be useful, but usually with limited depths and results;
- Later slide shows Wenner 4-pin testing profiles;
- County soil conservation maps/USDA Web Soil Survey are good sources, along with shallow geology descriptions. Geotechnical reports may include some helpful sampling and analysis.

SOIL AS THE ELECTROLYTE – WHAT'S THE MAKE-UP?



http://www.ext.colostate.edu/mg/gardennotes/213.html



http://water.usgs.gov/edu/watercyclegwstorage.html

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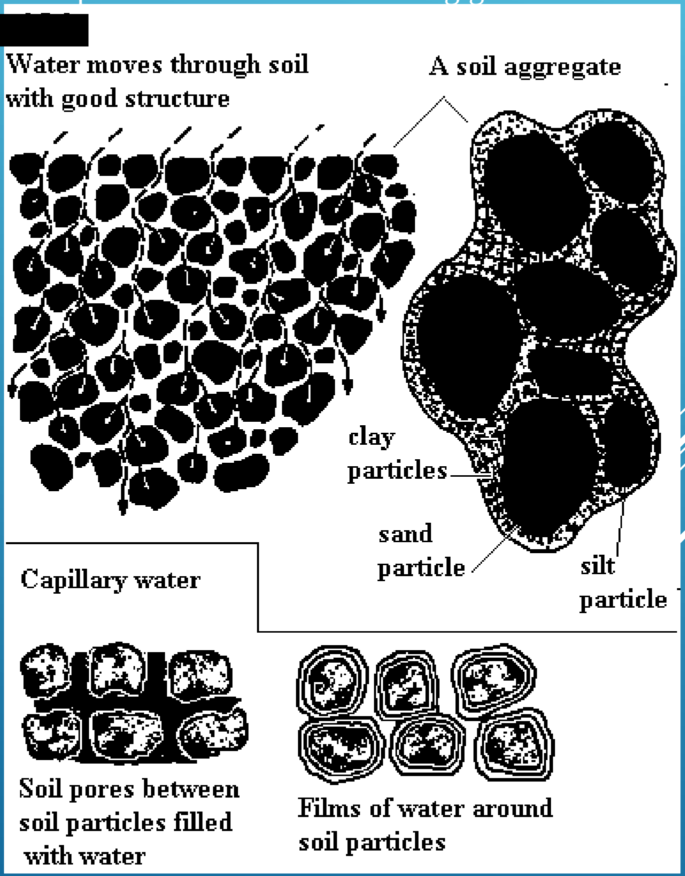
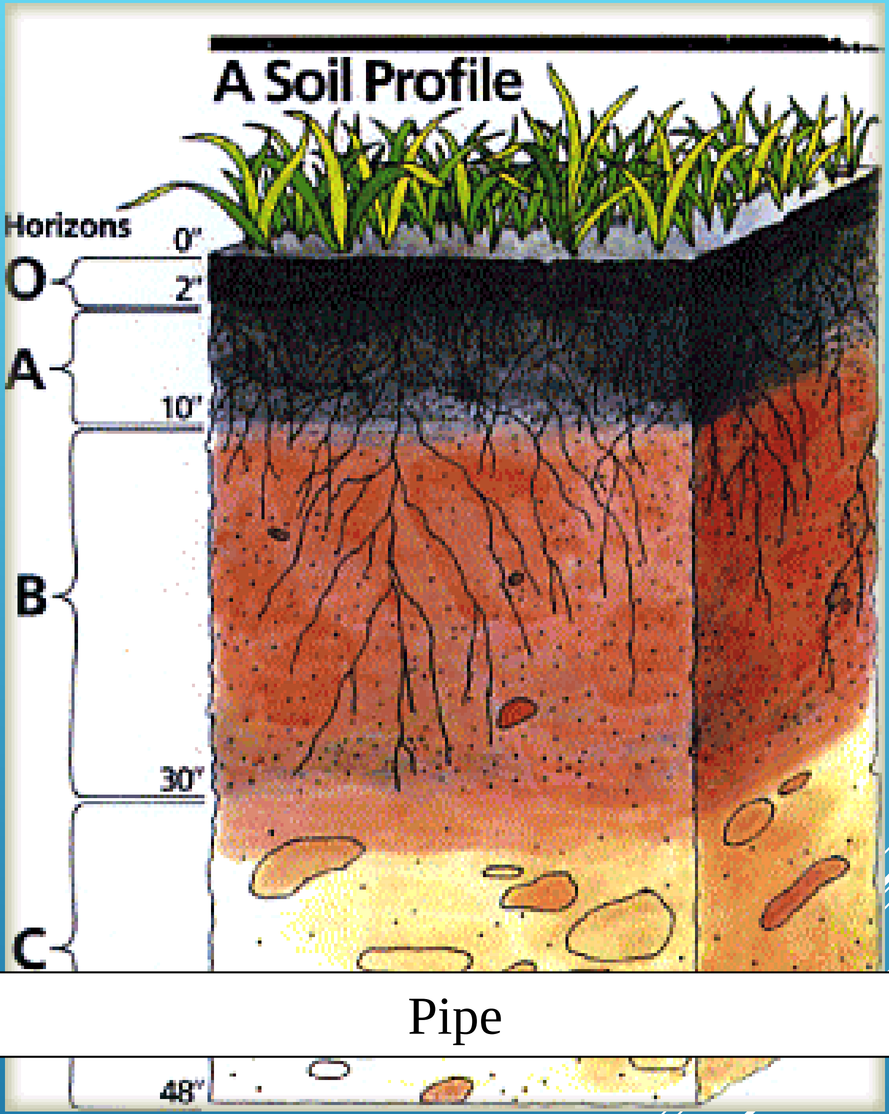


http://www.uq.edu.au/_School_Science_Lessons/Soils.html

SOIL "HORIZONS" CHANGE WITH DEPTH

- "O" horizon rich in organisms, roots, vegetative debris ("top soil" with A);
- "A" horizon rich in roots and organic material;
- "B" horizon has less roots, less air recharge, more CO_2, some methane (CH_4);
- "C" horizon more like geology below, very little organic activity, low oxygen.



Pipe

http://www.terrapsych.com/ecology.html

These horizons change with other factors, too. Irrigation? Fertilizer?

AC CURRENT DENSITY, EXAMPLE 1

LOW SOIL RESISTIVITY

AC INTERFERENCE EQUATION: $I=8(Vac) / ((\rho)(\pi)(d))$	
ρ = Soil Resistivity in Ω-cm	**350 Ω-cm**
d = diameter of holiday in cm	**1 CM**
π = Pi	**3.1415927 . . .**
V = recorded/measured AC voltage	**2.5 VAC**
I = Current Density in A/m^2	**Total: 182 A/m^2**

A dime has a diameter of 1.8 cm.
A penny has a diameter of 2.0 cm.
A nickel has a diameter of 2.2 cm.
A quarter has a diameter of 2.5 cm.

AC CURRENT DENSITY, EXAMPLE 2

HIGH SOIL RESISTIVITY

AC INTERFERENCE EQUATION: $I=8(Vac) / ((\rho)(\pi)(d))$	
ρ = Soil Resistivity in Ω-cm	**10,000 Ω-cm**
d = diameter of holiday in cm	**1 CM**
π = Pi	**3.1415927**
V = recorded/measured AC voltage	**30 VAC**
I = Current Density in A/m^2	**Total: 76 A/m^2**

If you want this spreadsheet, please contact
us, and we will send you a copy.

AC INTERACTION, WITH GEOMETRY FACTORS

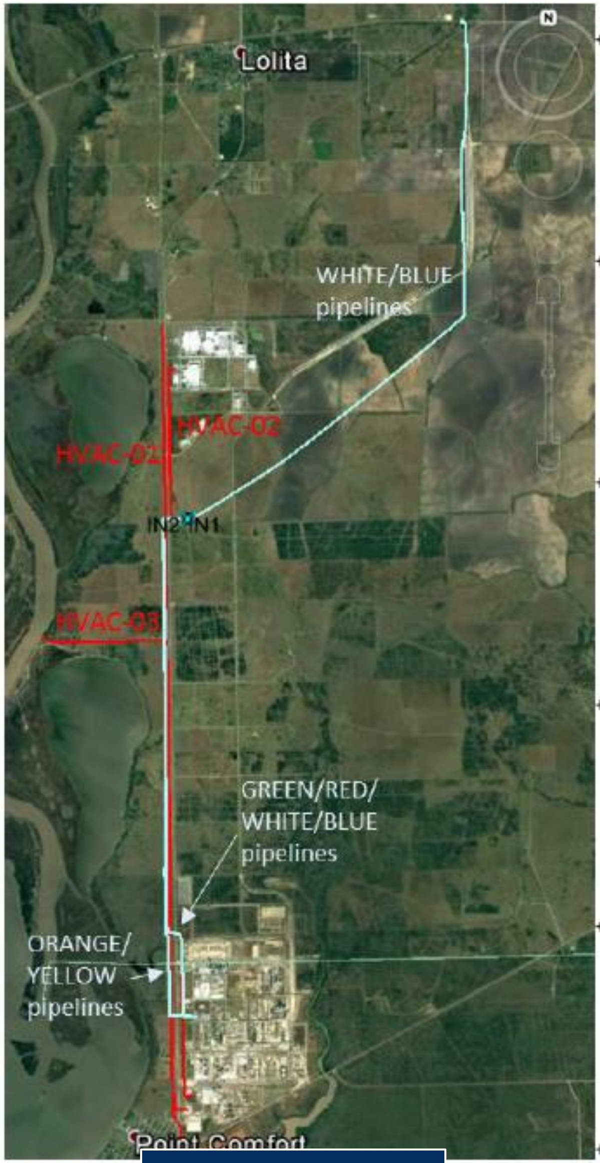


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Figure 1 - An[redacted]es in collocation with high voltage power lines

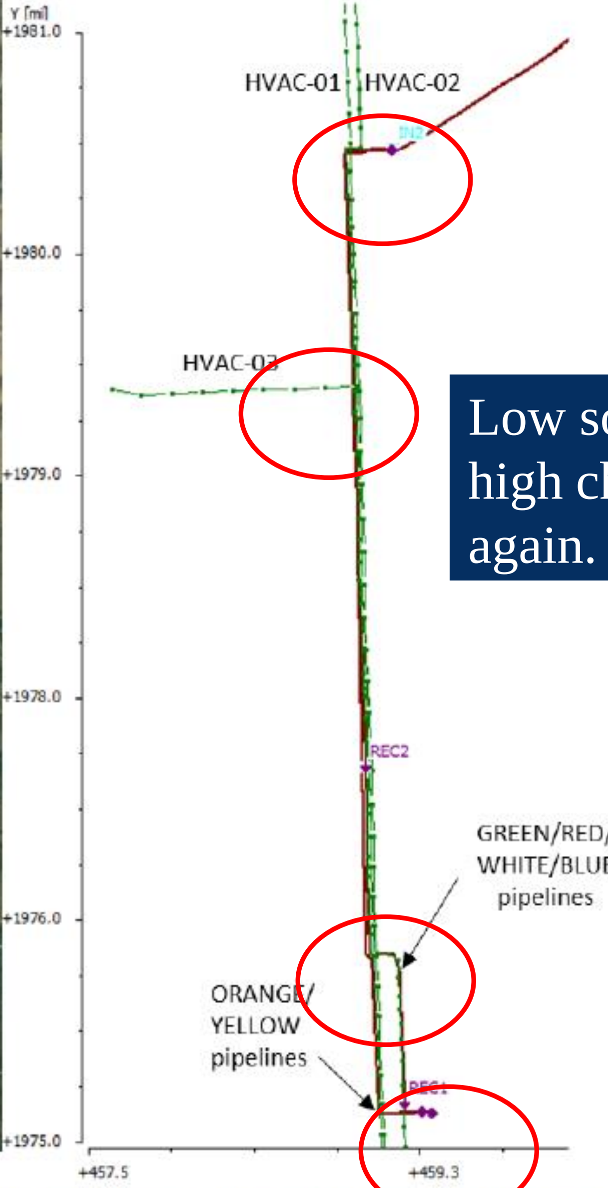
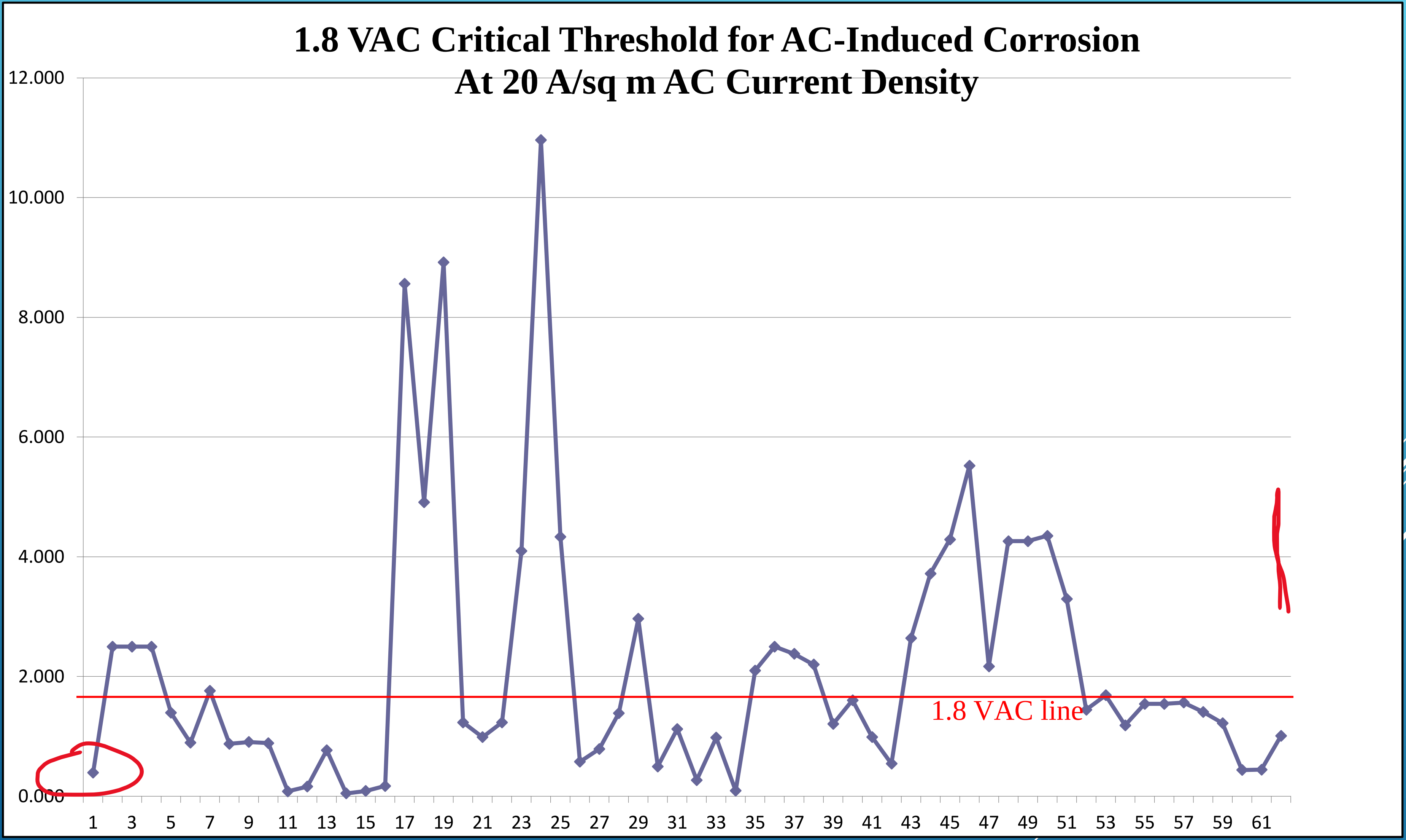


Figure 2 - Layout of the model as created in IRIS (zoom in)

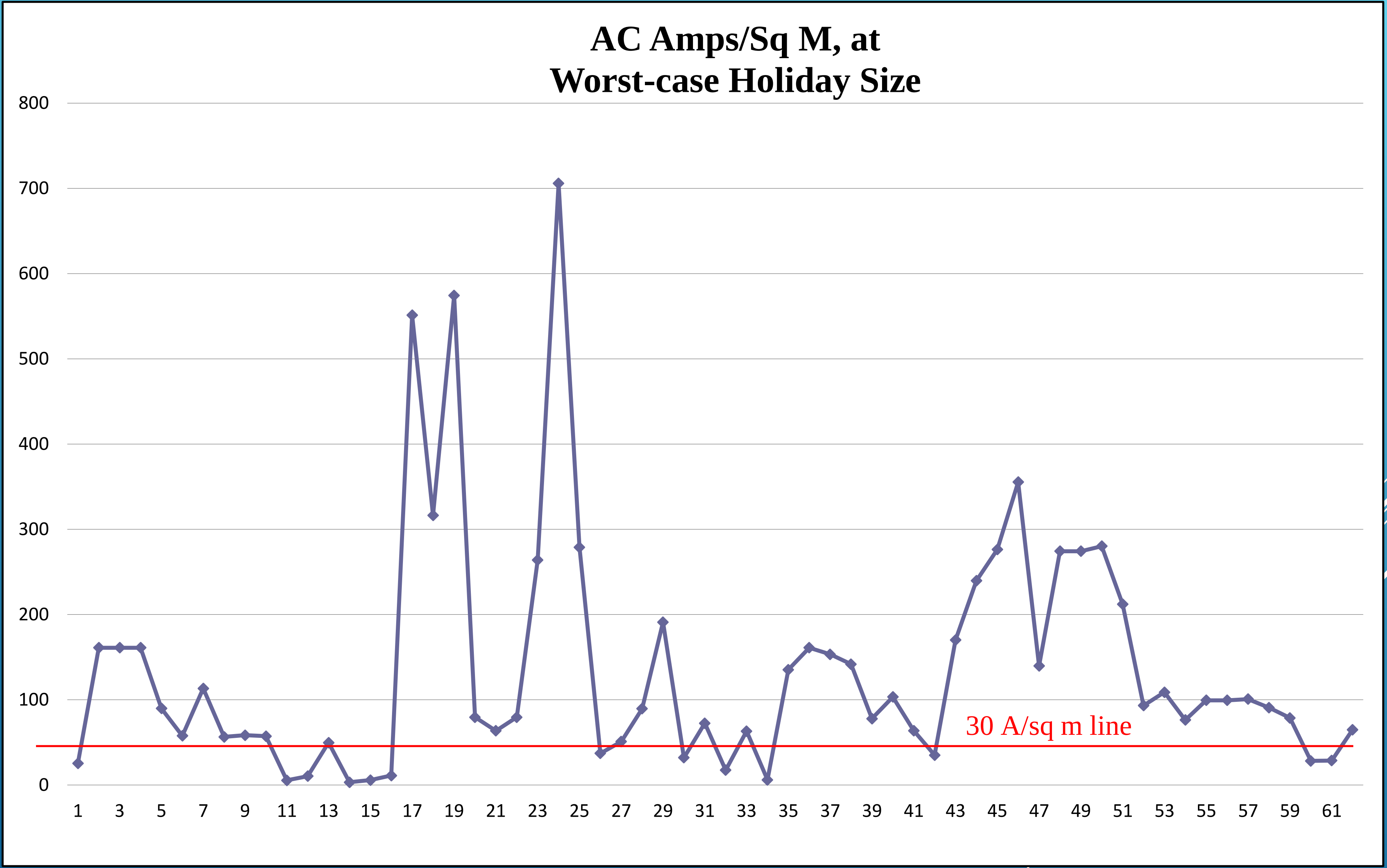
Low soil resistivity, high chlorides again. Six pipelines.

PART OF THIS ROW, WITH PIPELINES AT LEFT

AC VOLTAGE MEASUREMENTS ALONG ROW, AT AVAILABLE TEST POINTS

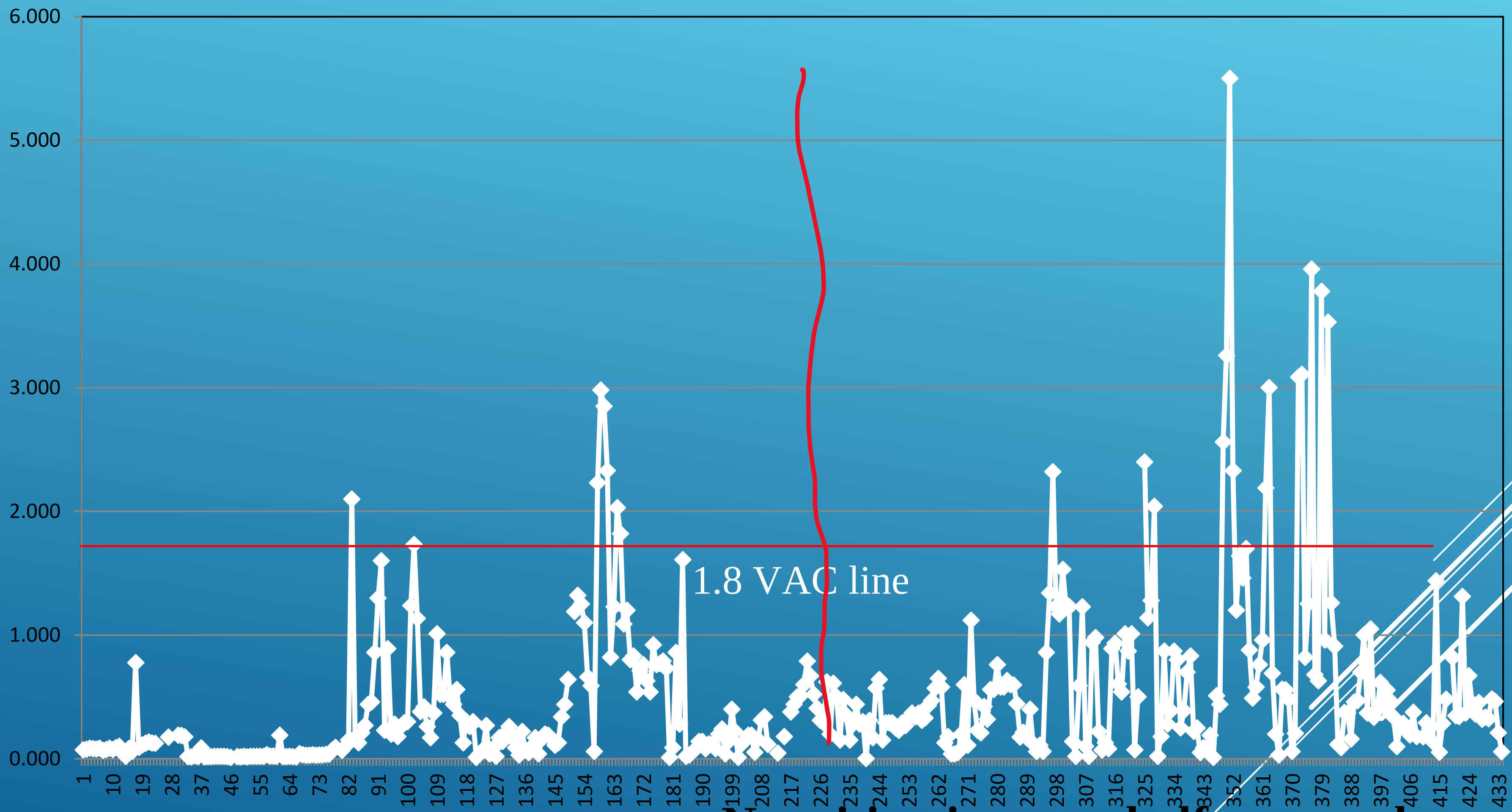


CALCULATED AC CURRENT DENSITY, BY TEST POINTS



FIELD INSTALLATIONS OF LINEAR AC DRAINS (NOTE THE AC LINE GEOMETRY CHANGE, BACKGROUND LEFT)

GRAPHED AC VOLTAGES, POST-MITIGATION (VAC DOWN 70 TO 95%)



No mitigation past halfway mark. Landowner issue.

AC SAFETY HAZARDS

- Test leads attached directly to the pipeline can have dangerous AC voltages. Test stations should be the “dead front” style, so no electrical contact is possible to the person taking readings;
- Pipeline bonds also may have high AC voltages. They must be constructed so no physical contact is made by the technician;
- **Can you think of another significant, possible shock hazard item in these areas?**

RECTIFIER NEGATIVE LEADS!

The negative lead connects to the pipeline. Will have same high AC voltage as pipe.

What if the rectifier is off? Danger still there, as these voltages come from the pipeline, not the rectifier power source.

Does an equipotential mat protect the person? Possibly not, as the mat is not connected to the pipeline, and cannot be trusted to protect the worker from pipeline AC!

Photo by Mike Ames

Put protective cover over rectifier face.
Tape any exposed leads.

HOW IS AC SAFETY MITIGATED?

- Test stations and any surface pipeline appurtenance can be measured for AC voltages, to identify risks. Accurate modeling will also disclose areas of expected safety issues;
- These locations can be mitigated with short runs of material that can permanently shunt the current to the power line ground system economically;
- Step/touch potentials must be considered in these areas. Step potential mats are often needed for surface pipe appurtenances such as block valves and risers to protect personnel;
- All Test Lead contacts in high potential power line ROW parallel systems should be dead-front style to prevent metal contact with personnel. Covers may also be used as further personnel or public safety protection.

ZINC MAT FOR LOCAL STEP/TOUCH SAFETY, BEING CONSTRUCTED (TEST STATION & DE-COUPLER)

Photo by Mike Ames

ZINC MAT FOR LOCAL STEP/TOUCH SAFETY, WORK FINISHED

Photo by Mike Ames

One issue: chain-link fence did NOT get tied to zinc matting. Still a touch risk.

DEAD-FRONT TEST STATION EXAMPLE

All connections are touch-free for technician, under TS cap.

MEASURING AT COUPON TEST STATION

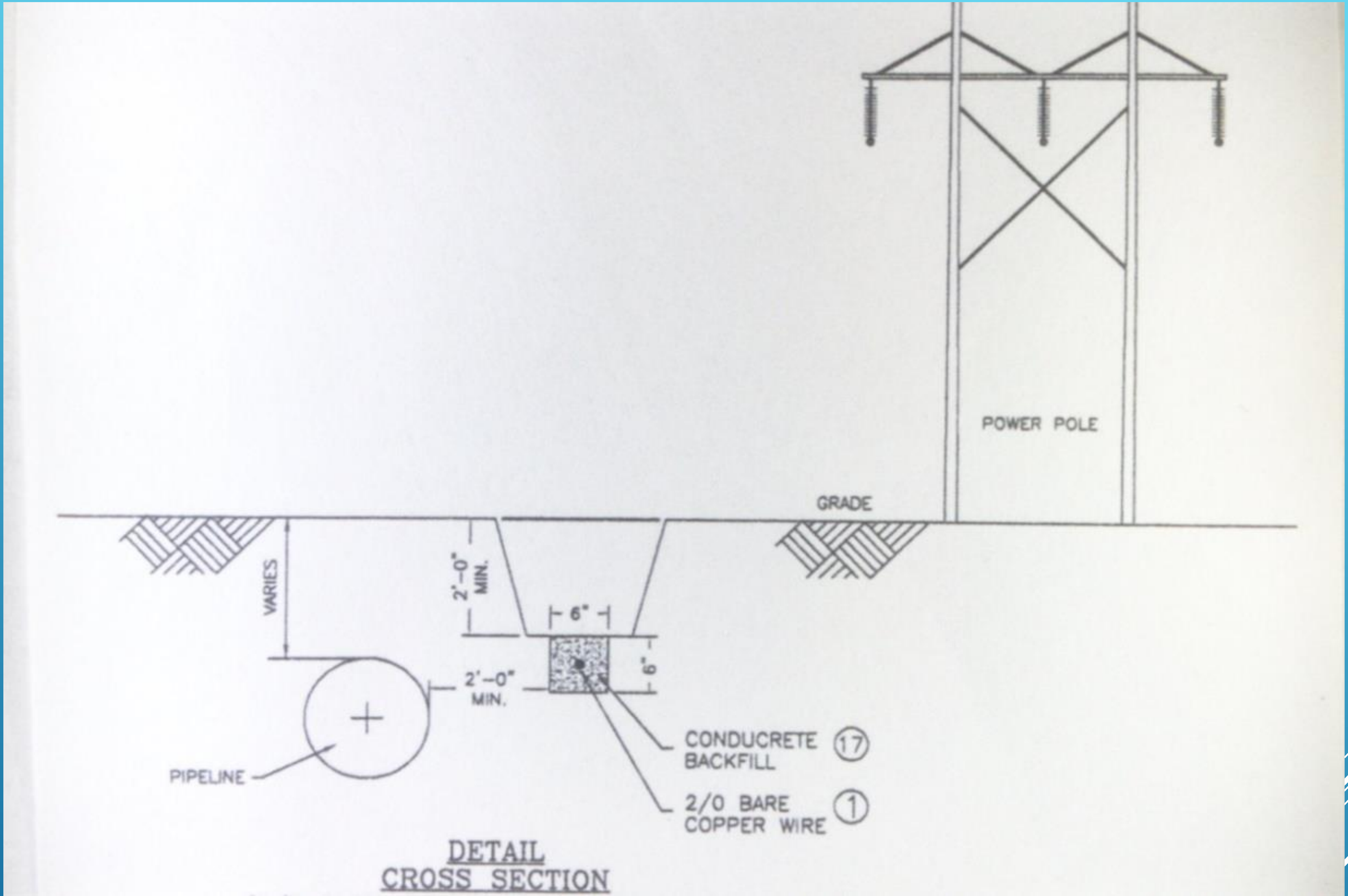
THIS TS HAS STATIONARY REFERENCE CELL & COUPONS

- TS hardware comes with stationary reference cell and two or more coupons – built into reference cell;
- Both the reference cell and internal coupons have to come into “equilibrium” with soils after installation; could be 45 to 90 days before reliable data can be taken;
- Compare readings from stationary reference cell and each coupon to a portable reference cell, two or three times over a period of weeks, to see when equilibrium is reached;
- Coupons can work in a variety of ways – one coupon might be only “native earth” contact; one might be wired to pipeline through interrupter switch.

HOW ARE AC CORROSION ISSUES MITIGATED?

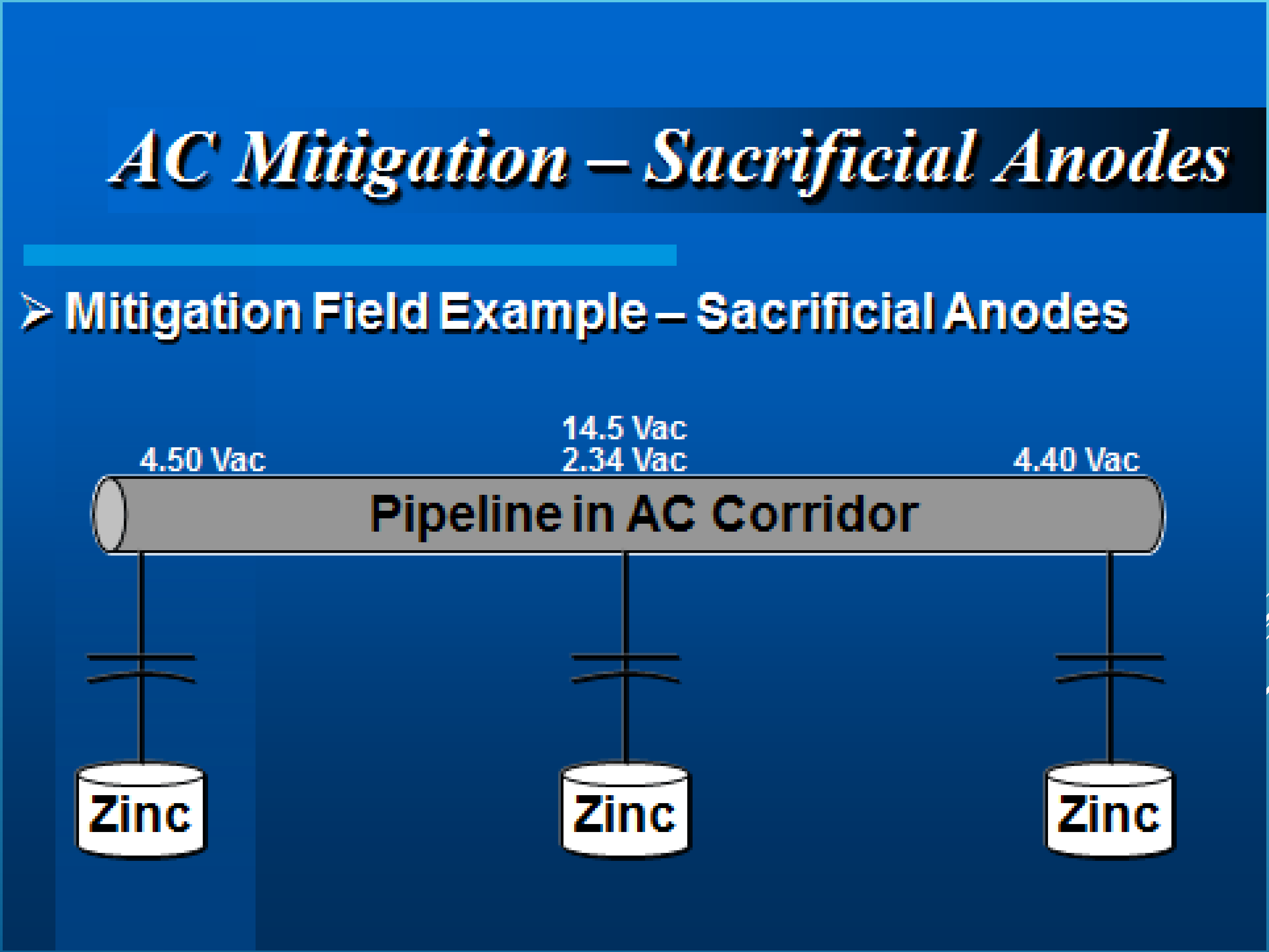
- Cookie-cutter approaches NOT recommended. Must model a broader reach of pipeline to arrive at solution. Don't take short-cuts on field evaluation or model "box;"
- Mitigation materials and layouts may be figured out by topography, resistivity and shallow geology study, plus looking for areas of divergence and convergence between the pipeline and the power lines involved;
- Highest current densities are often seen at major divergence points and near electric substations. Perform excellent field survey work, and combine it with appropriate modeling.
- Any line with discovered AC corrosion wall losses should have field study, formal modeling done, and an engineered, complete mitigation system installed.
- **Follow-up monitoring also needed.**

TYPICAL AC MITIGATION APPROACH – SINGLE LINEAR INSTALLATION



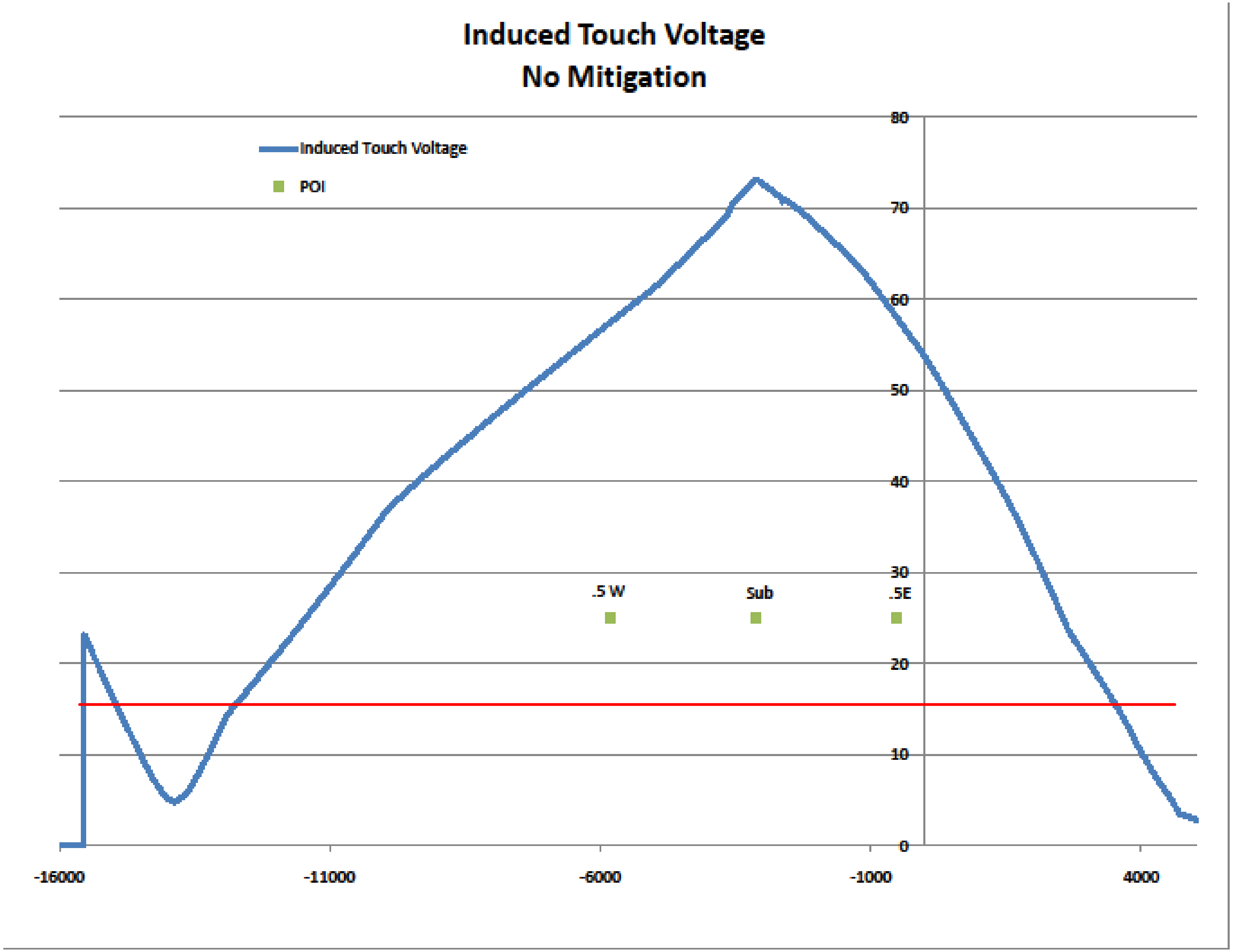
Long trench, bare copper wire encased in conductive concrete, which lowers resistance of the system, protects copper wire from corrosion, and lowers AC impedance of wire for faster dissipation of fault currents. Zinc wire or ribbon possible, but should have a high-quality surrounding backfill.

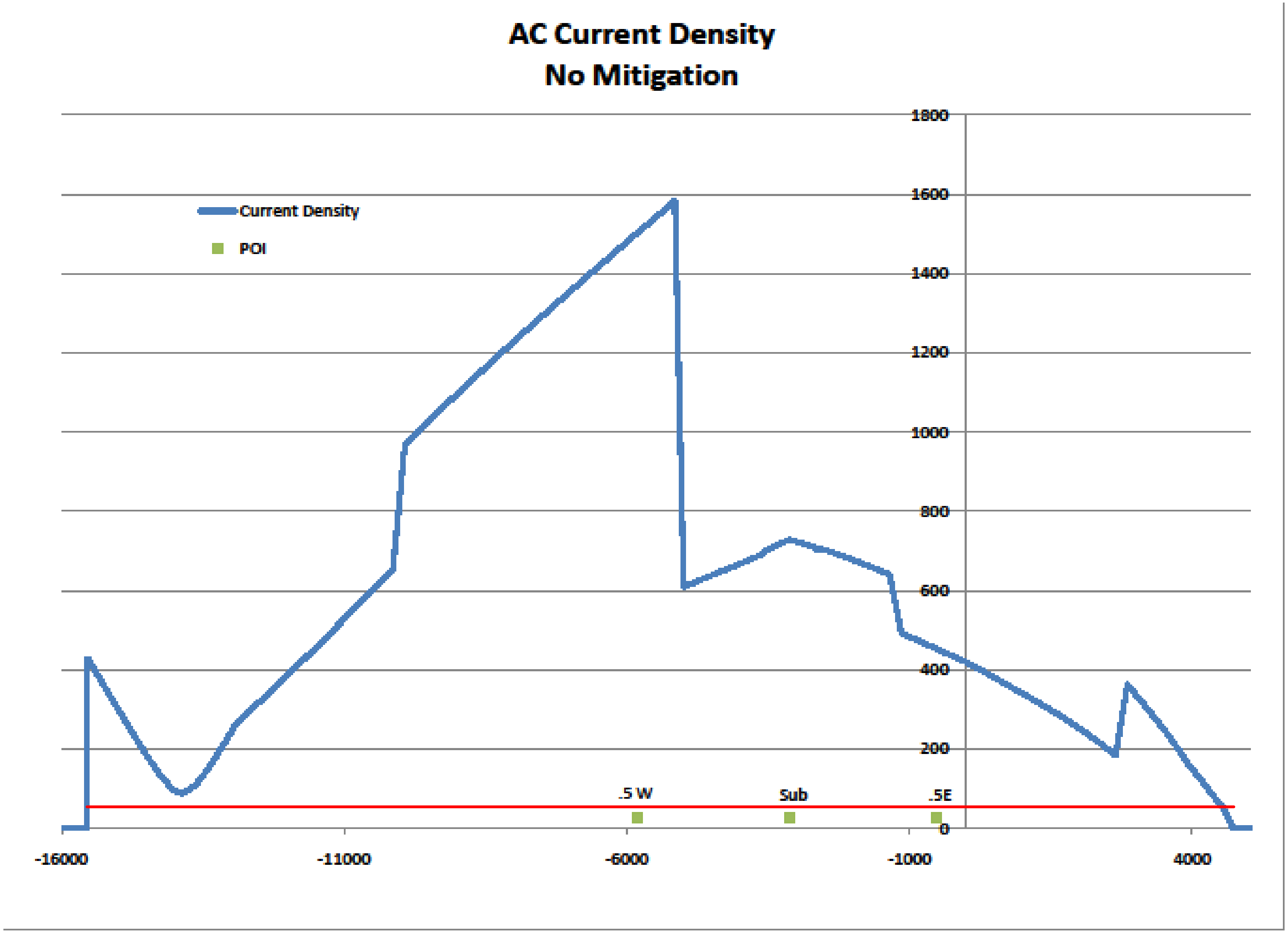
ARE SIMPLE FIXES ENOUGH?



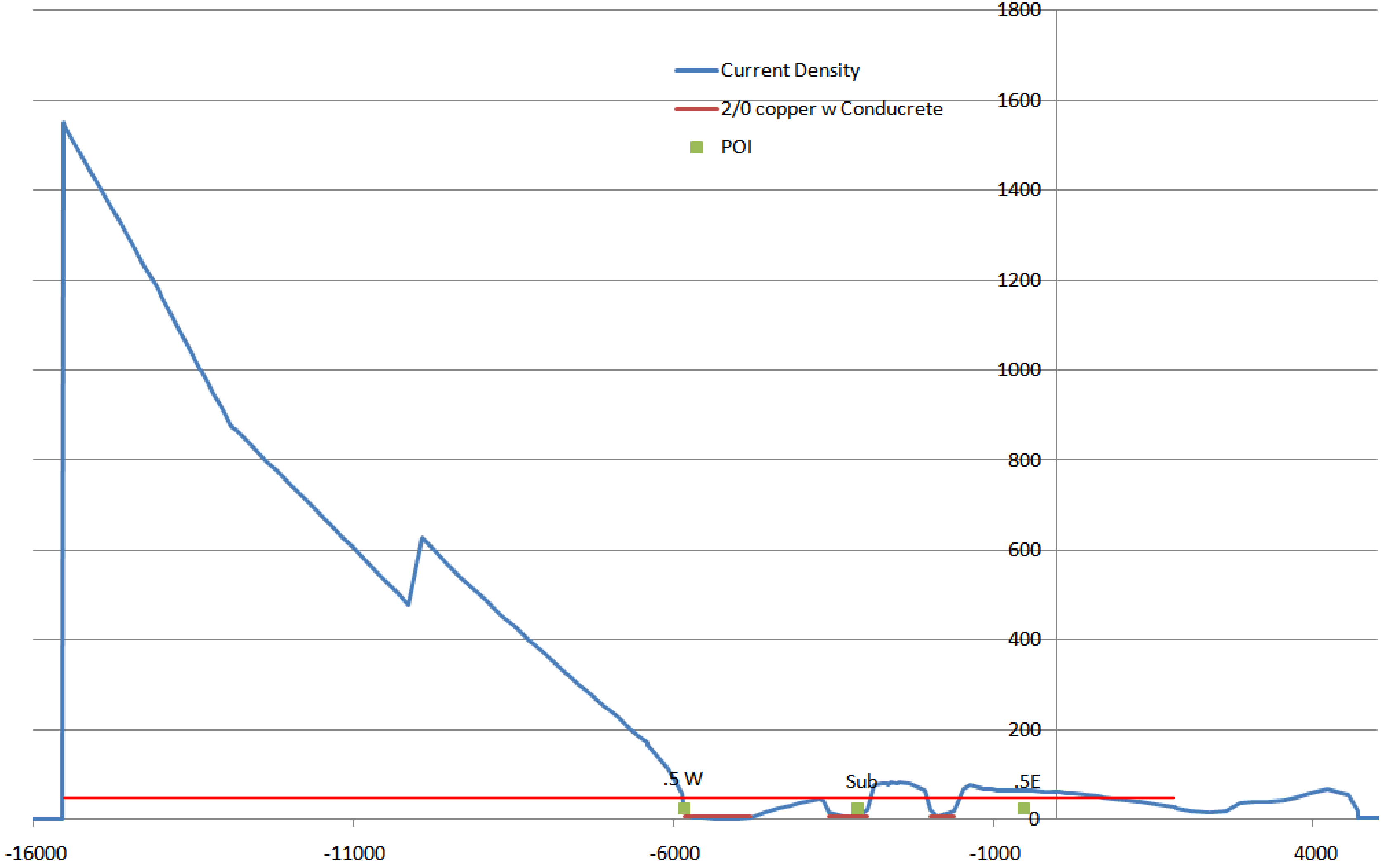
AC Mitigation – Sacrificial Anodes

- **Mitigation Field Example – Sacrificial Anodes**


Induced Touch Voltage
No Mitigation
Induced Touch Voltage
🟩 POI
.5 W
Sub
.5E
80
70
60
50
40
30
20
10
0
-16000
-11000
-6000
-1000
4000


AC Current Density
No Mitigation
Current Density
POI
1800
1600
1400
1200
1000
800
600
400
200
0
.5 W
Sub
.5E
-16000
-11000
-6000
-1000
4000

AC Current Density Mitigation



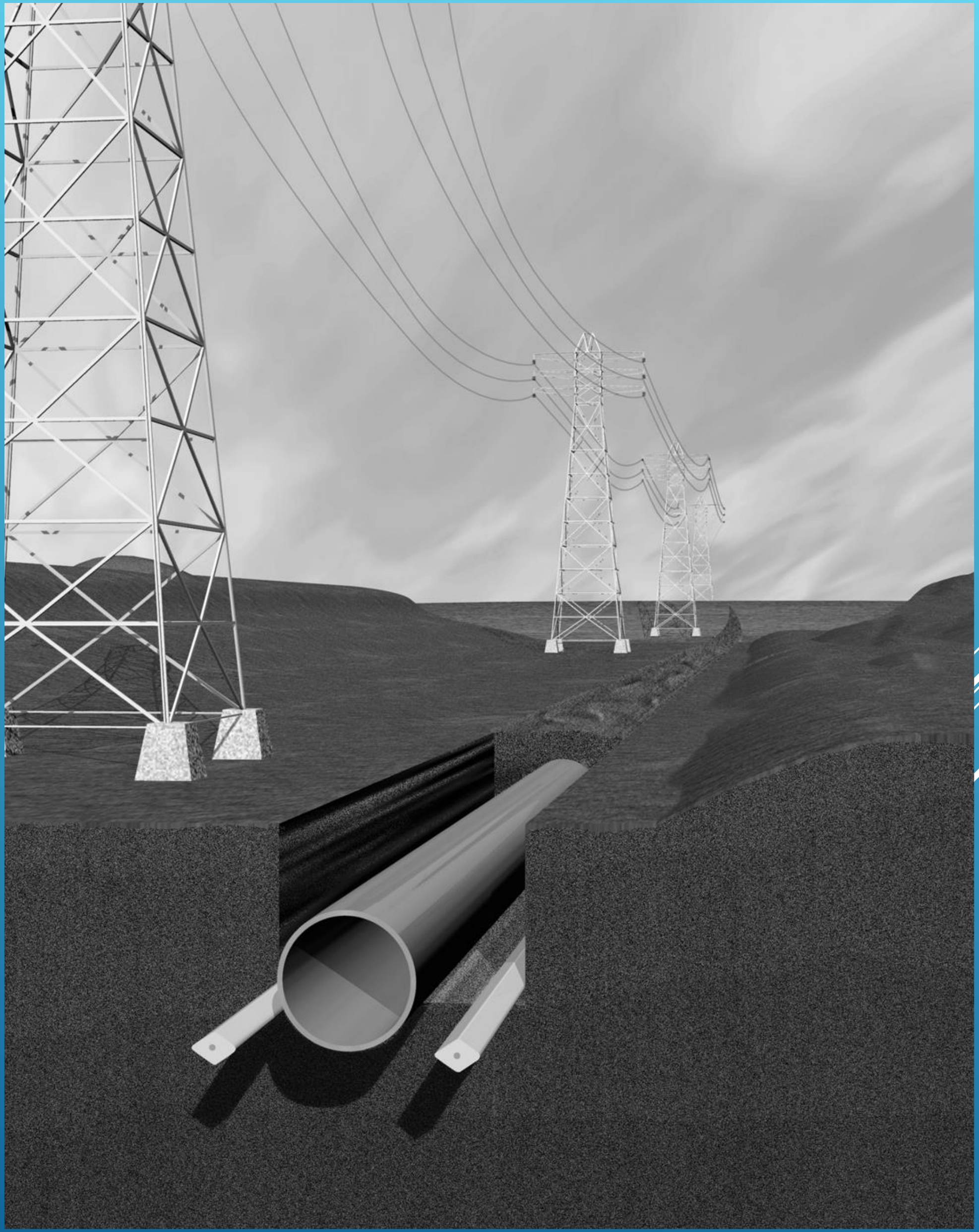
GROUNDING MATERIALS AVAILABLE

- Zinc Ribbon or Wire
- Zinc over Steel Wire
- Stranded Copper Wire
- Combination, Steel over Copper Wire
- Steel Wire

Common Backfills

  - Native Soil
  - Coke breeze w/inhibitor
  - Bentonite
  - Conductive Concretes

- Zinc may passivate when pH goes alkaline (can be just from adding CP to it!)



ISSUES WITH GROUNDING MATERIALS

Zinc systems may suffer major ill effects:

1) passivation by alkaline soil conditions (or impressed-current CP applied, with higher pH);

2) corrosion on zinc media and at jointing areas (if zinc direct-coupled to steel, it is anode);

3) In areas of high sulfur content in the soil (agricultural fertilizers, naturally occurring gypsum, etc.), a surface coating of Zinc Sulfate forms, with resistivity of 6,000,000 ohm-cm. NO current flow to ground;

Directly connecting zinc to pipeline can increase the burden on associated CP systems.

FIELD INSTALLATIONS OF LINEAR AC DRAINS

Photo by Mike Ames

RIPPER INSTALLATION

Photo by Mike Ames

POINT DRAINS (LIKE DEEP ANODE BEDS)

Photo by Mike Ames

POINT DRAIN INSTALLATION

This job was on old coal-tar enamel pipeline! Houston, TX area.

LONG LINEAR CABLES FOR MITIGATION

MITIGATION WITH LINEAR GROUNDING & MATS

138-kV Lines


Photos by Sam Williams

Zinc Ribbon Anodes used as linear grounding “wire,” as soils were acidic. Zinc is not always good material choice.

MITIGATION WITH LINEAR GROUNDING

De-Coupler Device

Zinc Ribbon Connected Back to De-Coupler, and to Pipeline Leads

Photos by Sam Williams

INDUSTRIAL CORRIDOR AC PROJECT

Grounding Mat Work

Photos by Sam Williams

DCD Used as “Spark Gap” (or over-voltage protection)

BONDING TO PIPES FOR MITIGATION CIRCUIT

Anybody here like “Yellow Jacket” coating?!

MORE MITIGATION INSTALLATION EXAMPLES

Dead-Front Test Station On Pipe Outside Pig Receiver Pen

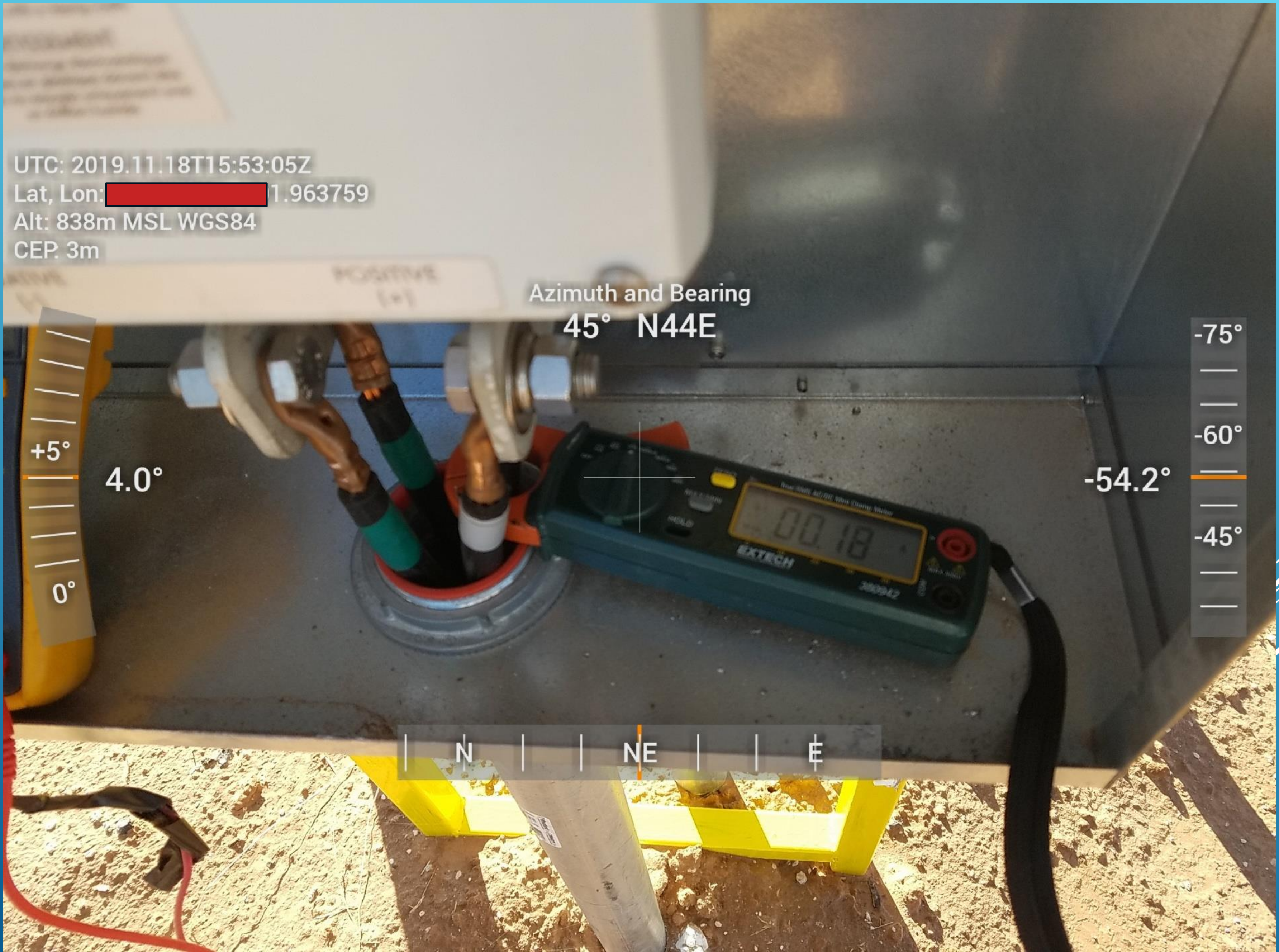
PCR Device Mounted in Box

Ground mats going in at left

Photos by Sam Williams

MEASURING VOLTS AC AT A PCR

MEASURING AMPS AC AT A PCR



MEASURING DCV AT COUPON TEST STATION

DATA TO SHOW MITIGATION WORKS!

	AC Volts	AC Volts	AC Current Flow
	(PCRs Off)	(PCRs On)	(PCRs On)
South End PCR	8.5	1.65	1.8 amps AC
TS (rebuilt) at 3500/Plain Xing	10.8	1.41	NA
East End PCR	10.2	1.13	1.7 amps AC

As of the measurements made and shown above, this AC mitigation system was reducing the AC “power load” on the pipeline by 82 to 89 percent.

SHOULD WE DO MORE DATA-LOGGING?!

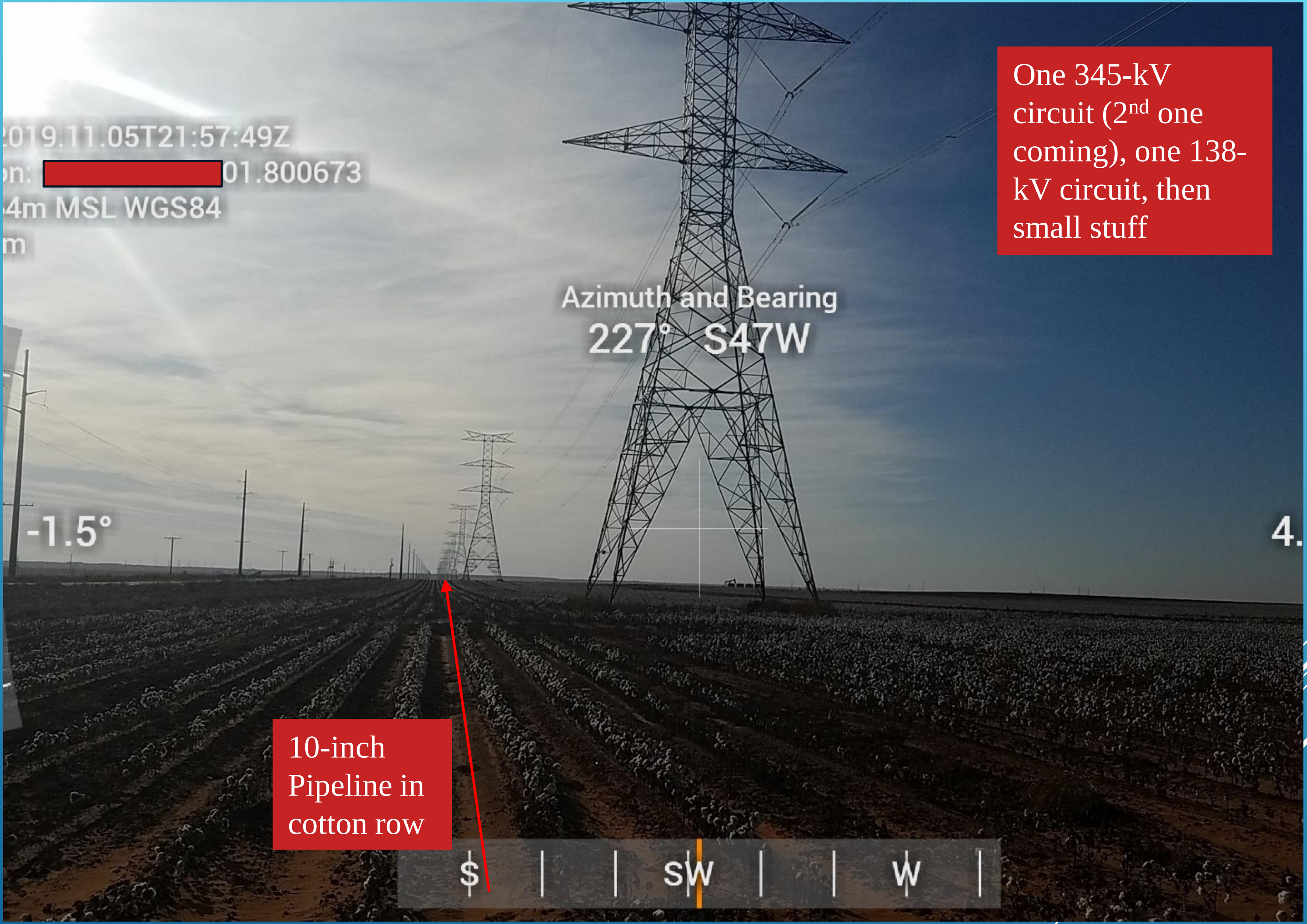
WOULD YOUR AC MITIGATION SYSTEM SURVIVE? HOW ABOUT PIPELINE?

Photo by Mike Ames

TWO CASE STUDIES

1. Influence of local soils, geology, geometry, and even shallow, salty ground water in AC power induction onto well-coated steel pipeline;
2. Medium-Voltage AC (MVAC) Power Lines Causing Pipeline Interactions, **Due to Complicated MVAC Geometries & Unfavorable Geology**

AC INTERACTION EXAMPLE #1



One 345-kV circuit (2^{nd} one coming), one 138-kV circuit, then small stuff

10-inch Pipeline in cotton row

345-kV lines, 138-kV lines and a new 10-inch crude oil pipeline interacting – but changes in geography, soils/moisture, geology and geochemistry causing **different expressions of the trouble.**

CASE #1, INDUCED AC MEASURED, NOV-DEC 2019

Data Logger Locations

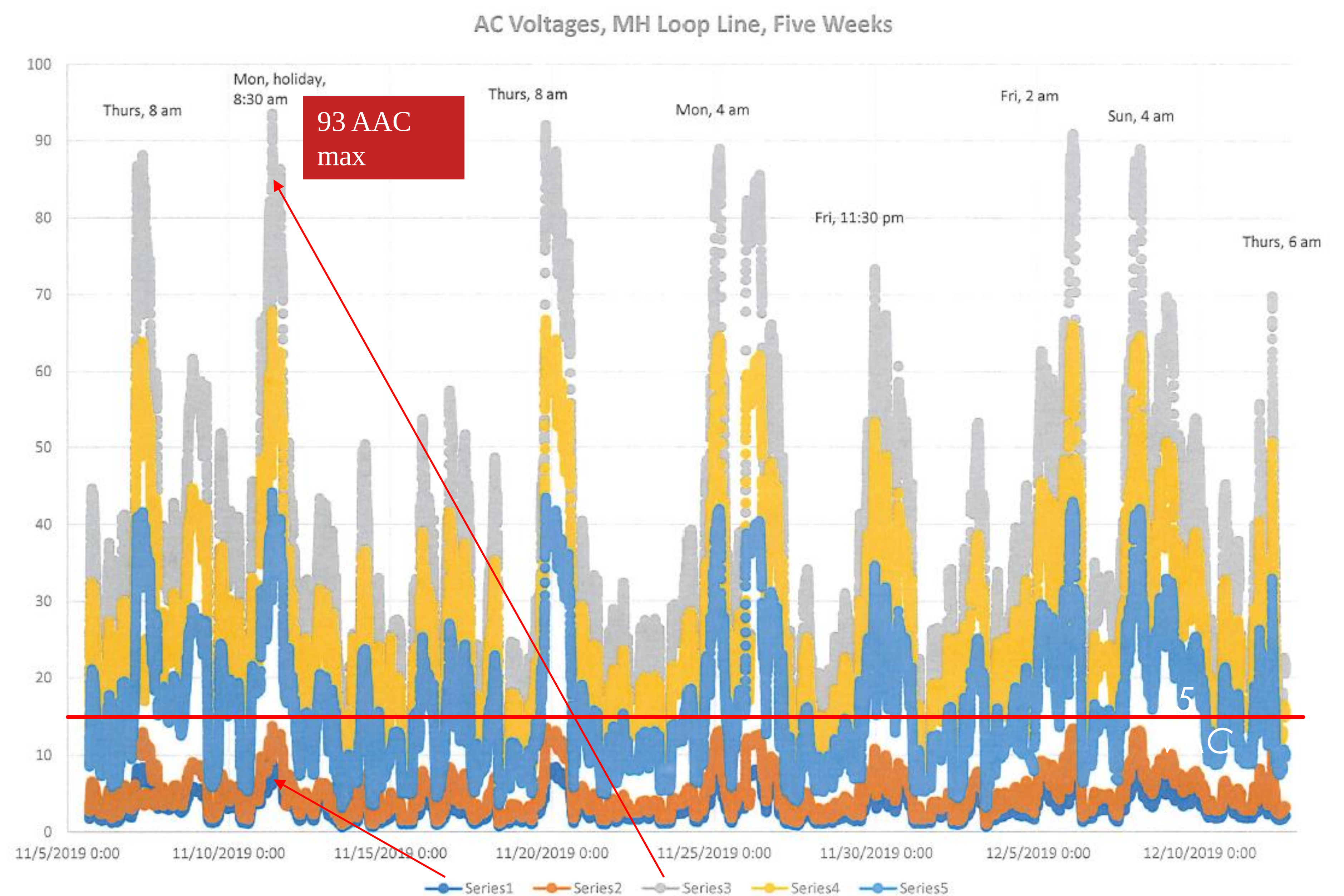
Target Pipeline, white dash

DL 5, Xing w/ME 12-in, west DL 4, 138kV to S DL 3, valve pen SH 137, 345kv to S DL 2, valve pen DL 1, creek

RED – 345,000-V Lines, Two Circuits Yellow – 138,000-V Lines

Pipeline length shown of 12 miles, +/- (19.5 km)

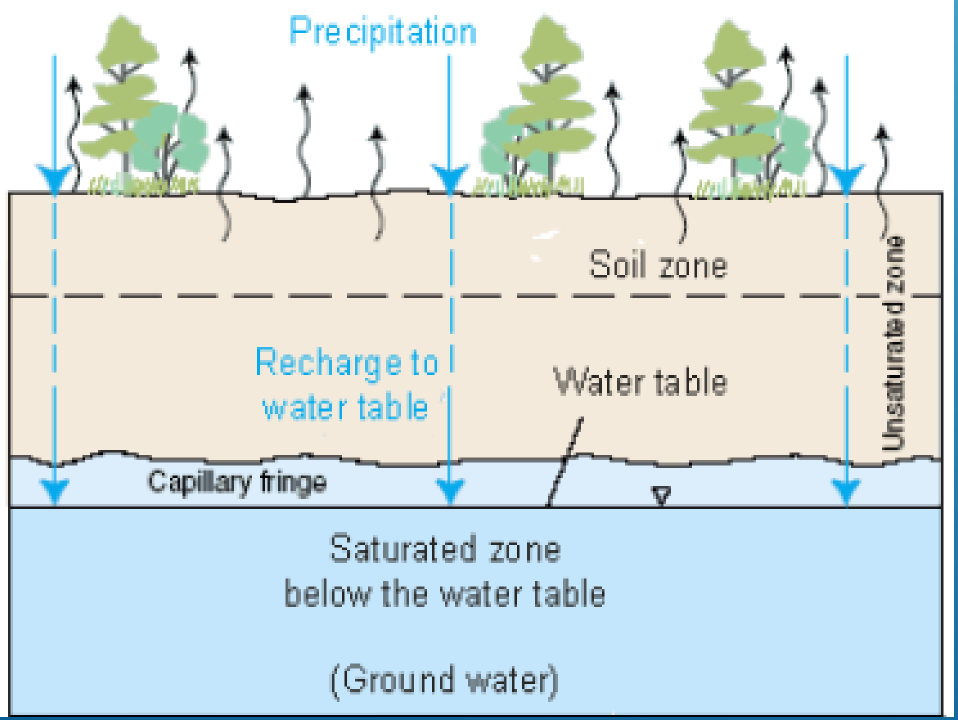
INDUCED AC LINKAGES, CASE #1, WEST TEXAS



93 AAC max

CASE #1 CHARACTERISTICS

This single pipeline shows wide variability in geometry of high-voltage AC (HVAC) power systems versus pipeline, topographic highs and lows, along with shallow geology, soil composition, geochemistry and soil resistivity changes in top 20 feet (6 meters).



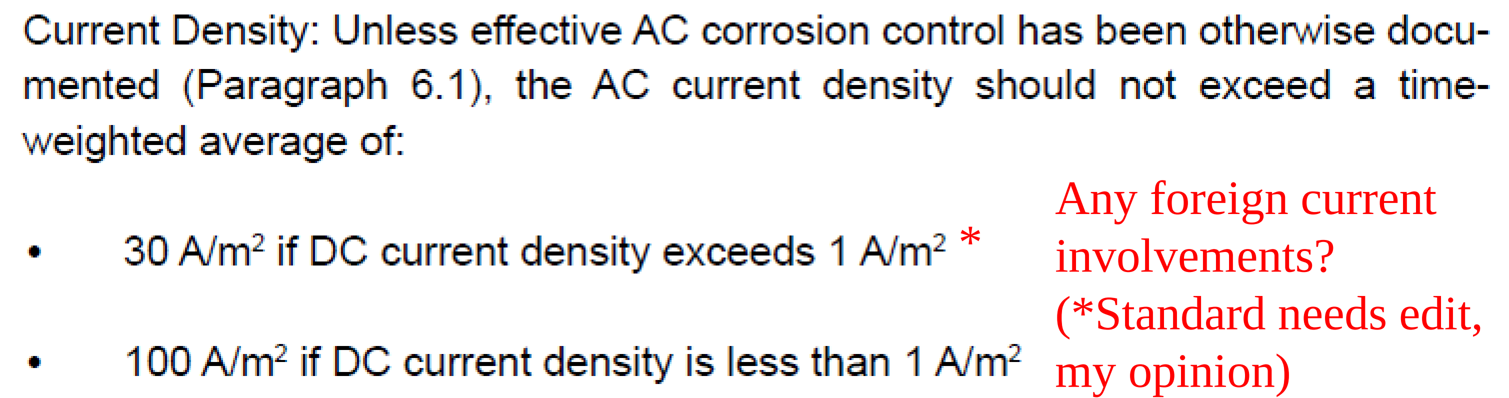
Low topography, more moisture content. In drainages, resistivity often lower, AC-induced corrosion risk higher.
Higher-resistivity soils (dry, higher ground?) often cause larger induced AC voltages, locally.
Soil/shallow geology properties need study locally and across area.

AC-INDUCED CORROSION THEORY & CURRENT DENSITY

From NACE International Publication 35110-2010:

Iac = (8 * Vac) / (rho * π *d) , where

- Iac is AC Current Density, Amps per square meter (A/sq m) at holiday;
- Vac is measured AC Voltage value (or a weighted average, discussed later);
- Rho (ρ) is soil resistivity in **ohm-meters (NOT ohm-cm);**
- D is **worst-case holiday diameter**, of 0.0113 meter (slightly more than one centimeter). From 21424-2018, 6.2:



Current Density: Unless effective AC corrosion control has been otherwise documented (Paragraph 6.1), the AC current density should not exceed a time-weighted average of:

- 30 A/m^2 if DC current density exceeds 1 A/m^2 *
- 100 A/m^2 if DC current density is less than 1 A/m^2

Any foreign current involvements?
(*Standard needs edit, my opinion)

FOR DATA LOGGER #3, CURRENT DENSITY & HIGHEST AC VOLTAGES:

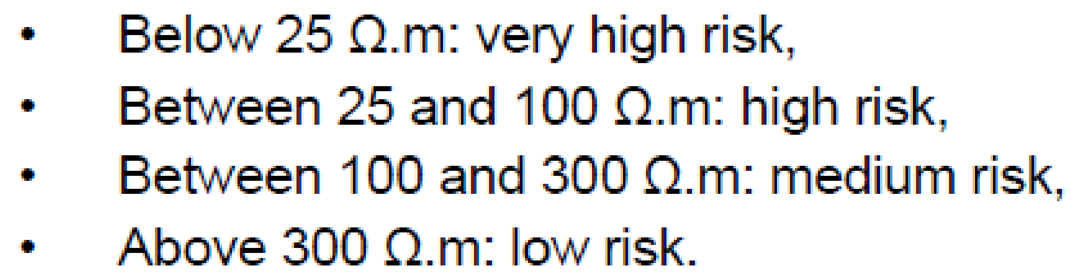
Iac = (8 * Vac)/(rho * π * d)

- **Vac** high measured was **93 VAC. BAD SAFETY RISK;**
- Resistivity was in range of 9,000 ohm-cm, or 90 ohm-m, in high-risk range;
- **Iac(MAX) = 233 A/sq m;**
- Take a "weighted average" of 63.5 VAC – even then,

  Iac = 166 A/sq m – 5.5X over 30 A/sq m threshold;
- Power use on 345-kV line varies widely with interconnect needs between El Paso and DFW markets;
- Mitigation needed for both safety and corrosion by AC, over more than 12 miles of pipe studied to date. Will include safety fixes (dead-face-front test head hardware, gradient control mats at valve pens, pig traps, etc.).

FOR DL #1 CURRENT DENSITY, SULFUR SPRING DRAW

- Vac high measured was 11 VAC. The pipeline owner first asked, “No issue here, right?”
- Resistivity was in range of **200 ohm-cm**, or **TWO ohm-m**, due to naturally salty soils, elevated moisture. From 21424-2018, Section 5.4.4, risks for AC-induced corrosion:



- Below 25 Ω.m: very high risk,
- Between 25 and 100 Ω.m: high risk,
- Between 100 and 300 Ω.m: medium risk,
- Above 300 Ω.m: low risk.

- This local area is not quite a safety risk, but has **HUGE AC-INDUCED CORROSION RISK;**
- Mitigation needed LOCALLY. Will include specialty grounding with DC current blocking (PCR’s or De-Couplers).

FOR ALL FIVE DATA LOGGERS, CASE #1:

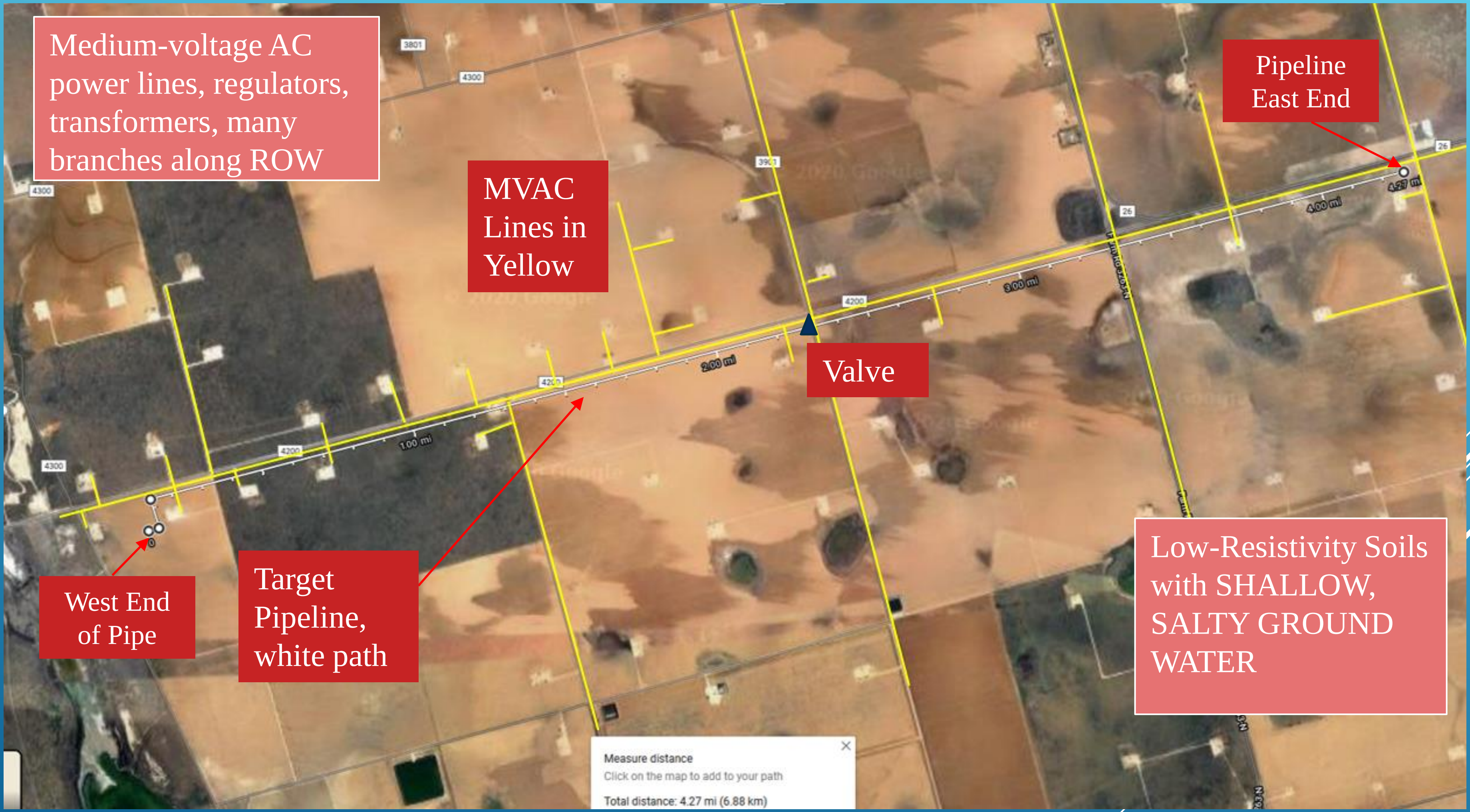
Iac = (8 * Vac)/(rho * π * d), at worst-case holiday

	DL #	High VAC	Rho, ohm-m	High Iac	Iac/30 Ratio	"Weighted Ave" VAC	"Weighted Ave" Iac	Weighted Ave Iac/30 Ratio
Location, East to West:								
E of Drainage w/Salt	1	11	2	1,239	41.3	8	901	30.0
Valve Pen N of FM 846	2	20	56	80	2.7	10.7	43	1.4
AC PI at 137 and FM 846	3	93	90	233	7.8	63.5	159	5.3
1.0 mi E of 829, CR 3101	4	72	68.5	237	7.9	51.2	168	5.6
ME-12 Xing W of 829	5	45	90	113	3.8	31.9	80	2.7

BIG SAFETY ISSUES, FOUR OF FIVE DATA LOGGERS!

Substantial risks of AC-induced corrosion, ALL Five.

SECOND CASE, UGLY SHALLOW GEOLOGY CONDITIONS PLUS MVAC, WITH COMPLEX GEOMETRIES. STRONG AC INDUCTION TO PIPELINE.



Medium-voltage AC power lines, regulators, transformers, many branches along ROW

MVAC Lines in Yellow

Pipeline East End

Valve

West End of Pipe

Target Pipeline, white path

Low-Resistivity Soils with SHALLOW, SALTY GROUND WATER

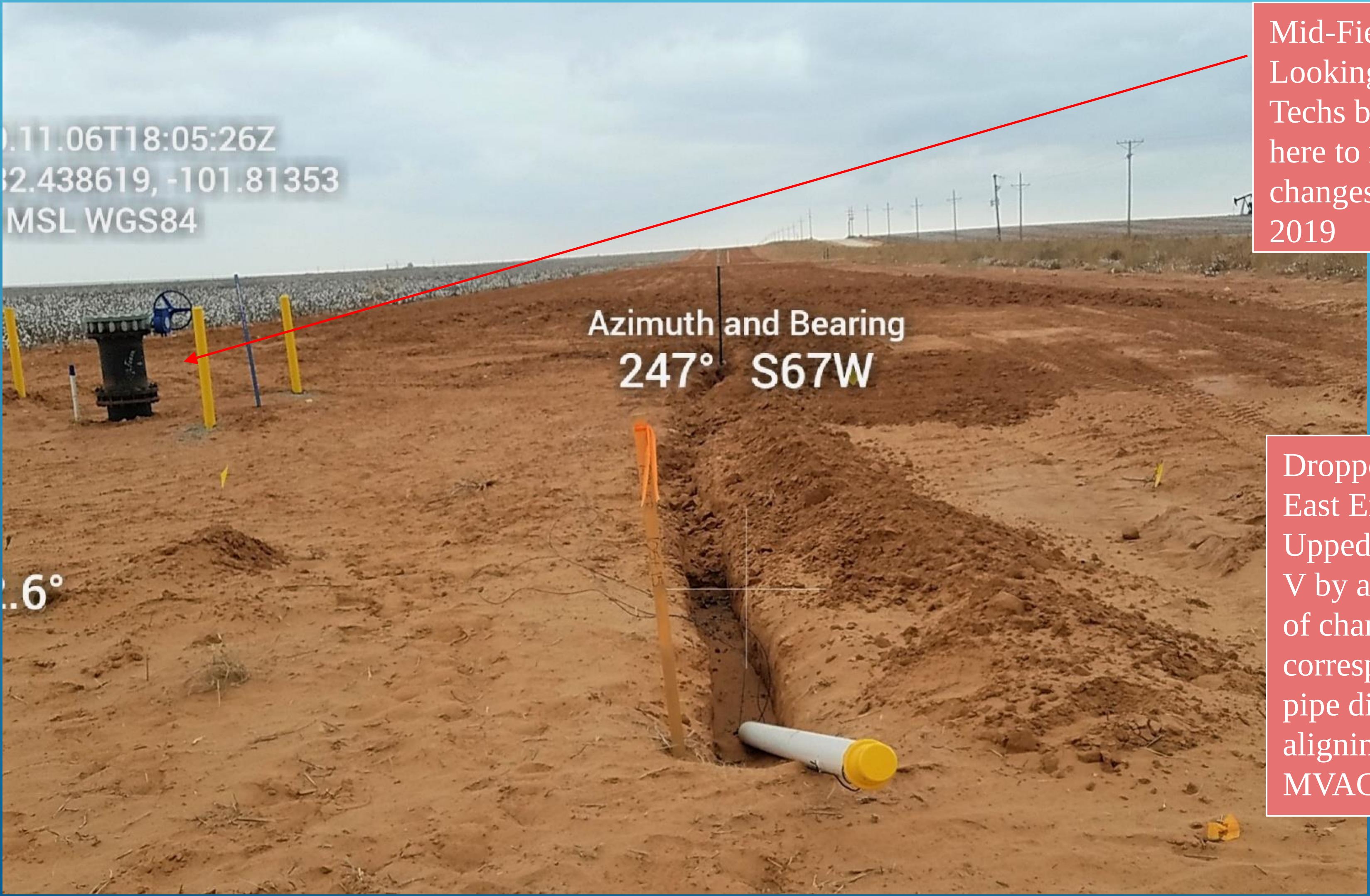
Measure distance

Click on the map to add to your path

Total distance: 4.27 mi (6.88 km)

Six-inch Pipeline Length Of 4.27 miles, +/- (6.9 km)

PIPELINE AT MID-FIELD VALVE – 2.5 MILES (4.0 KM) FROM WEST END, 1.8 MILES (2.9 KM) FROM EAST END

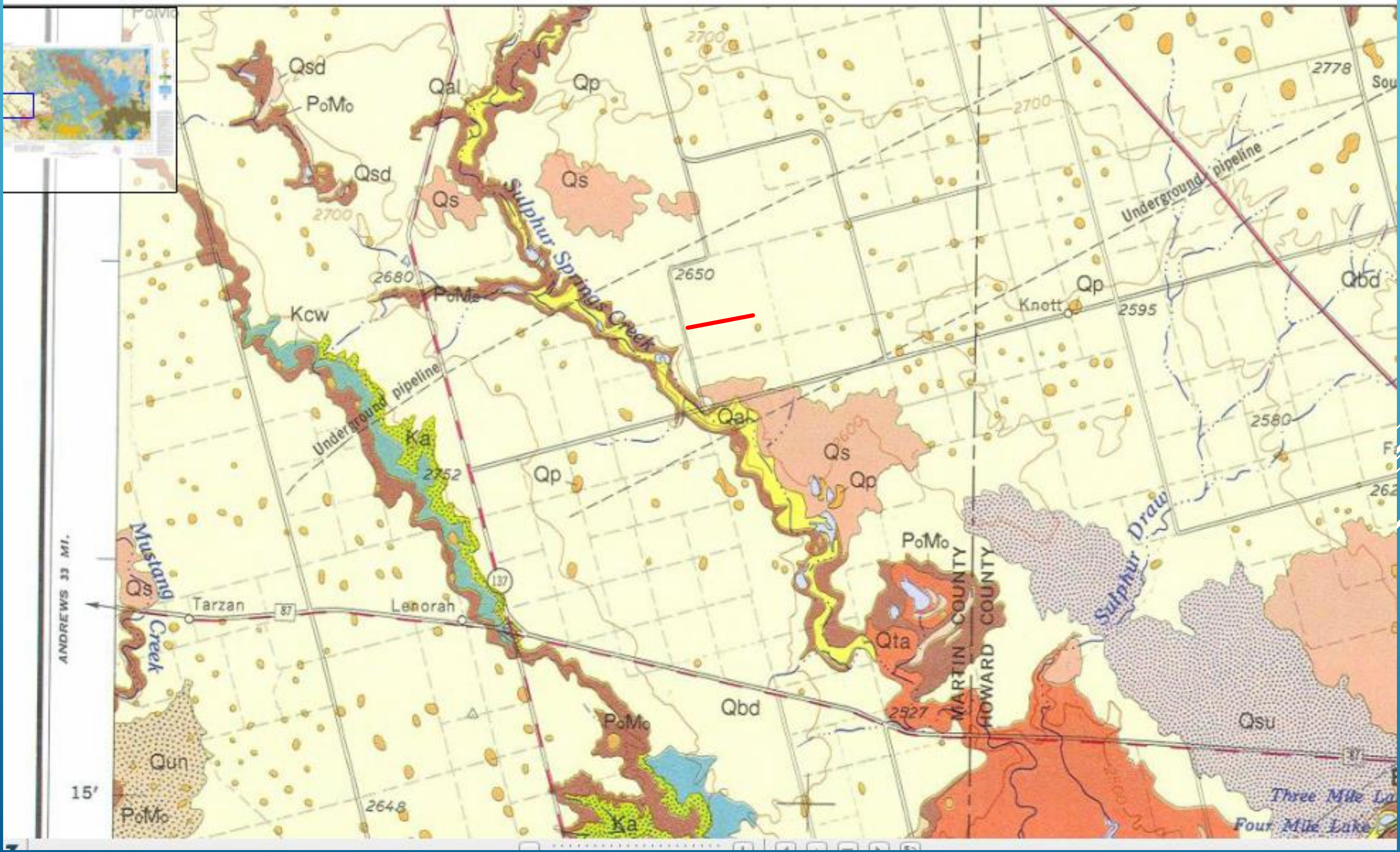


Mid-Field Valve Looking West; PL Techs broke a flange here to measure AC V changes, summer 2019

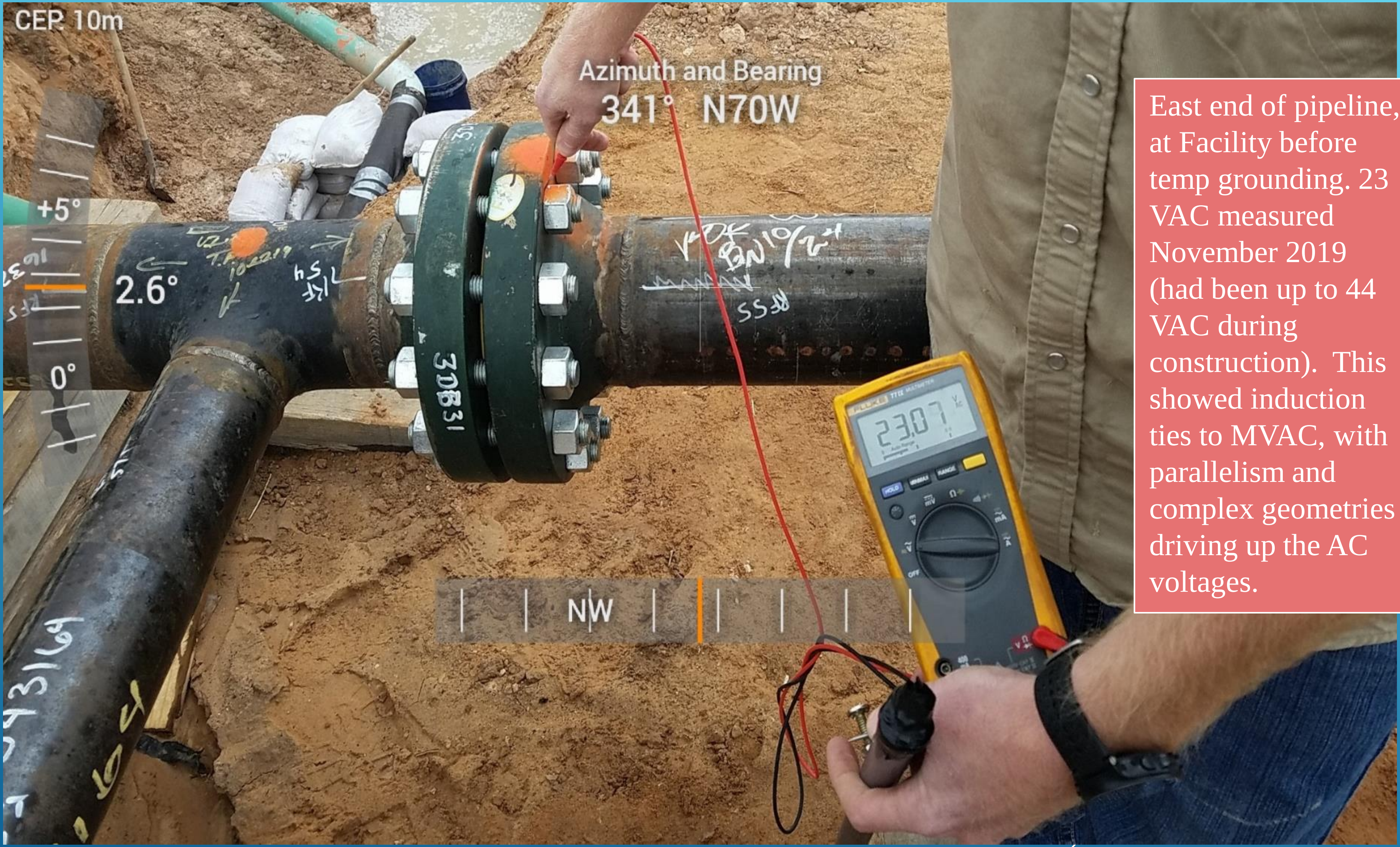
Dropped AC Volts at East End by half. Upped West End AC V by a third. Ratio of change corresponded to pipe distances aligning with overall MVAC system.

SURFACE SOILS AND SHALLOW GEOLOGY, CASE #2

- From U. S. Geologic Survey “Pocket Texas Geology” Map, Surface Geology
- Five to eight feet (1.8 to 2.4 meters) of sandy loam soils, and wind-deposited sands, on top of caliche beds; **salty ground water six to 20 feet deep.**



CASE #2, WITH MVAC EFFECTS



East end of pipeline, at Facility before temp grounding. 23 VAC measured November 2019 (had been up to 44 VAC during construction). This showed induction ties to MVAC, with parallelism and complex geometries driving up the AC voltages.

FOR CASE #2 PIPELINE:

	High VAC	Rho, ohm-m	High Iac, A/sq m	Iac/30 Ratio	“Wtd Ave" VAC	“Wtd Ave" Iac	Iac/30 Ratio
Location, West to East:							
West Valve, Tank Battery	16	15	240	8.0	15	225	7.5
Mid-Field Valve	21	12	394	13.1	21	394	13.1
East End Tanks	44	6	1653	55.1	25	939	31.3
Mid-Field Valve Flange Opened	High VAC	Rho, ohm-m	High Iac, A/sq m	Iac/30 Ratio	"High Ave" VAC	"HA" I ac	Iac/30 Ratio
Location, West to East:							
West Valve, Tank Battery	20	15	300	10.0	20	300	10.0
Mid-Field Valve	NA	12	NA	NA		NA	NA
East End Tanks	10	6	376	12.5	10	376	12.5
East End Current Drain, 3.5 A DC, 6.8 V DC (Flange closed)	High VAC	Rho, ohm-m	High Iac, A/sq m	Iac/30 Ratio	"High Ave" VAC	"HA" I ac	Iac/30 Ratio
Location, West to East:							
West Valve, Tank Battery	12	15	180	6.0	12	180	6.0
Mid-Field Valve	4.4	12	83	2.8	4.4	83	2.8
East End Tanks	6.8	6	255	8.5	6.8	255	8.5

AC CORROSION CONCERNS HIGH, ENTIRE LENGTH, with ONLY MVAC INVOLVEMENT.
BIG SAFETY ISSUES OVER MOST OF LENGTH.
Does Low-Resistance Geology COUPLE BETTER? POWER ON AC SYSTEM STEADILY HIGH.
It may be that coating quality is REALLY GOOD, TOO.

TEMPORARY CURRENT DRAIN BEHAVIOR

- Four 500-bbl frac tanks were set at east end of pipeline. Bonded them together to use as temporary grounding point;
- **AC voltage, no current flow, of 23 to 25 VAC at pipe's east end;**
- **With 3.5 AAC flowing, AC voltage declined to 6.8 VAC. Power involved? About 23 watts AC. Grounding resistance? About 1.7 ohms;**
- Is it plausible to assume that about one amp of AC current is flowing off pipeline at various holidays, at 23 VAC, due to steady-state AC induction? Power relationship, of P1 = P2, as V1 x A1 = V2 x A2?

REMEDY? BUILD SIGNIFICANT MITIGATION ON A SMALL, LOW-PROFITABILITY PIPELINE.

- Worldwide virus slowdown halted this work;
- Safety risks present, entire alignment. Can put in dead-face-front hardware, ground mats, but AC corrosion risk also VERY HIGH, entire length!
- The many branches of MVAC cause much more AC field complexity. These plus shallow soil, geology and ground-water factors cause **much more power induction;**
- **This small pipeline "system" shows interactions similar to Case 1. Strong coupling, due to large power needs in area. Good "natural transformer core" present, thanks to geology, ground water;**
- **HOW ELSE SHOULD COMPANY MANAGE THESE RISKS AND LIABILITIES?**

QUESTIONS OR COMMENTS? THANKS.

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