Autonomous Geophysical Monitoring for Leak Detection

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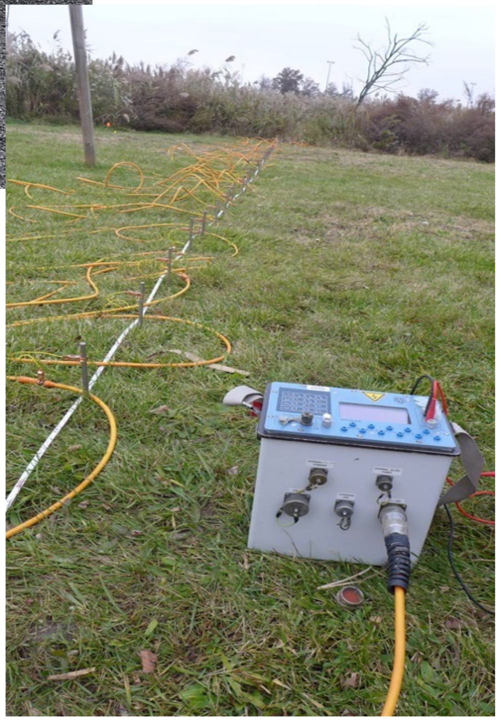
Outline

- Hydrogeophysical 'Toolbox'
- Electrical resistivity monitoring:
  - Why resistivity?
  - Physical basis
- Examples
  - Synthetic
  - Field example
- Conclusions

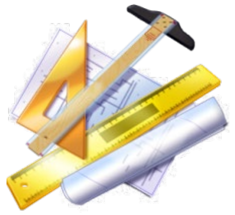
Hydrogeophysical Toolbox

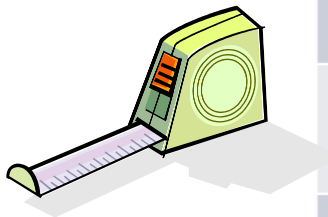
Monitoring methods:

- Electrical resistivity
- Fiber-optic distributed temperature sensing (DTS)
- Fiber-optic distributed acoustic sensing (DAS)
- Ground penetrating radar
- Electromagnetic Induction
- Microgravity
- Seismic



Physical Basis





Method	Geophysical Property	Relevant Hydrologic Property/Parameter	Acquisition method(s)
Seismic refraction & reflection	Seismic velocities & reflectivity (bulk & shear moduli)	Depth to bedrock, water table, aquifer boundaries	Lab, borehole, crosshole, surface
DC Electrical Resistivity (ER)	Electrical resistivity	Water content, salinity, pore fluid, porosity, lithology	Lab, borehole, crosshole, surface
Induced polarization (IP)	Chargeability	Surface area of pores/grains, lithology	Lab, crosshole, surface
Spontaneous Potential (SP)	Spontaneous potential	Flow through porous medium, redox potential	Lab, borehole, crosshole, surface
Ground penetrating radar (GPR)	Dielectric constant, electrical conductivity	Water content, salinity, pore fluid, porosity, lithology	Lab, crosshole, surface
Electromagnetic (EM)	Electrical resistivity	Water content, salinity, pore fluid, porosity, lithology	Lab, borehole, crosshole, surface, airborne
Conventional borehole logging: caliper, gamma, sonic, etc.	Many	Many: fracture locations, clay content, lithology, etc.	Borehole
Advanced borehole logging: ATV/OTV, flowmeter, etc.	Many	Many: fracture locations, lithology, transmissivity, etc.	Borehole

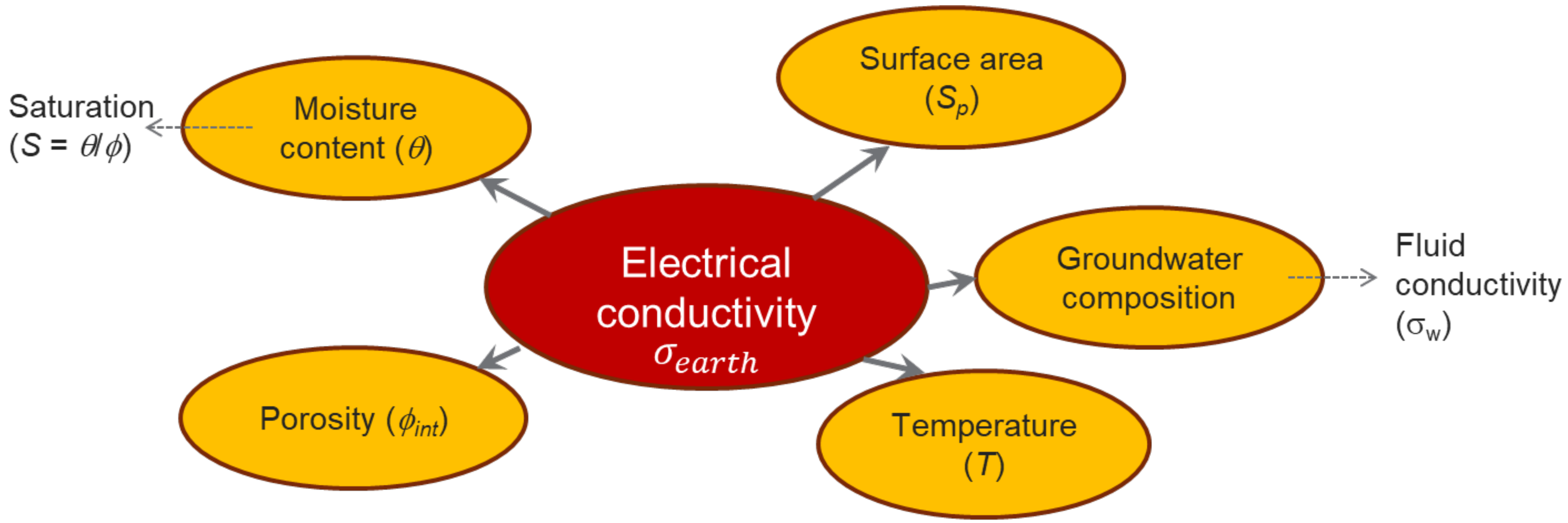
- → Indirect measurement
- → Some methods labor-intensive
- → Some potentially autonomous
- → Some allow for towed or flown surveys
- → Some amenable to long-term deployment
- → Some capable of 2D/3D imaging
- → Methods vary in terms of
  - Resolution
  - Coverage

[after ***Day-Lewis, F.D., Slater, L.D, Johnson, C.D., Terry, N., and Werkema, D., 2017, An overview of geophysical technologies appropriate for characterization and monitoring at fractured-rock sites, Journal of Environmental Management,*** [***http://dx.doi.org/10.1016/j.jenvman.2017.04.033***](http://dx.doi.org/10.1016/j.jenvman.2017.04.033)]

Electrical Resistivity

Sensitive to:

- **Saturation**
- **Fluid conductivity (fluid, total dissolved solids)**
- **Temperature**
- Porosity / lithology
- Minerology/solid phase materials (e.g. rock type, buried metal).



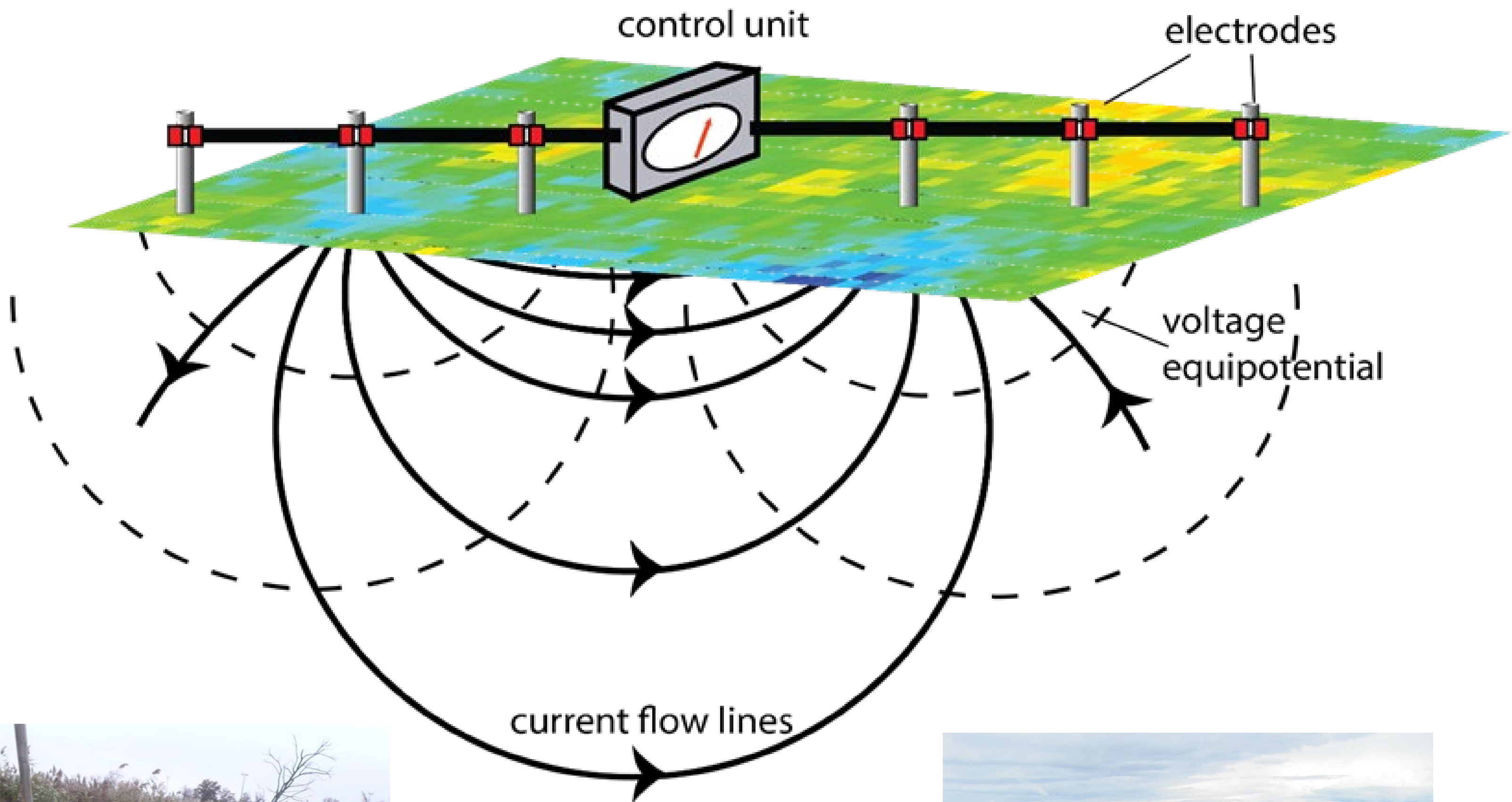
$$\sigma_{earth} = \frac{1}{\rho_{earth}} = \sigma_w(T)\phi_{\text{int}}^m S_w^n + \sigma_{surf}\left(S_p, \sigma_w, S, T\right)$$

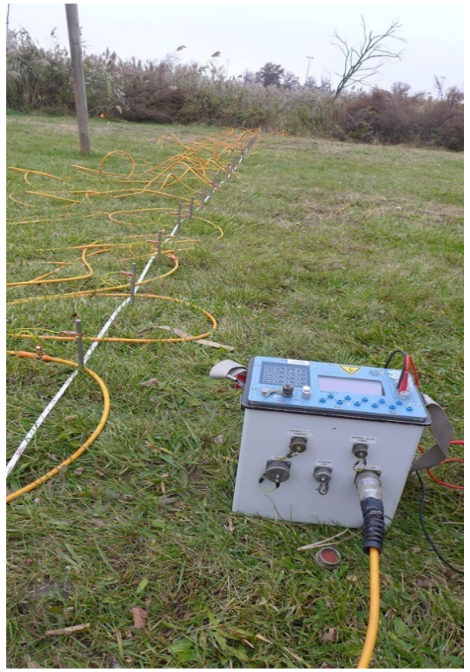
m and n are exponents related to pore space connectivity/tortuosity

Electrical Resistivity

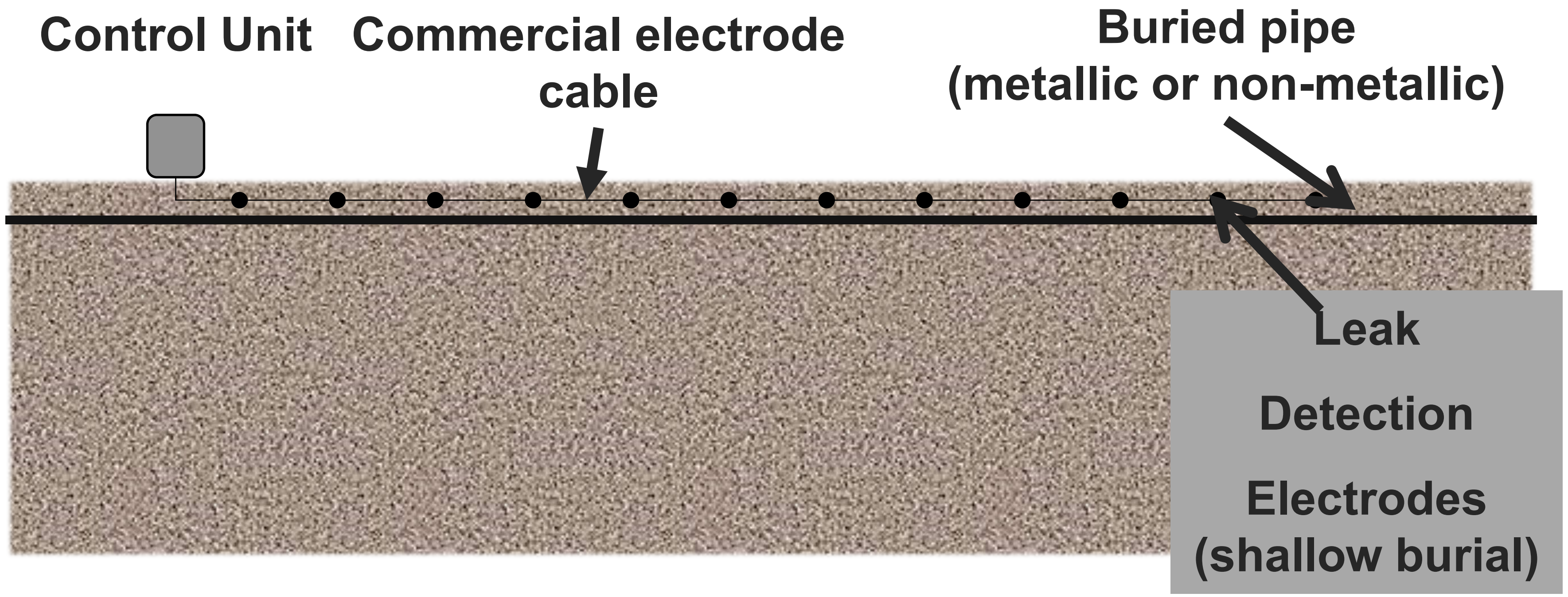
Electrical Resistivity

- Amenable to time-lapse monitoring
- Permanent installation possible
- Commercially available instrumentation
- Autonomous control possible
- Anomaly detection or imaging
- Measurements:
  - Apply current between pairs of electrodes
  - Measure potential difference between other pairs



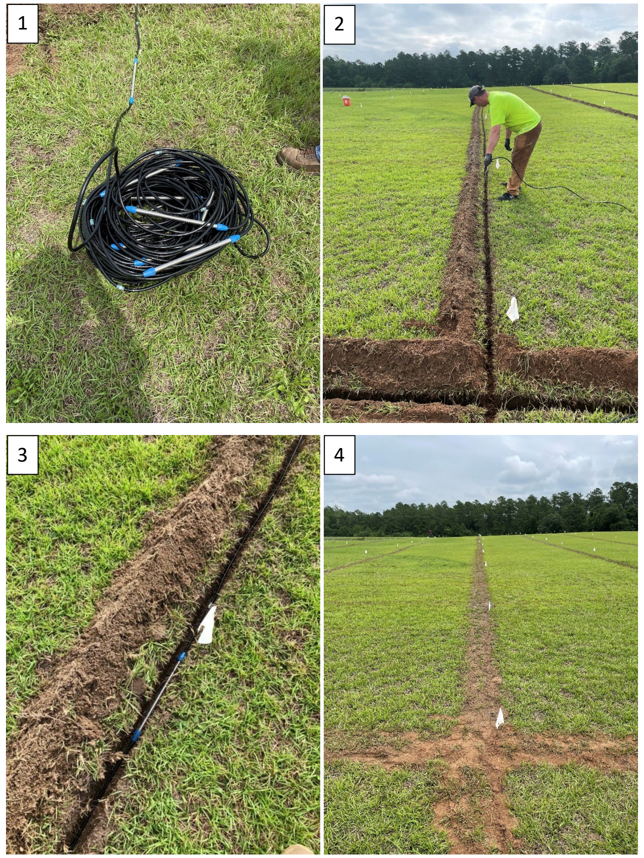


Electrical Pipe Leak Detection Monitoring: Principles of Operation



Electrode: electron conductor (metal or carbon)
Electrodes can be installed on surface or in many other configurations.

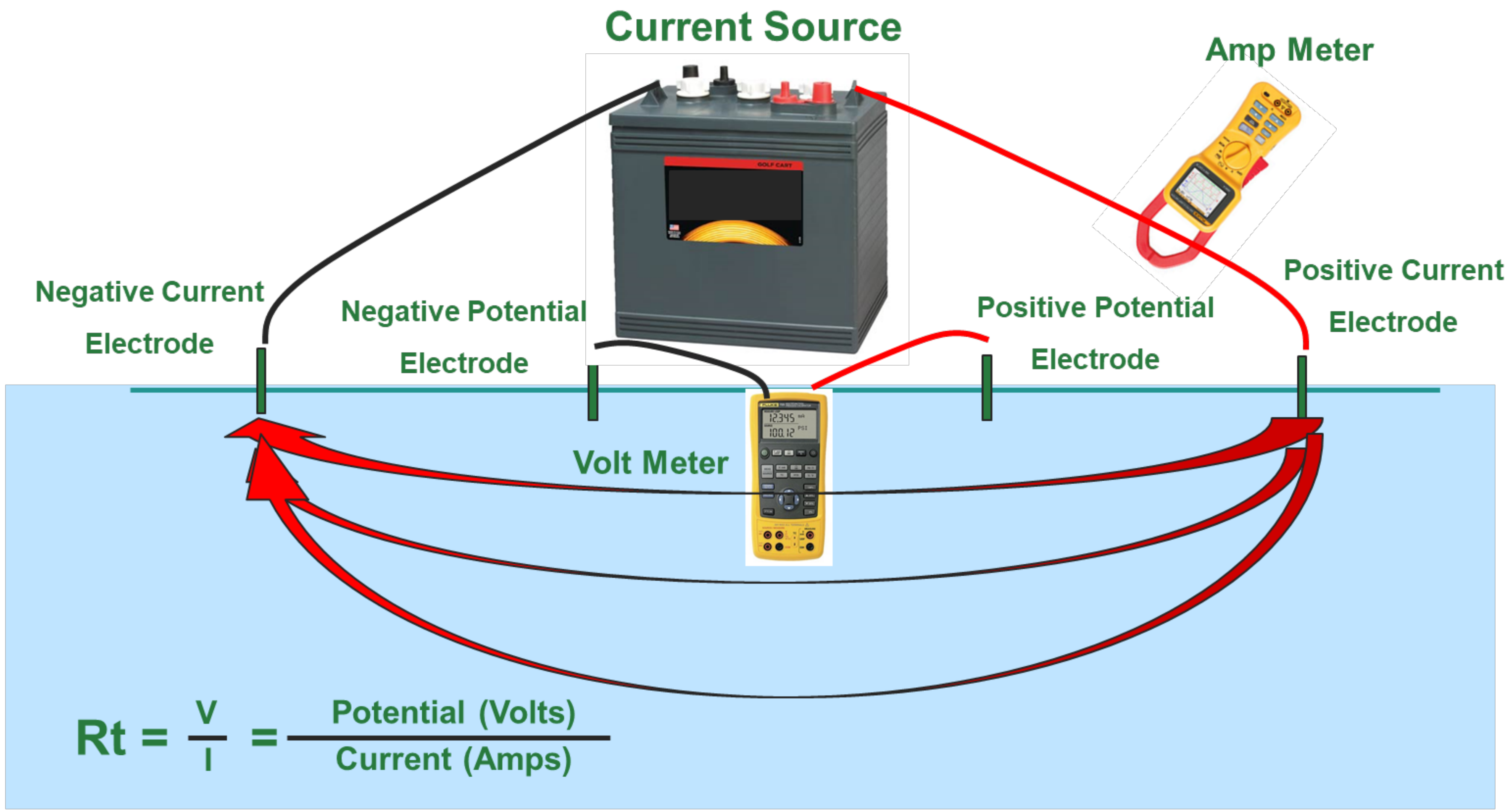
Example Electrode Installation



Credit: T.C. Johnson

Electrical Pipe Leak Detection Monitoring: Principles of Operation

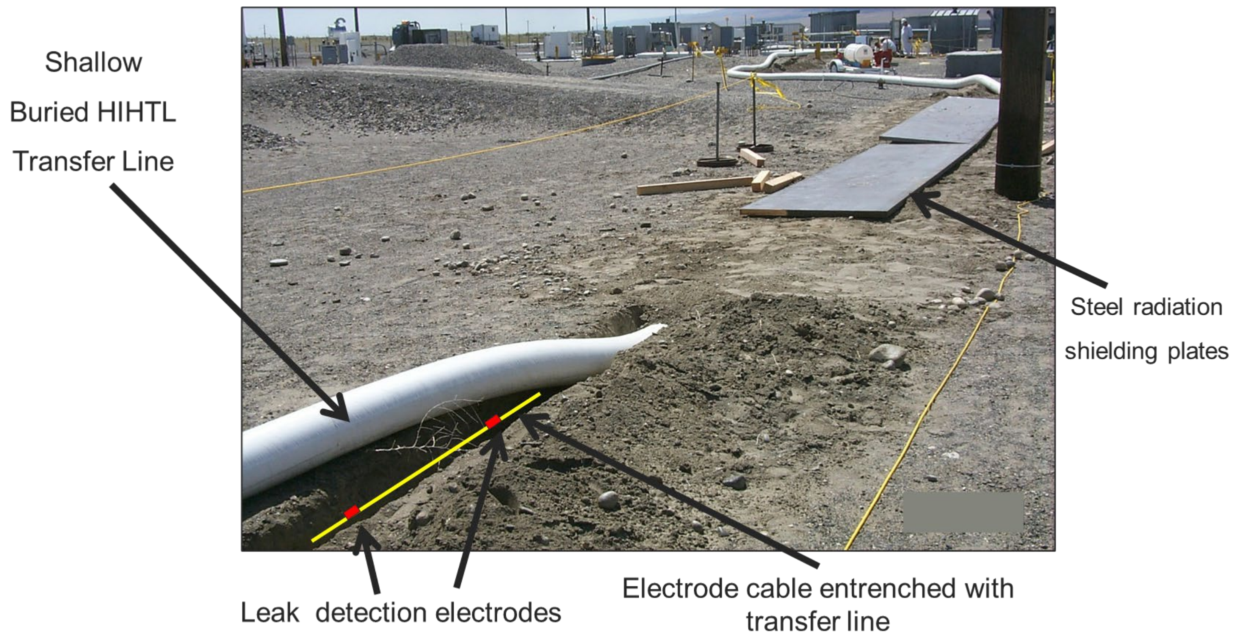
- **Electrodes are used to monitor the resistance of the subsurface to current flow (i.e. the resistivity)**
- ***Leaking pipe must cause a change in subsurface resistivity to be detected.***



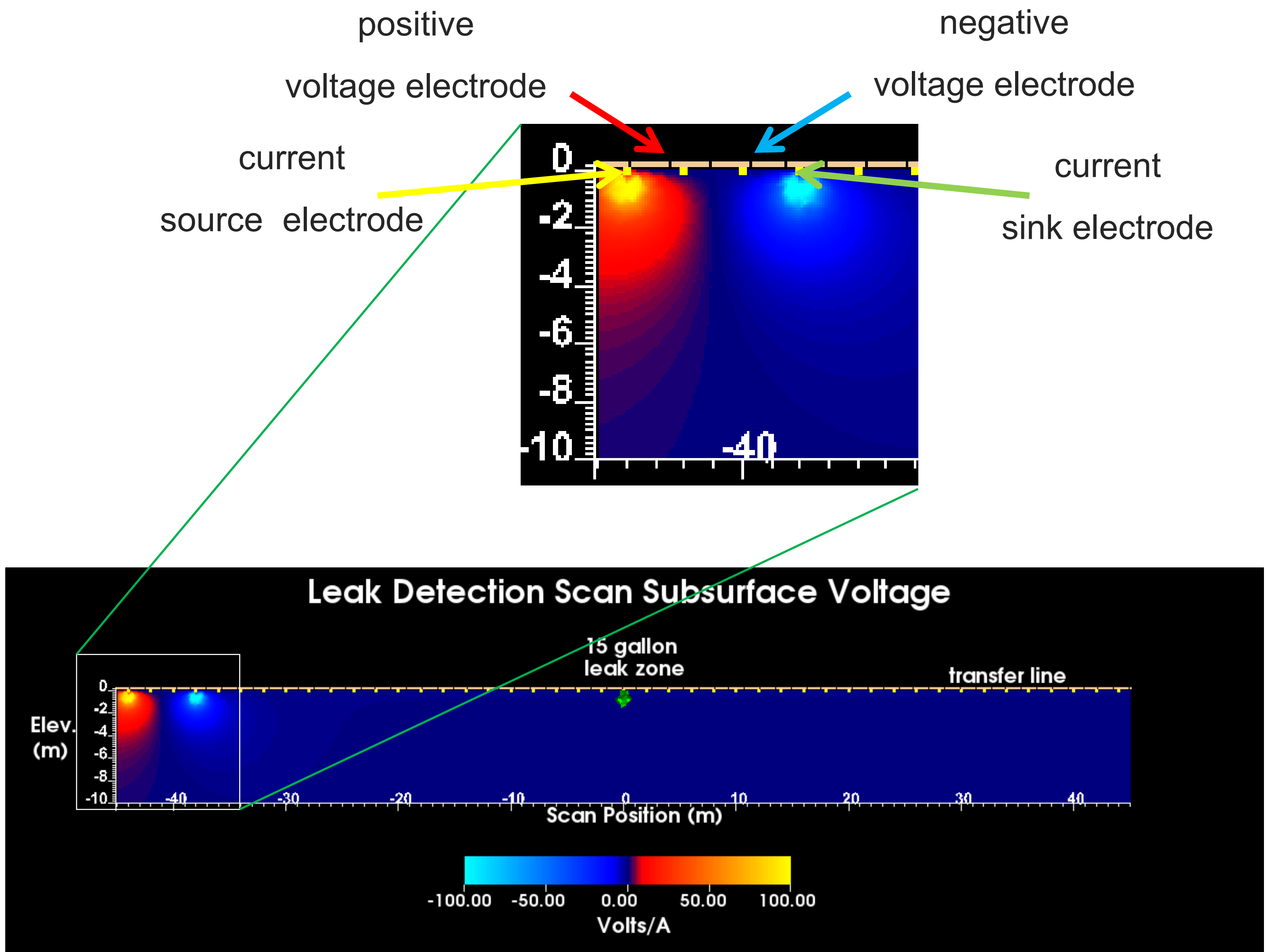
Credit: T.C. Johnson

Simulated Leak Monitoring on a Waste Transfer Pipe

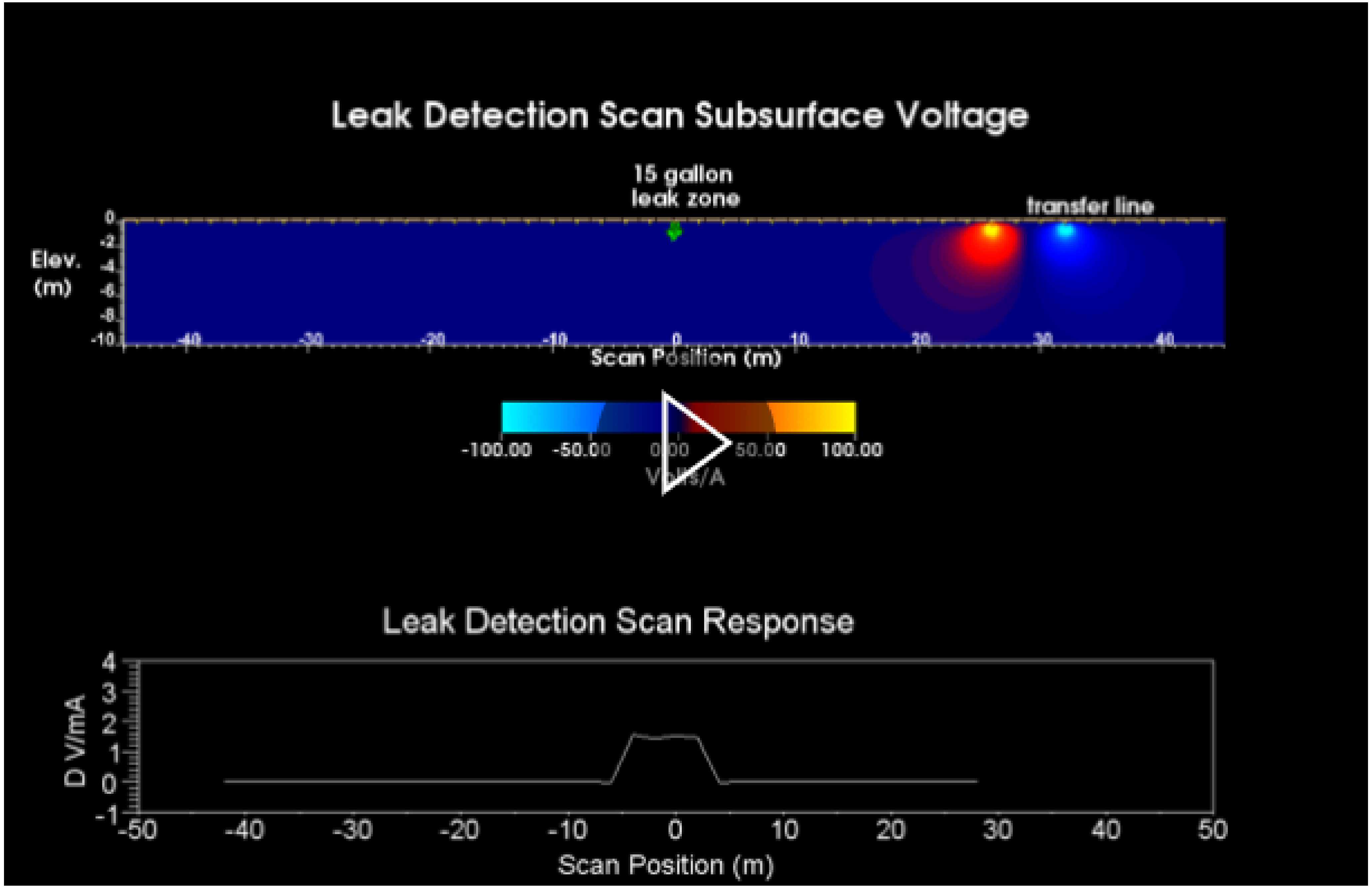
Field Site Conditions for Radioactive Waste Transfer Pipes



Normalized Subsurface Voltage During a Measurement

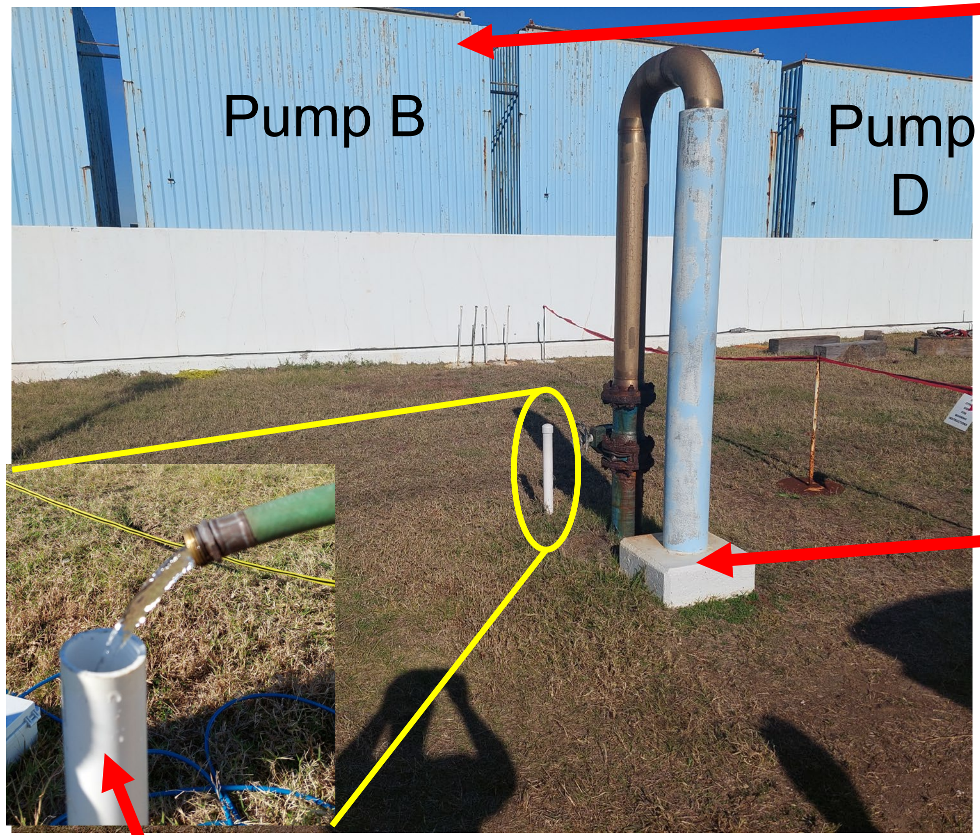


Simulated Leak Detection Scan



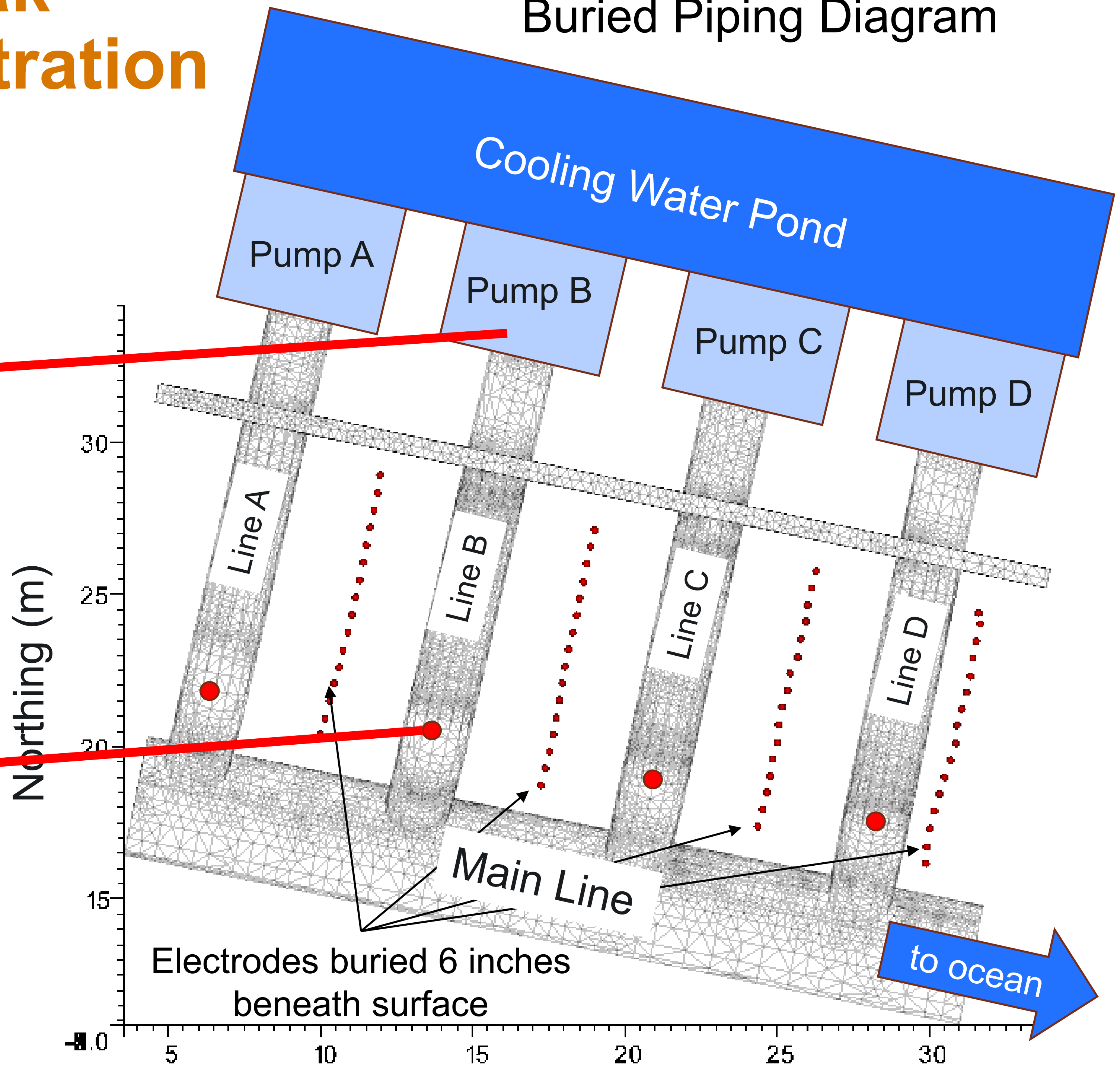
Autonomous 4D Leak Monitoring Demonstration

Physical Leak Simulation Setup



Leak simulation tube terminated at top of discharge Line B

Buried Piping Diagram

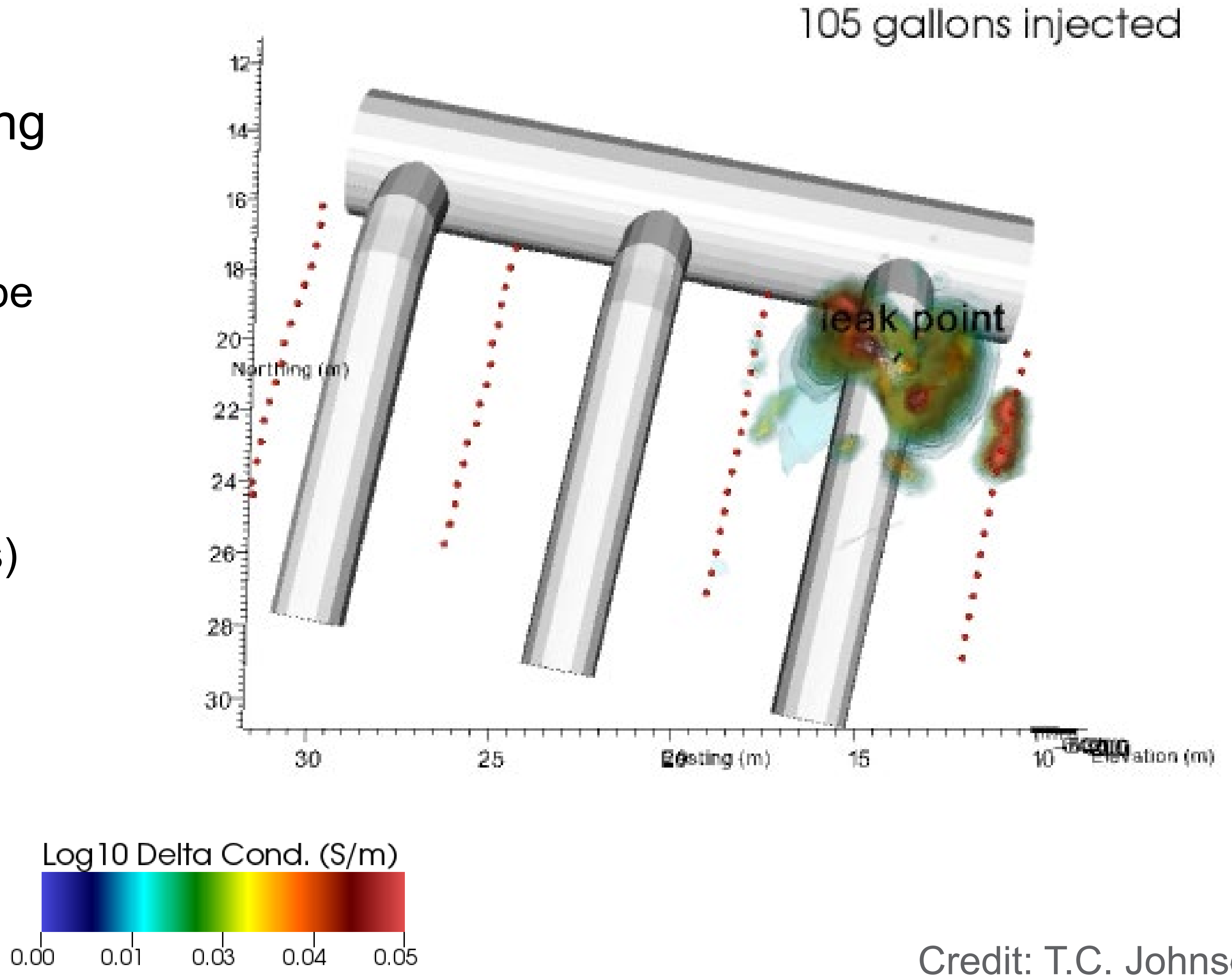


Credit: T.C. Johnson

Potable Water Leak Imaging

- 375 uS/cm
- Tap water applied to leak tube at 1 gal/min
- 105 gallons total
- ERT scan every 10 minutes
- First detection at 15 minutes after start of leak (15 gallons)

Time-Lapse 3D ERT Image

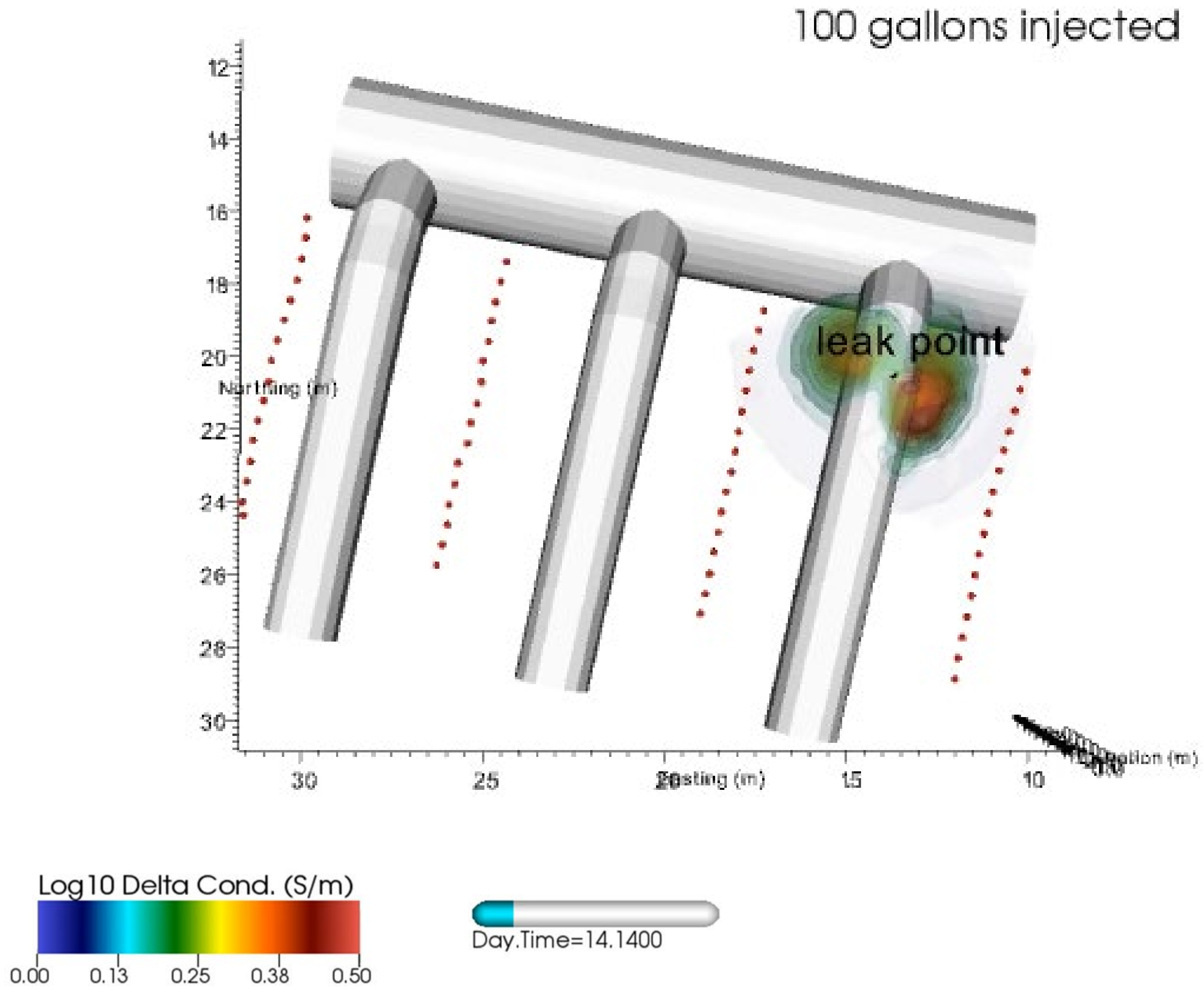


Credit: T.C. Johnson

Time-Lapse 3D ERT Image

Cooling Water (Brackish) Leak Imaging

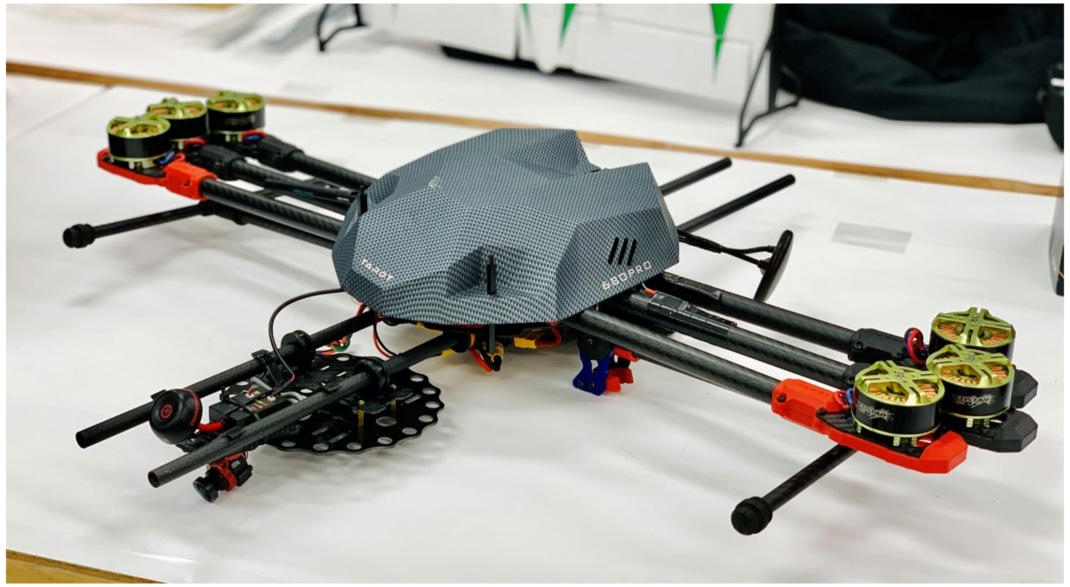
- 44,000 uS/cm
- Pond water applied to leak tube at 1 gal/min
- 100 gallons total
- ERT scan every 10 minutes
- First detection at 10 minutes after start of leak (10 gallons)



Note color scale range 10X that of potable water

Conclusions

- Numerous geophysical methods have potential for leak detection
- Electrical methods are well suited to
  - autonomous long-term monitoring, either continuous or snapshot
  - near real-time delivery of results
  - anomaly (change) detection
  - imaging
- Other geophysical methods well suited to support excavation and extent of leak-impacted areas
- Drone surveys possible with some geophysical methods



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Thank you