Fast, accurate, and cost-effective mapping of groundwater flow paths.

October 30, 2018

willowstick

Acknowledgements

- Jud Kennedy – CEO, Willowstick Technologies
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  - Sole proprietor, ASH Mineral Solutions
  - Consultant, Secondary Minerals
  - Independent Sales Representative, Willowstick Technologies

“ALL Models Are Wrong, But Some Are Useful.”

- George Box, Statistician

Groundwater Modelling

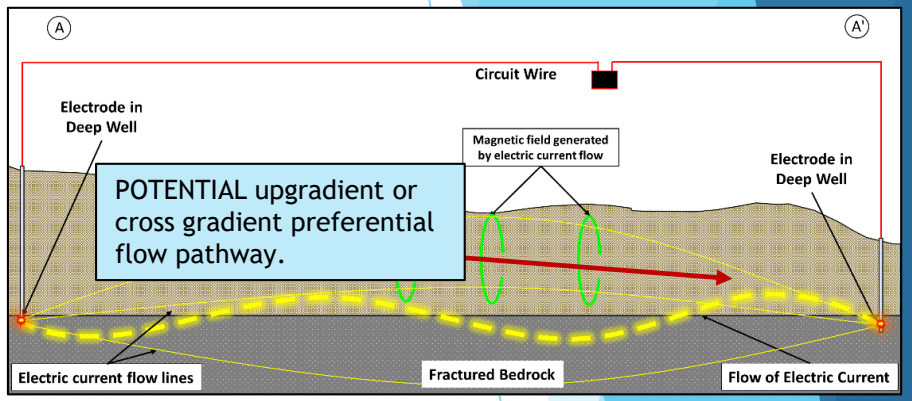
- Predicts the fate and transport of constituents from coal ash basins during pre-closure and post-closure conditions.

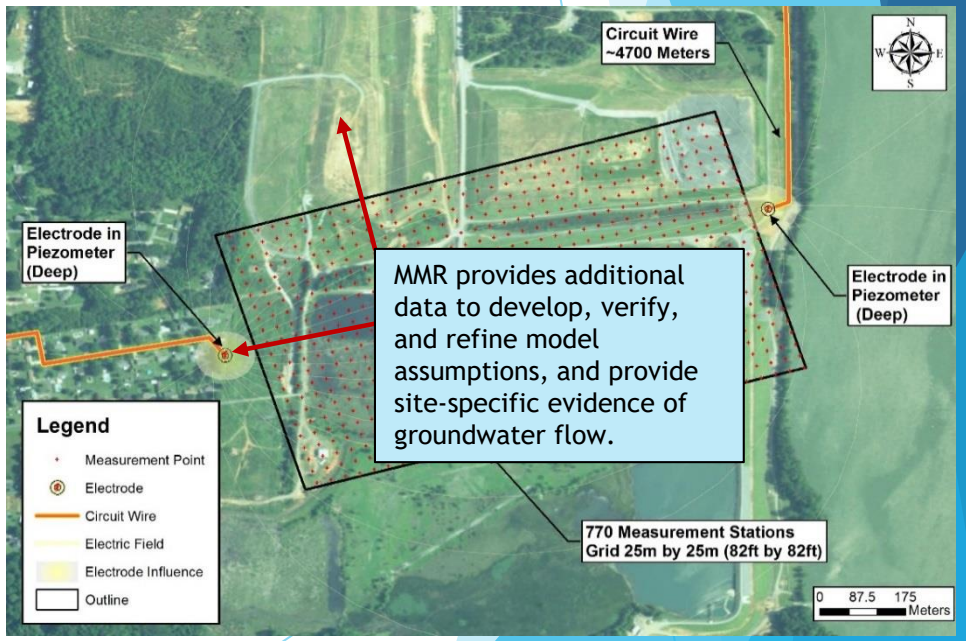
- Applicability of GW model depends on the input data, typically from a limited number of borings/wells.

QUESTIONS

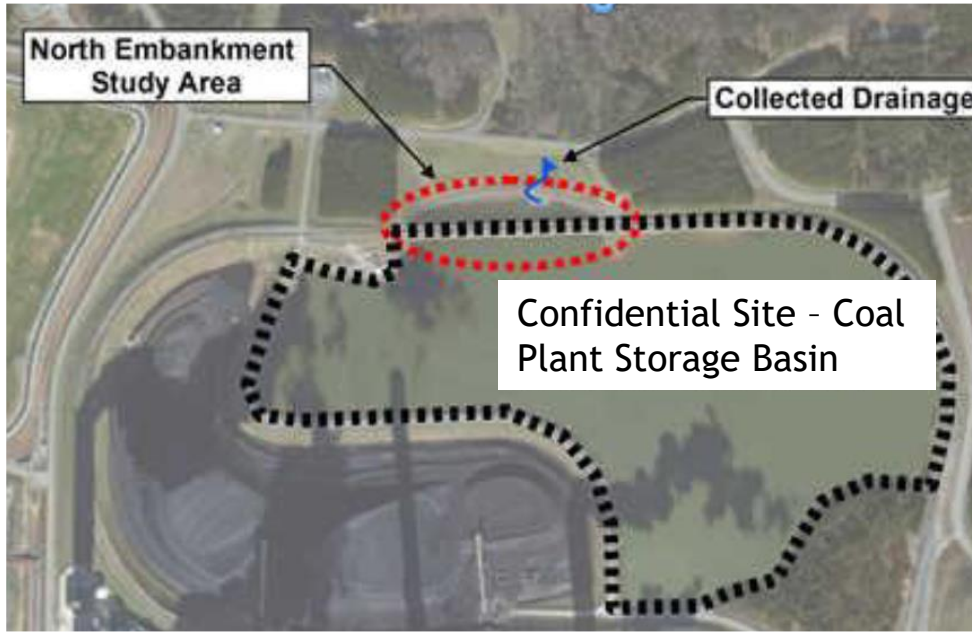
- What happens between measurement locations?
- Are there preferential flow pathways (cross-gradient, etc.)?

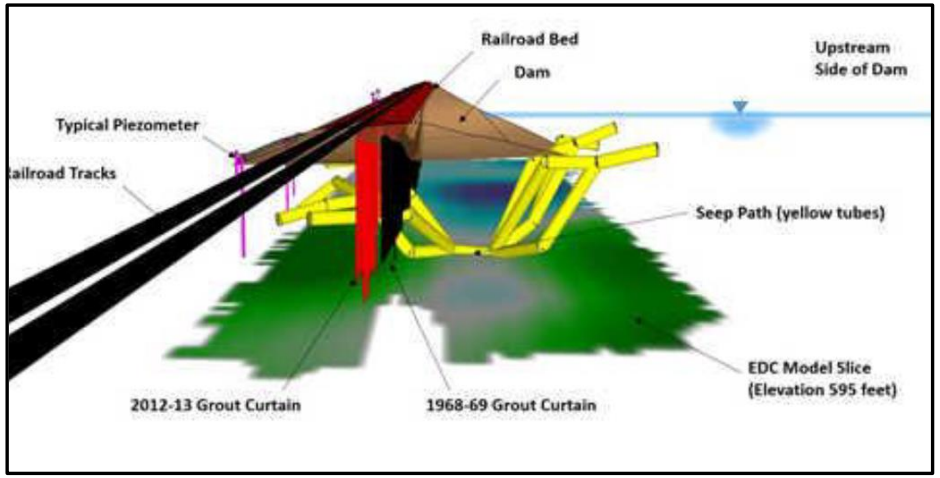
- **How would data from an additional 100-200 measurement locations improve the usefulness of GW models?**





Addressing Subsurface Anomalies and Seepage Channels





- Ash basin closure designs are based on technical decisions made from a **finite number of test borings and data points**.
- Even with a reasonable design method and a conservative approach, challenging subsurface conditions and anomalies can result in seepage beneath or around some facilities.
- MMR surveys can provide valuable information to locate these unseen, difficult to identify subsurface anomalies and to modify containment structures.
- Proactive evaluation of Potential seepage pathways can minimize the risk from unseen, difficult to locate subsurface conditions.

Could data with higher spatial resolution have prevented these incidents?

October 11th, 2000—Martin County, KY

- Spilled overver 300,000,000 gallons of coal slurry into two tributaries of the Tug Fork River.
- 30 times the volume spilled by Exxon Valdez
- Contaminated water supply for over 27,000 residents was.
- Killed all aquatic life in Coldwater Fork and Wolf Creek.
- “One of the worst environmental disasters ever in the southeastern United States.”
  - Environmental Protection Agency (EPA)

Recent Incidents

February 2, 2014—Eden, NC

- 27 million gallons of water & 38,000 tons of coal ash released into Dan River.
- **$102 million in fines** and restitution.
- Increased State and Federal regulation of ash basins near U.S. streams and rivers.

Recent Incidents (cont.)

August 23, 2005—Lower Mount Bethel Township, PA:

- Released 100 million gallons of fly ash slurry across local fields and into the Oughoughton Creek and the Delaware River.
- **$1.3 million settlement** with state regulators for damages caused by spill.

February 14, 2007—Morgan County, IN:

- Levee failure releases 30 million gallons of ash sluice water to a discharge canal, which led to the White River.
- Less than one year later, the levees failed again in the same location, releasing another 30 million gallons of sluice water.
- The incident prompted a legal action involving the ash basin owner and its third party engineers.

January 2009—Jackson County, AL:

- Just weeks after the Kingston spill, 10,000 gallons of gypsum slurry leaks from a break in an impoundment at TVA's Widows Creek Fossil Plant.

** Aerial photos sourced from Google Maps*

Kingston Event Prompts EPA Review, 2015 CCR Rule Change

December 22, 2008—Kingston, TN:

- 5.4 million cubic yards of fly ash mixed with 327 million gallons of water spilling into the Emory River and covering 330 acres.
- Over **$1 billion** in estimated remediation costs.
- Additional **$40 million cost** for long-term monitoring**.**

So What Have We Learned from These Historic and Recent Failures and Events?

- **Failures are expensive:**
  - Potentially hundreds of $MM's in remediation costs, fines, settlements.
  - Negative publicity, increased regulatory burdens and compliance costs.

- **Undetected Seepage:** Many of the failures were caused by underground seepage or infrastructure leakage.

- **SMALL amounts of undetected seepage → BIG problems.**

- **Prevention and early detection are essential** for avoiding future costly repairs and unexpected environmental impacts.

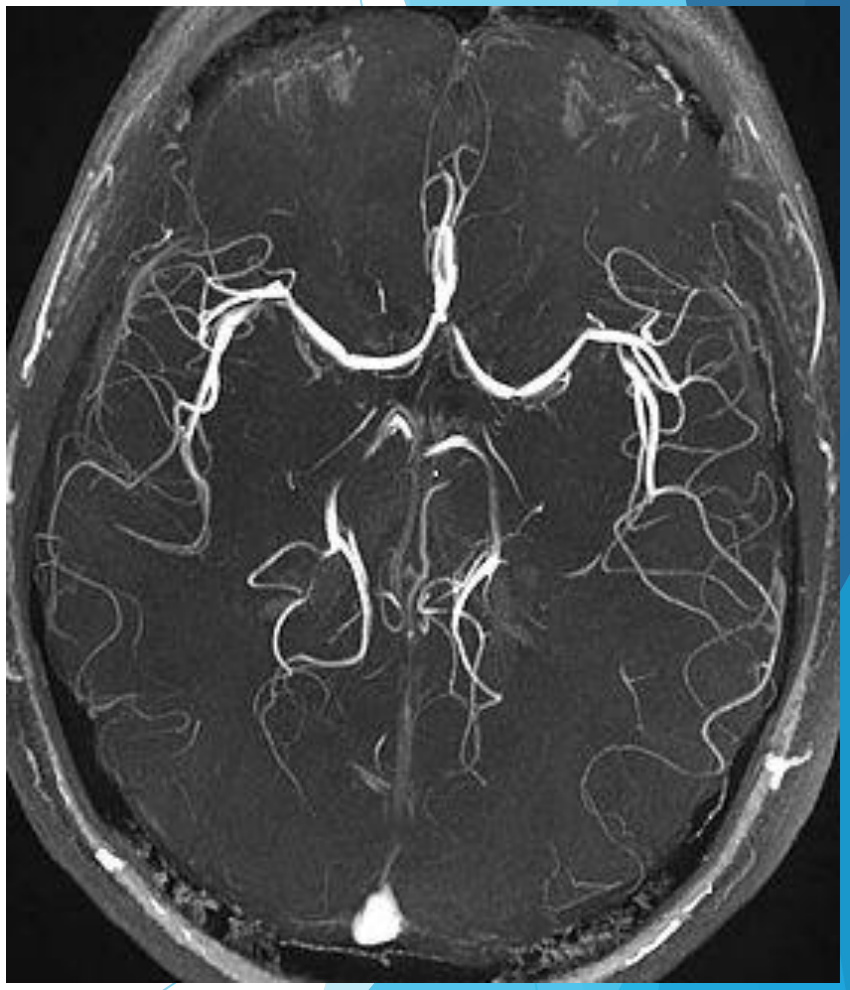
- **Surface inspections are insufficient for detecting seepage.**
  - Some sites passed inspection just weeks before an incident.

What if you could see groundwater as easily as you can surface water?

Introducing Magnetometric Resistivity (MMR) Measurements

MMR is a powerful diagnostic tool

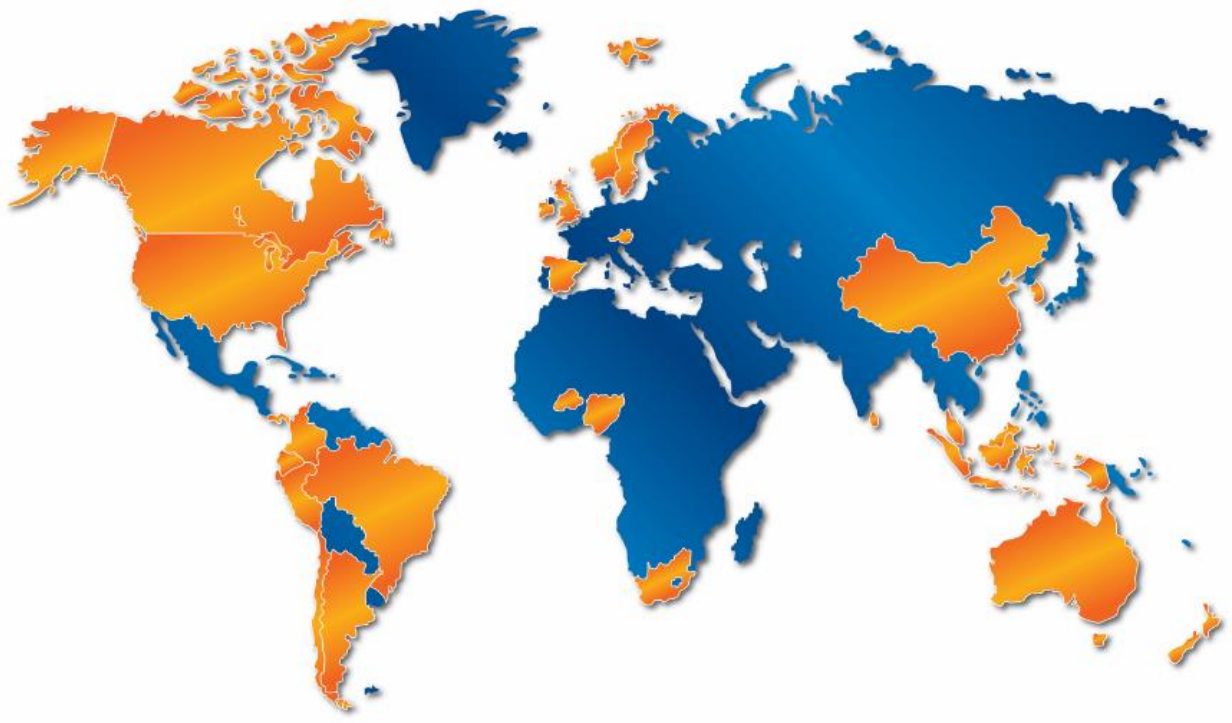
- **Hydrogeology's answer to magnetic resonance angiography**
- Maps, models, and predicts flow paths and patterns of subsurface water
- Demonstrated in other (non-CCR) systems:
  -Dams, canals, mining, environmental restoration
- Magnetic resonance imaging has changed medicine … why not our industry?



Angiogram showing blood flow in the brain

Does MMR Really Work?

- ✓ Over 300 successfully completed groundwater characterization projects around the world
- ✓ Over 80 unique sites – Lots of return customers
- ✓ Application of fundamental scientific principles



MMR Utilizes Principles of Applied Physics

(Sorry Folks, No Magic Here)

- **Electrical current will follow the subsurface water when an electrical potential is applied.**

  - Earthen materials are poor electrical conductors (10^{-12} and 10^{-17} mho/m)

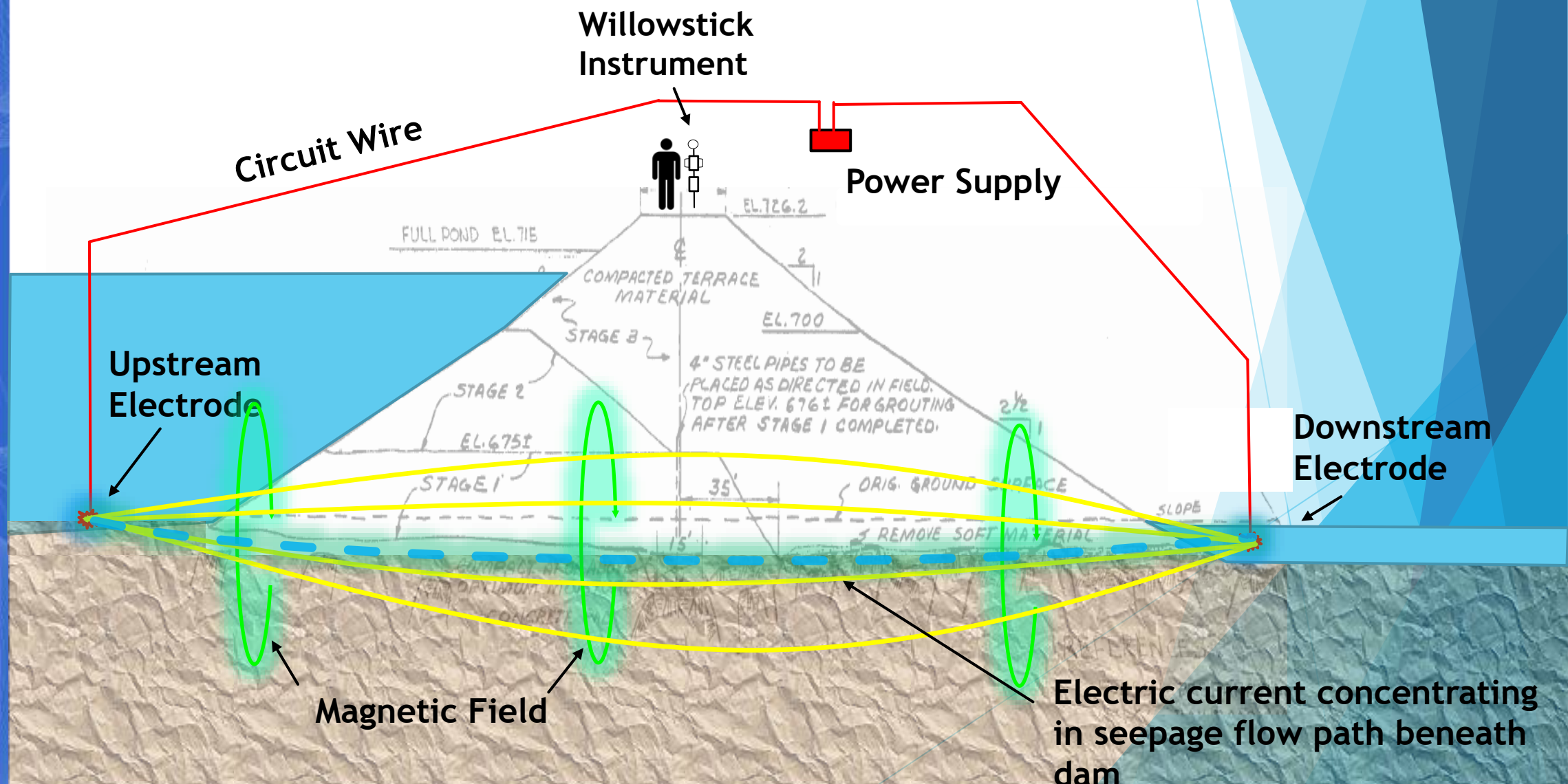
  - Water substantially increases conductivity (10^{-1} and 10^{-8} mho/m)

  - Water and electricity follow same path of least resistance

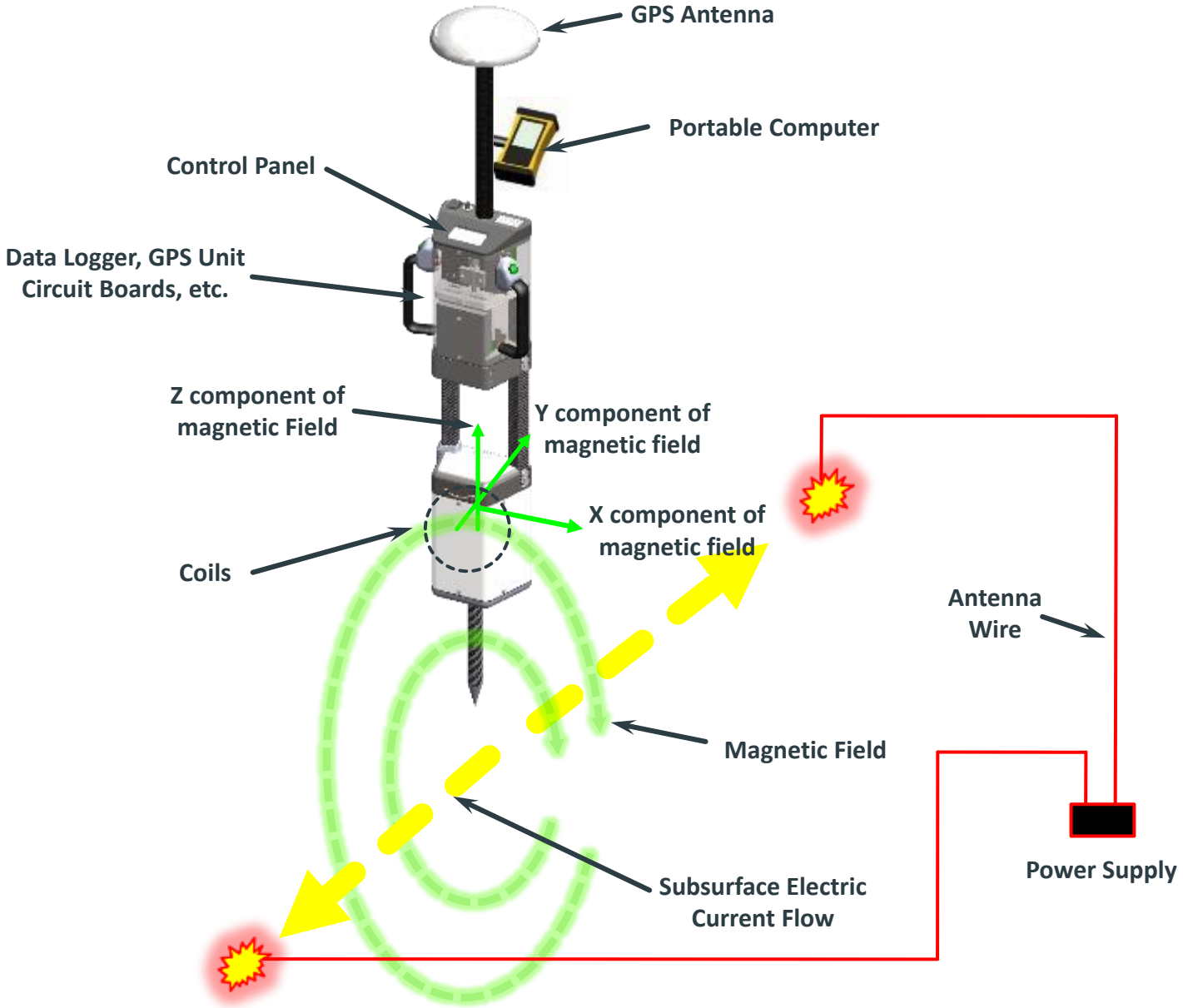
- **All electrical currents generate magnetic fields and the intensity of the magnetic field is proportional to the magnitude of the electrical current (Biot-Savart Law)**

- ***Measuring magnetic field intensity at the surface is an accurate method to determine zones of highest conductivity or transport porosity***

Typical MMR Survey Configuration



Willowstick Instrument (v8.1)



- Sensitivity: 1-2 pT
- Collection time: 8 sec
- V9 Weight: 12 lbs

Field Work Is Efficient, Non-Invasive, & Flexible

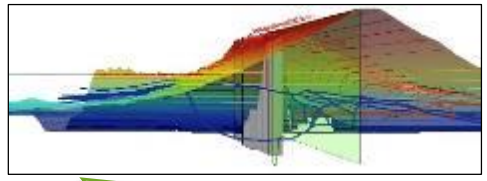
- ✓ Surveys are completed in days, not months
- ✓ No holes poked into the ground
- ✓ Real time – MMR surveys can be adjusted “on the fly” as data comes in.
- ✓ Adapted to most any environment

Willowstick Drone Platform
Under development

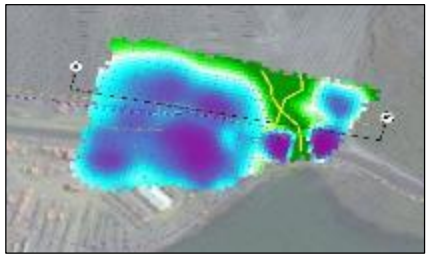
Mapping CCR Impoundments is a Sweet Spot for MMR

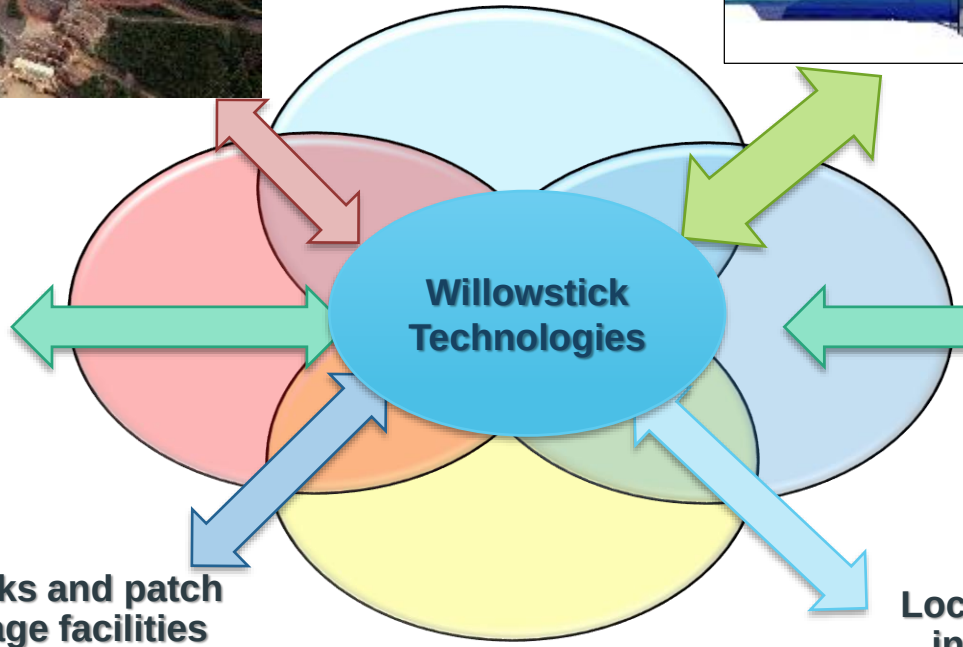
Identify leaks or seepage (or absence thereof)

Map subsurface GW flow paths to determine fate & transport

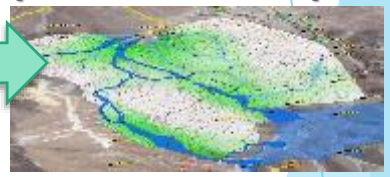


Compare™ temporal changes to manage risk





Track and mitigate impoundment leak paths



Identify leaks and patch lined storage facilities

Locate and stabilize leaks in pipelines or tunnels

MMR enables targeted monitoring and remediation

- ✓ Locating subsurface anomalies and seepage pathways that cause temporary instability during construction.
- ✓ Identification of preferential flow pathways that allow migration of groundwater contamination.
- ✓ Focusing subsurface investigations to reduce cost, and increase reliability of design assumptions.

** Aerial photos sourced from Google Maps*

Demonstration of the Technology

Coal-fired Power Plant

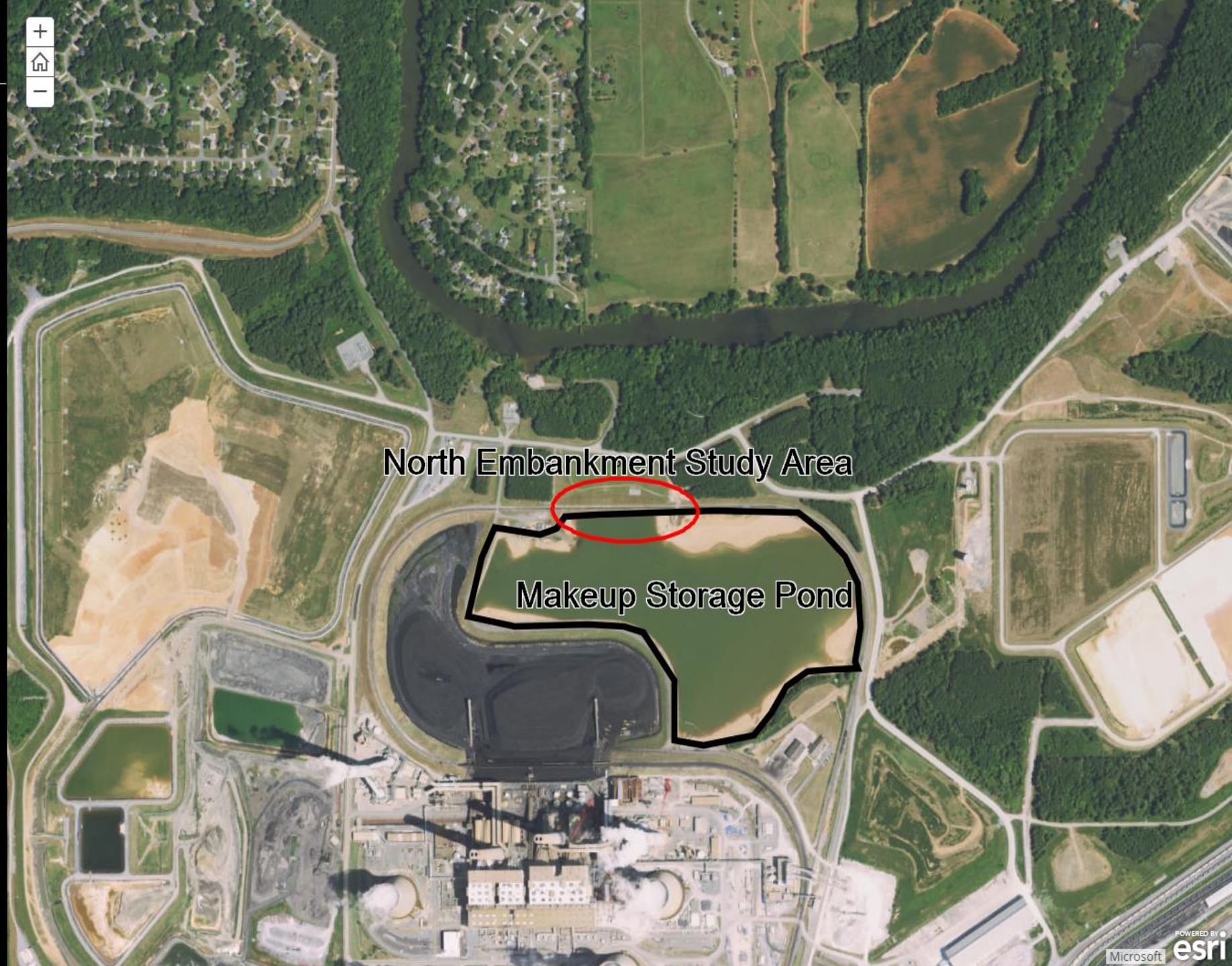
- Makeup Storage Pond
- Leaks have been observed through the embankment

Willowstick Survey

- Grout Curtains have been installed to reduce seepage
- Multiple Piezometers have been installed to monitor seepage
- Willowstick completed a survey to identify seepage locations

Expected Magnetic Field

- Based on survey design
- Other factors
- Electrode Placement



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- Based on survey design
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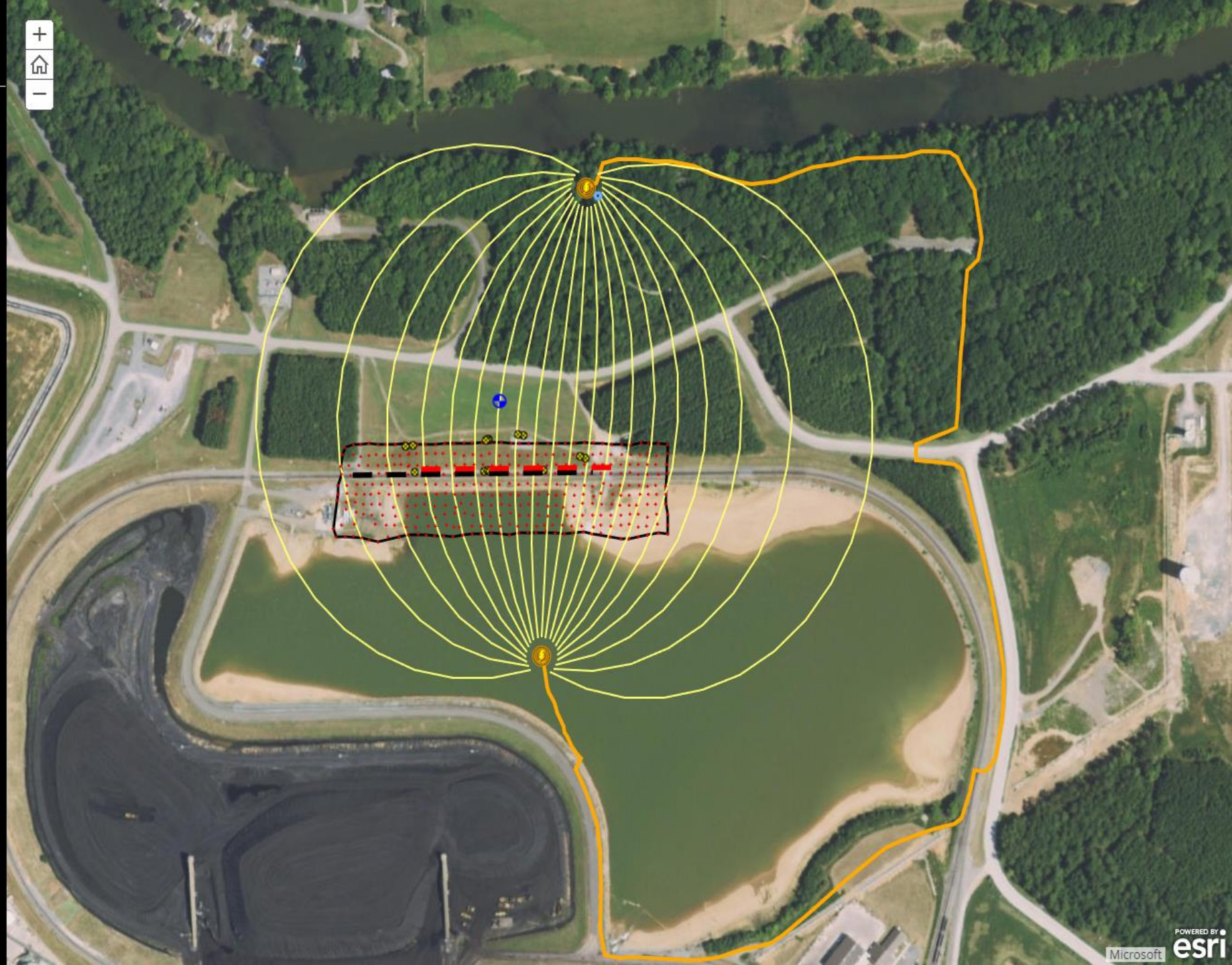
- Wire configuration

Observed Magnetic Field

- Every measurement point takes approximately 8 seconds
- Instruments measure the intensity of the magnetic field



Willowstick CCR Demonstration

Expected Magnetic Field

- Based on survey design
- Electrode placement
- Wire configuration

Observed Magnetic Field

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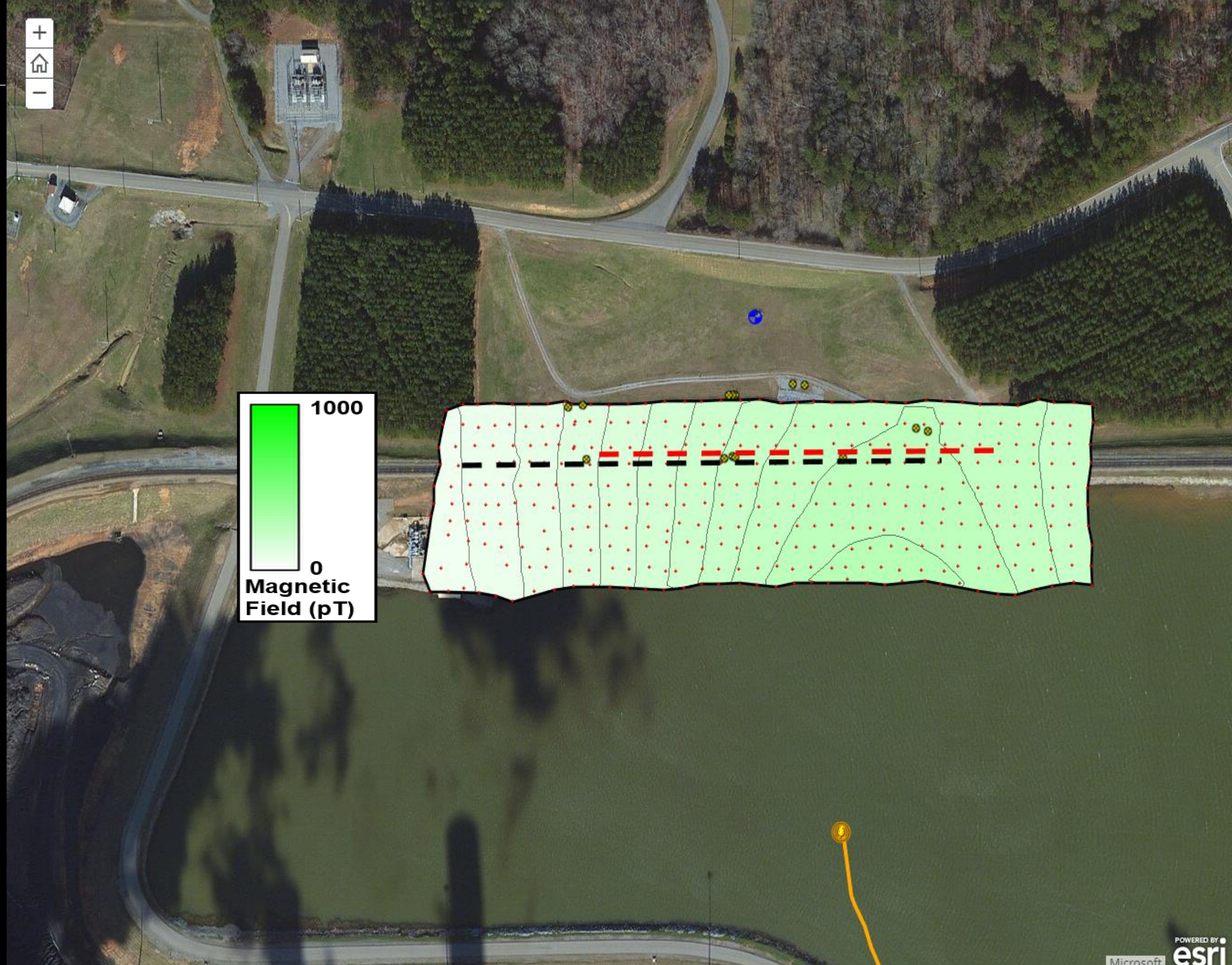
Ratio of Observed Readings to Expected Readings

Electric Current Distribution Model

- Inversion model reveals slices in all three dimensions
- Seepage is manifest 131 feet below the dam crest



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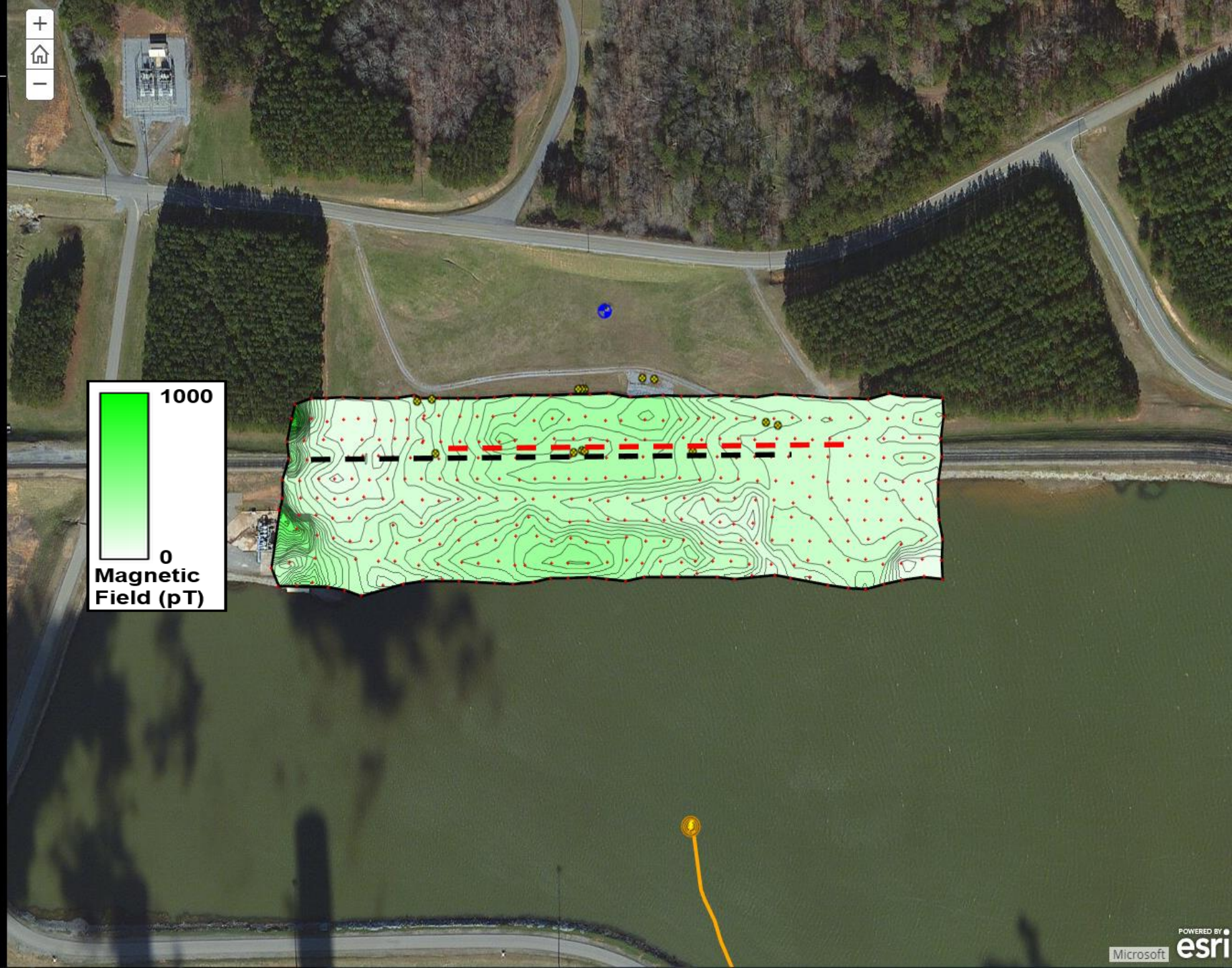
Preferential Flow Paths

- Willowstick models identify flow paths in 3 primary coordinates
- Willowstick delivers precise flow paths to facilitate remediation



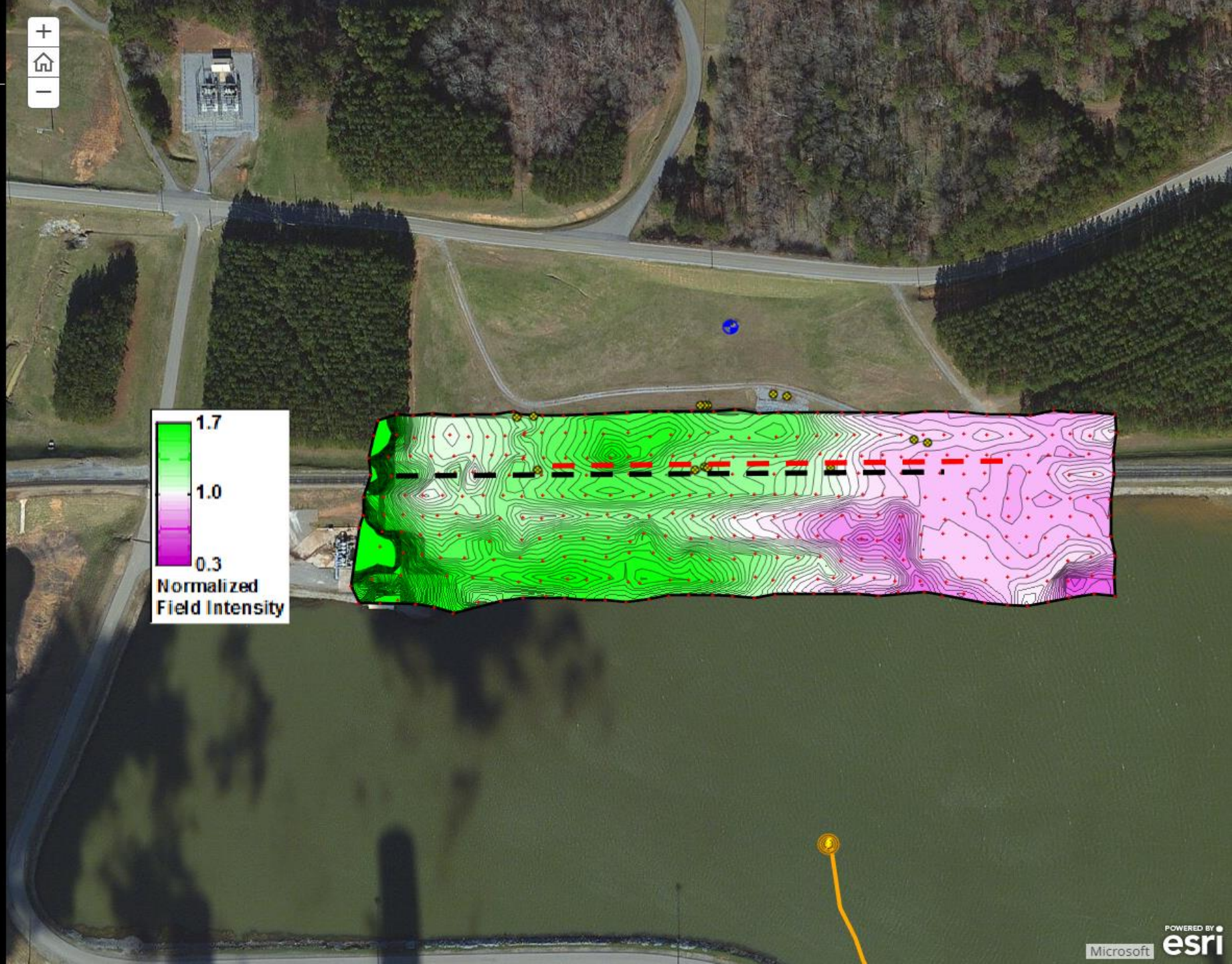
Ratio of Observed Readings to Expected Readings

3D Model

- 3D Inversion Slices
- Location of the Dam
- Water is seeping through the dam at 131 feet below the dam crest

Preferential Flow Paths

- Willowstick Identifies the seepage flow paths through 3D modeling
- The flow paths pass below the two grout curtains
- The results have been verified & more surveys have been planned



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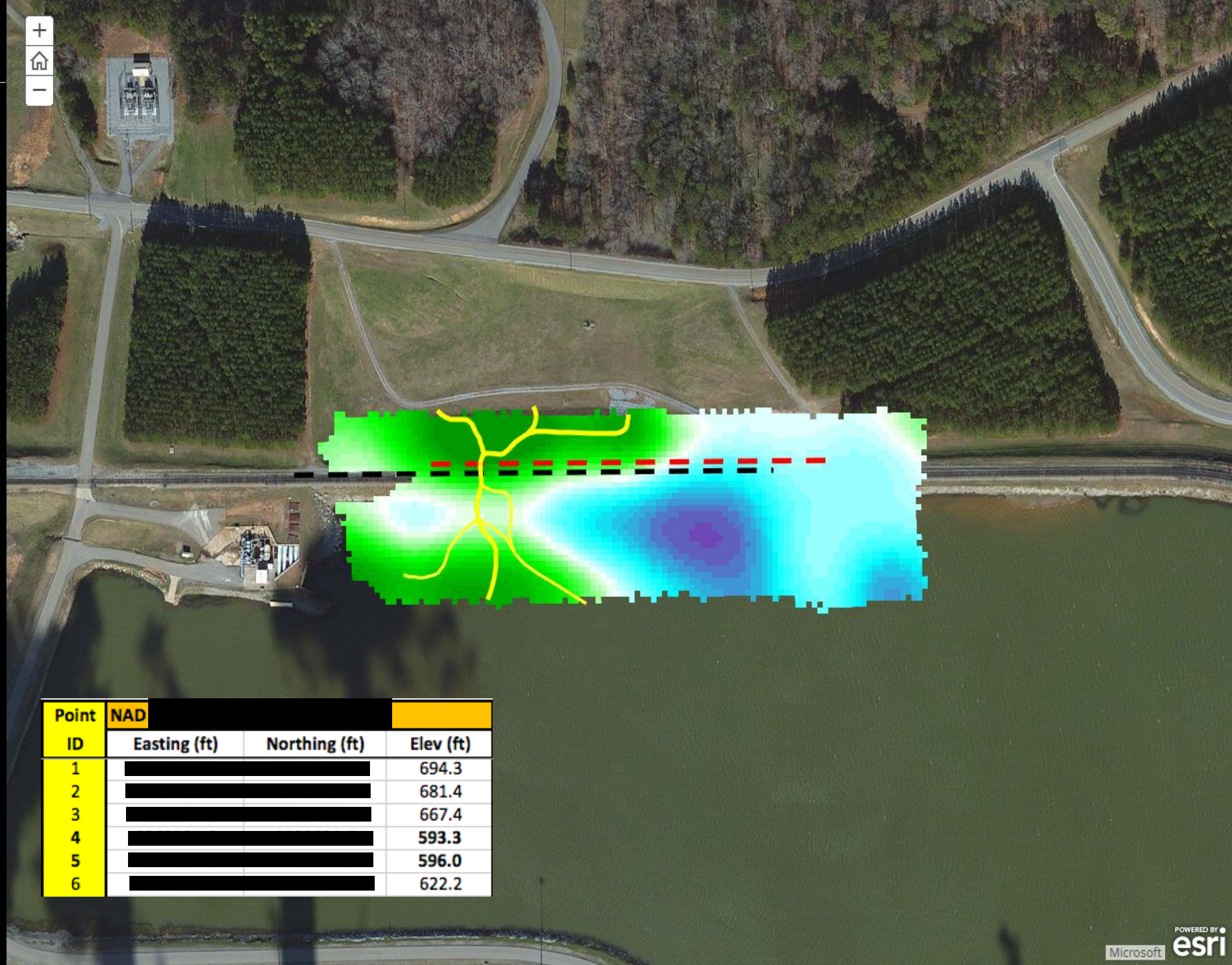
3D Model

- Yellow tubes represent center of flow path
- Flow is under both grout curtains
- Flow bifurcates after passing under the grout curtain



Point ID	NAD [redacted]		
	Easting (ft)	Northing (ft)	Elev (ft)
1	[redacted]		694.3
2	[redacted]		681.4
3	[redacted]		667.4
4	[redacted]		**593.3**
5	[redacted]		**596.0**
6	[redacted]		622.2

Electric Current Distribution Model

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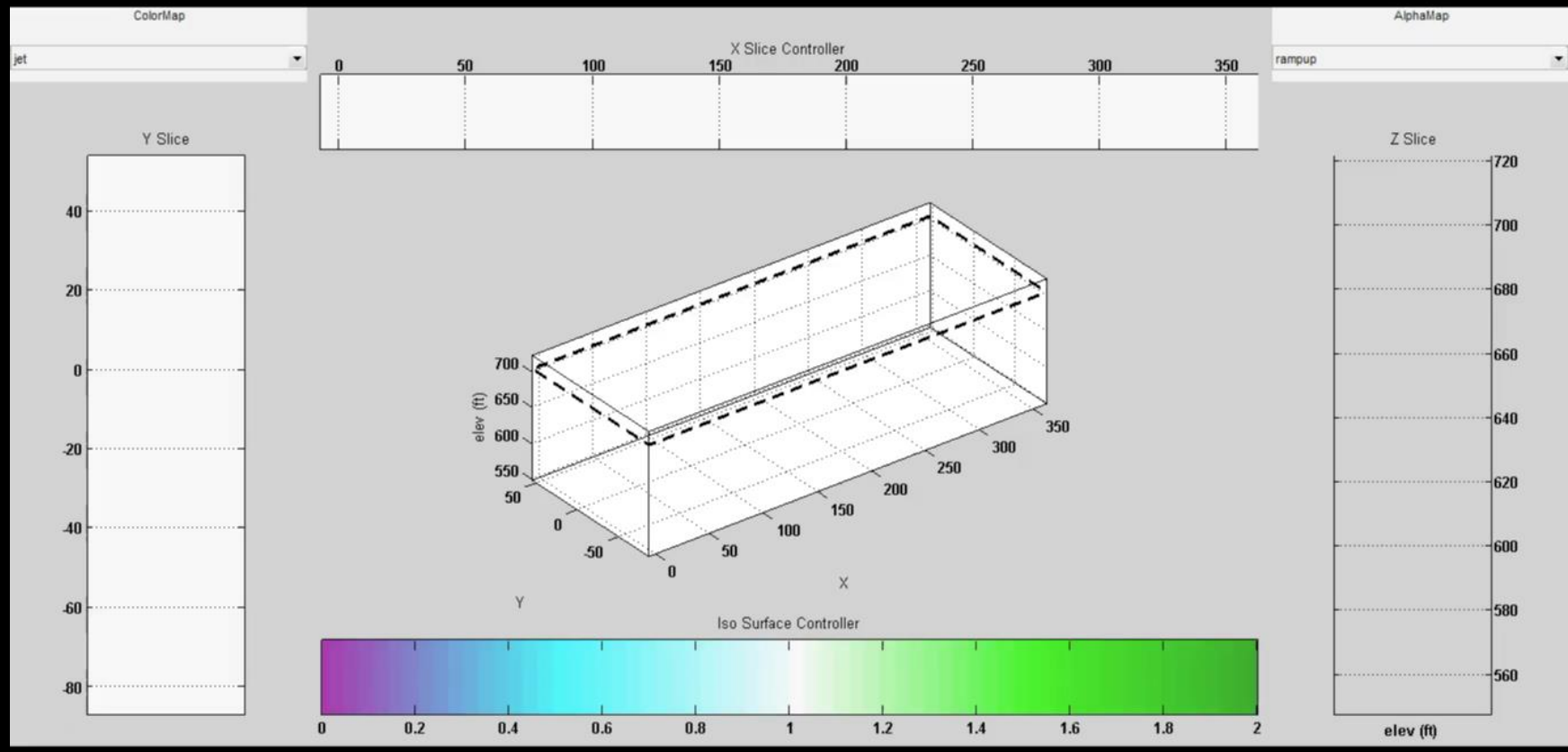


3D Site Model

- Yellow tubes represent center of flow path
- Seep paths flow under both grout curtains
- Flow bifurcates after passing under the grout curtain

Case Studies

Copper Mine in South America

- Major increase in well level
- Significant cost to repair liner

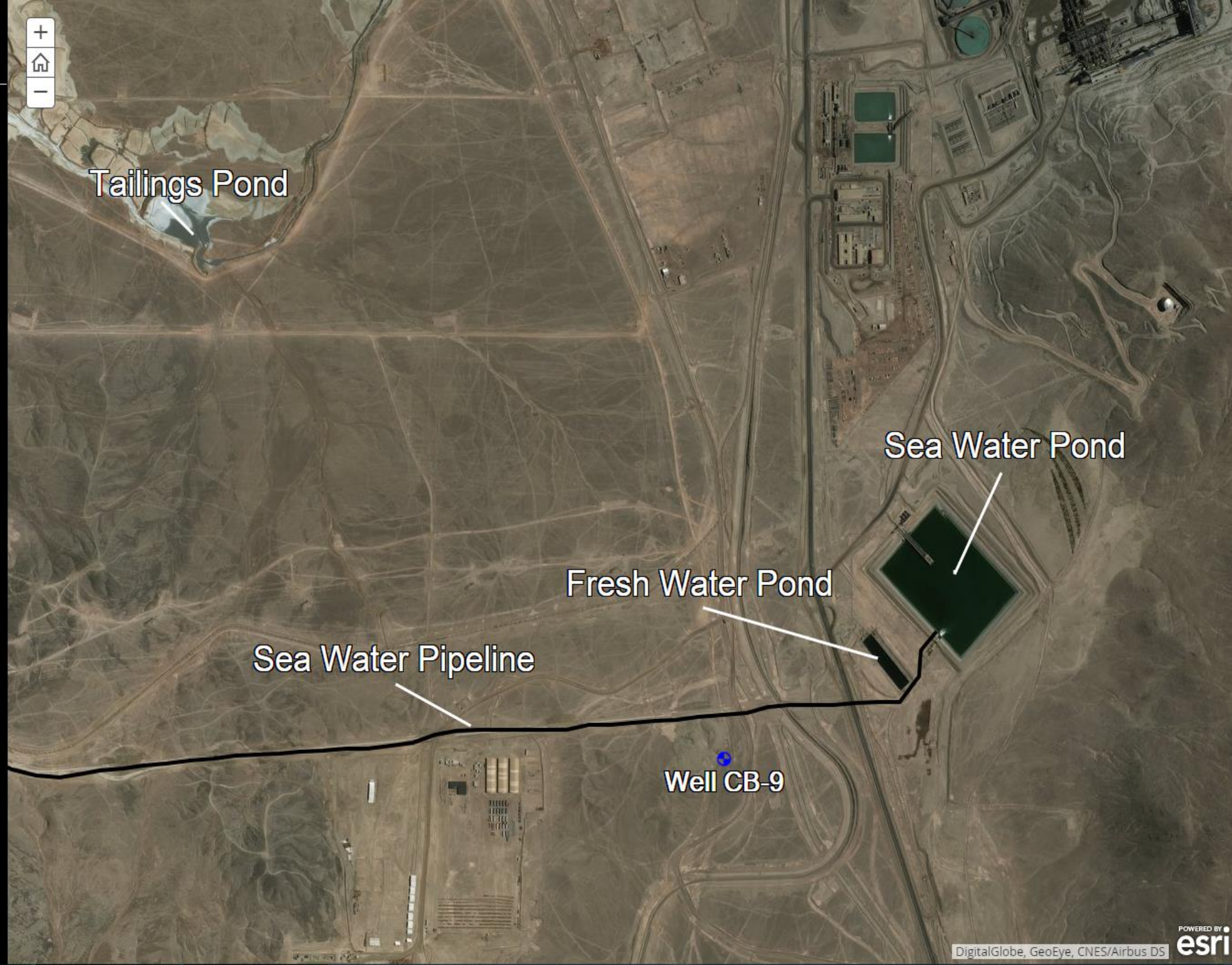
Survey Layout

- Broad survey design
- More readings than normal

Final Results

- No leakage from expected sources
- Leaking from remote tailings impoundment
- Solution was "relatively inexpensive" compared to alternative

3D Model Showing Preferential Flow Paths



Survey Layout

- Broad survey design
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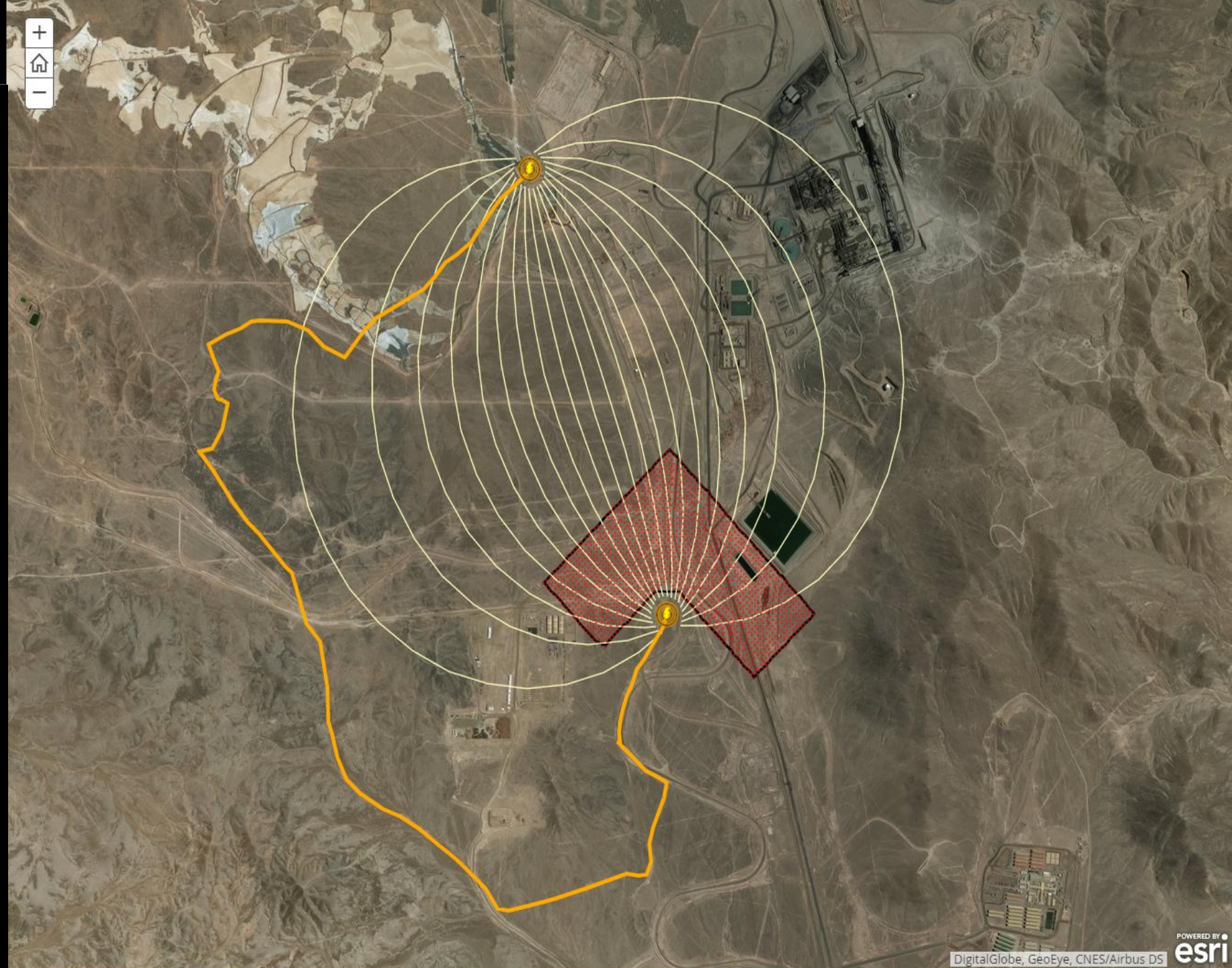
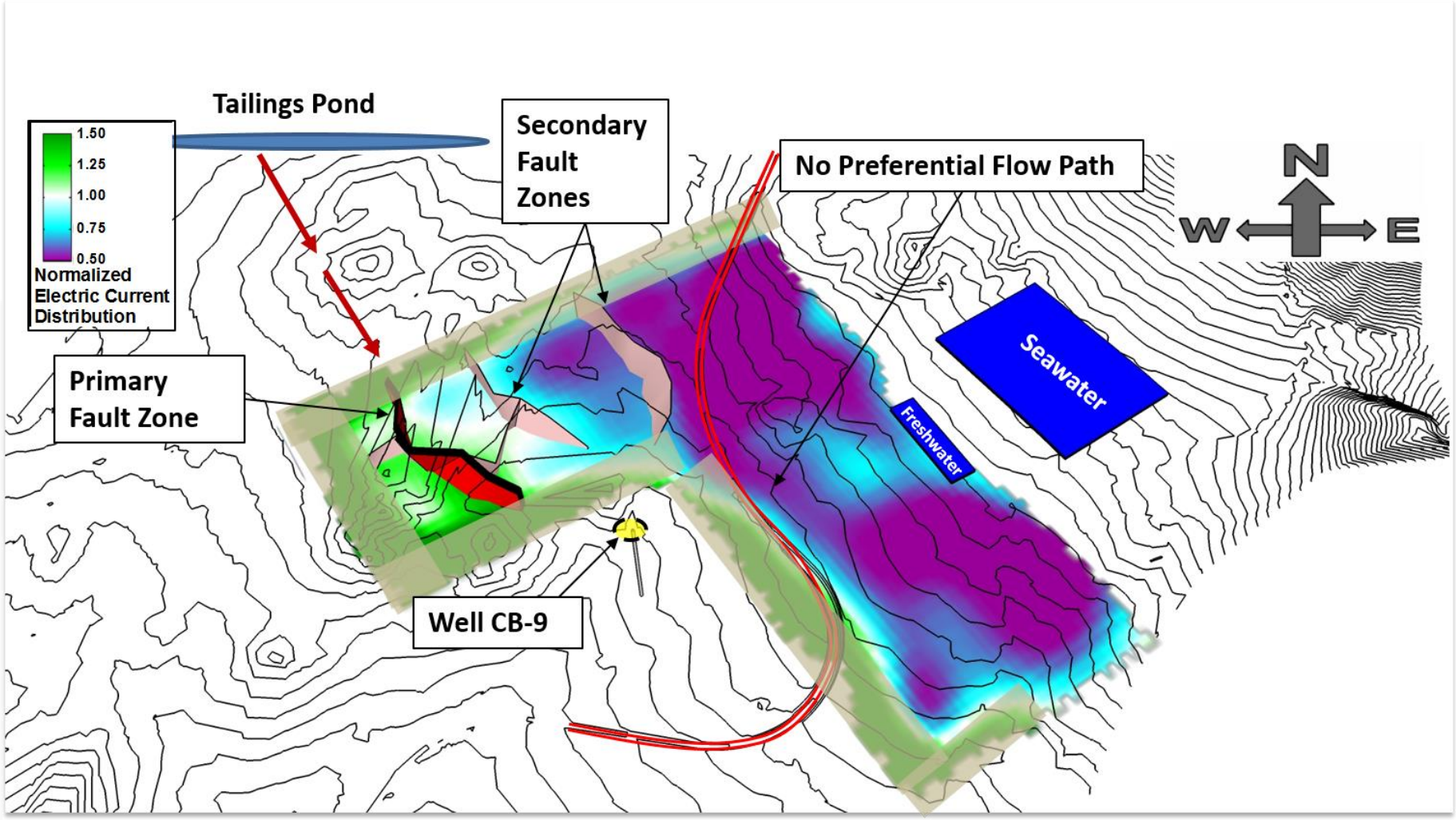


Copper Mine in South America

Final Results

- No leakage from expected sources
- Leaking from remote tailings impoundment
- Focused remediation is always less expensive



Questions?

For the audience:

- Based on what you've seen today, can MMR help eliminate groundwater monitoring requirements entirely through a "no migration" demonstration?

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