PYRAMID
ENVIRONMENTAL & ENGINEERING, P.C.

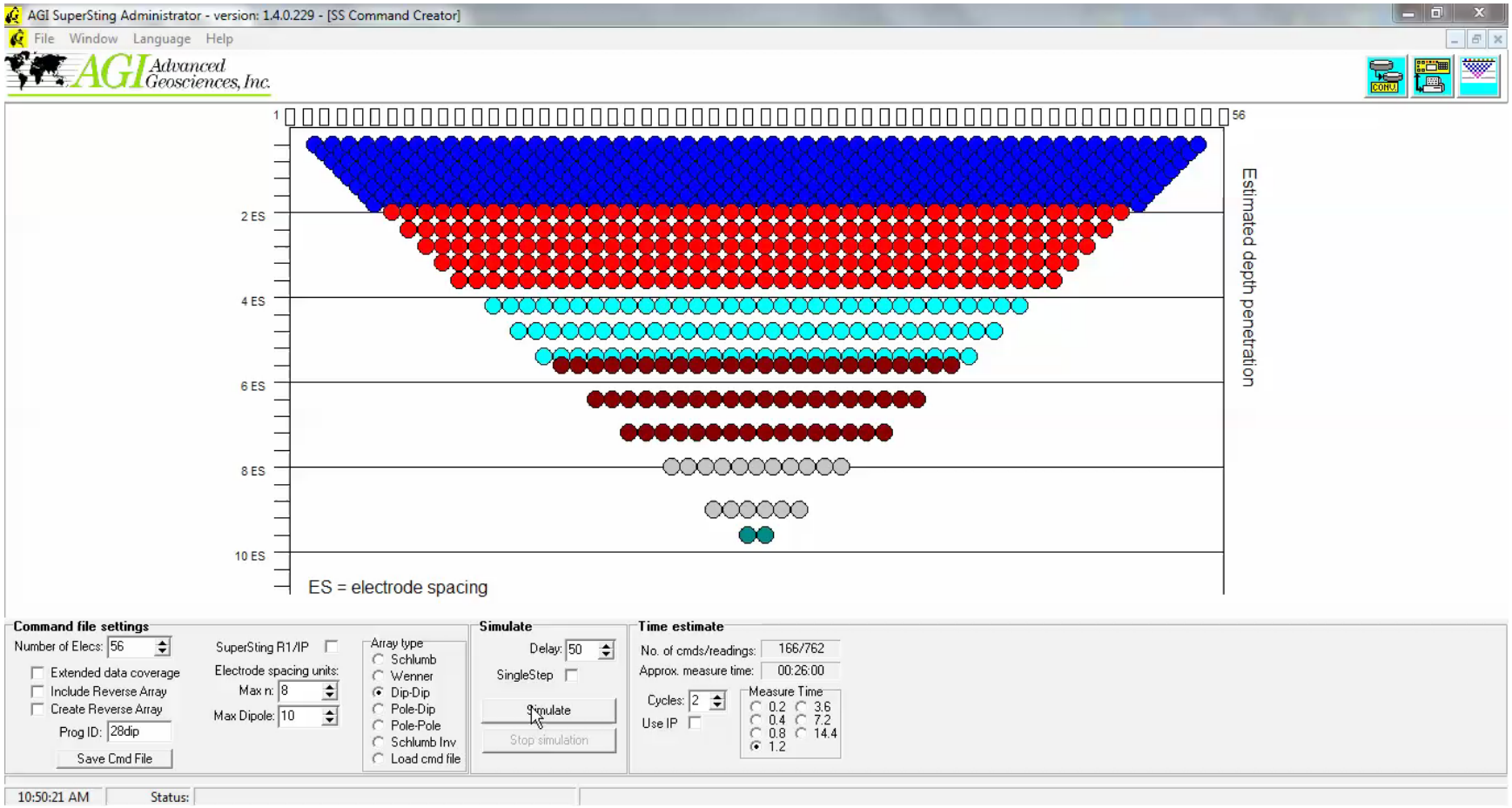
Sinkhole Mapping & Void Detection in Karst – Electrical Resistivity Case Studies at Carlsbad Caverns and in Tennessee

2015 Geohazards Forum

What is Electrical Resistivity?

- Surface geophysical method that measures the electrical resistance of subsurface materials
- Multi-electrode systems incorporate a series of electrodes along a cable, allowing for 2D profiles/cross sections of resistivity
- Electrical current is injected into ground by active electrodes and the resistance of the current is measured at various locations along the line by potential electrodes
- A variety of testing methods (i.e. Dipole-Dipole, Schlumberger, Wenner, Gradient, etc.) can be used to collect data using different combinations of electrodes
- Electrode spacing determines depth of penetration

Dipole-Dipole Method



Applications of Electrical Resistivity

- General geologic site characterization
  - Differentiate between stratigraphic units, water table, rock integrity
  - Differentiate porosity and variations in grain size within a single stratigraphic unit
- Cavity/void detection, karst mapping, sinkholes
- Hydrogeologic investigations (saturated vs. unsaturated, determine production zones for water supply, fracture mapping)
- Geotechnical investigations
- Environmental investigations (plume mapping, flow pathways, top of rock)

Case Studies: Sinkhole Evaluation and Cave/Void Detection

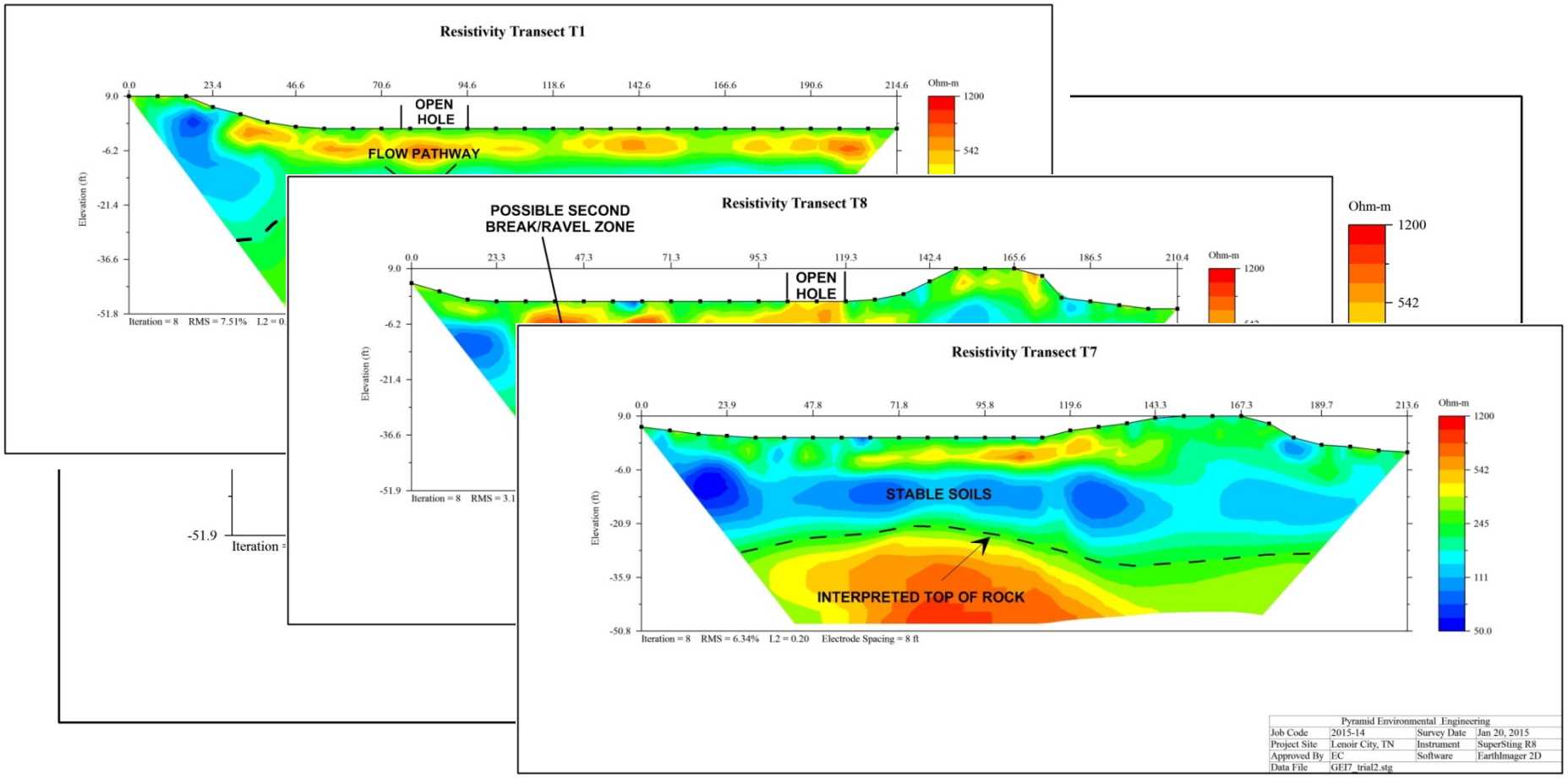
Sinkhole Evaluation - Project Approach

- Establish 2D resistivity transects across and surrounding the open sinkhole
- Evaluate resistivity results for signs of fractures, collapse zones, and/or flow pathways
- Combine 2D results into a 3D model for more comprehensive evaluation of sinkhole conditions
- Provide interpretive reasoning for collapse to be used in remediation discussions

Locations of Resistivity Transects

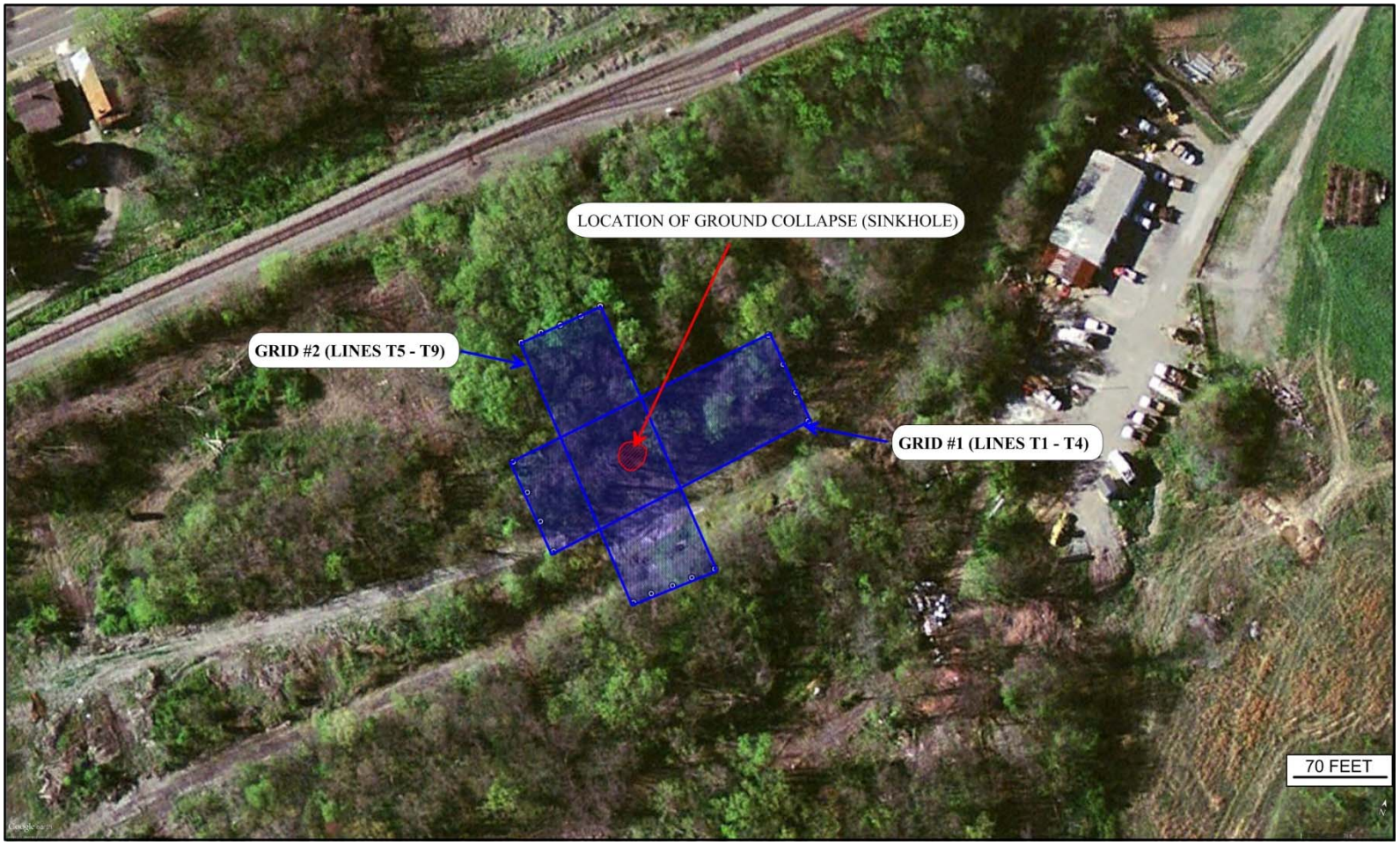
Locations of 2D Resistivity Transects Performed at the Property.
Note: The site is currently cleared, the trees presented in this aerial no longer exist.

Example Resistivity Results

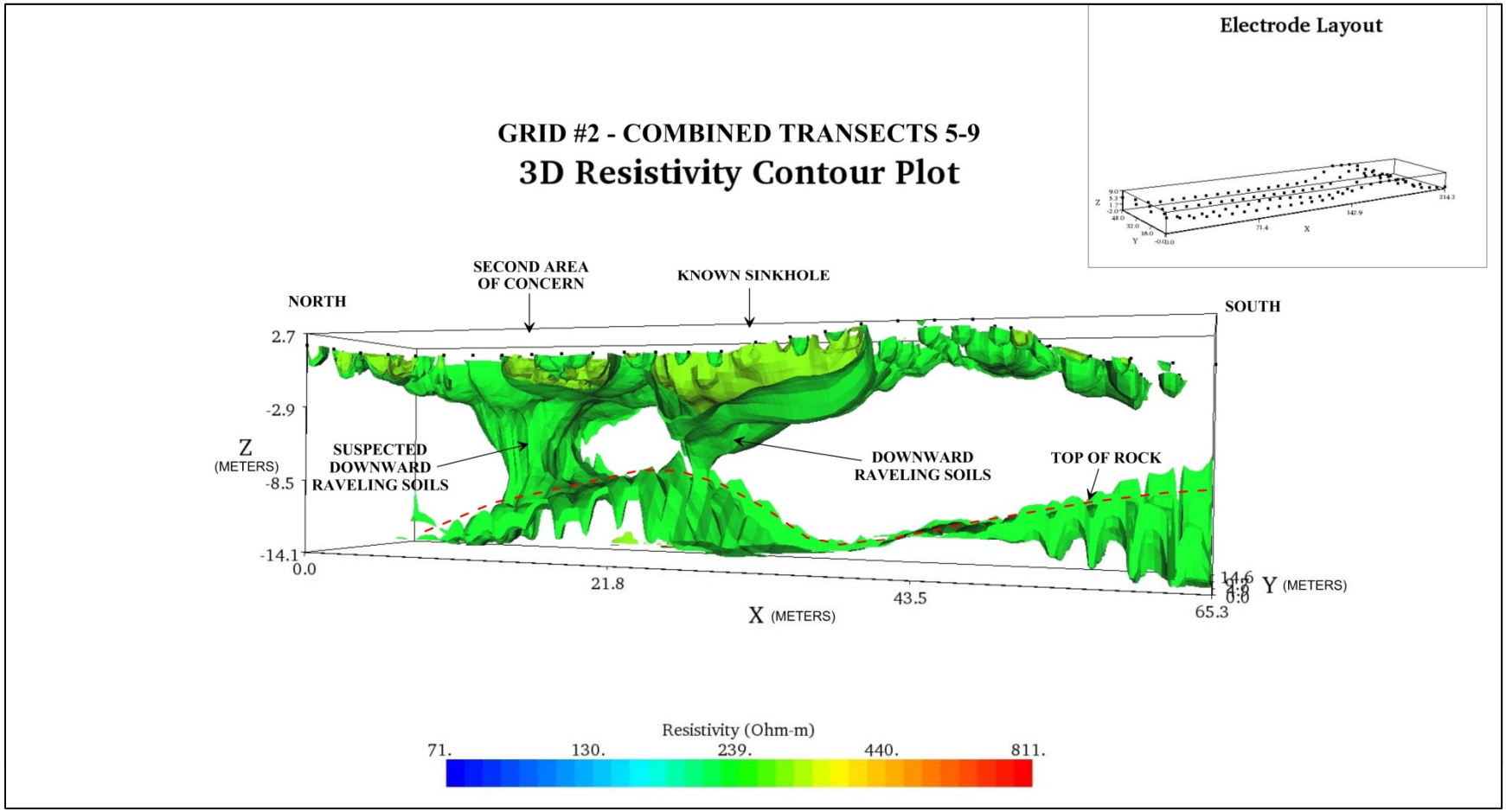


Locations of Possible Collapsing/Flowing Soils

Locations of 3D Resistivity Grids



3D Resistivity Modeling Results

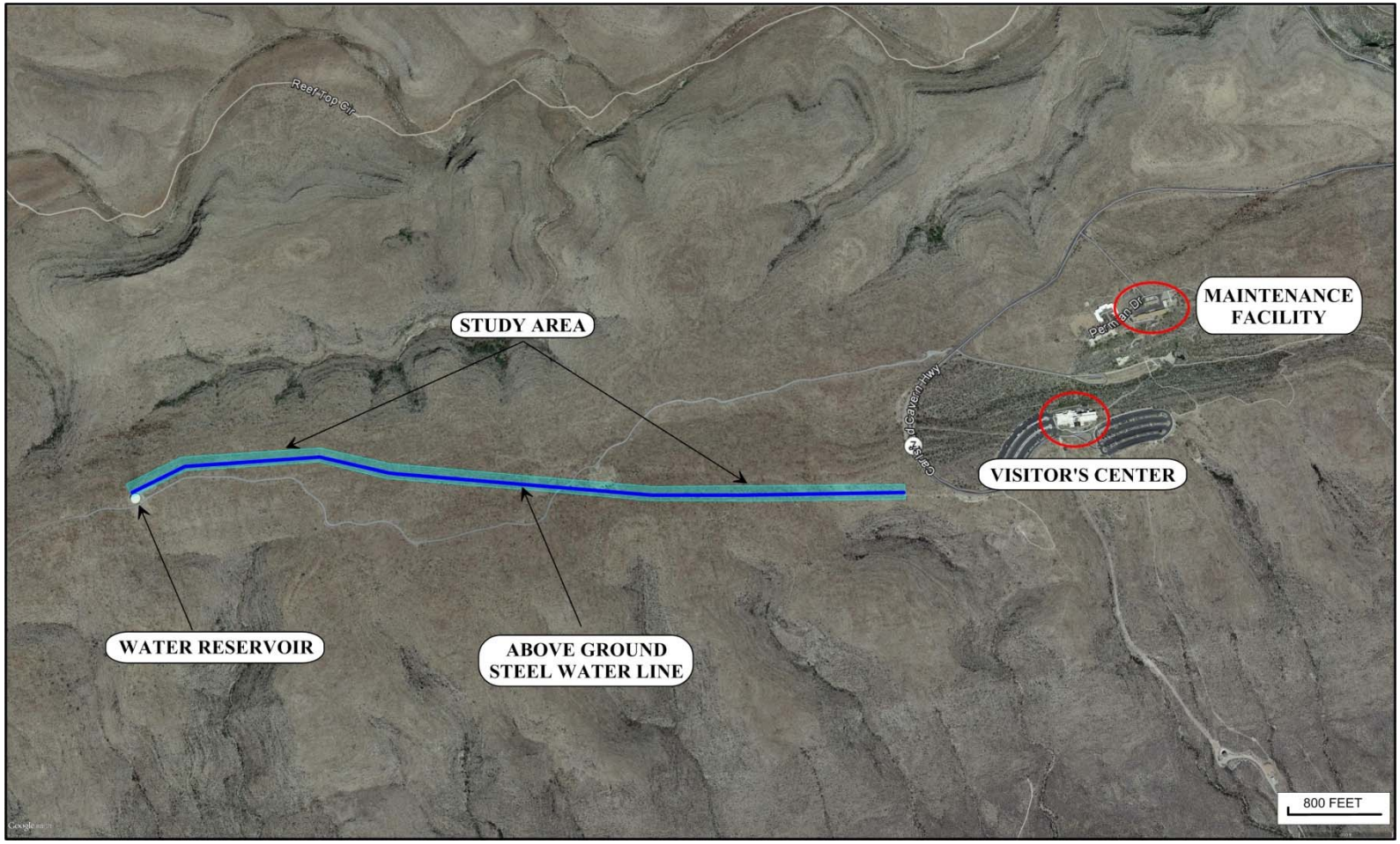


Results of Sinkhole Mapping

- The resistivity survey provided reliable electrical data to make geologic interpretations
- 2D resistivity transects identified geologic anomalies that were indicative of flowing soils and collapse
- 3D resistivity grids further confirmed raveling soils and provided more comprehensive delineation
- Subsequent soil borings provided excellent correlation with interpreted stratigraphy and depth to rock

Carlsbad Caverns Cave/Void Detection

Carlsbad Site Map

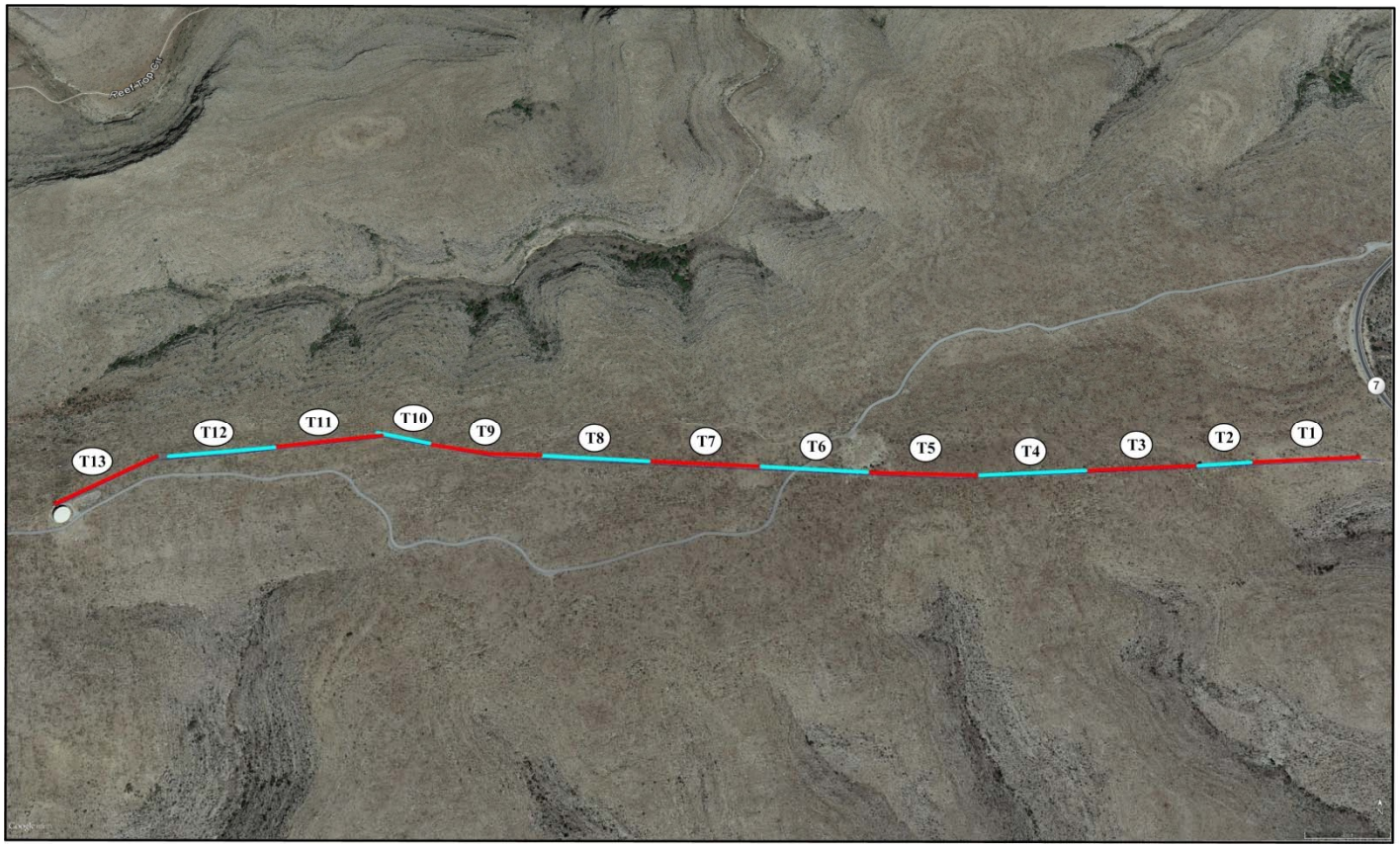


Carlsbad Project Approach

- Perform 2D resistivity mapping along entire length of proposed subsurface water line
  - Use roll-along method
  - Separate results into individual profiles for analysis
- Review 2D geophysical profiles for possible caves/voids
  - Air-filled voids exhibit infinite resistance (theoretically)
  - Effects of possible stalactites/stalagmites and materials surrounding a void can decrease its resistivity
- Perform 3D resistivity surveys at locations of possible caves
  - Series of parallel 2D lines are combined and inverted in 3D
  - 3D models help to further delineate and constrain possible caves observed in 2D profiles

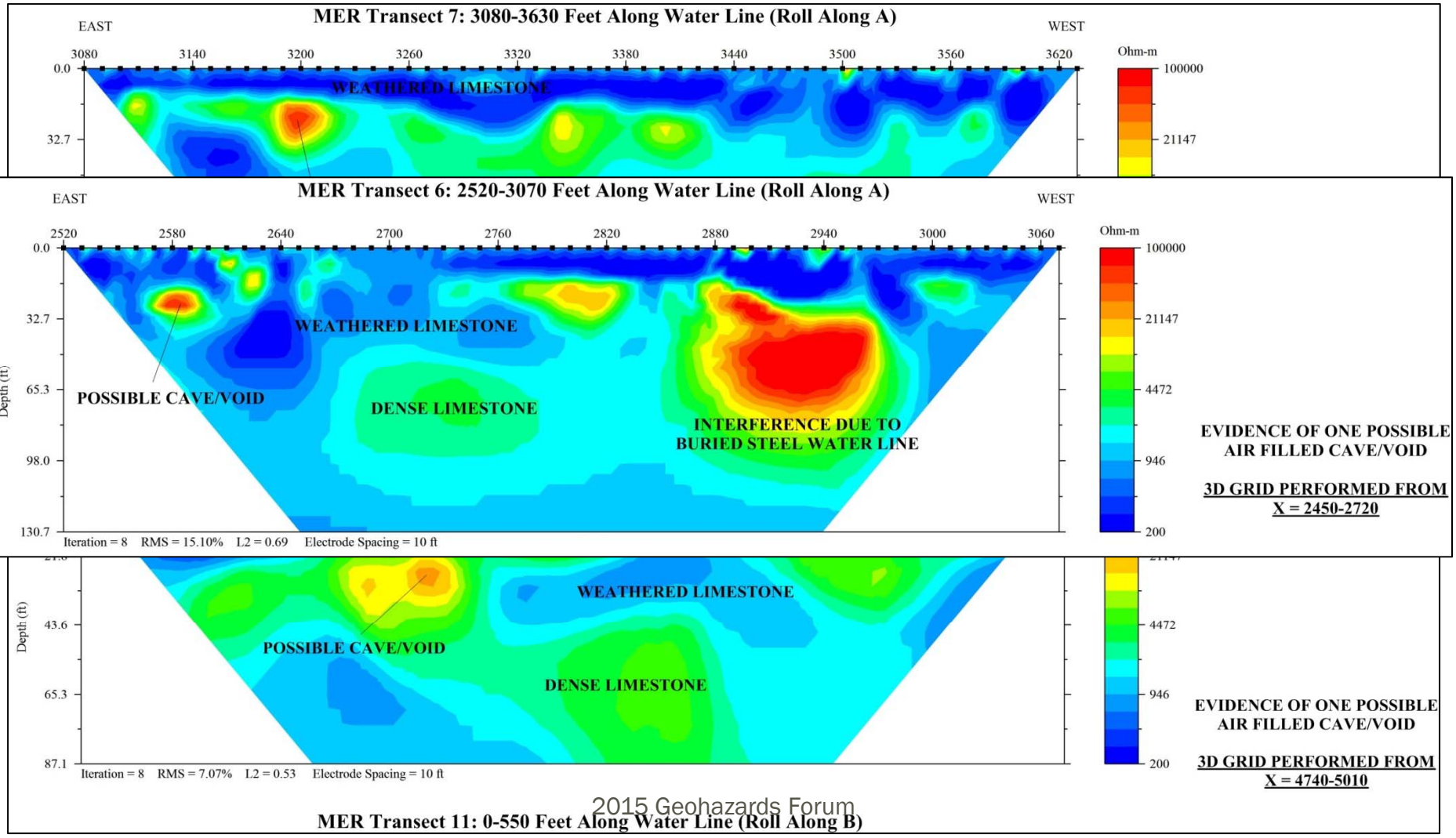
Site Photos

Locations of 2D MER Transects

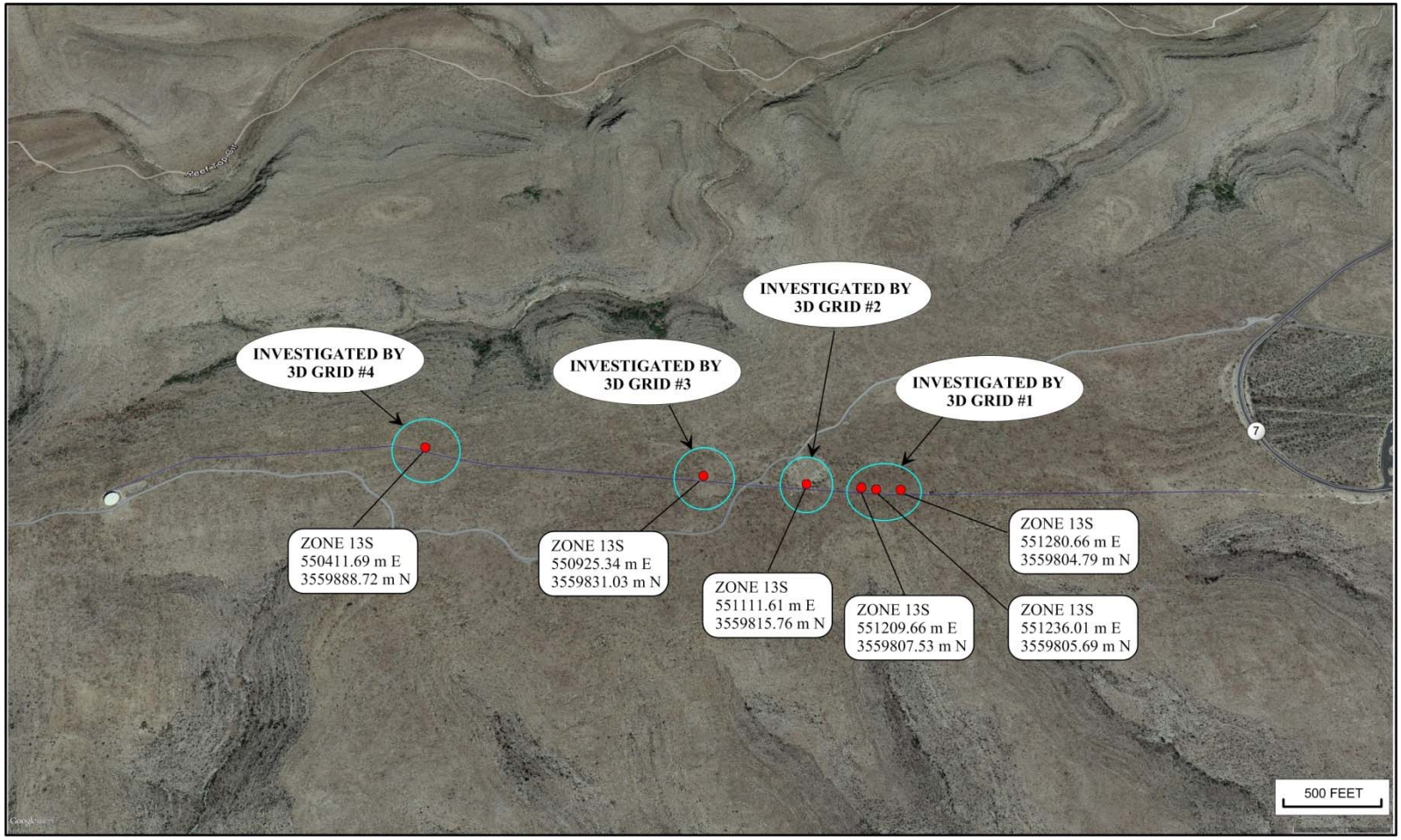


Transect ID	Total Length
T1	550 Feet
T2	270 Feet
T3	550 Feet
T4	550 Feet
T5	550 Feet
T6	550 Feet
T7	550 Feet
T8	550 Feet
T9	550 Feet
T10	370 Feet
T11	550 Feet
T12	550 Feet
T13	540 Feet

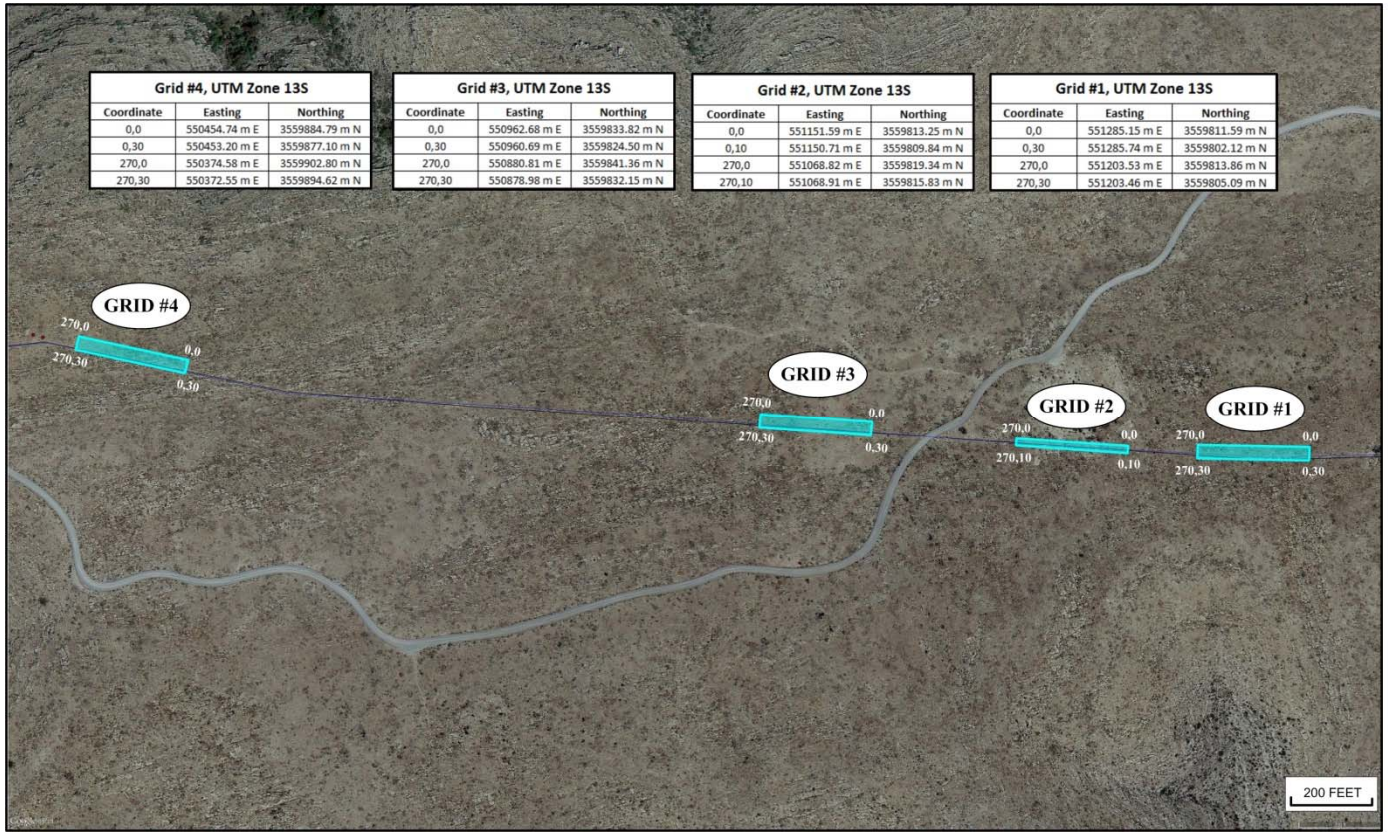
Examples of 2D Resistivity Results

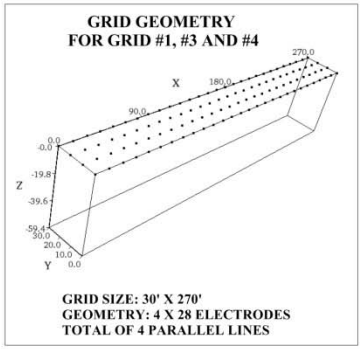


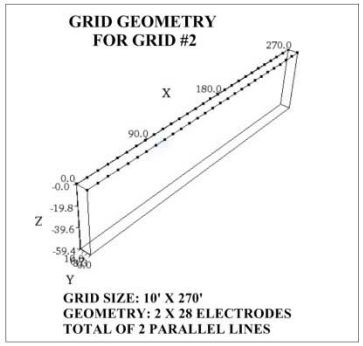
Locations of Possible Voids



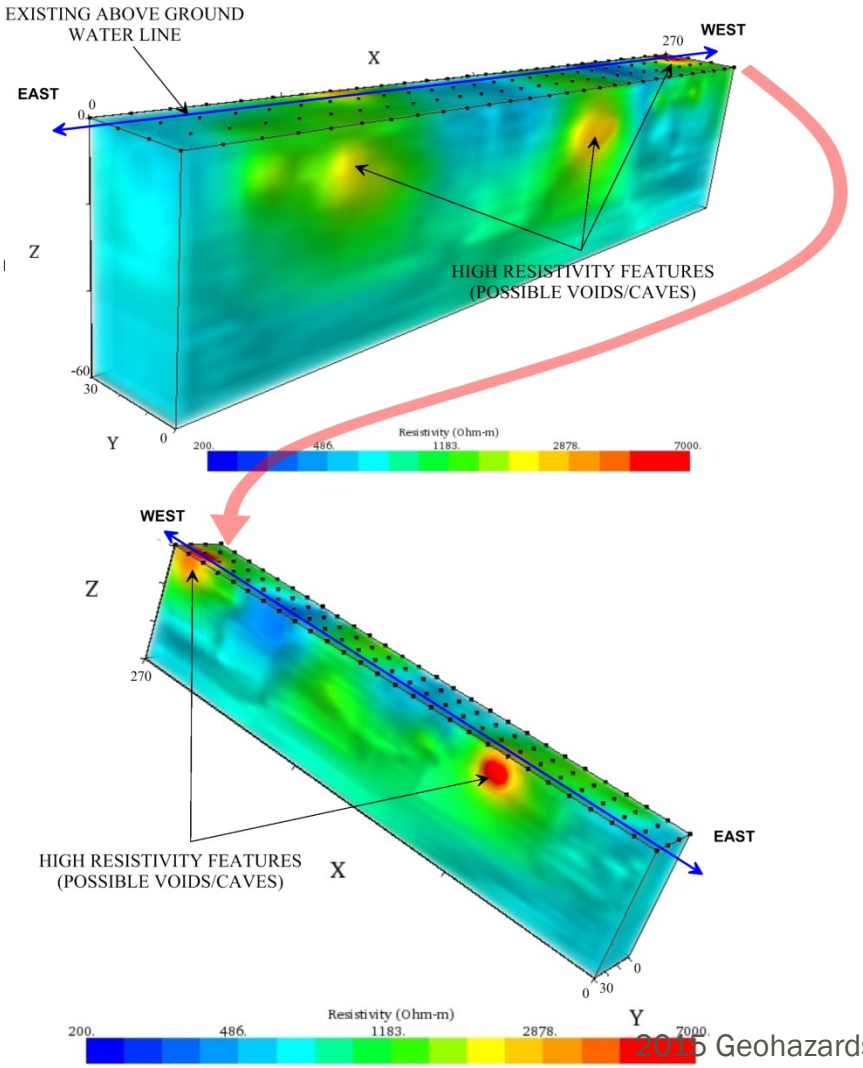
Locations of 3D Grids

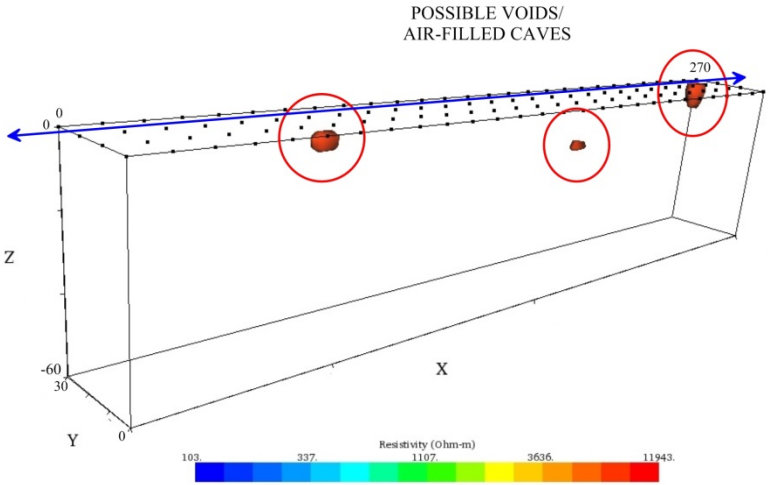






Examples of 3D Model Results

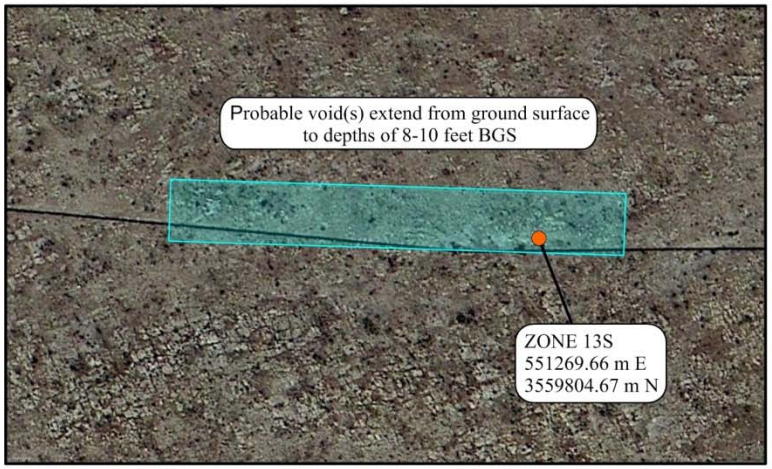




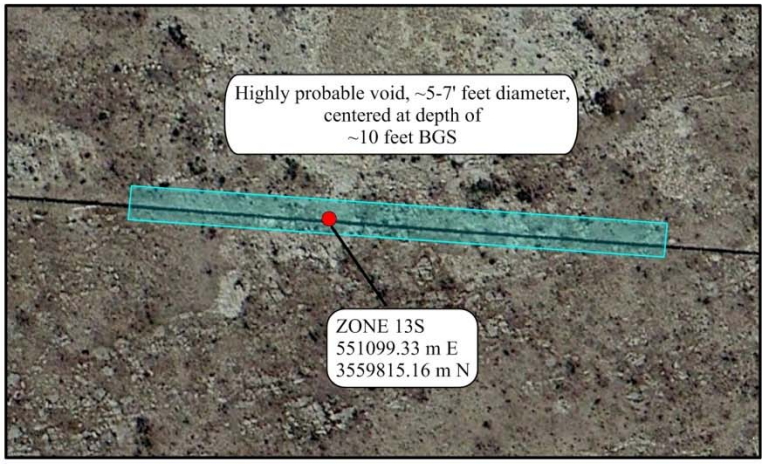
Grid #3, UTM Zone 13S		
Coordinate	Easting	Northing
0,0	550962.68 m E	3559833.82 m N
0,30	550960.69 m E	3559824.50 m N
270,0	550880.81 m E	3559841.36 m N
270,30	550878.98 m E	3559832.15 m N

Final Void Locations and Classifications

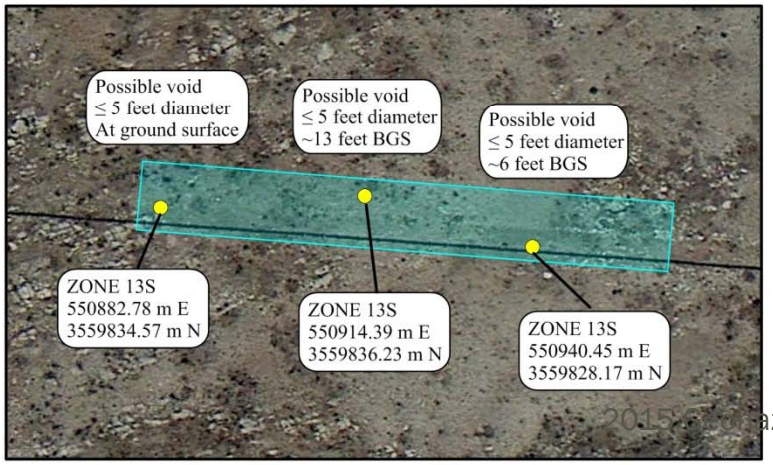
GRID #1 PROBABLE VOID/CAVE



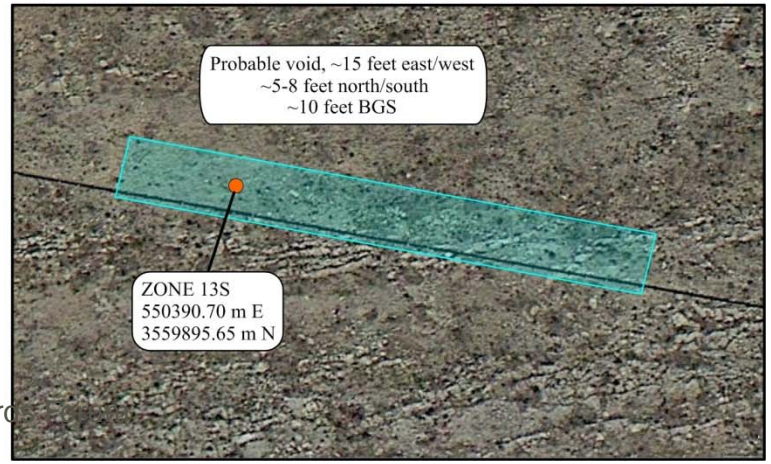
GRID #2 HIGHLY PROBABLE VOID/CAVE



GRID #3 POSSIBLE VOIDS/CAVES



GRID #4 PROBABLE VOID/CAVE



Results of Cave Mapping

- 2D resistivity mapping provided accurate analysis of possible voids along water line route
- Buried metal pipe resulted in interference at road crossing
- 3D surveys allowed for more detailed delineation and classification of voids
  - One highly probable void
  - Two probable voids
  - Three possible voids
- GPS integration provided the NPS with accurate locations for construction design purposes

Questions?