

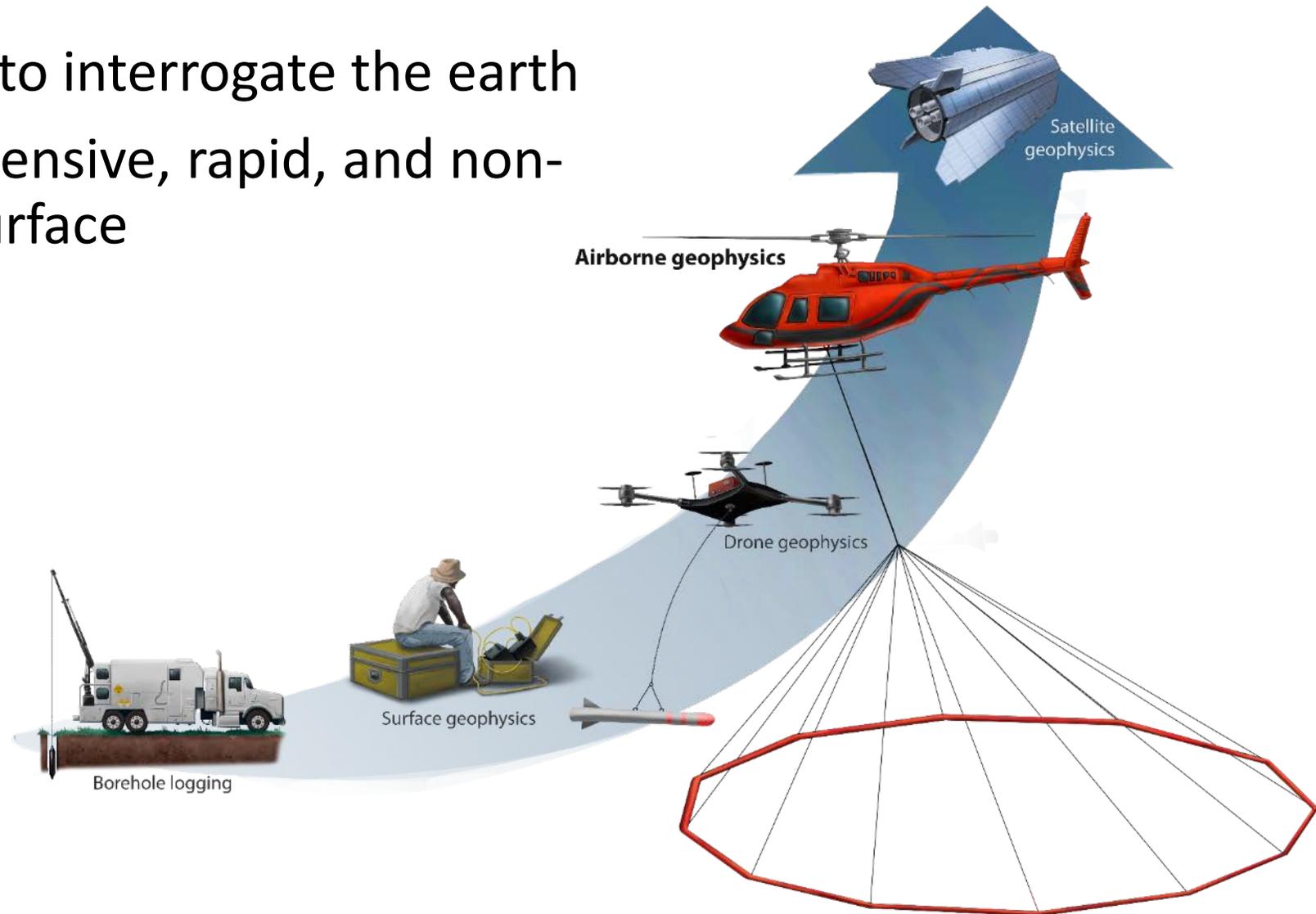
Helicopter-based Electromagnetic Imaging of Clinch River and Bellefonte Nuclear Sites



Dale Rucker, hydroGEOPHYSICS, Inc

Why Geophysics?

- There are only a few ways to interrogate the earth
- Geophysics offers an inexpensive, rapid, and non-intrusive view of the subsurface
- **Airborne geophysics** can deploy a variety of tools without terrain or vegetation issues
 - Cover **up to 200 miles per day**
 - Investigate to **depths that exceed 1000 ft.**

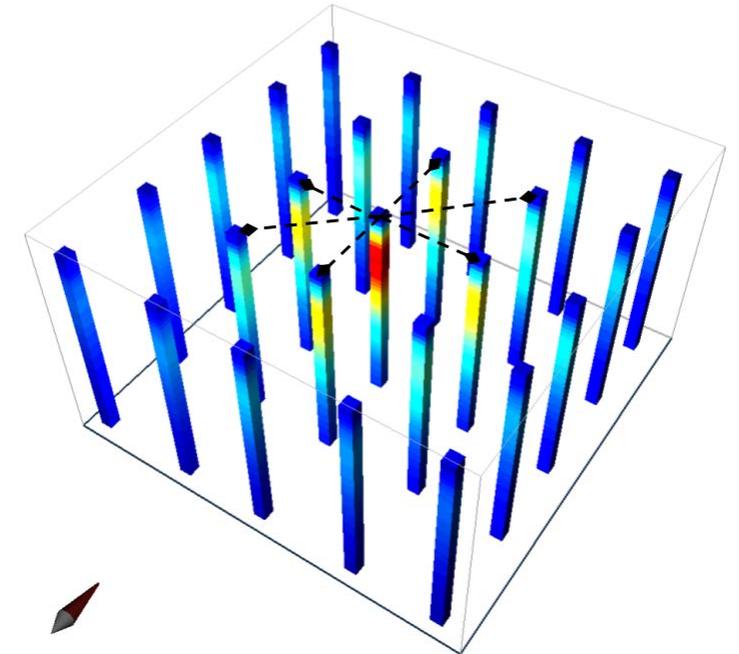
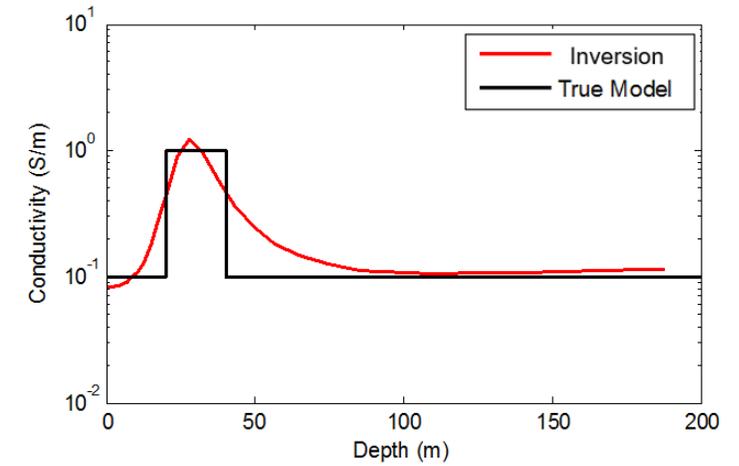
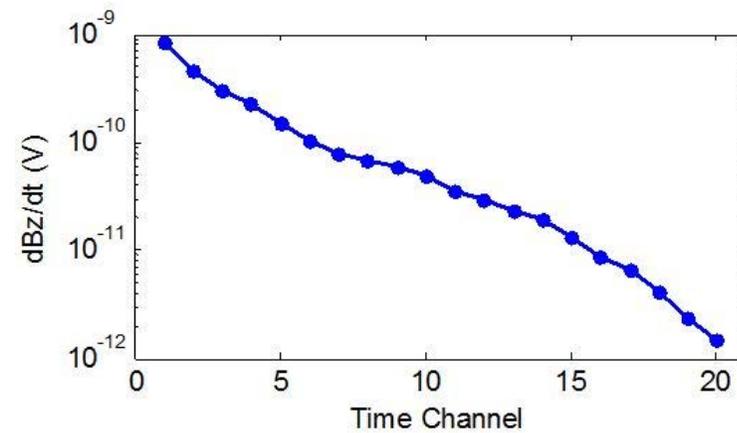
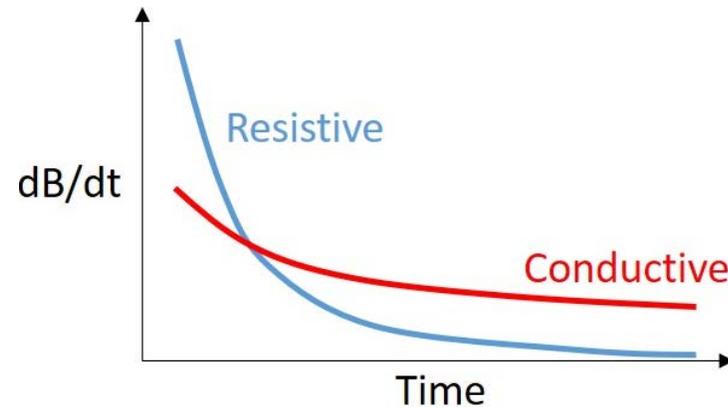
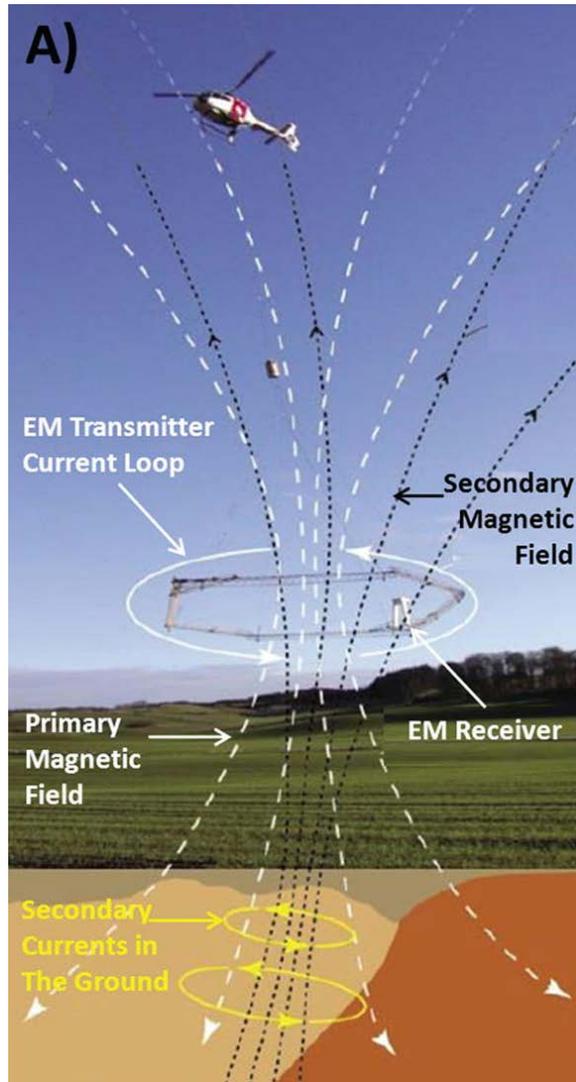


What is Electromagnetic Geophysics

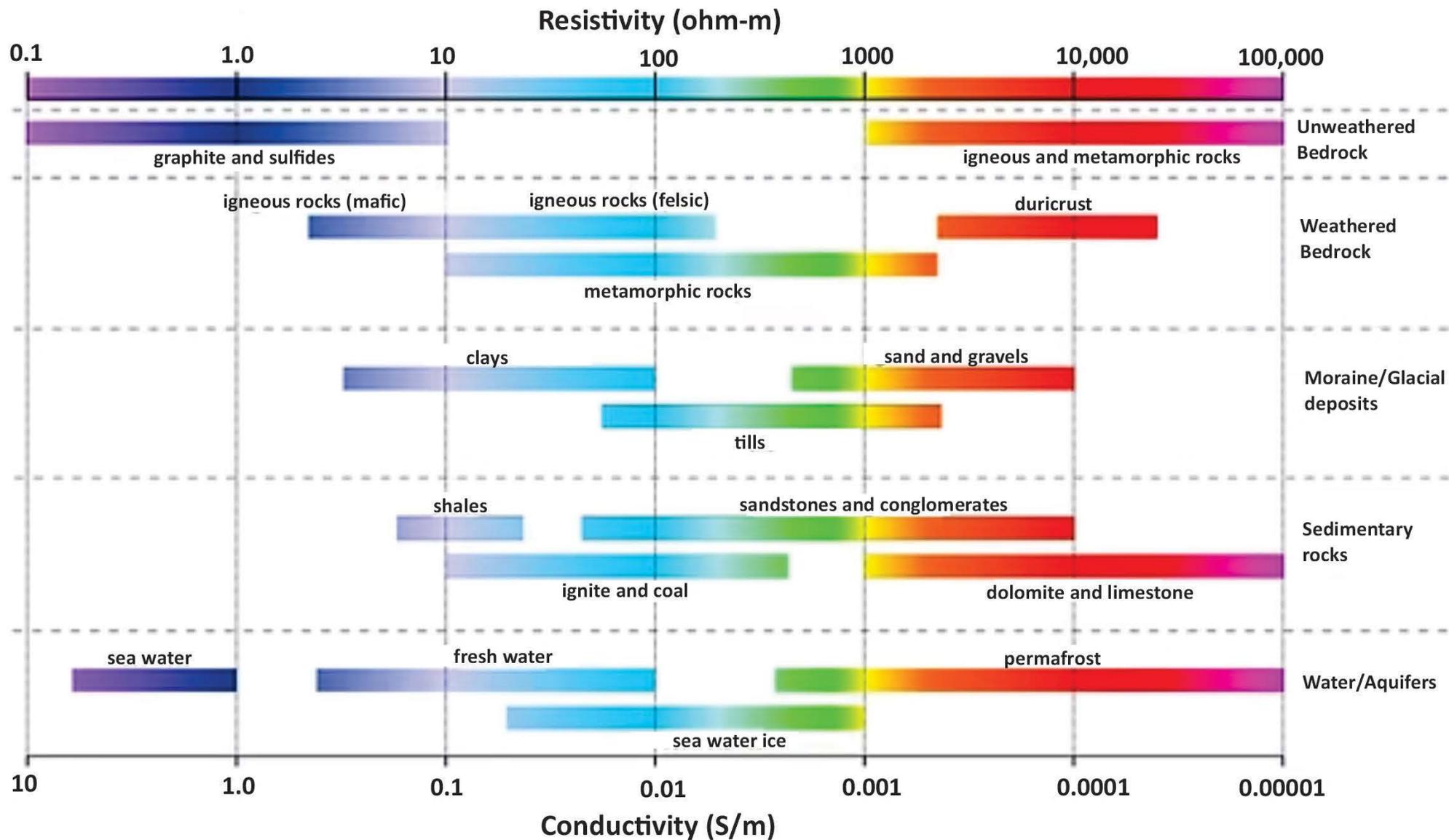
- Electromagnetics relies on induction
 - Alternating current in a transmitting loop
 - **Primary magnetic field** penetrates the earth, finds conductive bodies
 - New electrical current generated in the body, emits **secondary magnetic field**
 - Receiver loop measures the strength of the secondary magnetic field
 - The data are modeled as 1-D soundings of resistivity vs depth.



Schematic, Data, Model

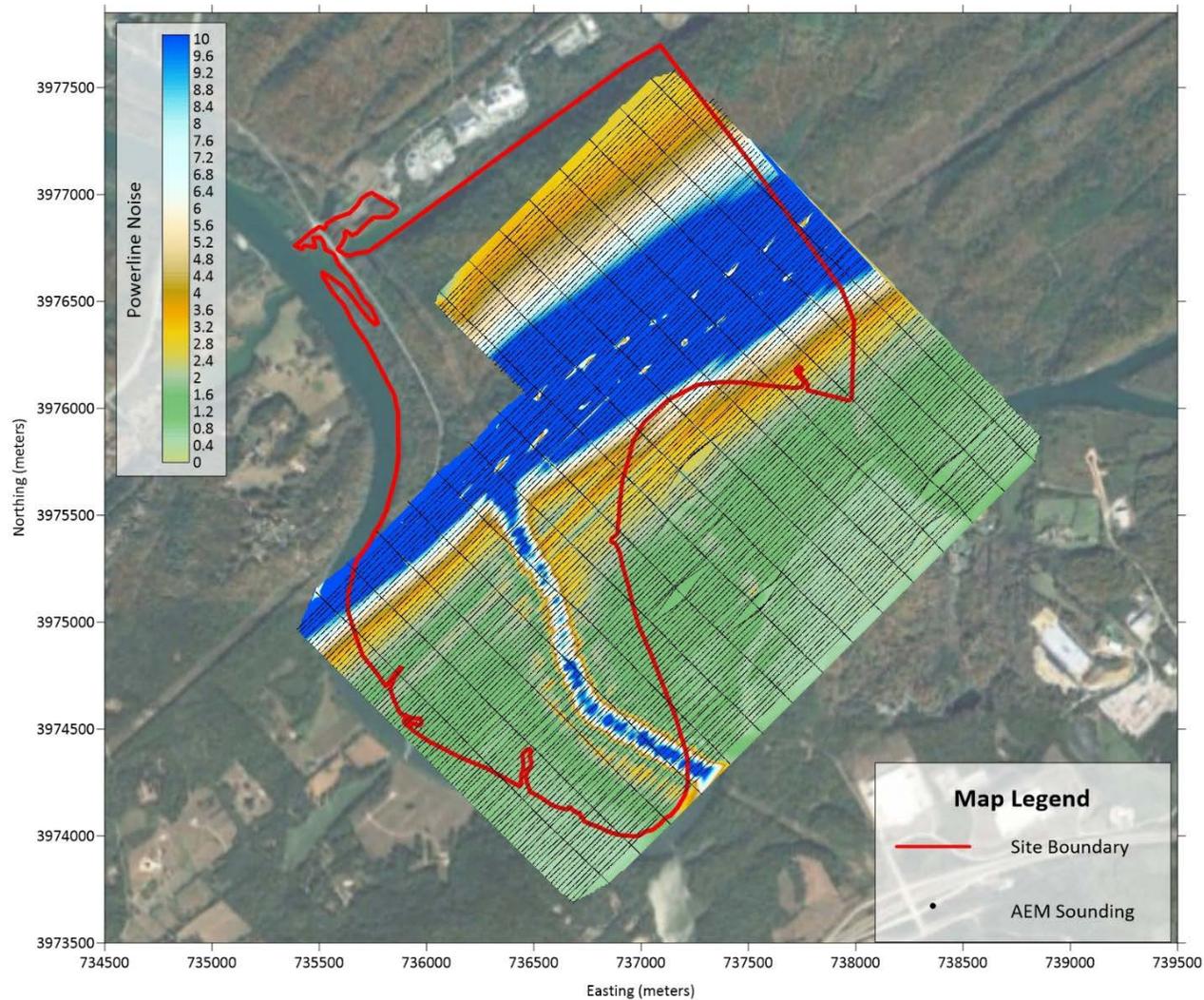


Electrical Properties of Earth Materials

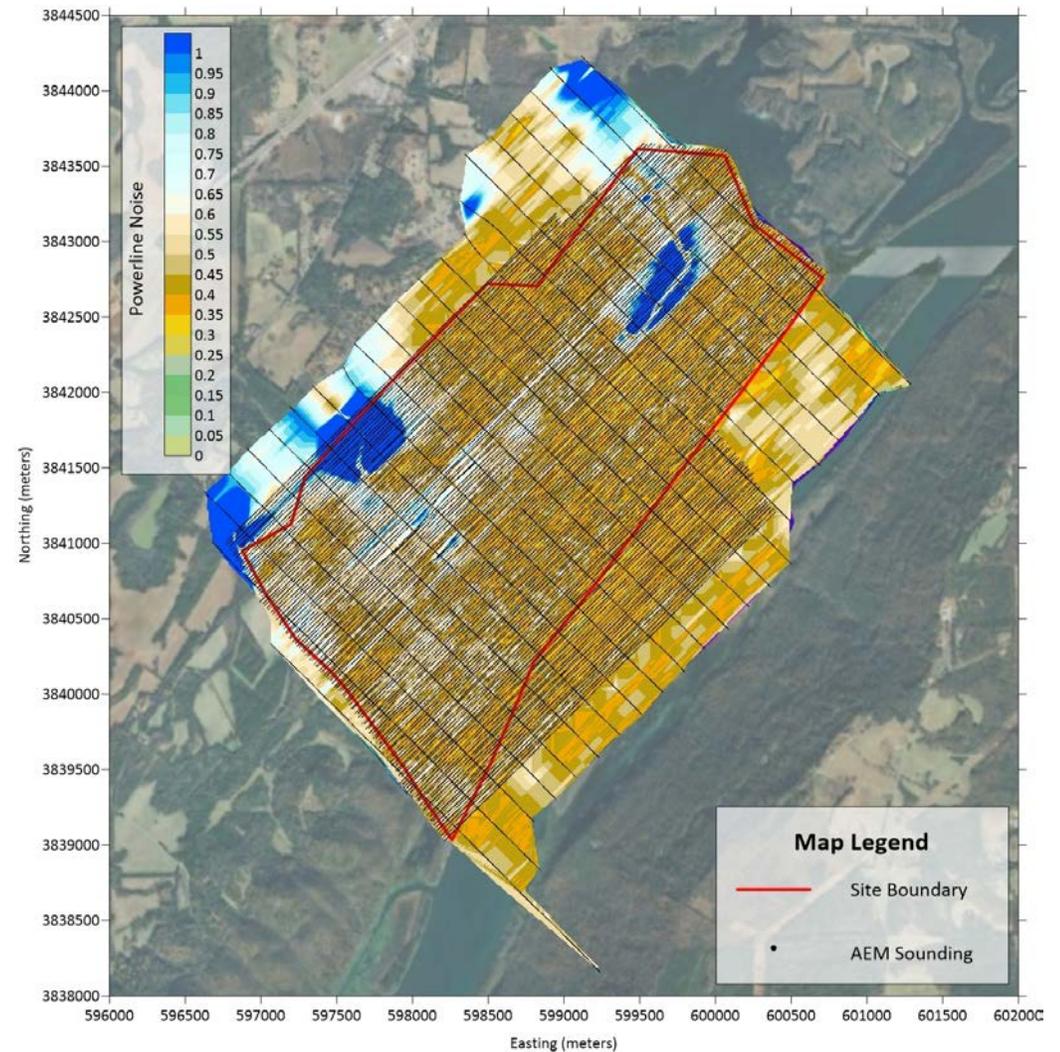


Scope for the Two Sites

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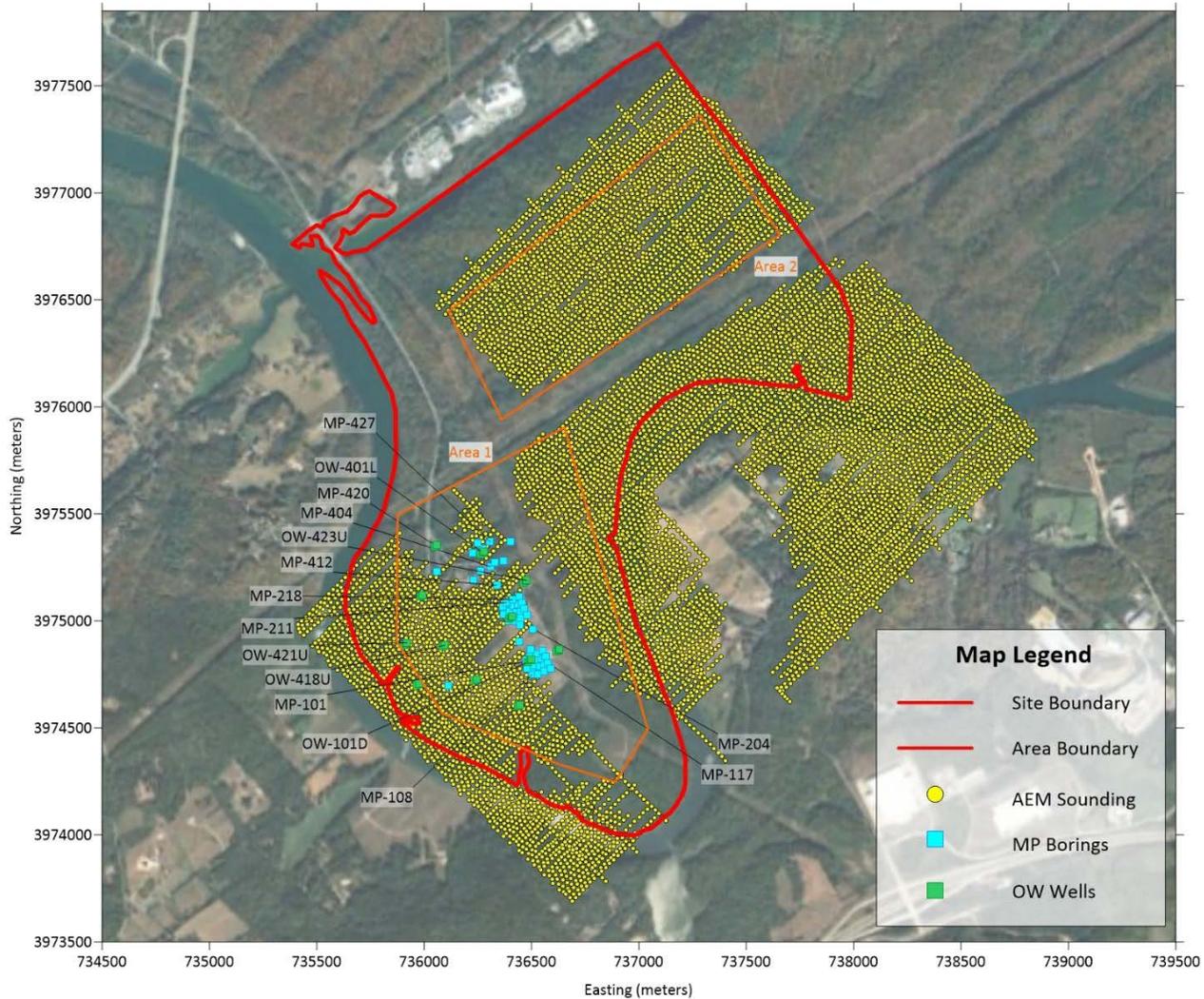


Bellefonte (BLN)

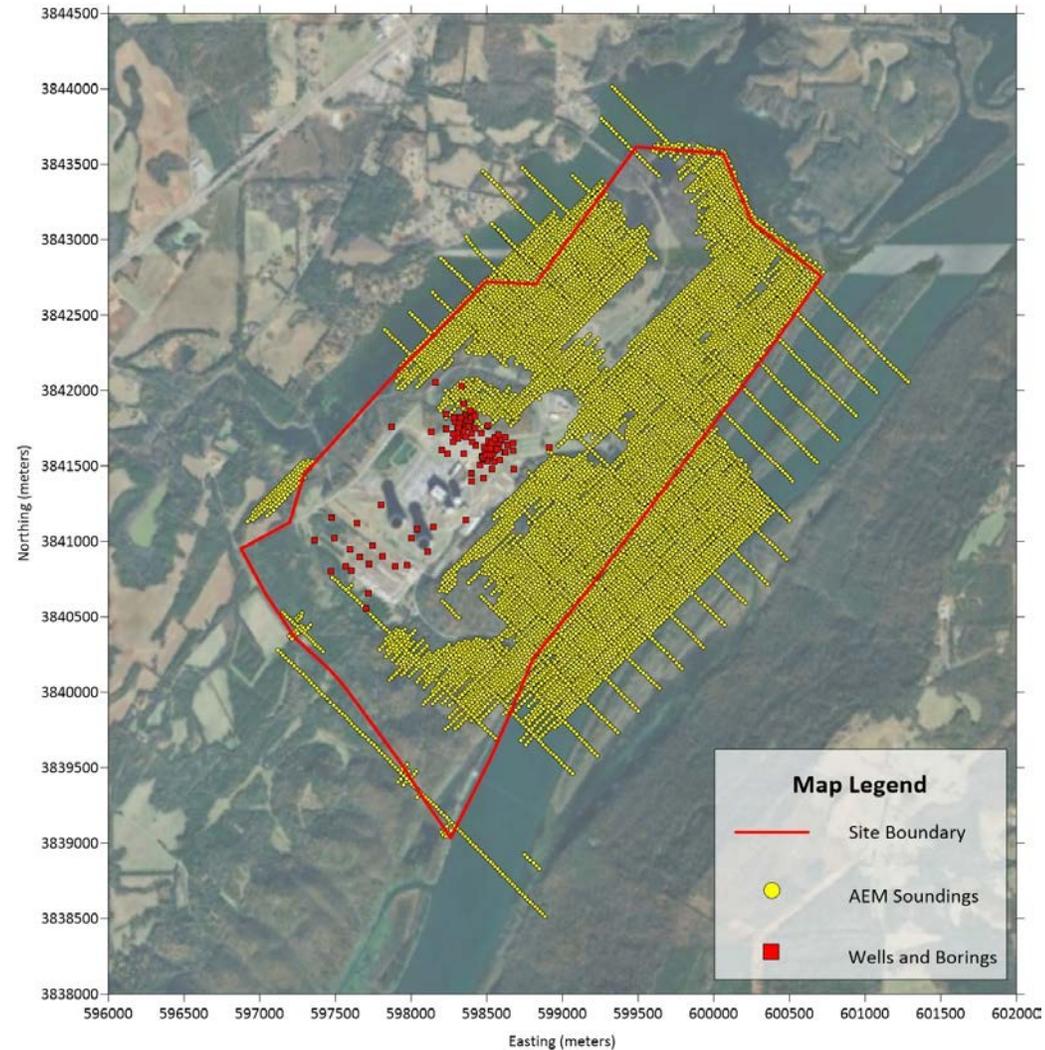


Remaining Data (after noise removal)

Clinch River (CRN)



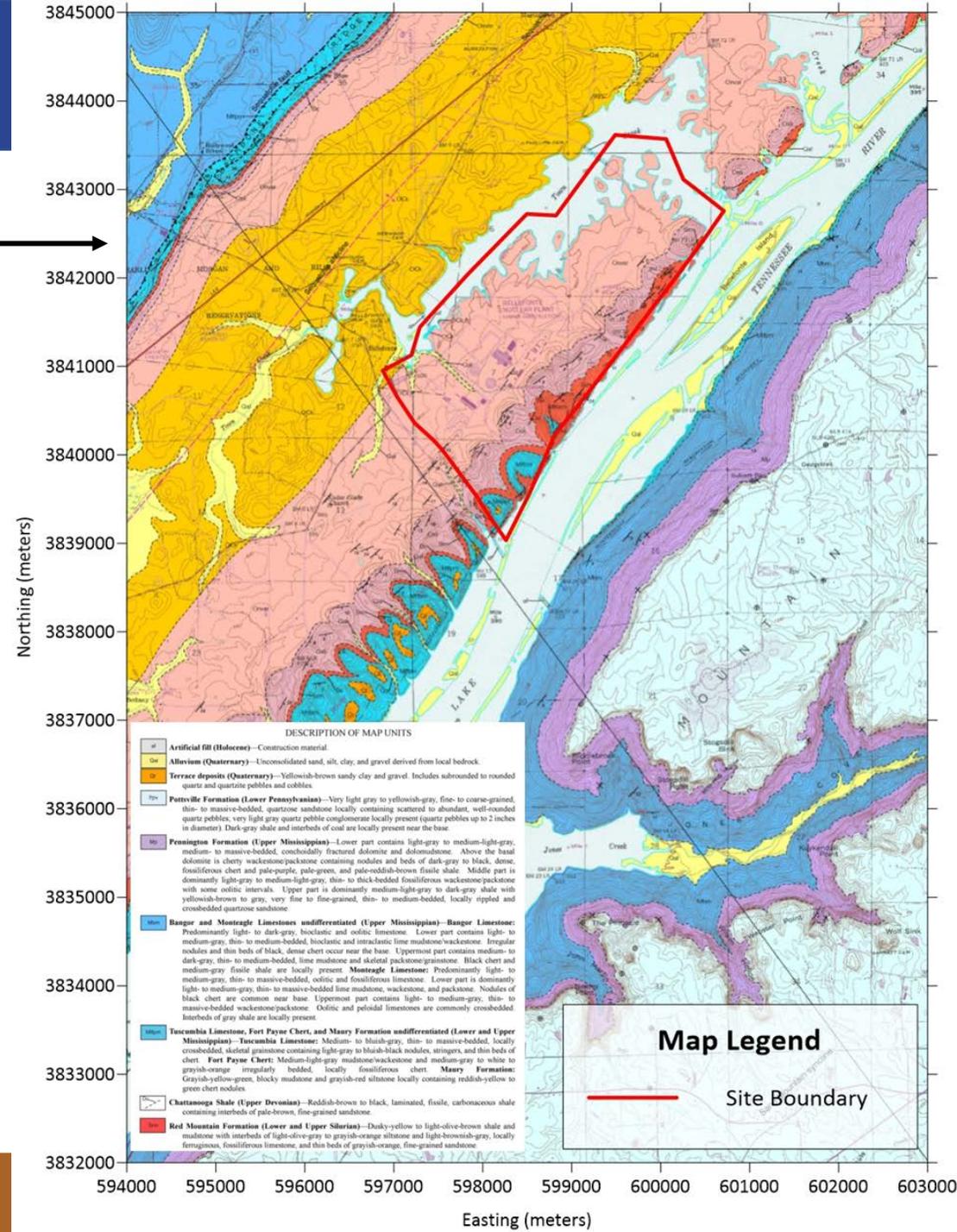
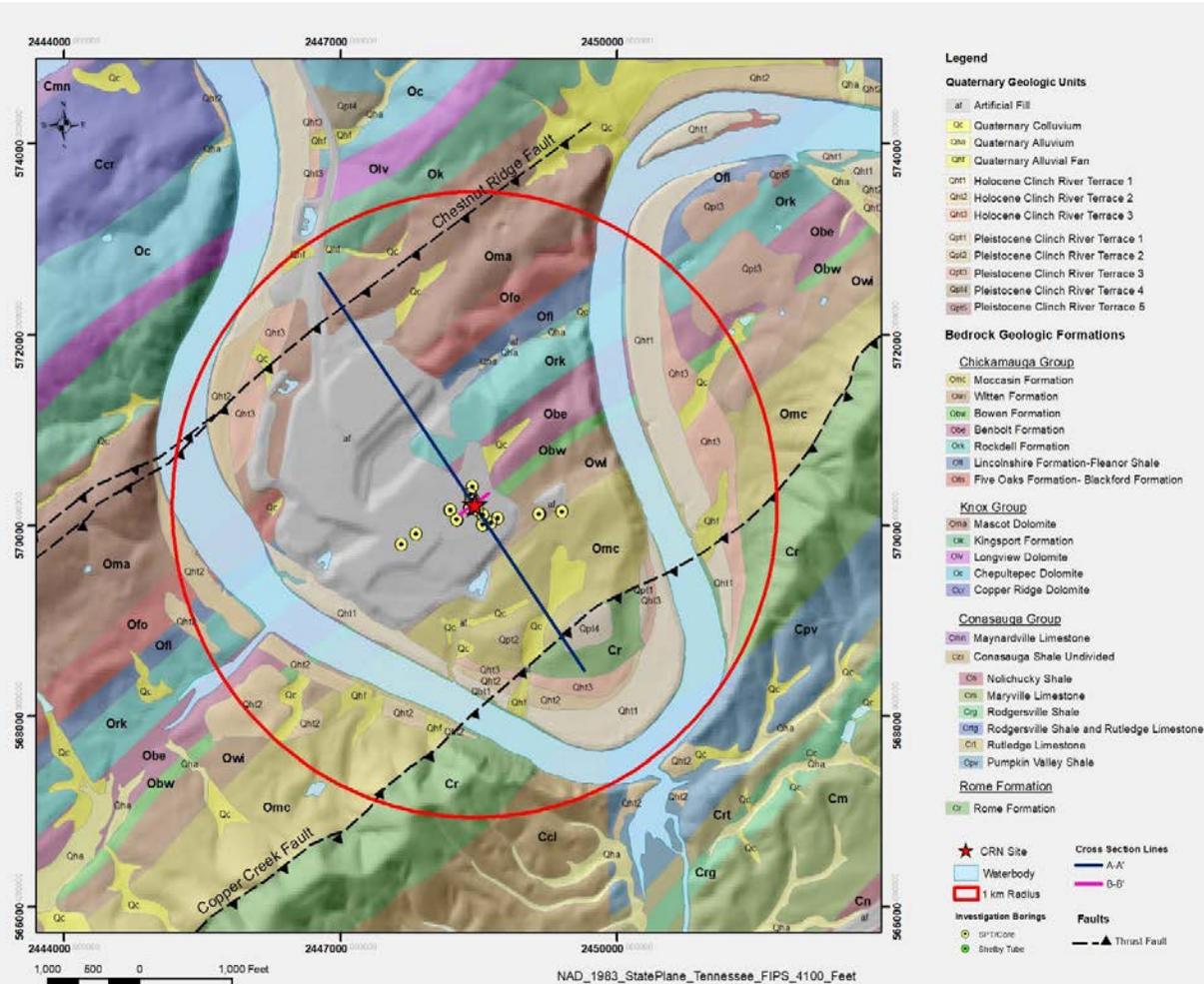
Bellefonte (BLN)



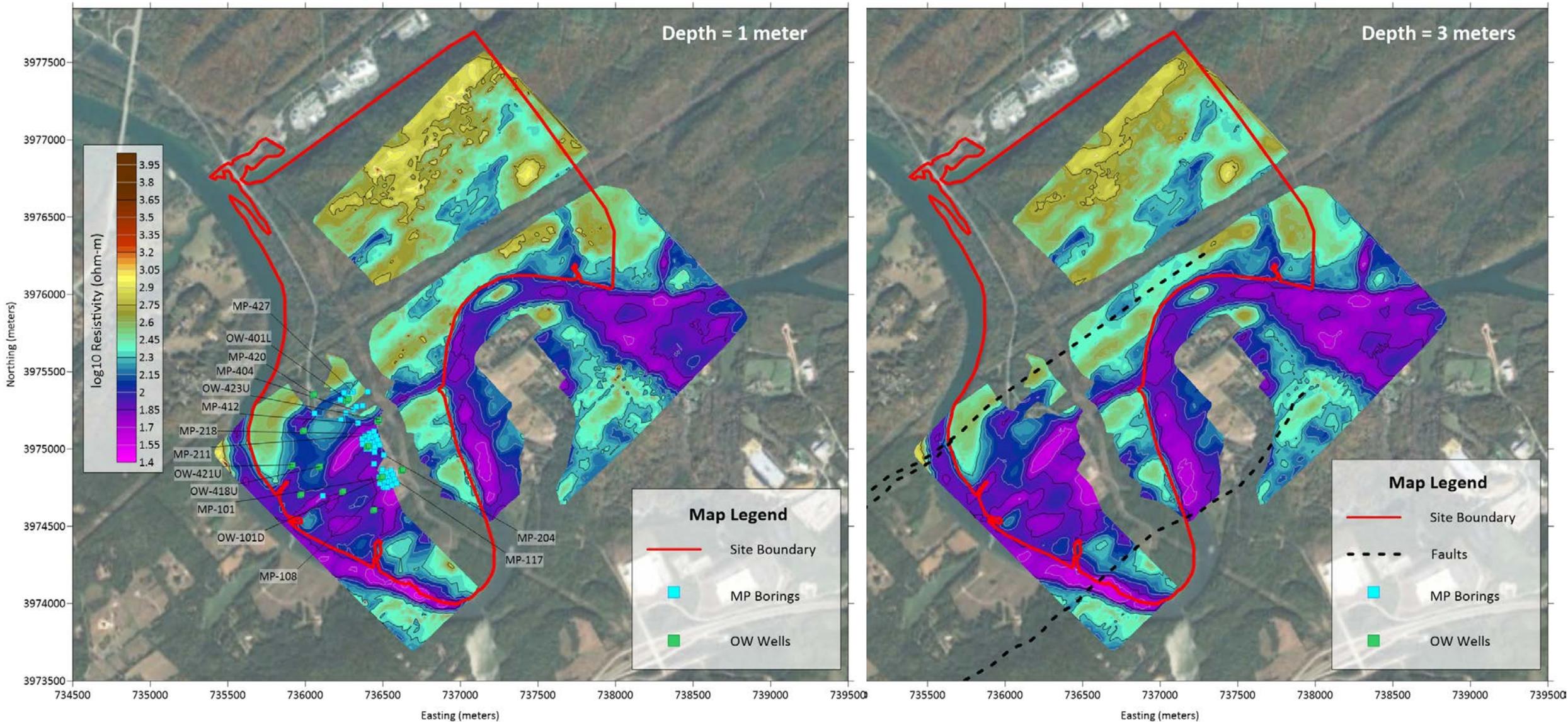
Geology

Clinch River (CRN)

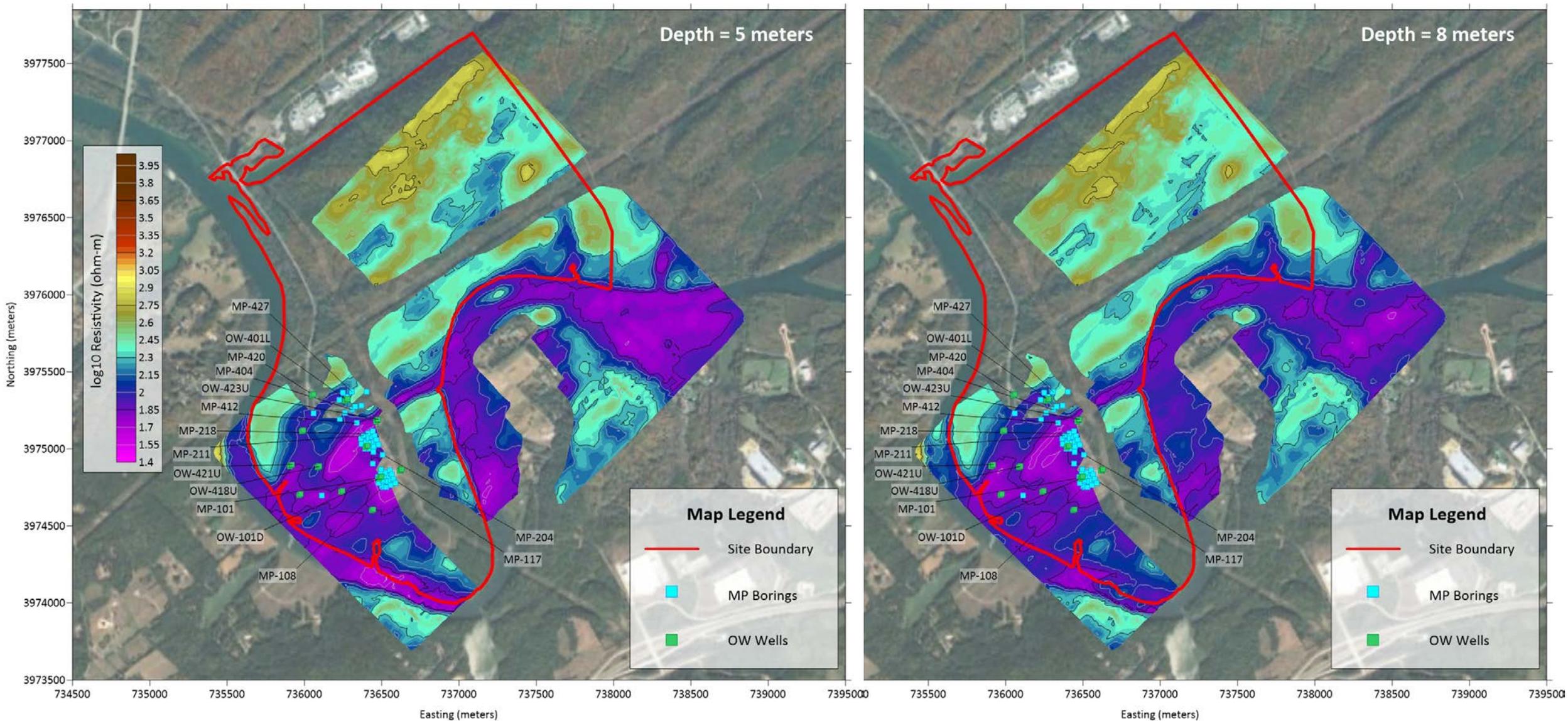
Bellefonte (BLN)



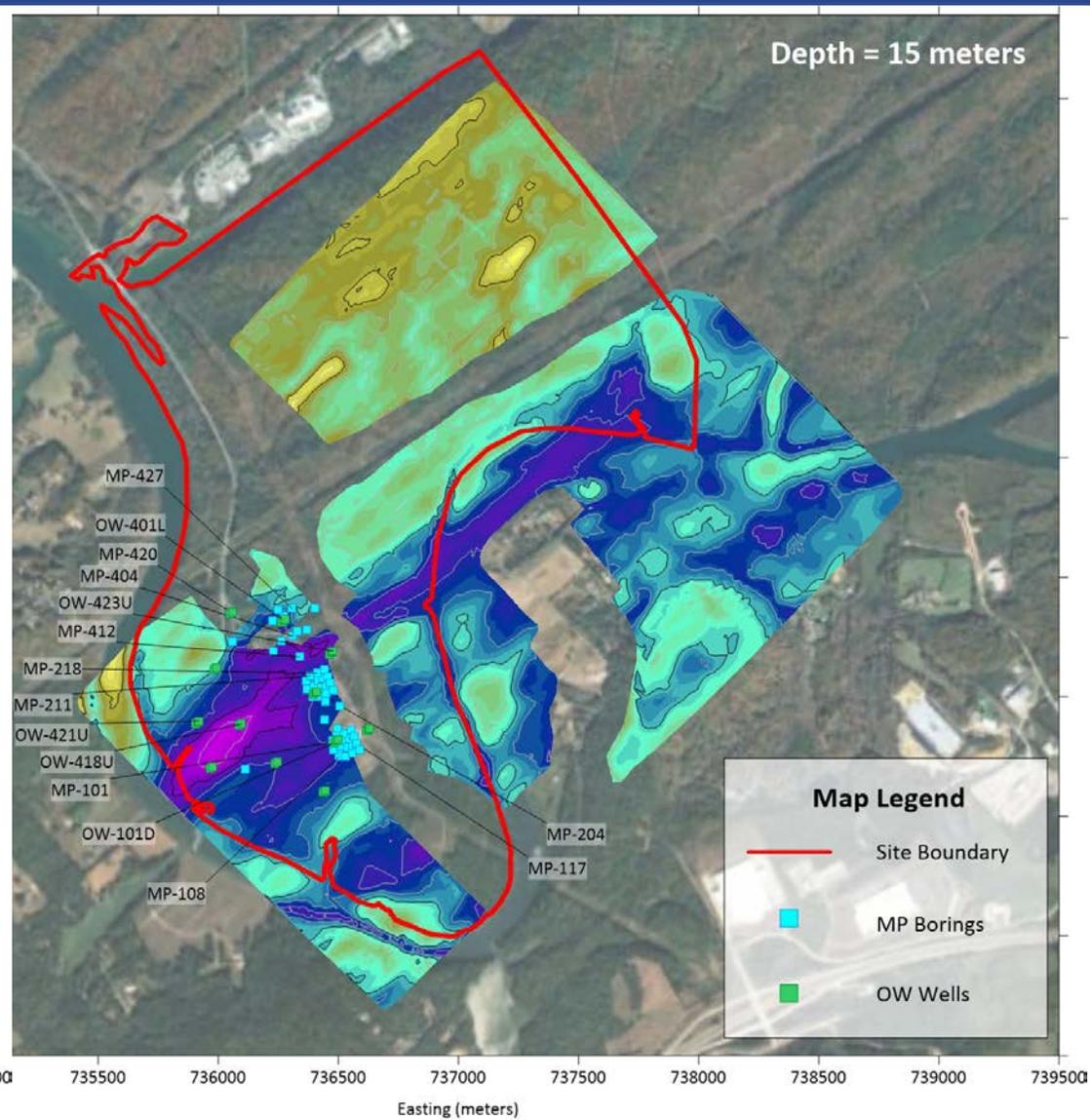
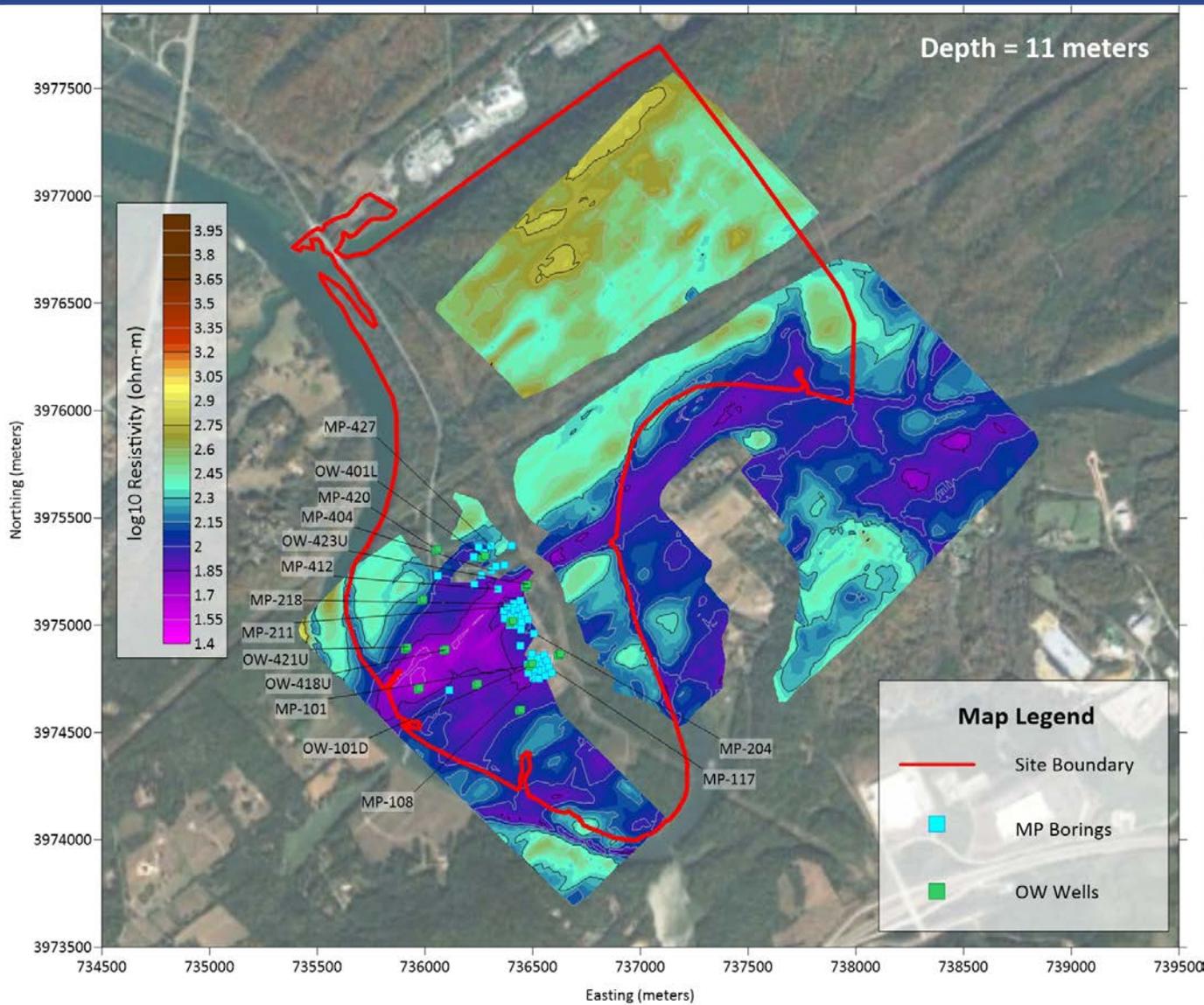
CRN Site Horizontal Slices



CRN Site Horizontal Slices



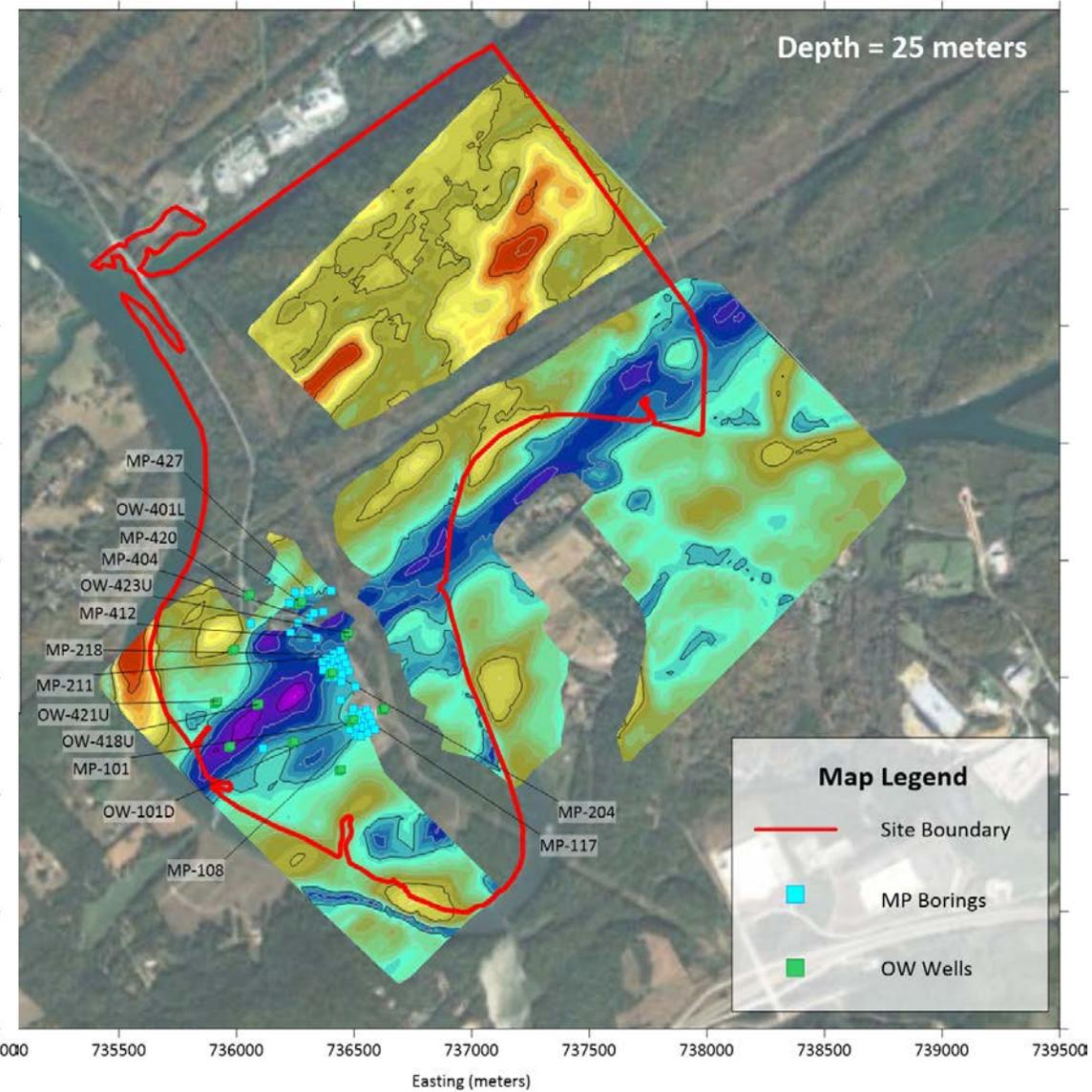
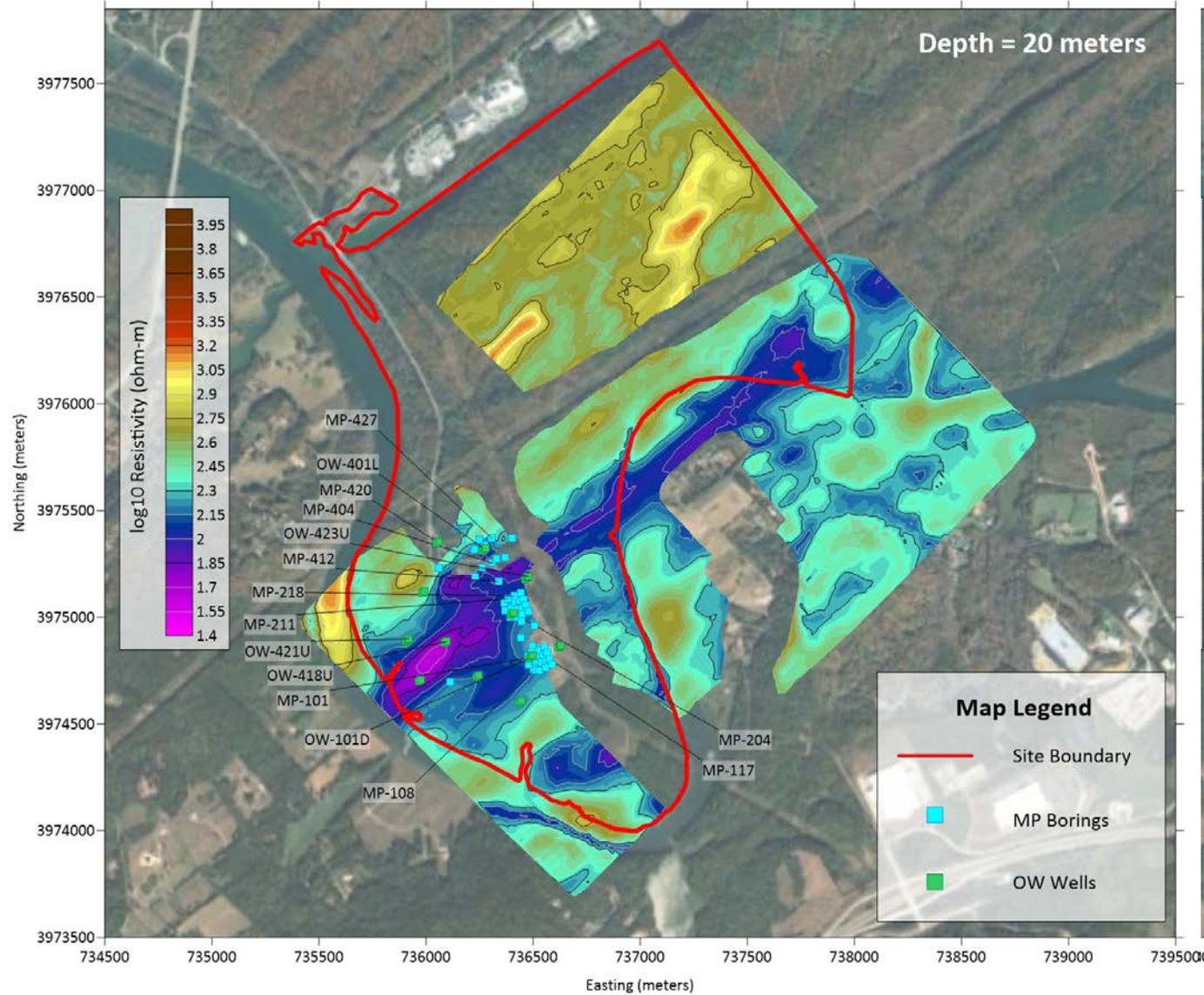
CRN Site Horizontal Slices



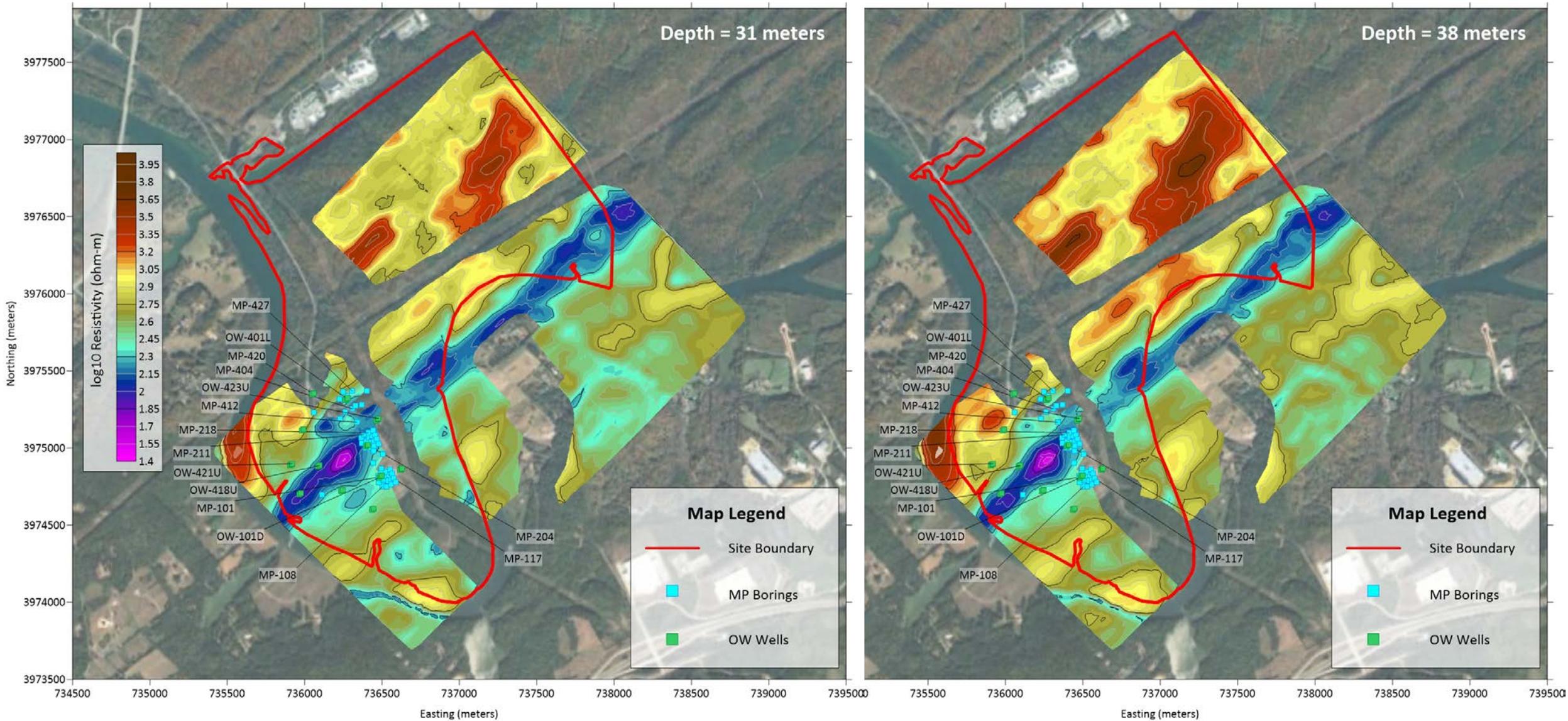
CRN Site Horizontal Slices

Depth = 20 meters

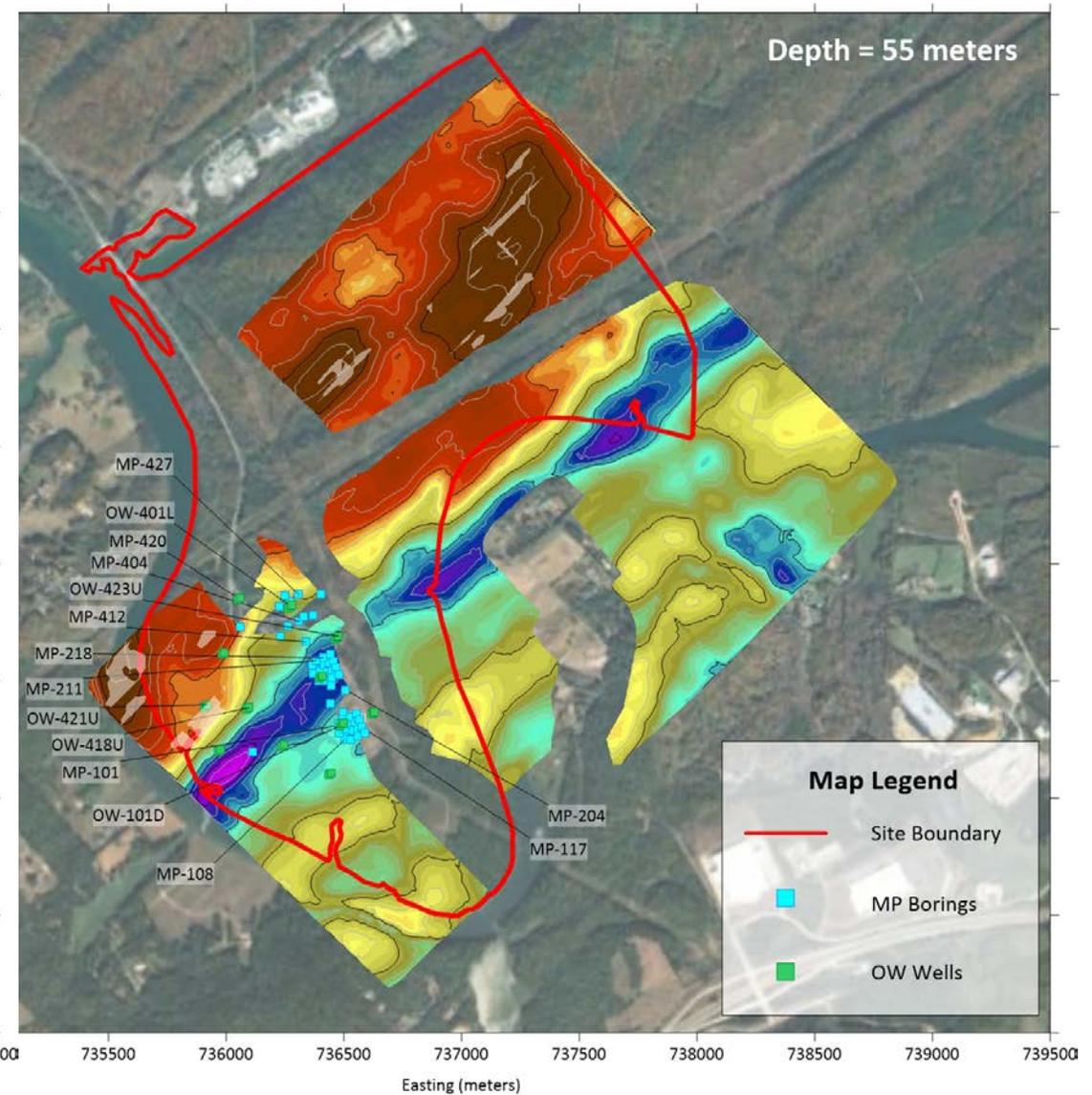
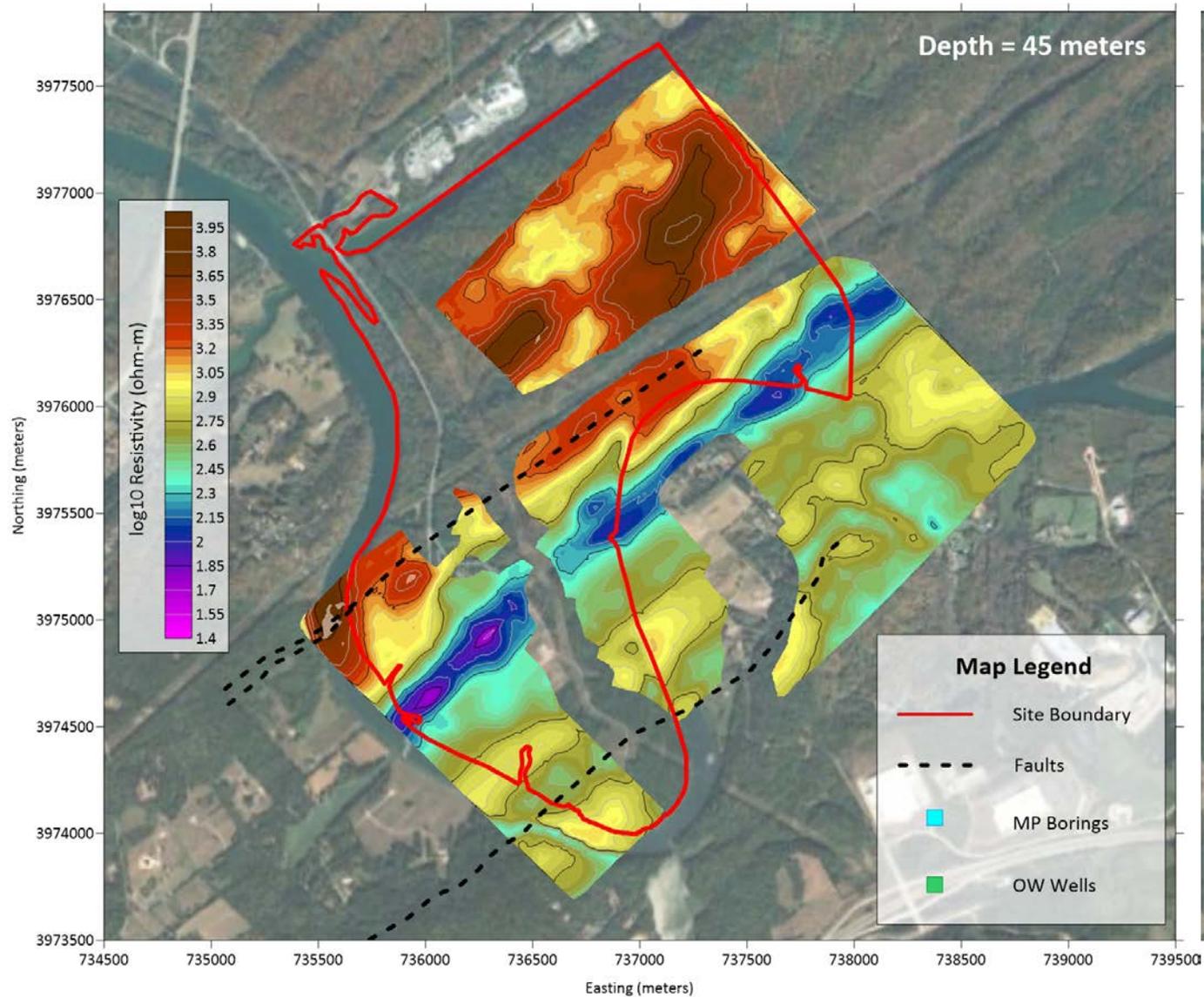
Depth = 25 meters



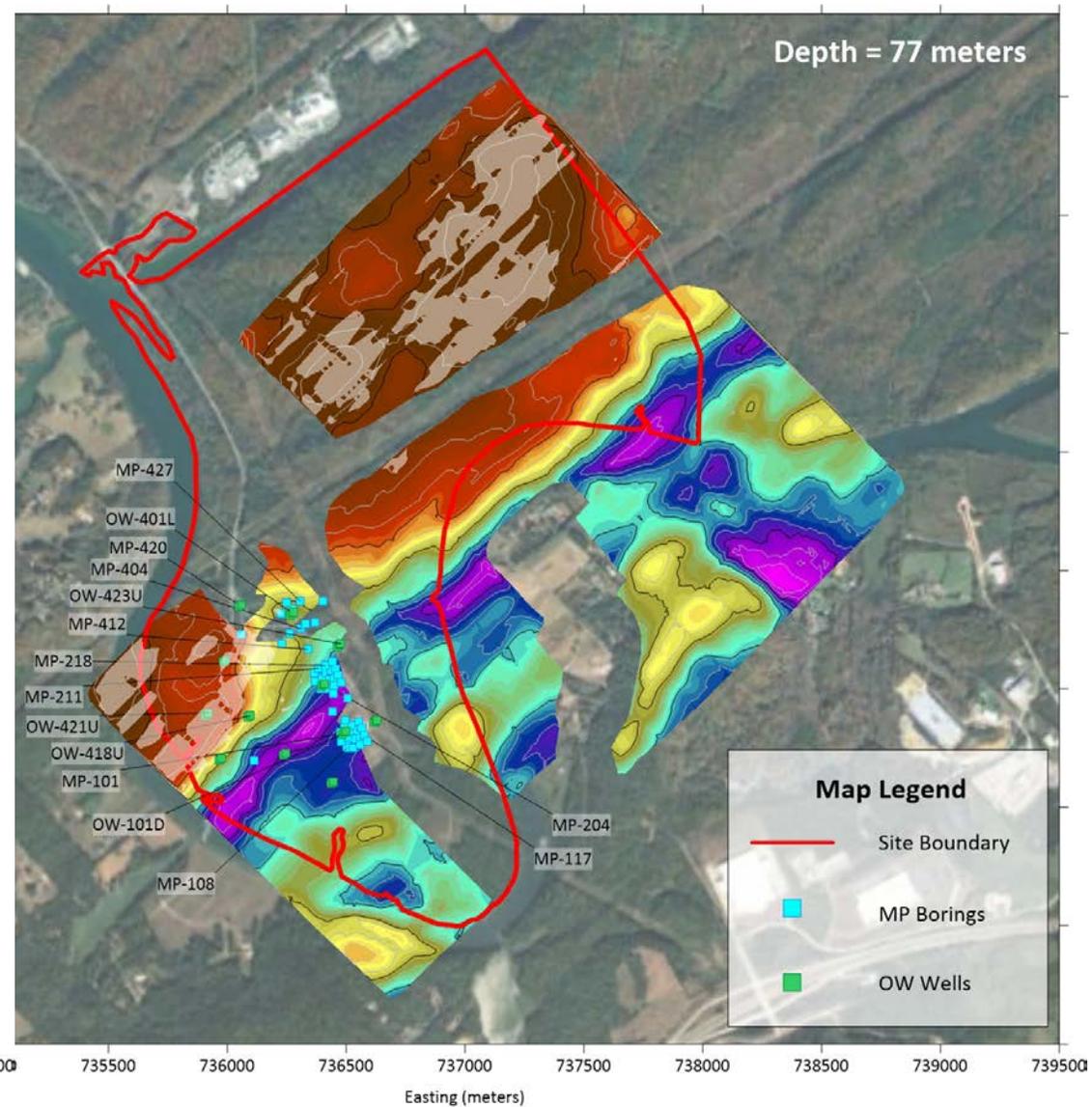
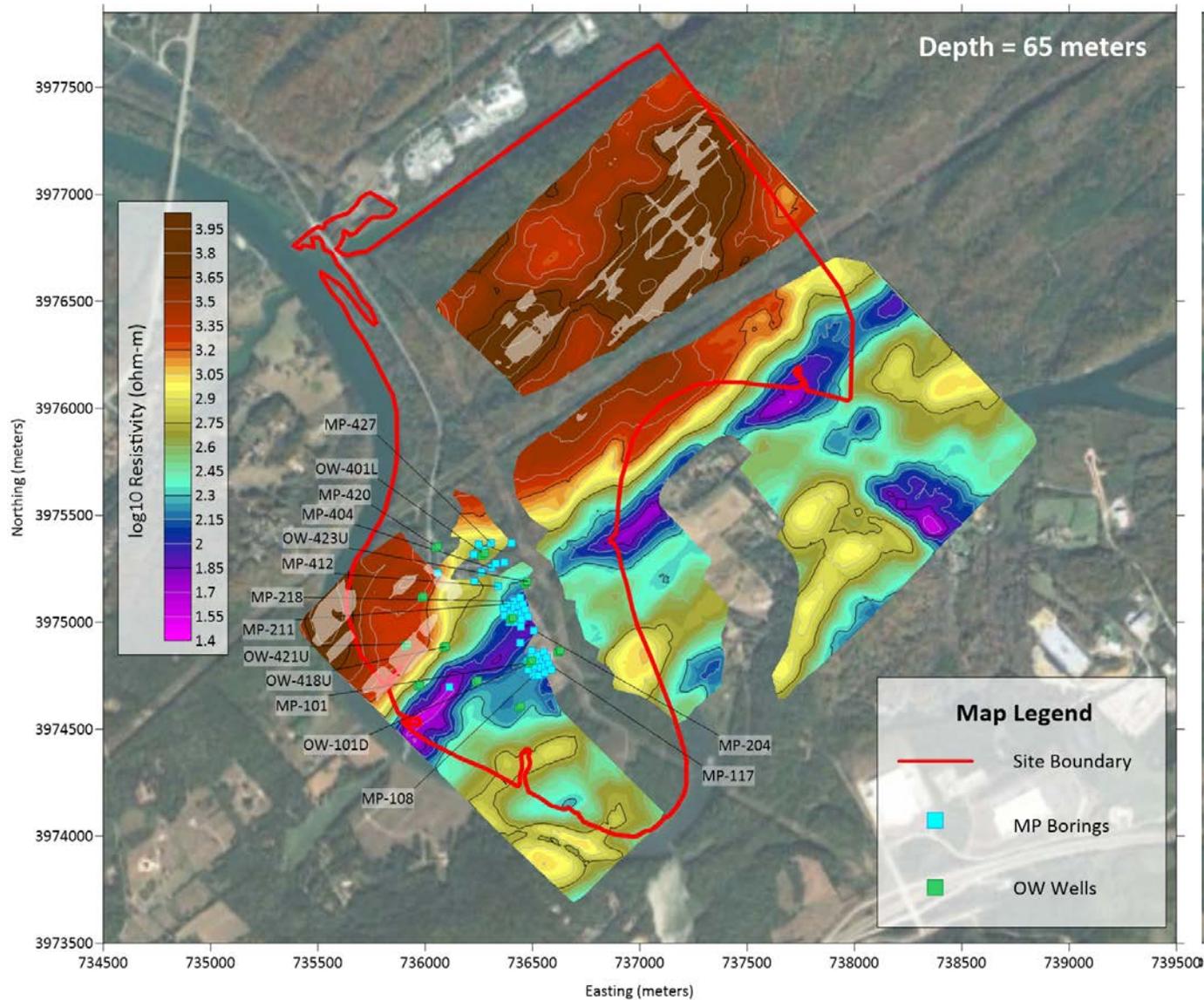
CRN Site Horizontal Slices



CRN Site Horizontal Slices



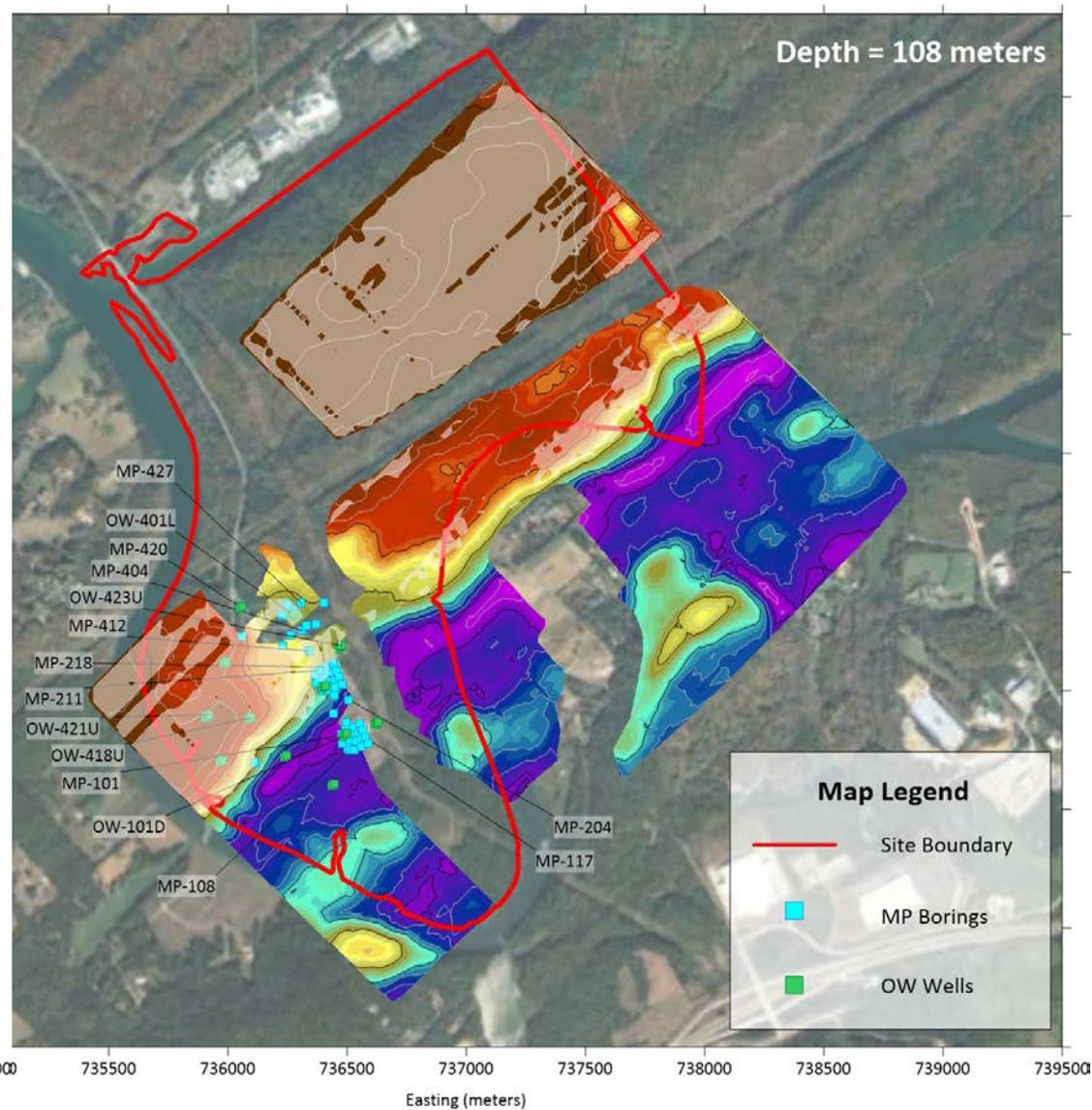
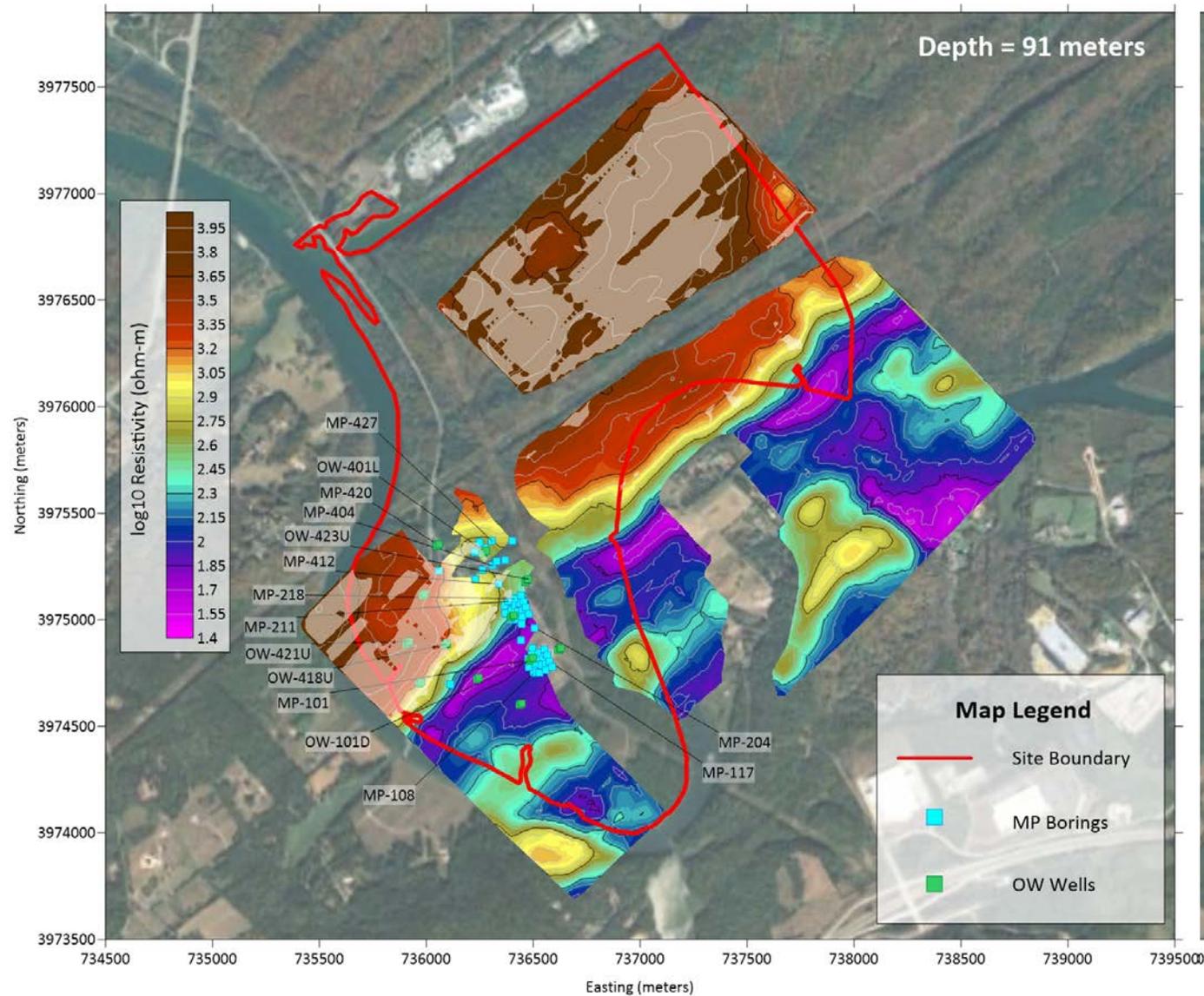
CRN Site Horizontal Slices



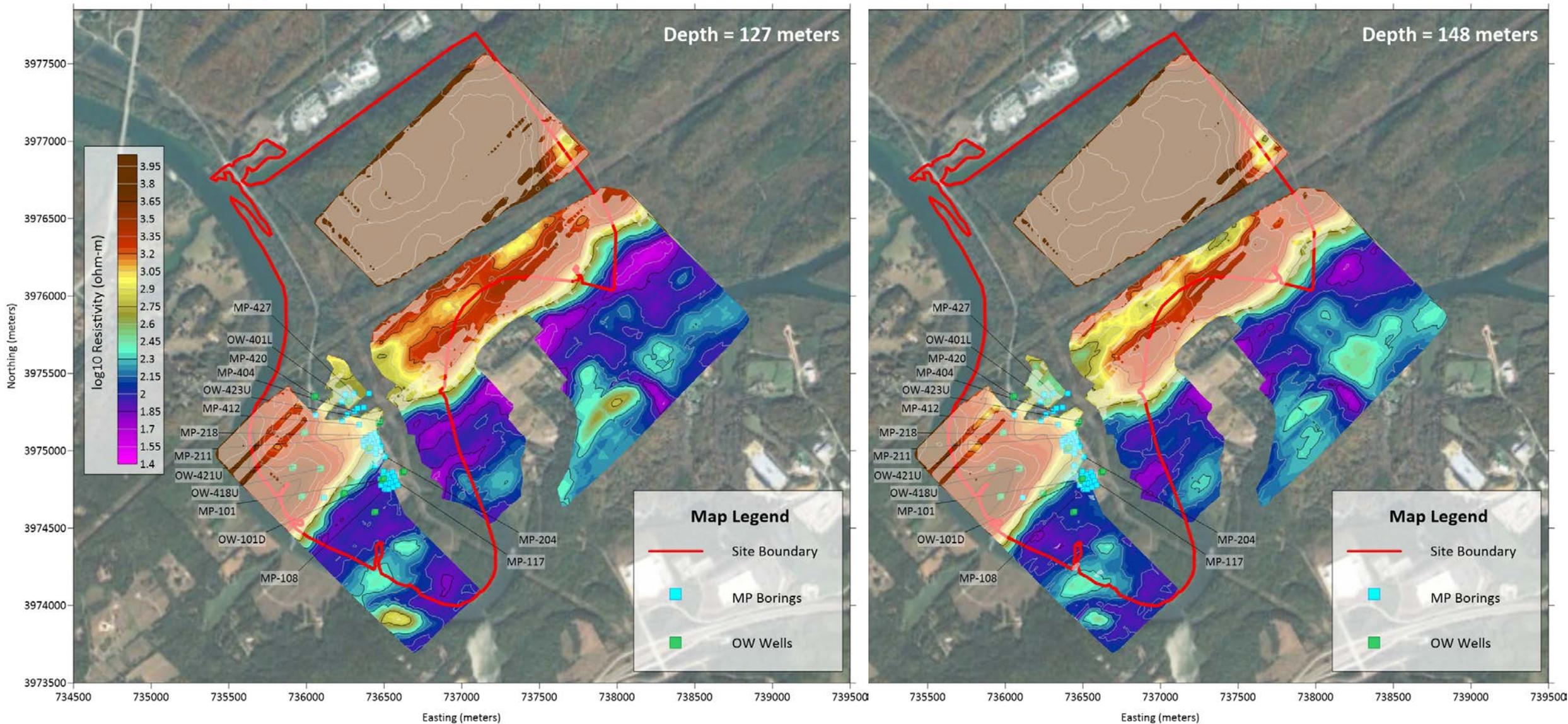
CRN Site Horizontal Slices

Depth = 91 meters

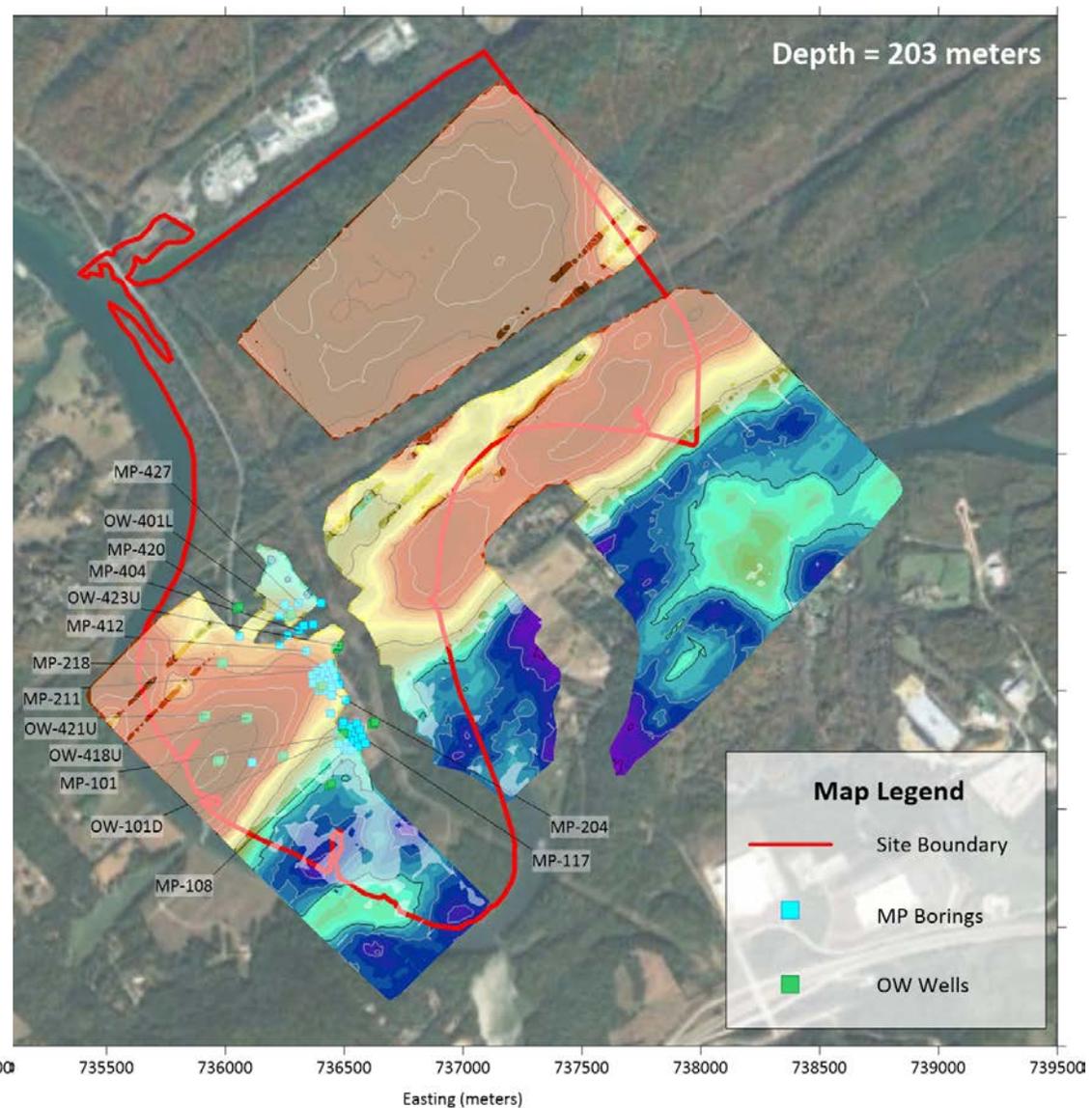
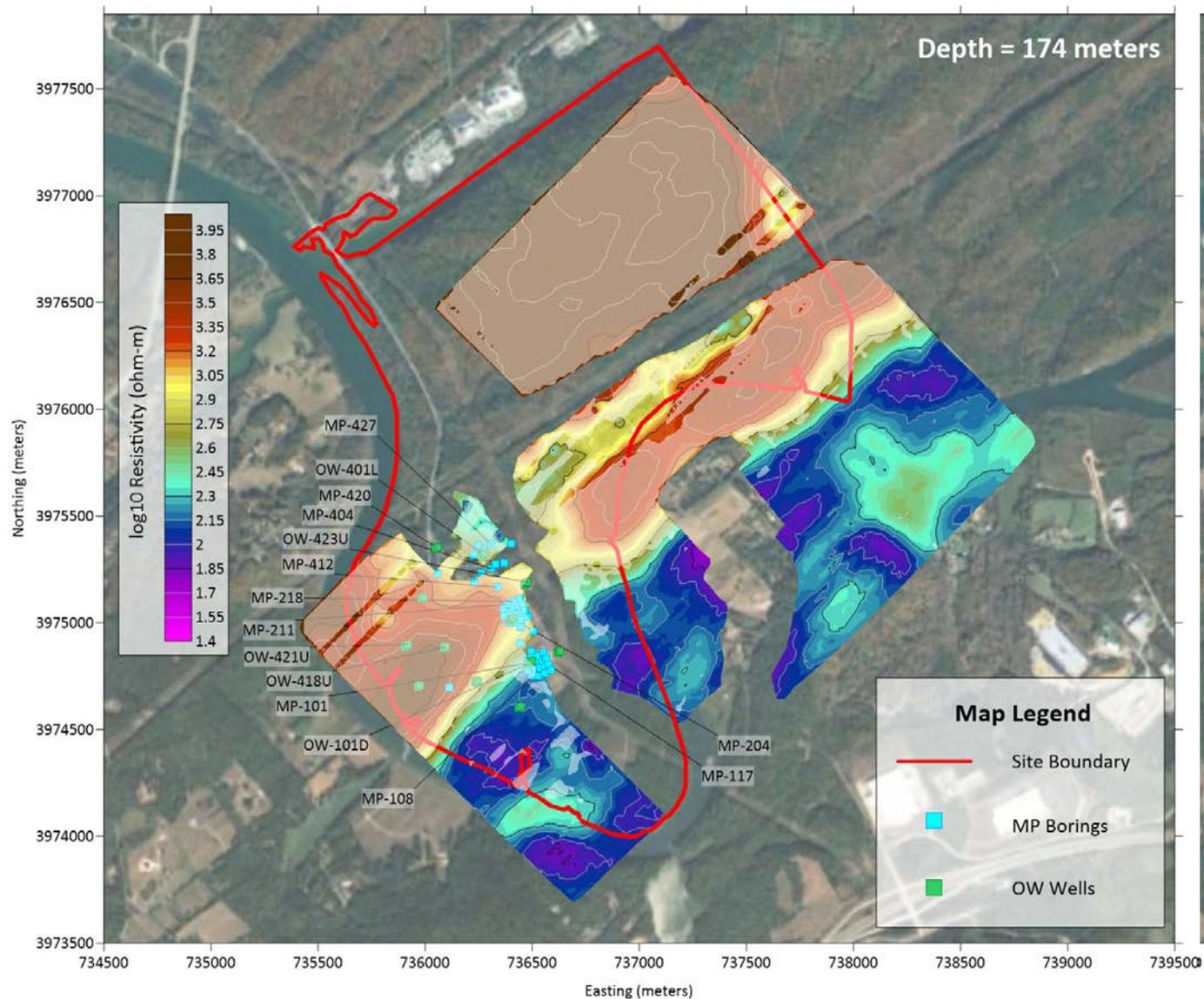
Depth = 108 meters



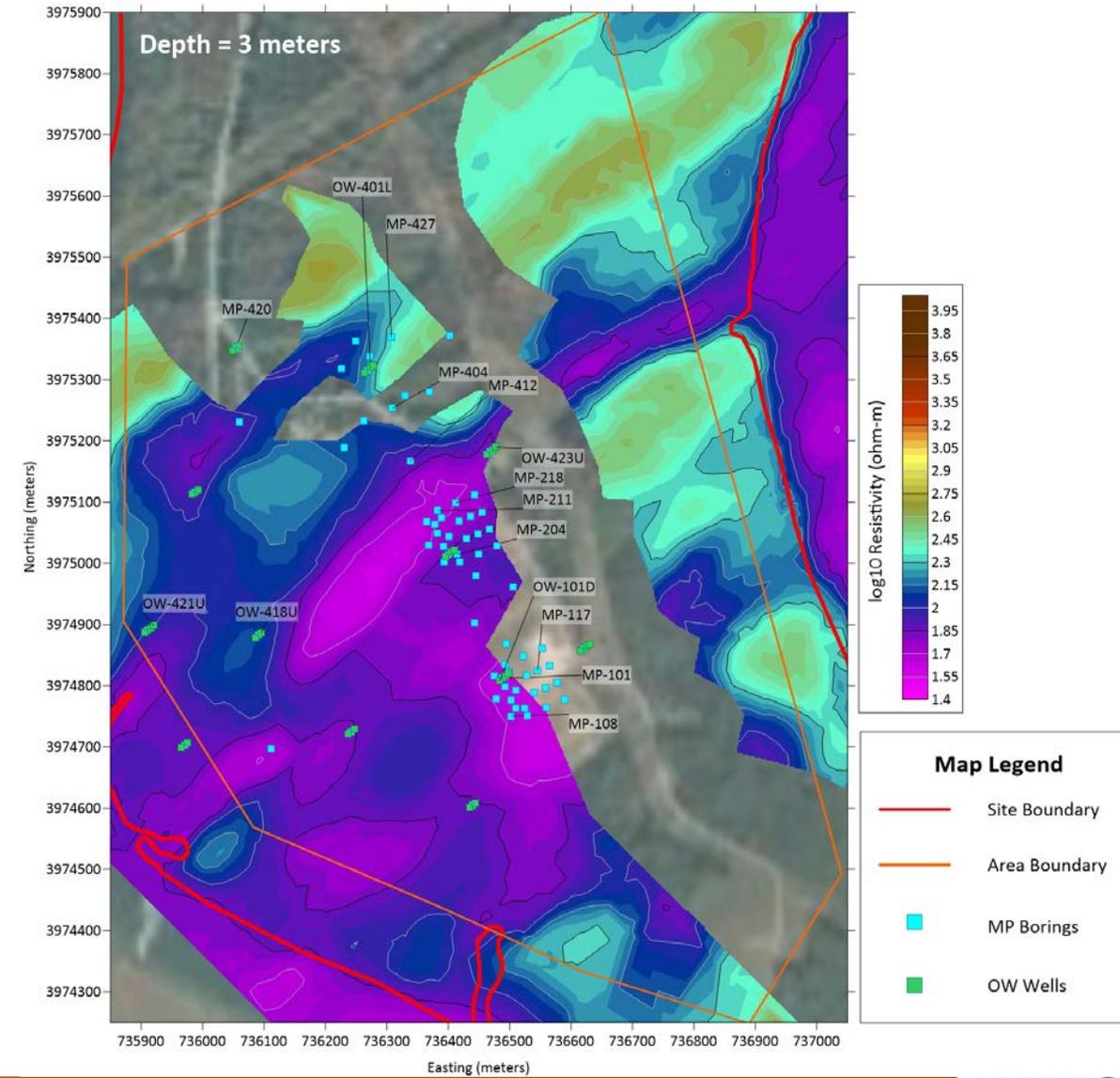
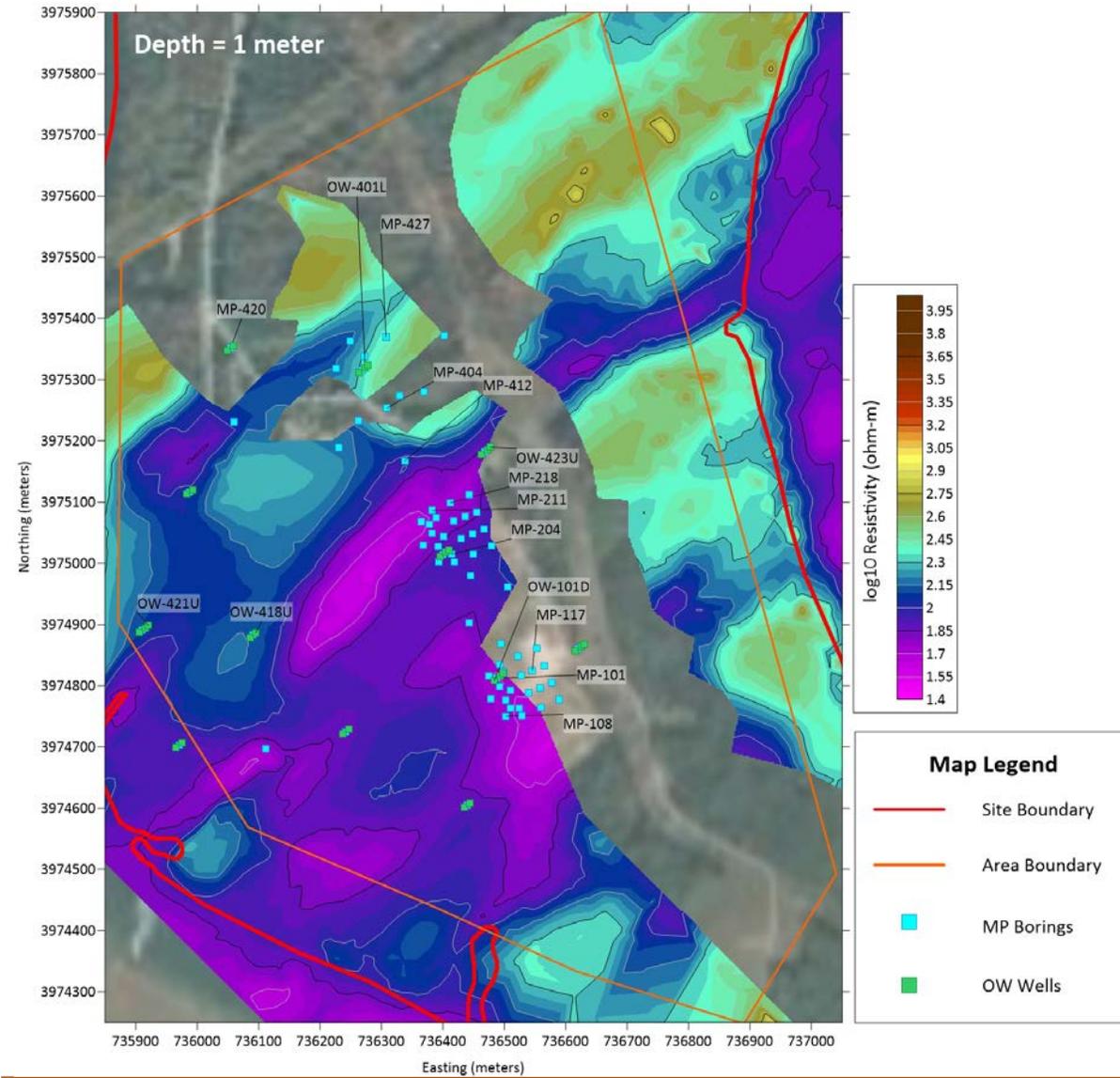
CRN Site Horizontal Slices



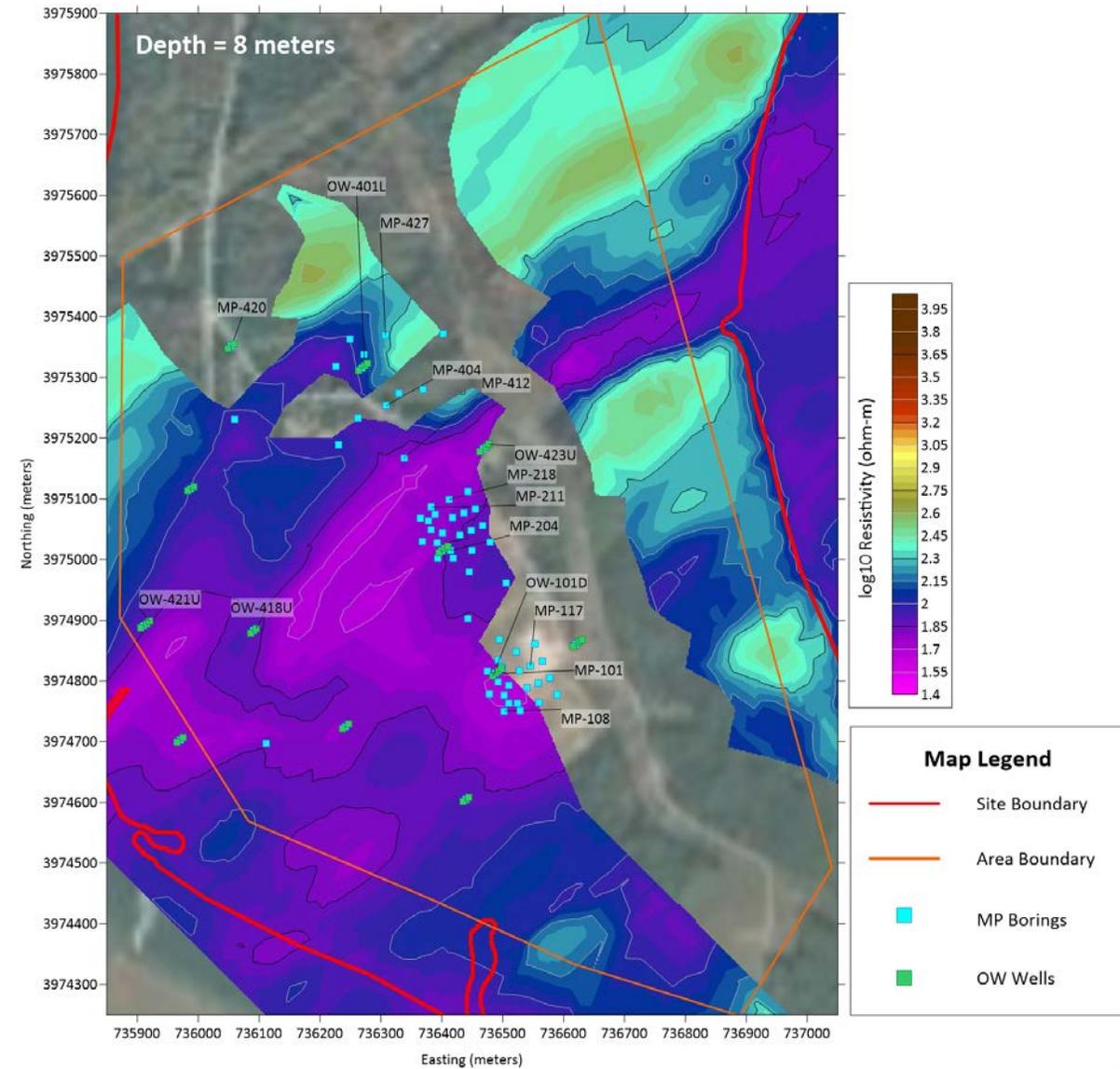
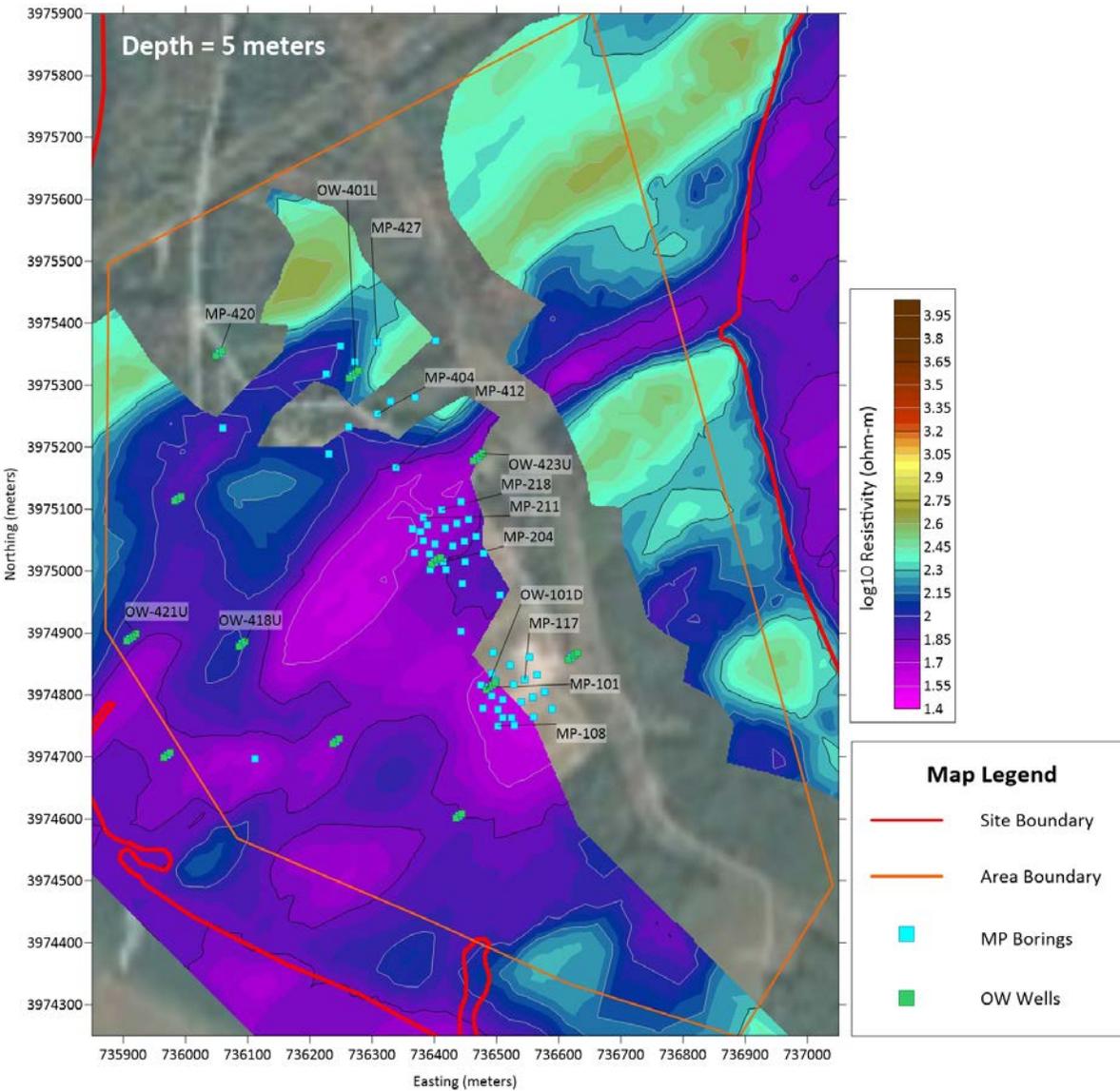
CRN Site Horizontal Slices



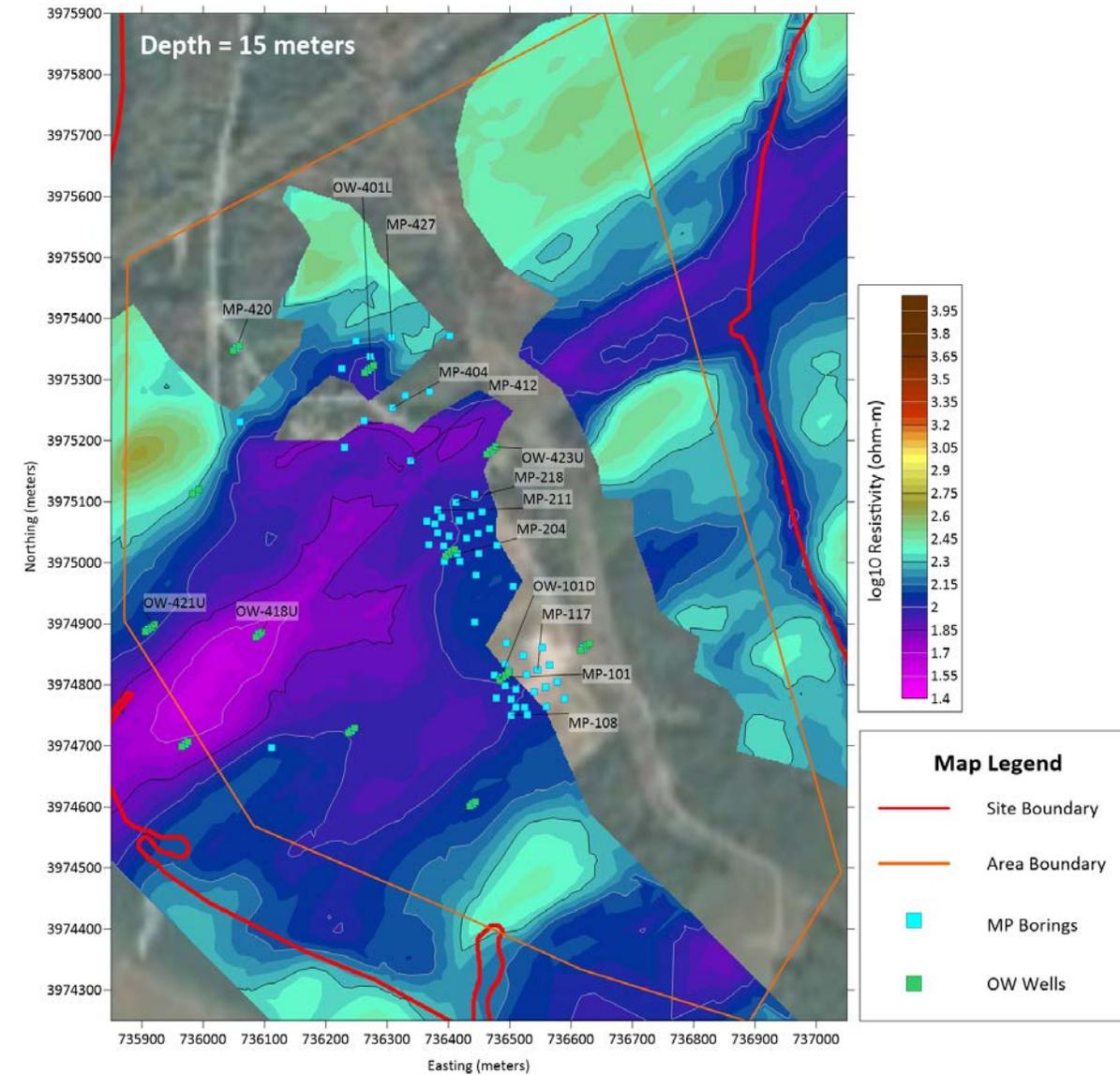
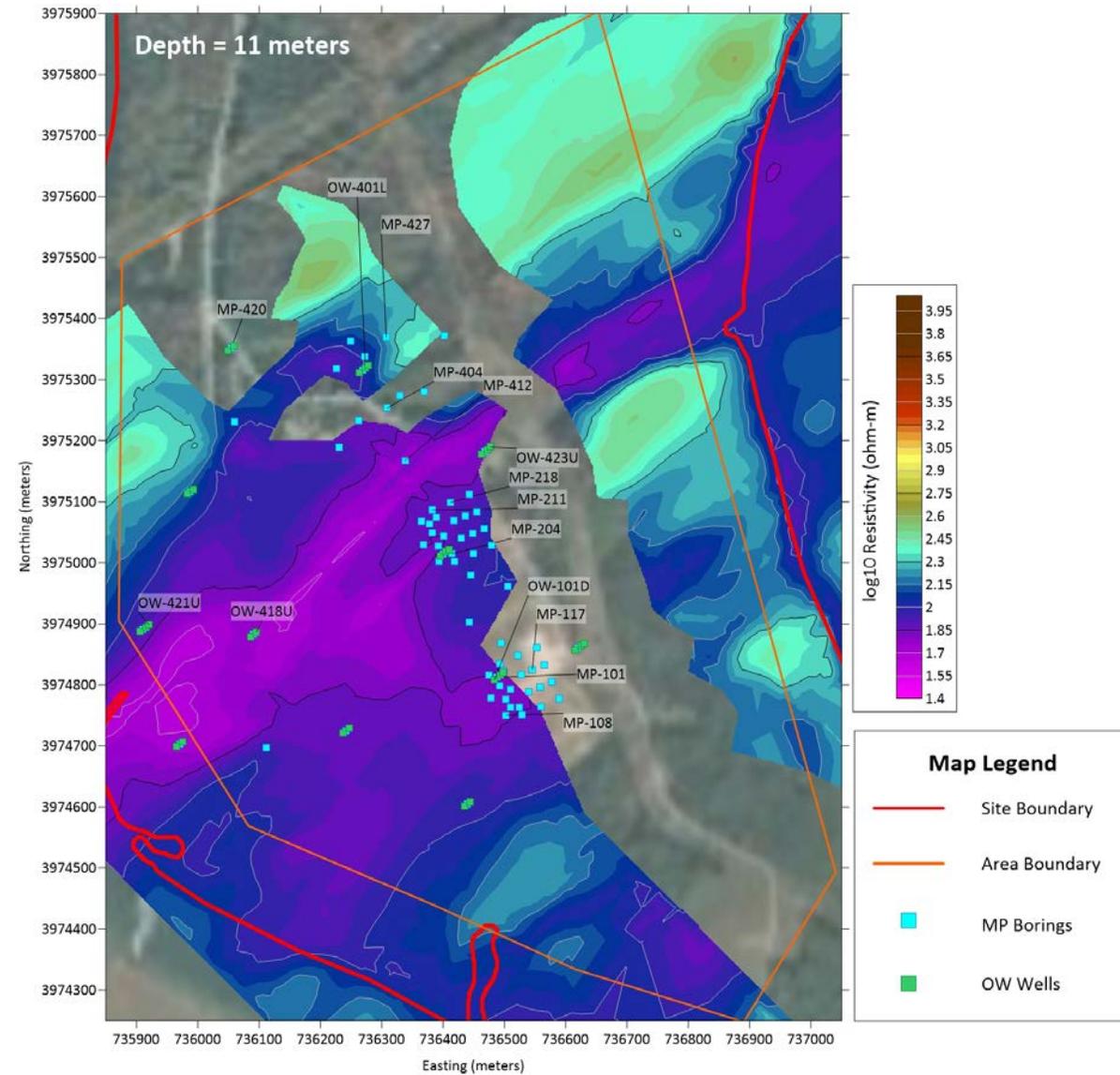
CRN Site Horizontal Slices – Area 1



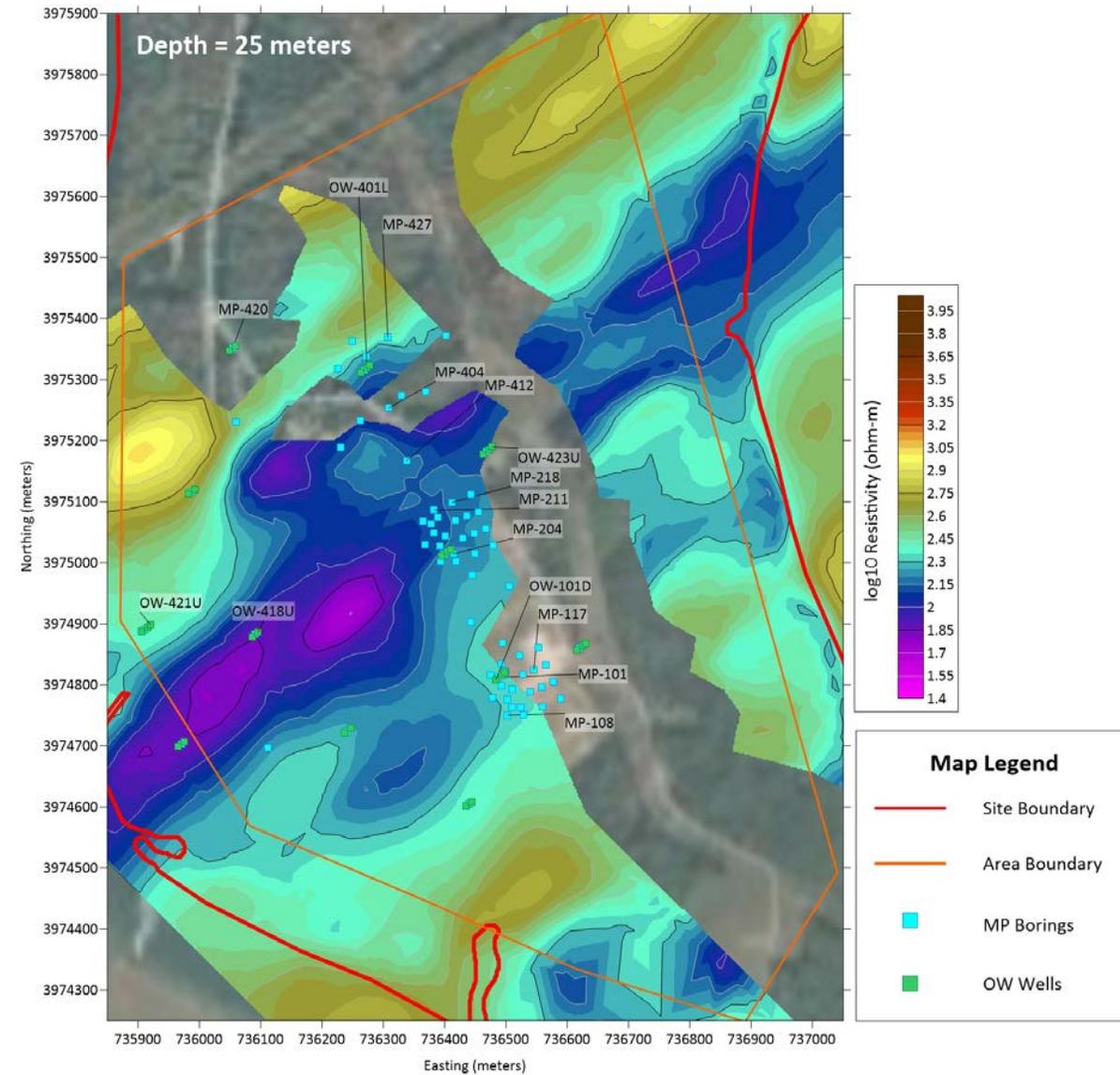
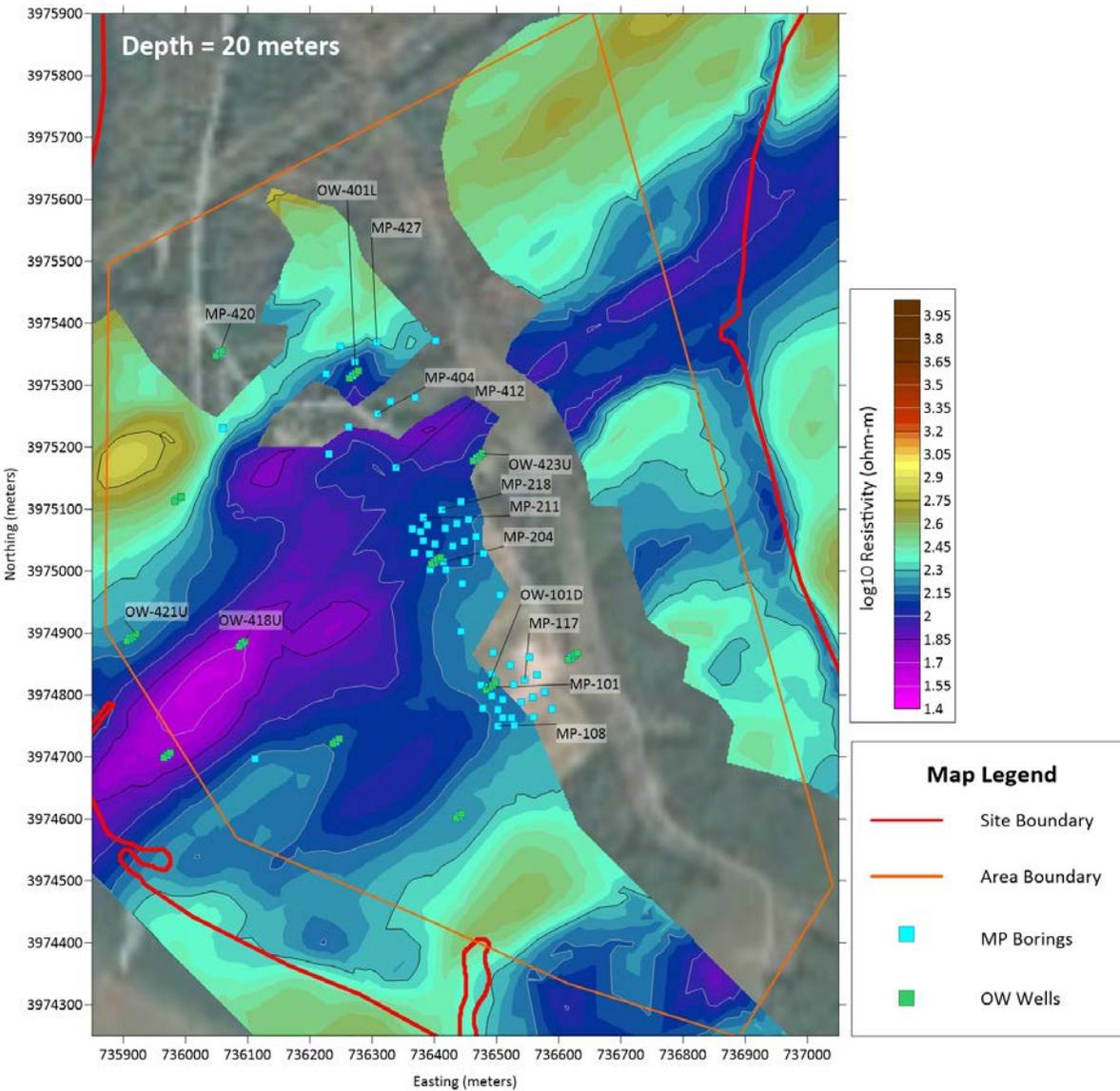
CRN Site Horizontal Slices – Area 1



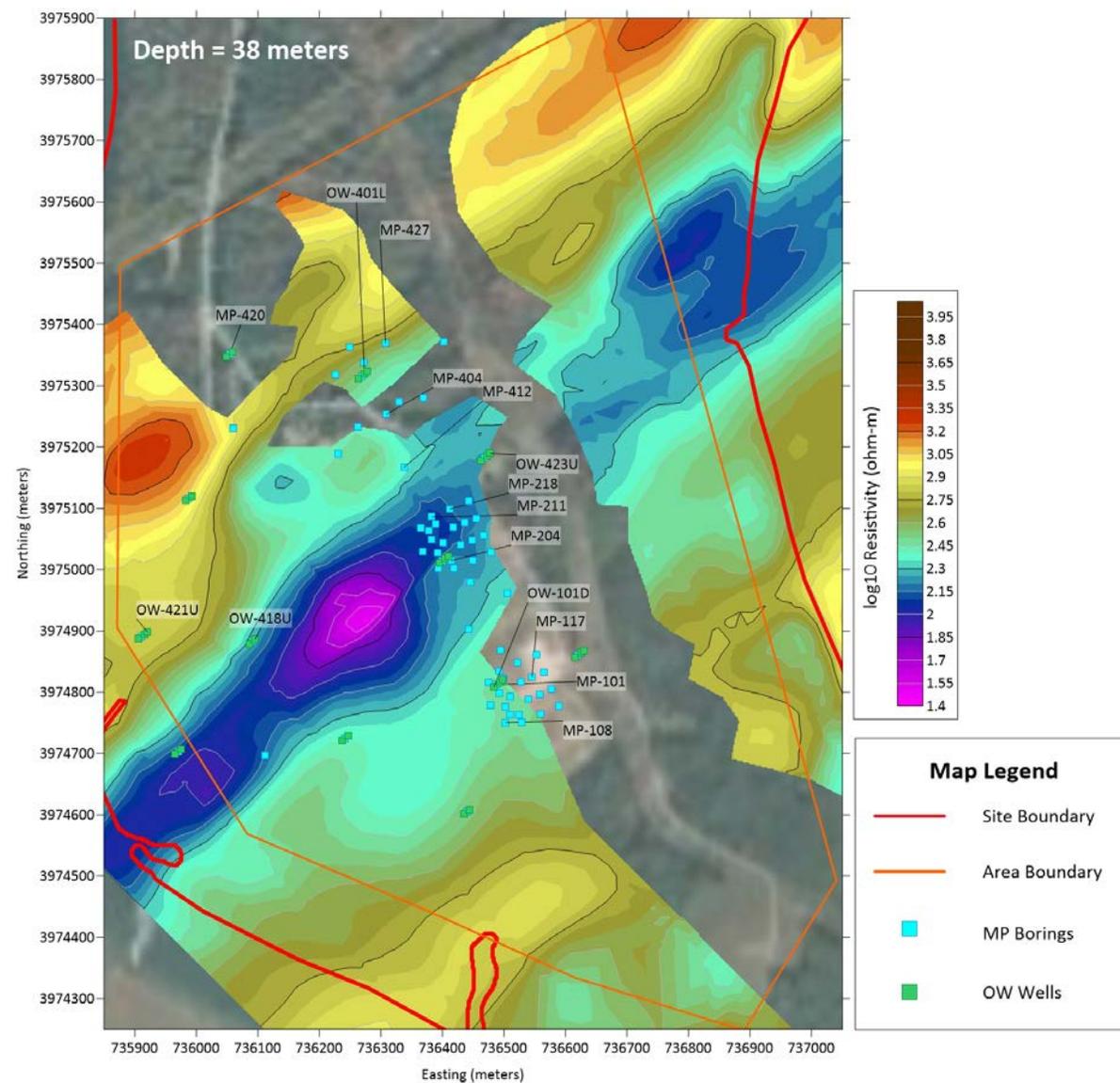
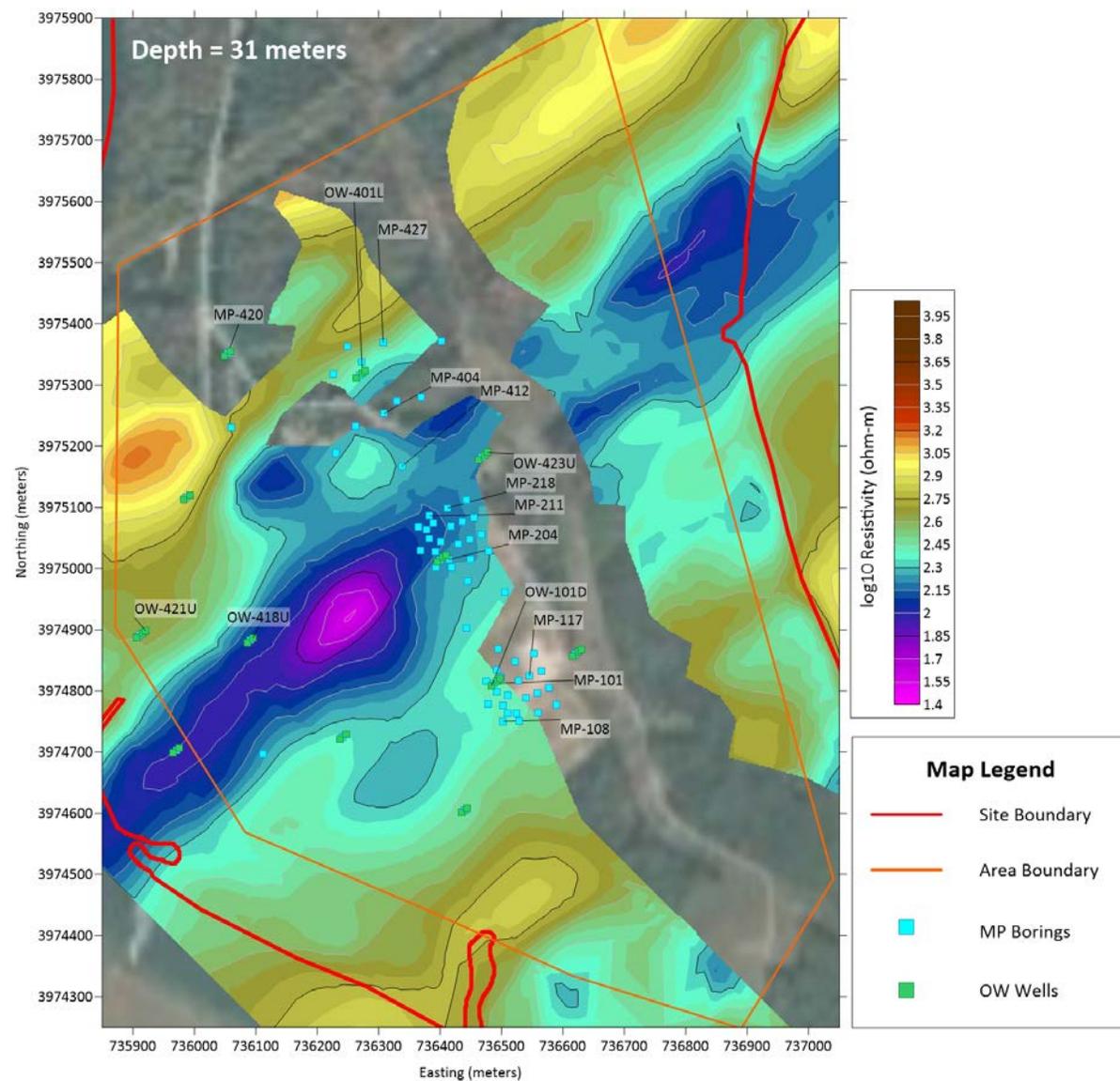
CRN Site Horizontal Slices – Area 1



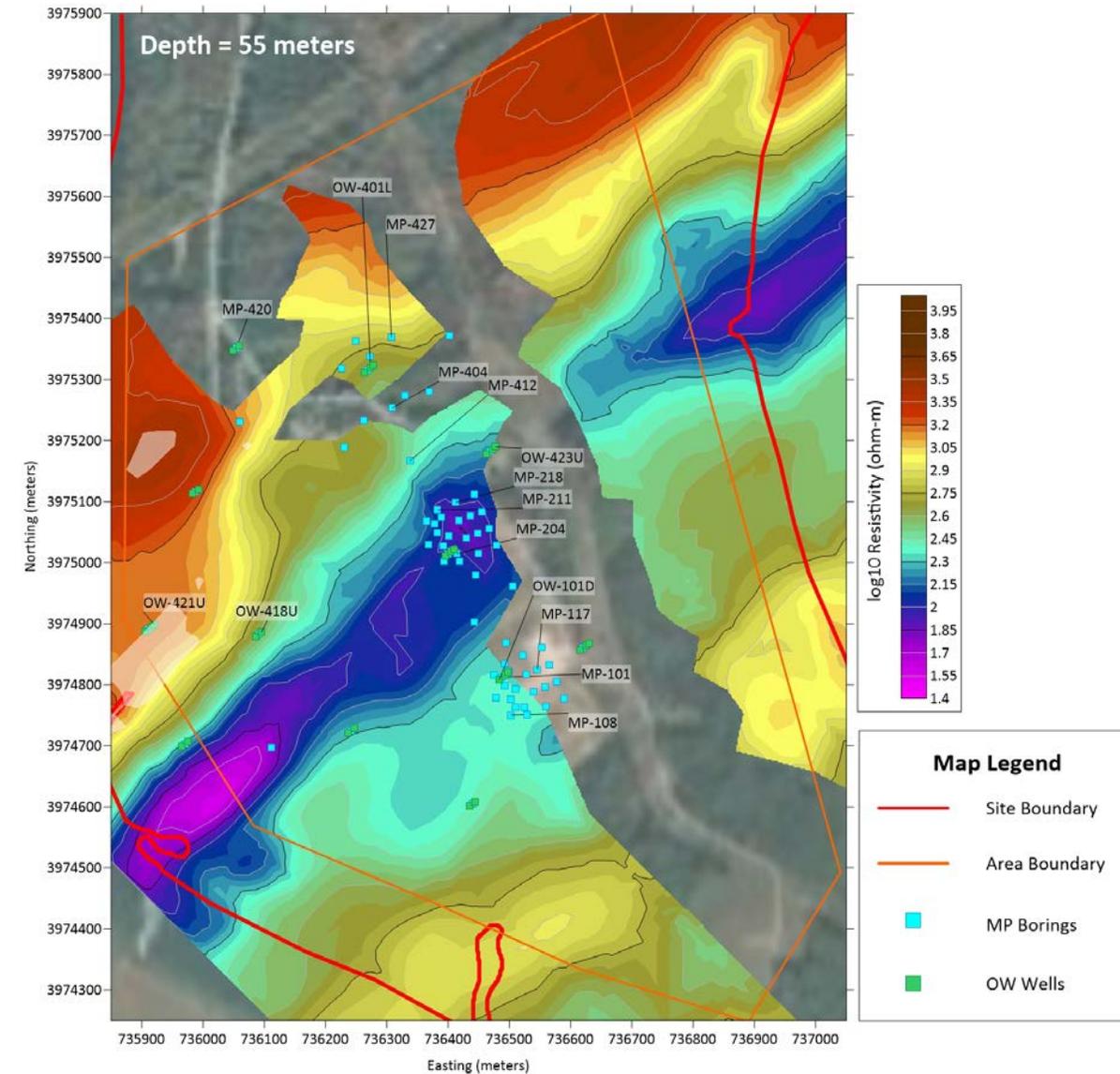
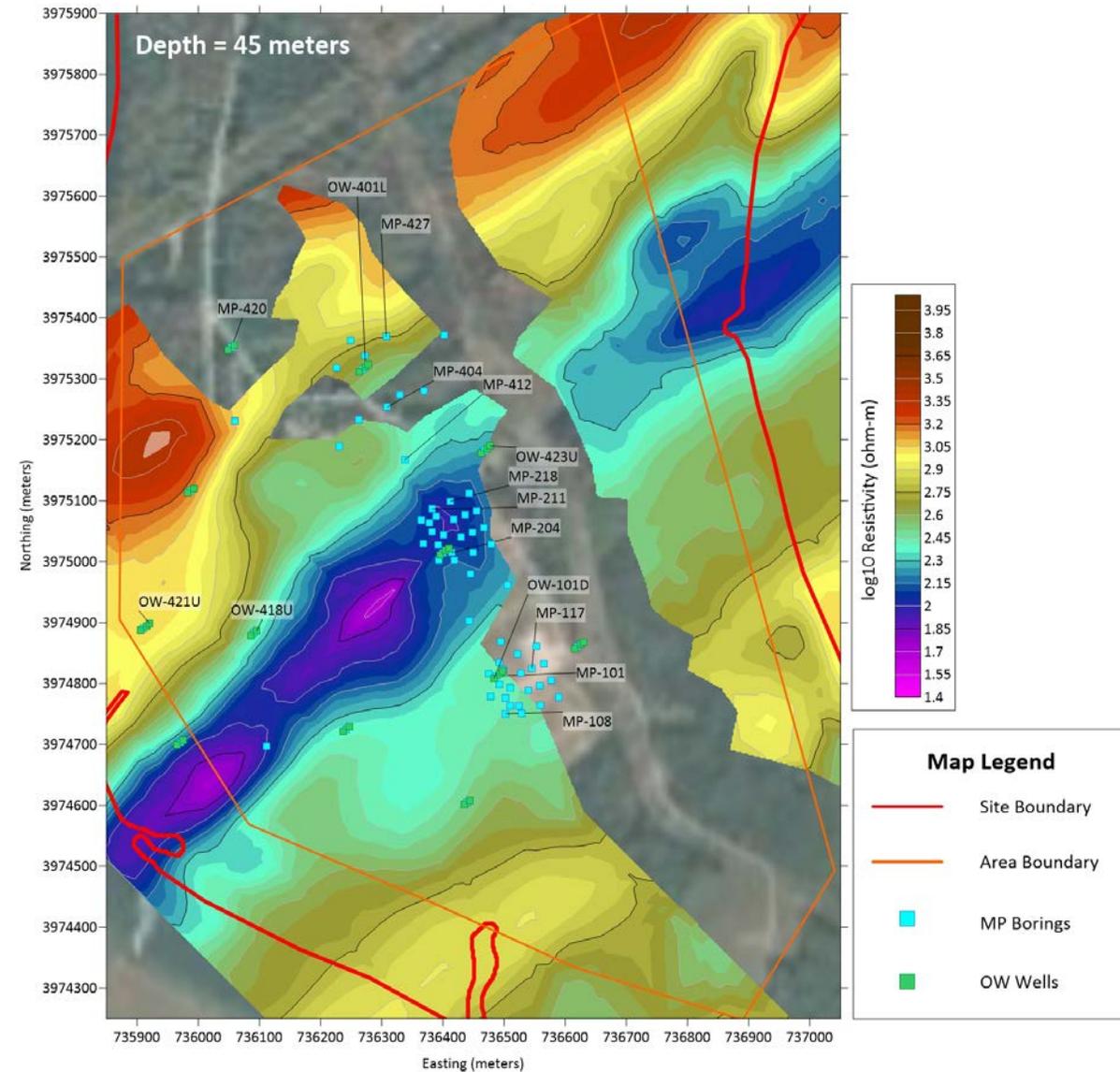
CRN Site Horizontal Slices – Area 1



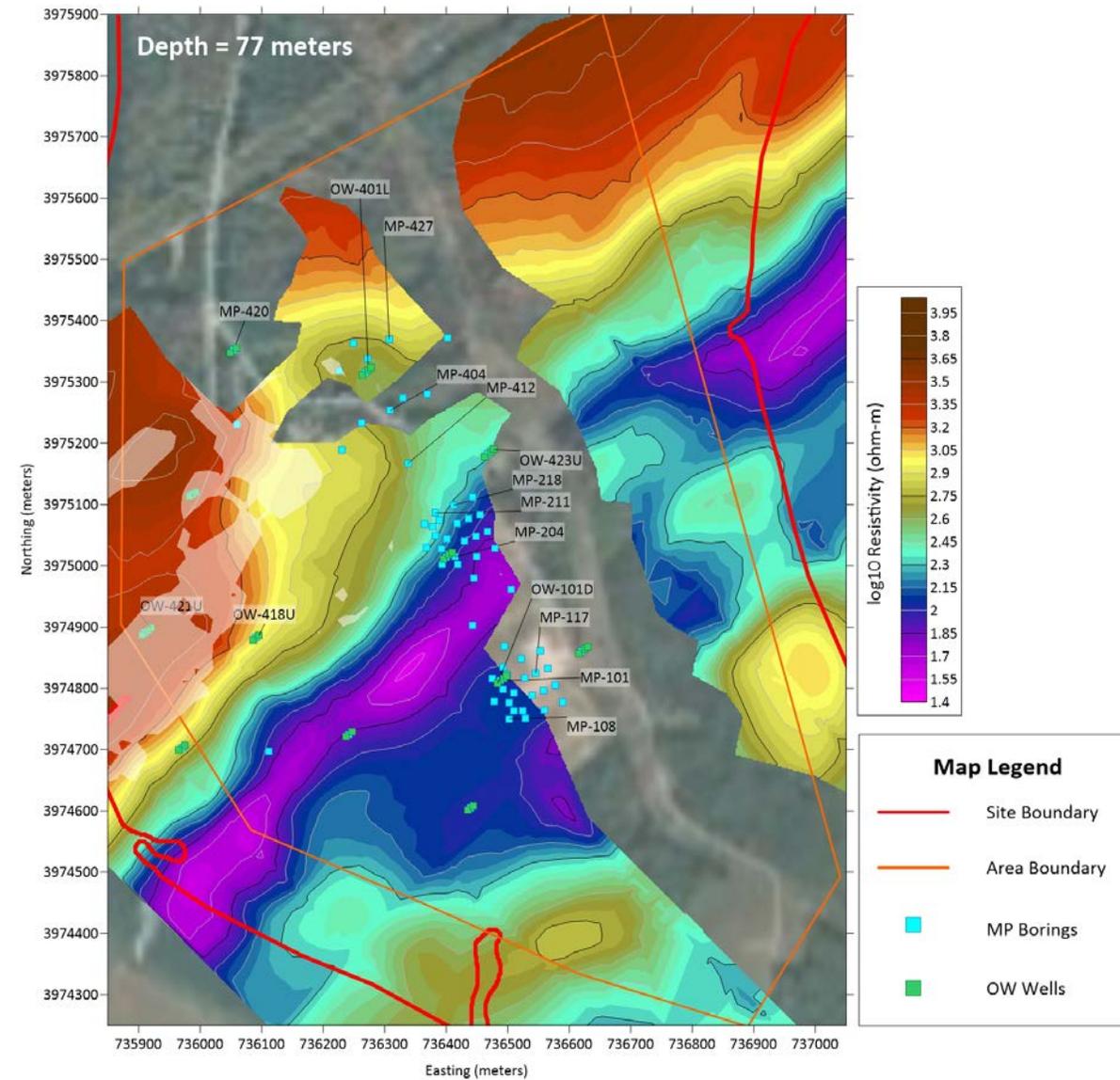
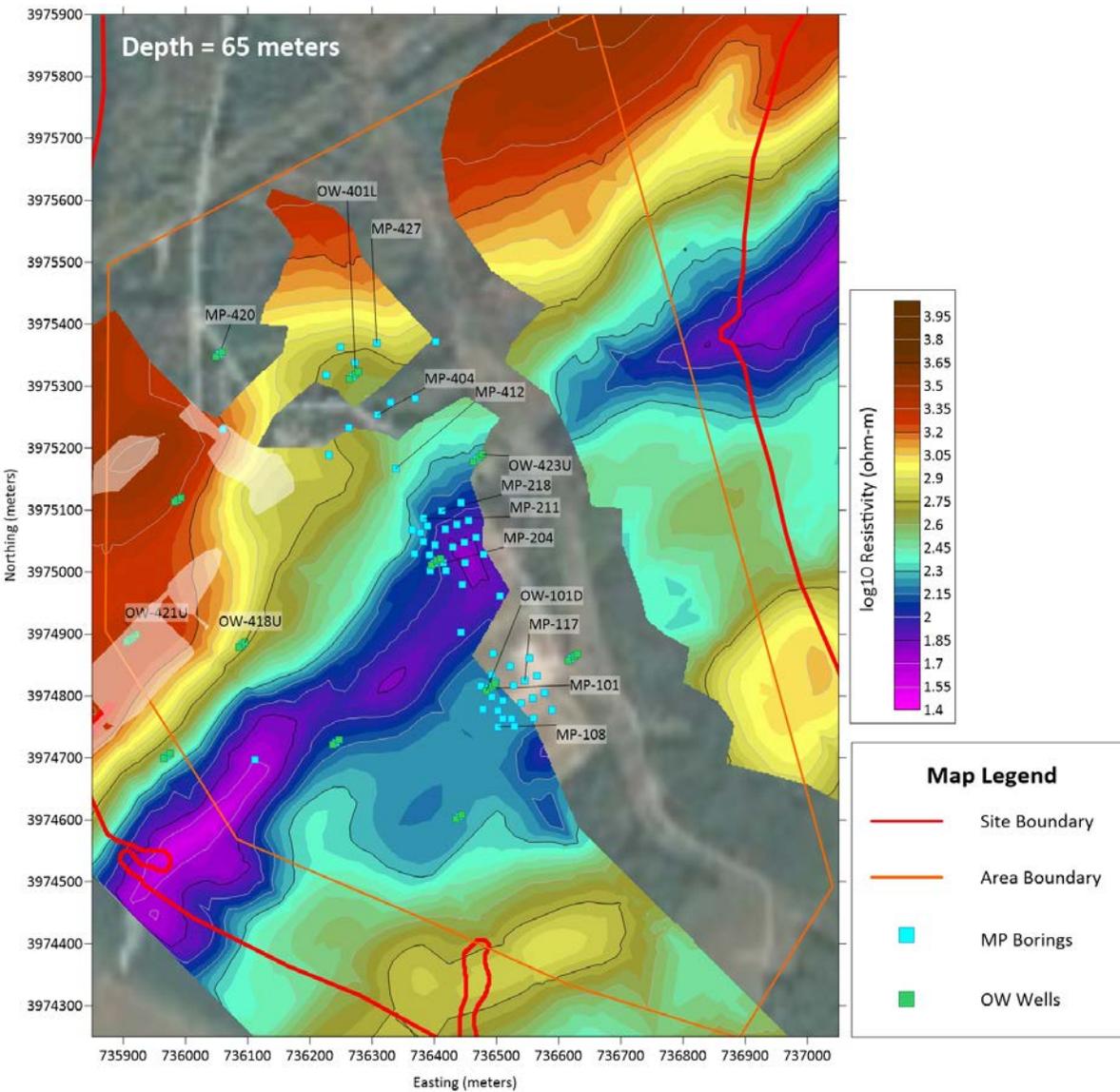
CRN Site Horizontal Slices – Area 1



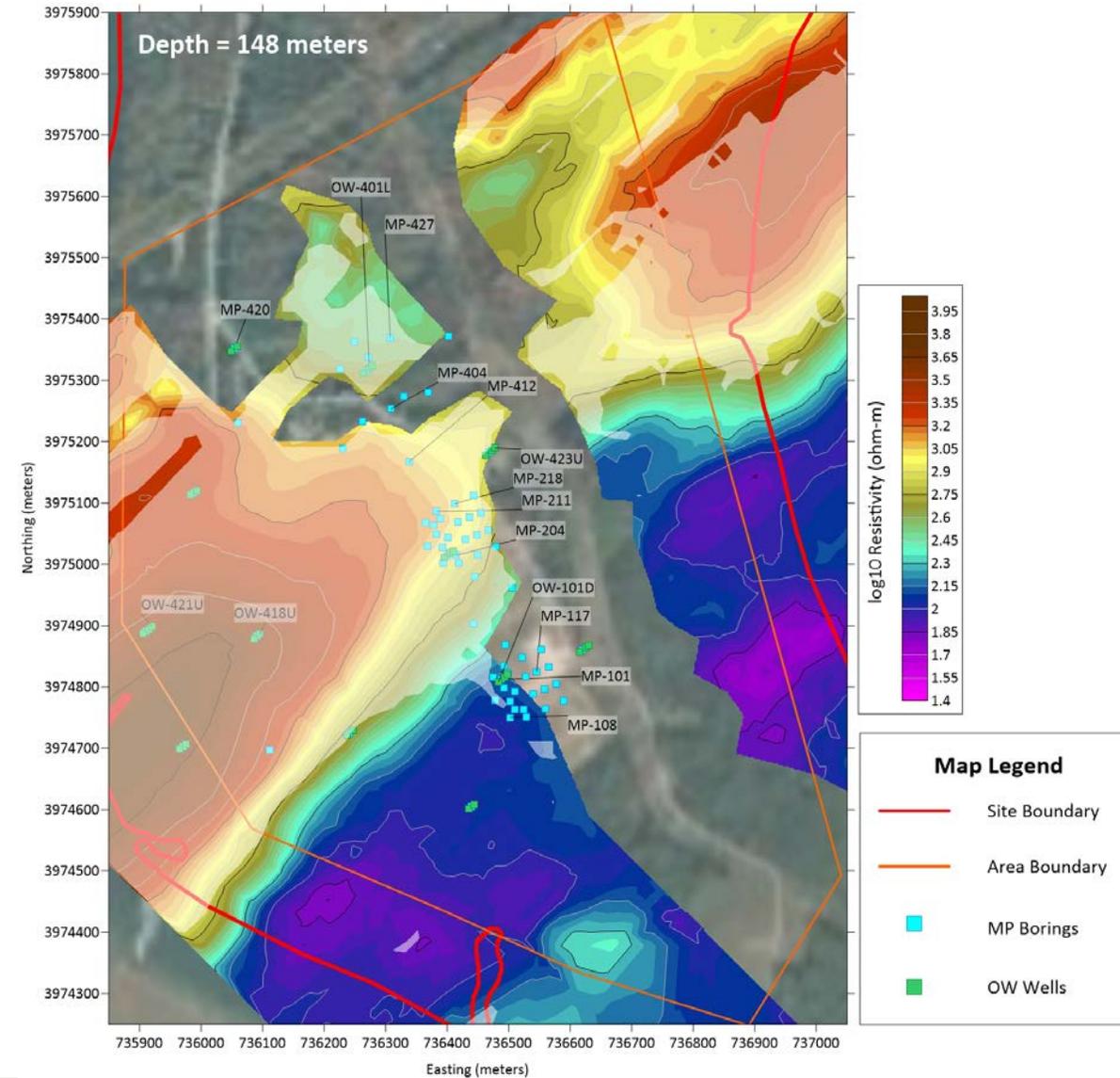
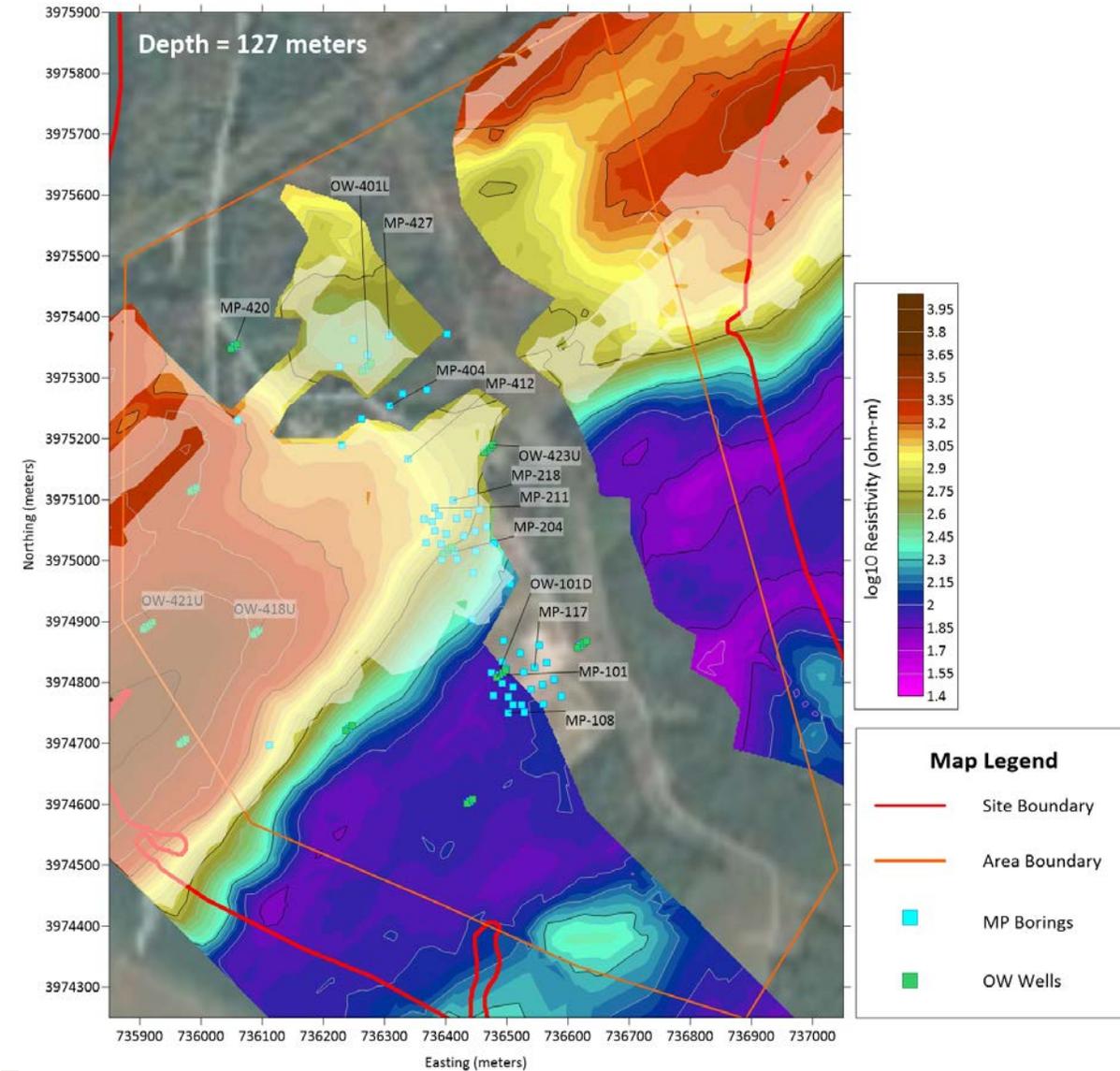
CRN Site Horizontal Slices – Area 1



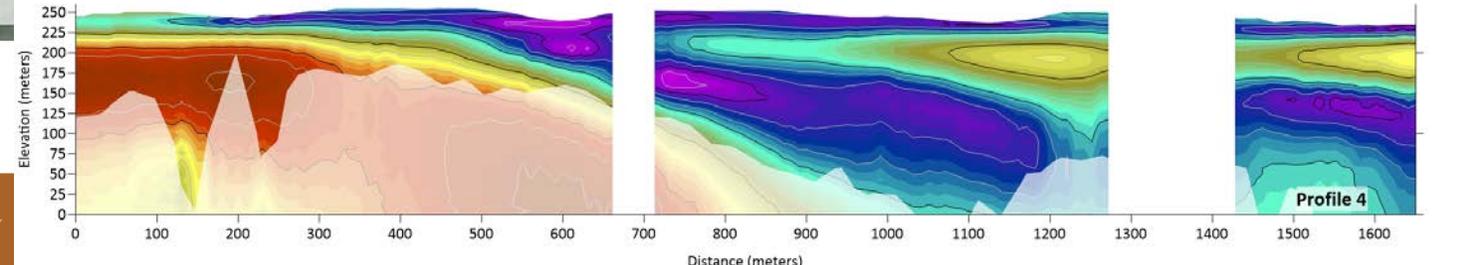
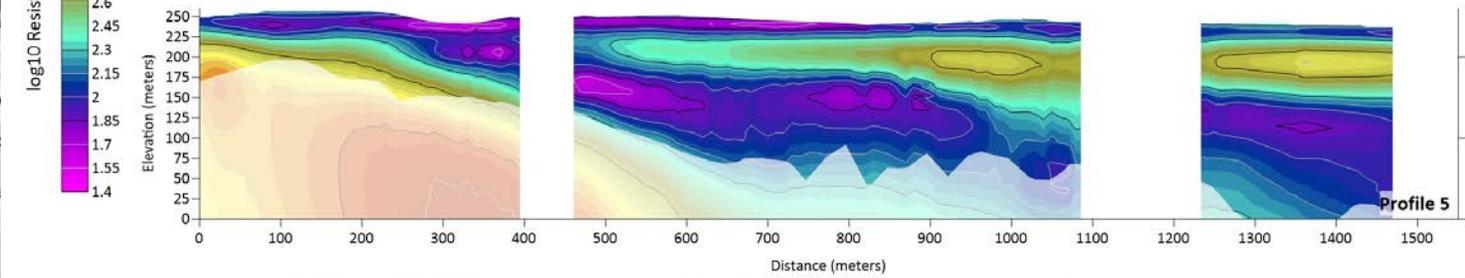
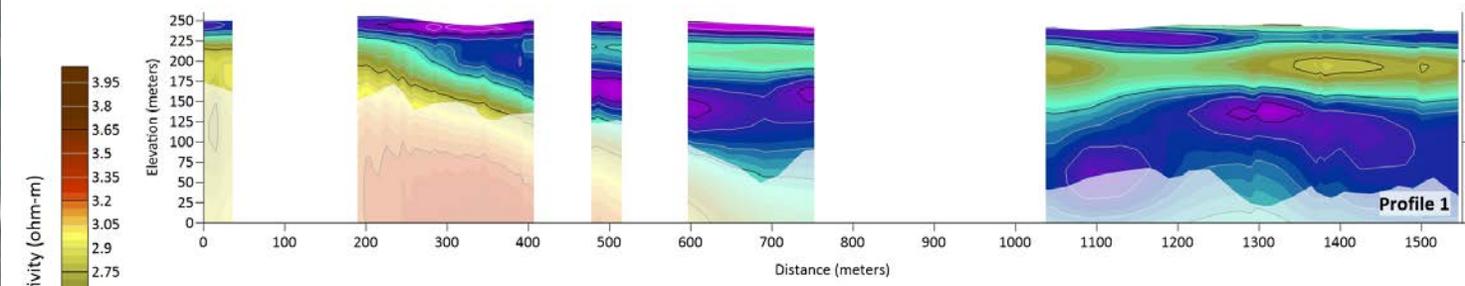
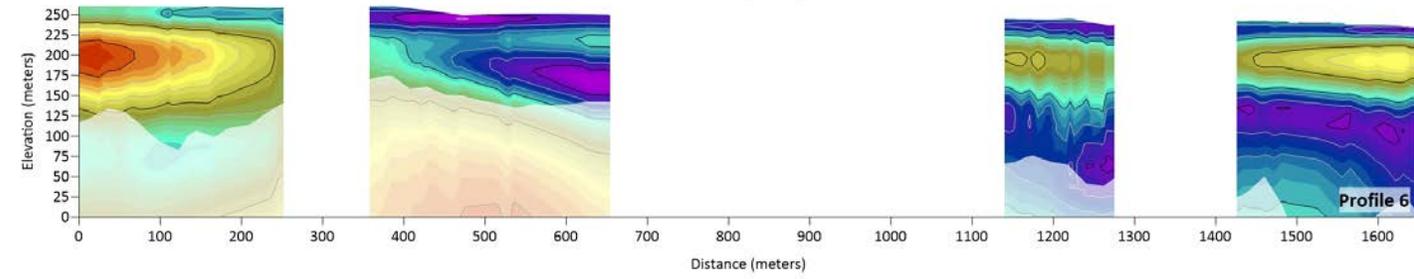
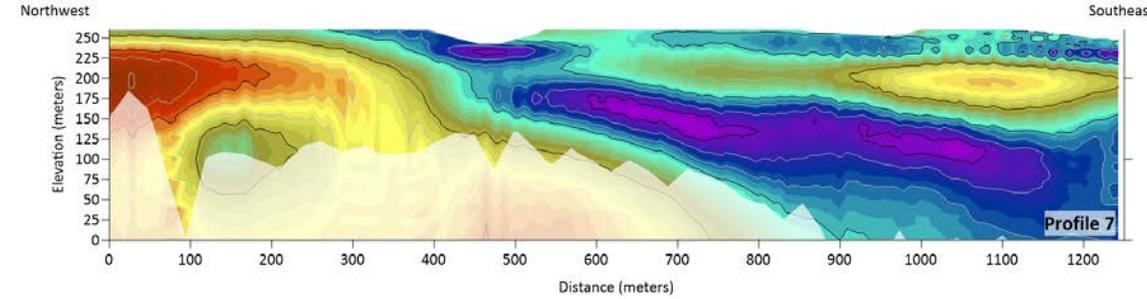
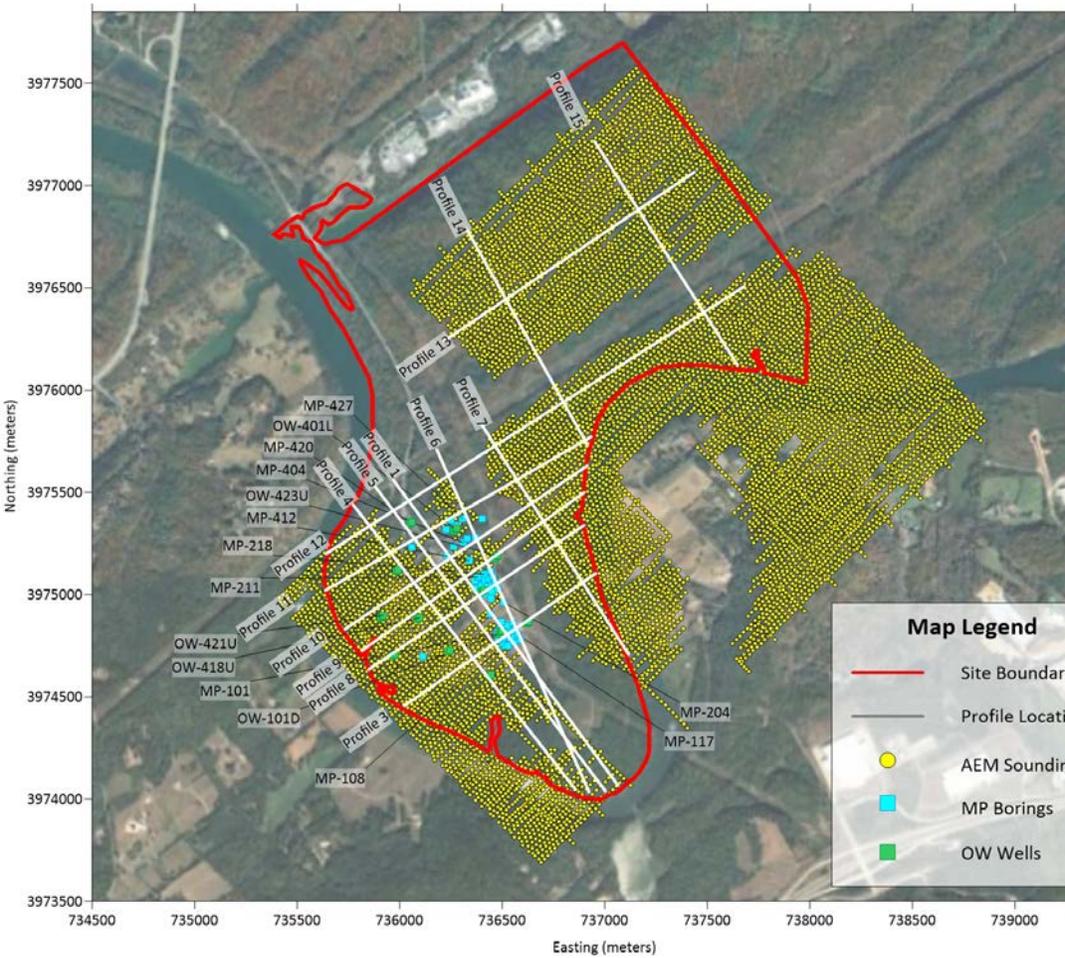
CRN Site Horizontal Slices – Area 1



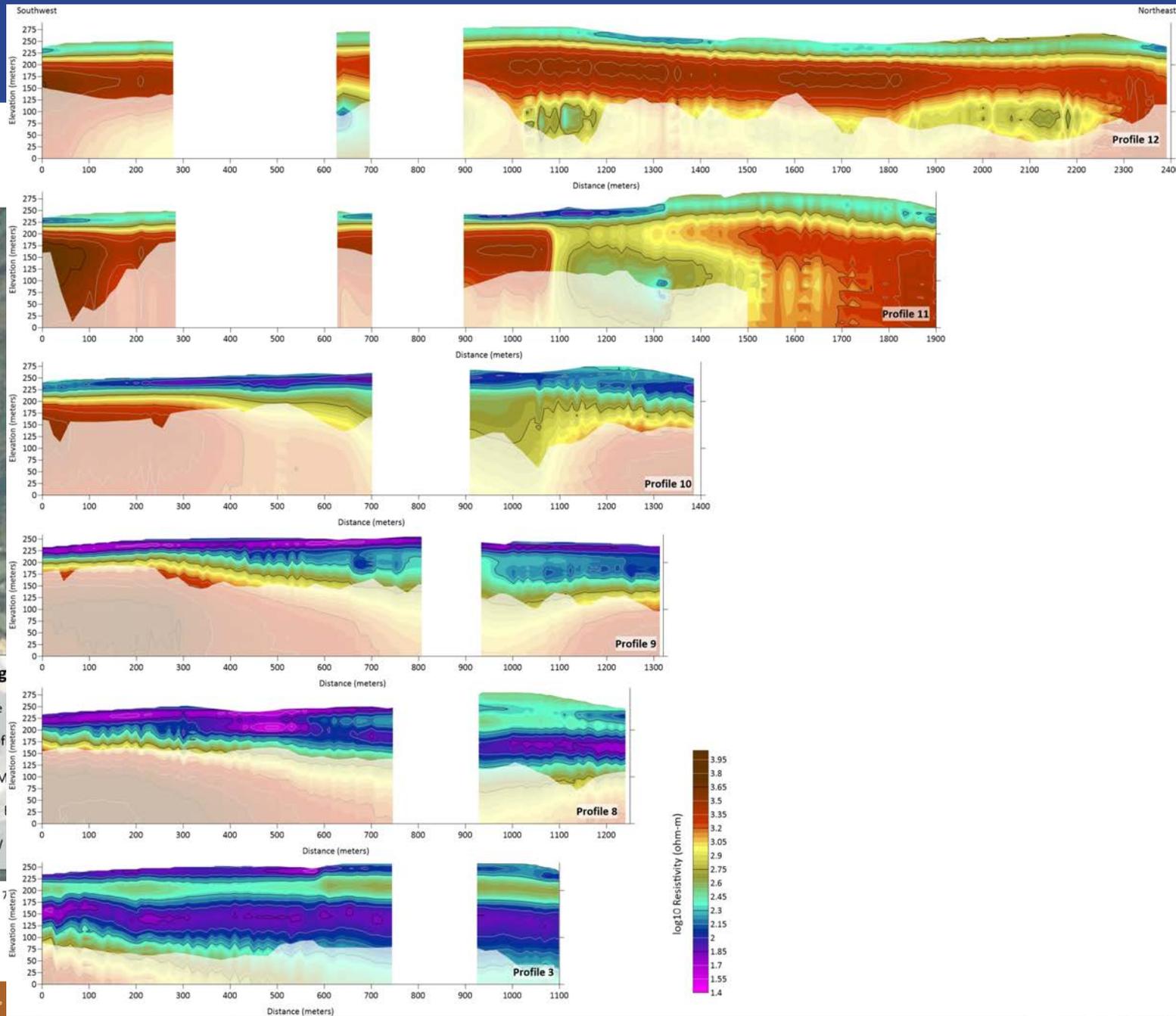
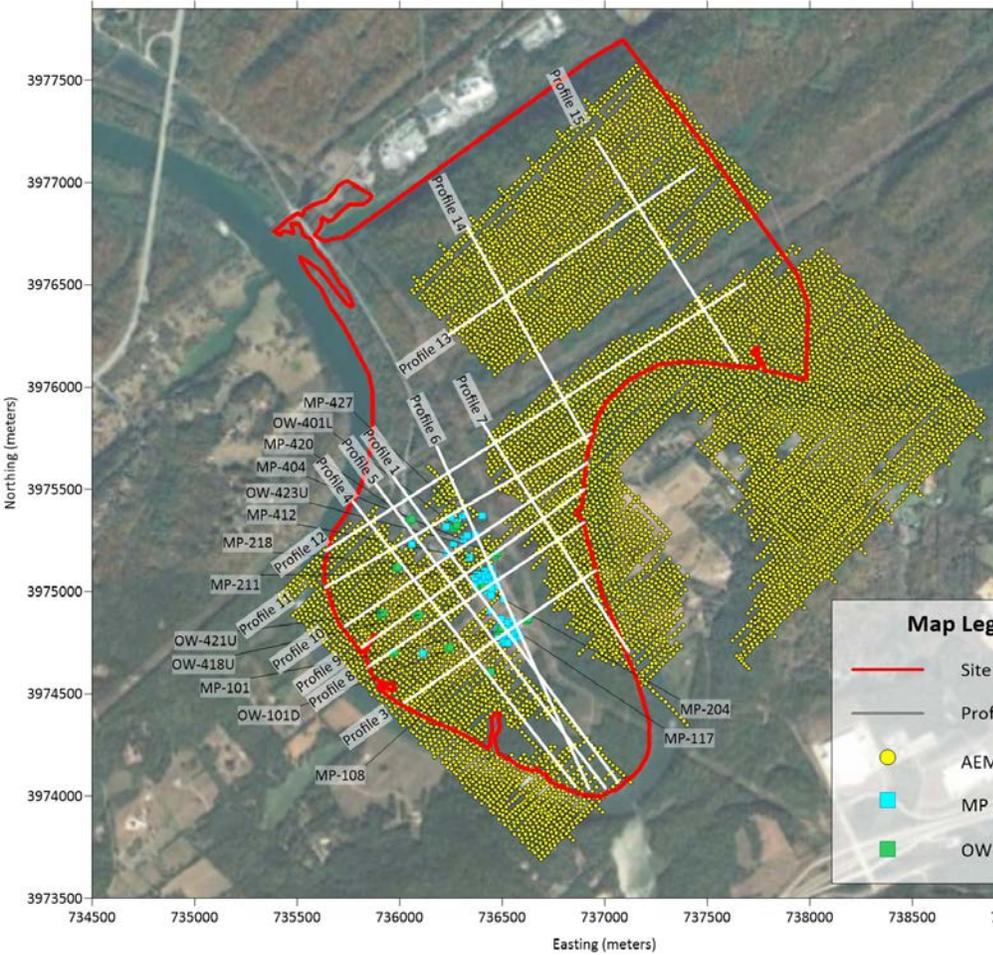
CRN Site Horizontal Slices – Area 1



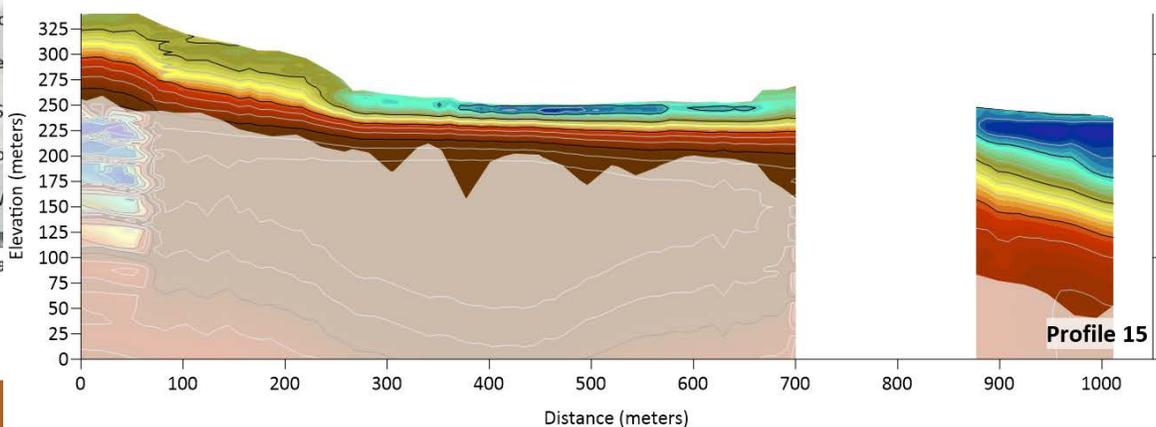
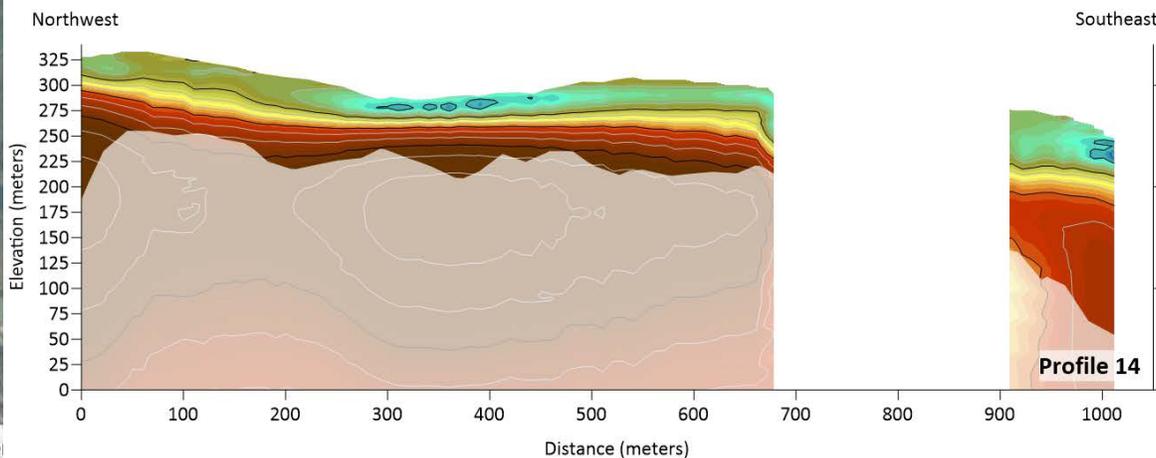
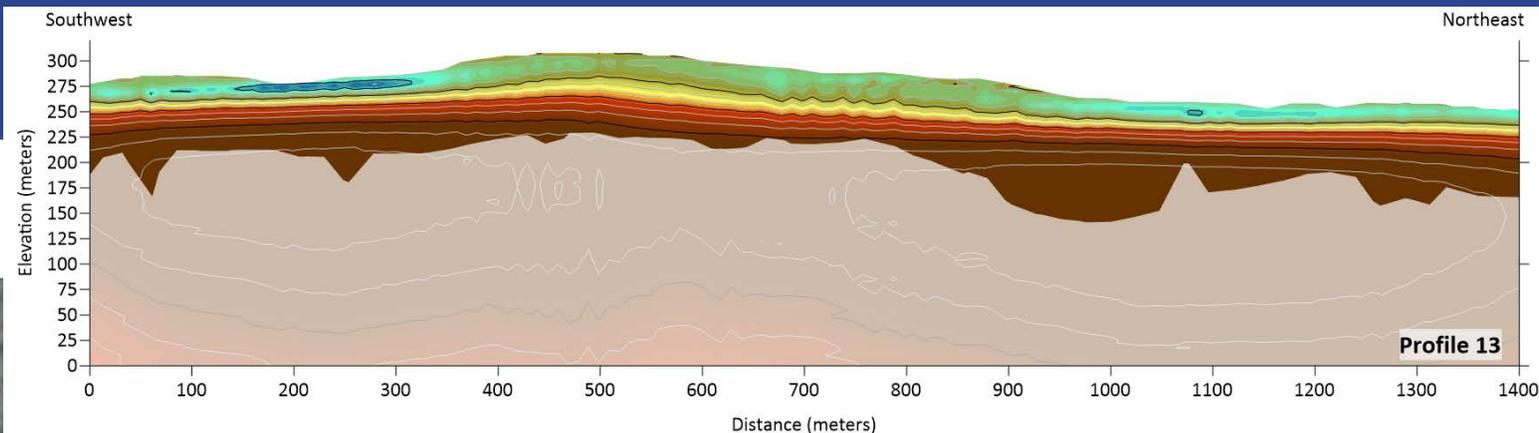
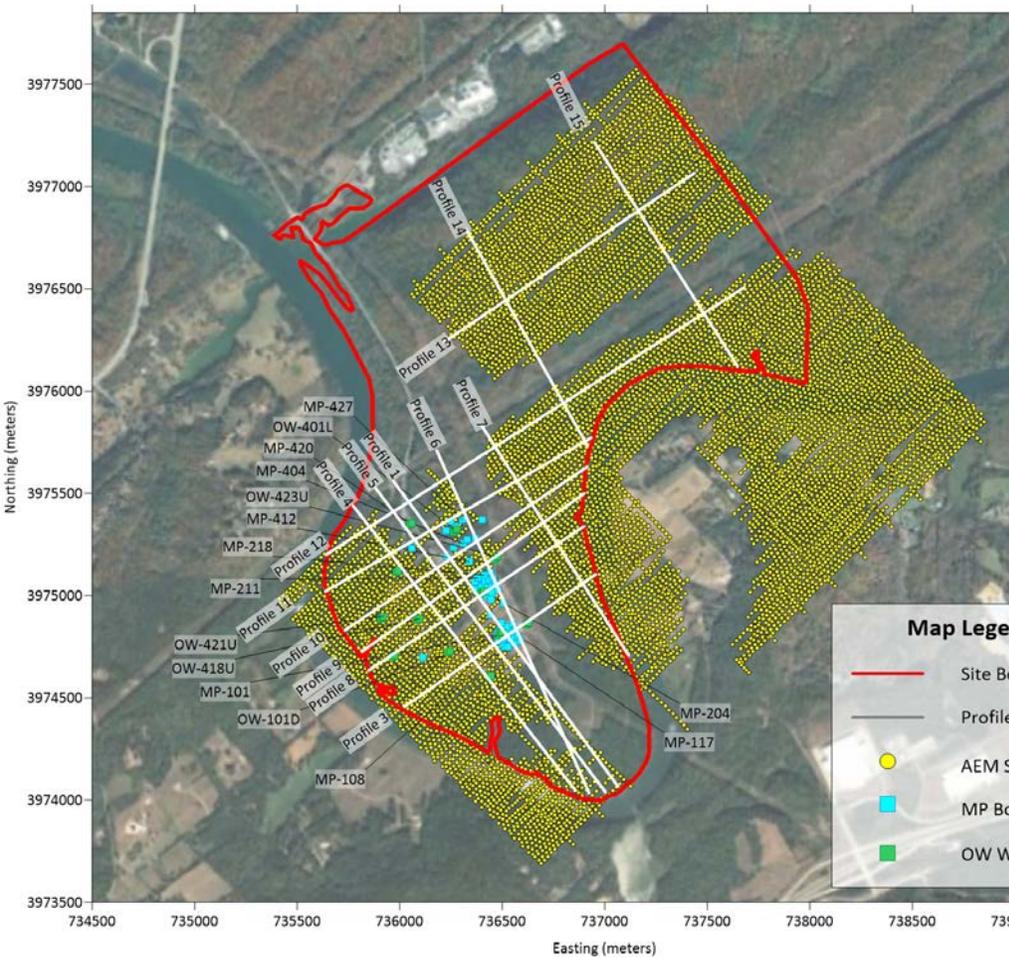
CRN Site Profiles



CRN Site Profiles



CRN Site Profiles



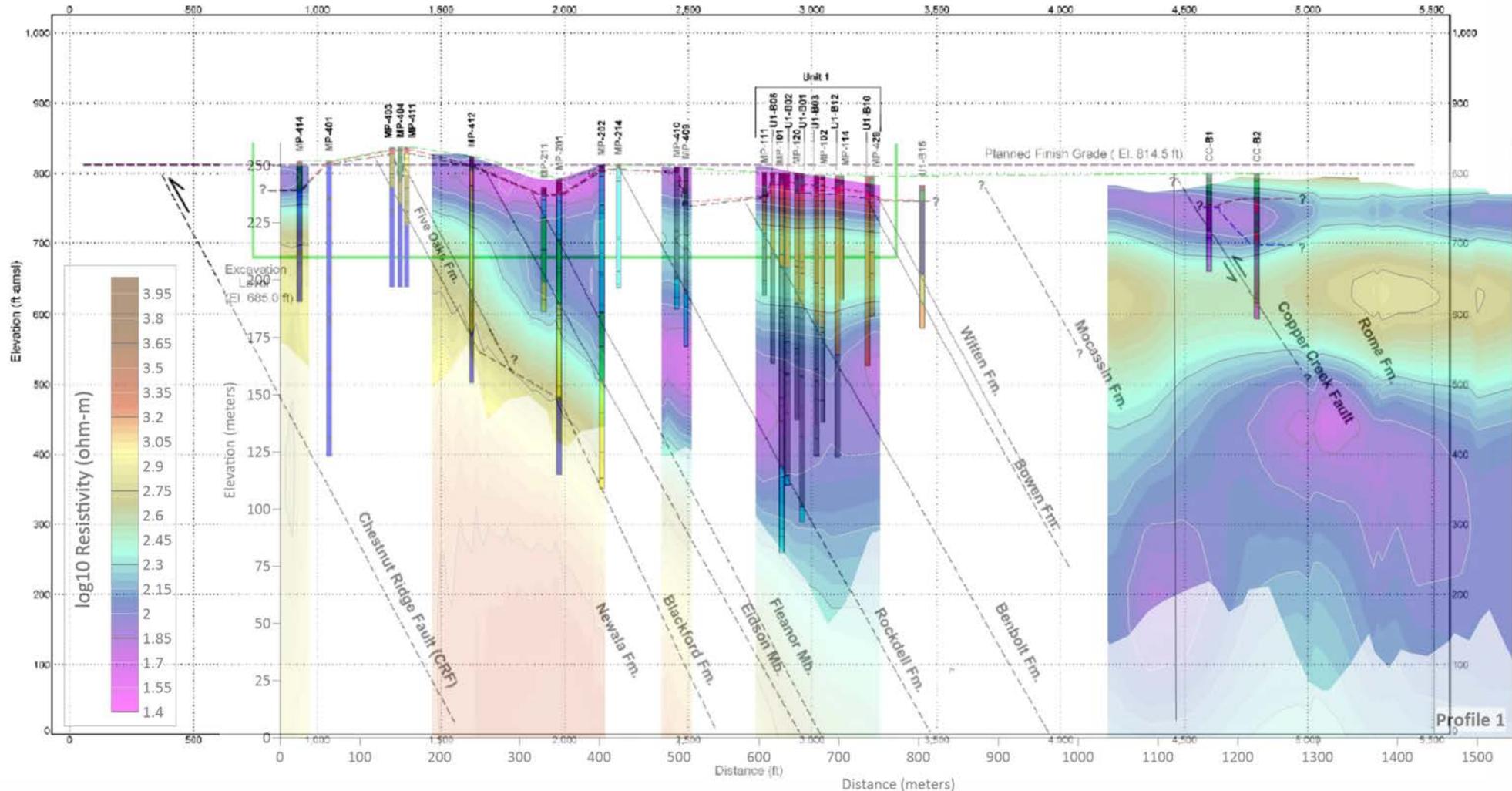
CRN – Geological Cross Section



GEOLOGIC CROSS-SECTION OF THE CLINCH RIVER NUCLEAR SITE Cross Section A-A' (NW-SE) WITH 2023 BORINGS

CLIENT Tennessee Valley Authority
PROJECT NUMBER 185737B

PROJECT NAME Clinch River SMR Project
PROJECT LOCATION Oak Ridge, Tennessee



Sub



CRN – Geological Cross Section



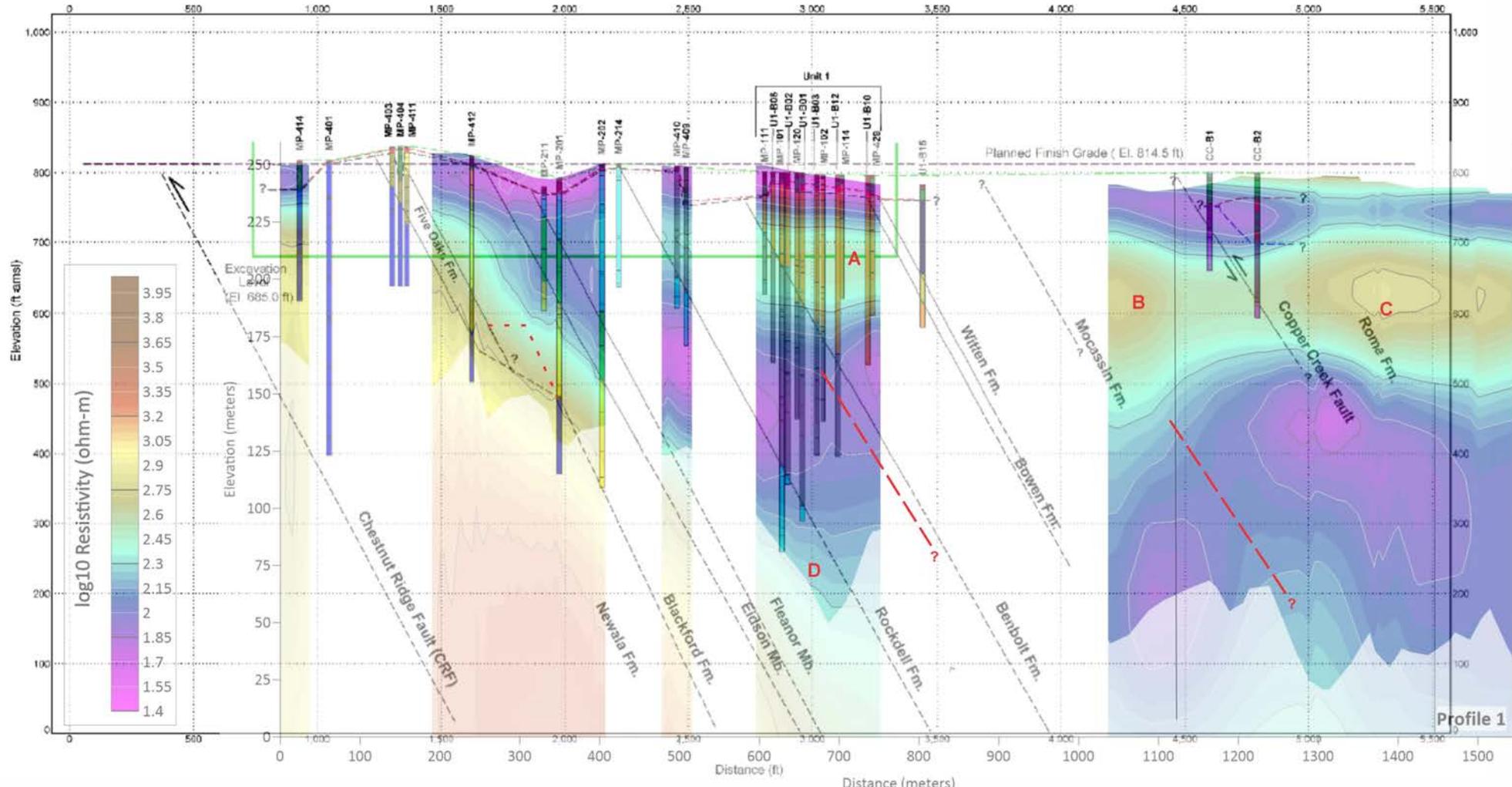
GEOLOGIC CROSS-SECTION OF THE CLINCH RIVER NUCLEAR SITE Cross Section A-A' (NW-SE) WITH 2023 BORINGS

CLIENT Tennessee Valley Authority
PROJECT NUMBER 186737B

PROJECT NAME Clinch River SMR Project
PROJECT LOCATION Oak Ridge, Tennessee

- | | | | |
|----------------|--------------------|--|--------------------------------------|
| Topsoil | Rome Formation | Rockwell Formation | Nevala Formation |
| Colluvium | Moccasin Formation | Unconformity Formation - Flexor Member | Five Oaks (Lower) Backford Formation |
| Residual Soil | Fill | Unconformity Formation - Ector Member | Bowen Formation |
| Weathered Rock | Bentley Formation | Blackford Formation | Witten Formation |

- Finished Grade (El. 816 ft)
- Ground Surface
- Top of Weathered Rock (Est.)
- Top of Rock (Est.)
- Geologic Contacts (Est.) (dashed where inferred)
- Excavation Level (El. 685.0 ft)
- ? Indicates lack of information



Subs



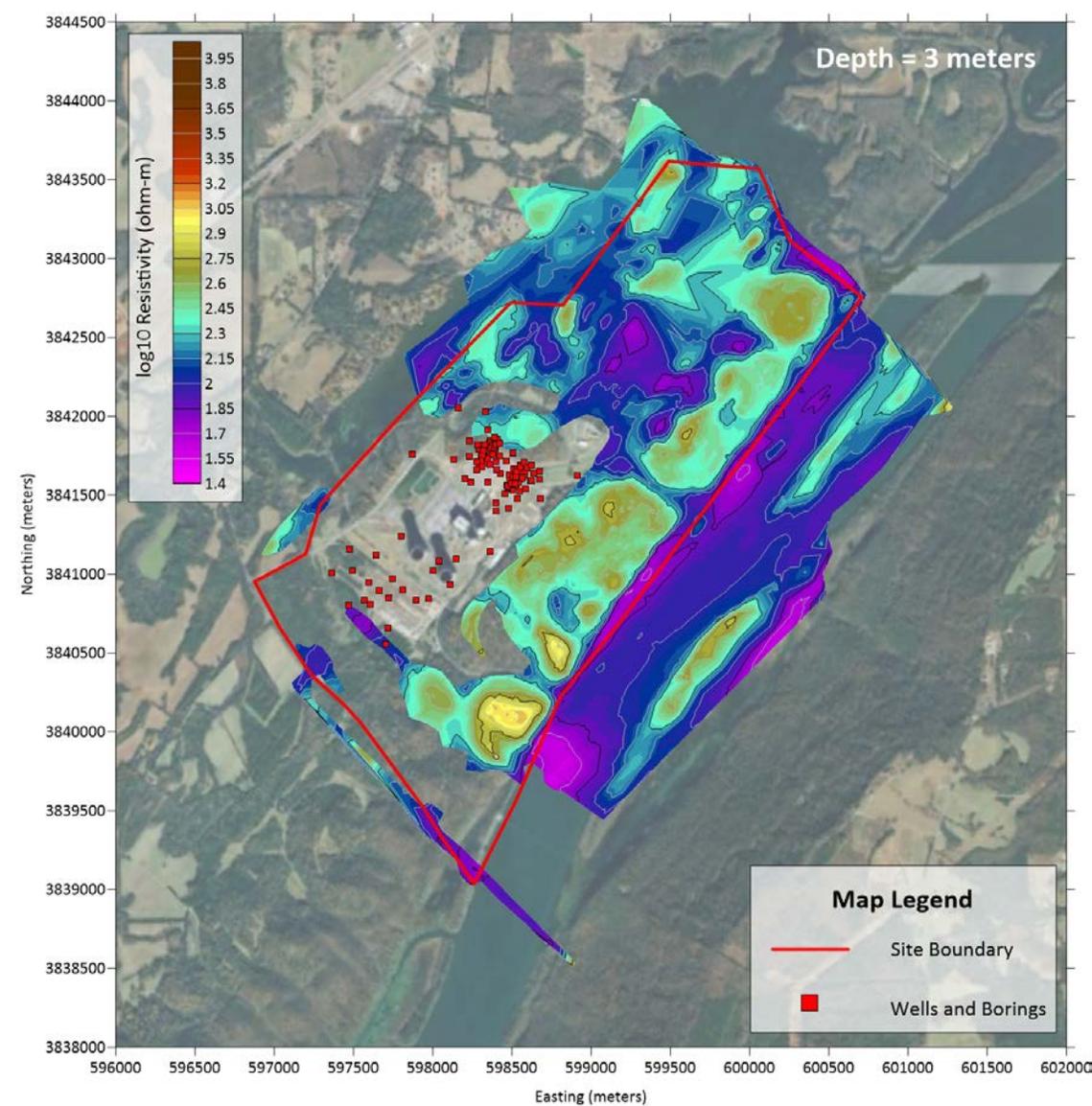
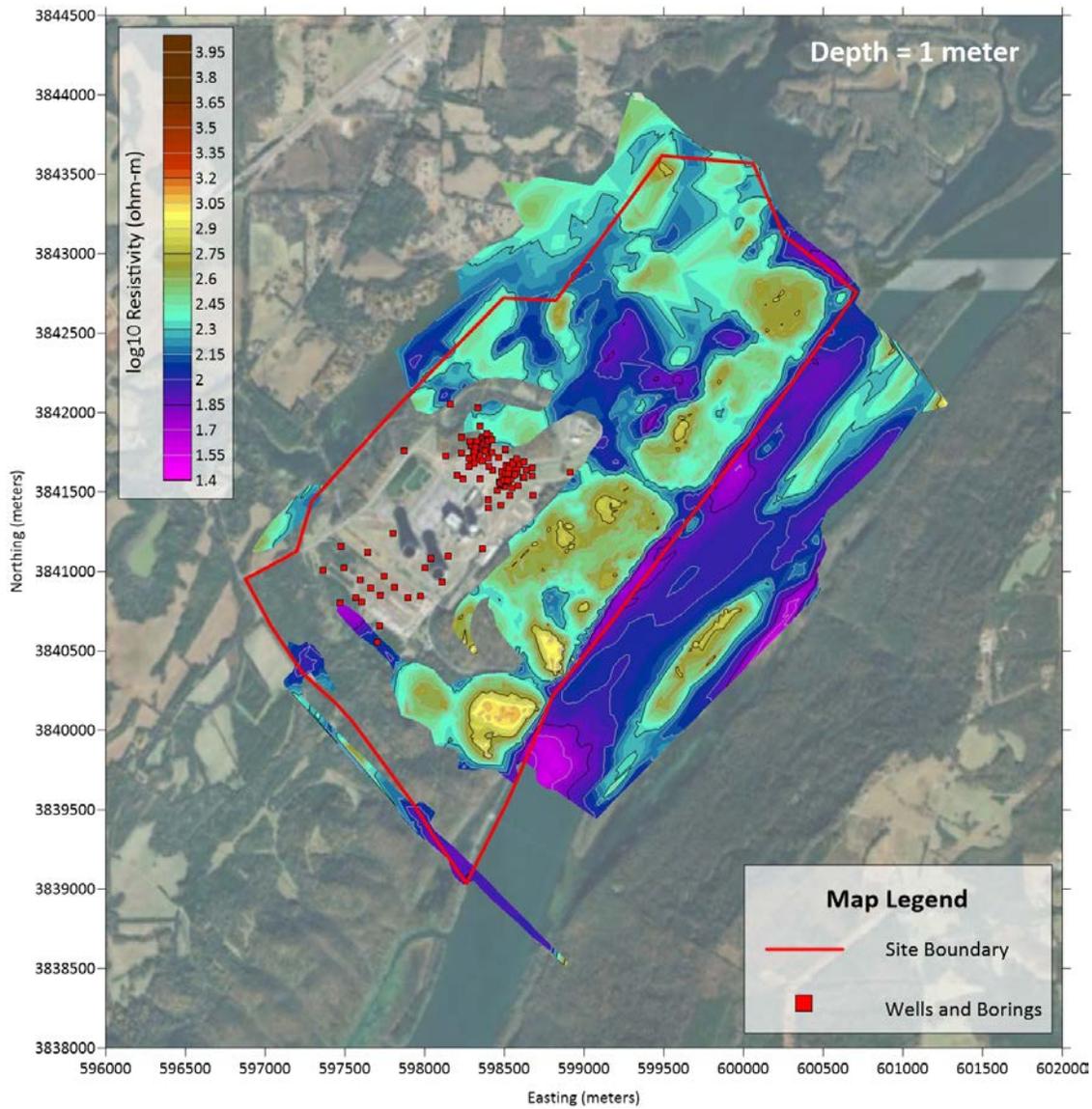
CRN - Summary

- Surficial low-resistivity cover following the Clinch River and its terraces, approximately 1 to 11 meters deep. In the western area, the lower resistivity values are attributed to backfilled spoil material consisting of high plasticity clays and organic materials. The same area has slightly elevated resistivity, which is likely crushed limestone.
- A persistent low-resistivity bedrock marker that was between 50 and 100 ohm-m correlated to the Blackford/Lincolnshire Fm. This band steepens toward the northwest and migrates southeast with depth, providing a structural datum that matches the mapped bedding and the Chestnut Ridge fault trend noted on site geological map.
- Resistive, competent bedrock in Area 2, 10,000 ohm-m was consistent with Knox Group dolomite at depth and at higher elevations. This unit imposes a shallow DOI in the north due to high resistivity, limiting confidence below 45 to 65 meters.
- Deeper conductivity increases to the southeast is consistent with Witten/Benbolt argillaceous carbonates and calcareous shales.
- Profile Set 1 indicates offset/warping of the conductive marker at the southeastern ends of several profiles, potentially suggesting one or more buried faults or shear zones subparallel to strike. The overlay with the geologic cross-section shows good stratigraphic concordance, with local departures at marked features (A–D) that may reflect alteration.

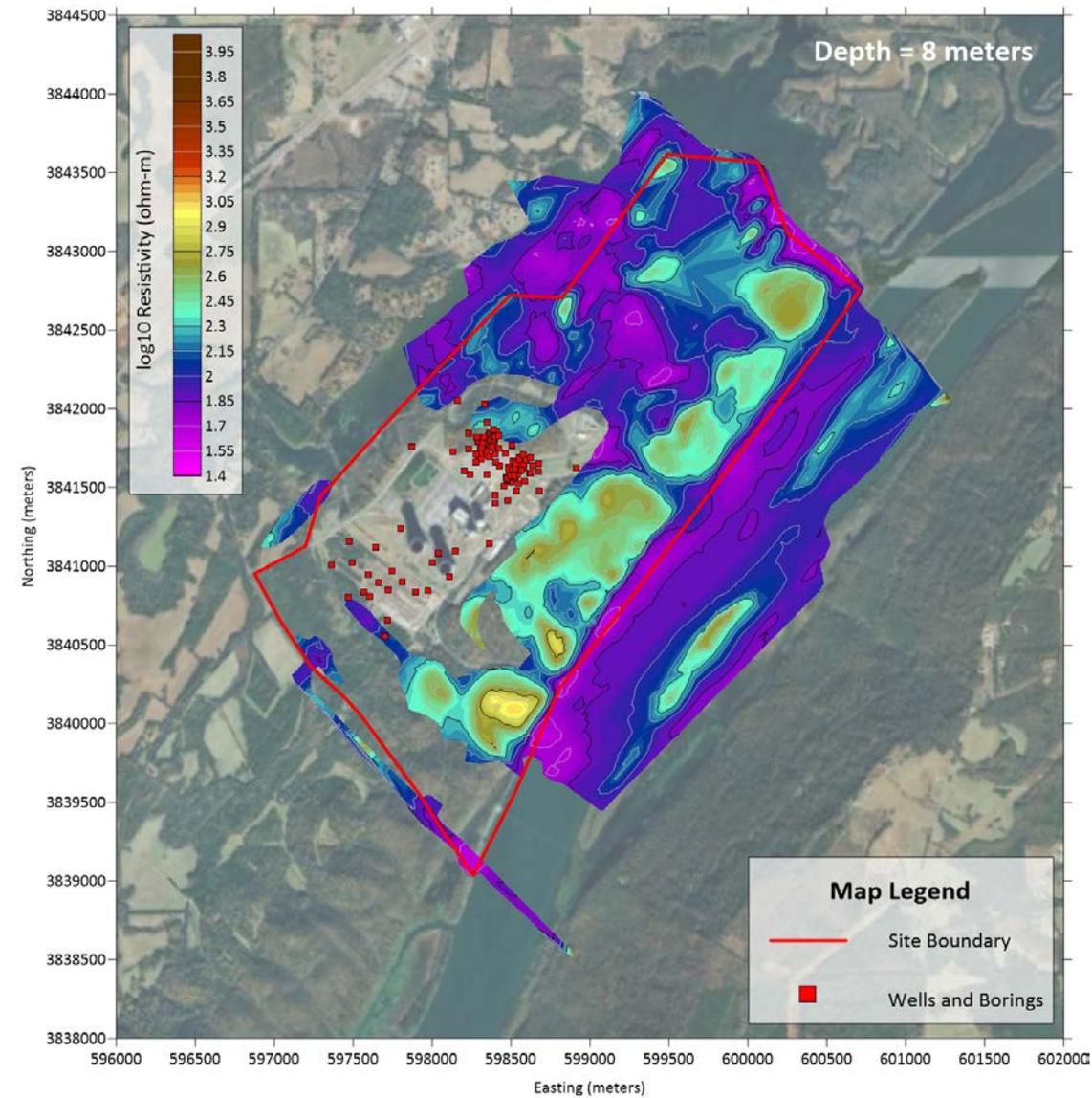
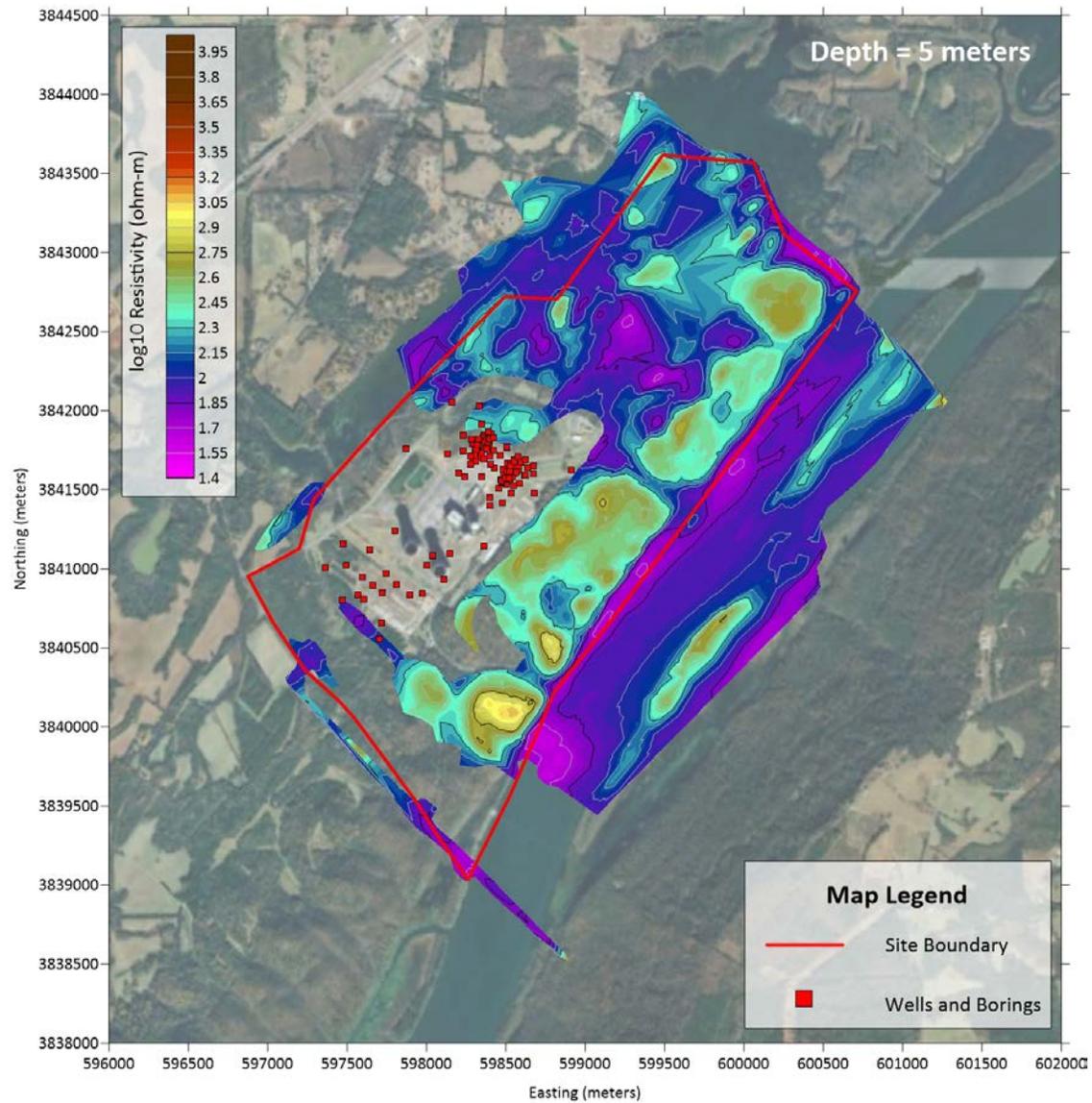
CRN - Recommendations

- New borings / hydro tests:
 - Two across the low-resistivity Blackford/Lincolnshire band (one near MP-412 corridor) to verify lithology, clay content, fracture density, and water levels.
 - Two within resistive Area 2 to quantify rock quality (RQD), karst risk, and depth to competent bearing strata.
 - Two straddle-fault tests across the suspected offsets in Profile Set 1 (Fig. 61) to confirm displacement and measure fracture permeability.
- Additional geophysics
 - Downhole logging
 - ERT at missing AEM soundings (due to noise) and in Area 2 below the 45m DOI

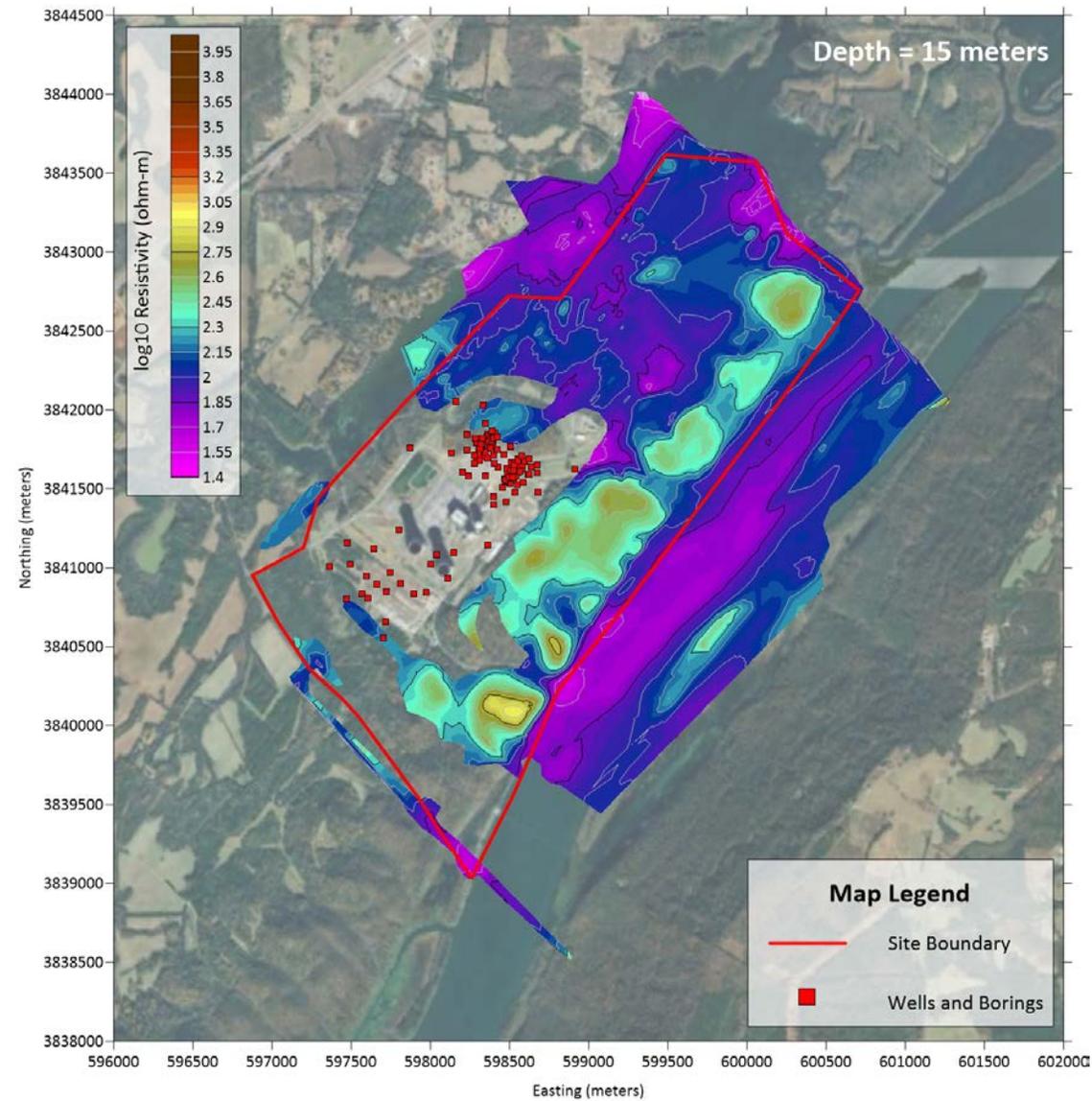
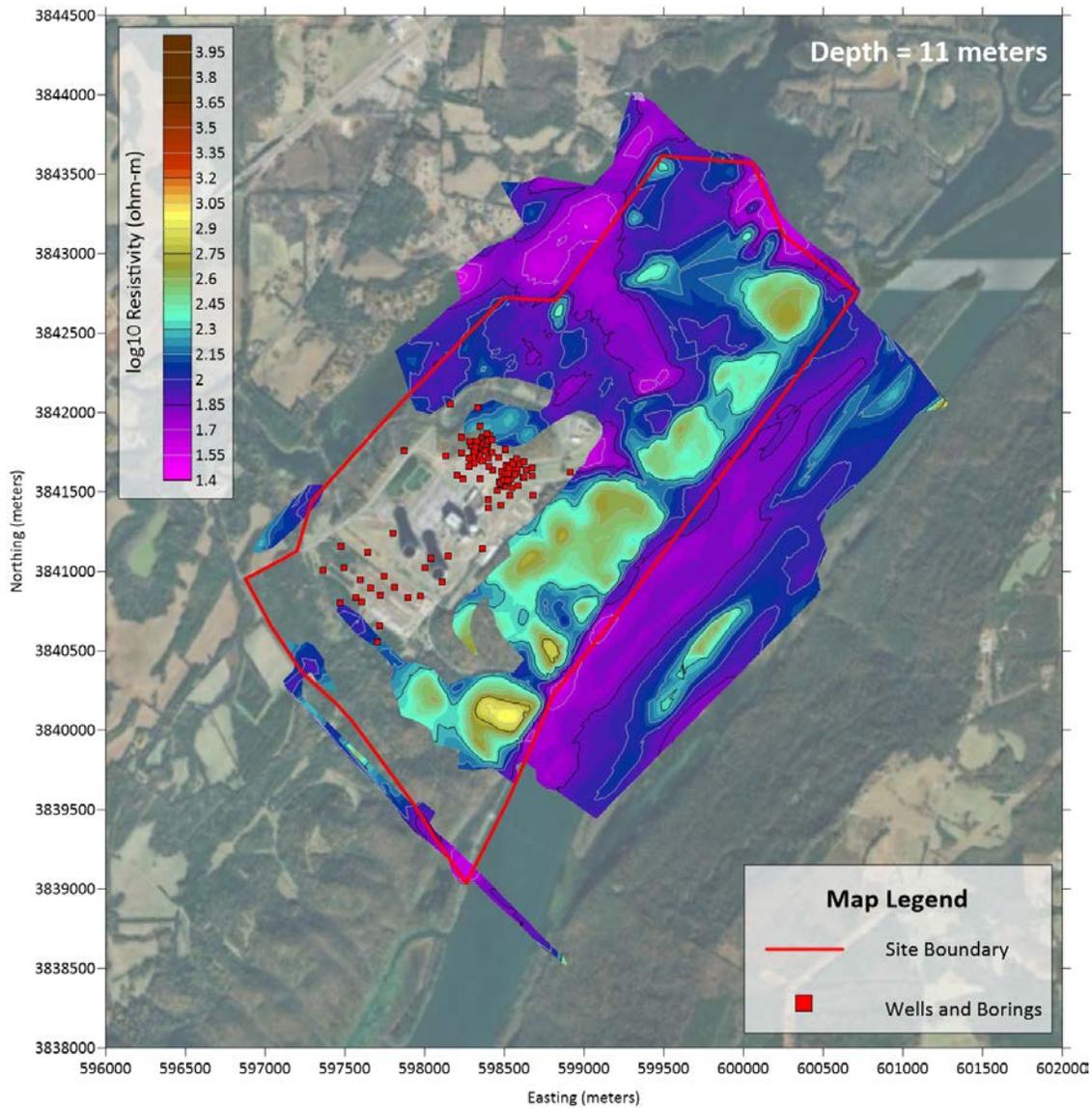
BLN Site Horizontal Slices



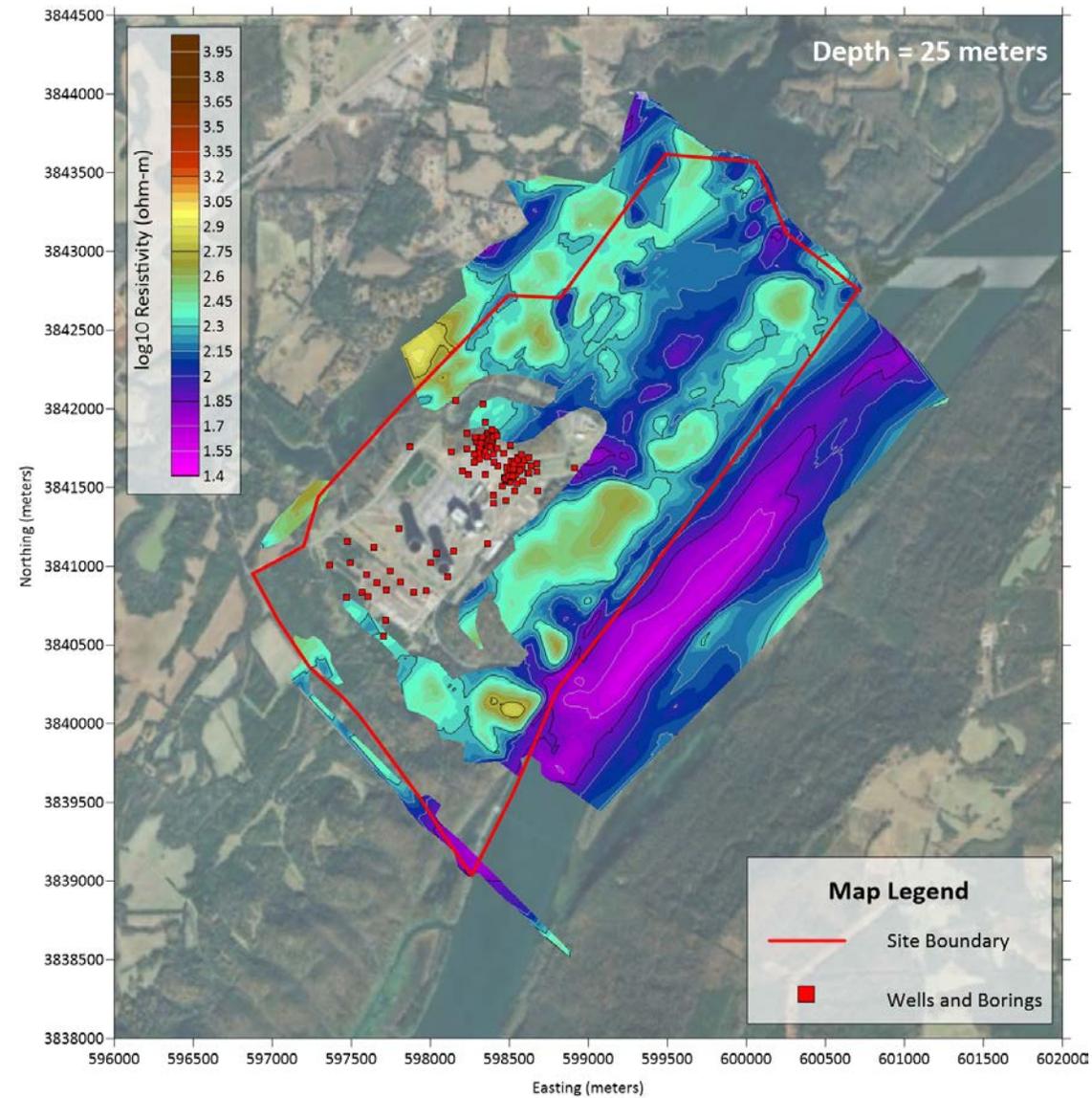
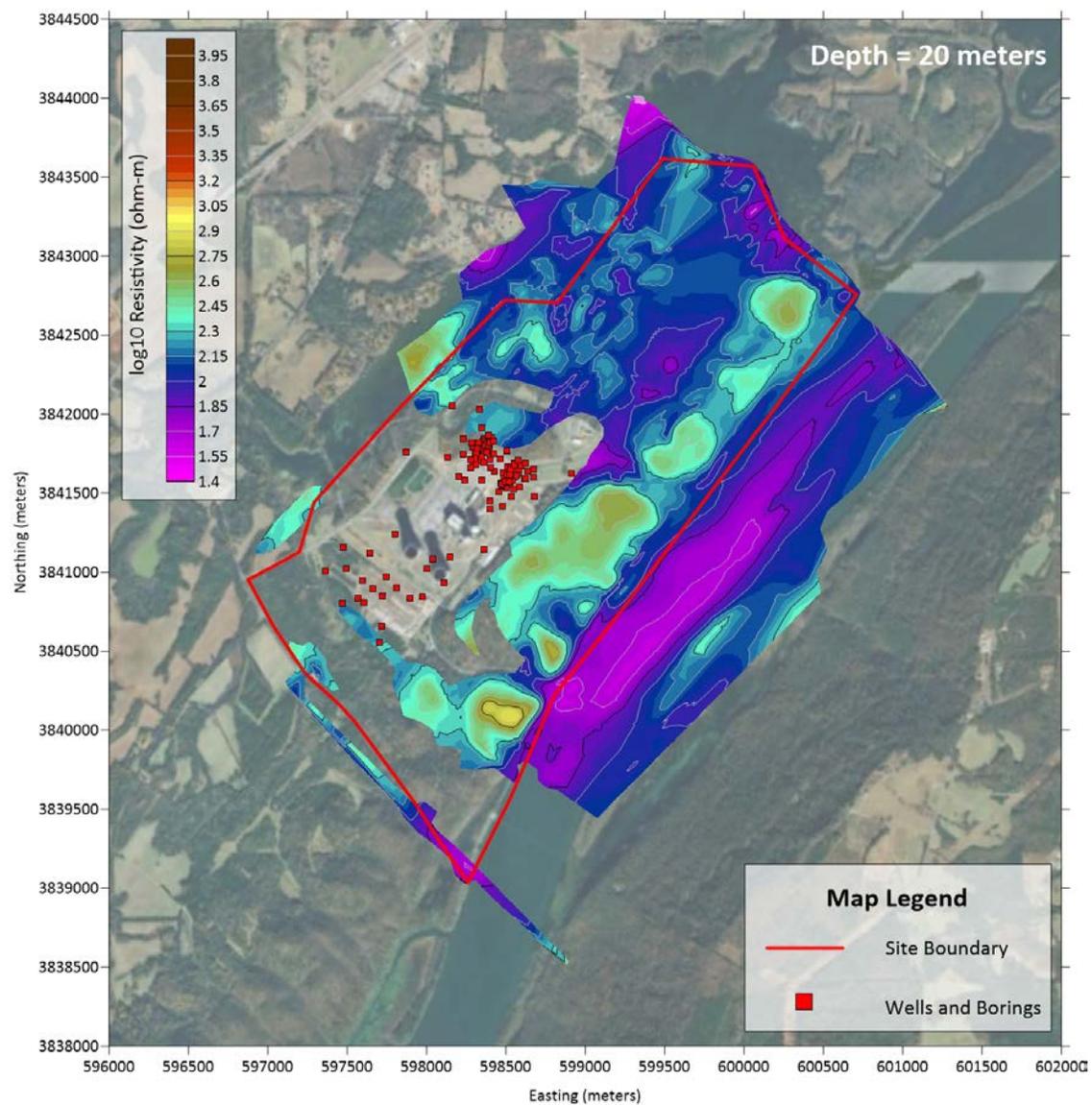
BLN Site Horizontal Slices



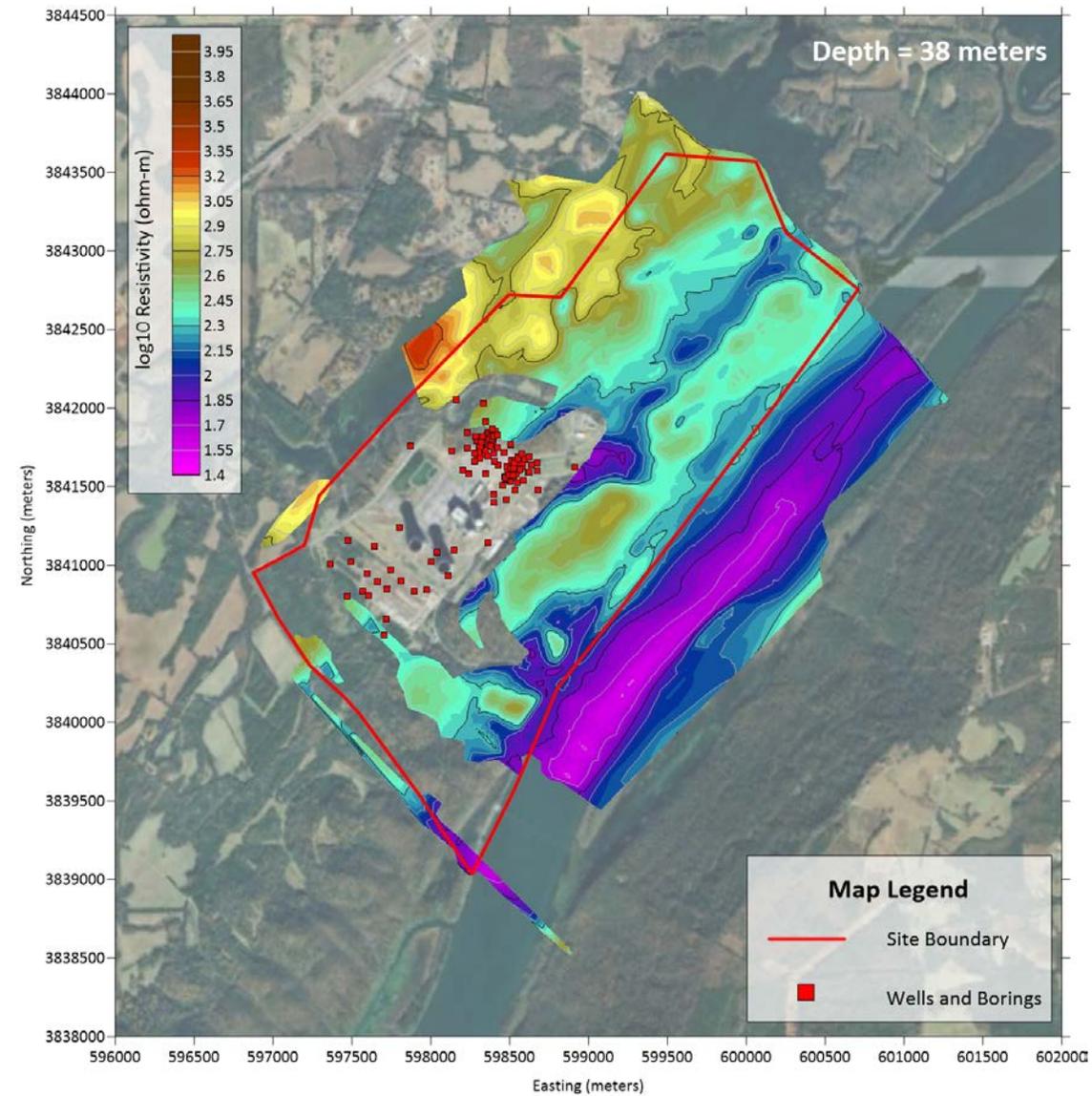
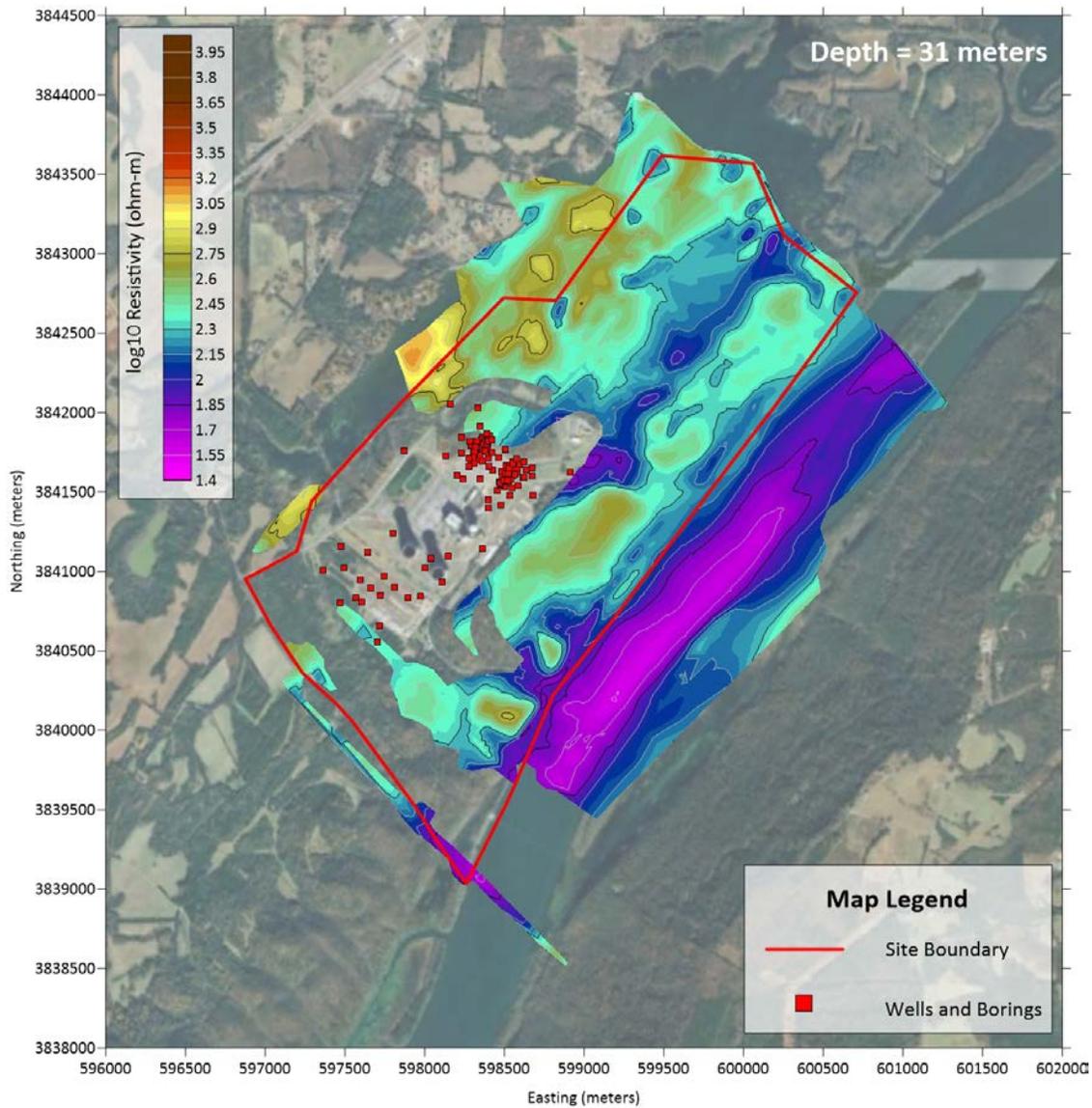
BLN Site Horizontal Slices



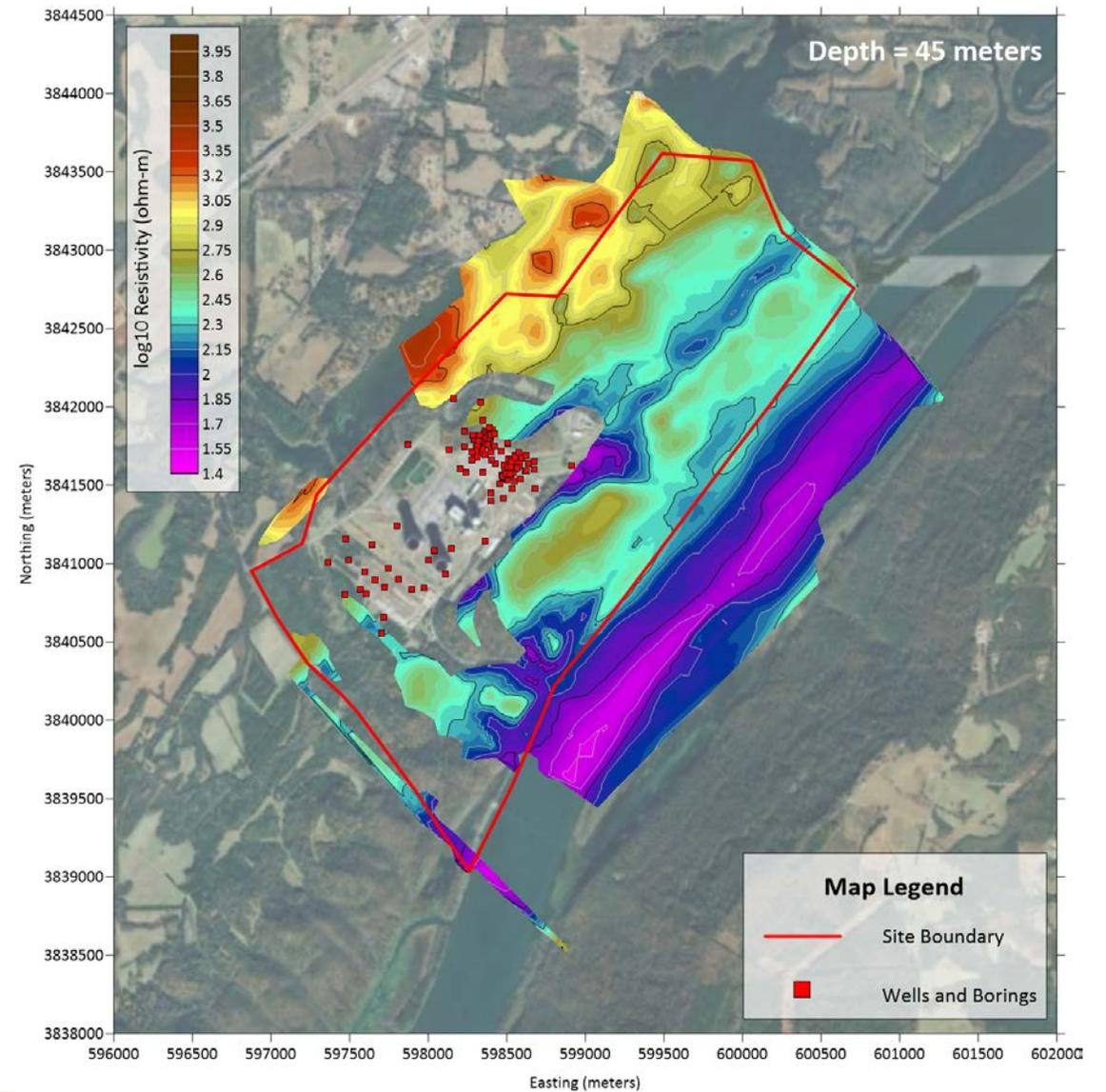
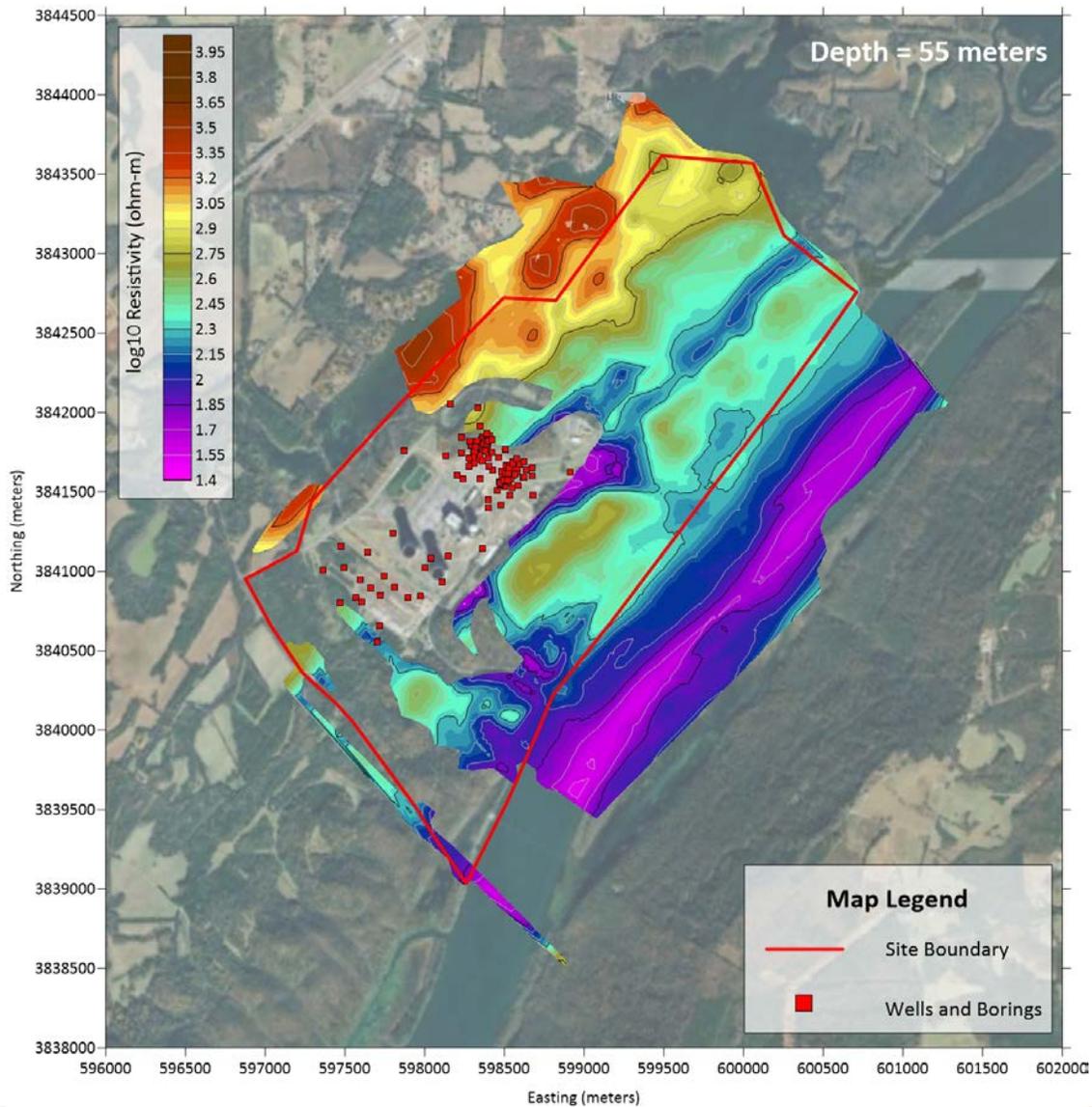
BLN Site Horizontal Slices



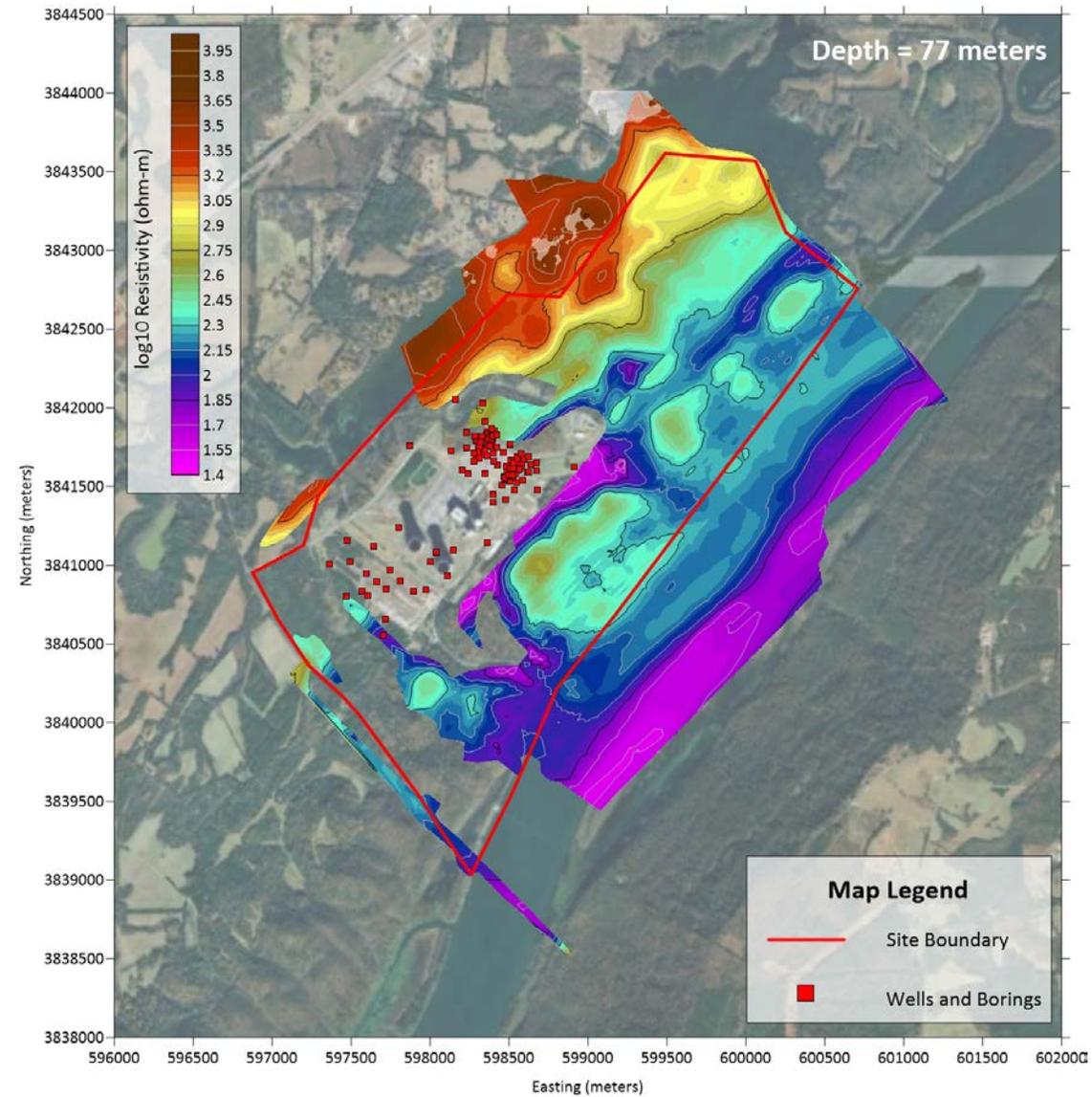
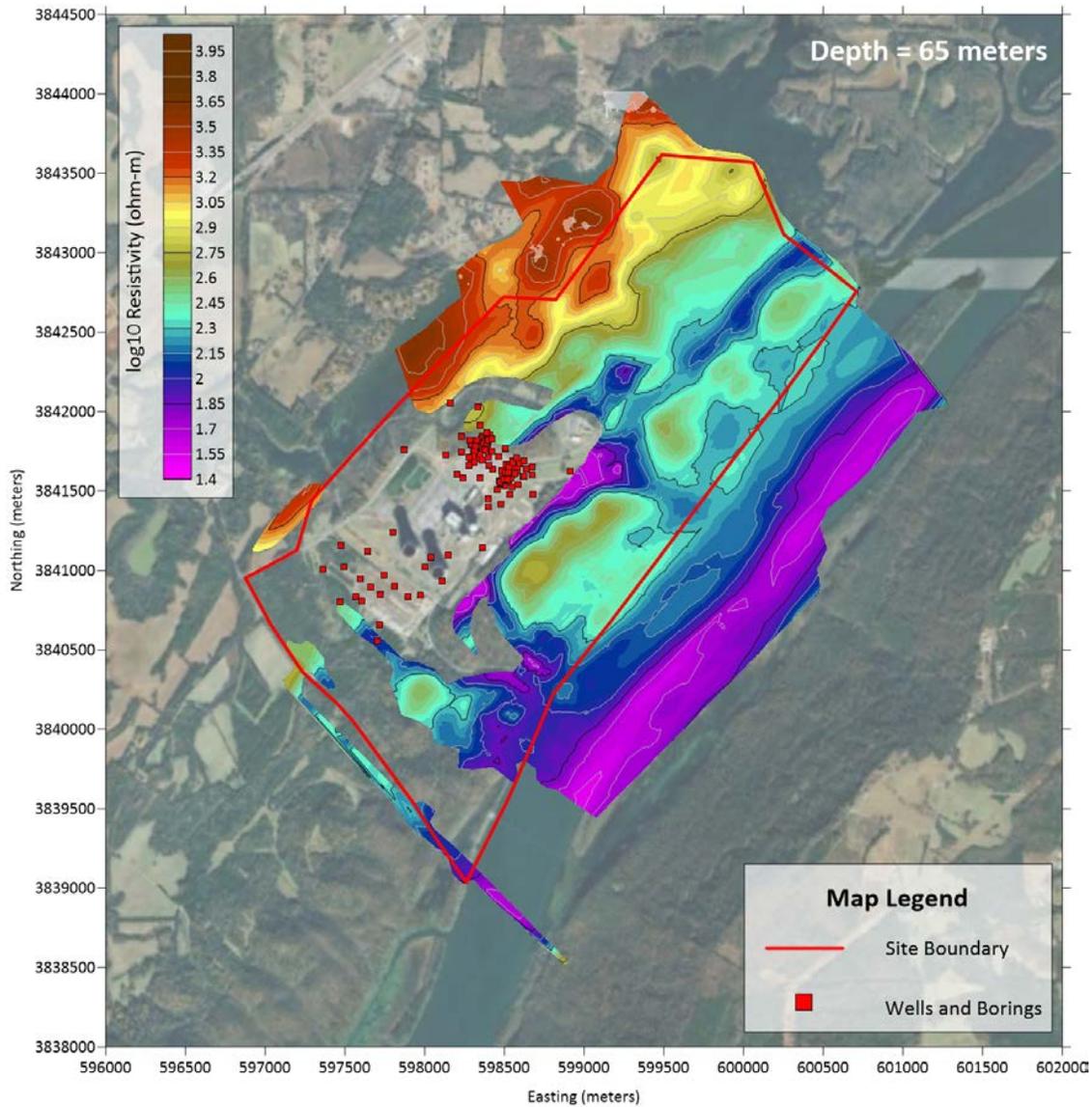
BLN Site Horizontal Slices



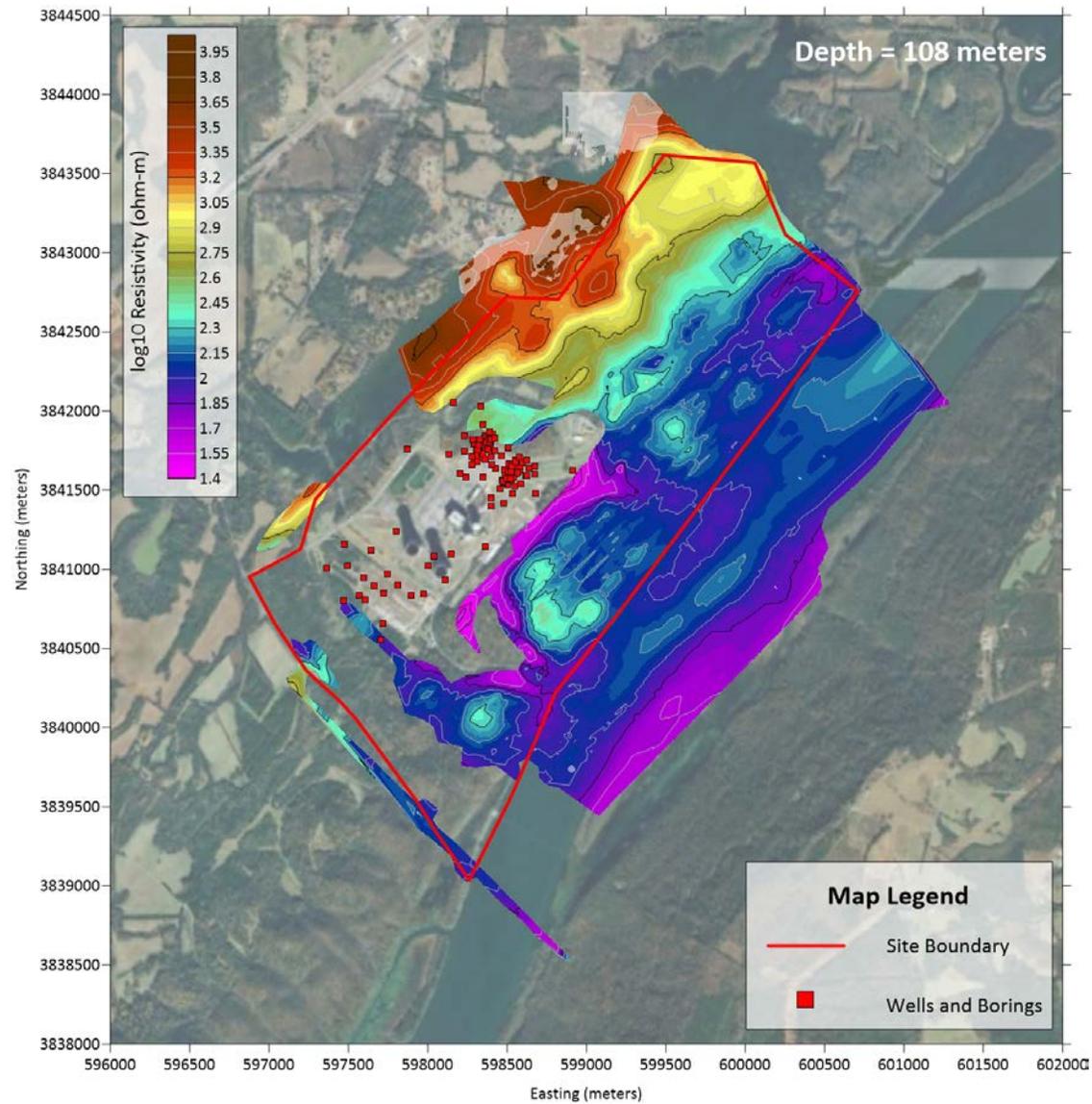
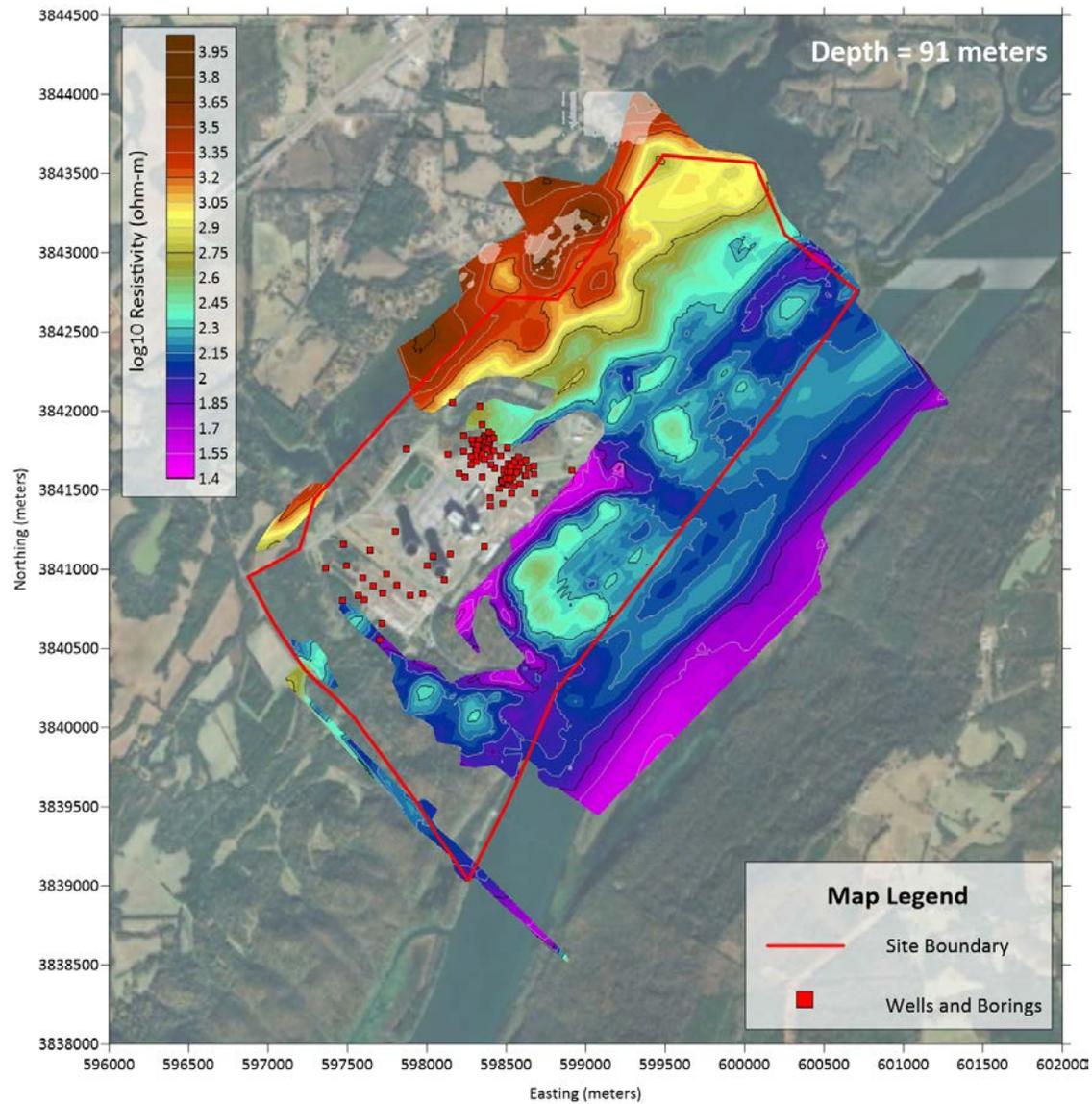
BLN Site Horizontal Slices



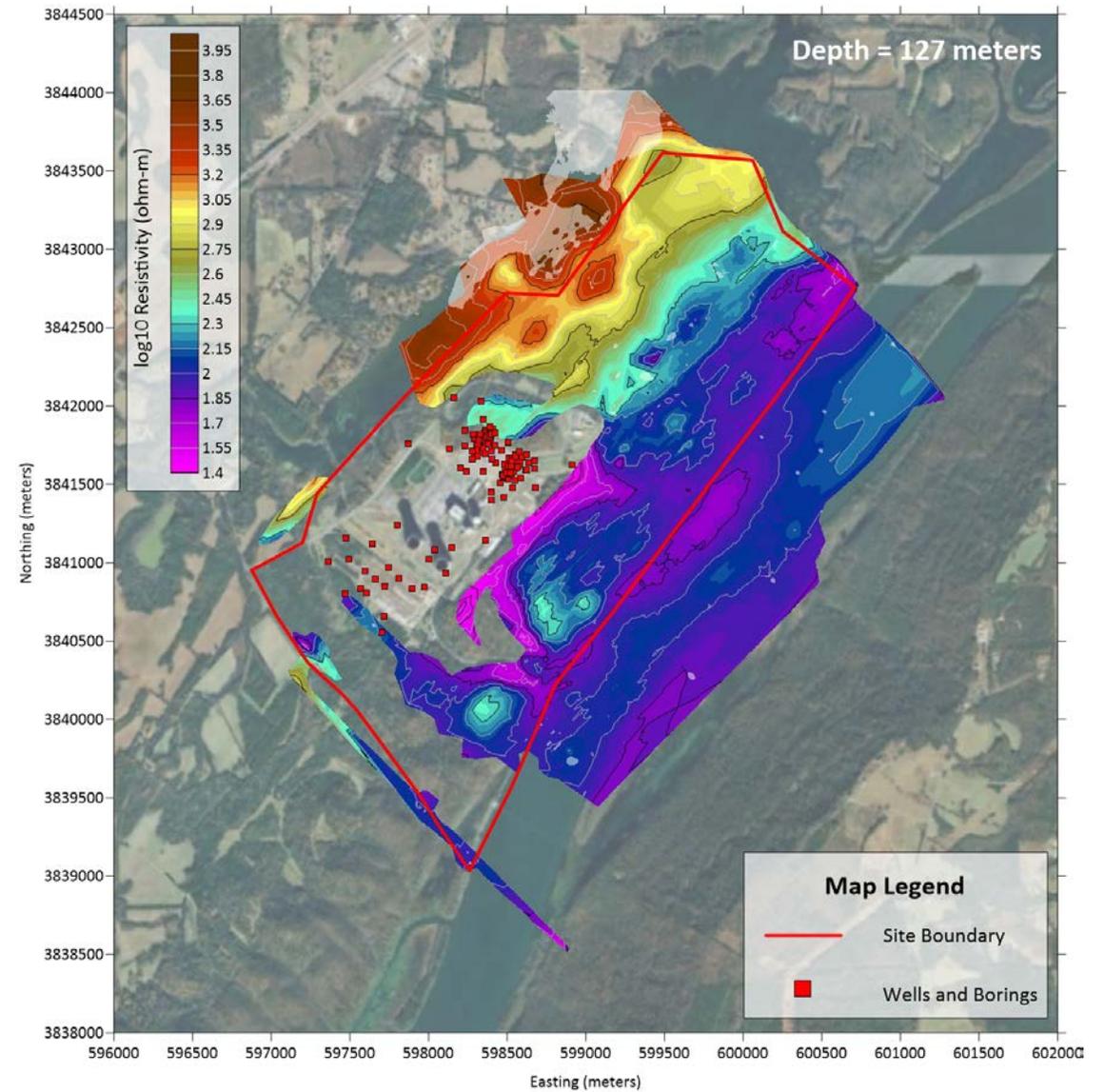
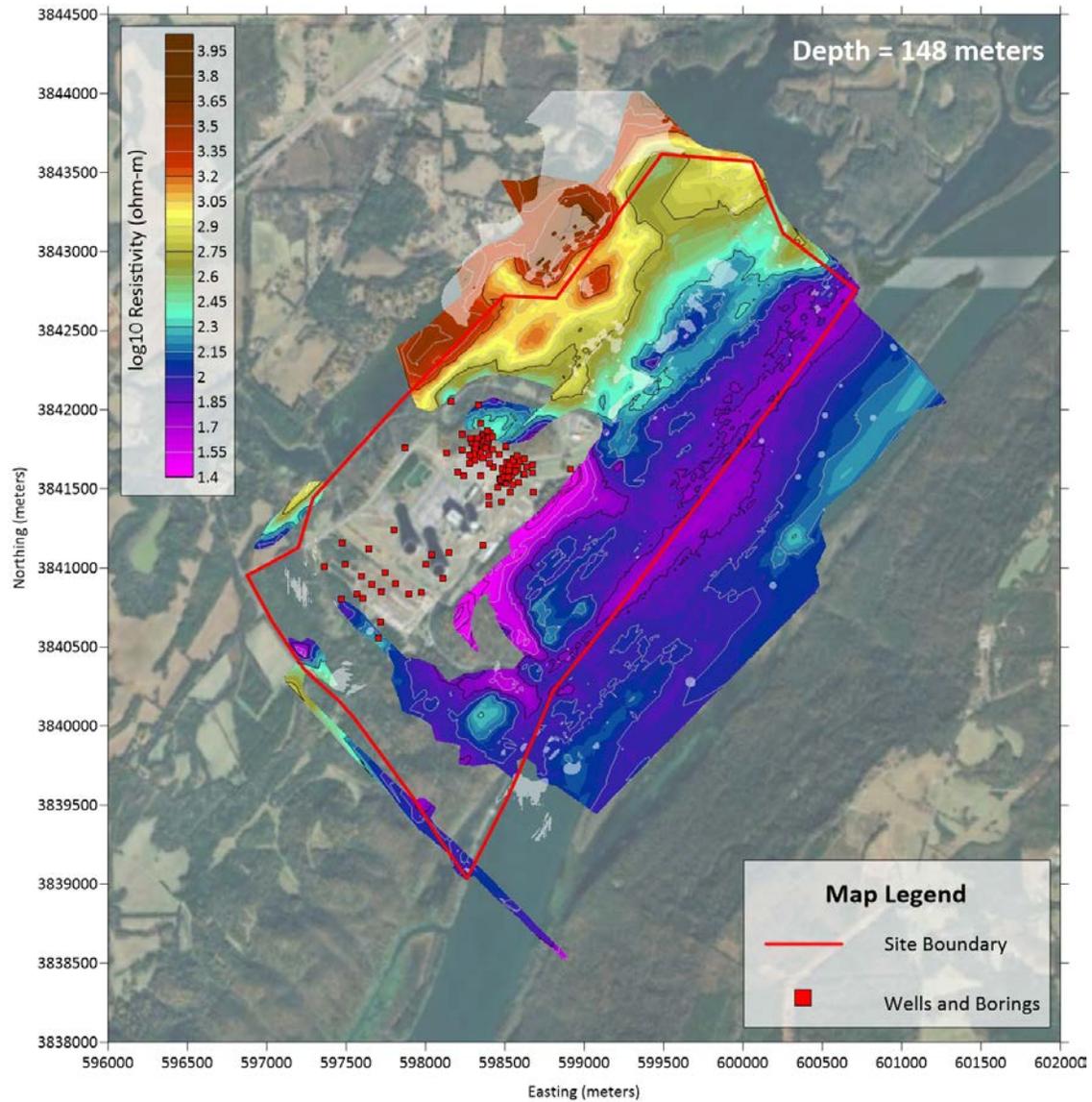
BLN Site Horizontal Slices



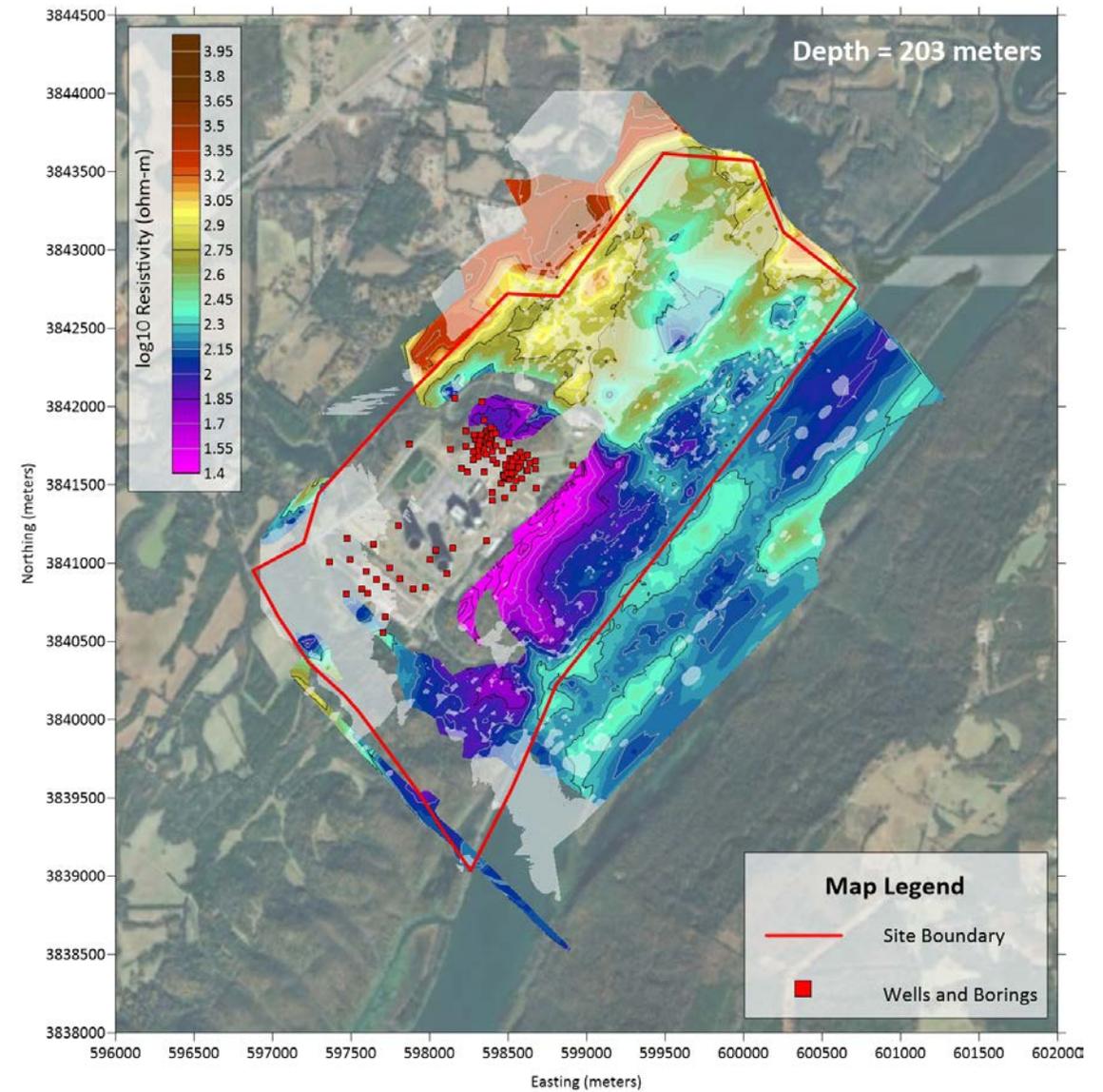
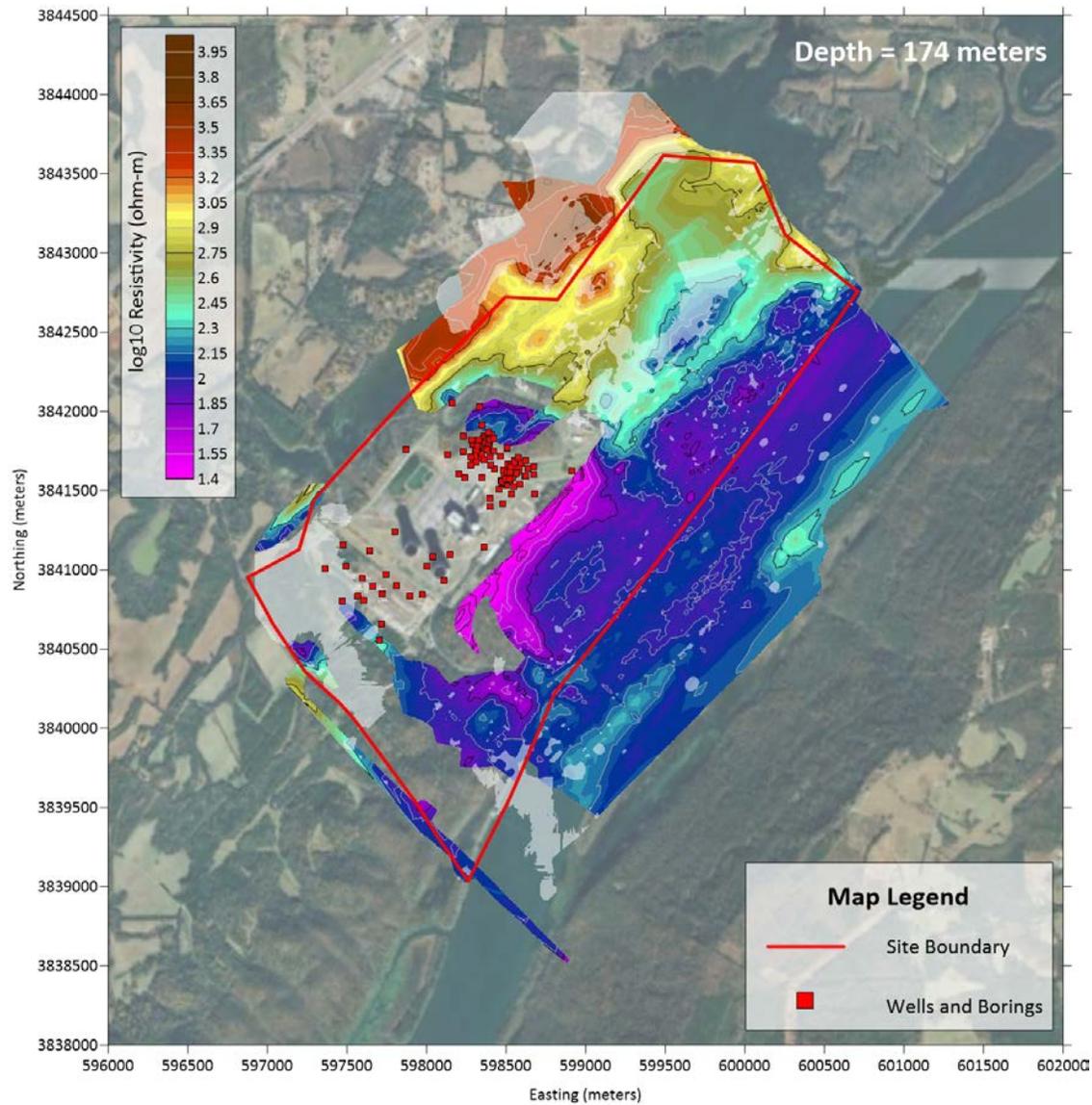
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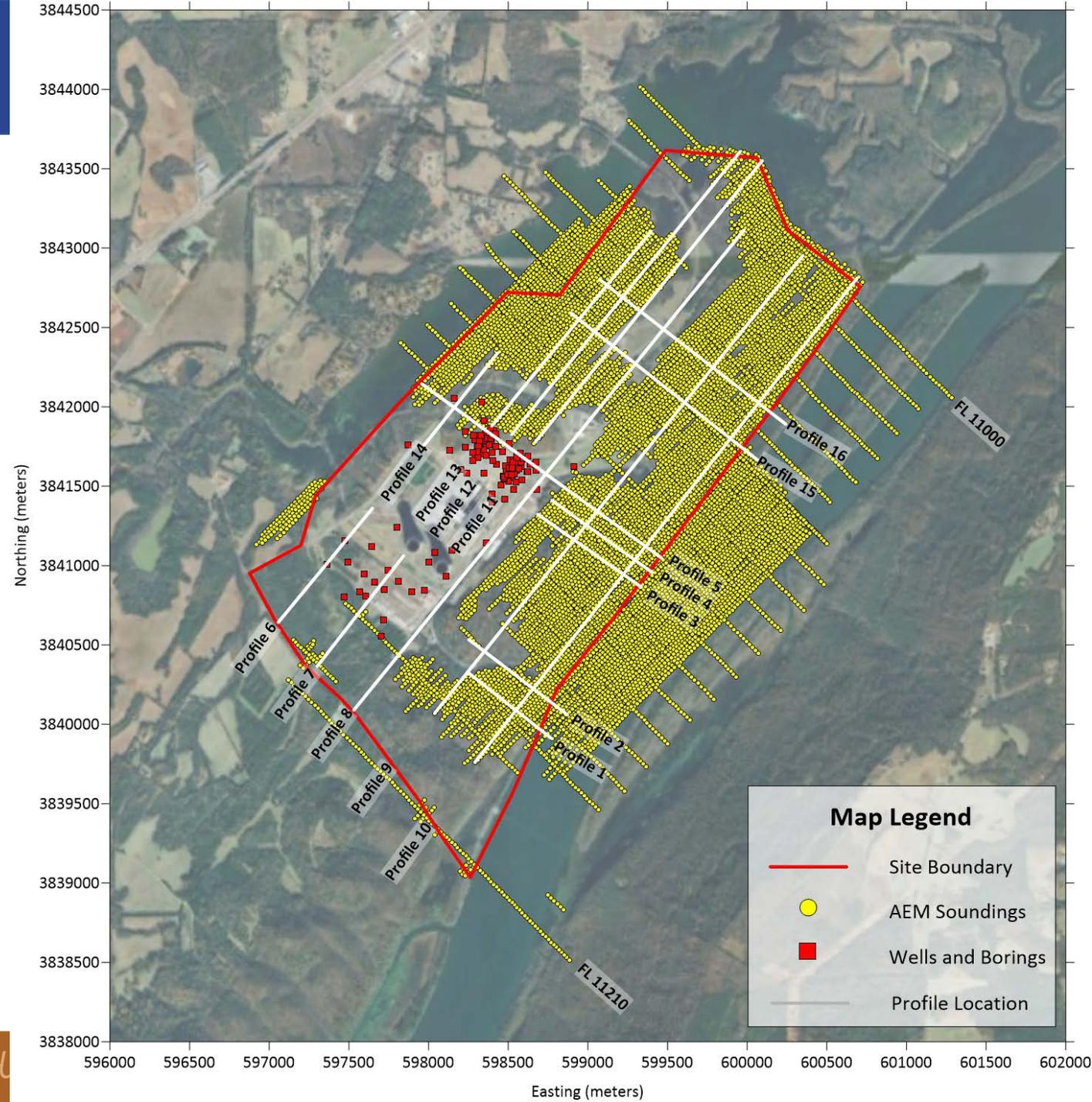
BLN Site Horizontal Slices



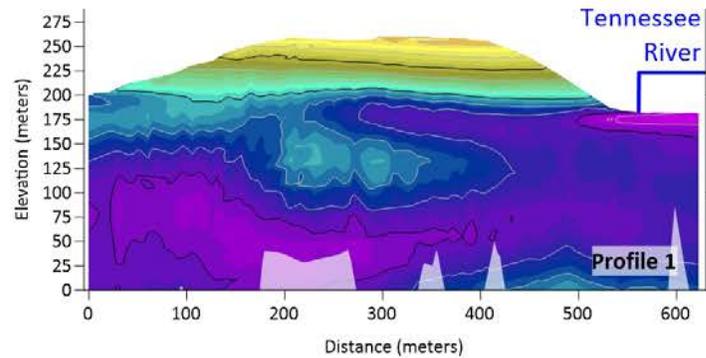
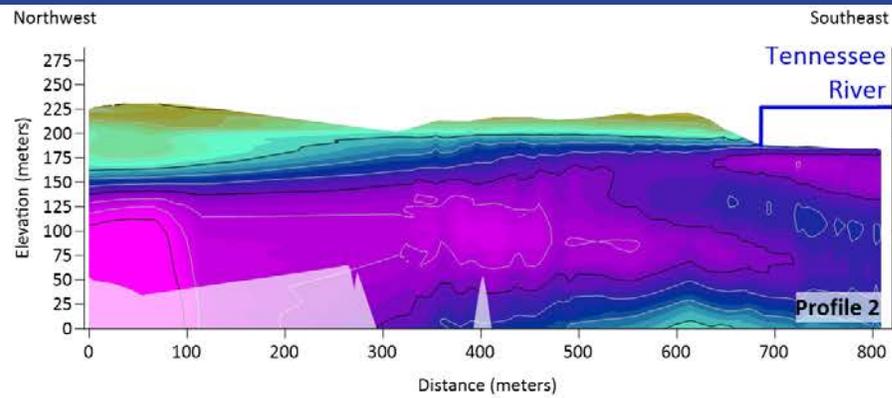
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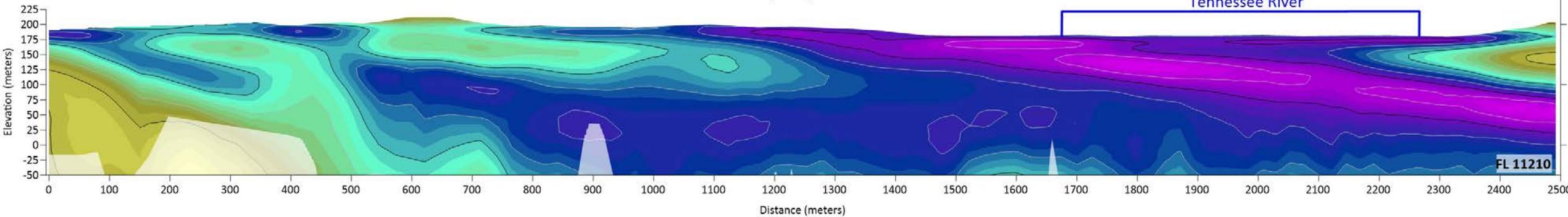
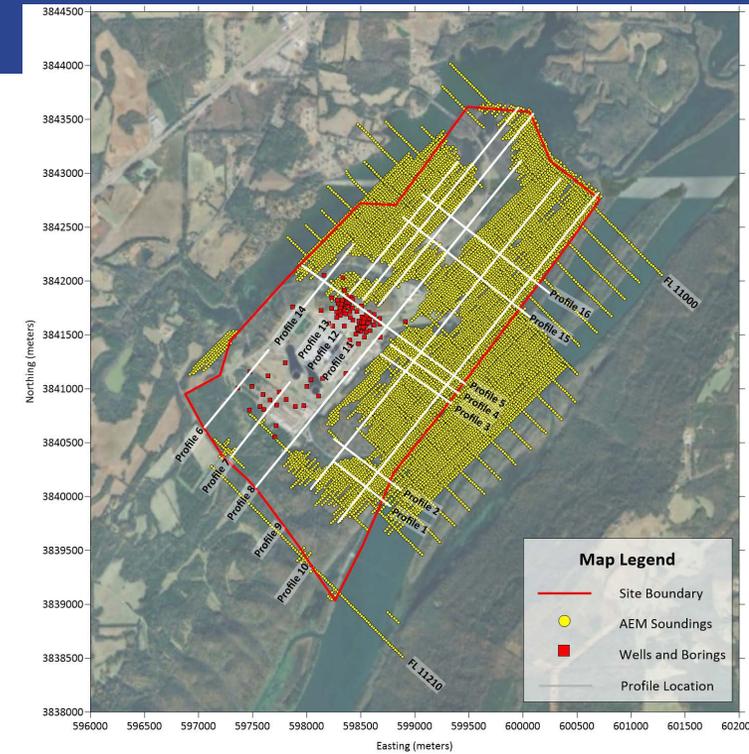
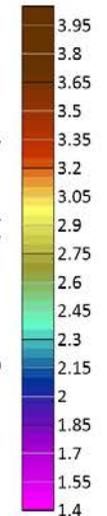
BLN Profile Locations



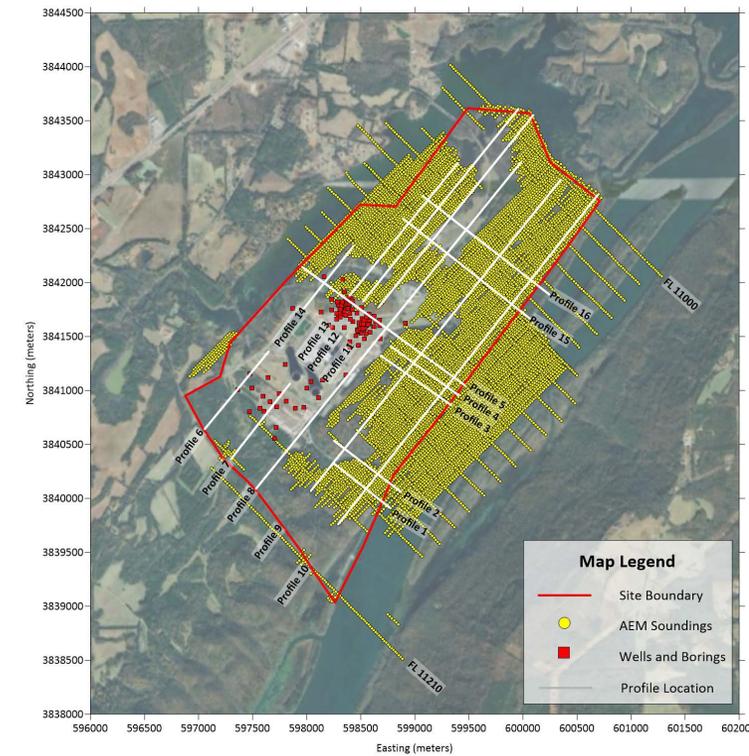
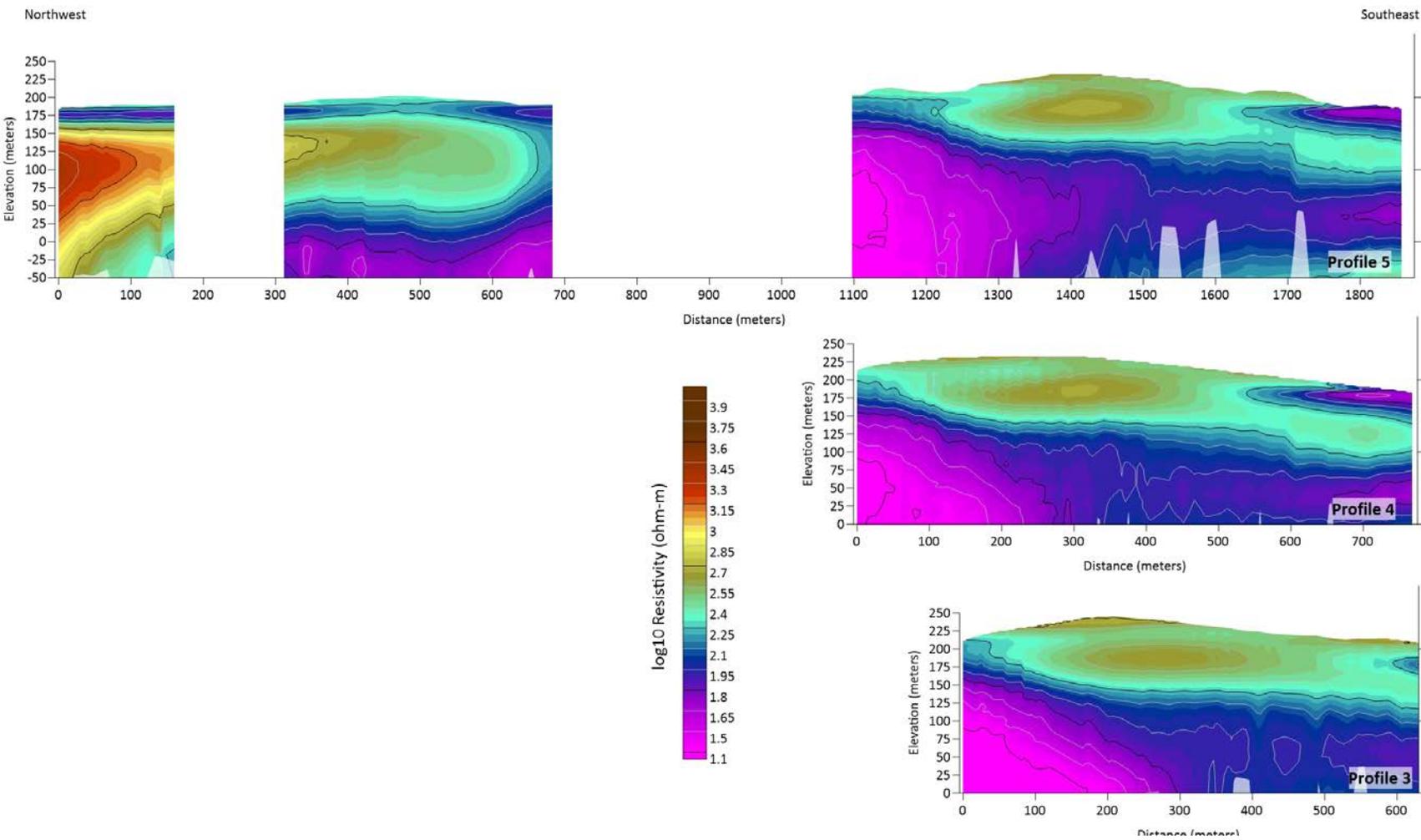
Profile Set 1



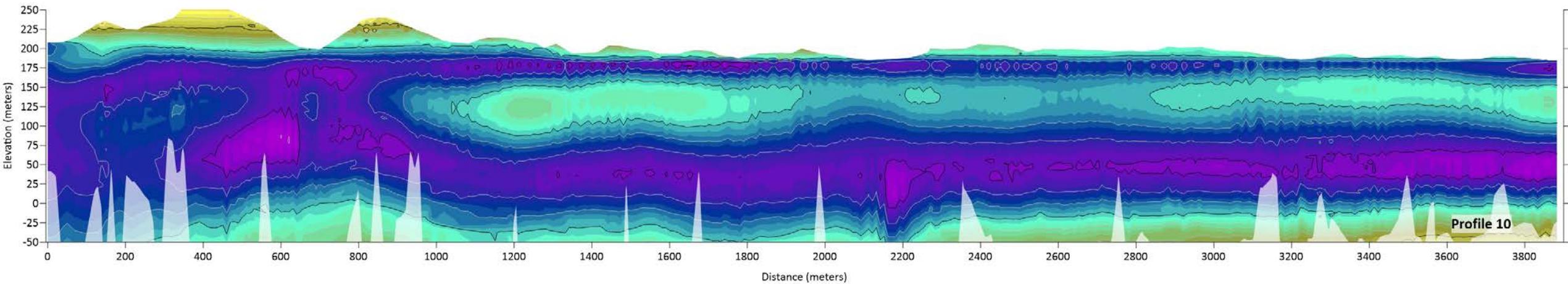
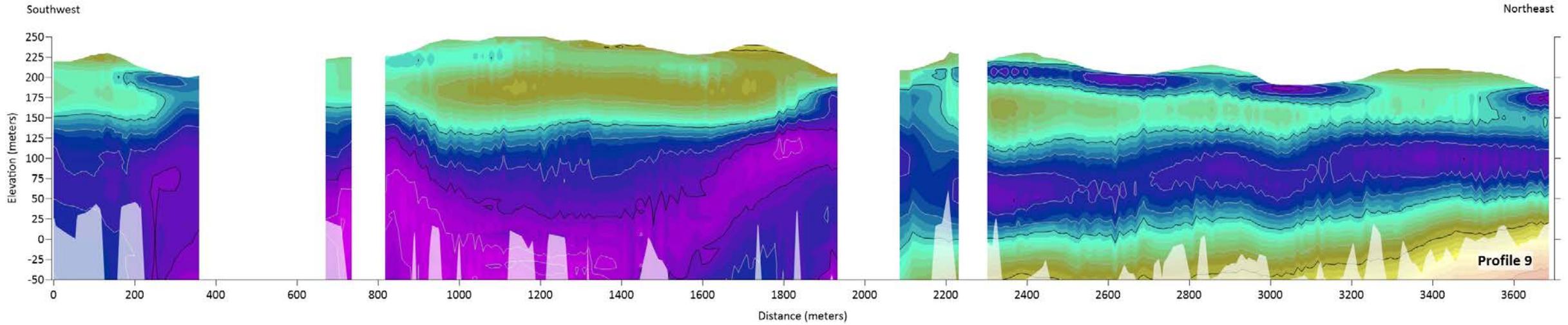
log10 Resistivity (ohm-m)



Profile Set 2

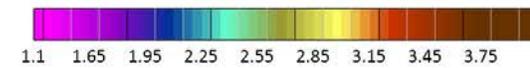


Profile Set 4

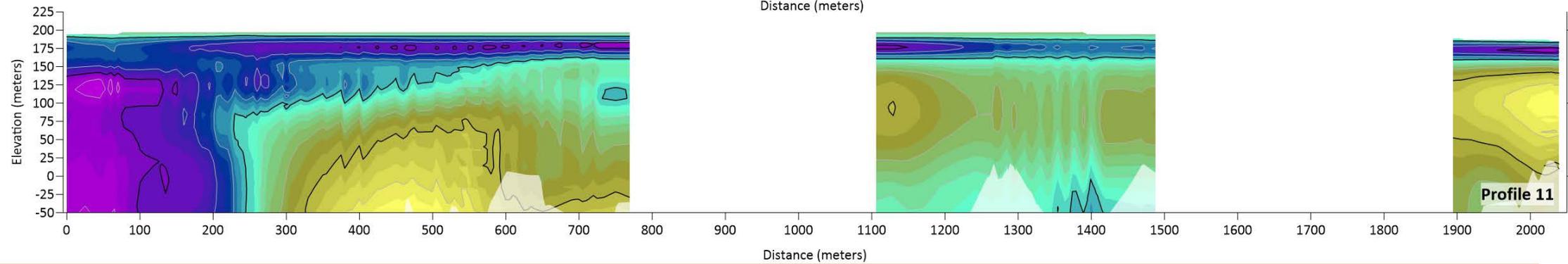
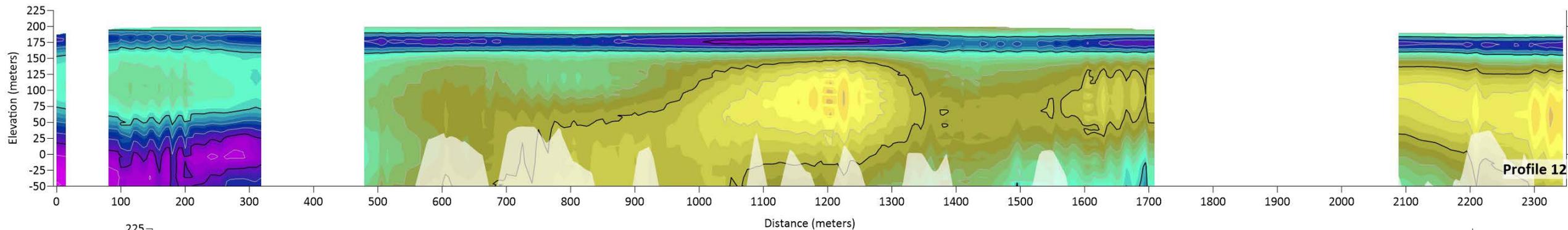
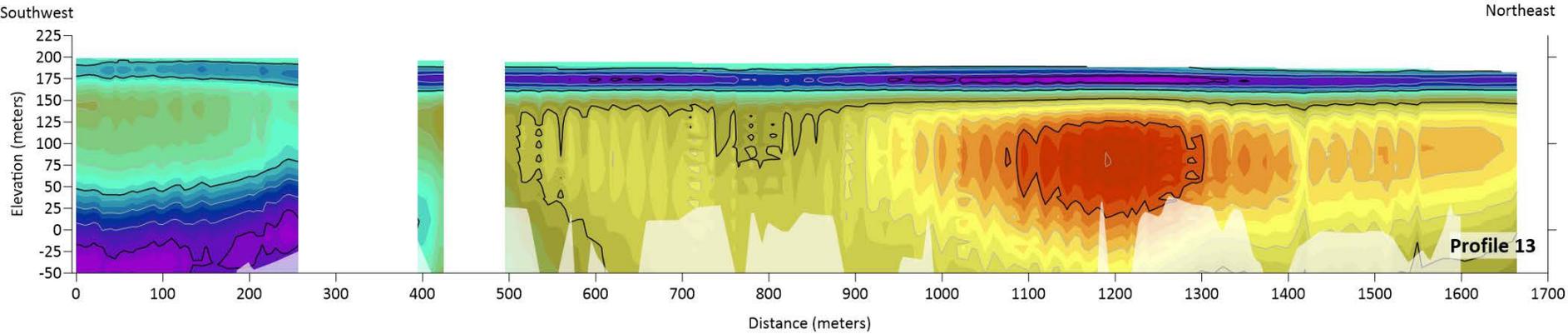


Vertical Exaggeration = 2:1

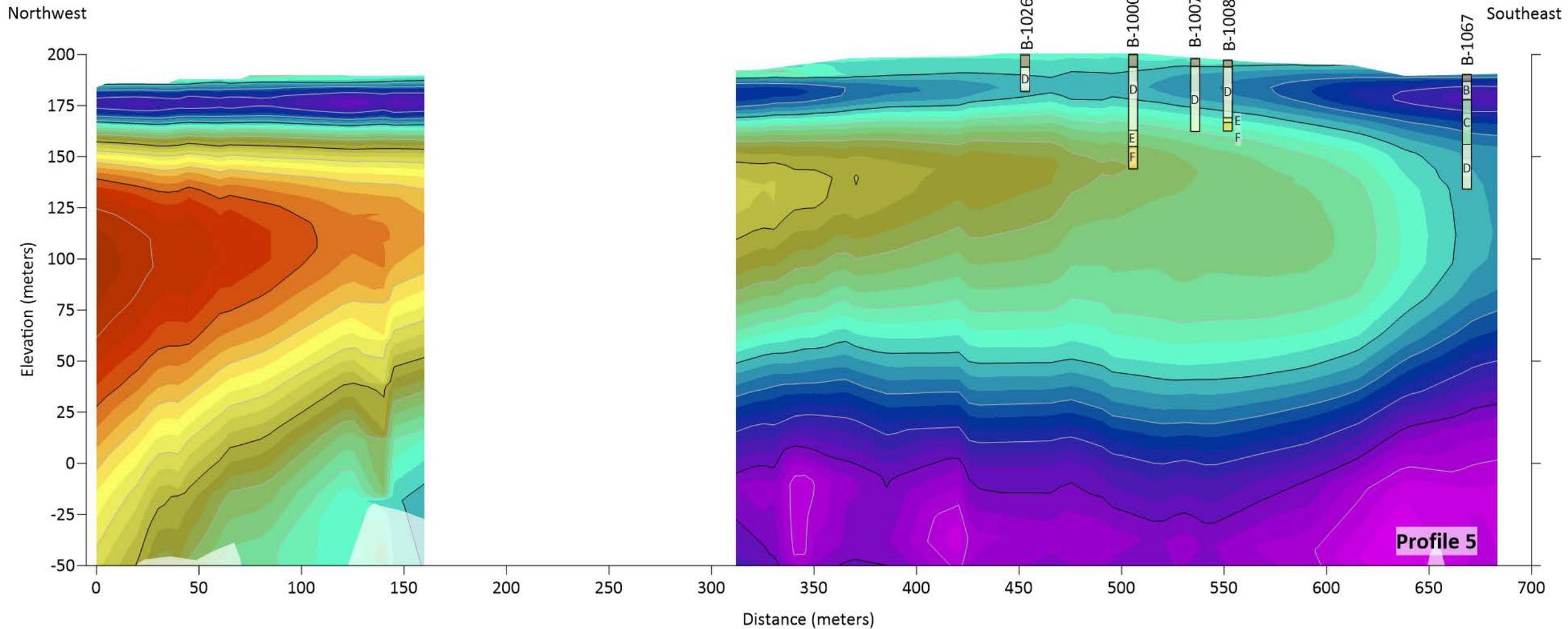
log₁₀ Resistivity (ohm-m)



Profile Set 5



Profile 5 with Borings



Lithological Mapping

- Alluvium
- USR, Unit B
- USR, Unit C
- USR, Unit D
- USR, Unit E
- USR, Unit F

BLN Summary

- Stratigraphic framework dominated by Paleozoic carbonates of the Knox and Chickamauga Groups, overlain locally by Mississippian and Pennsylvanian formations,
- Quaternary alluvium and terrace deposits observed along the Tennessee River margins.
- The resistivity data successfully delineated alternating high- and low-resistivity bands that correspond to mapped geological formations, paleochannels, and terrace deposits,
- The data generally highlighted the extents of karst-prone carbonates and alluvial infill. However, karst itself was not explicitly identified in the resistivity data.
- Vertical profiles confirmed southeast-dipping bedding consistent with regional structure,
- The overall dataset showed no evidence of major hidden faults or structural disruptions beneath the plant site.
- Comparison with existing borehole data further validated the correspondence between resistivity contrasts and lithological variations of the Upper Stones River Group.

Recommendations

- Targeted ground truthing with five to eight borings placed along key resistivity boundaries, for example at the Knox-Nashville/SR or Sequatchie/Red Mountain contacts, terrace/alluvium margins in order to pin lithology and weathering depth.
- Collect petrophysical samples for lab resistivity, porosity, and clay content to reduce uncertainty in the AEM-to-lithology correspondence.
- Downhole geophysics in new or existing wells to potentially include optical or acoustic televiewer to map bedding and fractures, NMR logging to distinguish bound water from mobile water layers, and gamma to distinguish shale thickness and quality.
- Seismic screening with MASW to correlate shear velocity with AEM layering, and flag zones of soft sediments or weathered karst residuum.

Recommendations (lower-tier priority)

- High-density electrical resistivity tomography (ERT) and induced (IP) transects to map karst-prone carbonates and terrace/alluvium margins to image voided or weathered zones along with clayey horizons seen as conductive layers in the AEM data. The ERT would also be used to fill in gaps of the AEM data.
- Microgravity grids over karst-suspect areas to detect meter-sized density deficits that would be indicative of voids or sinkholes where AEM shows anomalously high resistivity and thin cover.