GREENBAUM ASSOCIATES, INC.
GEOTECHNICAL & MATERIALS ENGINEERS
994 Longfield Avenue
Louisville, Kentucky 40215
502/361-8447
FAX 502/361-4793

February 27, 2020

Ms. Ramona Vasta
LDG Development, LLC
1469 S. 4th Street
Louisville, KY 40208

Re: **Karst Survey**
Apartment Community
South Park Road
Louisville, Kentucky
Project Number 19-285G

Dear Ms. Vasta:

On December 29, 2020, we provided the report of a geotechnical investigation that included a study of the geology, soils survey, and historic aerial photos along with the results of a program of drilling and laboratory testing. As part of that investigation, we walked the entire property and found no subsidence features that would result from karst development. We did note the possibility that shafts could have been excavated below the property as part of a quarrying operation that is exposed across South Park Road from the site. However, as a result of our concern, a seismic survey was performed by Dr. Kalinski and found that no mining has occurred below this property.

I will not elaborate more on the geology of the site here since that is discussed in detail in the geotechnical report referenced above, but no surface manifestation of karst development is present at this site, which includes the absence of:

- Sinkhole collapse features
- Sinkholes
- Surface drainage that flows into ground
- Ephemeral lakes
- Cave entrances
- Subsurface cave passages (verified by seismic survey)
- Springs
- Sinking streams

If you have any questions in regard to either the geotechnical or karst surveys, please call.

Sincerely,

GREENBAUM ASSOCIATES, INC.

Sandor R. Greenbaum

Digitally signed by Sandor R. Greenbaum
DN: cn=Sandor R. Greenbaum, o=Greenbaum Associates, Inc., ou, email=srg@geo-engineers.com, c=US
Date: 2020.02.27 11:18:37 -05'00'

Sandor R. Greenbaum, P.E.
Principal Engineer

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February 21, 2020

Ms. Ramona Vasta
LDG Development, LLC
1469 S. 4th St.
Louisville, KY 40208

RE: Report of findings of geophysical DC resistivity survey to identify and delineate tunnels under the LDG Development site in Louisville, Kentucky

Dear Ms. Vasta,

SUMMARY

I am pleased to provide this report describing the results of my geophysical direct-current (DC) resistivity survey at the LDG Development site in Louisville, Kentucky. The site is situated on an 18.64-acre tract of land adjacent to a water-filled quarry near the intersection of South Park Road and Blue Lick Road in Louisville, Kentucky. The site covers the following addresses in Louisville:

- 4011 South Park Rd.;
- 4201 South Park Rd.; and
- 9007 Blue Lick Rd.

The geophysical survey consisted of a grid of survey lines along which the direct-current (DC) electrical resistivity method was applied. The survey revealed the presence of a thin layer of soil over limestone. Values for electrical resistivity derived from analysis of the field data reveal that some of the limestone is weathered and contains some moisture. However, none of the zones in the limestone possessed unusually low electrical resistivity that could be associated with a water-filled cavity. Therefore, there was no indication on the geophysical data of the presence of any underground quarry workings beneath the site.

SURVEY DESCRIPTION

Prior to the survey, I conducted research to identify any information that may exist regarding the location of quarry workings at the site. Sources of information that I explored included the Kentucky Geological Survey, the University of Kentucky Department of Mining Engineering, the United States Geological

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Survey, the Mine Safety and Health Administration and the Mining Division of the Kentucky Energy and Environment Cabinet. Unfortunately, none of these sources yielded any information regarding the presence of existing mine workings at the site. I also spoke to the owner of the quarry, Jason Stanford, about the possibility of exploring an existing tunnel at the quarry. After discussing the matter with Jason, I concluded that entering the cave was too risky.

The geophysical survey was carried out in early February 2020 at the site. Field activities consisted of clearing brush and surveying the individual lines using a handheld GPS on February 3 and 7 and acquiring geophysical data on February 8, 14, 15 and 19. Line locations were selected to provide a uniform distribution of coverage over the entire site. It was also necessary to position the lines in the survey to maintain a reasonable distance between the survey lines and the existing metal fences at the site because the presence of the metal fences can negatively affect the quality of the field data. The locations of the lines (labeled A through E) are summarized in Table 1 and depicted on Fig. 1.

Direct-current (DC) electrical resistivity geophysical testing (Appendix A) was performed using an 84-electrode Advanced Geosciences Inc. (AGI) Sting-Swift data acquisition system (Fig. 2). Field acquisition includes installing a row of 84 steel electrodes into the ground and injecting current into the ground using a 12-volt car battery. Current is injected using different pairs of electrodes along the line and voltage is measured across separate pairs of electrodes. The magnitude of the measured voltage is a function of the position of the electrodes being used for the measurement and the electrical resistivity of the ground beneath the electrodes. Data are automatically acquired by computer and a dataset consisting of hundreds of individual measurements along the line is acquired. These measurements contain information about how the electrical resistivity varies in the ground beneath the line. By analyzing the data, a two-dimensional profile showing variations in electrical resistivity is generated. This profile is interpreted to infer subsurface conditions at the site. For this site, zones of low (less than 10 ohm-meters) electrical resistivity were considered to be indicative of water-filled tunnels.

RESULTS

Direct-current resistivity testing was performed along five profile lines as described in the previous section. Data were acquired using an 84-electrode AGI Sting-Swift data acquisition system and analyzed using the AGI EarthImager 2D software. Results from analysis of the data are shown in Figs. 3-8. Each figure contains three profiles that depict the field data (top), the modeled data (middle) and the model that was used to calculate the modeled data (bottom). The x-axis of the profiles depicts the distance along the line on the ground surface in units of feet, and the y-axis depicts depth below the ground surface in units of feet. The colors on the profiles indicate values of electrical resistivity as shown in the attached legends, with red colors indicating high resistivity and blue colors indicating low resistivity.

The bottom profile in each figure (the model) is the one that most directly illustrates subsurface conditions in Figs. 3-8. The model profiles reveal the presence of a thin (a few feet) layer of soil with relatively low resistivity underlain by limestone. The electrical resistivity of the limestone varies from 100s to 1000s of ohm-meters, which indicates varying levels of weathering and moisture content within the limestone as expected. Cavities filled with groundwater, including karst features and flooded tunnels, typically possess electrical resistivity of around 10 ohm-meters or less as shown in the example from Thailand in Fig. 9. On the profiles acquired at the Louisville site, water-filled tunnels would appear as deep blue in color with dimensions on the order of tens of feet across. There are no anomalies on the profiles acquired in Louisville that indicate the presence of water-filled tunnels beneath the LDG site in Louisville. Moreover, an air-filled tunnel would possess an electrical resistivity in the hundreds of thousands of ohm-meters on the profiles. There is no evidence to indicate the presence of air-filled tunnels.

Thank you very much for providing me with the opportunity to provide geophysical services on this project. Please do not hesitate to contact me if you have any questions or require any additional information.

Sincerely,

Michael E. Kalinski

Michael E. Kalinski, Ph.D., P.E.
University of Kentucky
Department of Civil Engineering
161 Raymond Bldg.
Lexington, KY 40506-0281
tel: (859) 321-3057
email: michael.kalinski@uky.edu

Exp. 6/30/2021

Attachment: Table 1
Figures 1-9
Appendix A

Line	Date Acquired	Electrode Spacing (ft)	Number of Electrodes	Total Length (ft)
A	Feb. 8, 2020	10	84	830
B	Feb. 14, 2020	6	84	498
C	Feb. 14, 2020	12	84	996
D	Feb. 15, 2020	15	84	1,245
E	Feb. 19, 2020	8	84	664

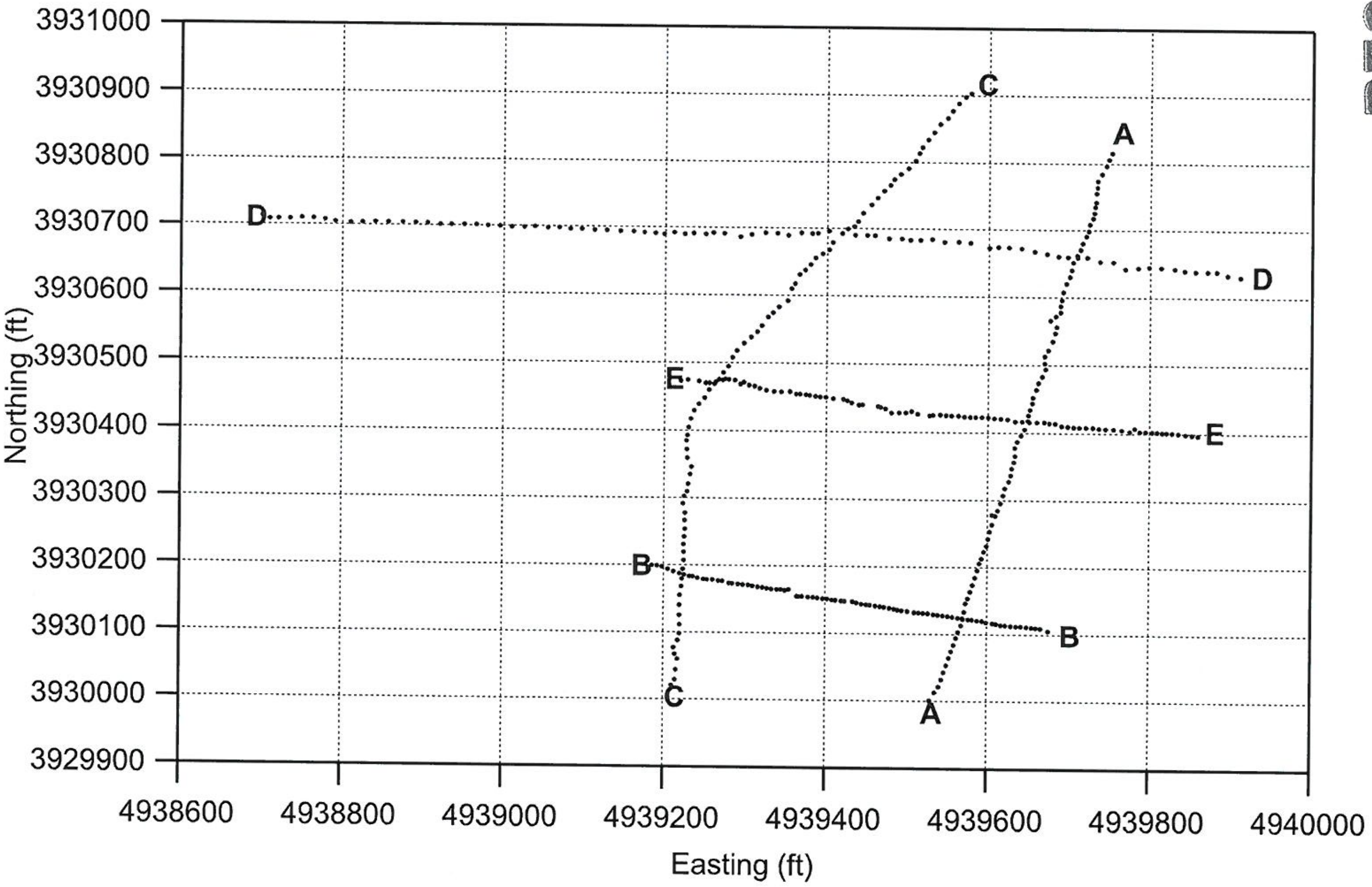


Figure 1. Location of DC resistivity lines (A through E) used for this investigation.

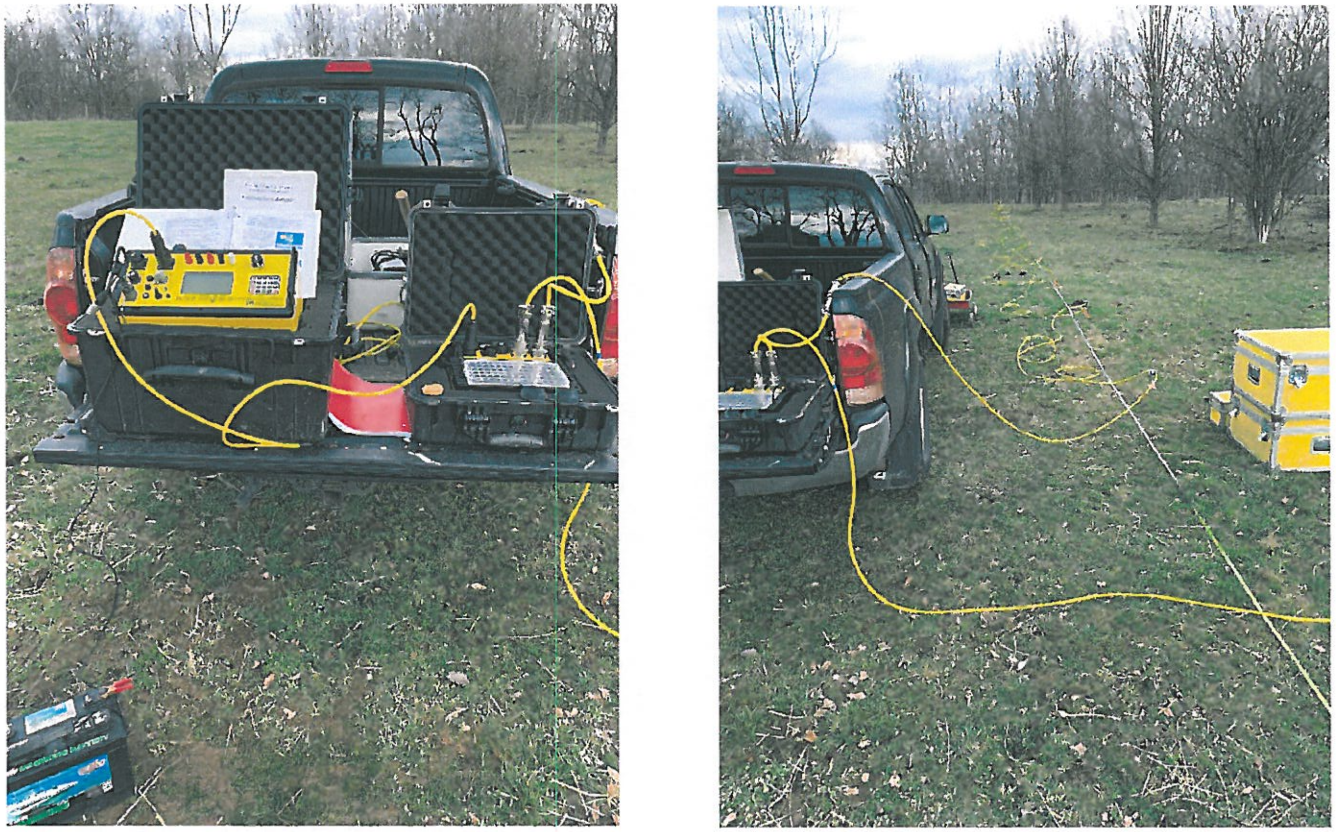
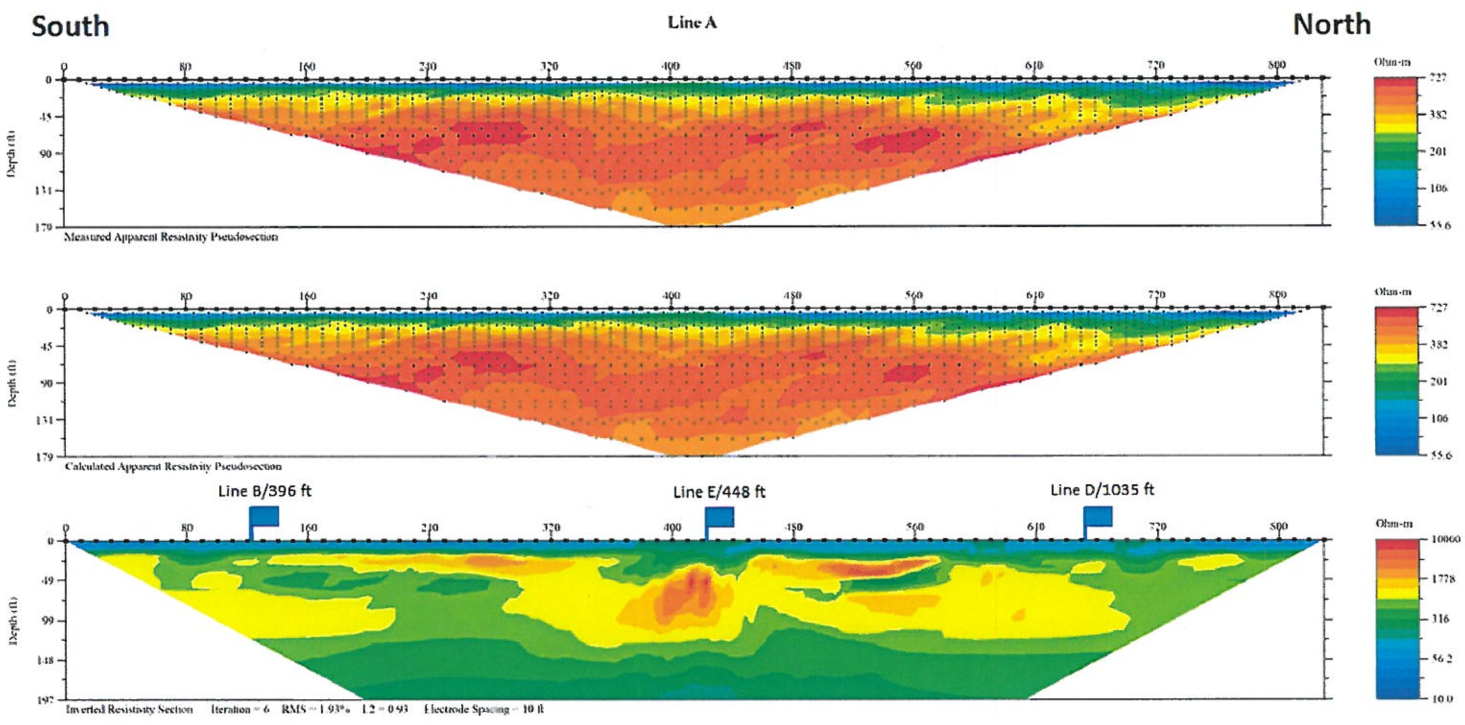
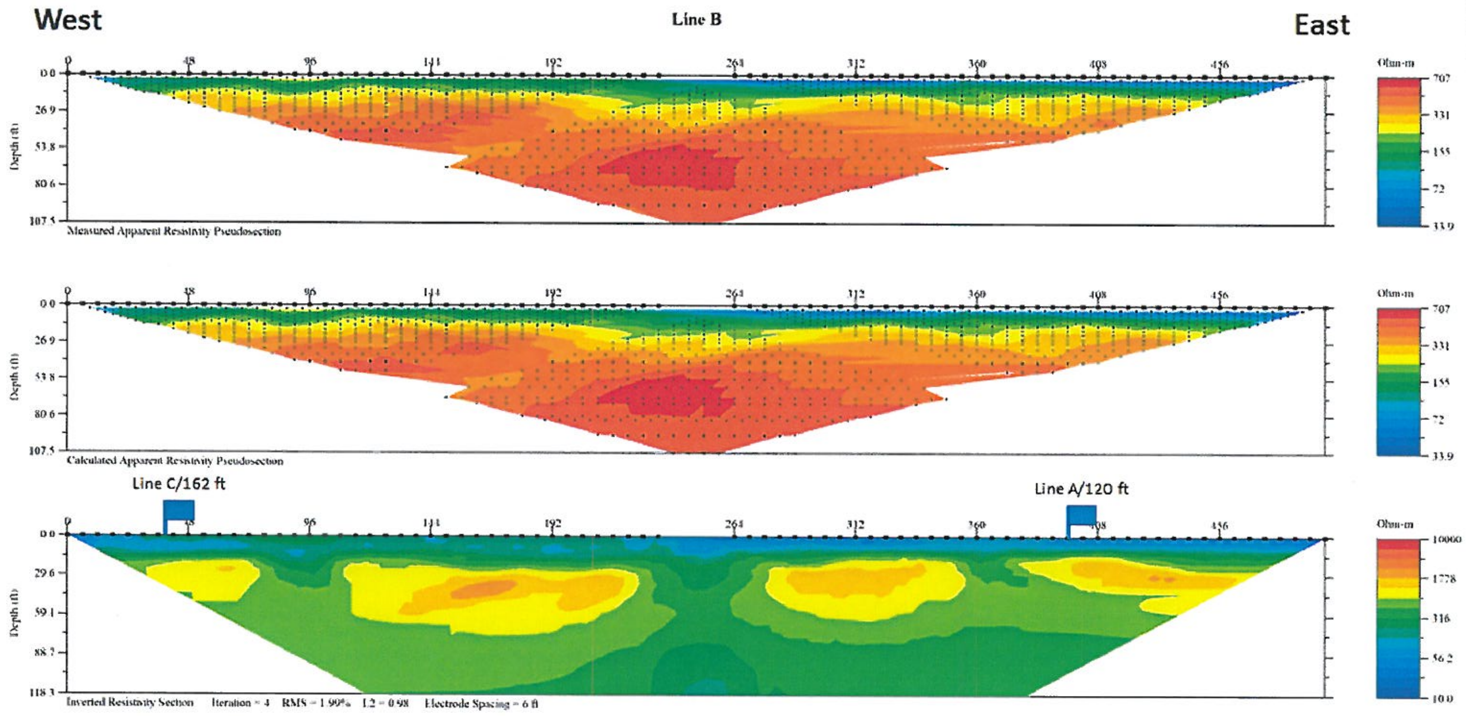


Figure 2. Photograph of DC resistivity data acquisition activities along Line A showing Sting data acquisition system and electrical source (left) and electrode array (right).



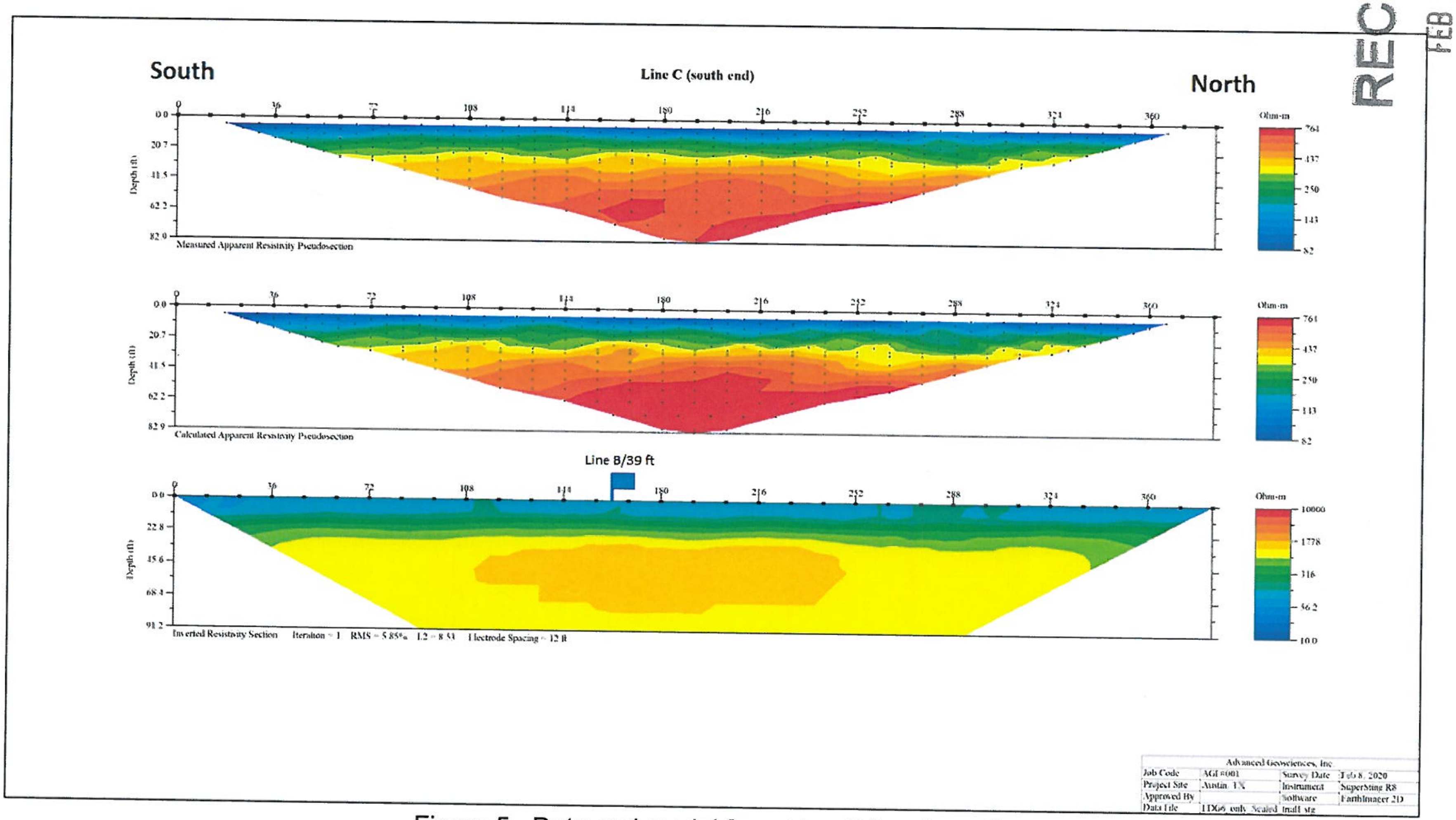
Advanced Geosciences, Inc			
Job Code	AGI #001	Survey Date	Feb 8, 2020
Project Site	Austin, TX	Instrument	SuperSting R8
Approved By		Software	EarthImager 2D
Data File	TDG5_trialB.stg		

Figure 3. Data and model from Line A.



Advanced Geosciences, Inc			
Job Code	AGI #001	Survey Date	Feb 14, 2020
Project Site	Austin, TX	Instrument	SuperSting R8
Approved By		Software	EarthImager 2D
Data File	LDGS final6.stg		

Figure 4. Data and model from Line B.



Advanced Geosciences, Inc.			
Job Code	AGI #001	Survey Date	Feb 8, 2020
Project Site	Austin, TX	Instrument	SuperSting R8
Approved By		Software	EarthImager 2D
Data File	LD66_only_Sealed_trudl.stg		

Figure 5. Data and model from Line C (south end).

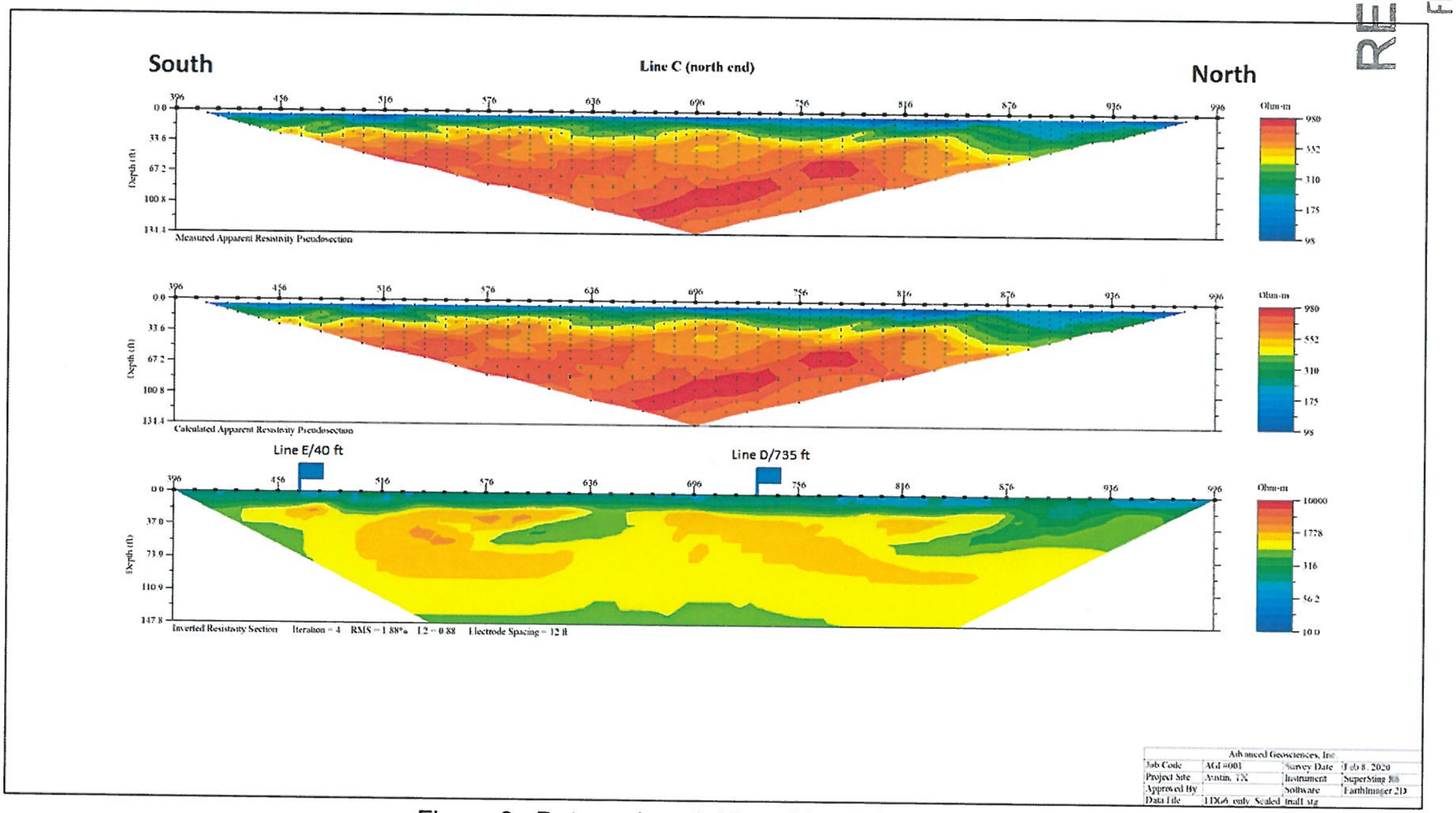
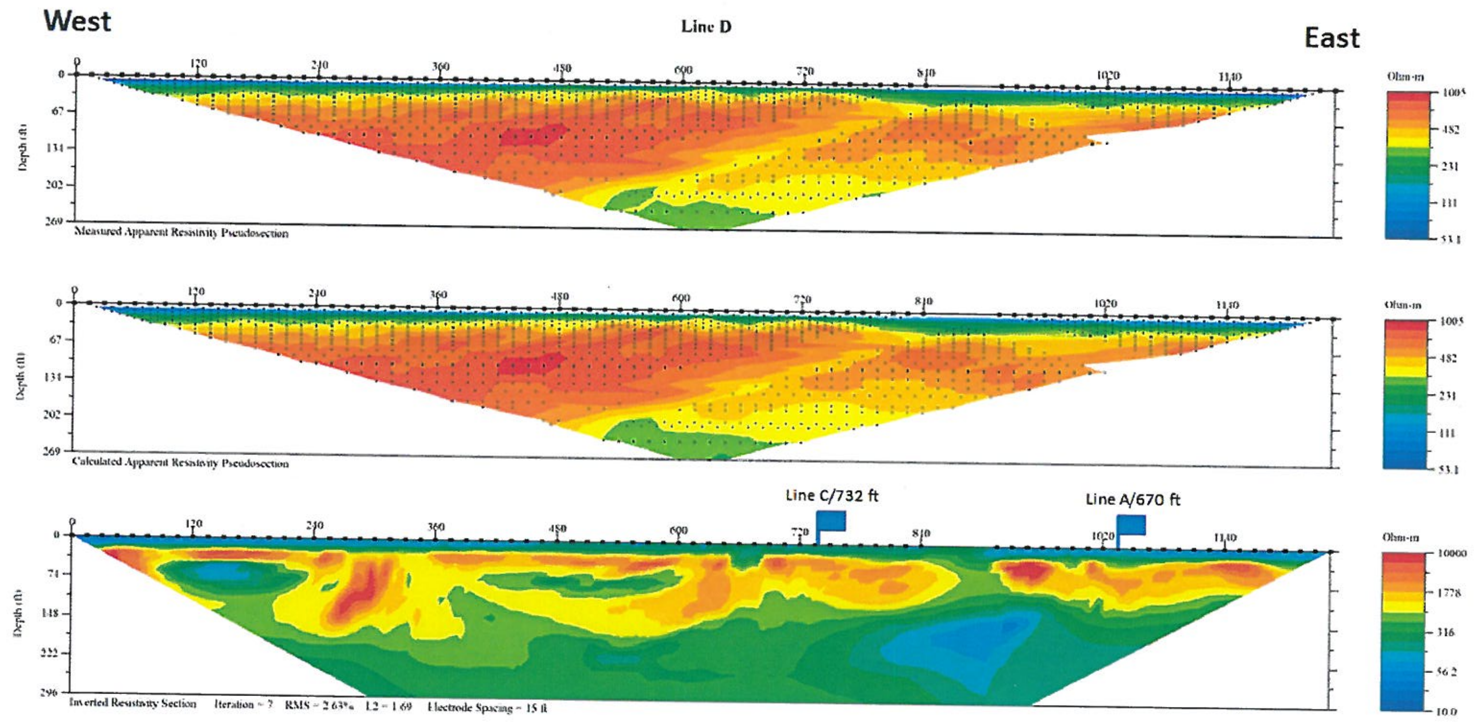
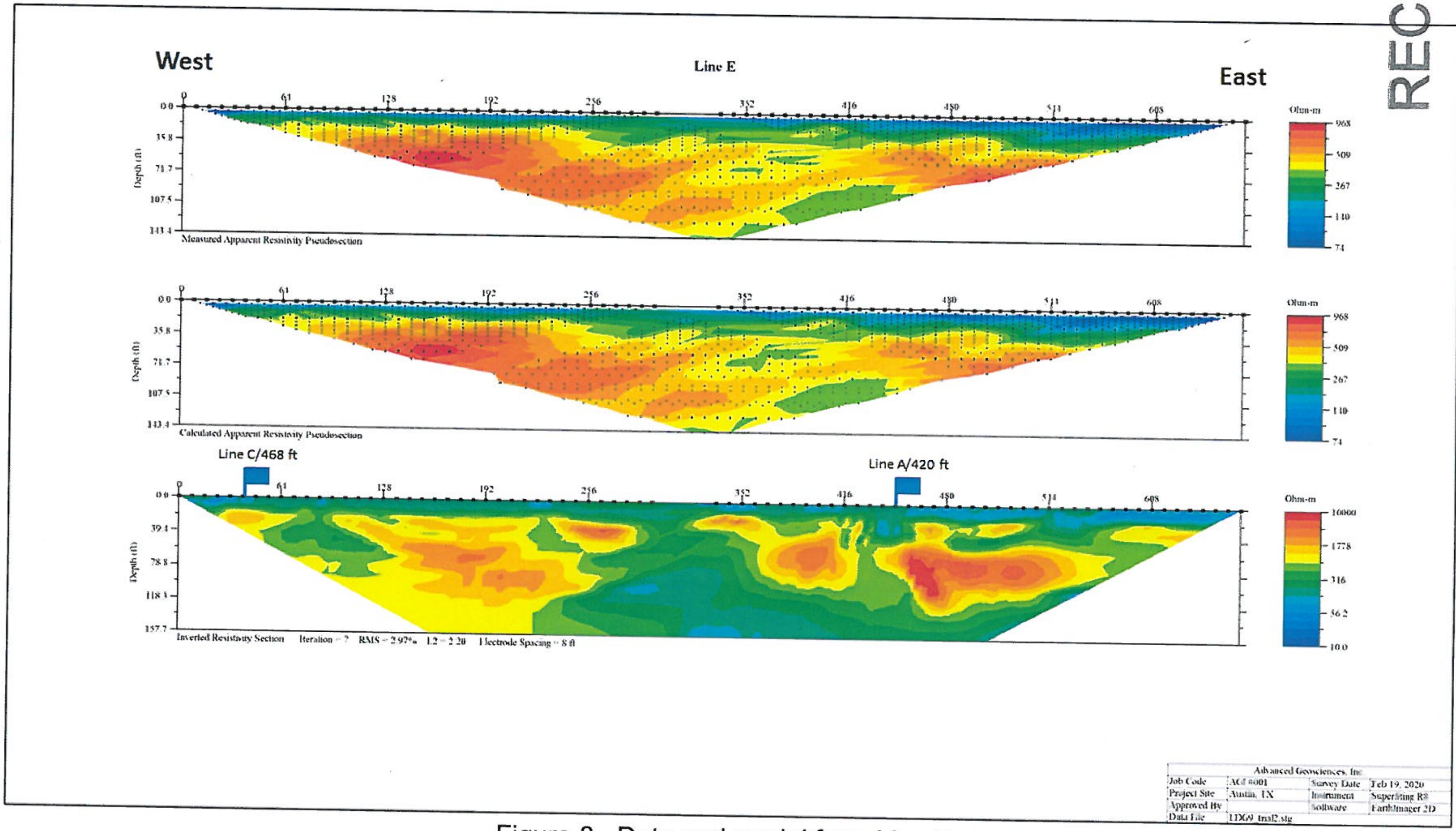


Figure 6. Data and model from Line C (north end).



Advanced Geosciences, Inc			
Job Code	AGI #001	Survey Date	Feb 15, 2020
Project Site	Austin, TX	Instrument	SuperSting R8
Approved By		Software	EarthImager 2D
Data File	LDG IR5_trial7.stg		

Figure 7. Data and model from Line D.



Advanced Geosciences, Inc			
Job Code	AGI #001	Survey Date	Feb 19, 2020
Project Site	Austin, TX	Instrument	SuperSting R8
Approved By		Software	EarthImager 2D
Data File	LDG9_trial2.stg		

Figure 8. Data and model from Line E.

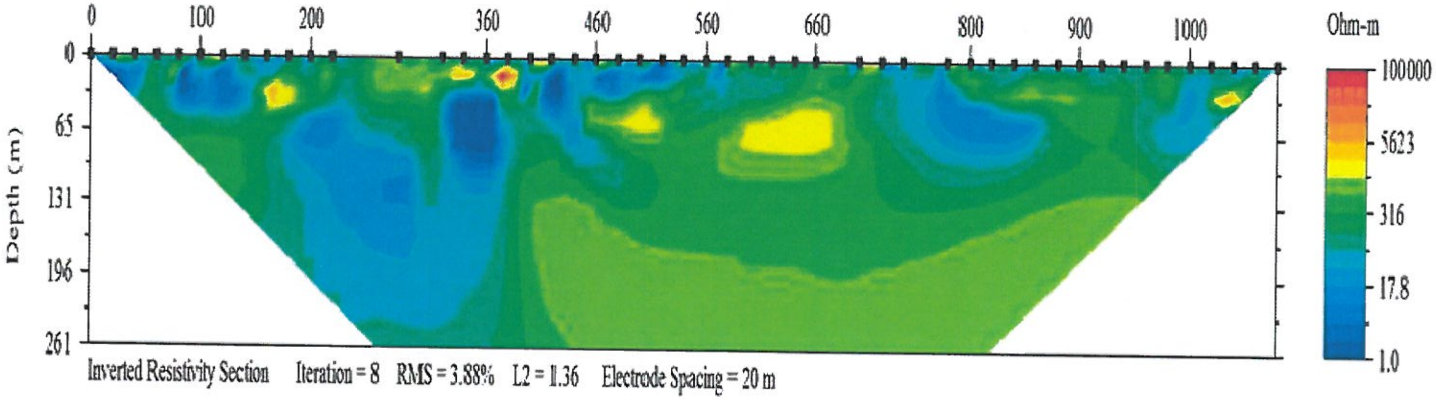


Fig. 9. Example of an inverted resistivity profile from a site in Thailand revealing a water-filled void at Station 360 with resistivity less than 10 ohm-meters .

APPENDIX A
DESCRIPTION OF THE DC RESISTIVITY GEOPHYSICAL METHOD

Geophysical exploration is the practice of performing physical measurements at the surface of the earth in order to ascertain subsurface properties and conditions. Geophysics can be used for many different specific purposes, including mineral exploration, prediction of dynamic behavior, or characterization of groundwater resources. Geophysical methods allow measurement of the physical properties of soil and rock, including elastic properties and electrical properties[1]. Electrical properties include parameters such as resistivity, conductivity, inductance, and capacitance. Once these properties are measured, they must be interpreted to infer subsurface conditions. Ultimately, such interpretations must be validated, and validation is typically achieved through exploratory drilling. However, the use of geophysical data as an interpretive aid allows a site investigation to be performed using fewer borings, which reduces the cost of the investigation and increases the likelihood of producing an accurate depiction of subsurface conditions.

Groundwater can exist in the pore spaces of soil or rock under saturated conditions (i.e. all of the pores, voids, and fractures are filled with water) or unsaturated conditions. It can also exist as underground rivers and lakes in karst environments. Since electricity can move more easily through water than soil or rock, the bulk electrical resistivity of the earth is highly dependent on the presence of water, as well as the salinity of the water. In general, the electrical resistivity of carbonate rock is on the order of thousands of ohm-meters. The electrical resistivity of soil is on the order of hundreds of ohm-meters, and the electrical resistivity of groundwater is on the order of ten ohm-meters. These ranges are general estimates, but illustrate the relative difference in electrical resistivity of earth materials. Other factors also play a role, including:

- Rock petrology: rocks containing large amounts of ferrous minerals tend to be less resistive;
- Soil mineralogy: clayey soils tend to be less resistive than sandy soils;
- Water content: saturated soils with more water tend to be less resistive than unsaturated soils; and

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[1] Reynolds, J. M., 1997, *An Introduction to Applied and Environmental Geophysics*, John Wiley & Sons, New York.

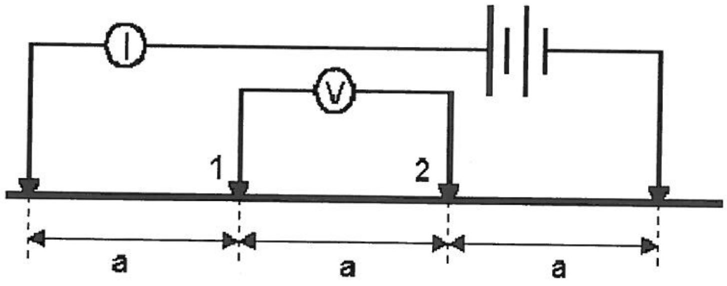
- Ground water salinity: groundwater with a large amount of dissolved salts tends to be less resistive.

The dependence of soil petrology, rock mineralogy, water content, and ground water salinity on the bulk electrical resistivity of the earth is exploited using the direct-current (DC) resistivity geophysical method. With the DC resistivity method, variations in the bulk electrical resistivity of the earth are quantified. These values are then interpreted to infer groundwater conditions.

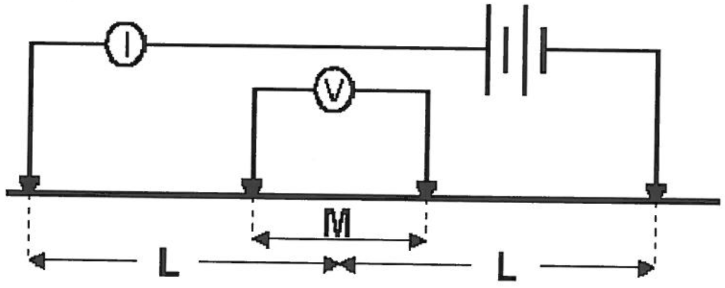
Traditional DC resistivity testing has been performed using the DC sounding method. To perform a sounding, a single stationary point is set at the center of the array. Two different types of arrays have been most commonly used as illustrated in Fig. A1. To perform a measurement, current (I) is passed through the current electrodes, while voltage (V) is measured across the potential electrodes. To use the Wenner array, electrodes are placed using a uniform spacing (*a*). After a measurement is made, the electrodes are moved further apart from each other. Larger electrode spacings correspond to deeper depth of investigation. The Wenner array is easy to deploy and provides good data in noisy environments. To use the Schlumberger array, the potential electrodes are kept at a fixed location with spacing (*M*), while the current electrodes are moved further and further apart as (*L*) is increased for successive measurements. The Schlumberger array is easier to deploy than the Wenner array, but the Schlumberger array is not as good as the Wenner array in noisy environments.

The Wenner and Schlumberger arrays are both effective for quantifying variations in resistivity with depth. Apparent resistivity is calculated for each electrode spacing and is a function of electrode spacing, current, and voltage. Plots of apparent resistivity versus electrode spacing are inverted to calculate a sounding of true resistivity versus depth for a single point as illustrated schematically in Fig A2.

Traditional four-electrode DC resistivity surveys using the Wenner or Schlumberger arrays were widely used in the past because data acquisition was very simple. These methods provided one-dimensional soundings showing variations in electrical resistivity with depth. However, the development of multiple-channel, multiple-electrode systems with automatic electrode switching capabilities has led to the practice of resistivity profiling, where electrical resistivity is calculated in two dimensions as a function of depth and lateral position. Dipole-dipole arrays (Fig. A3) are often used for resistivity profiling and are beneficial for resolving lateral variations in resistivity. To perform a surface resistivity survey, an array of electrodes (typically 56 or more) is deployed along a line with a uniform spacing. Readings are taken by using various combinations of current and potential electrodes, and the multiple channel array is used to perform a series of four-electrode measurements. The lateral position of the electrodes and the electrode spacing are varied between measurements so that the zone of earth material sampled in the measurement varies with lateral position and depth (Fig. A4). A pseudo section of apparent conductivity is generated, where apparent resistivity is displayed as a function of dipole spacing and lateral position as seen in Fig. A5. The pseudo section is inverted to delineate zones of anomalously high or low electrical conductivity indicative of water-filled or air-filled subsurface voids, such as mine workings or karst features. Inversion is typically performed using commercially available computer software.



Wenner array



Schlumberger array

Figure A1. Wenner and Schlumberger arrays commonly used for DC resistivity sounding.

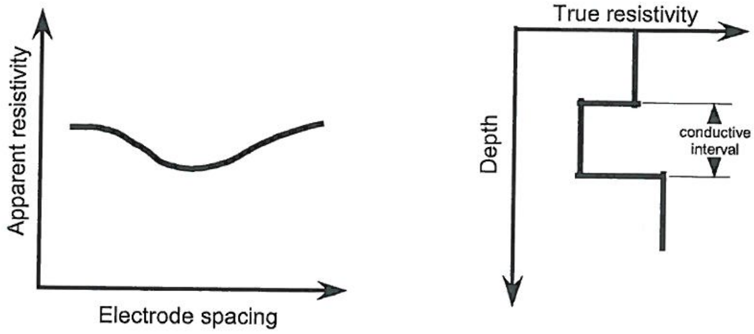


Figure A2. Apparent resistivity curve and inverted profile of true resistivity versus depth

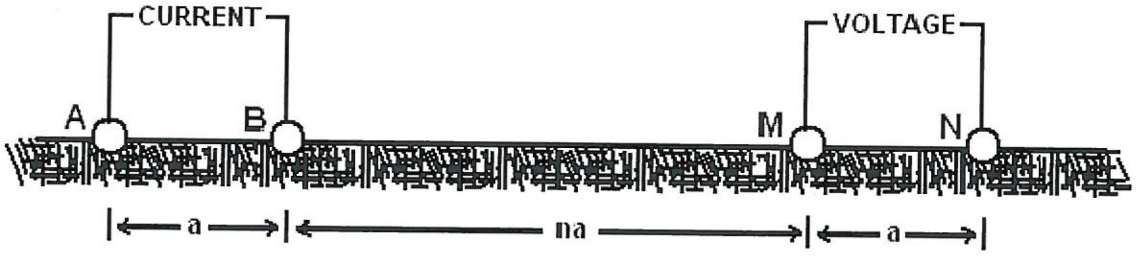


Figure A3. Dipole-dipole array used for surface resistivity prospecting.

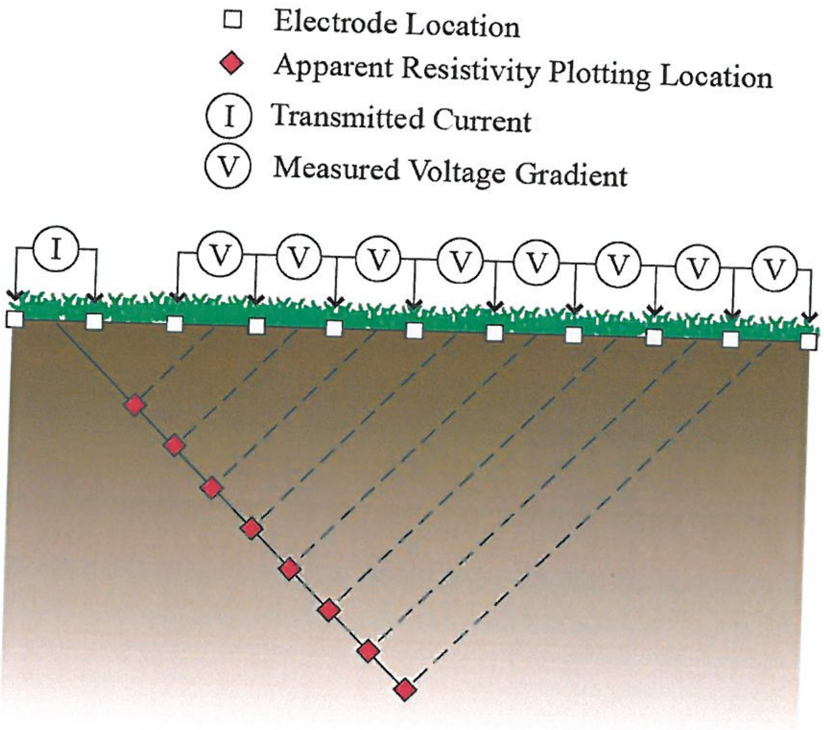


Fig. A4. Two-dimensional resistivity profiling using the dipole-dipole array.

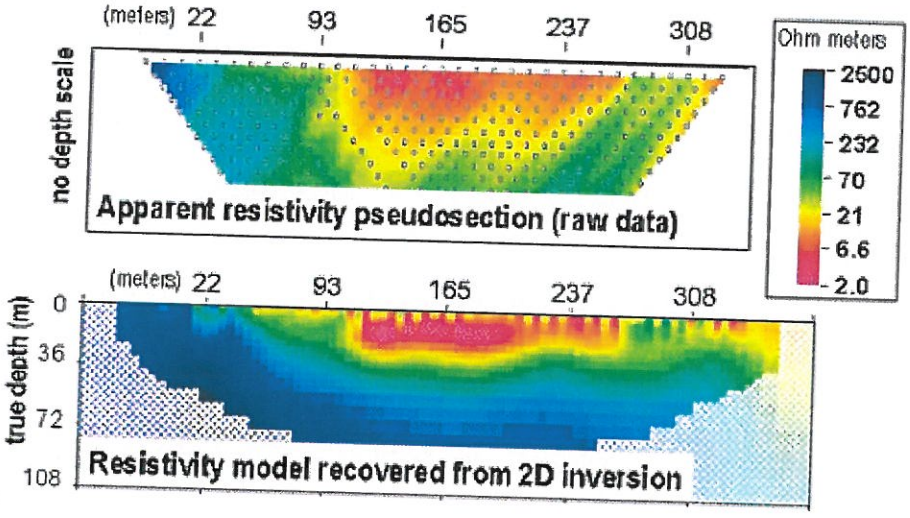


Figure A5. Pseudosection and inverted 2D resistivity profile derived from multiple-electrode DC resistivity measurement.

The current state-of-practice method used today for DC resistivity data acquisition employs the use of an AGI Sting/Swift data acquisition system (Fig. A6). This system typically employs the use of 56 or more electrode with electrode spacings ranging from 5-20 ft. Using this system, dipole-dipole data are rapidly and automatically acquired along the entire line so that lateral variations in electrical resistivity indicative of tunnels or karst features be resolved. The resulting pseudosections are typically inverted using the RES2DINV software.

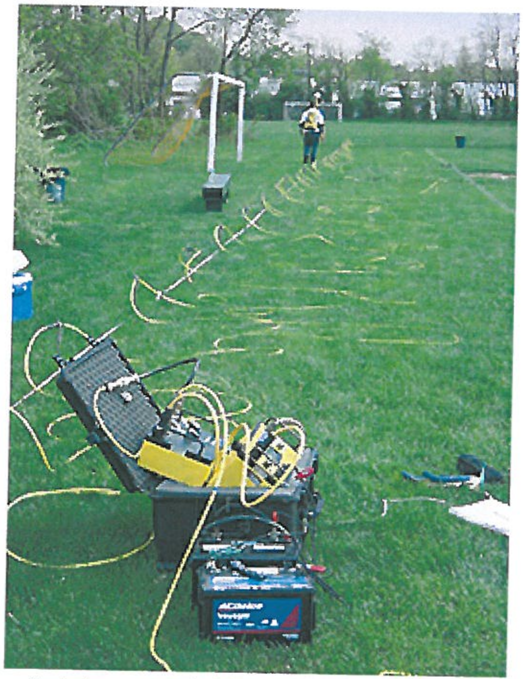


Figure A6. Typical data acquisition activities using the Sting/Swift system.