NCKRI REPORT OF INVESTIGATION 9

EXPLORING THE UPPER LIMITS OF ELECTRICAL RESISTIVITY PROFILING: GEOPHYSICAL SURVEYS OF A PROPOSED UTILITY LINE, CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

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National Cave and Karst Research Institute
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Exploring the Upper Limits of Electrical Resistivity Profiling: Geophysical Surveys of a Proposed Utility Line, Carlsbad Caverns National Park, New Mexico

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Cover photo: These closely spaced electrodes test the limits of shallow electrical resistivity survey methods.

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NCKRI Organization and Mission

NCKRI was created by the US Congress in 1998 in partnership with the State of New Mexico and the City of Carlsbad. NCKRI is administered by the New Mexico Institute of Mining and Technology (aka New Mexico Tech or NMT).

NCKRI's enabling legislation, the National Cave and Karst Research Institute Act of 1998, 16 USC, §4310, identifies NCKRI's mission as to:

1) further the science of speleology;
2) centralize and standardize speleological information;
3) foster interdisciplinary cooperation in cave and karst research programs;
4) promote public education;
5) promote national and international cooperation in protecting the environment for the benefit of cave and karst landforms; and
6) promote and develop environmentally sound and sustainable resource management practices.

NCKRI Report of Investigation Series

NCKRI uses this report series to publish the findings of its research projects. The reports are produced on a schedule whose frequency is determined by the timing of the investigations. This series is not limited to any topic or field of research, except that they involve caves and/or karst. All reports in this series are open access and may be used with citation. To minimize environmental impact, few or no copies are printed. They may be downloaded at no cost from the NCKRI website at www.nckri.org.

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Exploring the Upper Limits of Electrical Resistivity Profiling: Geophysical Surveys of a Proposed Utility Line, Carlsbad Caverns National Park, New Mexico

Lewis Land and Michael Jones
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Background

The visitor center, park headquarters and associated structures at Carlsbad Caverns National Park are located on the southeast-facing escarpment of the Guadalupe Mountains in southeastern New Mexico. The buildings are constructed on dolomite outcrops of the middle Permian Tansill Formation, which is the host rock for the natural entrance and upper passages of Carlsbad Cavern.

National Park Service (NPS) personnel plan to excavate a trench for a utility line near structures adjacent to the service vehicles parking lot. Because the excavation will cut into karstic dolomite bedrock, the park staff are concerned about encountering possible void space (i.e., small caves) along the course of the excavation. Park service personnel inquired about the possibility of the National Cave and Karst Research Institute (NCKRI) conducting an electrical resistivity (ER) survey along the route of the proposed utility line to detect potential voids.

The trench for the utility line will be ~55 cm deep and 36 m long. Conventional 2D ER methods are not commonly employed to investigate such shallow features. Geotechnical surveys requiring a depth of investigation less than one meter below ground level (bgl) usually employ geophysical methods such as conductivity profiling or ground penetrating radar. The minimum exploration depth we have conducted to date with 2D ER methods has been ~10 m. This study will thus allow us to explore the upper (shallower) limits of the electrical resistivity method.

Methods

Electrical resistivity surveys have been demonstrated to be a very reliable technique for identifying subsurface voids. (e.g., Land, 2012; Land and Veni, 2012; Land et al., 2018). The basic operating principal involves generating a direct current between two metal electrodes implanted in the ground, while measuring the ground voltage between two other implanted electrodes. Given the current flow and voltage drop between the electrodes, differences in subsurface electrical resistivity can be determined and mapped. Modern resistivity surveys employ an array of multiple electrodes (45-cm long stainless steel stakes) connected with electrical cable. Over the course of a survey, pairs of electrodes are activated by means of a switchbox and resistivity meter. The specific array configuration employed (e.g., Wenner, Schlumberger, Dipole-Dipole) is dictated by a command file that is uploaded to the resistivity meter. The depth of investigation for a typical ER survey is approximately one-fifth the length of the array of electrodes. Specialized software is used to process the raw data and generate resistivity profiles, which illustrate vertical and lateral variations in subsurface resistivity. The presence of air-filled cavities will strongly affect the results of an ER survey, displaying as zones of higher resistivity on ER profiles relative to the surrounding bedrock.

A SuperSting R8/IP electrical resistivity system built by Advanced Geosciences, Inc. (AGI) was used to collect resistivity data, employing a dipole-dipole array configuration. While resistivity data were collected, a Topcon GR3 Global Positioning System (GPS) instrument package was used to collect survey-grade GPS coordinates for each electrode in the array. Elevation data from the GPS survey were used to correct the resistivity data for variations in topography. ER data were processed using EarthImager-2D™ software.

The data quality of a resistivity survey is in part a function of contact resistance (CR), which is an indicator of how well-connected the electrodes are with the ground. Prior to conducting the actual ER survey, a contact resistance test measures the electrical resistance between pairs of electrodes along the length of the array. Ideally the contact resistance should not exceed ~2000 ohms, although meaningful data can still be collected at higher CR values. Very high contact resistance can result in extremely noisy data sets that may be difficult or impossible to interpret, although the results can be improved by removing outliers during data processing. Contact resistance can be reduced in the field by driving the electrodes deeper into the ground and moistening the ground around the electrodes with saltwater.

Results

Field trials

To achieve a shallower depth of investigation for more detailed resolution of the proposed trench depth, we employed the shortest possible electrode array length and reduced the electrode spacing. Initial field trials in an open field on the Pecos River floodplain employed a 28-electrode array at 0.5 m electrode spacing, for a target exploration depth of approximately 3 m. We used a modified 112-electrode dipole-dipole command file provided by AGI technical support staff, designed for a shallower exploration depth. The modified command file instructs the SuperSting to collect all the highest resolution dipole-dipole readings down to the 5-m depth level and has the deeper commands removed by limiting the expansion of unique transmitter dipole positions, or a-spacings, to two. We also lowered the SuperSting's output current from the default 2 amps down to 250 milliamps, and the output voltage down from 400 to 100 volts.

The results of these initial surveys were not acceptable, with almost 20% of data points flagged for removal by the EarthImager™ software. After consultation with AGI technical support we concluded that high contact resistance associated with dry soil conditions in the field area, combined with the very close spacing of electrodes, created too much noise. At such close electrode spacing, the electrodes themselves apparently become sources of interference.

In a subsequent field trial, we reset the SuperSting to the factory defaults (2 amps output current, 400 V output voltage) and ran a second survey using a 1-m electrode spacing and the modified 112-electrode command file. However, taking into consideration the space limitations at the park, we used an end address at electrode 80, thus the survey was not a full 112-electrode array. This array configuration provided an exploration depth of 4.93 m. The resulting ER profile (Figure 1) shows mostly uniformly conductive material (<20 ohm-m), which we interpret to represent fine grained silts and clays—alluvial deposits of the Pecos River floodplain, consistent with results we have observed during previous field trials conducted in this area (Figure 2).

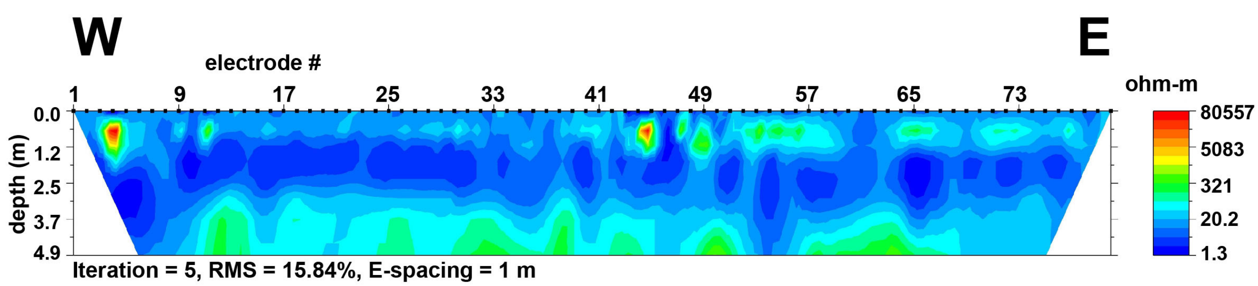

Figure 1. *ER profile from a survey conducted in an open field next to NCKRI Headquarters on the Pecos River floodplain, using a modified 112-electrode dipole-dipole command file and an end address at electrode 80. No terrain correction was applied in processing the data because of the subdued topography of the field area.*

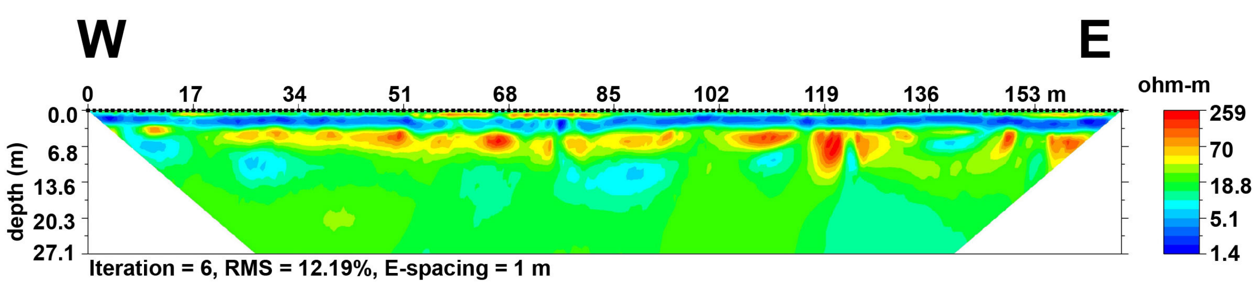

Figure 2. *ER profile from a 2019 survey conducted in the same NCKRI Headquarters field location that employed a conventional 112-electrode dipole-dipole array and an unmodified command file. Note the much greater depth of investigation (27 m). The discontinuous layer of higher resistivity below ~3 m probably indicates the presence of air-filled porosity in coarse-grained lenses of sand and gravel, representing old channel sand deposits.*

Two small pods of high resistivity less than 1 m bgl can be observed on the ER test profile conducted for this study (Figure 1), embedded in more conductive material. These high resistivity pods are probably caused by air-filled animal burrows (their size is exaggerated by EarthImager™'s iterative process), which are abundant in the field area. These results were encouraging because they suggested that we would be able to identify any cavities that might be present along the proposed utility line trench at very shallow depths.

ER survey of proposed utility trench area

On 14 October 2020, NCKRI personnel conducted two electrical resistivity surveys parallel to the proposed utility line trench at Carlsbad Caverns National Park (Figure 3). The first survey used a 112-electrode dipole-dipole array configuration and the modified dipole-dipole command file discussed above. Because of space restrictions we applied an end address at electrode 62, thus the array was only 61 m long (electrode one is at 0 m on the array). The substrate in the survey area consists of a few centimeters of old compacted roadbed material overlying dolomite bedrock, making installation of the stainless steel electrodes to an appropriate depth physically challenging (cover photo and Figure 4). For this reason, initial contact resistance was extremely high, up to 200,000 ohms (100 times higher than recommended by AGI). We used 76 liters of saltwater to water the electrodes, eventually reducing the contact resistance to <25,000 ohm. These very high CR values resulted in an extremely noisy data set, with a root-mean square (RMS) error of 13.91% (AGI recommends a target RMS error <10%) even after removing a large number of data outliers while processing the data with EarthImager™ software. A second ER survey was conducted using the same array but with a standard unmodified dipole-dipole command file. The RMS error for this survey was >37% after removing over one third of the data points as outliers during data processing.

Because of the high noise level of these two data sets, we revised the EarthImager™ resistivity inversion

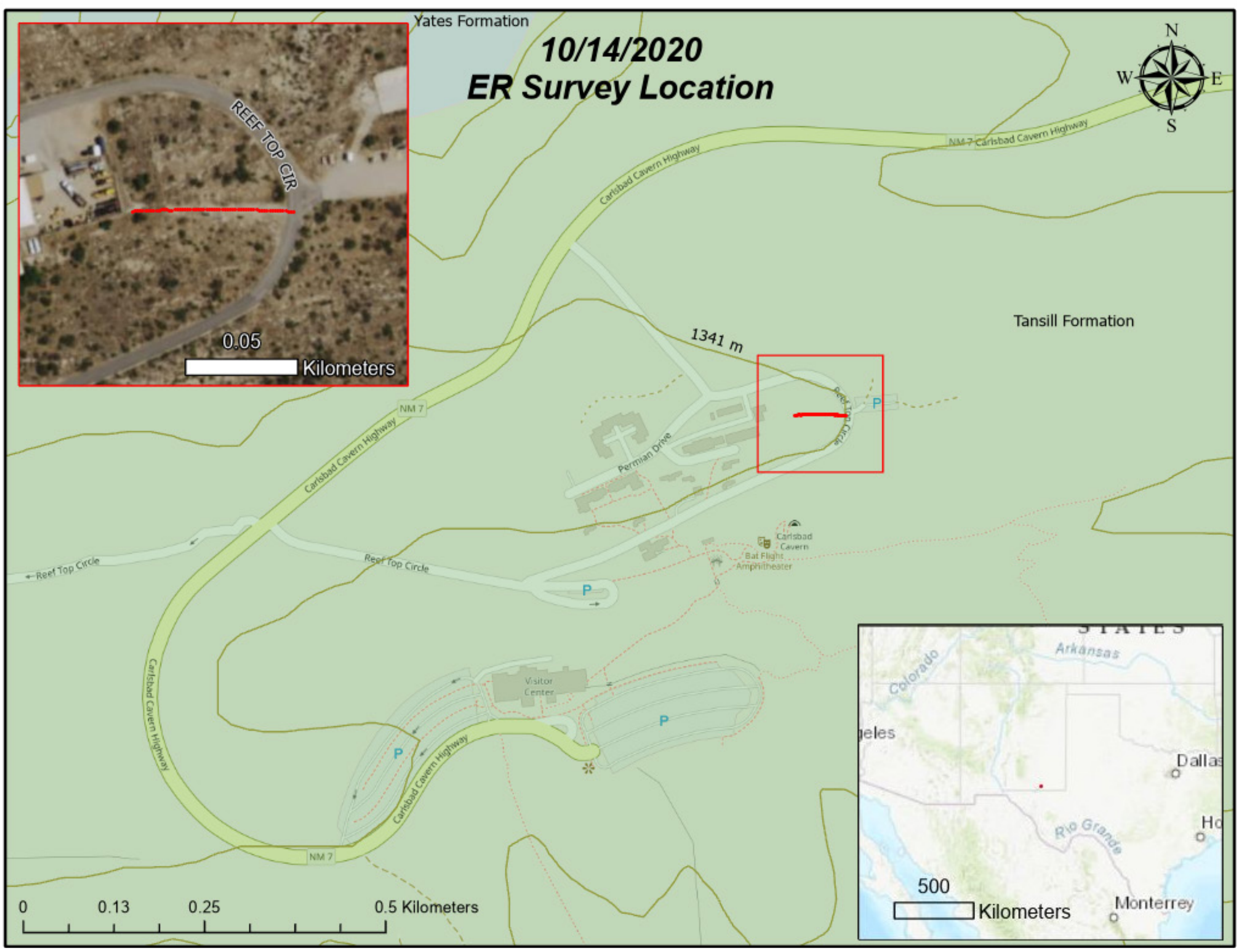

Figure 3. ER survey area at Carlsbad Caverns National Park. Red line shows location of array on Google Earth imagery.

Figure 4. Photo of the ER survey line along the route of the proposed utility trench.

settings to use the Suppress Noisy Data option. This option employs the L2-norm weighted data misfit approach rather than RMS to determine data convergence of the inverse model, with a target L2-norm value <1.0. Having made these changes, we achieved an L2 value of 0.73 after three iterations of the inverse model for our initial survey. Maximum exploration depth is approximately 5 m (Figure 5). Maximum resistivity of this survey is 15,885 ohm-m, thus it does not appear that there are any air-filled voids present within the surveyed area. Air, which has near-infinite electrical resistivity, will usually display resistivity values >100,000 ohm-m. The near-continuous layer of resistivity values greater than 6,000 ohm-m that extends across the profile reflects the presence of highly resistant dolomite bedrock at or very near the surface beneath the survey line.

The second survey used the same array of electrodes but employed a standard dipole-dipole command file. As with the data set discussed above, we applied the Suppress Noisy Data option in the EarthImager™ resistivity inversion settings when processing the data. This procedure results in a high but still acceptable L2 value of 6.15. As expected, the standard dipole-dipole configuration achieves a much greater exploration depth of ~16 m (Figure 6) and is consistent with the shallower results from the previous survey (Figure 4). The conductive zones at ~5 m depth may indicate a perched aquifer formed in the Tansill dolomite where it overlies the less permeable upper Yates sandstone.

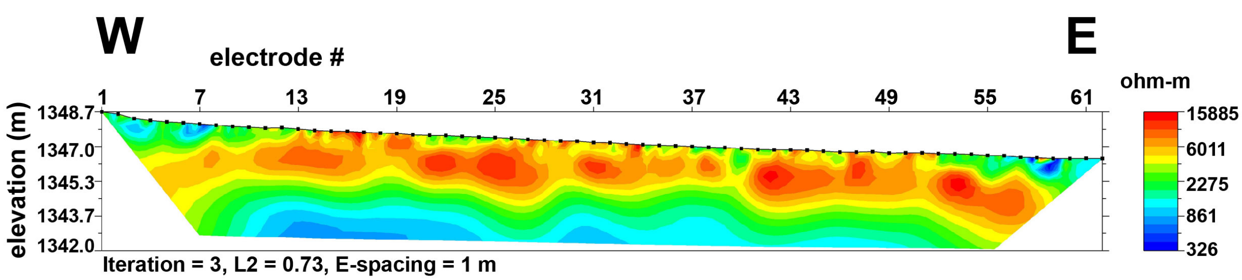

Figure 5. ER survey along the proposed utility line trench using a 112-electrode dipole-dipole array and modified dipole-dipole command file.

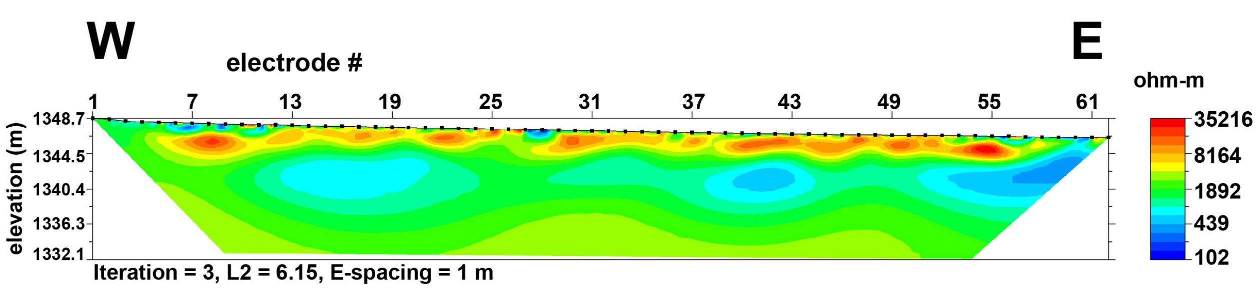

Figure 6. ER survey along the proposed utility line trench using a 112-electrode dipole-dipole array and standard dipole-dipole command file.

Seepage from this perched aquifer can be observed where water seeps from the Yates-Tansill contact in the roadcut at the Walnut Canyon overlook, ~800 m northeast of the survey area.

Conclusions

This study found no geophysical evidence of a cave or related significant conduit within the route of the proposed utility trench. Additionally, it has provided a useful test of the shallower limits of conventional resistivity surveys. Geophysical investigations with a target exploration depth of less than one meter usually employ other tools, such as ground penetrating radar or frequency-domain electromagnetics. We have nevertheless demonstrated that ER surveys, when configured for such a shallow depth of investigation, can also provide useful information about near-surface conditions.

References

Land, L. 2012. Geophysical prospecting for new cave passages: Fort Stanton Cave, New Mexico, USA. Carbonates and Evaporites 27 (2): 97–102.

Land L, Veni G. 2012. Electrical resistivity surveys of anthropogenic karst phenomena, southeastern New Mexico. New Mexico Geology 34 (4): 117–125.

Land L, Cikoski CK, Veni G. 2018. Sinkholes as transportation and infrastructure geohazards in mixed evaporite-siliciclastic bedrock, southeastern New Mexico. In: Sasowsky ID, Byle MJ, Land L, editors. Proceedings of the Fifteenth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impact of Karst, Shepherdstown, WV. National Cave and Karst Research Institute Symposium 7. Carlsbad (NM): National Cave and Karst Research Institute. p. 367–377.

Land L, Jones M, Veni G. 2020. Using electrical resistivity methods to map cave passages and conduits in the San Solomon Springs karstic aquifer system, West Texas, USA. In: Land L, Kromhout C, Byle M, editors. Proceedings of the Sixteenth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impact of Karst, San Juan, Puerto Rico. National Cave and Karst Research Institute Symposium 8. Carlsbad (NM): National Cave and Karst Research Institute: 93–104.

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