Report for 2001OK4481B: Resistance Tomographic Imaging, Digital Mapping, and Immersion Visualization of Evaporite Karst in Western Oklahoma

- Conference Proceedings:
    - Zume, Joseph, A. Tarhule, S. Christenson, 2002, Resistivity Conductivity Anomalies at the Norman Landfill Site, Annual Meeting of the Geological Society of America, Denver, CO.

Report Follows:

Resistance Tomographic Imaging, Digital Mapping, and Immersion Visualization of Evaporite Karst in Western Oklahoma

Problem and Research Objectives

The objective of this proposal is to employ subsurface imaging techniques, specifically Electrical Resistivity Tomography (ERT) and immersion visualization software to provide a digital imagery of the subsurface conduit system in a karst environment. The research objective addresses the need to monitor contaminant flow in karst conduits, which is difficult to detect with discrete network of monitoring wells.

The product of the study will be a procedure for imaging hidden cavities in the karst aquifer system in Northeastern Oklahoma. The information is useful for directly monitoring contaminant occurrence and movement and for drilling targeted wells for groundwater monitoring and aquifer characterization.

Funding Arrangement

The total budget for the proposal was $50,000, over two years (March 2001-March 2003). Of this amount, the Oklahoma Water Resources Research Institute (OWRRI) provided $18,000 while the Oklahoma Department of Environmental Quality (ODEQ) decided to make up the balance ($32,000). However, delays related to the approval of the Quality Assurance Plan (QAP) held up the ODEQ portion of the funding until August 1, 2002 when it was finally approved.

This report describes how the funds received from OWRRI have been spent, with supporting comments to the research activities since the approval of the ODEQ portion.

Research Activities

The Department of Geography owned one AGI Sting Resistivity meter (R1-IP), which was operated in manual mode. During the summer of 2001, the funding provided by OWRRI enabled us to acquire a Swift converter, 28 smart electrodes and 150 m of cable for the Sting R1 earth meter. The new additions facilitate automatic resistivity surveys that were not possible in the manual mode. The total cost of the swift converter and cables came to $14, 230

Fig. 1. The Sting Swift System acquired with funding provided by OWRRI

Reconnaissance Surveys

As specified in the proposal, our goal is to evaluate the feasibility of using resistivity methods to detect groundwater contamination in karst aquifers. Because the conduits in which the groundwater travels are inaccessible it is critical to determine the detection accuracy of the proposed method and to develop confidence in its use. Consequently, we designed a three-phase evaluation procedure. Phase I consists of detecting large conduits with known locations and dimensions, which would serve as ground truth in evaluating the accuracy of resistivity models. Phase II will determine the detection capability of resistivity by establishing the depths and sizes of cavities that could be detected using array configurations. Finally, Phase III will involve imaging small inaccessible cavities, relying on experience gained from Phases I and II to interpret the modeled curves.

During the summer of 2001, several reconnaissance surveys were carried out to locate suitable sampling sites. With assistance provided by the Central Oklahoma Grotto, the Oklahoma Geological Survey and Scott Christensen of the USGS (Oklahoma City), we surveyed Nescatunga caves, The Corn Caves and Jester Caves.

Figure 2. One of the cave passages at Corn Caves near Weatherford, investigated during the reconnaissance survey.

Norman Landfill Study

To test the new equipment, preliminary investigations were carried out at the Norman Landfill site, in collaboration with Scott Christensen (USGS). The old Norman landfill, located on the floodplain of the Canadian River (Fig. 3), was the major repository for municipal waste between 1922-1985. During that time, it is estimated to have received approximately 1,128 tons of municipal waste per week. Leachate plume emanating from the landfill has contaminated a good portion of the underlying alluvial aquifer. The site is therefore ideal for testing the ability of resistivity methods for mapping groundwater contamination.

Our objectives were to

(i) Delineate the pathways through which the leachate flows out of the landfill, and

(ii) Determine the extent of the migration plume that results.

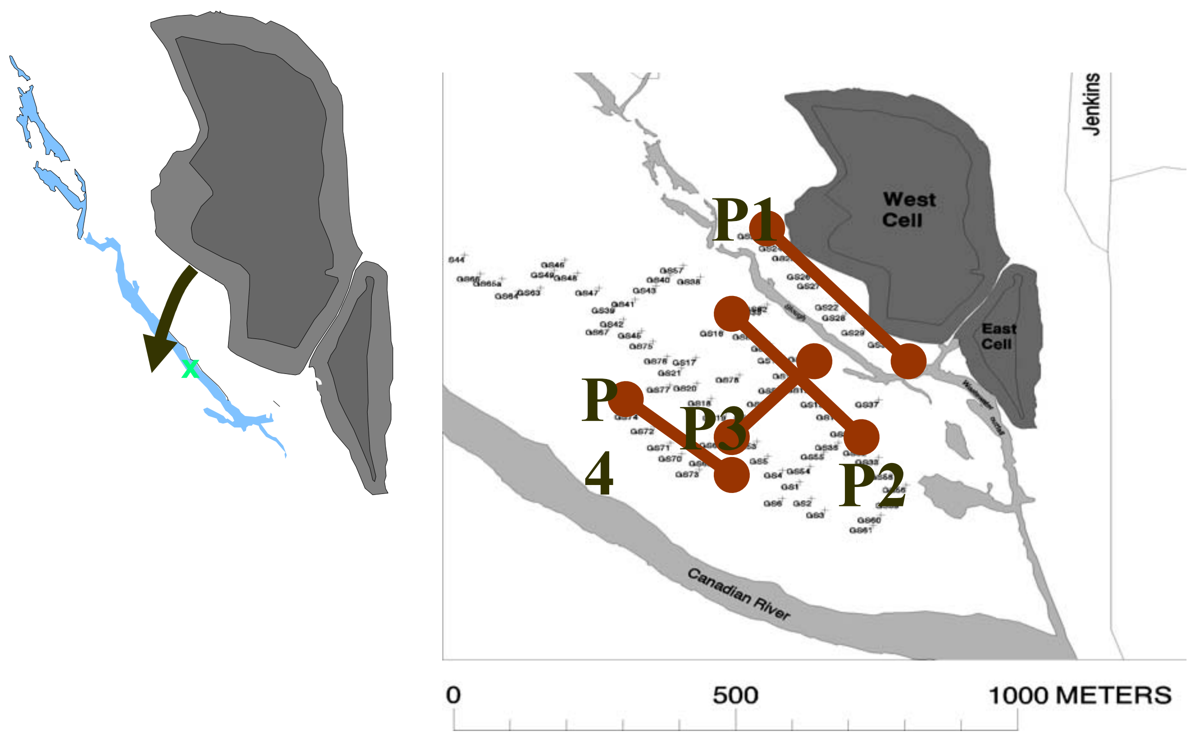

Fig 3. The old Norman Landfill site on the floodplain of the South Canadian River. Resistivity transect lines are shown in red. Conductivity points are shown as dots.

Methodology

Electrical Resistivity methods including Wenner, Wenner-Schlumberger, and dipole-dipole array types were used at 5 m spacing. Four resistivity transects, each 135 m long were completed. For each transect, all three array types were used, resulting in a total of 12 surveys. 36 conductivity logs at 0.5 m depth intervals supplemented the data. Additionally, water chemistry and soil core data provided by the USGS facilitated ground truth and resistivity interpretation.

Principal Findings and Significance

The results presented below integrate the information generated from soil water chemistry (i.e. conductivity in monitoring wells), 2D resistivity modeling plotted as conductivities and geoprobe conductivity logging.

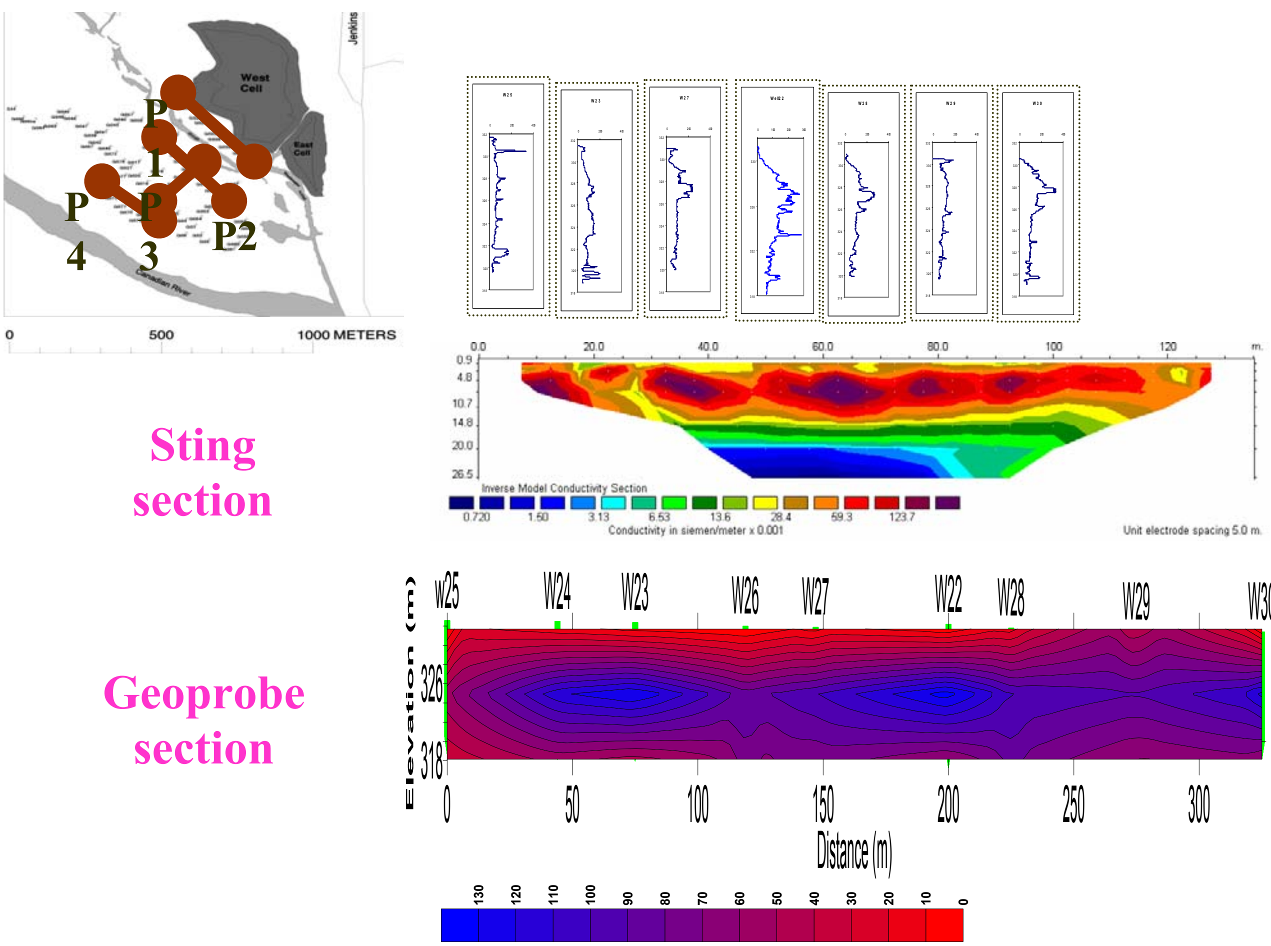

Figure 4. Results of water chemistry (i.e. conductivity analysis; top panel), 2D resistivity modeling (middle panel) and geoprobe section (bottom panel) for profile 1 (insert, top left). Dark red colors in the 2D resistivity profiles (middle panel) show areas of high conductivity (i.e. low resistivity) and blue colors are areas of high resistivity (low conductivity). The color bands are reversed in the bottom panel; blue colors are high conductivity areas and red colors are low conductivity areas.

The three methods utilized reproduce the subsurface conductivity profile in different ways. Measurements of conductivity in monitoring wells provide only the conductivity of the liquid water. The resistivity approach provides an average of the soil resistiviy (or conductivity) along a half space under the four electrodes in the horizontal dimension. Finally, the SC400 soil conductivity meter is a four-pole "Wenner" array type probe: it provides an average of the soil conductivity matrix between the four electrodes in the vertical dimension. The major difference between the methods therefore is that both the water chemistry and geobrobe measurements are site specific whereas the resistivity methods integrates values for a larger area.

Despite such differences, there is good agreement between the methods. In particular, the 2D resistivity (dipole-dipole) and geoprobe profiles for P1 (10 m away from the landfill) show striking similarities: the areas of high conductivity agree quite well both in terms of depth and horizontal position. The dipole-dipole method consistently provided superior image resolution relative to the array types. Results of water chemistry analysis (top panel) suggest that these areas of high conductivity represent the pollutant plume migrating from the landfill.

To test this hypothesis, surveys were conducted along parallel transects P1, P2, and P4, located respectively at 10, 180 and 460 m away from the landfill towards the river channel. Our goal was to image the pollutant profile along each transect and to track its migration towards the river. Finally, transect P3 was oriented concordantly between the landfill and the river channel in the expectation that the leading edge of the contaminant plume could be detected. Figures 5 – 7 show the results.

Figure 5 (P2) detected two areas of pollutant concentration compared to the several blotches or fingers of pollutant plume seen in P1, consistent with the result of water chemistry analysis. Transect P4, near the river channel detected no evidence of the contaminant plume, suggesting that the plume has not migrated this far (Fig. 6). Finally, Fig. 7 attempts to determine the leading edge of the migrating plume but the results are inconclusive beyond the fact that past the slough (see fig. 1), the contaminant occurs deeper beneath the surface.

Conclusions (Norman Landfill Study)

The conductive leachate plume from the landfill concentrates along preferential pathways. Between the landfill and the slough, the contaminant is closer to the surface (0-6 m). Beyond the slough the contaminant dives down toward the bedrock and moves toward the Canadian River. However, beyond 300 m from the landfill, neither resistivity nor the conductivity probing detected any presence of this contaminant. The finding is consistent with conductivity measurements in monitoring wells

These results indicate that resistivity/conductivity methods could be used to detect and map groundwater contaminants in alluvial sediments. Further studies are needed to determine whether the rate of contaminants migration could be monitored using the same methods.

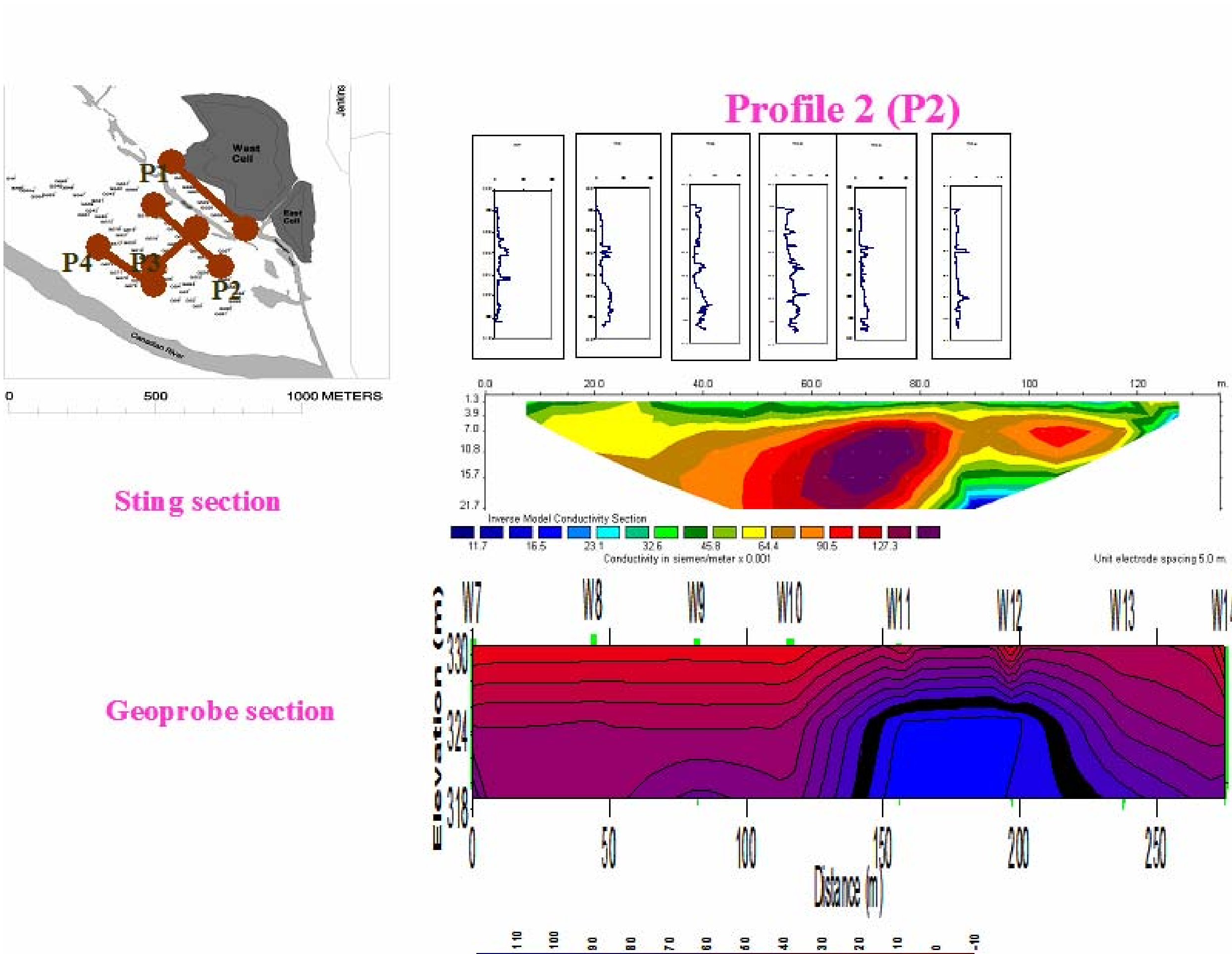

Figure 5. (Top panel): conductivity in a USGS monitoring wells along profile 2; (middle panel): RES2DINV model of the conductivity along profile 2; and (bottom panel): Geoproble profile along profile 2. The color scheme is the same as for profile 1 (fig. 4).

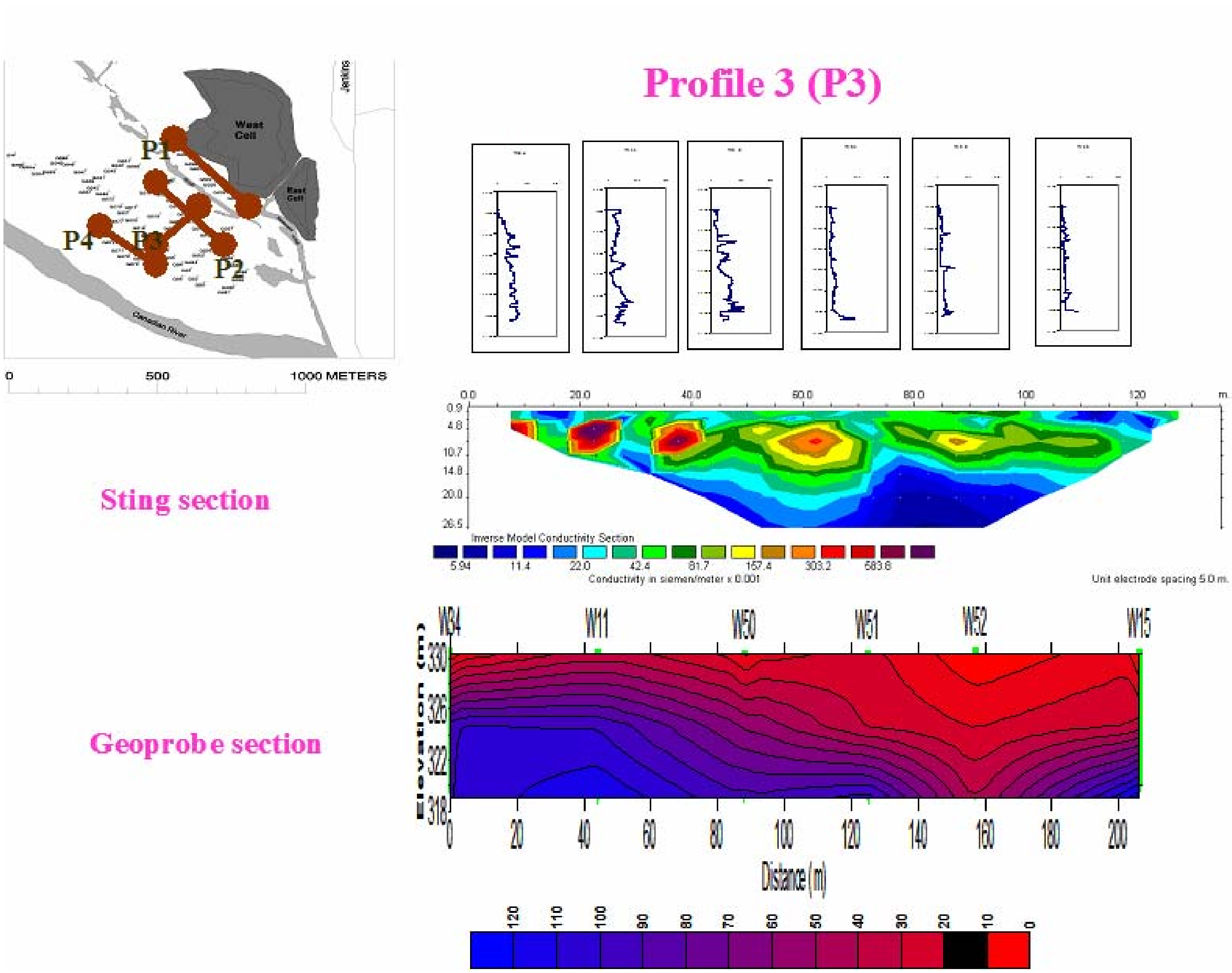

Figure 6. (Top panel): conductivity in a USGS monitoring wells along profile 2; (middle panel): RES2DINV model of the conductivity along profile 2; and (bottom panel): Geoproble profile along profile 2. The color scheme is the same as for profile 1 (fig. 4). Notice that in all three profiles, the conductivity values diminish appreciably beyond 120 m.

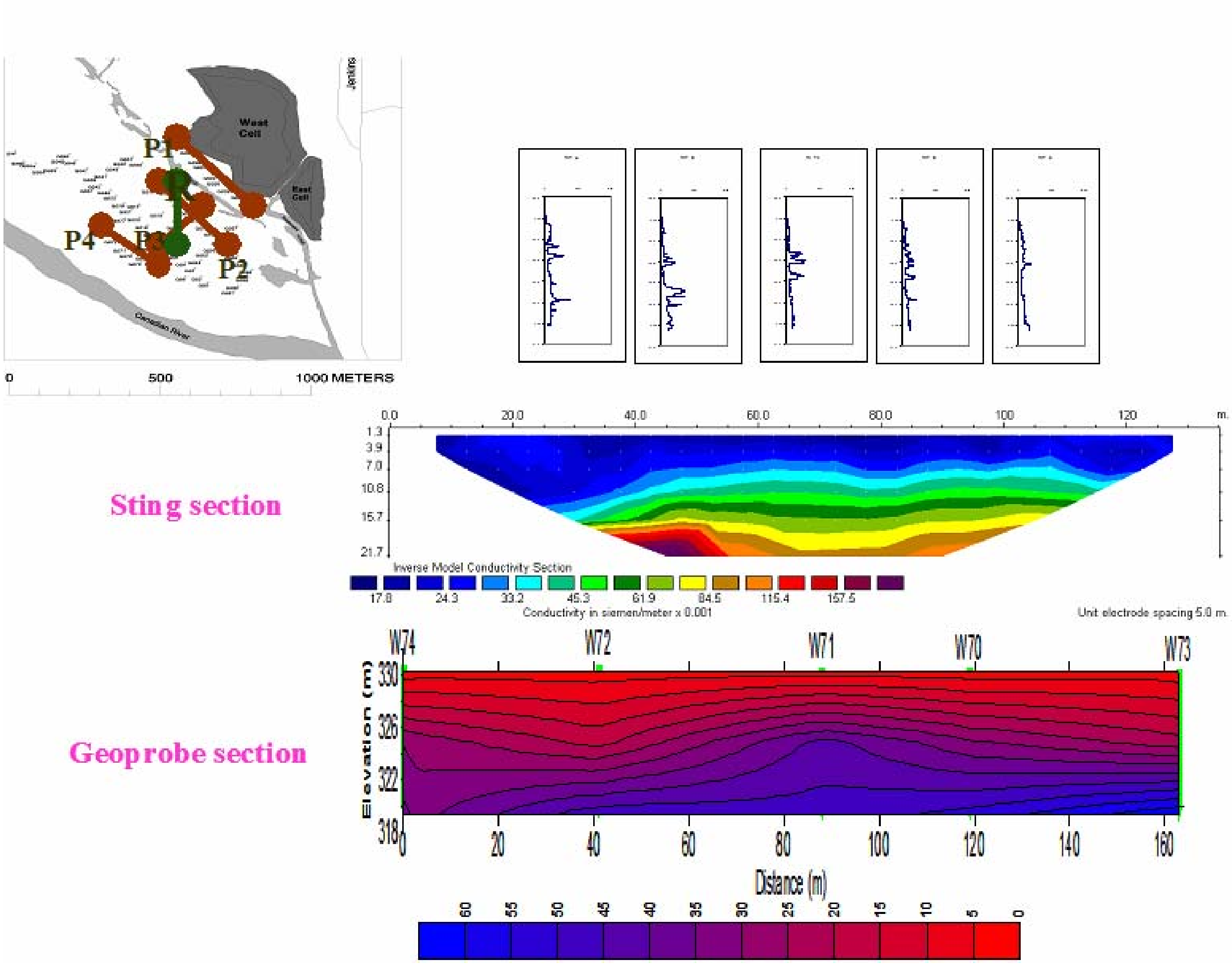

Figure 7. (Top panel): conductivity in a USGS monitoring wells along profile 2; (middle panel): RES2DINV model of the conductivity along profile 2; and (bottom panel): Geoproble profile along profile 2. The color scheme is the same as for profile 1 (fig. 4). None of the methods detected any evidence of the contaminant plume along this profile, next to the river channel and f arthest from the landfill.

Future Work

Approval of the ODEQ portion of the funding in August 2002 allowed us to begin substantive investigations on detecting solutional conduits in karst aquifers. Five (5) surveys were conducted between September and October 2002. The cave systems investigated are the Corn caves near Weatherfold, and Jester caves in southwestern Oklahoma.

Internal Cave Mapping

As specified in the proposal, our rationale for mapping large diameter cavities is to enable us develop confidence in the detection capability of resistivity methods. Consequently, the first step in the research is to produce an accurate and high-resolution image of the cave conduits.

A Trimble ProXRS system http://www.trimble.com/pathfinderproxrs.htm, LaserTech reflectorless rangefinder, and MapStar digital compass http://www.afds.net/lasertech.html#B (with a Compaq IPAQ running the SOLOField data logging software) were used together to generate accurate GPS and elevation position of the known cavities for comparison against the voids detected from modeled curves. This facilitates the assessment of the relative efficiency of each array configuration in detecting the voids.

To map the caves, the ProXRS GPS system was mounted on a tripod near an entrance to the cavern system being surveyed, along with the reflectorless laser rangefinder and digital compass. A DGPS carrier phase location was sited at this initial position. Differential corrections were obtained onsite using the OmniStar system and later via internet resources. A series of control points or stations were then located within the cavern itself spatially referenced to the GPS position by a series of offsets using mounted reflectors. Beginning at the entrance to the cave, the laser configuration occupied each of these control stations successively, permitting a survey of the surrounding cavern walls (consisting of locations referenced to the control points) to be conducted. Although positioning error invariably increases with each successive control point occupied within the cavern, we achieved sub-decimeter accuracy in distance and inclination from each control point, and confirmed the accuracy by reoccupying control stations. Positioning data was then stored and analyzed using GIS (e.g. ESRI ARCVIEW) and CAD.

One survey approximately 60 m long was completed at Corn caves. At Jester, only GPS points directly underneath the surface transect line was collected. This was possible because of a "window" or collapse that opened up into the cave near the survey transect. Figure 5 shows Gaylen Miller, staff of the Oklahoma Geological Survey setting up the laser system.

Resistivity surveys were carried out at the surface concurrent with the internal cave mapping, using a Sting R1-IP resistivity meter produced by AGI, in Austin, Texas. A total of six transects (3 at each location) were completed. Four of the transects utilized 28 electrodes at 5 m spacing, resulting in a survey length of 135 m. To investigate the effect of electrode spacing on resolution of target voids, two other transects were completed at 3 m spacing. For each survey transect, four array types (dipole-dipole, pole-dipole, Wenner, and Wenner-Schlumberger) were used. This was to determine which array type most consistently detected voids with the best resolution.

The internal cave mapping allowed us to determine the true positions of cave passages underneath the survey lines, which could then be compared with the voids detected by surface resistivity imaging. Figures 6a, b illustrates the concept.

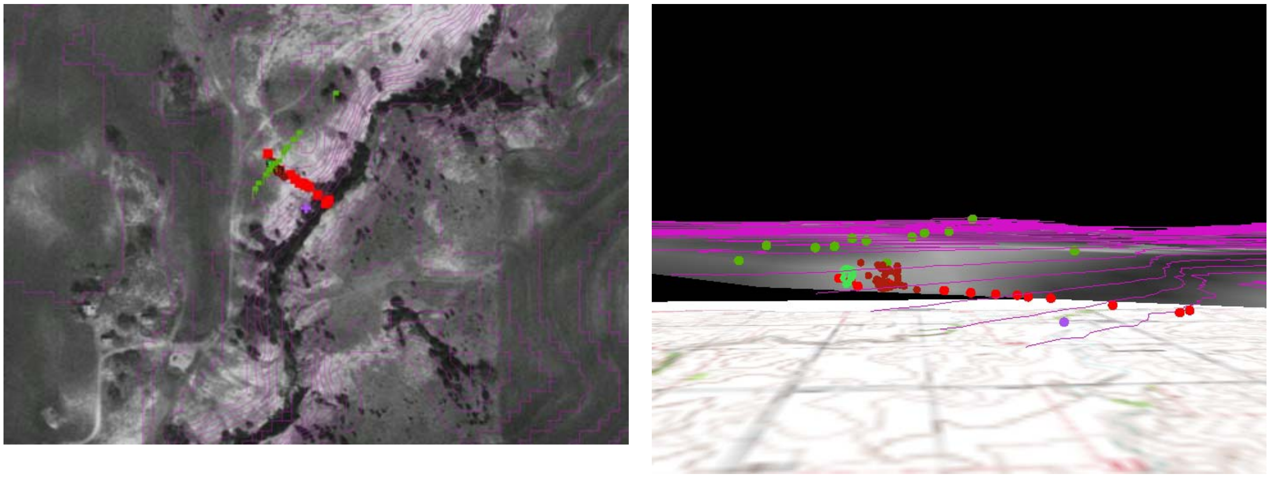

Fig. 6(a). Combined surface resistivity and GPS/laser mapping. The red dots are GPS positions inside the cave. The green line shows the survey transect line. (b). Side view of the image in Fig 4a. Notice the high density of GPS points underneath the survey line. These points were subsequently plotted on the modeled image of the resistivity survey to establish the accuracy of void detection with resistivity.

A quarterly report detailing the preliminary results achieved has been submitted to ODEQ.

Conclusions

Funding provided by OWRRI allowed us to

(i) acquire a Swift converter and smart electrodes to complete our Sting Swift resistivity system.

(ii) Support field investigations by one Ph.D graduate student to test the equipment

(iii) Map the migration of leachate plume from the old Norman landfill. The results of the test were corroborated by other methods and subsequently presented at the annual general meeting of the Geological Society of America in Denver, 2002. A manuscript is in preparation to be submitted to a reputable journal for publication.

(iv) Approval of supplementary funding by ODEQ was obtained in August and subsurface mapping as specified in the original proposal is in progress.

Acknowledgement

We are deeply grateful to the Oklahoma Water Resources Institute for providing the funding that made this study possible. We would also like to thank the Department of Geology and

Geophysics, University of Oklahoma, for permission to use the GPS/laser range finder system. Additional assistance was provided by the USGS, Oklahoma City and the OGS based at the University of Oklahoma.