Figure 3. A student from the University of Houston operates the portable EM system, demonstrating its maneuverability around surface structures. The red arrow points to oil well 1.

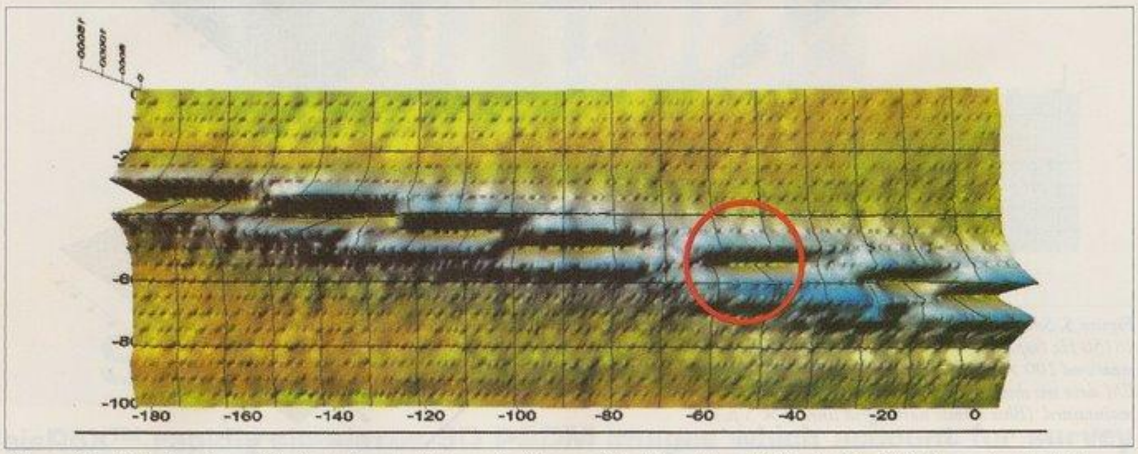

***Figure 4.** An EM subsurface profile detected a potential anomaly (blue-grayish color) next to a pipeline (red circle). Subsequent excavation revealed a small cavity or sinkhole that was later backfilled as preventive maintenance. (Grid lines: 20 × 20 ft.)*

the oil and gas wells up to mandated operating and environmental standards. There are cases in which neglected small oil fields required major cleanup and workovers in order to pass inspection for an operating license. There also are cases of unauthorized dumping and waste burial in old oil fields that were later discovered, resulting in prohibitive remediation costs for the new owner/operator.

The Louisiana oil field in this example has eight producing oil wells. It rests on top of a salt dome where oil production began in the 1970s. The producing zones are from shallow reservoirs, ranging in depth from 1500–3200 ft beneath the surface. With little stimulation, the average production from each well is between eight and 10 barrels of oil per day. Figure 1 shows the cleared and well-kept surface conditions of well 7. A concrete bunker is beside the well head. The surface cap measured about 4×8 ft, but its depth was unknown. It was probably used previously for temporary oil storage.

Four large metal storage tanks, each capable of storing 200+ barrels of oil are behind the tree line in the background (Figure 2). The study area extended only up to the tree line. Since all eight oil wells are within an 800-ft radius, the owner/operator connected an innovative surface jet-pump system to all eight wells (Figure 2).

Survey parameters. In order to better investigate and image the near-surface and buried infrastructure of the oil field as well as any potential seepage problems, a noninvasive, digital multifrequency source EM system was selected to profile the shallow subsurface. The EM system can be programmed to sound at different depth intervals by selecting a number of source frequencies. A noise test was conducted to determine the background EM noise, and five source frequencies were subsequently selected (630, 2010, 6150, 18 150, and 42 150 Hz) for this project. Given these field acquisition parameters, a total of 22 subsurface profiles can be generated from a single

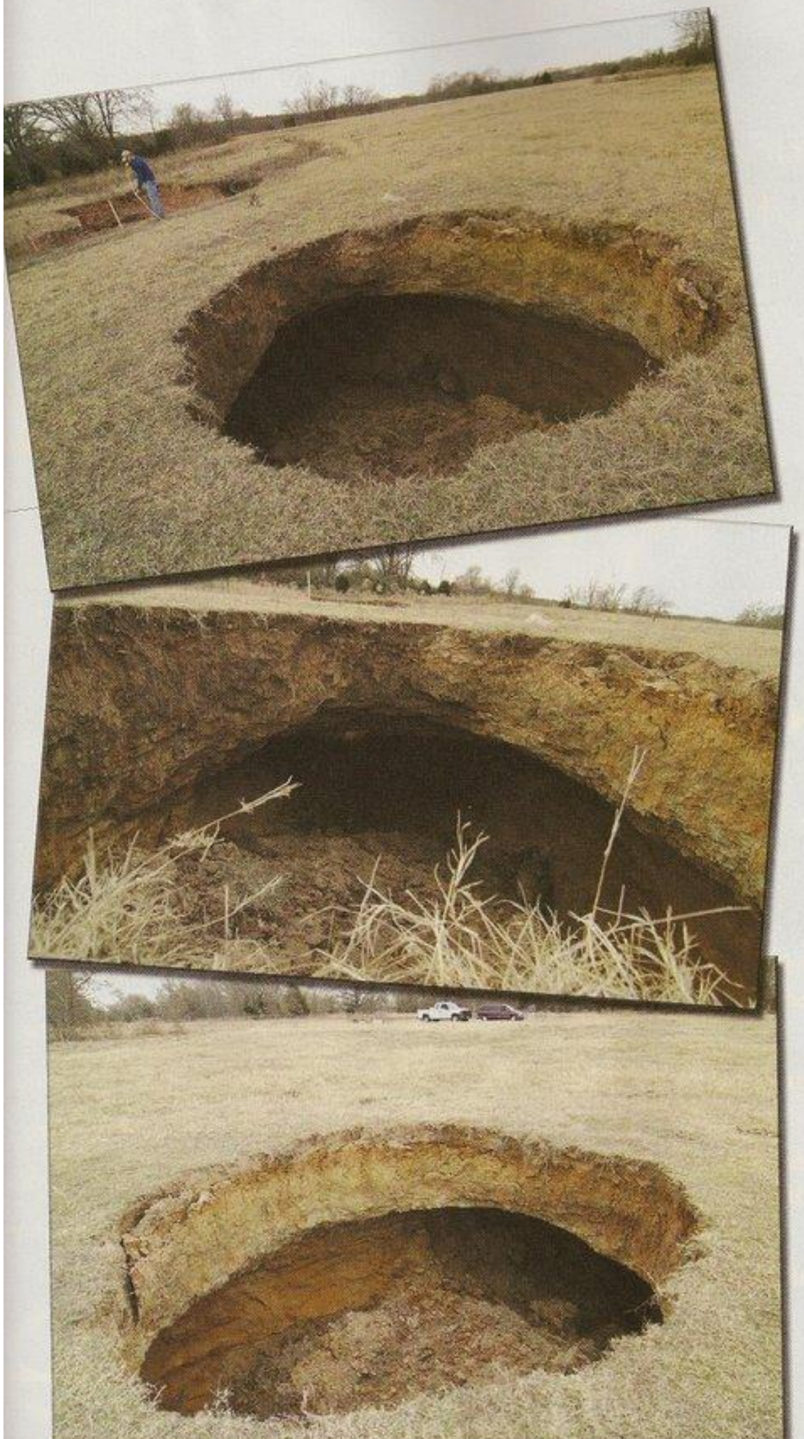

Figure 9. *New sinkhole (~30 ft in diameter) found in Malakoff, Texas, in January 2008, which later became the focus of the EM survey.*

a sinkhole was discovered that was not present at their last inspection more than a year ago (Figure 9). The new sinkhole measured about 30 ft in diameter and became the focus of the EM survey. The study area measured 100 × 100 ft in size and a line interval of 5 ft was used. The five source frequencies selected for this project were 450, 1230, 4050, 12930, and 39930 Hz.

Interpretation. Since the majority of the EM profiles collected in the study area yielded similar subsurface images, only the EC-39930 Hz profile will be presented to highlight the overall results of the EM survey (Figure 10). The EM subsurface profile is associated with measured electrical conductivity (EC) values of the near-surface soils. A cavity or sinkhole would yield very low EC values while water-saturated soils would result in much higher EC values. The 3D surface expression with a 30°-perspective view (Figure 10, top) highlights the location of the new sinkhole (red circle). The sinkhole located on the southwest corner of the study area is much larger in size than its surface manifestation. The red dot near coordinate (25, 65) is the location where a sinkhole was repaired or backfilled in 2003. The EM data verified the successful remediation effort performed in 2003; the grayish-white zone indicates no cavity was detected beneath coordinate (25, 65).

A map view of the EC-39930 Hz subsurface profile (Figure 10, bottom) shows other interesting features. The northwest and northeast corners of the study areas seem to show similar EM properties as the new sinkhole. These two features may indicate the edge or the early stages of other subsidence features on the property. The two blue-shaded, more conductive zones might indicate water-saturated soils or voids and will require more investigation.

According to the Texas RRC geologists, this field demonstration was their first experience in which geophysical data acquired via the digital multifrequency source EM system was successful in detecting and imaging subsidence features. They are encouraged, and more field tests are planned.

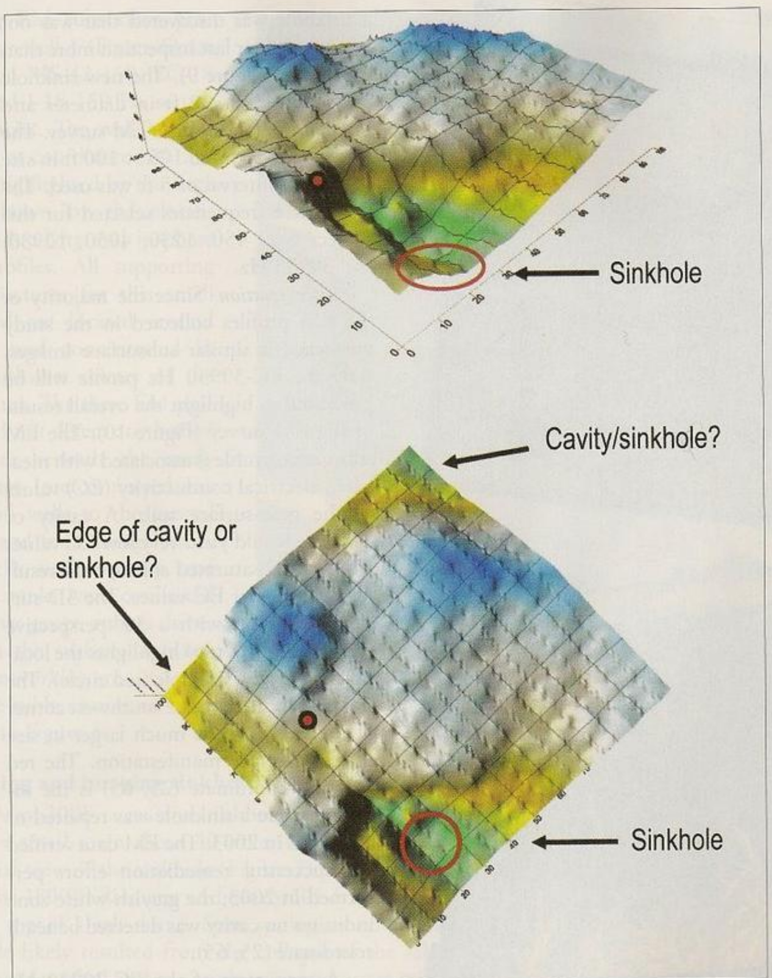

Figure 10. *The EM data based on EC-39930 Hz show the cavity beneath the sinkhole to be larger and more extensive than the surface manifestation. The "red dot" indicates where the Texas RRC previously backfilled a sinkhole. The NE and NW corners seem to indicate the edge of cavities or early stages of new sinkholes that have not reached the surface.*

Conclusion

Overall, the digital multifrequency source EM system is a versatile, noninvasive geophysical tool that can address a variety of detecting and imaging problems. In the first example, the EM data did not detect any potential problems beneath the two areas of the oil field that could adversely impact the new owner/operator. The EM data sets properly imaged the two well heads and all supporting surface infrastructures of this Louisiana oil field. No buried pipelines were detected.

The good correlation of the EM data with known sinkhole problems is very encouraging. Since sinkhole problems are evolving and changing in real time, EM surveys will need to be conducted on a larger scale and more frequently. Subsequent and significant changes in detected anomalies shown by the geophysical data may indicate sinkholes to the surface. In addition, the geophysical data can also show whether remediation efforts to backfill sinkholes were successful by measuring differences in soil electrical conductivity properties.

Suggested reading. "Detecting and imaging hard-to-find legacy abandoned oil/gas wells and pipelines" by Gochioco and Ruev (*TLE*, 2006). TLE

Acknowledgments: The authors thank Jon Brandt, Texas Railroad Commission geologist, for providing valuable field support and geological background of the Malakoff worksite.