

# Detecting and imaging hard-to-find abandoned wells and pipelines

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In 1859, Colonel E. L. Drake drilled a successful oil well in Oil Creek, Pennsylvania, USA, and ignited a frenzied era of oil and gas exploration in the country. Several thousand oil and gas wells were drilled in the next few decades, a time when no government regulations or guidelines were in place to document drilling activity and there were no laws requiring exploration and/or drilling companies to remediate and/or plug abandoned wells. As a result, there are thousands of poorly documented or undocumented oil and gas wells scattered across the country, creating serious public safety and environmental issues.

This was highlighted on 15 October 1987 when an 18-month-old girl fell 22 ft down an abandoned well in Midland, Texas. It took rescuers two-and-a-half days to dig a tunnel and safely rescue her. Although this event received considerable attention in major news media, the safety issues remain. Other small children and animals have fallen into abandoned wells in other parts of the country and there are instances where people unknowingly built homes on top of abandoned wells—a hazardous situation because gas build-up can occur or oil can seep through foundations via cracks and plumbing.

Open holes act as conduits for natural gas to migrate from deeper strata or from coal seams. Abandoned and unplugged open wells also are a serious public safety issue because they can funnel untreated surface runoff into shallow aquifers used as a source of drinking water.

Unfortunately, and somewhat surprisingly, finding abandoned oil/gas rigs can frequently be difficult. For example, as shown in Figure 1, they are often barely visible on forested hillsides in the Appalachian Basin where many have been abandoned for decades. Plugging such wells is also often complicated by surface topography which makes it difficult to access the area (Figure 2). To compound the problem of detecting these abandoned wells, steel casings from many were removed and recycled during World War II. These wells were rarely plugged and, consequently, detecting them became more difficult and would require the development of portable, advanced geophysical tools.

This article is based on field trials we conducted, with support from several coal companies, over two years to determine the best technology to directly and indirectly detect/image abandoned wells. Our conclusion is that the digital multifrequency electromagnetic (EM) method is the best technique for this purpose. However, as indicated in the following case histories, each site also had its own unique set of problems and challenges and, thus, required conducting various tests to determine the proper source frequencies that would make any anomalies detectable.

**A twin well problem.** The thickly forested study area is near the top of a mountain ridge in West Virginia. Based on vintage maps and an old timer's recollection, two abandoned wells were assumed. It was common practice at the turn of the 20<sup>th</sup> century for drillers who encountered problems with a hole to just simply swing the rig 180° and drill a second hole nearby. Coal company engineers found the first well and, using the length of typical drill rigs of that vintage era, looked for the second second well within a 30-ft diameter.

In Figure 3, a digital EM image of the study area, the



Figure 1. An abandoned oil/gas rig in a forest in the Appalachian Basin.



Figure 2. A site where access/data acquisition is difficult.

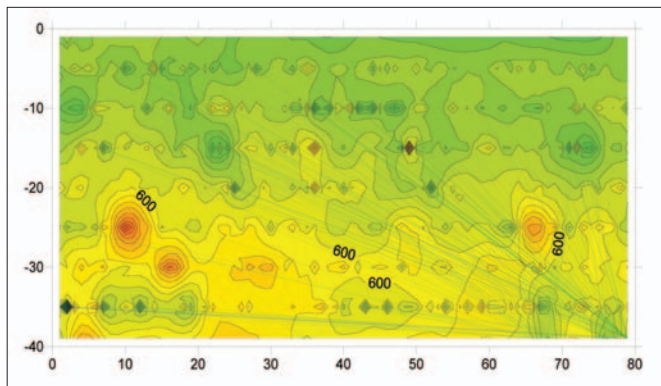
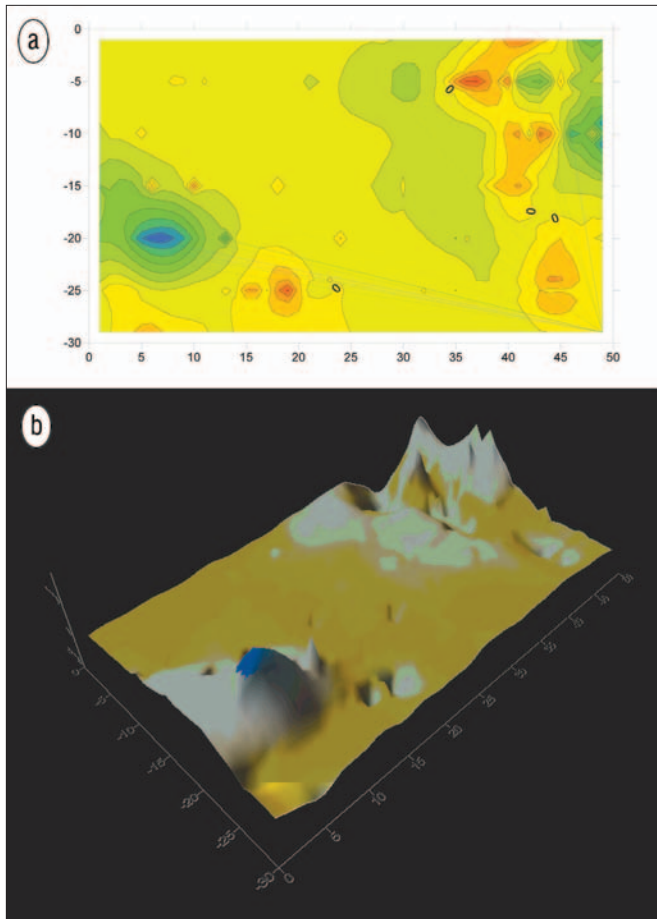


Figure 3. A twin-well problem. The first abandoned well was found near (65, -25), but finding the second (10, -25) required a digital EM survey.

first abandoned well is near coordinates (65,-25). The survey was expanded to cover a larger area which measured 40 × 80 ft and a similar signature was detected at (10,-25), 55 ft away from the first abandoned well instead of the expected 30 ft. Apparently, the drillers not only swung the rig around, but also moved an extra 25 ft for some unknown operational reason.

A similar but smaller signature near coordinates (15,-30) was interpreted to be an artifact of the survey. A straight



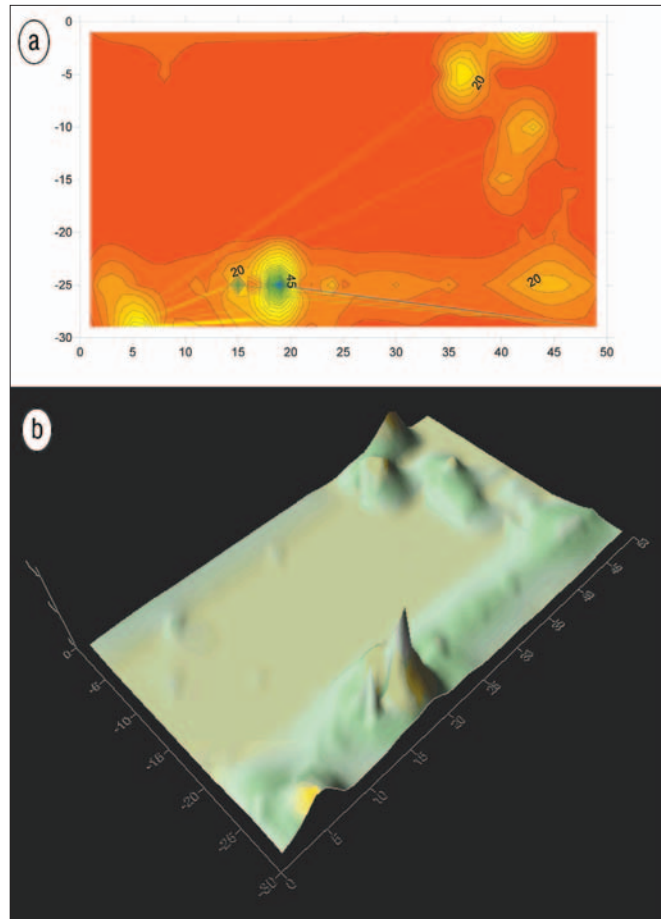
**Figure 4.** 2D (a) and 3D (b) EM images of the study area based on the In-Phase response of a source frequency of 9830 Hz.

acquisition line could not be maintained in the heavily wooded area (see Figure 2) and the surveyor came close to the second well on the return pass. Engineers did later confirm the location of the second well.

**Abandoned well by jeep trail on hillside.** The problem was to find an abandoned well near a jeep trail on a hillside in West Virginia. Figure 4a shows the In-Phase EM image at 9830 Hz of the 50 × 30 ft study area. A large distinct (blue) peak and distinct (red) troughs may indicate an abandoned well. However, the blue positive peak is associated with an exposed aluminum culvert. Thus, one of the red troughs is likely associated with the abandoned well. In order to improve our interpretation, we generated a 3D surface expression of the EM data (Figure 4b) to highlight the recorded values.

Resolving some uncertainties and providing better discrimination required additional EM profiles. Figure 5 shows an EM profile based on magnetic susceptibility (MS) properties at a source frequency of 24 570 Hz. The 3D EM image of this profile distinctly shows a large peak near coordinate (18,-25). The linear features of the other peaks are associated with legacy buried pipelines that measured between 2 inches and 4 inches in diameter. The short broken pipeline feature along the *y*-coordinate resulted from data acquisition footprint and should be adjusted to make the pipeline signature straight.

The EM survey results confirmed what the engineers already knew as they found the well prior to the survey and wanted to test this technology. However, the engineers were unaware of the existence of the pipelines.



**Figure 5.** A 2D and 3D EM image of the study area based on the magnetic susceptibility response at a source frequency of 24 570 Hz. The data pinpointing the abandoned well (largest peak) connected to a legacy pipeline, suggesting that this was once a producing oil/gas well.

**Valley of legacy pipelines.** Figure 6 shows a valley with two abandoned pipelines. In the foreground is a ruptured 3-inch pipeline that runs parallel to the valley. In the background is an 8-inch pipeline that came down a hillside. These two pipelines were known to intersect at a “T” junction inside the narrow valley floor. They had been decommissioned for more than 50 years. As a result of anticipated high background noise, the data acquisition program was conducted in two phases. The first produced an EM image, source frequency of 28 290 Hz, associated with the magnetic susceptibility properties of the near-surface with (Figure 7a). The EM profile shows a lot of anomalies, including the effects of the acquisition footprint.

The second phase repeated the survey but incorporated techniques that would remove or minimize the effects of the acquisition footprint. In addition, different source frequencies were used to determine the resonant frequency that would maximize the excitation of near-surface anomalies. Figure 7b shows an EM image associated with magnetic susceptibility readings at 10 530 Hz. The new profile is much improved with high signal-to-noise ratio. The two legacy pipelines are now clearly shown. A small disturbance was detected near (-20, 40) and could be associated with the abandoned well. The interpretation was subsequently confirmed by excavation.

**Minimizing impact on private property.** Even though coal companies have the legal right to conduct due diligence in finding and plugging abandoned wells before mining, the

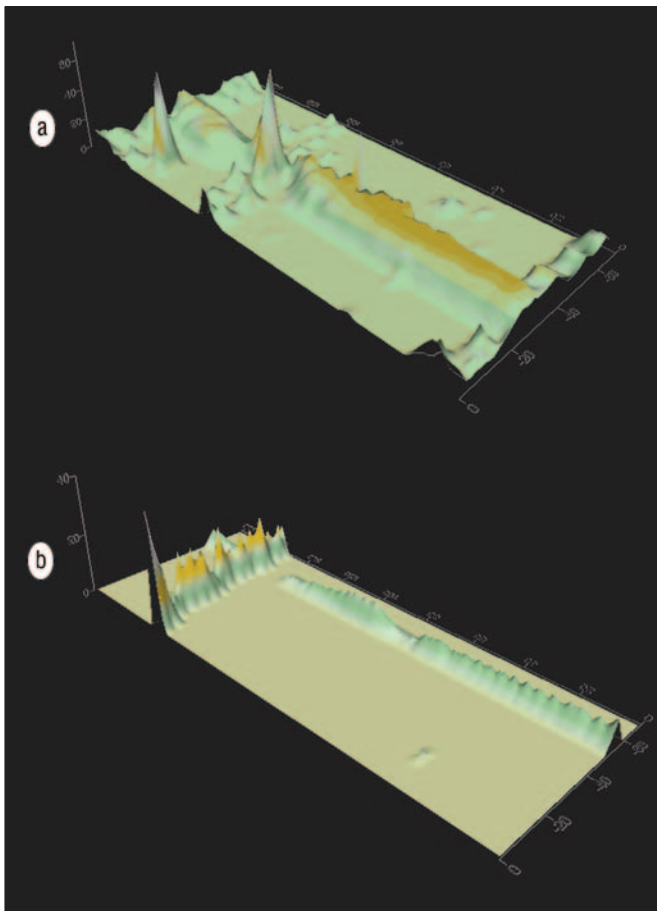


companies try to cooperate with landowners—especially farmers who are very concerned about having heavy equipment like bulldozers and backhoes on their property. In this case study, the landowner requested the coal company make the search area as small as possible. Consequently, an EM survey was just  $100 \times 100$  ft. A small creek meandered inside the study area and exposed a 6-inch pipe that was previously buried at a depth of 4 ft. The presence of the exposed pipe suggested a possible pipeline nearby. This assumed pipeline in turn could indicate an abandoned well.

Figure 8a shows a 3D EM image based on the electrical conductivity properties of the near-surface having a source frequency of 25 080 Hz. An image of a pipeline is clearly visible which made a  $90^\circ$  dog-leg turn. A disturbance was also detected right next to the pipeline near (-30, -30). To enhance this anomaly, the effect of

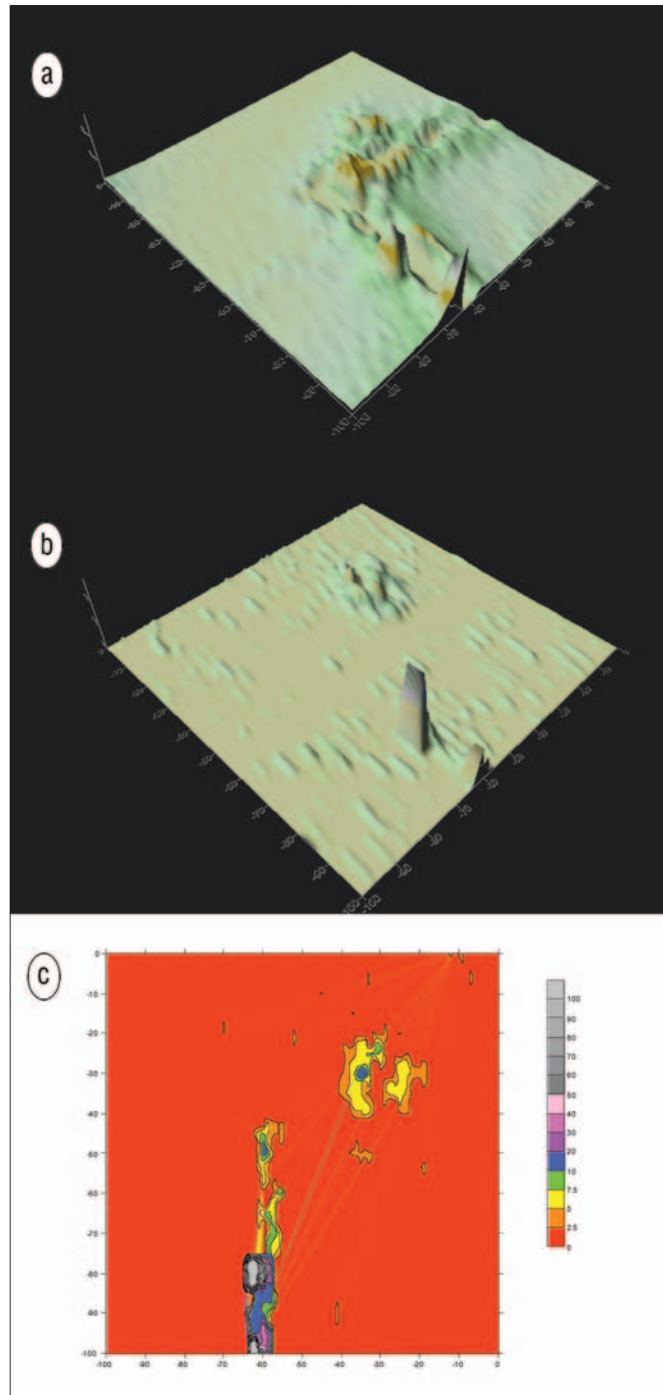


**Figure 6.** A valley floor with decommissioned pipelines evident in the background and foreground.



**Figure 7.** Two EM profiles collected from the same valley floor on two different dates and using different source frequencies show how highly variable the EM results can be. The 28 290 (a) and 10 530 Hz (b) profiles are shown. The abandoned well was interpreted to be near (-20, 40) which was later confirmed by excavation.

the pipeline was attenuated by simply selecting an EM image having a much lower source frequency in order to achieve greater sounding depths. Figure 8b shows the magnetic susceptibility properties at 1530 Hz, resulting in estimated sounding depths of between 15 and 20 ft beneath the surface. The effects of the pipeline have been filtered and the same disturbed zone is more clearly defined. The disturbed zone suggested a small debris area around the well-bore or extra piping that connected the oil/gas well to the



**Figure 8.** (a) The electrical conductivity properties based on a source frequency of 25 080 Hz shows a buried pipeline making a  $90^\circ$  turn. (b) By examining a different EM profile based on the magnetic susceptibility properties with a source frequency of 1530 Hz, the effects of the pipeline are filtered out, highlighting the location of abandoned well (middle). (c) A 2D map view of the study area is shown and a circular feature in blue (perhaps the actual well?) is evident inside the disturbed zone (bottom).

pipeline, indicating that this was once a producing well.

Figure 8c shows a map view of the area. The data set was of unusually high quality because images of the disturbed zone show a circular (blue) feature that could be the abandoned well itself. In this example, both the coal company and landowner were extremely happy with the results as we were able to provide them useful information that permitted them to minimize excavation work on the property in finding the abandoned well. It also realized savings for the coal company.

**Summary.** The four case studies in this paper were selected from dozens of field examples collected over a two-year period. The apparent success of these four examples should not be construed or interpreted that this novel digital multifrequency EM tool will find all abandoned wells scattered across the United States. We have examples in which the EM survey did not find any direct or indirect indication of abandoned wells in study areas where they were expected, possibly because the abandoned well was outside the study area or that, in fact, the suspected abandoned well did not exist.

Three factors that cause this technique to fail to detect wells that are present in an area are:

- High cultural background noise levels overwhelmed the anomaly generated by the well.
- Electromagnetic property contrasts with surrounding soils are too small to be detected.
- The correct source frequencies were not determined and employed in the field.

Despite these cautionary comments, we believe that the digital multifrequency EM method is the best geophysical tool currently available for abandoned well detection and imaging. Considering the serious public safety and environmental issues raised earlier, a 50% success rate is a significant improvement over historical searches which have relied mainly on personal communication and hunches for these hard-to-find abandoned wells, especially those whose steel casings had been removed. **TJE**

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