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*Technical Communication*

# Methods for Removing Signal Noise from Helicopter Electromagnetic Survey Data

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**Abstract.** A geophysical analysis was conducted over the abandoned T&T subsurface mines and portions of the Muddy and Roaring Creek watersheds in northeastern Preston County, West Virginia. The data were collected using helicopter-borne measurements of frequency-domain electromagnetic (FDEM) conductivity (390, 1555, 6254, 25,800, and 102,680 Hz). Noise was a significant issue in the lowest frequency EM conductivity data, especially the 390 Hz and 1555 Hz data; noise removal was accomplished by standard spatial frequency filtering, using homomorphic filters and Fourier filtering along individual flight lines. We interpret the filtered FDEM apparent conductivities and apparent resistivities as showing regions of potential mine pools and regions of contrasting groundwater conductivity related to discharge.

**Key words:** Acid mine drainage; airborne electromagnetic survey; EM; frequency domain electromagnetic conductivity; noise removal

## Introduction

The objective of this study was to determine the lateral extent of a contaminated mine pool associated with the abandoned T&T subsurface mines in Preston County, West Virginia. Acid mine drainage (AMD) is an important water quality issue in the Appalachian region of the United States (Kleinmann 1989). In addition, safety issues related to water-filled abandoned mines in regions of renewed mining activity has highlighted the importance of accurate detection and subsurface imaging of such voids (Ramani et al. 2002).

The geophysical data analyzed in this study were collected during a helicopter-borne frequency domain electromagnetic (FDEM) survey. After processing and removal of cultural noise-related components, the data were interpreted to constrain subsurface resistivities and conductivities in the region of a subsurface mine pool.

## Study Location

The study area is underlain by gradually to moderately folded, consolidated sedimentary rocks of the Allegheny Formation and Conemaugh Group (Hennin and Reger 1914; Hobba 1991). The stratigraphic column in the study area consists of Pennsylvanian age rock ascending from the Lower Freeport sandstone of the Allegheny Formation through the top sandstone of the Conemaugh Group, representing approximately 100 m of sandstone, shales, clays, limestones, and coals (Meehan 1980). The Upper Freeport coal is about 70 m below the land surface at the top of the Allegheny Formation.

The geophysical data were collected by Fugro Airborne Surveys (www.fugroairborne.com) using a Bell 412 helicopter for the National Energy Technology Laboratory (NETL) of the U.S. Dept. of Energy. FDEM conductivity (390, 1555, 6254, 25,800, and 102,680 Hz), very low frequency (VLF) electromagnetics (VLF1 from the Cutler, Maine station and VLF2 from the Seattle, Washington station), and total field magnetics were measured. In general, the VLF data were not useful in determining the location of the subsurface AMD-impacted regions and are not discussed in this article.

The FDEM data were collected using a Dighem VRES multi-coil, multi-frequency system of five coplanar coil pairs with a frequency spread of 390 to 102,680 Hz. This system provides optimum definition of the conductive properties of the upper 100 m of a surveyed region (Anonymous 2000). The total survey area encompasses approximately 1,475 line km flown along 124 East/West traverse lines and two orthogonal tie lines (Fugro 2000), within a spatial polygon with coordinate longitudes of 79º 30′ W – 79º 45′ W and latitudes 39º 30′N –39º 40′ N.

## Methods of Analysis

Airborne systems are widely used in electrical resistivity mapping, mineral exploration, and other applications (Fraser 1978; Huang and Fraser 1998).

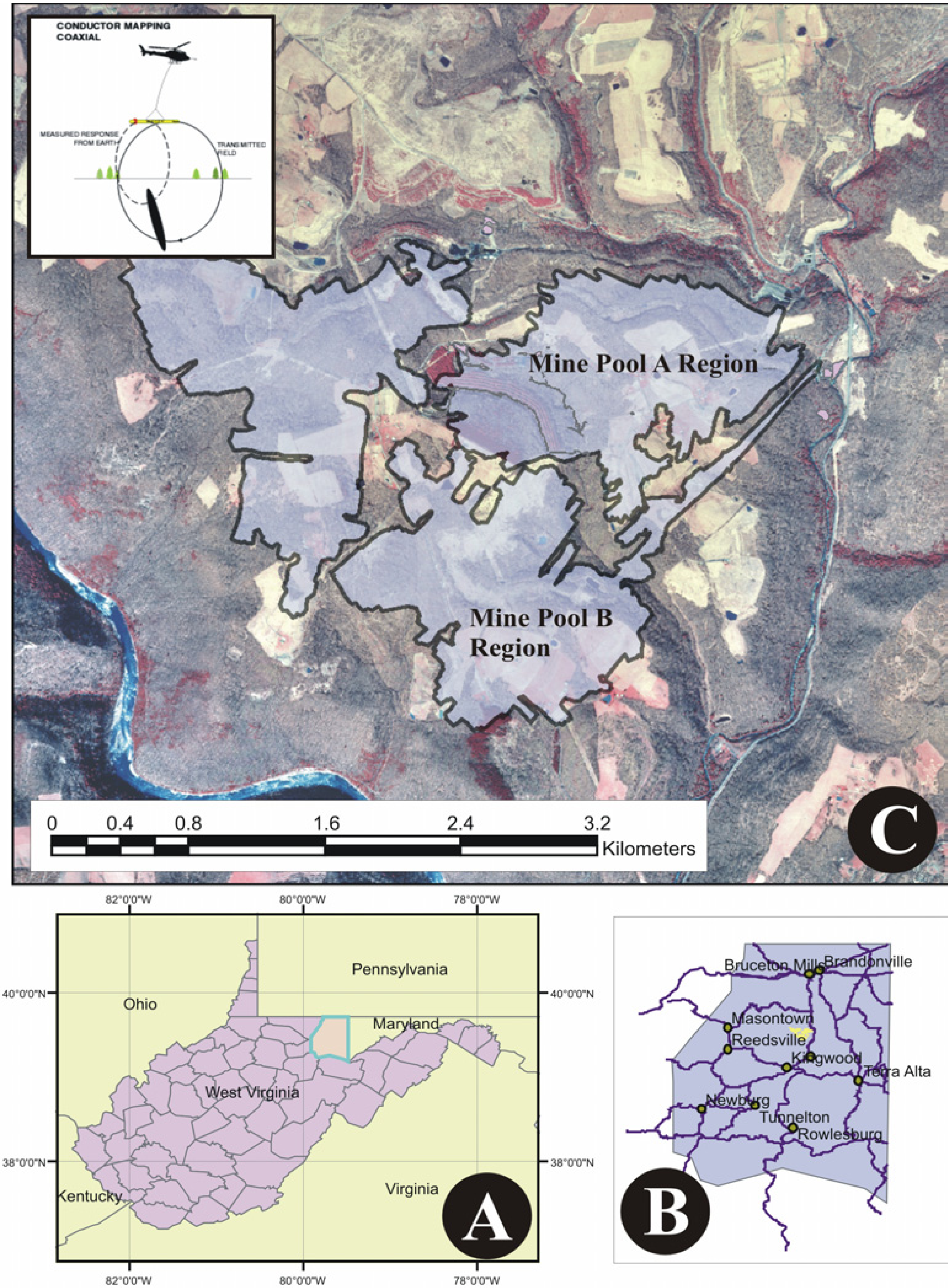


**Figure 1.** (A) The highlighted (yellow) region of study in Preston County, WV; (B) outlines of the T&T Mines shown as a polygon due east of Masontown; (C) mine outlines overlain onto a color digital orthophoto mosaic of the region, with mine pools A and B labeled. A cartoon showing a Fugro helicopter electromagnetic survey, described in the text, is shown in (C)

The Fugro system uses a 9 m long system suspended approximately 30 m below the helicopter. Because of the wide range of frequencies, the depth of exploration was thought to be appropriate for analyzing subsurface AMD associated with the abandoned T&T mines with target depths of 100 m or less. In addition, a survey product, apparent resistivity and apparent conductivity maps, were produced by the vendor. The apparent resistivities and apparent conductivities were calculated for the five coplanar frequencies using a pseudo-layer half-space model.

Unfortunately, electronic noise from power lines, pipelines, and unknown sources was significant in the lower frequency conductivity data, especially the 390 and 1555 Hz data. In general, electrical power lines are the most common source of interference to airborne FDEM surveys in the northeastern United States. Fortunately, most system noise can be removed through filtering (Valleau 2000). A variety of noise reduction techniques were applied to our data. Initially we analyzed the vendor-supplied apparent conductivities using ERMAPPER and ERDAS Imagine. We attempted to remove noise from the FDEM-derived apparent conductivities using standard spatial filtering (Anonymous 1998); noise components were removed from the 390 and 1555 Hz datasets using RASTER-based operations in ERMAPPER (http://www.ermapper.com) and ERDAS Imagine (http://www.erdas.com).

In the first method (Figure 2), ERMAPPER software frequency filtering was used to derive a high-spatial frequency layer that was subtracted from the original data. After subtracting the high spatial frequency noise in this manner, the overall data quality was significantly improved. Using the 390 Hz-derived resistivities, the region of mine pool A appears to be interpretable, although significant noise associated with electrical power lines and natural gas pipelines is still visible in the filtered FDEM-derived datasets.

In the second method (Figure 3), using ERDAS Imagine software and the associated Model Maker in the Spatial Model module, a homomorphic filter was applied to the conductivity data to create a dataset consisting of the isolated, high-amplitude, cultural noise. This isolated noise dataset was then subtracted from the original apparent conductivity dataset to remove the noise artifacts. In Figure 3-A, the original 390 Hz data are shown. In Figure 3-B and C, the homomorphic-extracted cultural noise are shown in map and perspective view (in the perspective view, the vertical exaggeration is set to 0.5). In Figure 3-D and E, the final 390Hz data, after removal of cultural noise, are shown in map and perspective view (in the perspective view, the vertical exaggeration is set to 60). An anomaly is observed in the mine pool A region when the FDEM-derived apparent conductivity is plotted as a 3D surface (Figure 4B).

To further remove noise from these data, we applied Fourier filtering techniques to the in-phase and quadrature-phase flight line data. Using MATLAB, a series of power spectra were calculated for the noisiest data. Generally, noise was observed in all phases and all frequencies; however, noise was especially clear in the in-phase 390 Hz component data. In a report associated with the delivery of the original and FDEM data (Anonymous 2000), this frequency was stated to be uninterpretable because of severe noise. Butterworth notch filters were constructed using the MATLAB filter design and signal processing toolboxes and applied to the in-phase and quadrature-phase data. Comparison of the data before and after filtering (Figure 5) shows

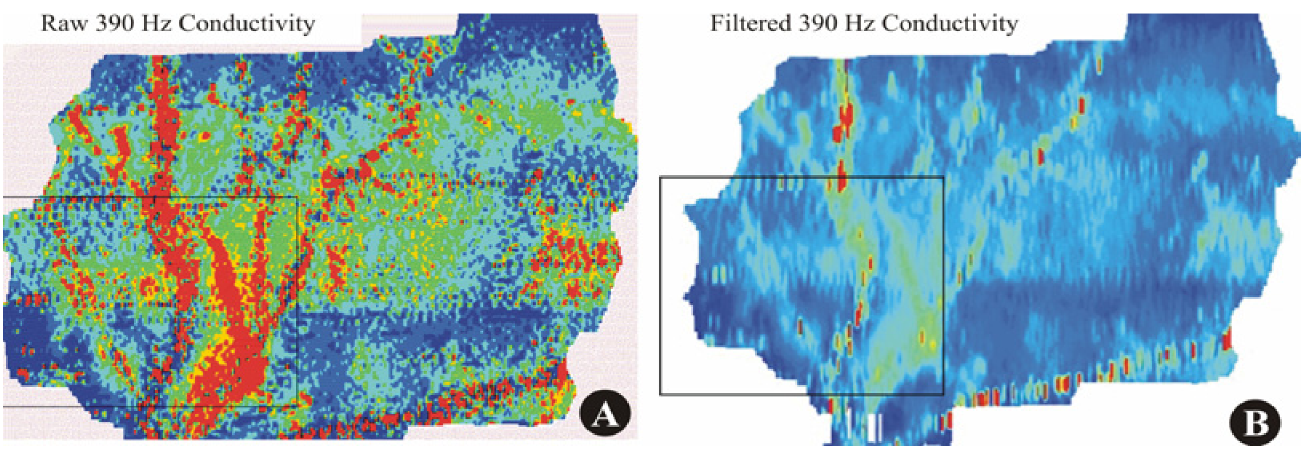


**Figure 2.** False color images of the Fugro Airborne calculated apparent conductivity results at 390 Hz shown before (A) and after spatial filtering (B). The prominent, high amplitude noise, shown in red, corresponds to electrical power lines and natural gas pipelines. Using ERMAPPER to perform a low spatial frequency filtering of the data reduced the amplitude of the cultural noise.

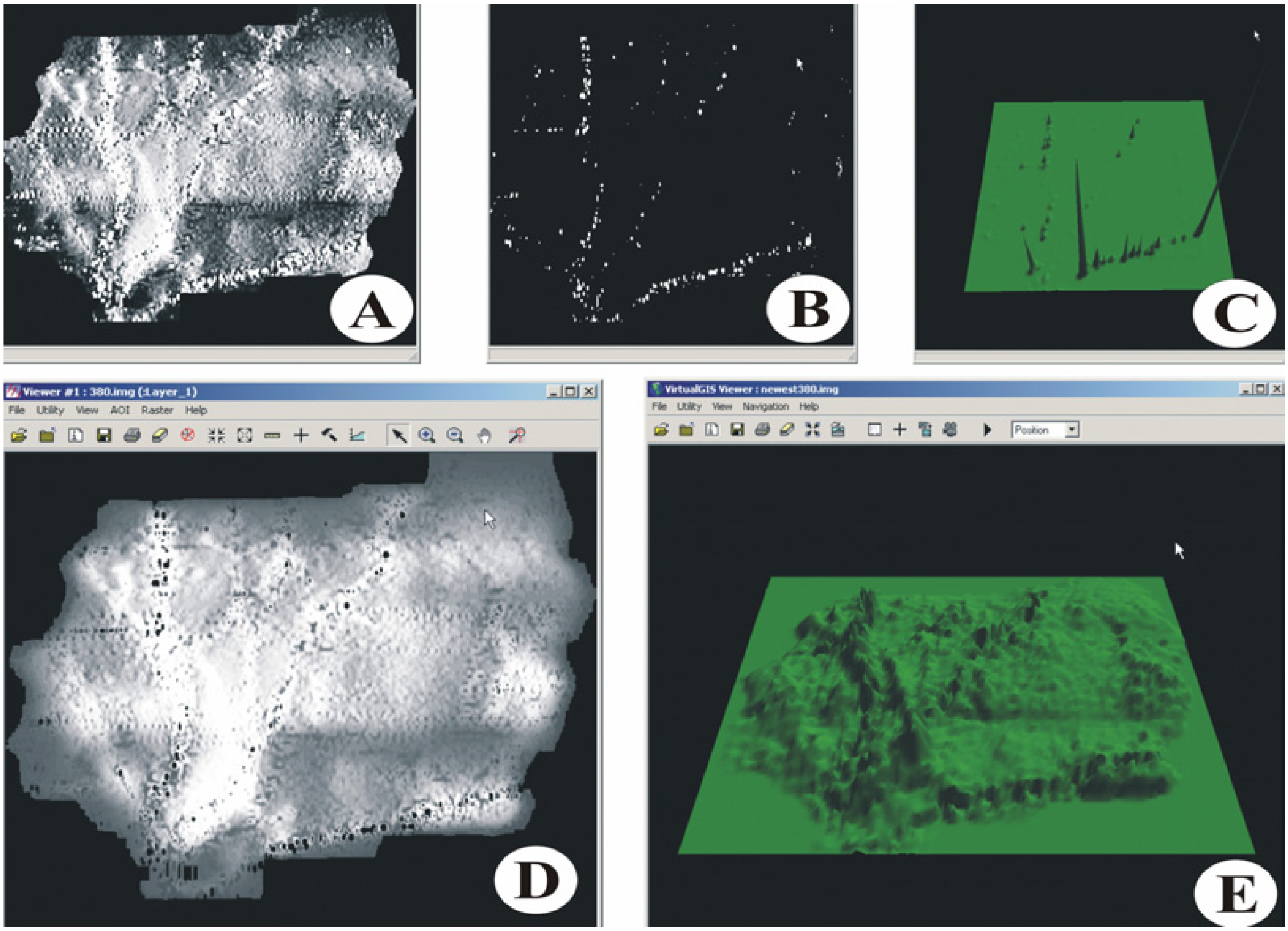


**Figure 3:** An example of homomorphic filtering: (A) the 390 Hz FDEM-derived apparent conductivity data; (B) the data plotted in a grey-scale intensity variation transform that shows the highest amplitude data generally located along electrical power lines; (C) the same data in a perspective view (vertical scaling factor 0.5); (D) the data after applying a homomorphic-based filtering method; (E) the homomorphic-based filtered data shown in perspective (vertical scaling factor 60). Note the removal of the noise spikes prominent in (B) and (C).

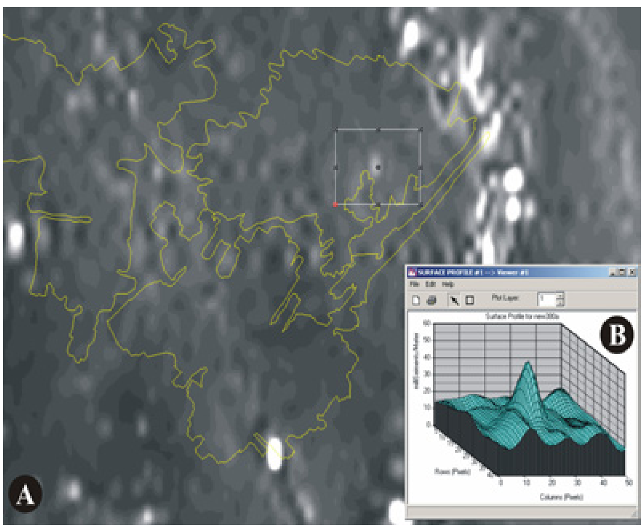


**Figure 4.** (A) The 390 hz filtered FDEM-derived apparent conductivity; (B) the anomaly shown in (A) is clearly visible in this perspective representation; the vertical axis of (B) has units of mS/m.

successful removal of the noise. Isolation of the removed component from the in-phase 390 Hz data shows removal of up to 40 ppm in peak to peak amplitude of noise (Figure 6). These data were then used to calculate apparent resistivities for each frequency using the in-phase and quadrature-phase components and a pseudo-layer half-space model. In addition, apparent resistivity depth sections were calculated using a pseudo-layer half-space model for selected flight lines.

## Geophysical Data Interpretation

Using the FDEM-derived apparent conductivity data, 3-D surface profiles were created for the mine pool A region. Following the homomorphic filtering, an interpretable region was observed in the 390 Hz derived data and an apparent conductivity anomaly was identified (Figure 4). The observed local increase in apparent conductivity is interpreted to be related to subsurface AMD. In the deepest penetrating frequency, this high conductivity anomaly is seen in

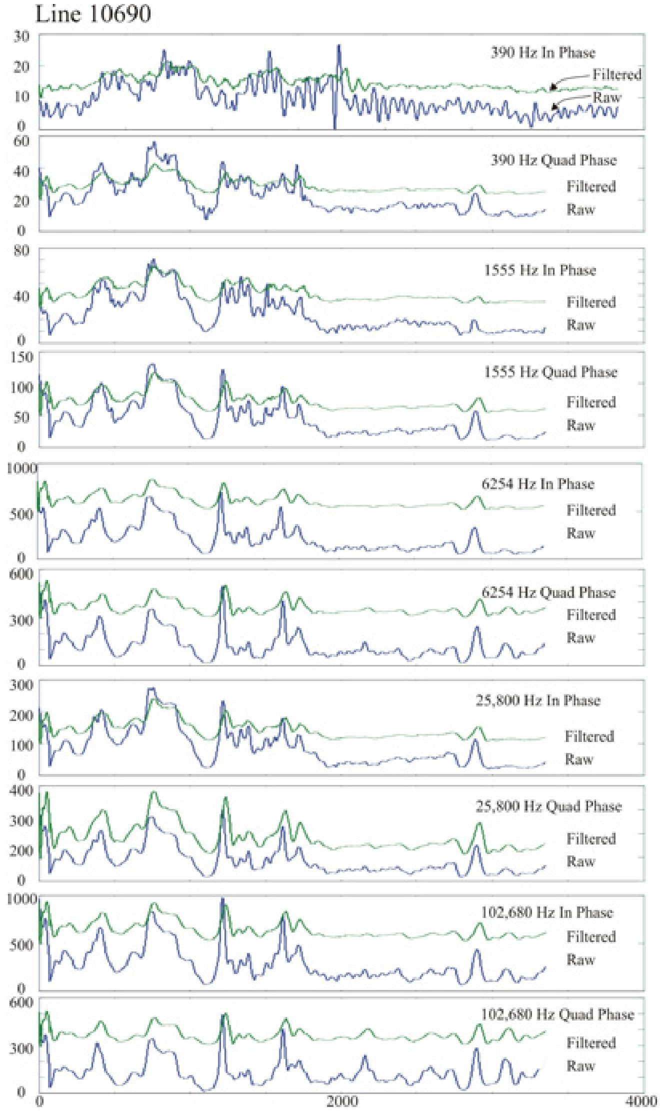


**Figure 5.** PPM records of flight line 10690 showing the 390, 1555, 6254, 25,800 and 102,680 Hz in-phase and quadrature-phase data before and after frequency filtering. The recorded data are shown as a blue line; the filtered data are shown as a green line. For clarity, the filtered data has been offset along the Y axis and positioned slightly above the raw data.

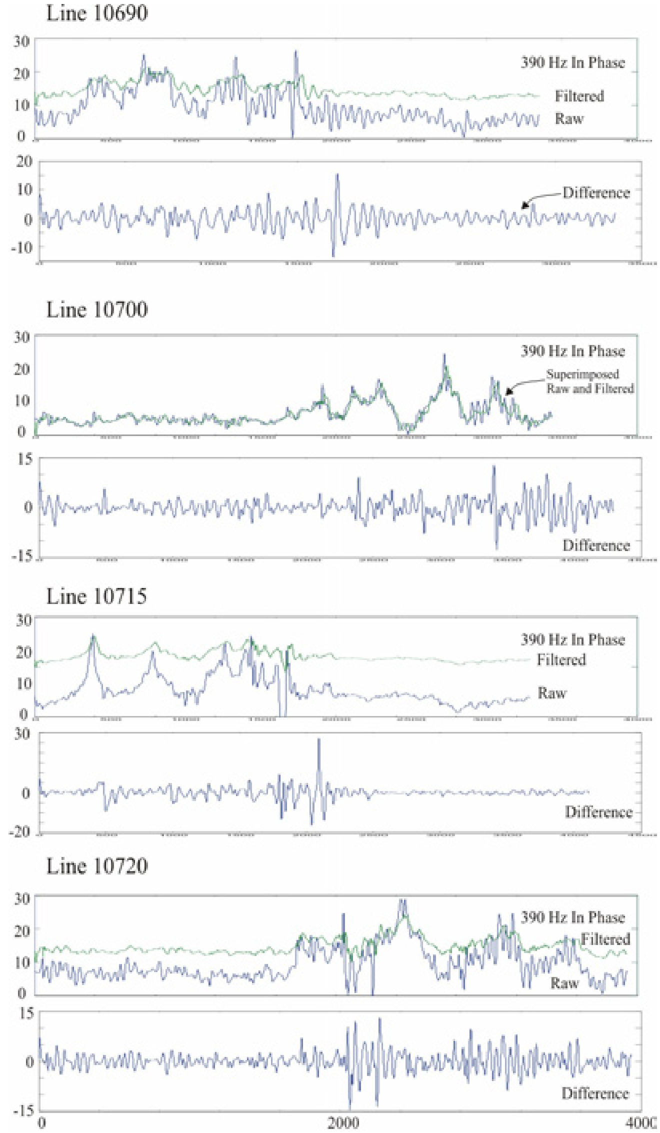


**Figure 6.** PPM records of the in-phase 390 Hz data before and after filtering using the convention of Figure 5, and a separate plot of their difference for four flight lines. For flight lines 10690, 10715, and 10720, the filtered signal is shown offset above the raw data along the Y axis for clarity. For line 10700, the raw and filtered data are shown in the same Y axis coordinate system. The difference between the raw and filtered records was interpreted as noise.

the mine pool A region depth (Al-Fouzan 2002). Fourier filtering of the in-phase and quadrature-phase flight line data successfully removed noise. Apparent resistivities were calculated for the filtered data using a homogeneous half space model and pseudo-layer half space model with the software package EMIGMA 7.5. A comparison of apparent resistivities before and after Fourier filtering shows an improvement in signal and a region of high FDEM-derived apparent conductivities in the mine pool B region. In the filtered pseudo-layer half space model, a region of very low resistivity, which we interpret as related to AMD in mine pool B, can be identified as a potential region for further investigation (Figure 7).

## Conclusions

The goal of this project was to determine the lateral extent of AMD-contaminated mine pools located at a depth of about 80 m at the T&T site. Noise was the significant issue in the lowest frequency conductivity data, especially the 390Hz and 1555 Hz data. Common noise sources such as electrical power lines and pipelines were removed from the FDEM-derived datasets using ER MAPPER and ERDAS Imagine by applying spatial frequency filters. Another approach

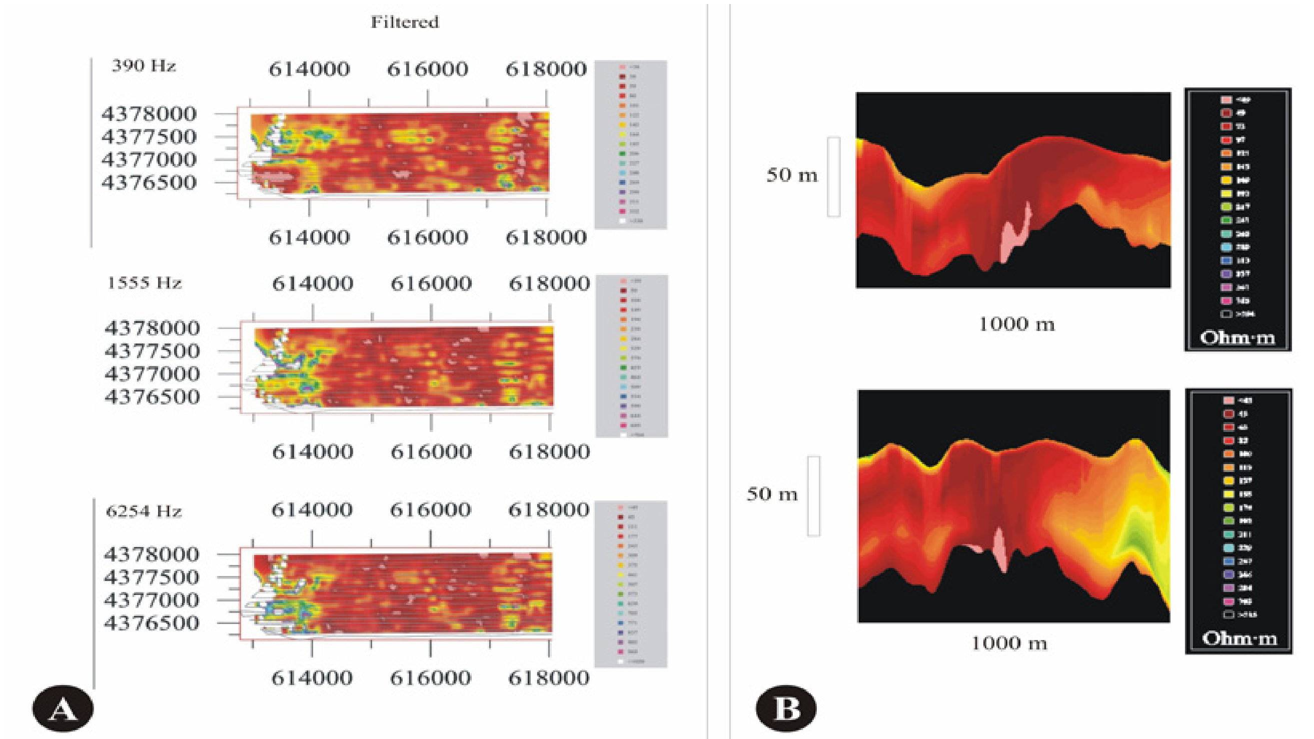


**Figure 7.** (A) A homogeneous half space representation of the FDEM-derived apparent resistivities calculated using the 390, 1555, and 6254 Hz filtered data for the mine pool B region. (B) Two FDEM-derived apparent resistivity profiles calculated using the filtered data. These profiles traverse 1 km between easting coordinates 615000 to 616000 and show the region of mine pool B located at approximately northing 4376600 in (A), using universal transverse Mercator (UTM) zone 17 coordinates.

used in this study was to Fourier filter the in-phase and quadrature-phase data using a notch filter and then, using a pseudo-layer half-space methodology, calculate apparent resistivities. Mine pools A and B represent regions of potential further study.

## References


Al-Fouzan F (2002) Environmental Geophysical Analysis of a Portion of the Muddy and Roaring Creek Watersheds, West Virginia, PhD thesis, Univ of Pittsburgh, 128 pp

Anonymous (1998) ER MAPPER User Guide 6.0, Earth Resource Mapping Pty Ltd, 922 pp

Anonymous (2000) Final Report for United States Dept of Energy, Fugro Geoterrex Dighem, Inc

Fraser DC (1978) Resistivity mapping with an airborne multi-coil electromagnetic system. Geophysics 43: 144-172

Hennin RV, Reger DB (1914) Preston County: WV Geol and Economic Survey County Report. 566 pp

Hobba WA (1991) Relation of fracture systems to transmissivity of coal and overburden aquifers in Preston County, West Virginia, USGS WRI Report 89-4137

Huang H, Fraser DC (1998) Magnetic permeability and electric resistivity mapping with a multi-frequency airborne EM system. Expl Geophysics 29: 249-253

Kleinmann RLP (1989) Acid mine drainage: U.S. Bureau of Mines researches and develops control methods for both coal and metal mines. Eng Min J 190: 16I-16N

Meehan GM (1980) Geologic factors affecting the mining of the upper Freeport coal seam in west central Preston County, West Virginia. MS Thesis, Univ of Pittsburgh

Ramani RV, Harbert W, Kirby FR, Kohler JL, Kravits S, Roberts JS, Smith DL, Szalankiewicz JJ (2002) Abandoned Mine Voids and Mine Safety, www.dep.state.pa.us/hosting/minesafetycommision

Valleau NC (2000) HEM Data Processing – A Practical Overview. Proc, 14th ASEG Conf and Exhibition, Perth, Australia


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