NON-INVASIVE GEOPHYSICAL METHODS APPLIED TO SANITARY LANDFILLS: SOLID WASTE MANAGEMENT UNIT 059, FORT LEONARD WOOD, MISSOURI

Niklas H. Putnam*, Neil L. Anderson*, Steven J. Cardimona* and Jon Shawver*

*Department of Geology and Geophysics, University of Missouri-Rolla, Rolla, MO, 65401
nisiputnam@jobe.net; nanders@umr.edu; cardi@umr.edu; jshawver@umr.edu

Abstract

Magnetic data, multi-frequency EM induction data and monostatic ground penetrating radar (GPR) data were acquired at a shallow, abandoned landfill site (ALS site; northern section of Solid Waste Management Unit 059) as part of the environmental assessment phase of a proposed road construction project at Fort Leonard Wood Military Reservation (FLW), Missouri. The original landfill consisted of a series of shallow, north-south trending, near-parallel trenches that were in-filled with trash and covered with excavated soil. The ground surface across these original trenches has subsided as a result of the compaction of in-filled trash and soil, and the study site is now characterised by subtle geomorphological features (suite of parallel trenches and intervening raised ridges or crests).

The non-invasive geophysical data sets proved to be useful in terms of establishing and mapping the boundaries of the abandoned landfill, and estimating the locations and depths/breadths of individual waste disposal trenches. More specifically, the contoured 4470 MHz electomagnetic quadrature phase data were characterised by a pattern of near-linear, north-south trending anomalies (consistent with the deposition of ferromagnetic trash in a suite of parallel trenches). The same trenches were characterised by anomalous values on the contoured magnetic data and corresponding profiles, and by pronounced diffractions on the unfiltered, 400 MHz, GPR profiles. The interpretation of the magnetic and GPR data indicates maximum trench depths on the order of 3m.

Introduction

The Fort Leonard Wood Military Reservation abandoned landfill study site (ALS) study area is situated in the northern part of Solid Waste Management Unit FLW-059, south of interstate I-44, and approximately 190km from St. Louis (Figure 1). Geologically, the study area is within the Ozark Uplift. Dolomitic bedrock (early Ordovician-age Roubidoux and Gasconade Dolomite formations) is overlain by a thin veneer of alluvium, consisting of a gravely sub-stratum and a sand-silt top-stratum (Figure 2). The gravel is predominantly derived from weathering of cherty dolomites and reworking of the colluvium. The sands are derived from sandy dolomites and sandstones, and reworked colluvium and former alluvium. The silt is derived from loess-capped uplands.

A preliminary USGS site assessment of Solid Waste Management Unit FLW-059 (Water-Resources Investigation Report 00-4178; Schumacher and Imes, 2000), indicates the land surface at the 18,000m^2 ALS site is characterised by near-parallel, north-south trending surficial features (trench and crest geomorphology, with crest-to-crest spacing averaging about 7m). Schumacher and Imes (Report 00-4178) suggest these subsidence features are waste disposal trenches. (The presence of trash in at least some of these trenches has subsequently been confirmed through detailed visual inspection of the site.)

During the 2001 Spring field season, the geophysics crew at the University of Missouri-Rolla acquired a suite of non-invasive magnetic, electromagnetic and GPR data at the ALS site with the goal of determining the boundaries of trash deposition within the ALS site. A north-south geophysical base line (Figure 1) was established along the fence running parallel to FLW Road 8 (and adjacent underground power cable). Geophysical survey lines were oriented east-west (parallel to trenches) to ensure maximum contrast along the individual geophysical profiles. The east-west GPR profiles were spaced at 15m intervals. The magnetic and electromagnetic profiles were spaced at 5m intervals. The lengths of the survey lines were primarily dependent on fence geometry and ranged from 140 m to 120 m. Station locations were mapped via the global positioning system using the Trimble TSC1 Asset Surveyor Model PRO XR System and are accurate to within $\pm$ 1m.

The UMR studies were conducted as part of the broader environmental assessment phase of a proposed “West Gate” road construction project currently being conducted by FLW and the Missouri Department of Transportation (MoDOT).

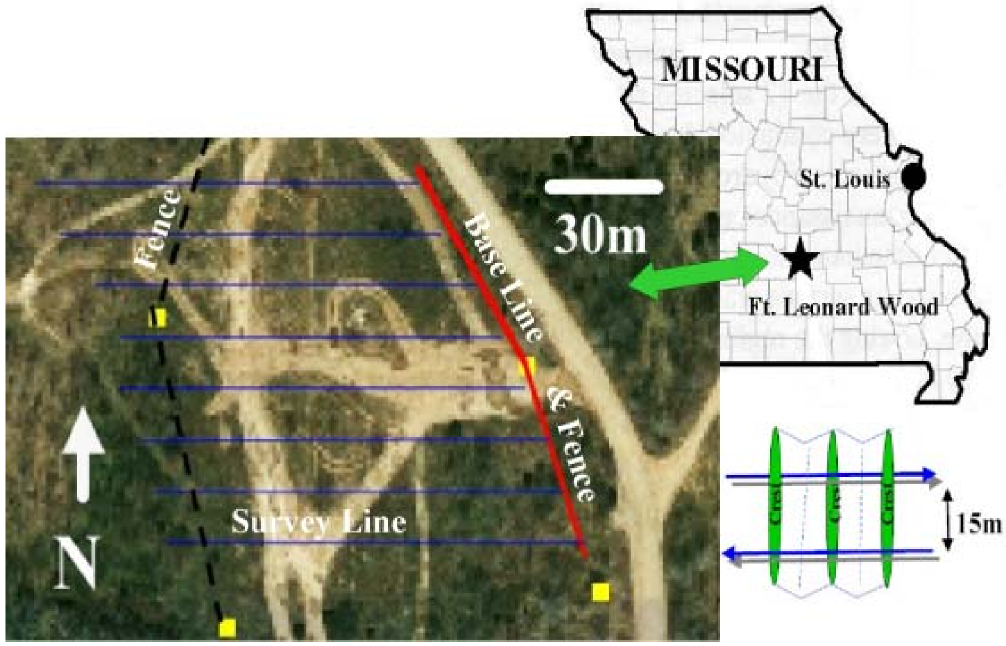

Figure 1: Satellite image of ALS site location. The ALS study area is bounded by gravel road FLW 8 to the east, and by the Roubidoux Creek to the north and west. The mostly N-S trending geophysical base line is located immediately adjacent to the fence (shown in red).

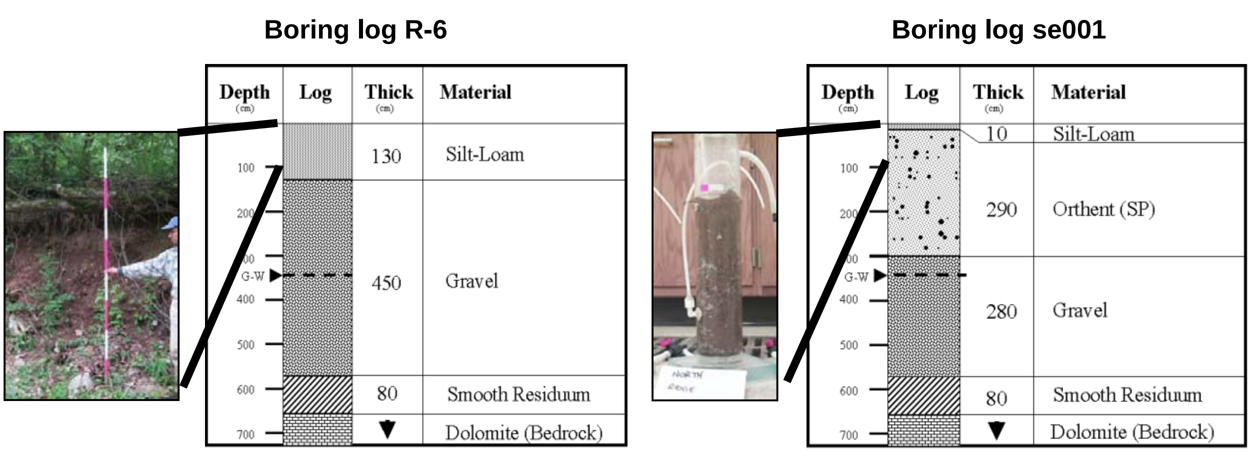

Figure 2: Boreholes logs from the lower Roubidoux Creek Valley (about 1.5 km northwest of the ALS study area). Boring log R-6 represents the typical shallow natural stratigraphy of the immediate study area. The descriptive boring log se001 was acquired at Solid Waste Management Unit FLW-059 in 1997 by the USGS (after Albertson, 1995).

Magnetic Survey

The primary goal of the magnetic survey conducted at the ALS site was to delineate the areal extent of the abandoned landfill on the basis of the interpretation of contoured total magnetic field data. A secondary goal was to determine if the individual waste disposal trenches were characterised by identifiable total magnetic field signatures. The expectation was that the trenches would contain ferromagnetic waste material - whereas the undisturbed soils would not. It was anticipated the excavated, trash-filled trenches at ALS site would be characterised by relatively high-amplitude, low-wavelength total magnetic field anomalies.

The total magnetic field data were acquired at 2m station intervals along a suite of east-west survey lines spaced at 5m intervals. The magnetic survey was conducted using a cesium vapour G858 magnetometer in continuous mode. Information provided by the Sunspot Index Data Center indicated geomagnetic activity was relatively low during the field acquisition period. The acquired magnetic data were processed using Geosoft software.

Contoured total magnetic field strength data are plotted in Figure 3. Example east-west profile #6 (extracted from the data set of Figure 3) is shown as Figure 4. The visual inspection of profile #6 (Figure 4) shows that the north-south trending trenches are characterised by relatively high-amplitude total magnetic field anomalies (relative to the adjacent crest features). More specifically, the number of interpreted “magnetic anomalies” on Figure 4 matches the number of trenches observed (during visual geomorphologic field inspection of ALS site and surrounding area) along the length of the magnetic profile. Additionally, the locations of the magnetic anomalies correlate almost exactly with trench locations. The conclusion, based on the analyses of all acquired magnetic profiles and trench location information, is that the waste disposal trenches are characterised by anomalous total magnetic field signatures. Euler deconvolution indicates the relatively low-wavelength magnetic anomalies originate at depths less than 3m. This is probably an indication of maximum trench depths.

A visual inspection of Figure 3 indicates the north-south trending trenches are not characterised by a visually pronounced pattern of north-south trending magnetic anomalies. This is probably because the concentration of ferromagnetic material varies significantly within the trenches, and because the asymmetric magnetic signatures of closely spaced ferromagnetic bodies are superposed and interfere. However, as evidenced by the contoured data, the gross magnetic signature of the landfill (based on mapped trench locations) differs appreciably from that of undisturbed areas (not shown), indicating total magnetic field data can be used to delineate the areal extent of the landfill.

Electromagnetic Survey

The primary goal of the electromagnetic (EM) survey conducted at the ALS site was to delineate the areal extent of the abandoned landfill on the basis of the interpretation of contoured EM data. A secondary goal was to determine if the waste disposal trenches were characterised by anomalous EM signatures. The expectation was that the EM signature of the excavated, trash-filled trenches at ALS site differ from that of the surrounding undisturbed soil because of the presence of conductive waste material and because the conductivity of the soil is altered by the processes of excavation and in-fill. It was anticipated the excavated, trash-filled trenches at ALS site would be characterised by relatively high-amplitude, low-wavelength EM anomalies.

The electromagnetic data at ALS site were acquired using a GEM-300 in a vertical magnetic dipole mode. In-phase and out-of-phase data were acquired at three different frequencies (2010, 4470, and 10050 MHz) and expressed as total intensity values in part-per-million. The profiles were spaced at 5m intervals. Station spacing along each line was 1m.

Contoured 4470 MHz quadrature (out-of-phase) EM data are plotted in Figure 5. As interpreted, the anomaly pattern correlates closely with the superposed visually determined locations of the near-parallel north-south trending disposal trenches. This correlation indicates the EM signature of the landfill (based on mapped trench locations) differs appreciably from that of undisturbed areas (not shown), indicating contoured EM data can be used to delineate the areal extent of the landfill. The GEM-300 data also correlate well with the total magnetic field data (Figure 3).

Example east-west EM profile #6 (extracted from the data set in Figure 5) is shown as Figure 6. The visual inspection of profile #6 (Figure 6) shows that the north-south trending trenches are characterised by high-amplitude EM anomalies (relative to the adjacent crest features). More specifically, the number of interpreted “EM anomalies” on Figure 6 matches the number of trenches observed along the length of the profile. Additionally, the locations of the electromagnetic anomalies correlate almost exactly with trench locations. The conclusion, based on the analyses of all acquired profiles, is that the waste disposal trenches are characterised by anomalous EM signatures.

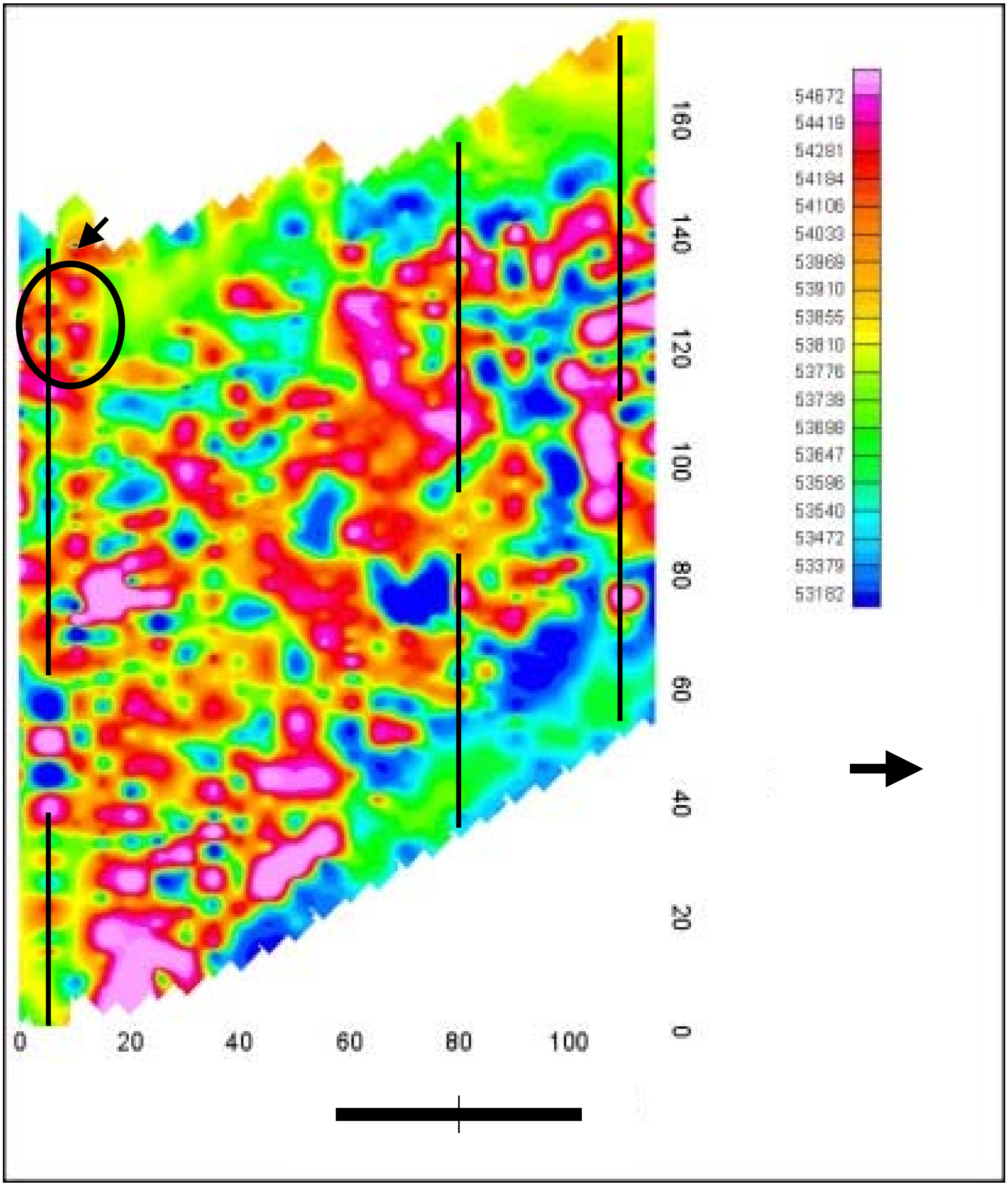

Figure 3: Contoured total magnetic field strength map.

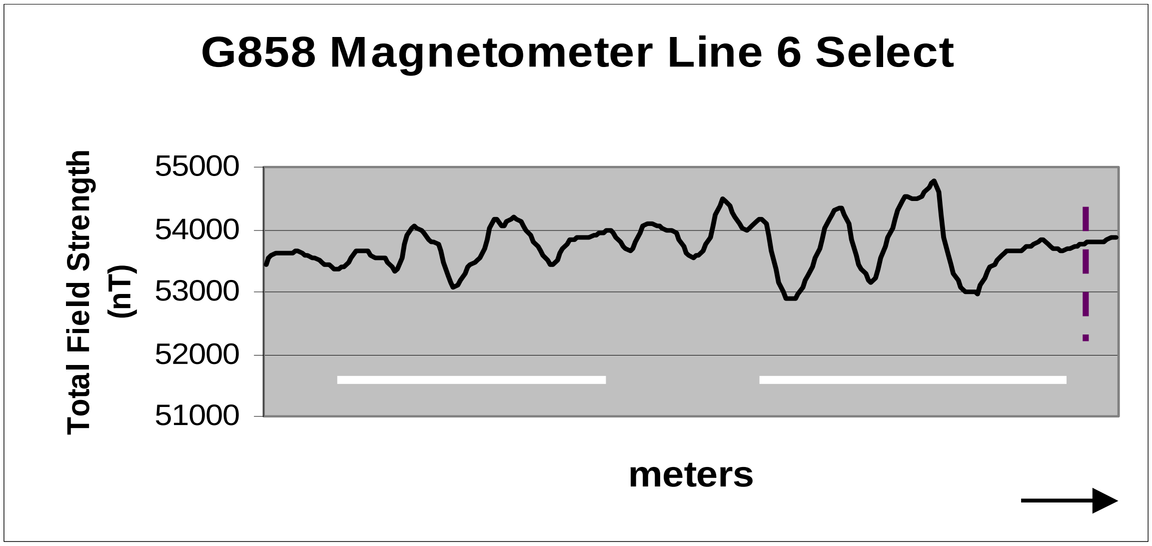

Figure 4: Magnetic profile of east-west survey Line #6 (extracted from data set displayed as Figure 3). Trench locations (denotated by cross-hatched marks) are characterised by high-amplitude total magnetic field anomalies.

Ground Penetrating Radar Profiling

The primary goal of the ground penetrating radar survey conducted at the ALS site was to determine if the waste disposal trenches were characterised by anomalous GPR signatures. The expectation was that the GPR signature of the excavated, trash-filled trenches would differ from that of the surrounding undisturbed soil because the sediment within the trenches had been disturbed and because isolated metallic materials within the trenches would generate high-amplitude diffractions on the GPR profiles.

The GPR data were acquired using a Geophysical Survey System (GSSI) SIR-10B unit equipped with a 400 MHz monostatic antenna. A sampling rate of 50 scans/second and a range (trace length) between 125 and 350 nanoseconds were employed. A profile spacing of 15m was employed. The acquired GPR data were not migrated during processing, because the migration process would (ideally) "collapse" the diffractions that are so diagnostic of trench locations.

Interpreted, unfiltered GPR profile #6 is shown in Figure 7. The GPR image of undisturbed strata is characterised by a pattern of laterally continuous reflections (originating from depositional facies contacts) and essentially devoid of diffractions. The excavated and in-filled trenches, in contrast, are characterised by less continuous events (representing disturbed soil) and superposed diffractions. The abrupt contact at the base of the trench is also identified on the GPR profile.

The morphology of a landfill trench may be inferred on the basis of the GPR image. More specifically, the trenches appear as convex subsurface features with tapered edges. As noted, the depths and breadths of the trenches can be estimated from the analysis of the acquired GPR data. (Estimated maximum trench depths are on the order of 3m.)

Integrated Analysis: Correlation of Geophysical Data Acquired along Profile #6 and Trench #8

Figures 8 and 9 were constructed to demonstrate the degree to which the magnetic, EM, GPR and trench-location data correlate. As demonstrated by the graphical data depicted in Figures 8 and 9, the in-filled trenches are characterised by magnetic and EM anomalies, and can be mapped using the GPR profiling technique. Perhaps most importantly, the acquired geophysical data sets establish that (at the ALS site), complementary geophysical data can be used to define the areal extent of a landfill and the disposal practices employed (i.e., width of trenches, depth of trenches, and locations and orientations of trenches).

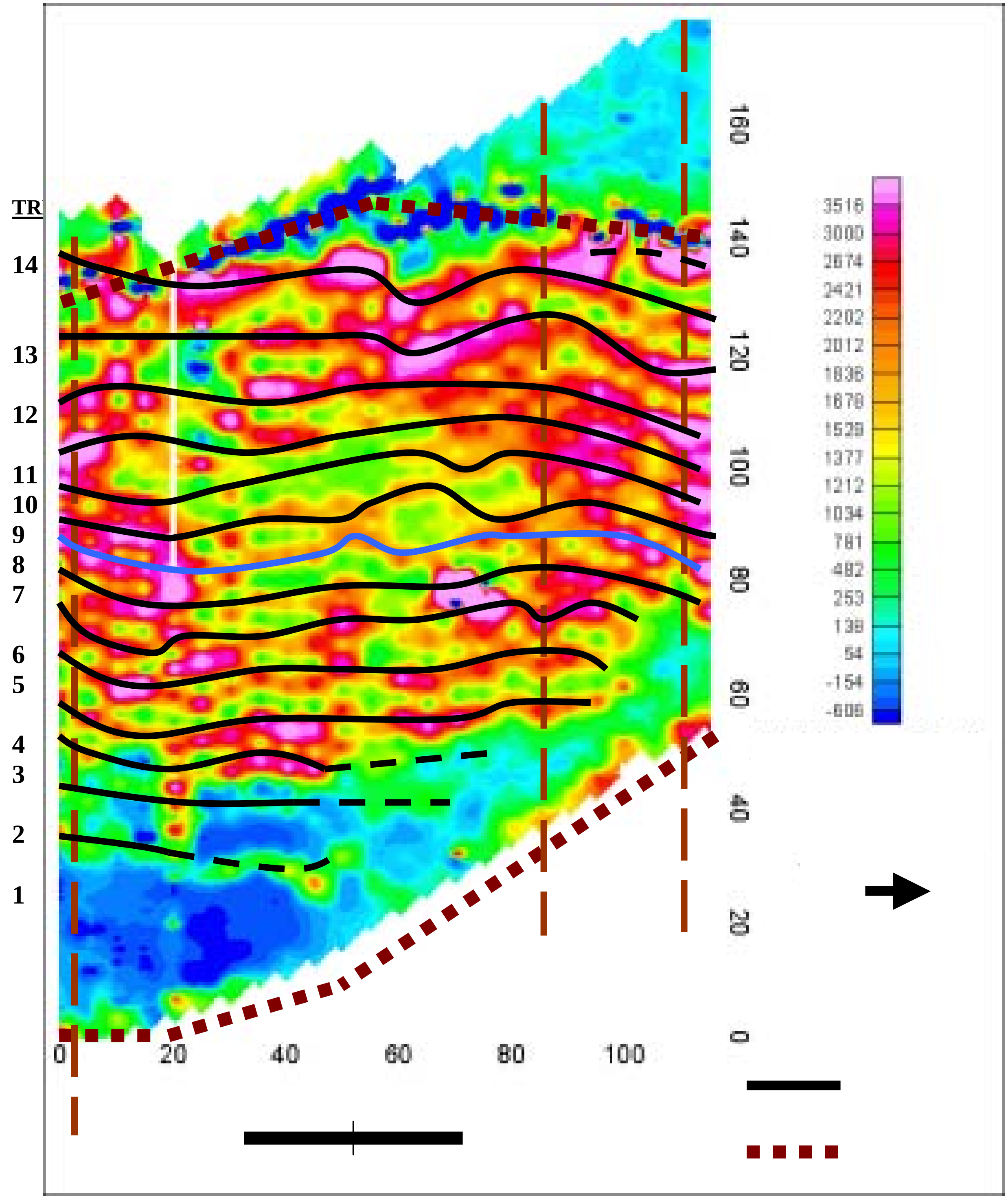

Figure 5: Contour map showing GEM-300 4470 MHz Quadrature Phase (PPM). The waste-disposal trenches are characterised by anomalous conductivity. The superposed locations of the trenches (as determined through site reconnaissance) correlate well with the north-south trending EM anomalies indicating the trenches are characterised by high conductivity as a result of the presence of ferromagnetic material.

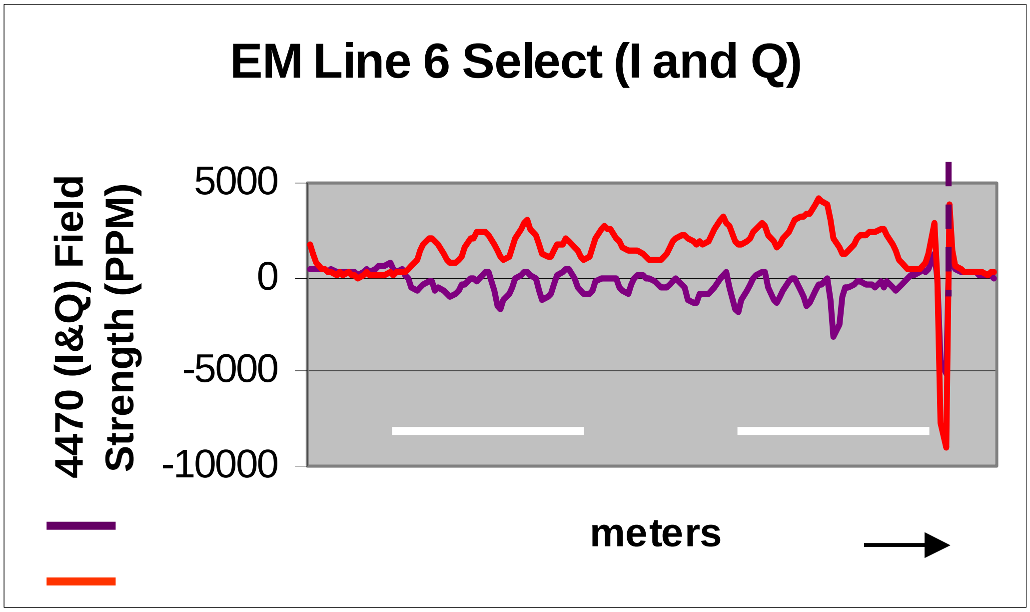

Figure 6: Graph of Quadrature (out-of-phase) and Real (in-phase) EM data acquired along east-west line #6. Trench locations are superposed. Interpreted data indicate the waste-filled trenches are characterised by prominent EM anomalies.

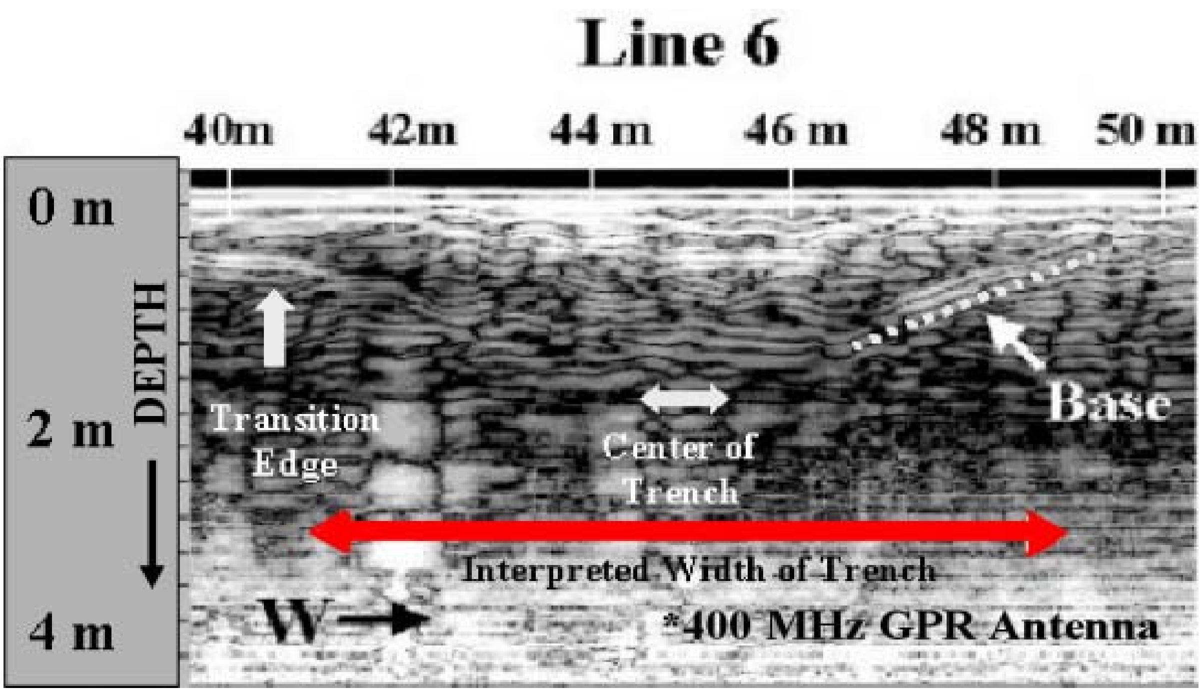

Figure 7: Section of interpreted GPR line #6. This section of GPR profile #6 crosses a known waste disposal trench. The GPR image of undisturbed strata is characterised by a pattern of laterally continuous reflections (originating from depositional facies contacts) and essentially devoid of diffractions. The excavated and in-filled trench, in contrast, is characterised by less continuous events (representing disturbed soil) and superposed diffractions. The abrupt contact at the base of the trench is also identified on the GPR profile.

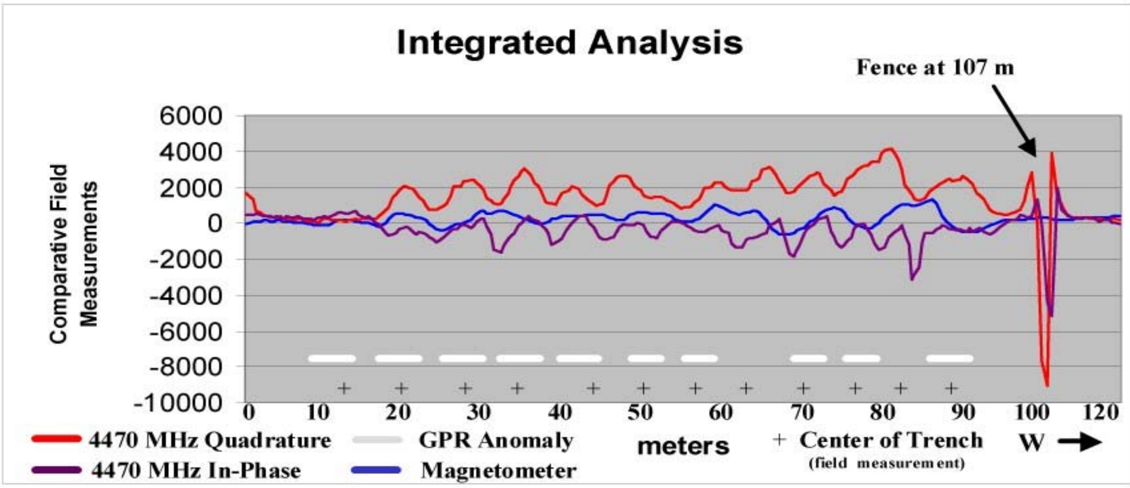

Figure 8: Correlation of geophysical methods along Line 6.

	Line 1	Line 6	Line 8	Background
Width (m)	6.5	7.1	7.6	
Width Average (m)	9.14	7.36	7.22	*along line*
Depth (cm)	400	200	100	
Depth Average (cm)	480	170	110	*along line*
In-Phase (PPM)	- 735	101	- 84	- 84
Quadrature (PPM)	3,258	2,107	3,258	1,377
Field Strength (nT)	54,450	54,100	54,900	53,810
GPR (Trench)	YES	YES	YES	

Figure 9: Analysis of geophysical data along Trench 8.

Summary

The effectiveness of complementary magnetic, electromagnetic, and ground penetrating radar methods as tools for mapping the areal extent of the shallow landfill at ALS study site and estimating the depth/breadth of individual disposal trenches has been demonstrated through this study. The data from these methods also support the supposition that the linear features in the study were a continuous northward extension of the adjacent established landfill known as FLW-059.

The non-invasive geophysical data sets proved to be useful in terms of establishing and mapping the boundaries of the abandoned landfill, and estimating the location and depth/breadth of individual waste disposal trenches. More specifically, the contoured 4470 MHz quadrature-phase electromagnetic data were characterised by a pattern of linear anomalies (consistent with the deposition of ferromagnetic trash in a suite of parallel trenches). The same trenches were characterised by total magnetic field anomalies on the contoured magnetic data and by pronounced diffractions on the unfiltered, 400 MHz, GPR profiles. Although the areal extent of landfill and the locations of the encompassed waste-disposal trenches could have been determined on the basis of single method studies alone, the integrated analyses provided a greater level of confidence.

References

Albertson, P.E., 1995, Geomorphic Evaluation of Fort Leonard Wood: United States Army Corps of Engineers, Waterway Experiment Station, Technical Report GL-95-19, 18-73.

Schumacher, J.G. and Imes, J.L., 2000, Geohydrological and Water Quality at Shanghai Spring and Solid-Waste Management Units at the Fort Leonard Wood Military Reservation, Missouri, 1995-98: United States Geological Survey, Water-Resources Investigation Report 00-4178, Missouri, 48-53.