GPR JET FUEL SPILL INVESTIGATION

Mario Carnevale and Jutta Hager
Hager GeoScience, Inc.
174 Lexington Street
Waltham, MA 02452

ABSTRACT

Hager GeoScience, Inc. used ground penetrating radar as part of an integrated study to investigate a jet fuel spill at Logan International Airport in Boston, Massachusetts. The survey was performed at night on airport taxiways and runways. The primary objective was to characterize soil stratigraphy and delineate trenches for utility conduits, areas of excavation, and the boundary between granular fill and the underlying native material that could act as migration pathways for contaminants. Also considered was the response of GPR signals to varying levels of sediment contamination.

In addition to GPR, several types of data were integrated to characterize the subsurface conditions, including borehole and probe data regarding soil stratigraphy, water table elevations, and measured VOC concentrations. Cross sections were constructed and used to integrate all available data and characterize the effect of confined and unconfined groundwater regimes on contaminant migration.

The cross sections and maps showing a series of horizontal slices of the subsurface were used to decipher the spatial distribution of jet fuel at various depth intervals. The study showed that an integrated geological and geophysical subsurface evaluation program is an effective tool in deciphering contamination at complex sites.

BACKGROUND

In June and December of 1997, Hager GeoScience, Inc. (HGI) performed a ground penetrating radar (GPR) survey at Logan International Airport in Boston, Massachusetts (Figure 1). The survey was in support of a larger investigation of a spill from jet fuel lines beneath the tarmac. The survey covered an L-shaped section of airport taxiway and runway north and west of the jet fuel lines, 700 feet long and 200 feet at its widest. The survey area is shown in Figure 2.

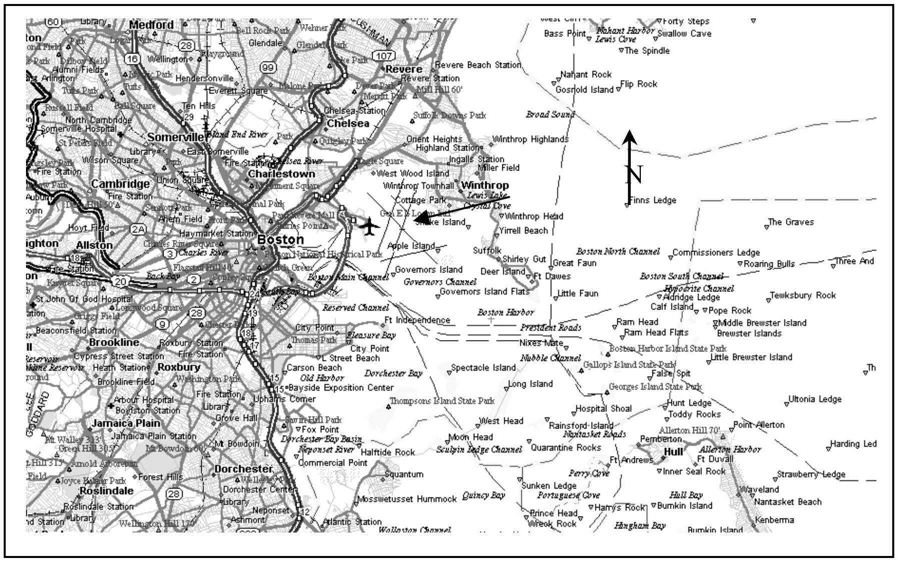

Figure 1. Location of the survey: Logan International Airport, Boston, Massachusetts.

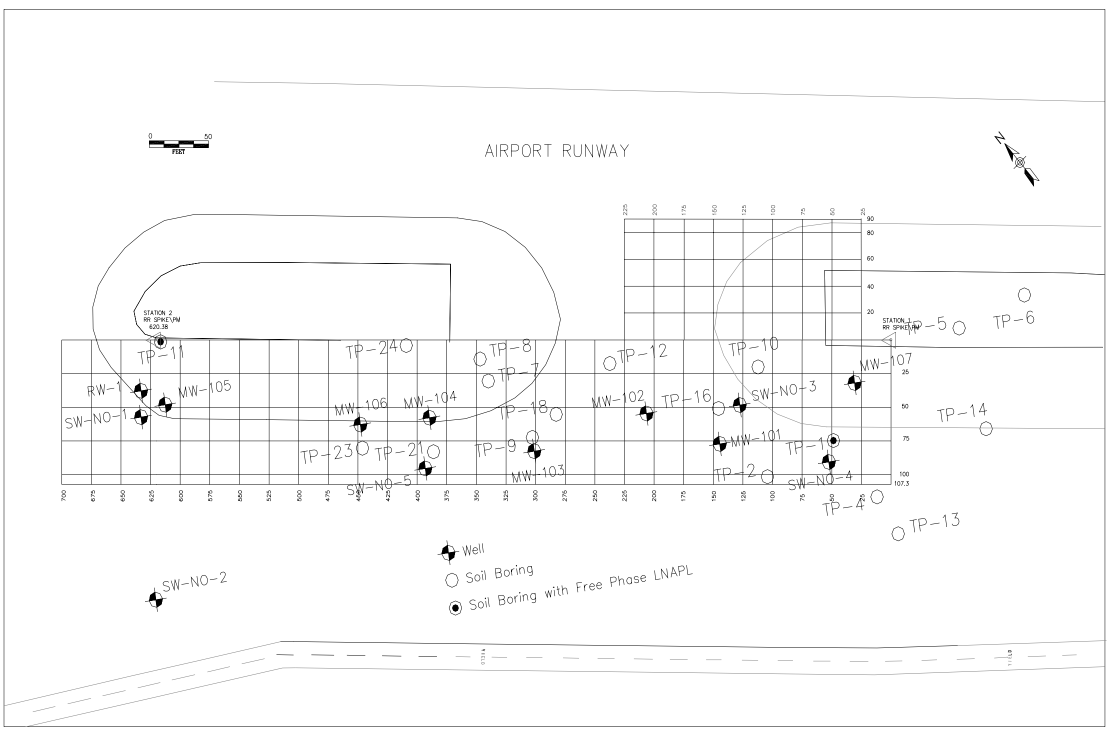

Figure 2. GPR survey area at Logan Airport showing locations of traverses and borings.

Investigations up to this point included approximately 26 wells with water sampling and PID measurements. The data did not provide a clear pattern of groundwater flow or jet fuel migration. Concentrations of VOCs with depth varied from well to well, and wells with free product were separated by wells with no detectable hydrocarbon levels. Because of this variability, it was suspected that contaminant migration was controlled, at least in part, by utilities with associated trenches and backfill materials and variations in soil strata across the study area. Therefore, it was felt necessary to design an integrated subsurface geological and geophysical study.

The primary objective of the survey was to delineate trenches for utility conduits, areas of excavation, and the boundary between granular fill and the underlying native clay and silt. Existing utility maps were incomplete, and the locations of older existing utilities were not known. A secondary objective was to investigate the possibility of detecting the jet fuel spill directly via interpretation of GPR records. The presence of free product in two wells suggested that the high concentration of jet fuel in surrounding sediments, along with unique electromagnetic properties of a highly refined product such as jet fuel, could provide an opportunity to detect the contaminant by GPR.

The study required integrating several types of data to characterize the subsurface conditions. These included borehole and probe data on soil stratigraphy, water table, and VOC concentrations. The geologic setting of Logan Airport is quite variable from one end to the other. Some sections of the airport are constructed from reclaimed harbor (fill, including dredged material), others over glacial moraine sediments, and still others are excavated from a drumlin composed of highly compacted glacial till. Previously inhabited portions of the Airport contain foundations and buried utilities emplaced almost 100 years ago. From a cursory examination of Boston Harbor geology and borehole data, we concluded that our study area consists of fine-grained glacio-marine sediments overlain by interbedded sand, coarse gravel, silt, and clay. All these horizons have been disrupted to some degree by excavation during construction related to utility emplacement.

GPR SURVEY PROCEDURE AND APPROACH

The GPR survey was performed using a Geophysical Survey Systems, Inc., (GSSI) SIR System 2 digital ground penetrating radar system with 400 MHz antenna. A survey wheel attachment was used to enhance survey accuracy. The operator carried the electronics in a harness and pulled the antenna behind him at the end of a 3-meter attenuated control cable. GPR data were displayed on a color monitor and simultaneously recorded on a hard drive.

The survey was conducted between 11 p.m. and 5 a.m. while the runway and taxiways were closed to air traffic. Data were collected in two perpendicular directions along traverses spaced 25 feet or less apart. The client provided an AutoCAD base plan of the survey area on which to plot the locations of utilities and other target features. Where possible, utility locations were marked in the field at the time of the survey.

The GPR propagation velocity through the soils at the site was obtained by calibration over existing wells and the jet fuel lines. The GPR propagation velocity was used to determine depth below ground surface of reflectors along the GPR traverses. Based on the depth conversion, the range setting of 100 nanoseconds (ns) was chosen to provide a signal penetration of approximately 14 feet below ground surface.

Following the field data collection, the GPR data were downloaded to a PC and processed using GSSI's RADAN for Windows® post-processing software.

With good subsurface control, we hoped to relate the soil and groundwater parameters to the GPR records and to observe the effects of VOCs on GPR signal characteristics. HGI prepared groundwater contour maps, permeable zone isopach maps, impermeable zone structure maps, isograd maps of VOC concentrations expressed as averages per foot of depth, and stratigraphic cross sections. Continuous records obtained from GPR traverses were reviewed to identify and plot utilities, trenches, and other anomalous subsurface features. Selective records were reviewed in the context of the interpretive maps for the express purpose of observing the effect of jet fuel on GPR reflections.

GPR RESULTS

Figure 3 shows the locations of utilities, deep excavations, and interpreted areas of low GPR signal reflections in the survey area. Initially, zones of low GPR signal reflections appeared to be zones of elevated contaminant concentrations. However, further analysis indicated that these signal characteristics are probably caused by homogeneous soils, possibly fine sand or silt and bedded clays. These zones of low signal return may provide preferential pathways for contaminant migration.

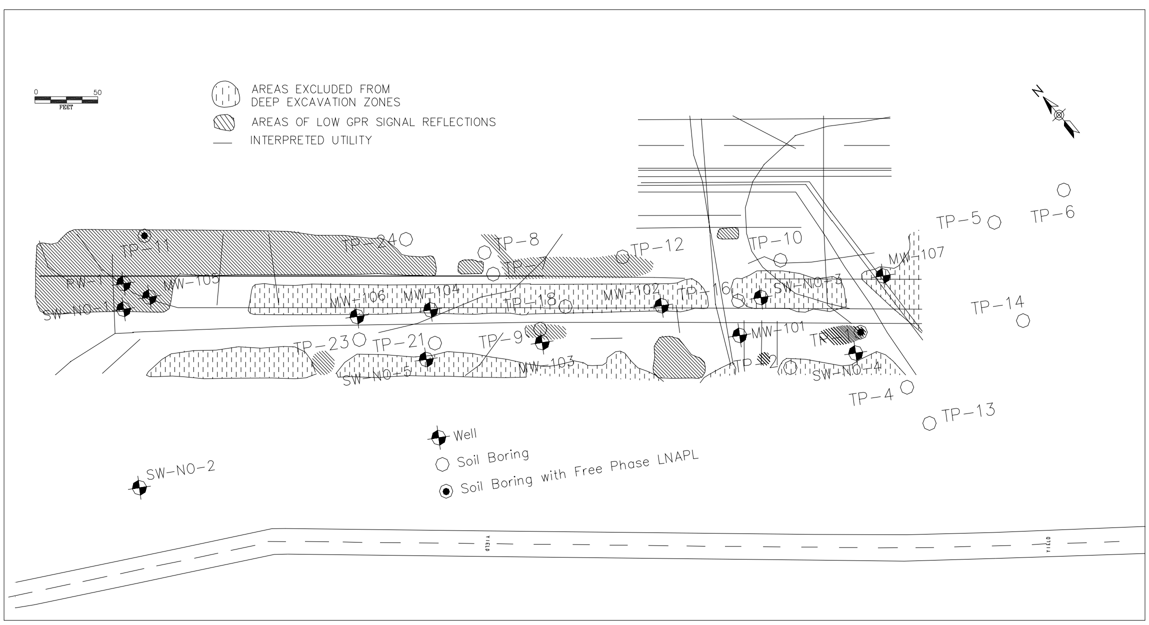

Figure 3. GPR interpretation map showing locations of utilities, deep excavations, and areas of low GPR signal reflections.

Utilities were detected at variable depths, from electric lines at approximately 1 foot to jet fuel lines at over 6 feet. Deep excavations (7 to 9 feet) are present in a large portion of the survey area; one type appears to be related to excavation for the sewers and nearby utilities; the other is situated under the grassy area separating the taxiway and runway.

STRATIGRAPHY

Several detailed variations of fine and coarse-grained sediments were described in the boreholes. Figure 4 illustrates some of these variations in a GPR cross section across the study area. To simplify the characterization of the variable soil sequences, we have divided the stratigraphy into three main categories:

- An upper zone of fill and older pavement.
- A middle zone of fine to coarse sand and gravel interbedded with silt and silty clay and broken by excavation fill.
- A lower/basal zone of clay and silt interbedded with thin sand and gravel layers and occasionally broken by excavation fill.

The upper impermeable layer within the clastic sediments is not continuous. Pinching and swelling of this impermeable layer, as well as utility excavations through it, allow migrating fluids to travel laterally for some distance and then also vertically.

GPR confirmed several key subsurface horizons: an old surface 1 to 2 feet below ground; an upper stratigraphic horizon within the fill; and a lower horizon, probably the boundary between fill and natural material, at an average depth of 7 to 9 feet. Figure 4 shows these horizons, as well as several of the utilities. Lateral changes in soil composition were also detected in the GPR records and borehole logs.

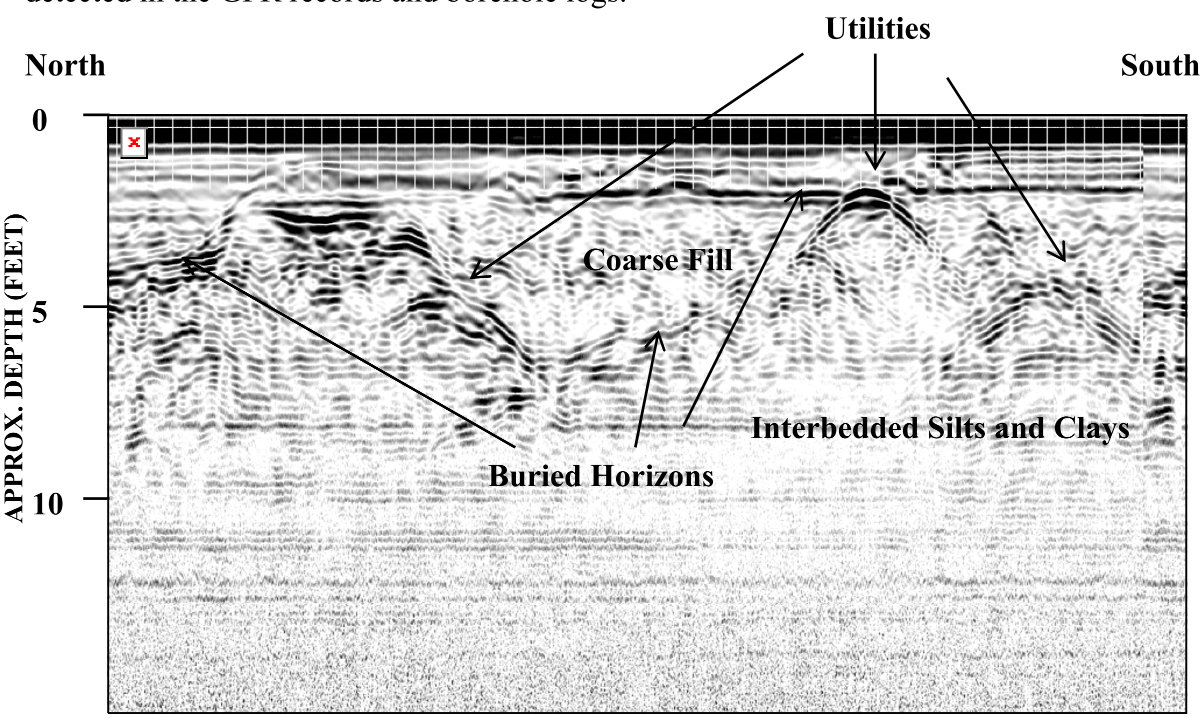

Figure 4. Portion of a GPR traverse showing anomalies produced by utilities and stratigraphic features. Ticks at top of record are one-foot distance marks produced by survey wheel attachment. Depths are approximate and not necessarily linear, based on calculated site-specific GPR signal velocities.

CONCLUSIONS

Our interpretive maps and cross sections (figures 5 through 9) indicate that contaminant migration is controlled by lateral and vertical stratigraphic changes across the site and excavations and backfill related to utilities. In the shallow zones (to approx. 7 feet), the jet fuel is apparently found within the permeable sand and gravel, and is confined by the upper and lower impermeable clayey strata. The upper impermeable layer has been mapped as a continuous horizon (Figure 8) to establish the surface configuration where present. The undulating expression produced by the structure contours roughly correlates with areas of utility excavation. If left undisturbed, this layer would probably have been relatively flat. The variable water table elevations also reflect confined and unconfined groundwater conditions (Figure 9).

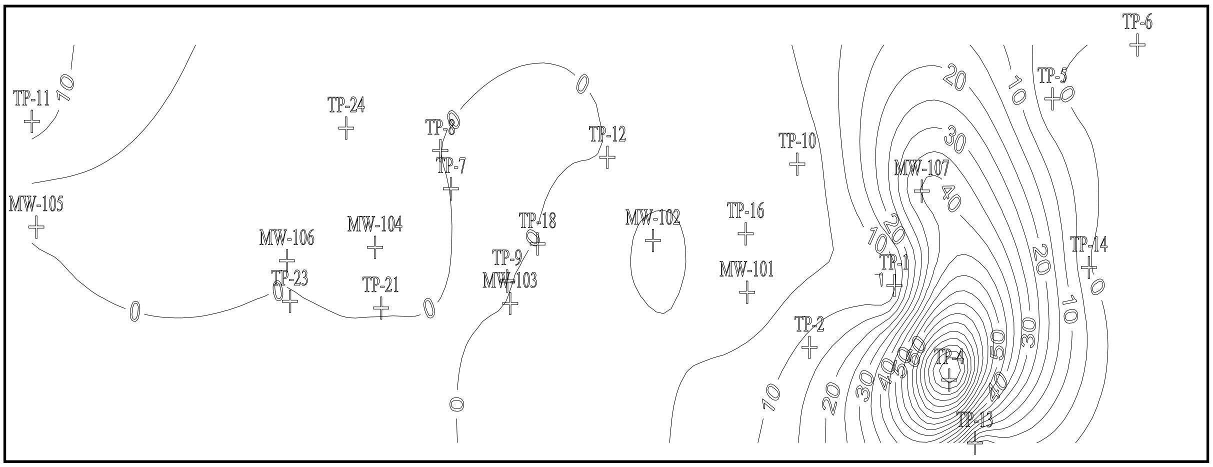

Figure 5. Contour map showing contaminant distribution at the 4- to 5-foot interval within the GPR survey area. North is toward the top of the figure.

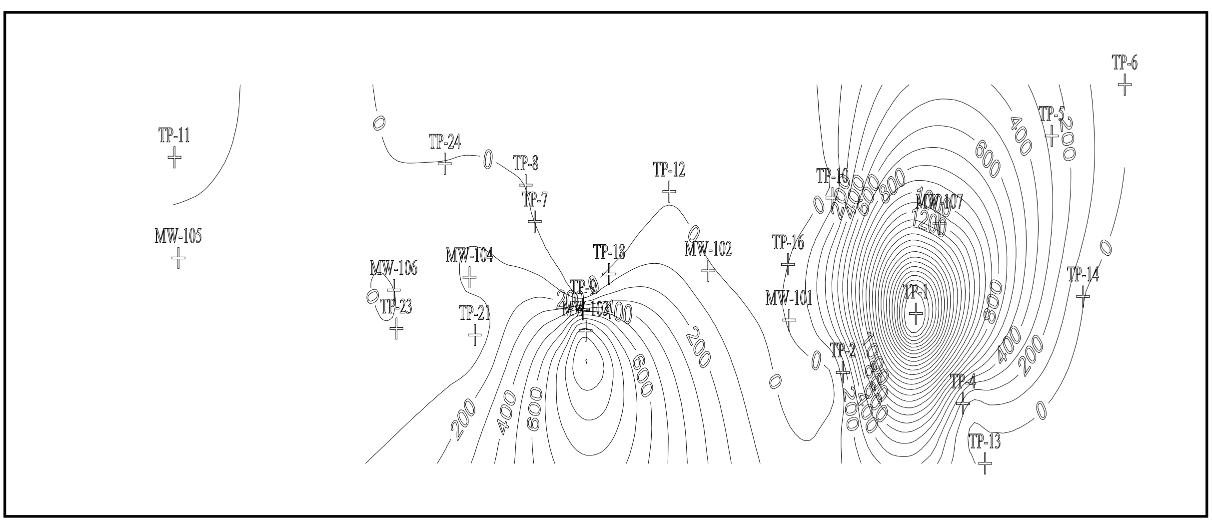

Figure 6. Contour map showing contaminant distribution at the 6- to7-foot interval within the GPR survey area. North is toward the top of the figure.

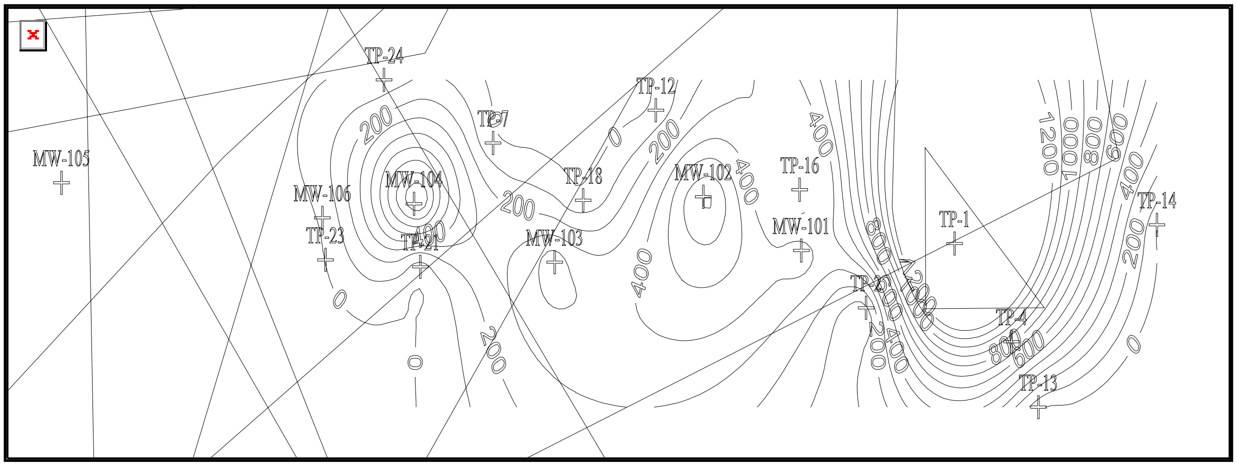

Figure 7. Contour map showing contaminant distribution at 9- to 10-foot interval within the GPR survey area. North is toward the top of the figure.

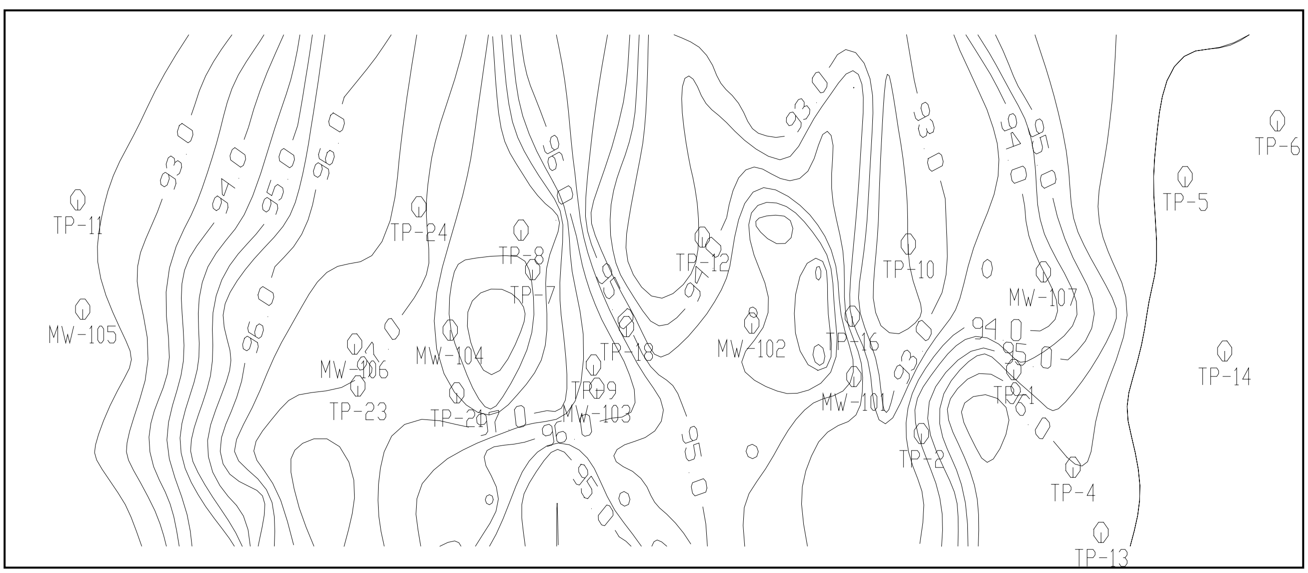

Figure 8. Contour map of the upper impermeable layer within the GPR survey area. North is toward the top of the figure.

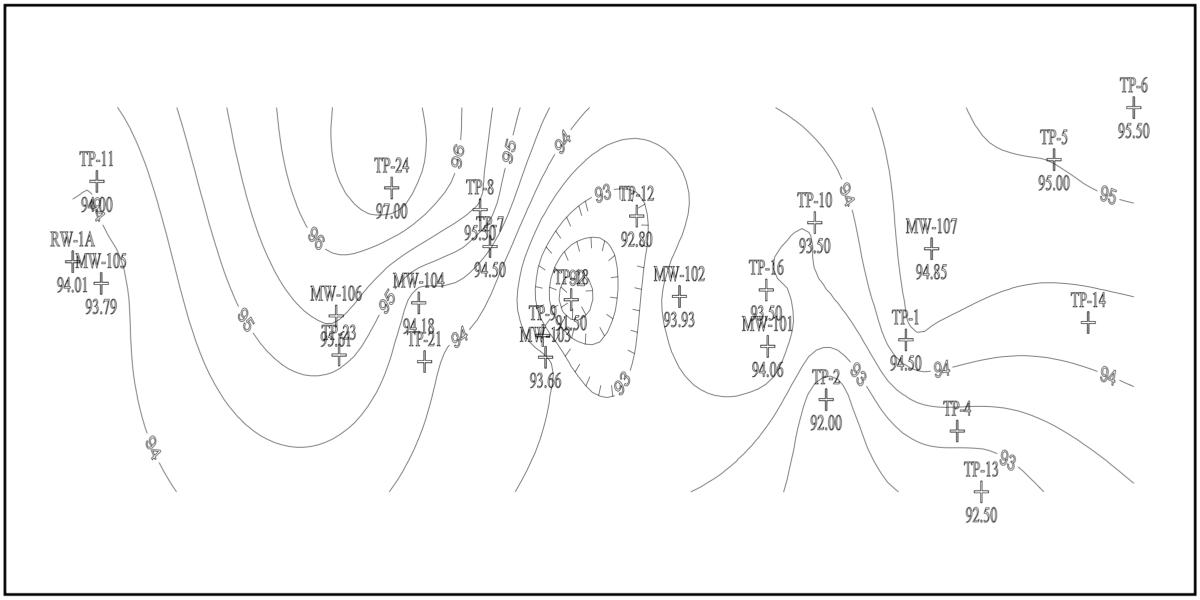

Figure 9. Contour map of the water table within the GPR survey area. North is toward the top of the figure.

A large east-west-trending drain appears to be pirating the migrating fuel. As the jet fuel migrates downward (via the utility corridors and pitchout of confining layers), it enters the confined permeable lenses that permit it to follow the hydraulic gradient westward under the utilities until it is trapped by confining layers and a depressed water table. The vertically downward and laterally outward migration is step-like and appears to occur between the 6- to 8-foot and again at the 9- to 10-foot depths. The step-like lateral migration is westward and appears to be controlled by both the east-west-trending deep utilities and a westward thinning coarse gravel layer that appears in borehole TP-1, where free product was detected.

Based on the study results, we conclude that the jet fuel migration is controlled by stratigraphy and deep utilities, and that there is potential for mapping jet fuel concentrations at the water table.

An analysis of the jet fuel provided by the client indicates that this material is highly resistive (approximately 2×10^9 ohm-meters) relative to normal sediments. Thus its electromagnetic contrast with surrounding soils that have resistivities in the range of 10^2 to 10^3 ohm-meters should produce a notable reflection pattern if it is present in sufficient concentration.

Although not conclusive, the results of our investigation suggest that where jet fuel has migrated through the vadose zone, it is present in very low concentrations and has little effect on the characteristics of the radar reflections. This is probably due to its volatile nature as a highly refined substance. At the water table and in the capillary fringe, the fuel appears to pool if soil conditions permit. Within this zone, it appears to produce a subtle, spatially variable "interference" effect on the radar signal (Figure 10). This effect, probably due to uneven saturation of sediments, may provide the opportunity to qualitatively target possible areas of jet fuel concentrations for probes. This conclusion is preliminary and will require further study.

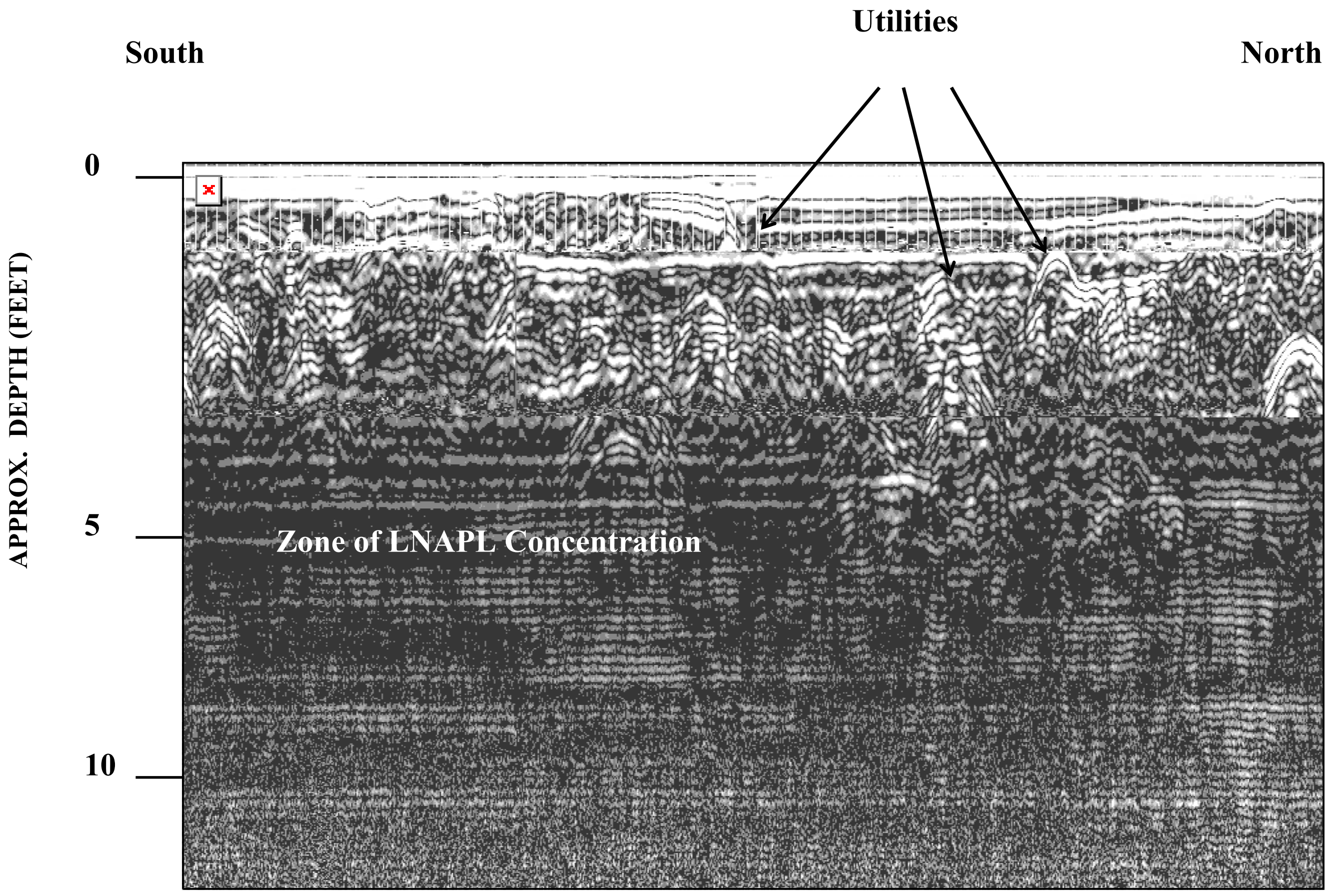

Figure 10. Portion of a GPR traverse showing reflections possibly produced by LNAPL pooled on the water table. Ticks at top of record are one-foot distance marks produced by survey wheel attachment. Depths are approximate and not necessarily linear, based on calculated site-specific GPR signal velocities.