United States Department of Agriculture | **Natural Resources Conservation Service** | **5 Radnor Corporate Center, Suite 200 Radnor, PA 19087-4585**

Subject: Ground-penetrating radar Assistance; **Date:** 21 December 1998
New York City Soil Survey Project

To: Richard Swenson
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Purpose:

The purpose of this study was to use ground-penetrating radar (GPR) to characterize dredged materials in Gateway Estate, Brooklyn, New York. Ground-penetrating radar was used to estimate water table depths and to map the thickness of dredge materials within the study area. In addition, the feasibility of using GPR for soil investigations and culture resource projects within Flushing Meadows, Queens, New York was evaluated.

Participating Agencies:

Natural Resource Conservation Service
NYC Soil and Water Conservation District

Participants:

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Activities:

All field activities were completed during the period of 30 November to 3 December 1998.

EQUIPMENT:

The ground-penetrating radar (GPR) unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. Morey (1974), Doolittle (1987), and Daniels and others (1988) have discussed the use and operation of GPR. The models 3110 (120 mHz), 5106 (200 mHz) and 5103 (400 mHz) antennas were used in this investigation. A 12-volt battery powered the system. Radar profiles included in this report have been processed through the WINRAD software package.[1] Processing was limited to signal stacking, horizontal scaling, color transforms and table customizing. Color transformation and table customization were used to reduce signal amplitudes and background noise.

The positions of all observation points within Gateway Estates were obtained with a Rockwell Precision Lightweight GPS Receiver (PLGR)[1]. The receiver was operated from a vehicle in the continuous mode using an

[1] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

external power source. An external antenna was mounted on the roof of the vehicle. The Universal Transverse Mercator (UTM) coordinate system was used.

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc. [1] was used to construct two-dimensional simulations. Grids were created using kriging methods.

FIELD PROCEDURES:

Following calibration, the 120 mHz antenna was towed behind a 4WD vehicle along 15 traverse lines located within Gateway Estates. Traverse lines were based on accessible trails that were visible on an aerial photograph. Although, GPR provides a continuous record of the subsurface, interpretations were restricted to observation points. These observation points were spaced at time intervals of 15 to 20 seconds along each traverse line. At each of the 362 observation points, the radar operator impressed a dashed, vertical line on the radar profile. This line identified an observation point on the radar record. Simultaneously, a waypoint was recorded on the PLGR. Radar records were printed and reviewed in the field. To help confirm interpretations and verify the depth scale, the anthrotransported dredge materials were observed at eight observation points.

Figure 1 shows the locations of the 362 observation points. The irregular spacing of observation points along traverse lines was caused by variations in vehicle speed. The 4WD vehicle's speed was slowed over rough and debris littered terrain. In addition, along the western-most, north-south traverse line, excessive noise interfered with the antenna's reception. As a consequence, radar profiles were uninterpretable at several observations and these data points were omitted. In Figure 1, several bounding roadways have been identified.

SUMMARY:

1. Ground-penetrating radar provided interpretable results at both Gateway Estates and Flushing Meadows. Computer simulations have been prepared showing the distribution of depths to the water table and construction debris within Gateway Estates.

2. A layer of construction debris was verified to underlie sandy anthrotransported dredge materials at four observation points. This layer was discernible on radar profiles and mapped across the entirety of Gateway Estates. Based on radar interpretations, the average depth to construction debris was 1.83 m with a range of 0.43 to 3.82 m. One half of the observations had depths to construction debris between 1.42 and 2.18 m. Depths to construction debris were shallow (0 to 0.5 m) at 1 percent, moderately deep (0.5 to 1.0 m) at 7 percent, deep (1.0 to 1.5 m) at 20 percent, and very deep (>1.5 m) at 71 percent of the area surveyed within Gateway Estates.

3. Within Gateway Estates, based on radar interpretations, the average depth to the water table was 1.3 m with a range of 0.40 to 2.61 m. One half of the observations had depths to water table between 0.97 to 1.59 m. Variations in the depth to water table are attributed principally to variations in surface topography.

4. An oily smelling layer appears to overlie the water table in portions of Gateway Estate. This layer is discontinuous and appears to be variable in thickness, composition, and expression (grades from gray to black).

5. At Flushing Meadows, the higher frequency 400 mHz antenna was used to chart the presence of disturbance, the depths to buried cultural features (i.e. utility lines, construction debris, layers of buried pavement), and the extent of different soil map units.

It was the pleasure of the National Soil Survey Center to be of assistance to you in this project.

With kind regards,

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DISCUSSION:

Gateway Estates:
Calibration:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil feature, debris layer, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (d), two-way, pulse travel time (t), and velocity of propagation (v) are described in the following equation (Morey, 1974):

$$v = 2d/t \qquad [1]$$

The velocity of propagation is principally affected by the dielectric permittivity (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2 \qquad [2]$$

Where c is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meter per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state (temperature dependent) of water have the greatest effect on dielectric permittivity.

All antennas were tested at a calibration site located within Gateway Estates. The 120 mHz antenna provided the most satisfactory observation depth and resolution of subsurface features and was used to complete this investigation. At the calibration site, a metallic reflector was buried at depths of about 0.48 m. Based on the round-trip travel time to this buried reflector, the averaged velocity of propagation through the upper part of the sandy, anthrotransported soil materials was determined. For the upper part of these sandy sediments (unsaturated zone), the dielectric permittivity was estimated to be 10.5. The velocity of propagation was about 0.0926 m/ns. This value was used to estimate the depth to water table.

The water table was detectable only within the sandy dredged materials. A continuous subsurface reflector, presumed to be the water table was observed on radar profiles at 288 of the 362 observation points. A second continuous subsurface reflector was also detected on the radar profiles. This interface was observed at four observation points and confirmed to be the contact between the sandy dredged materials and underlying construction debris. At 74 observation points, the construction debris was shallower than the water table and was measured directly using the velocity of propagation for unsaturated sandy sediments (0.0926 m/ns). Where the underlying construction material was shallower than the water table, the water table could not be detected. Because of the limitation imposed by our sampling devices, the saturated dredge materials and the underlying construction debris were not adequately probed.

Tabled values had to be used to estimate the dielectric permittivity and the velocity of propagation through the saturated dredge materials. Morey (1974) assumed a dielectric permittivity of 30 and a velocity of propagation of 0.0548 m/ns for saturated sands. This velocity (0.0548 m/ns) was used to estimate the thickness of saturated dredge materials. At 288 observation points, the thickness of the unsaturated and saturated sands was added to provide a measure of the depth to the underlying construction debris. Though depth scales and estimates are provided in this report, these should be viewed as rough estimates. The multilayer subsurface environment of Gateway Estates has variable and unpredictable porosity, moisture and clay contents that affect signal propagation and depth scales.

Multiple velocity tests were not conducted in the study area. It is common for velocity to change both vertically and laterally. Buried anthropogentic features and contrasting layers of dredge materials create layers that affect water contents. Because of changes in soil moisture and lithology, spatial variations in velocity were assumed to occur. During survey operations, observations were made at eight observation points using a 1.83-m soil auger. These observations helped to verify radar interpretations and confirm the depth scale. Based on these auger observations and the calibration site, the correlation, r, between observed and predicted depths to interfaces was 0.939563. The difference between observed and predicted depths averaged 5.022 inches with a ranged –13.5 to 6.3 inches. Table 1 summarizes the results of auger observations and radar interpretations.

Table 1

Comparison of Observed and Interpreted Depths to Subsurface Feature
(All depths are in inches)

Observed	Predicted	Difference	Feature
49	43.7	5.3	Dark oily smelling layer
54	53.2	0.8	Water table
50	43.7	6.3	Construction debris
61	57.0	4.0	Water table
72	85.5	–13.5	Water table
50	43.7	6.3	Construction debris
65	60.8	4.2	Construction debris
56	60.8	–4.8	Construction debris
19	19.0	0.0	Metallic reflector

Radar Interpretations:
Figure 2 is a portion of a representative radar profile from Gateway Estate. This profile was obtained with the 120 mHz antenna. In Figure 2, the vertical scale is a time scale expressed in nanoseconds. The series of blue and red parallel lines at the top of the radar profile represents the soil surface. Judging from the number of interfaces and clutter in the upper part of the soil profile, the anthrotransported dredge materials are presumed to be variable and stratified.

In Figure 2, the first distinguishable, continuous subsurface interface is the water table. A dark line highlights this interface. In some auger observations, a gray to dark black, oily smelling layer overlaid the water table. Oil may have been used at this site as a dust suppressant and soil stabilizer. As oil is less dense than water, it tends to float near the surface of the water table. In soils, free oil can migrate along the water table. The location and fluctuation of the water table as well as soil and fluid characteristics affect the thickness and location of this layer (Barber and Morey, 1994). It is uncertain whether the interface shown in Figure 2 represents the upper surface of the water table or the oily smelling layer. A smear layer of oil may have produced the moderate amplitude of this layer. A layer of oil can create a wider capillary fringe. A

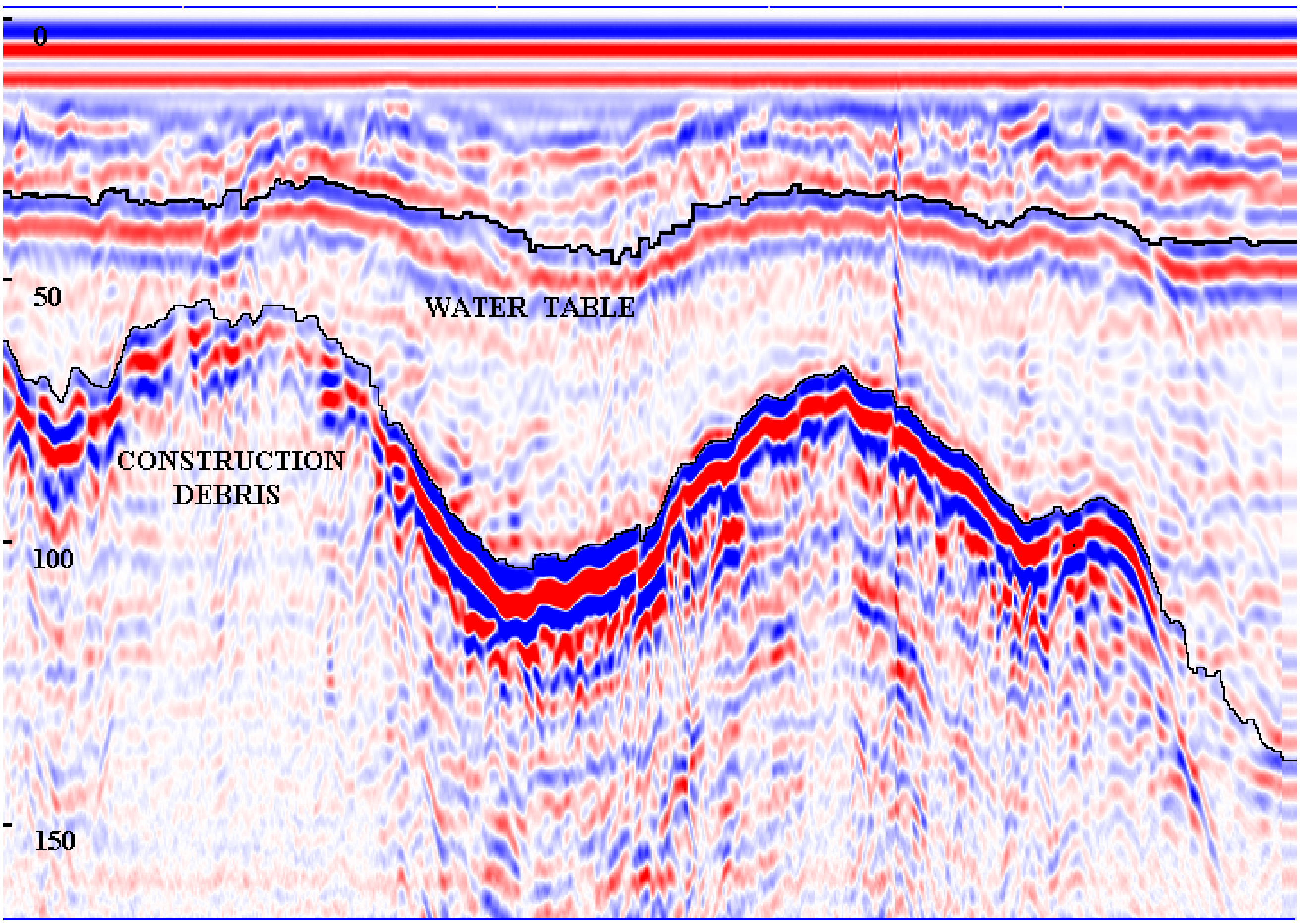

Figure 2. Representative radar profile from Gateway Estates.

wider capillary fringe results in a more gradual transition between unsaturated and saturated conditions, and weaker reflections on radar profiles. In addition, oil and dry sands have similar dielectric properties (Barber and Morey, 1994). Along an interface where oil has replaced water, the reflection coefficient is reduced resulting in a weaker radar reflection. The reflection coefficient of this interface may also have been reduced because of destructive interference caused by reflections from three closely spaced interfaces (dredge material, oily layer, water table).

In Figure 2, the second distinguishable, continuous subsurface interface is believed to represent buried construction debris. A dark line highlights this interface. At four observation points (see Table 1), layers of construction debris were encountered close to the estimated depth to this interface. These layers are composed of highly attenuating materials that
restrict radar penetration. Other than noise and signal reverberations, no meaningful reflections were detected below this interface. In areas where this interface occurred at a shallower depth than the water table, the water table was not discernible.

Results:

Figure 3 show the interpreted depth to construction debris. In general, depths to construction debris tend to be greater in the central core area and be less near the periphery of the site. Depths to construction debris were shallow (0 to 0.5 m) at 2 percent, moderately deep (0.5 to 1.0 m) at 7 percent, deep (1.0 to 1.5 m) at 20 percent, and very deep (>1.5 m) at 71 percent of the area surveyed within Gateway Estates. The average depth to construction debris was 1.83 m with a range of 0.43 to 3.82 m. One half of the observations had depths to construction debris between 1.42 and 2.18 m. Variations in depth to construction debris are a result of changes in the thickness of the overlying, sandy, anthrotransported dredge materials.

Figure 4 show the interpreted depth to the water table. The water table was not apparent at 76 observation points. At a majority of these observation points, layers of construction debris occurred at depths shallower than the anticipated depths to the water table. Because of high rates of signal attenuation, the water table was not distinguishable within the finer-textured construction debris. In many of the areas simulated as having depths to water table of less than 1.0 m, the water table was not observed. Depths to the water table were shallowest in the strip of land that immediately borders the Belt Parkway.

Within Gateway Estates, the average interpreted depth to the water table was 1.3 m with a range of 0.40 to 2.61 m. One half of the observations had depths to water table between 0.97 to 1.59 m. Variations in the depth to the water table are attributed principally to variations in surface topography. In several areas of Gateway Estate, the surface is undulating. These areas contain dune-like features and depressions. In areas having moderately deep deposits of anthrotransported dredge materials, the water table was not observed at 74 percent of the observation points. In areas of moderately deep deposits, the water table was shallow at 7 percent and moderately deep at 19 of the observation points. In areas of deep deposits of anthrotransported dredge materials, the water table was not observed at 24 percent of the observation points. In areas of deep deposits, the water table was shallow at 1 percent, moderately deep at 26 percent, and deep at 49 percent of the observation points. In areas of very deep deposits of anthrotransported dredge materials, the water table was not observed at 14 percent of the observation points. In areas of very deep deposits, the water table was shallow at 6 percent, moderately deep at 13 percent, deep at 26 percent, and very deep at 41 percent of the observation points.

Flushing Meadows:

The purpose of this study was to evaluate the potential of using GPR to map anthropogentic soils at the World Fair site and park in Flushing Meadows, Queens, New York. The 400 mHz antenna provided high-resolution profiles of the fill layers.

Figure 5 is a radar profile showing the variable depth to a buried asphalt layer. A known, metallic reflector was buried atop the asphalt layer at a depth of 0.18-m (7 inches; see A in Figure 5). The asphalt has been highlighted with a dark line. In Figure 5 it varies in depth from about 23 (B) to 36 cm (9 and 14 inches). With the 400 mHz antenna, high rates of signal attenuation restrict radar penetration below the asphalt layer.

Within Flushing Meadows, buried cultural features (i.e. utility lines, construction debris, and layers of buried pavement) were identifiable on radar profiles. Ground-penetrating radar can be used to chart the locations of buried cultural features and the extent of different soil map units.

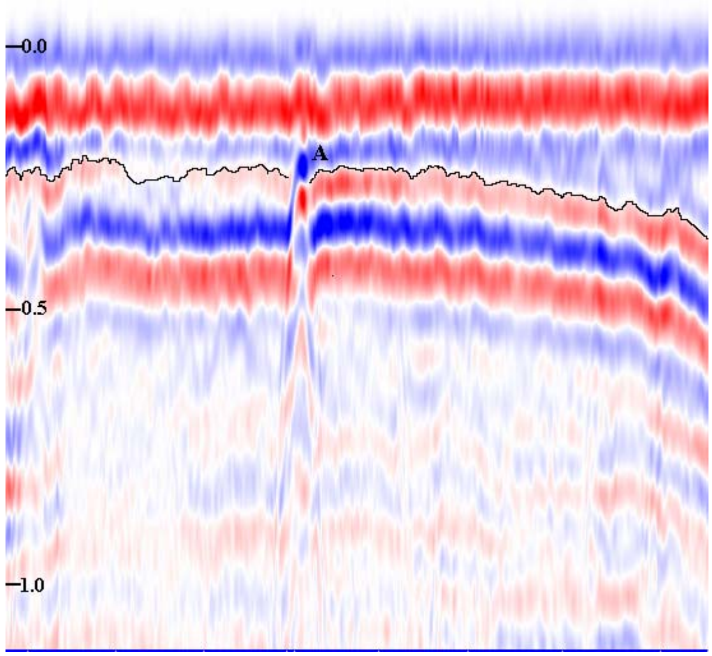

Figure 5. Representative radar profile from Flushing Meadows.

References

Barber, W. B. and R. Morey. 1994. Radar Detection of thin layers of hydrocarbon contamination. P. 1215 – 1228. IN: Proceedings of the Fifth International Conference on Ground-Penetrating Radar. Kitchner, Ontario, Canada. June 12 –16, 1994. Waterloo Centre for Groundwater Research, University of Waterloo, Waterloo, Ontario, Canada.

Daniels, D. J., D. J. Gunton, and H. F. Scott. 1988. Introduction to subsurface radar. IEE Proceedings 135: (F4) 278-320.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. pp. 11-32. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20. p. 98

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. pp. 212-232. In: Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.