MEMO

To: Peter Britz

From: Mike Deyling, Christopher Buckman

Re: Summary of Previously Performed Geophysical Investigations on the Western Portion of the GMZ for the Coakley Landfill and Proposed Surface Geophysical Investigation for Deep Bedrock Well Siting

Date: May 01, 2018

Below is a summary of previous geophysical investigations conducted in the western portion of the Groundwater Management Zone (GMZ) for the Coakley Landfill (Site), a summary of a site visit completed by CES on April 11, 2018, and a discussion of proposed surface geophysical surveys tentatively scheduled for the week of May 7, 2018 to site deep bedrock monitoring well couplets. The GMZ and proposed geophysical profile locations are illustrated on Figure 1.

A previous site related geophysical investigation was completed by John F. Kicks, a consulting geophysicist on behalf of the New Hampshire Water Supply and Pollution Control Commission (now the New Hampshire Department of Environmental Services), during August and September of 1986 to determine the depth to bedrock and to provide information on the extent and nature of strata and potential for presence of contaminated groundwater (Kicks, 1986; Appendix A). The geophysical survey included the use of seismic refraction, magnetometry, electrical resistivity soundings, and terrain conductivity. The investigation focused on the wetlands west of the Site, the area immediately northeast of the Site, and an area southeast of the Site (east of Lafayette Road and north of North Road).

Based on the current investigation activities as outlined in the Draft Deep Bedrock Investigation Work Plan (CES, 2018), the initial focus will be on the review and summary of the previous geophysical investigations having occurred within the western portion of the GMZ. Other areas of investigation within the GMZ will be further evaluated and used in the interpretation of newly acquired site data (e.g. borehole and surface geophysical information) relative to the Coakley Landfill conceptual site model. The locations and orientations of the geophysical surveys completed in 1986, photo lineaments identified during the fracture trace analysis performed by BCI Geonetics, Inc. in August 1986, and proposed geophysical investigation profiles for deep bedrock well siting are presented in Figure 1.
SUMMARY OF PREVIOUSLY PERFORMED INVESTIGATIONS WESTERN GMZ

◆ One seismic survey line (SE-001) was completed in the wetlands area west of the Site and was oriented in an approximate east-west direction as illustrated in Figure 2 of Appendix A. A “channel-like” feature was interpreted within the bedrock surface from the results of this profile. Low velocity zones characteristic of fractured bedrock were interpreted between SP2 and SP3 (Appendix A), and correlate with mapped lineaments along the west side of the GMZ. The depths to bedrock as interpreted from the seismic refraction profiles performed by Kicks will be used a primary means of confirming bedrock depths as recorded during the proposed deep bedrock investigation and used in the planning, execution, and interpretation of proposed surface geophysical data as outlined below.

◆ Four magnetometry profiles (M.G. 003, MG-004, MG-005, and MG-006) were collected in the wetlands area west of the Site. Investigation results describe “smooth” type A and “rough” type B segments in the east-west trending profiles MG-003 and MG-004, which Kicks suggested correlate with bedrock types. The results also describe a, “somewhat hypothetical,” interpretation of the differences between the segments representing a type of bedrock contact (normal contact or fault contact). A line shown on Figure 1 illustrates the interpretation of this potential contact. The east-west-trending MG-005 and the north-south-trending MG-006 do not show clear segments and the summary suggests these lines are entirely within the same bedrock unit (Kicks, 1986). The magnetic profiles for the lines discussed above are presented in Figures 4 through 6 of Appendix A.

• An attempt was made by Kicks to correlate the results of the individual magnetic anomalies with fracture trace lineaments by overlaying color-coded residual anomalies on the fracture trace map. According to the investigation summary it was “difficult to establish,” a clear relationship.

◆ Although clear relationships to geologic features were not identified in the findings of the magnetic survey, anomalies (or variations) in magnetic data in the general area of the wetlands is consistent with other site data provided both by previous investigations and current site monitoring. In addition, CES has recently conducted a review of scientific publications relating to bedrock structures which strongly suggest northeast/southwest orientations of bedrock structures in this area and corroborate the suggested findings of the magnetic survey. It is of CES’ opinion that although there is general qualitative agreement between the results of the magnetic survey as performed by Kicks and established regional bedrock fracture information, the magnetic survey is of limited value to the understanding of the deep bedrock environment, the ability to provide strategic placement of proposed deep bedrock well couplets, and to understanding the effect of the bedrock structures on potential migration of groundwater downgradient from Coakley Landfill.
Although two resistivity soundings were collected within the area of interest (RS-001 and RS-002) as illustrated in Figure 1 of Appendix A, resistivity sounding surveying is described by Kicks as being subject to, “interpretation.” In addition, due to the finite, point location of these soundings, very little information is provided relating to potential bedrock fracturing. It is of importance to note that the modeled resistivity data collected along RS-002, specifically the interpreted depth to bedrock (>60 ft below ground surface (bgs)), does not correlate with the interpreted depth to bedrock along SE-001 at the approximate intersection (est. <20 ft bgs) or to areas of interpreted lower seismic velocities. Though the lower relative apparent resistivities observed at RS-002 could be interpreted as the orientation of the sounding profile coincident with the regional fracture trace trend, no information of the sounding profile orientation is known to be available to substantiate this potential interpretation. Resistivity sounding profiles RS-001 and RS-002 are provided in Figure 10 and Figure 11 of Appendix A. Though resistivity information within the overburden and shallow bedrock environment are of interest given the proposed surface geophysical investigation, insufficient information regarding the collection methods (e.g. profile orientation) and poor correlation with other geophysical techniques performed by Kicks, previously collected resistivity sounding information will not be used in future Site subsurface evaluations.

One ground conductivity survey line (EM-002) was collected in the area of interest and oriented in a roughly south-north direction. The results were interpreted as, “rising” then “deepening” bedrock from south to north and is consistent with the saddle that separates Little River watershed (south) from Berry’s Brook watershed (north). According to the results, there is no direct evidence of a large volume of sediment saturated with ionic water; however, Site characterization investigations after 1986 have identified migration of contaminated groundwater to the west of the landfill. It is likely that the concentrations of contaminants are too low to be identified by an EM survey of this type, though some information regarding the specific EM collection techniques were not discussed by Kicks. The EM-34-3 survey utilized a 40-meter transmitter/receiver coil separation; however, it was not mentioned whether the coils were oriented in the horizontal or vertical dipole orientations. These dipole orientations affect the depth of investigation of the technique (30-meters for horizontal dipole and 60 meters for vertical dipole) and can greatly affect the correlation of interpreted EM ground conductivity response with known Site geologic and chemical information. The ground conductivity profile for EM-002 is presented in Figure 16 of Appendix A.

Although geophysical surveying technology has improved since the publication of the 1986 report, the results and interpretations are generally consistent with CES’ current interpretation of bedrock and bedrock structures in the wetland area west of the Site. In addition, the report offers valuable general insight into the depth and behavior of the bedrock surface, the approximate locations of the potential contacts and a general knowledge of potentially fractured areas. However, due to the Site-wide and regional scope of these investigations, these results are not adequately targeted or focused to determine the locations and orientations of individual fractures or dense networks of fractures in the wetland area west of the Site to meet current objectives. The use of current
technology for a targeted survey with a more focused goal will likely provide more insight into the nature, extent and orientations of fractures in this area.

The Geophysical Surveys Report, as issued by John F. Kicks in Weston's Remedial Investigation (RI) of Coakley Landfill (Weston, 1988), is presented in Appendix A.

**PRELIMINARY SITE VISIT**

CES conducted a site visit on April 11, 2018 to investigate the accessibility and suitability of the western portion of the GMZ for potential geophysical surveys. CES also identified general rock type and orientations of fractures at several bedrock outcrops in this portion of the GMZ during this visit. Although a substantial amount of brush and vegetation requires removal, the area should be accessible from Breakfast Hill Road via a tracked vehicle. Accessibility notwithstanding, efforts will be made to orient resistivity profiles as orthogonal to interpreted lineaments as possible, generally north-south, to achieve the greatest likelihood of imaging features significant to the potential downgradient migration of groundwater. In many cases for this area, the distance between the GMZ boundary and the wetland is less than 300 ft. For the proposed geophysical survey results to provide the most useful information of the subsurface and achieve the requisite depth of investigation for deep bedrock, profile length and electrode separation will be selected to optimize both factors. The average depth of investigation for electrical resistivity surveying is estimated at approximately 20% of the total deployed line length. Based on the Site reconnaissance visit performed, it is estimated that individual resistivity profiles may vary between 500 and 700 feet in length; however, potentially longer lines may be possible. Profile lengths will be selected based on depth requirements, site accessibility, potential sources of electrical interference (e.g. utility alignments), and achievable resolution capabilities of the deployed profiles.

Three substantial bedrock outcrops were observed during the Site Visit on the western portion of the GMZ. These rock types can best be characterized as belonging to the Rye Complex metamorphic group, as described in Weston's RI (Weston, 1988). The exposed outcrops were weathered and fractured along foliation planes. Foliation (and therefore, fracture) fabric was measured by a CES New Hampshire Licensed Professional Geologist. Foliation/fractures were measured as having a strike of between 17 and 33 degrees east of north and a dip of between 55 and 66 degrees to the west-northwest. These measurements are in agreement with the various local and regional geologic studies, literature and publications, as well as the previous Fracture Trace and Fracture Fabric Analyses Report submitted by BCI Geonetics, Inc. in August 1986.
PROPOSED WORK TO BE PERFORMED

The proposed surface geophysical investigation is designed to “micro-locate” two proposed well couplets in the northern and northwestern portion of the GMZ and to investigate lineaments identified west of the Site to provide a better understanding of the nature, extent and orientation of bedrock fractures in this area. To further assess whether a significant deep bedrock migration pathway is present at the Site and to determine if a significant risk to receptors is present due to migration of contaminants in deep bedrock, well couplet placement within potentially open and transmissive deep bedrock fractures is of primary importance.

Based on a review of available geophysical survey data and our verification of fracture trace analysis work presented in the RI, it appears that seismic refraction surveys along with subsequent drilling efforts have resulted in a reasonable and consistent interpretation and understanding of the bedrock surface. “Low velocity zones,” have been interpreted at the Site via seismic surveying and these zones correlate spatially with several lineaments identified during fracture trace analysis; however, seismic refraction surveys conducted to date provide limited data with respect to the precise location, extent, and orientation of potential fracture zones in bedrock.

As a result, CES recommends that electrical resistivity surveys be completed as a method more suitable for determining the location, extent and orientation of potential water bearing fractures for micro-locating the two monitoring well couplets and to evaluate a series of east-west trending lineaments located west of the Berry’s Brook/Little River divide. The mapped wetland (identified with wetland symbols to the west of the Site) exists to the east of the area of the proposed geophysical investigations, therefore potential survey lines trending north/south are more accessible for geophysical investigations and suitable for drilling than survey lines trending east/west.

Specifically, CES proposes the following work be performed:

- One electrical resistivity profile is proposed along the south side of Breakfast Hill Road, extending from the northwestern boundary of the GMZ for approximately 700 ft. east to characterize potential north/south-trending fractures, and align the bedrock trough with its location immediately west of the landfill in the wetland complex. One electrical resistivity survey from approximately 150 ft. west of the railroad right-of-way, adjacent to Breakfast Hill Road to approximately 700 ft. south, parallel with the railroad right-of-way, to characterize potential east/west-trending fractures. Data from this resistivity profile will be used in locating the most northerly well couplet (MW-20).
Two resistivity profiles, comprised of two separate parallel lines in the area approximately 150 ft. to the north/northwest of existing monitoring well cluster FPC-6. These lines will extend approximately 700 ft. in a northeast/southwest orientation and will be located within approximately 150 ft. of one another. These lines are intended to intercept potential northwest/southeast-trending fractures orthogonally, which will assist in determining the location of the northwesterly proposed well couplet (MW-21). Additionally, the location of these profiles relative to one another may aid in potential identification of fracture orientation between profiles to substantiate fracture trace analysis results.

Two electrical resistivity profiles involving two separate parallel lines in the area approximately 350 ft. to the west/southwest of existing monitoring well cluster FPC-5. Each line will extend approximately 1,200 ft. in a northeast/southwest orientation and will be located within 150 ft. of one another. Based on Site conditions at the time of geophysical data collection, these profiles may consist of one or more individual segments to achieve the total proposed length. These lines are intended to intercept previously mapped lineaments (potential fractures) in an area where westerly migration of contaminants would be in a direction toward residential water supply wells located approximately one-half-mile west of the GMZ boundary.

The locations of these proposed survey lines, as well as previously mapped lineaments and previous geophysical investigations is presented in Figure 1. It is anticipated that the targets of interest (e.g. water bearing fractures) will exhibit sufficient electrical conductivity contrast to surrounding bedrock to be imaged by the proposed geophysical technique. The results of the electrical resistivity surveying, including site conditions and potential sources of interference as observed during data collection, will be used in the evaluation of other geophysical techniques as listed in the EPA’s letter request for a bedrock investigation (EPA, 2018).
FIGURE 1

LINEAMENTS, PREVIOUS GEOPHYSICAL INVESTIGATIONS AND PROPOSED INVESTIGATIONS SITE MAP
FIGURE 1

COAKLEY LANDFILL SUPERFUND SITE
LINEAMENTS, PREVIOUS GEOPHYSICAL INVESTIGATIONS
AND PROPOSED INVESTIGATIONS

PROPOSED MONITORING WELL COUPLETS

DATE: 2018-04-23
BY: JN: Engineers

FIGURE 10424.016
BLQ

PROPOSED ELECTRICAL RESISTIVITY SURVEY LOCATIONS
- APPROXIMATE BOUNDARY OF GROUNDWATER MANAGEMENT ZONE (GMZ)
APPENDIX A

JOHN F. KICKS’S GEOPHYSICAL SURVEYS REPORT
APPENDIX H

DR. JOHN F. KICKS'S GEOPHYSICAL SURVEYS REPORT
GEOPHYSICAL SURVEYS
COAKLEY SANITARY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

Introduction

Seismic refraction, ground magnetic, terrain conductivity (EM - 34), and electrical resistivity surveys were completed on the Coakley Sanitary Landfill site and adjacent properties by John Kick, consulting geophysicist. The purpose of the seismic work was to determine depth to bedrock and other detectable interfaces, and the nature of subsurface materials. The main purpose of the resistivity and conductivity surveys was to provide information on the extent and nature of subsurface strata and possible presence of contaminated water. Ground magnetic surveys were implemented in order to detect changes in the bedrock including possible fracture zones.

The geophysical methods were needed to confirm, extend, and supplement the results from borings, test pits, fracture trace analysis, etc.

SEISMIC REFRACTION

Seismic Field Work

A total of 51 seismic lines (61 shot points), 12260 feet covering 6840 linear feet of traverse was completed on August 21, 22, 25, 26, 29, and September 11, 15, 16, 18, 1986. Each line is included between two shot points. All lines except outer lines were overlapped to obtain complete reversed coverage of the bedrock on each traverse. The location of the shot points and therefore of the lines are shown on the map of Figure 1.

The map of Figure 1, boring logs and other information as well as field direction and support were provided by Mr. George Cook and Mr. George Draper of Goldberg - Zoino. Mr. Mike Robinette, groundwater geologist for N.H.W.S.P.C.C. provided direction on behalf of the state.
A S.I.E. Model RS-4, 12 channel seismic system was used to obtain the data. Each seismic line is made up of a string of 12 detectors (geophones) planted in the ground along a straight line. The geophones are used to detect a seismic wave generated by the use of small explosive charges placed in holes at each end of the line (at shot points). The outputs of the 12 geophones are fed to a seismograph which records the signals on film. The arrival times are read from the film and plotted on time-distance graphs for analysis and interpretation. All lines were reversed and all were tied where possible. Supplementary shots were placed on lines where needed. Work progress was slowed on several of the lines where it was necessary to locate and cut lines through thick brush and wetland.

Data Interpretation

Data interpretation was accomplished by use of the critical distance method which is based on the analysis of graphs of travel time versus distance in combination with formulae based on refraction theory. Every opportunity was utilized to integrate geological knowledge of the site and thus increase the accuracy of the results.

Accuracy - In general, experience shows that the computed seismic depths are within ten percent of the true depth. The accuracy between shot points or for depths less than 15 feet or for unusual, unforeseen ground conditions may be somewhat less.

Results

The interpreted results are presented in the form of profile cross sections on Figures 2 and 3. The profiles show overburden (soils) and bedrock seismic velocities and the position of the bedrock surface as related to the ground surface.

Seismic Velocities - Seismic waves travel at different velocities in different materials. When interpreted with due care these velocities can provide useful information on soil and rock characteristics. Following are listed the correlations of
material types with seismic velocities that were encountered on this project.

<table>
<thead>
<tr>
<th>Velocity Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 - 2400 ft./sec.</td>
<td>Surficial layers of unsaturated silty to sandy and gravelly material or fill.</td>
</tr>
<tr>
<td>3000 - 4000 ft./sec.</td>
<td>Upper (coarse) till.</td>
</tr>
<tr>
<td>4800 - 5200 ft./sec.</td>
<td>Saturated sand and gravel, silt-clay or till.</td>
</tr>
<tr>
<td>5000 - 6000 ft./sec.</td>
<td>Till, silty clays depending on degree of compaction.</td>
</tr>
<tr>
<td>7800 - 13000 ft./sec.</td>
<td>Highly weathered and/or fractured bedrock at the lower range to highly foliated rock at higher range.</td>
</tr>
<tr>
<td>13000 - 18000 ft./sec.</td>
<td>Bedrock; well foliated at lower range to more massive and un-weathered at higher range.</td>
</tr>
</tbody>
</table>

Note: Seismic velocity ranges overlap; eg. a value of 13000 ft./sec. for a normally massive gneiss with a usual velocity of 16000 ft./sec. could be due to fracturing, whereas 13000 ft./sec. might be a normal velocity for unfractured but well foliated schist.

**Discussion of Profiles**

**SE - 001 (Fig. 2)** - Extends westward from a point west of the railroad tracks through a wetland. From SF 1 - 5 there is a channel-like feature with computed depths as great as 35 feet between SP2 and SP3. At SP5 bedrock is near the ground surface but slopes down from SP5 reaching a depth as great as 30 feet west of SP8. From this low point rock slopes generally upward to the end of the profile. Low velocity zones between SP2 and 3 and SP8 - 9 correlate with map lineaments. Other lineaments cross the profile where velocities are intermittent but no lineaments were mapped where velocities are high.

**SE - 002 (Fig. 3)** - Extends northeast to southwest from a point near Breakfast Hill Road toward the landfill. Depth to bedrock is computed to be 36 - 39 feet at SP1, sloping down to 54 feet.
near SP2. From SP2 - 5 the depth to rock decreases to about 14 feet. From SP5 - 8 it remains relatively constant before sloping down to a depth of about 30 feet west of SP9. From the low point the rock surface slopes upward. From SP10 - 18 bedrock is shallow ranging from 0 - 10 feet. Correlations with lineaments are limited. One lineament crosses the profile near SP4 where the rock surface is irregular and velocities are relatively low. A lineament projected would also intersect the profile at this location.

**SE - 003 (Fig. 3)** - Extends southeast - northwest from the landfill access road toward the railroad, subperpendicular to SE - 002. From SP1 - 3 very poor records indicate unusual ground conditions, perhaps an area of fill. The bedrock surface shallows westward from SP3, almost reaching ground surface at SP4. West of SP4 the rock surface slopes downward to depths as great as 38 feet between SP6 and 7. Within this bedrock low the seismic velocity gets very low indicating the possible presence of a shear zone. From the low point between SP6 - 7 the rock surface slopes upward to very shallow depths between SP9 and 10. From SP10 to 14 depths range from near surface to 14 feet, but are generally about 10 feet. A lineament intersects traverse 003 a short distance east of the low velocity zone near SP6. Observation well G2-115 located some 40 feet beyond SP6 revealed highly fractured rock. Relatively low seismic velocities were recorded near SP11 and SP14.

**SE - 004 (Fig. 2)** - From SP1, near the landfill, where a depth to rock of 58 feet was computed, the bedrock slopes generally upward reaching nearly to ground surface between SP7 and 8. From SP8 the rock surface drops off to depths of about 25 feet south of SP9 and from thence it rises. A map lineament intersects traverse SE - 004 near SP6 where there is a bedrock elevation low and a relatively low seismic velocity. Another map lineament, if projected, would cross SE - 004 at the bedrock surface low between SP9 and 10.
SE - 005 (Fig. 2) - Extends southwest to northeast in the area investigated southeast of the site and east of Rte. 1 (Lafayette Road). From SP1 to SP5 the bedrock depth is relatively constant varying from 35 to 45 feet. From SP5 - 9 the rock surface slopes upward reaching depths less than 10 feet near SP9. A map lineament intersects the profile at a low angle between SP2 and 3. In this location the seismic velocity is relatively low.

GROUND MAGNETIC SURVEY

The Magnetic Method

Magnetic exploration methods include the detection and measurement of anomalies of the earth's magnetic field caused by the presence of materials with contrasting magnetic susceptibility. Iron and steel objects, for example, generally form high susceptibility contrasts with usual surrounding materials and therefore produce magnetic anomalies. In natural settings anomalies are caused by susceptibility contrasts between adjacent rock units. Most such contrasts are due to changes in the concentration of the mineral magnetite. In some cases magnetic anomalies have been noted in association with fault zones.

The size and shape of an anomaly depends on the size, shape, and depth of burial of the source body as well as the susceptibility contrast between the body and surrounding materials.

Magnetic Field Work

Magnetometer measurements of total field intensity were made at 10 foot intervals on 14 traverses covering a total of 8740 linear feet at locations shown on the map of Figure 1. The traverses are in areas of special interest and cross lineaments discerned by fracture trace analysis. The field work was completed on August 21, 22, 25, and September 4, 18, 19, 29, 1986. Field equipment included an EG & G Memory-Mag G-856 proton precession magnetometer. The instrument has a resolution of 0.1 gamma. The magnetic field detector is separate from the rest of the instrument and is mounted on an
8 foot staff to provide measurements that are a constant height above the surface of the ground. A series of magnetic field measurements were made at a selected site near each survey line and used to form the basis for a daily variation correction curve. The base stations were located at sites with typical low gradient "background" magnetic field intensity measurements.

**Magnetic Data Analysis**

For the purposes of data reduction and anomaly delineation it was assumed that base station total field intensity measurements were typical background values for the site. Anomaly values were obtained by subtracting background values from measurements collected in the areas of investigation.

In addition to data reduction, the data was subjected to additional processing in order to separate small, residual anomalies due to minor features from larger scale, regional anomalies. A qualitative separation was accomplished by use of simple graphical smoothing. The graphical smoothing technique is subjective and somewhat arbitrary but suffices to make a qualitative separation. Mathematical methods were considered but found not to be practical.

Using a spectral color coding the residual anomalies were plotted on an overlay map of the area to test for possible relationships with geological features and inferred photolineaments. The large scale, regional anomalies were also plotted and contouring was attempted.

**Results**

The results are presented in the form of individual profiles (Figures 4 - 9), the map of Figure 1, and in the discussion following.

**General Characteristics**

The regional - residual separation shows that the anomalies can be separated into groups based on size and fabric.

**Size** - The large, "smooth", regional anomalies are easily
separated from the generally much smaller residual anomalies. The large anomalies most likely relate to comparable scale bedrock changes. The magnetic highs may relate to volcanic rocks while the low areas may correlate with felsic gneiss, schist, and other less magnetic rocks.

Fabric - Inspection of the profiles (Figures 4 - 9) shows the profiles can be broken into two types on the basis of fabric (frequency of residual anomalies). **Type A**: smooth regional, generally low with few prominent residuals; **Type B**: segments, especially regional highs, with many prominent residual anomalies.

The smooth, type A and "rough" type B segments seem to correlate across several of the profiles eg. profiles 001, 003, 004. A contour (areal rather than profile) map of the area would likely show a pattern of these areas that would correlate with bedrock types.

The borderline between the various types of magnetic terrain would represent some sort of bedrock contact; eg. a normal contact or a fault contact. A line drawn on the map of Figure 1 shows the approximate position of such a contact. The above interpretation is somewhat hypothetical. More extensive magnetic mapping or comparison with other work in the area would be needed for a stronger conclusion.

An attempt was made to correlate individual residual anomalies with fracture trace lineaments. Color coded residual anomalies were overlayed on the fracture trace map. With a few exceptions it was difficult to establish a clear relationship because of the large density of lineaments and the distance of profile separation. Anomalies appear where lineaments are not plotted and vice versa. It appears that a closer separation and larger number of magnetic profiles would be necessary for a more distinctive comparison. One exception is the anomalies of profiles 010 - 015 where a local anomaly of 25 - 50 gammas correlates well with a fracture trace.

Figure 9A is a contour map of the data on profiles 010 - 015. Contouring proved practical because of the density of
profiles. The profile distribution is also sufficient to cause the correlation between residual anomalies and photo lineaments to be discernable.

**FIGURE 9A**
MAGNETIC SURVEY
Southeast of Coakley Landfill
North Hampton,
New Hampshire
9/29/86

Description of Magnetic Profiles

Profile MG - 001 (Fig. 4) - The eastern portion is a low smooth type A profile. The west side is a typical type B high segment.

Profile MG - 003 (Fig. 4) - Similar to 001, but higher on the west.

Profile MG - 004 (Fig. 5) - Similar to 003 and 001, but local anomalies are less obvious on the western high.
Profile MG - 005 (Fig. 5) - Wholly type B terrain with profile dominated by unusually large local anomalies.

Profile MG - 006 (Fig. 6) - This traverse extends at high angle to MG - 003 - 005, and contacts them at their western ends in type B terrain so it is not surprising that its form is typically type B with many prominent residual anomalies. It traverses both high and low regional anomalies.

Profile MG - 007 (Fig. 7) - Regionally high with type B pattern.

Profile MG - 008 (Fig. 7) - This profile may have a type A character on the west but has a very pronounced high with very steep gradients on the east. Gradients such as this are often associated with buried iron and steel objects.

Profile MG - 009 (Fig. 8) - Similar to 008 with a relatively smooth western portion and steep gradients on the east. A sharp peak at 450 feet could be noise, or perhaps a fence or some sort of steel object.

Profiles MG - 010 - 015 (Figs. 8 and 9) - All located southeast of the site and east of Route 1; are type A curves but several have a single prominent peak that correlates with photolineaments as described previously. Also see map of Figure 9A.

RESISTIVITY AND TERRAIN CONDUCTIVITY

Electrical conductivity and resistivity values measured from the ground surface depend on the thickness and composition of subsurface layers. Electrically speaking, composition is a combination of soil or rock characteristics (mineralogy, texture, porosity, permeability, etc.) and the composition of interstitial water. Soils such as clay and silt for example, generally have lower resistivity and higher conductivity than sands and gravels. A sand and gravel saturated with water having a high ionic content could however, have a considerably lower
resistivity than a clay deposit containing water with a low ionic content.

On the Coakley site electrical methods were used to determine the presence and depth of possible clay layers and/or contaminated ground water.

ELECTRICAL RESISTIVITY (ER)

Electrical Resistivity Method

Electrical resistivity systems are made up of two pairs of electrodes, a power source, and a measuring apparatus. One pair of electrodes introduces current into the ground and therefore acts as a transmitter. The second pair of electrodes samples the resulting potential pattern and thus functions as a receiver. Knowledge of the current, potential, and the particular electrode configuration used allows one to compute the "average" resistivity of the volume of ground sampled. The resulting average resistivity is known as "apparent resistivity."

Apparent resistivity readings can be made for a series of electrode spacings varying from closely to widely spaced. With each increase in electrode spacing an increasingly larger and deeper volume of ground is sampled (thus the method is also referred to as electrical sounding). The results of a sounding are plotted as curves of apparent resistivity versus electrode spacing, termed a sounding curve. Sounding curves from the Coakley site are shown on Figures 10 - 15. The shape of the sounding curve reflects the change of resistivity with depth and therefore changes in the nature and thickness of materials. The shape of the sounding curve can be analyzed and interpreted by use of a variety of methods to yield thickness and "true" resistivities of subsurface layers.

Resistivity Field Work

On September 9, 10, 1986 soundings were made at 6 locations as shown on the map of Figure 1. Bison 2350A and ABEM Terrameter SAS with SAS 2000 Booster Transmitter systems were used in the
Schlumberger electrode configuration which involves two outer, current electrodes (transmitter) and two inner, potential electrodes (receivers). In the Schlumberger configuration the inner electrodes are spaced at less than one fifth the distance between the outer electrodes. The distance between the center of the configuration and either outer electrode is often referred to as the "L - spacing".

**Analysis**

Data from the field was plotted as curves of apparent resistivity versus electrodes spacing (L - spacing) on logarithmic graph paper. The curves were analyzed by modeling making use of a computer program that calculates Schlumberger electrical soundings for up to 10 horizontal layers of earth material.

The procedure for interpretation can be briefly explained as follows. An initial theoretical sounding curve is calculated by assuming a model made up of a sequence of layers and corresponding resistivities. The assumptions are constrained by field curves and well logs. The calculated curve is compared to the observed curve and differences are noted. A second theoretical curve is then calculated using model parameters that are likely to minimize the differences between the observed and calculated curves. The process is repeated until the calculated curve is sufficiently close to the observed sounding curve. The resulting model is interpreted in terms of geological structure and materials.

**Results**

The resistivity sounding results are shown on Figures 10 - 15. Each figure shows the observed and calculated (theoretical) sounding curves presented together for comparison and qualitative interpretation.

The sounding curves are difficult to interpret alone so each has been analyzed by modeling. Each model, listed above its appropriate sounding curve, provides a section of layers with thickness and resistivity that would be consistent with the observed field values. It should be kept in mind
that the layers listed in the models are electrical in nature and do not necessarily correspond exactly with geologically observed strata. The resolution of a sounding decreases with depth because the volume sampled increases and because of a general decrease in signal to noise ratio with depth.

Under the heading "Interpretation" is listed the stratigraphic types interpreted to be associated with each resistivity unit. The stratigraphic units listed are somewhat general. There are sure to be vertical and horizontal gradations and other complexities common to the types of sediments underlying this site. There is also likely to be some overlapping of the resistivity value ranges. Resistivities are given in units of ohm feet.

**GROUND CONDUCTIVITY (EM)**

Ground conductivity (EM) measurements were made with an electromagnetic device referred to as an EM-34-3 manufactured by Geonics Limited of Ontario, Canada. The EM-34-3 consists of transmitter and receiver coils and associated controls. The transmitter induces small electric currents in the ground which generate secondary magnetic fields, which can be sensed by the receiver coil. The secondary magnetic field is proportional to the conductivity of the ground which can then be read directly on the instrument in units of millimhos per meter.

The depth of penetration into the ground depends on the length of separation of the two coils. The EM-34-3 is set up for discrete vertical coil separations of 10, 20, and 40 meters. Depth of penetration as stated by the manufacturer, is approximately 75% of any given coil spacing.

With each increase in separation of the coils a larger but unknown volume of earth is sampled. The resulting conductivity value is a complex average of the conductivities of all the structures included in the volume sampled. The chief advantage of EM measurements is that they can be made easily and quickly; large areas can be covered in economically short times.
EM Field Work

More than 120 EM-34-3 measurements covering about 6000 linear feet were completed on August 29, and September 2, 1986, at locations as shown on Figure 1. The traverses were labeled EM - 001 and EM - 002. Readings were made at 50 foot intervals. The 40 meter coil spacing was used in order to achieve maximum probing depth.

EM Analysis - Readings from the field were simply plotted on profiles as shown on Figure 16.

Discussion of EM Profiles

Profile EM - 001 - Profile EM - 001 is located along the east side of the site. Much of the first portion of the traverse covers ground where bedrock is very shallow. Readings were negative and the instrument was highly oscillatory due to very low conductivity and cultural interference. The 40 meter span of the EM - 34 is highly sensitive to cultural effects. The southern portion shows increasing conductivity, likely due to the presence of clay and/or highly conductive (ionic) water, probably from the landfill.

Profile EM - 002 - Located in the wetland west of the site (west of the railroad tracks). Survey work progress was impeded by the necessity of wading through water and passing through thick vegetation. Values varied about a mean of approximately 5 millimhos/meter for the initial 1500 feet of traverse then declined to 0 at 2250 feet. From that low point to the south end values remained about 2.5 mm/M.

The low conductivity at 2250 may indicate rising bedrock or coarse sediments saturated with clean water. Values for the northern portion can be explained as due to deepening bedrock and thickness of clay and silt in agreement with resistivity soundings RS - 001 and RS - 002. There is no direct evidence of a large volume of sediment saturated with ionic water.
FIGURE 1

LOCATIONS OF GEOPHYSICAL SURVEYS
COAKLEY SANITARY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

by: J. F. Kick PhD
Geophysicist
Aug. - Sept. 1986
FIGURE 2:
SEISMIC REFRACTION PROFILES
COAKLEY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

by J. F. Kick PhD
Geophysicist
September 1982
FIGURE 3
SEISMIC REFRACTION PROFILES
COAKLEY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

by J. F. Kick, Ph.D
Geophysicist
September 1986
FIGURE 4

MAGNETIC PROFILES
COAKLEY LANDFILL
NORTH HAMPTON,
NEW HAMPSHIRE

by: J. F. Kish, PhD
Geophysicist
Aug. - Sept. 1986

average datum value: 55530 gammas
average datum value: 55540 gammas
MG-004
EM-002
average datum value: 55550 gammas

MG-005
average datum value: 55698 gammas

FIGURE 5
MAGNETIC PROFILES
COAKLEY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

by: J. F. Kick PhD
Geophysicist
Aug. - Sept. 1996

Scale
- dotted magnetic stations
- regional curve
datum
vert.: 1 inch = 100 gammas
horiz.: 1 inch = 100 feet
average datum value: 56053 gammas

MAGNETIC PROFILE
COAKLEY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

by: J. F. Kick PhD
Geophysicist
Aug. - Sept. 1987
FIGURE 7
MAGNETIC PROFILES
COAKLEY LANDFILL
NORTH HAMPTON,
NEW HAMPSHIRE

by: J. F. Kick PhD
Geophysicist
Aug. - Sept. 1986
Figure 8
Magnetic Profiles
Coakley Landfill
North Hampton, New Hampshire

by: J. F. Kick PhD
Geophysicist
Aug. - Sept. 1986

- Magnetic stations
- Regional curve
- Datum

Scale
Vert.: 1 inch = 100 gammas
Horiz.: 1 inch = 100 feet
FIGURE 9
MAGNETIC PROFILES
COAKLEY LANDFILL
NORTH HAMPTON, NEW HAMPSHIRE

by J. F. Kick PhD
Geophysicist
Aug. - Sept. 1966
FIGURE 10  Resistivity Sounding  RS - 001  
Coakley Landfill;  North Hampton, New Hampshire  
J. F. Kick PhD  
Geophysicist  
9/9/86

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Thickness</th>
<th>Resistivity</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>180</td>
<td>Clay, silts, and/or contaminated groundwater.</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>1200</td>
<td>Saturated sand and gravel.</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>K</td>
<td>3200</td>
<td>Bedrock.</td>
</tr>
</tbody>
</table>

**Apparent Resistivity (ohm ft.)**

- 2000
- 1000
- 500
- 200

**L - spacing (ft.)**

- 5
- 10
- 20
- 50
- 100
- 200
- 500

### Observed and Calculated Resistivity

- ... observed
- ... calculated

*RResistivity in units of ohm feet.*
FIGURE 11  Resistivity Sounding RS - 002
Coakley Landfill;  North Hampton, New Hampshire  J. F. Kick PhD Geophysicist 9/9/86

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Thickness</th>
<th>Resistivity</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.5</td>
<td>250</td>
<td>Top soil.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>550</td>
<td>Fine sand - silt.</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>200</td>
<td>Silty clay; possible contaminated water.</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>35</td>
<td>500</td>
<td>Silt - fine sand.</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>K</td>
<td>1000</td>
<td>Sand or till.</td>
</tr>
</tbody>
</table>

*Resistivity in units of ohm feet.

L - spacing (ft.)

... observed
--- calculated
Figure 12  Resistivity Sounding RS - 003  
Coakley Landfill;  North Hampton, New Hampshire  
J. F. Kick PhD  
Geophysicist  
9/9/86

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Thickness</th>
<th>Resistivity* (ohm feet)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>240</td>
<td>Silt - clay or contaminated water.</td>
</tr>
<tr>
<td>15</td>
<td>1650</td>
<td></td>
<td>Saturated sand and gravel.</td>
</tr>
<tr>
<td>30</td>
<td>14</td>
<td>100</td>
<td>Sand and gravel or till with contaminated water.</td>
</tr>
<tr>
<td>40</td>
<td>X</td>
<td>2800</td>
<td>Bedrock.</td>
</tr>
</tbody>
</table>

*Resistivity in units of ohm feet.
FIGURE 13  Resistivity Sounding RS - 004
Coakley Landfill;  North Hampton, New Hampshire

J. F. Kick PhD
Geophysicist
9/9/86

<table>
<thead>
<tr>
<th>Depth</th>
<th>Thickness</th>
<th>Resistivity *</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.5</td>
<td>6000</td>
<td>Unsaturated sand and gravel.</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>2500</td>
<td>Saturated sand and gravel.</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>400</td>
<td>Clay - silt.</td>
</tr>
<tr>
<td>30</td>
<td>K</td>
<td>7000</td>
<td>Bedrock.</td>
</tr>
</tbody>
</table>

*Resistivity in units of ohm feet.

![Graph]
**FIGURE 14**  Resistivity Sounding RS - 005  
Coakley Landfill; North Hampton, New Hampshire  
J. P. Kick PhD  
Geophysicist  
9/9/86

<table>
<thead>
<tr>
<th>Depth feet</th>
<th>Thickness</th>
<th>Resistivity* (ohm ft.)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>200</td>
<td>Sand and gravel.</td>
</tr>
<tr>
<td>20</td>
<td>7</td>
<td>400</td>
<td>Silt and clay.</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
<td>150</td>
<td>Possible contaminated water.</td>
</tr>
<tr>
<td>40</td>
<td>K</td>
<td>1000</td>
<td>Bedrock - possible contaminated water.</td>
</tr>
</tbody>
</table>

*Resistivity in units of ohm feet.

[Graph showing apparent resistivity vs. L-spacing (ft.), marked with observed and calculated lines.]
<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Thickness</th>
<th>Resistivity (ohm-ft)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>9500</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>4000</td>
<td>Dry sand and gravel on bedrock.</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td>Bedrock.</td>
</tr>
<tr>
<td>40</td>
<td>K</td>
<td>5000</td>
<td></td>
</tr>
</tbody>
</table>

* Resistivity in units of ohm-feet.

![Graph showing apparent resistivity vs. L-spacing]