Appendix C
Geophysical Survey Report
DRAFT
RESULTS OF GEOPHYSICAL SURVEY

Operable Unit 2 Landfills, Areas D and F
Former Fort Ord, California

TERC Contract DACW05-96-D-0011

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### Acronyms and Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>bgs</td>
<td>below ground surface</td>
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<td>GPR</td>
<td>ground penetrating radar</td>
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<td>GPS</td>
<td>global positioning system</td>
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<tr>
<td>mS/m</td>
<td>milliSiemens per meter</td>
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<td>Shaw</td>
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1.0 Introduction

This report presents the results of a geophysical investigation conducted by Shaw Environmental, Inc. (Shaw) at the Fort Ord Landfill Gas System Expansion at the Operable Unit 2 Landfills Areas D and F, former Fort Ord, California. This investigation was performed under Total Environmental Restoration Contract DACW05-96-D-0011. The investigation at Area F was conducted in January 2005 and at Area D in October 2007.

1.1 Objectives

The objective of the investigation was to locate buried trenches and the berms separating these trenches in order to install interior extraction wells at both sites. Shaw Environmental, Inc. utilized frequency domain (EM-31 MK2) and time domain electromagnetics (EM-61 MK2) as well as ground penetrating radar (GPR) to assess their locations at Area F. The Area F field area covered approximately 1.75 acres, and all three survey methods were performed in the same day subsequent to occasional rainy conditions leaving saturated ground conditions.

Due to a thick cover of approximately 20 feet of fill material at Area D, Shaw used an EM-34 frequency domain system. The Area D field area was approximately 2.2 acres.
2.0 Instrumentation

The following describes the instruments used during the geophysical survey conducted at the Operable Unit 2 Landfills. The deployment strategies for these systems are described in more detail in Section 3.0.

2.1 Geophysical Instruments

The following sections present description and capability of the different geophysical instruments used in Area F and Area D of the Operable Unit 2 Landfills.

2.1.1 Time-Domain Electromagnetics (EM61) – Area F

The Geonics EM61-MK2 electromagnetic time-domain electromagnetic (TDEM) metal detector (EM61) was used to acquire TDEM data at the Landfill Gas System Expansion at former Fort Ord. The EM61 is a four-channel high-sensitivity TDEM sensor designed to detect shallow ferrous and nonferrous metallic objects with good spatial resolution and minimal interference from adjacent metallic features.

The EM61 consists of two 1-meter by 0.5-meter rectangular coils stacked 40 centimeters apart with the source/receiver coil located below a second receiver coil. An electromagnetic pulse induces subsurface eddy currents with an associated secondary magnetic field. The decay of the secondary magnetic fields induced in subsurface materials are subsequently measured by the receiver coil and stored as milliVolts. Although the EM61 is capable of measuring a differential, calculated as the voltage difference between the top and bottom coils, for this project, data is being recorded at four time gates from the bottom coil as this typically proves better for larger and deeper material. The responses at these four specified time gates are recorded and displayed by an integrated system data logger. In practice, typical scattered metal debris can be located up to a depth of about 3 to 4 feet below ground surface (bgs) and large masses of metal may be detectable to approximately 7 to 9 feet bgs depending on surface and ground conditions.

The TDEM survey data are typically presented as a plan-view contour map. The maps are color-enhanced to aid in interpretation of subtle anomalies. The data can also be presented as profile data along any given profile.

2.1.2 Frequency Domain Electromagnetic Induction (EM31) – Area F

Frequency domain electromagnetic was used at former Fort Ord to assess the location of buried nonmetallic and metallic materials. The EM31 (Geonics, LTD) was utilized, which is commonly used to explore for buried metallic and nonmetallic debris to a depth of up to 18 feet. A Geonics EM31 terrain conductivity meter is commonly used to delineate landfill boundaries as it detects both buried metallic and nonmetallic debris.
The electromagnetic instrumentation consists of a transmitter coil at one end and a receiver coil at the other. An alternating current is applied to the transmitter coil, causing the coil to radiate a primary electromagnetic field, which generates eddy currents in conductive subsurface materials. These eddy currents have an associated secondary magnetic field with a strength and phase shift (relative to the primary field) that are dependent on the conductivity of the medium. The combined effect of the primary and secondary fields is measured by the receiver coil. Two components of the signal are measured. Components that are both in-phase (in-phase) and 90 degrees out-of-phase (quadrature) are measured. The quadrature component, also referred to as terrain conductivity, is representative of the conductivity of subsurface materials (in milliSiemens per meter [mS/m]). The in-phase component is an approximation of metal detection.

The Frequency Domain Electromagnetics survey data are typically presented as plan-view contour maps of both terrain conductivity and the in-phase component. The maps are color-enhanced to aid in interpretation of subtle anomalies. The data can also be presented as profile data along any given profile.

2.1.3 Ground Penetrating Radar – Area F
The GPR equipment utilized during these investigations consists of a GSSI SIR-2P system equipped with a 200-megahertz monostatic antenna. During a GPR survey, an antenna containing both a transmitter and a receiver is slowly pulled along the ground surface. The transmitter radiates short pulses of high-frequency electromagnetic energy into the ground. When the wave encounters the interface between two materials having different dielectric constants (dielectric permittivity), a portion of the energy is reflected back. The contrast in dielectric permittivity between the two media can be quantified by a reflection coefficient at the media interface. The magnitude of the reflection coefficient increases as the contrast in dielectric constant increases. The signal is transmitted to a control unit, displayed on a color monitor, and digitally recorded.

The GPR can be an effective tool for waste debris location due to the fact that it will detect all metallic and nonmetallic objects as long as their dielectric constant differs from that of the background material and is within the depth of penetration of the particular ground and subsurface conditions. Generally the surveyed area will be conducted in lines perpendicular to the expected direction of the trenches.

2.1.4 Frequency Domain Electromagnetics (EM-34) – Area D
Electrical conductivity is a physical property of soils and rock that determines how well that material will support the conduction of electrical currents. Materials such as dry, pure quartz sand would have very low electrical conductivity, clays would have higher electrical conductivity values, and saline groundwater would have very high electrical conductivity.
Generally, electrical conductivity of earth materials increases with increases in porosity, clay content, fluid saturation, and specific conductance of the saturant. The units of electrical conductivity are in mS/m. Sometimes we also refer to the inverse of conductivity, which is electrical resistivity. The units of electrical resistivity are ohm-meters.

The frequency domain electromagnetic method is commonly used in the industry to delineate landfill materials. The heterogeneous nature of the materials and high conductivity contrast caused by buried metallic objects and other materials make landfill materials a good target for the methodology.

The Geonics EM-34 Terrain Conductivity meter is an active geophysical technique for measuring the in situ electrical conductivity of the subsurface. By an “active” technique, we mean that we use a controlled source to inject electromagnetic waves into the ground and a sensor to observe how the ground reacts to these waves. In doing so, we measure the in situ electrical conductivity of the ground. The EM-34 accomplishes this measurement of bulk ground electrical conductivity using a pair of wound wire coils. One coil, the transmitter coil, is fed an alternating electrical current of fixed frequency. The current in the loop creates an alternating magnetic field (“primary field”) whose dipole direction is perpendicular to the plane of the coil (electromagnetic effect). The alternating primary magnetic field then interacts with subsurface materials. If those materials have some electrical conductivity, then the primary field causes weak electrical currents to flow in the ground. These weak currents in turn cause their own weak magnetic field (“secondary field”), which is out of phase with the primary field and is detected using a second coil (receiver coil). The component of the secondary field that is 90 degrees out of phase (“quadrature phase”) with the primary field has been shown to be directly proportional to the bulk electrical conductivity of the ground.

The depth of penetration for the EM-34 electromagnetic system depends on the distance between the two independent coils, the frequency of the alternating electrical current, and the orientation (vertical dipole or horizontal dipole) of the coils. Generally, the farther apart the two coils are the deeper the system “sees.” Vertical dipole orientation (coil laying flat on the ground) sees deeper (approximately 1.5 times the coil spacing) than horizontal dipole (upright coils) orientation, which sees approximately 0.75 times the coil spacing. The selectable coil spacings for the EM-34 system are 10 meters, 20 meters, and 40 meters. Due to the reported fill material covering the Operable Unit 2 Landfill the EM-34 system was chosen.

2.2 Navigation Equipment

The following sections discuss the navigation equipment used during the geophysical surveys.
2.2.1 Trimble Pro-XRS

Differential global positioning system (GPS) technologies provide location data at approximately 1.5 foot, real time accuracy. For this project, Shaw utilized the single frequency, Trimble Pathfinder Pro XRS. The Pro XR GPS system was used in conjunction with the EM31, EM61, and GPR systems. For the EM31 and EM61, GPS data was obtained in conjunction with the geophysical data. This assures that every data point has an associated northing and easting coordinate. Therefore, positional accuracy is tied into each geophysical map. For the GPR survey, the GPS was used to collect points every 10 feet along each GPR profile.

The availability of sufficient satellite coverage dictates the appropriate use of GPS. Two factors dictate sufficiency of satellite coverage: the view of the sky from the survey site, and the number and height of GPS satellites above the survey site. Tree coverage and proximity to buildings and topographic features such as cliffs and steep hills affect access to a clear view of the sky. The orbits of the GPS satellites can be readily viewed through use of GPS planning software such as Trimble’s Quick Plan software. By reviewing the satellite availability on a daily basis, optimal survey periods can be defined, and periods of poor satellite visibility coordinated with rest times, preventative maintenance, data downloading, and travel. The site conditions at former Fort Ord were favorable for the use of GPS at all sites due to the lack of high vegetation and buildings.
3.0  **Geophysical Survey Procedures**

The elongated shapes of the geophysical survey areas were chosen such that all of the trenches were crossed perpendicular to the assumed length of the trenches. The Area F survey was conducted in this manner so as the high resolution instruments crossed the interface from berm to trench several times along its length; it would create a high definition map of the trench edges. The entire length of the trenches was not surveyed as only a small area was needed for well installation.

The Area F field area was approximately 1,200 feet by 70 feet. The proposed well locations were along the central access road at Area F so the geophysical traverses were parallel to the road, which was perpendicular to the trenches.

The Area D field area was approximately 350 feet by 275 feet. The EM-34 geophysical traverses were conducted northwest-southeast, which is the assumed perpendicular direction. A site access road ran northeast-southwest through the area. Therefore the geophysical traverses were perpendicular to the access road.

3.1  **EM61-MK2 Electromagnetic Survey – Area F**

The EM61-MK2 data were collected in conjunction with the Trimble ProXRS that was carried on the back of the geophysicist approximately 8 feet in front of the center of the EM61-MK2 coils. Data were collected in an approximate east-west direction, following the path of the bordering gravel road with a line spacing of approximately 5 feet. For the first survey, each traverse was marked by lines spray painted by a second geophysicist traveling at a minimum of 10 feet behind the instrument. The GPS data streamed from the GPS data directly into the Allegro data logger of the EM61-MK2. The four-channel electromagnetic and GPS data were stored in the EM61-MK2 Allegro data logger and were downloaded following the field activities.

3.2  **EM31 Electromagnetic Survey – Area F**

The EM31 data were collected in conjunction with the Trimble ProXRS that was carried on the back of the geophysicist approximately centered over the midpoint of the EM31. Data were collected in an approximate east-west direction, following the path of the bordering gravel road with a line spacing of approximately 10 feet. As the EM61 data was first collected prior to the EM31, the painted lines were used also for this survey but due to the larger sampling space of the EM31, only every other line was used. The GPS data streamed from the GPS data directly into the Allegro data logger of the EM31. The four-channel electromagnetic and GPS data were stored in the EM31 Allegro data logger and were downloaded following the field activities.
3.3  **Ground Penetrating Radar Survey – Area F**

Subsequent to the collection of both electromagnetic data sets their data was downloaded and a quick field processing procedure was conducted in order to assess the best possible locations to collect GPR profiles. Two parallel profiles were collected that were approximately perpendicular to the trenches and each 150 feet in length. Two additional 150-foot profiles were collected starting from the endpoints of the previous profiles that effectively increased the length of each profile to 300 feet. The GPR data was stored on the hard drive on the GPR console and later downloaded to a computer subsequent to the field effort.

3.4  **EM-34 Electromagnetic Survey – Area D**

The EM-34 data were collected in conjunction with the Trimble ProXRS. Data were collected in a northwest-southeast direction along three traverses in the area. The traverses were conducted approximately perpendicular to the site access road which runs northeast-southwest. Due to the thick cover of fill and objective of the investigation the traverses were approximately 50 feet apart. Several repeat traverses were conducted. Ten meter horizontal dipole, 10 meter vertical dipole, 20 meter horizontal dipole, and 20 meter vertical dipole traverses were conducted. The four traverses were conducted to cover the depth interval in case materials were deeper than expected. One or two traverses were expected to give the best results depending on the site-specific subsurface conditions and depths.

Each of the traverses required a two man crew. Each field crew member had to control the dipole orientation of their given coil, as well as coordinate on the exact coil spacing (as displayed on the instrument console). The GPS data streamed from the GPS data directly into the data logger for the EM-34 and were downloaded following the field activities. Stakes were also used to mark each traverse and the locations of the traverse endpoints and stakes were also shot in with GPS later to backcheck locations. The electromagnetic and GPS data were stored in the EM-34 data logger and were downloaded following the field activities.
4.0 **Geophysical Data Processing**

This section presents the methods and software used to process the data collected from geophysical surveys.

4.1 **EM61 Data Processing**

Geonics DAT61-MK2 for Windows software was used to download the EM61 data to a laptop in the field. The EM61 data sets were verified and subsequently backed up prior to system demobilization. This software merges both of the datasets from the GPS and EM61 into a single xyz file with a coordinate for every EM61 data point collected. The resultant xyz file was imported into Geosoft’s Oasis montaj as this was used for post-processing, analysis, and map creation. Final map products were produced in ArcMap and are displayed as color enhanced contour maps with surface features overlain for reference and interpretation.

4.2 **EM31 Data Processing**

Geonics DAT31W for Windows software was used to download the EM31 data to a laptop in the field. The EM31 data sets were verified and subsequently backed up prior to system demobilization. This software merges both of the datasets from the GPS and EM31 into a single xyz file with a coordinate for every EM31 data point collected. The resultant xyz file was imported into Geosoft’s Oasis montaj as this was used for post-processing, analysis, and map creation. Final map products were produced in ArcMap and are displayed as color enhanced contour maps with surface features overlain for reference and interpretation.

4.3 **Ground Penetrating Radar Processing**

The GPR data was downloaded from the GPR console unit and color enhanced for ease of viewing. The two separate lines in each profile were also merged into one continuous profile, resulting in two parallel, composite profiles.

4.4 **EM-34 Data Processing**

Geonics DAT34 software was used to download the EM-34 data to a laptop in the field. The EM-34 data sets were verified and subsequently backed up prior to system demobilization. This software merges the both of the datasets from the GPS and EM-34 into a single xyz file with a coordinate for every EM-34 data point collected. The resultant xyz file was imported into Geosoft’s Oasis montaj as this was used for post-processing, analysis, and map creation. Final map products were produced in ArcMap and are displayed as color enhanced contour maps with surface features overlain for reference and interpretation.
5.0 Results

The results of this geophysical survey are presented on Figures 1 through 5. Figure 1 and Figure 2 are maps of the EM31 in-phase component (parts per thousand) and ground conductivity (mS/m) data, respectively. Figure 3 depicts the EM61, bottom coil response in milliVolts. Figure 4 and Figure 5 are the composite GPR profile data of the two 300 foot, parallel GPR lines collected during this survey. All of the maps are displayed in the coordinate system North American Datum 83, California State Plane Zone 4, United States survey feet. The following section discusses the results of the geophysical surveys.

5.1 EM31 Electromagnetic Results – Area F

The EM31 data are presented on Figure 1 and Figure 2. Of all of the data collected, these data provide the best indication of the lateral extents of the trenches. Figure 1 depicts the EM31 in-phase component of the data. The in-phase component is an approximation of metal detection, and this proved to delineate the inferred boundaries of the trenches with greater definition than other methods. Dashed lines were plotted on the maps primarily from the results of this dataset (although, with input from the other datasets) indicating the presence of material believed to be metallic debris within the trenches. Post processing and filtering results indicate that the rage of the data values is quite small at -2 to 2 parts per thousand. Maximum data values are typically -20 to 20 parts per thousand for large amounts of high density metal, at or near surface.

Figure 2 depicts the terrain conductivity and depicts a signal similar to that of the in-phase data, although the definitions of the boundaries of all of the apparent trenches do not appear to be as evident as the in-phase data. This could be due to a variety of reasons including ground conditions at the time of the survey. Recent rains had left the ground saturated with water, which can greatly affect the overall ground conductivity. Post processing and filtering results indicate that the rage of the data values is moderate at 0 to 20 mS/m. Maximum data values for extremely conductive material at or near the surface are typically up to 200 mS/m.

5.2 EM61-MK2 Electromagnetic Results – Area F

The EM61 data are presented on Figure 3. Although the trenches are not as well defined as they are in the EM31 data, debris appears to be evident, particularly near the eastern side of the field, in which there is slightly lower elevation. It is assumed that this may be due to a thinner layer of cap material near the edge of the trenches. The deviations found in the anomalies that differ from the EM31 data are believed to be due to debris at or near the surface that was scattered somewhat during activities associated with capping the trenches. As the EM61 is more sensitive to material near the surface and the total depth of penetration is less than that of the EM31, these
deviations from the trench boundaries are more evident. Dashed lines interpreted from the
EM31 in-phase data are included on this map to aide in comparing the lateral extents of the
anomalous areas interpreted as metal debris. Post processing and filtering results indicate that
the range of data values for the EM61 range from 0 to 100 milliVolts. Data values with dense
metal at or near the surface can extend to over 2,000 milliVolts.

5.3 Ground Penetrating Radar Results – Area F
The GPR data are presented on Figure 4 and Figure 5. These data include four separate files of
two different profiles, which consisted of two 150-foot profiles merged together to create a
single continuous profile. Dashed lines displayed bound areas of less disturbance than the
surrounding area. These areas are also displayed in map view as areas of low reflectivity and
correlate well with the other data methods.

5.4 EM-34 Electromagnetic Results – Area D
The EM-34 data are presented on Figure 6, “Map of EM34 Ground Conductivity and Traverses –
Area D.” Of all of the data collected (10 meter horizontal dipole, 10 meter vertical dipole,
20 meter horizontal dipole, and 20 meter vertical dipole) the 10 meter horizontal dipole furnishes
the best resolution of the landfill trench materials. In general, site conductivities range from 10
to greater than 30 mS/m. This narrower range is likely due to the fill materials, which tend to
repress conductivity values due to the effect or presence (averaging) of the fill material cover.
This effect is very typical for site conditions as described. The three traverses are also indicated
on Figure 6 as well as the site access road.

The interpreted landfill materials are represented by conductivities greater than approximately
19 mS/m (yellow and red colors). Note that there is a “relative low conductivity area”
approximately under the access road. The resolution of that area is not real high due to the depth
to the landfill materials (anomalies always larger the deeper they are). The overall area is
approximately 150 feet by 100 feet. The highest conductivity values are located in the southeast
section of the interpreted area. These higher conductivities likely represent the thickest
accumulation of subsurface landfill materials.

Figure 7, “Map Showing Proposed Boring Locations – Area D,” is a map of the interpreted
Area D (same data as Figure 6), which shows four proposed boring locations.
6.0 Conclusions and Recommendations

This section presents the proposed boring locations based on the results of the geophysical surveys conducted in Areas D and F.

6.1 Area F

The data set most indicative of geophysical signals representing parallel subsurface debris trenches is the EM31 in-phase component. Both this and the EM31 ground conductivity exhibited similar geophysical signatures that indicate as many as 18 trenches that exist in a sub parallel manner trending approximately north-northeast. Both of the EM31 methods have a maximum depth of penetration of approximately 18 feet bgs, although in practice typically 15 feet bgs is the deepest expected depending on surface and subsurface conditions.

The EM61 data was less conclusive. Although, many anomalies were evident in the data, they did not appear to clearly distinguish the locations of the trenches as the EM31 data did. This may have occurred for a variety of reasons, including surface and/or subsurface conditions, depth of anomalies, or various metals not associated or somewhat associated with the trenches that are not directly located inside the trenches (the EM61 is extremely sensitive to shallow small metallic debris). Realistic depths of penetration for the EM61 are about 4 to 5 feet bgs. It is believed that these trenches may be near the maximum detection limit of this instrument in the local ground conditions. It is also understood that as the cap was being placed on these trenches, some of the material was moved from the trenches to a small degree. These perturbations of the trench outlines in the anomaly may be due to this fact.

The GPR data provided some indication of a lack of reflectivity as exhibited on the figures that are interpreted to be associated with the berms in between the trenches. Although it is not believed that the reflective areas represent the debris within the trenches themselves, it is believed that the chaotic nature of the signal may be due to disturbed material or settling of material over the top of the trenches and therefore the signal is associated with the trenches. The location of these areas of nonreflectivity also correlate with the area interpreted as berms, as evident on Figure 1 and Figure 2.

It is recommended that drilling targets be chosen from those berms evident and marked in the EM31 data and verify that these locations are on the expected high location in topography across the site that indicates a lack of subsidence as expected in the areas in which trenches exist.

6.2 Area D

The Area D site was best resolved by the 10 meter horizontal dipole data. A 150 foot by 100 foot possible “berm” area was identified under the access road. The resolution of the berm
area is more difficult at Area D since the materials have a cover of approximately 20 feet of fill material. This tends to force the electromagnetic system to over-average all subsurface materials, which reduces the resolution of the area limits. However, an indication of the interpreted “berm” between possible trenches is expressed subtly in the data. Figure 7 is a map of the interpreted Area D (same data as Figure 6), which shows four proposed boring locations.
LEGEND

Survey Line
Road

Proposed EW35 Location
Survey Marker

Conductivity (mS/m)

11 17 18 19 20

1 = 5745847E, 2135761N
2 = 5745870E, 2135745N
3 = 5745806E, 2135671N

2A = 5745870E, 2135735N

SCALE

0 25 50 METERS

DEPARTMENT OF THE ARMY
ENGINEERING DISTRICT, WEST COAST DIVISION, SAN FRANCISCO, CALIFORNIA.

FIGURE 7
MAP SHOWING PROPOSED BORING LOCATIONS
AREAD

FORERIER FORT SRO, CALIFORNIA

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