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Report of Demonstrations of Two Geophysical Survey Techniques Fernald Environmental Management Project Cincinnati, Ohio

20400-RP-0003
Revision 0-Final

Prepared for

Fluor-Fernald

June 4, 2000

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Executive Summary

Two non-destructive geophysical survey methods were demonstrated in four task areas at the Fernald Environmental Management Project (FEMP) during January through March, 2000. The geophysical survey methods included Electromagnetic Terrain Conductivity Profiling (EM) and Ground-Penetrating Radar (GPR) augmented by an advanced 3-D visualization technique. Among the objectives of these surveys were to observe and evaluate the performance of these methods on real-world applications at the FEMP site. EM conductivity surveys were performed in three of the task areas and illustrated the use of EM in different survey settings for different exploration objectives. These surveys demonstrated the use of EM as a rapid, reconnaissance level site-screening tool. EM is useful for buried object and subsurface condition exploration and mapping. GPR surveys were performed in two of the task areas. The objectives of the GPR surveys included demonstrating the application of GPR for targeted exploration of the shallow subsurface. GPR was used to investigate various targets including utilities, structures and other anomalous objects and features in different survey settings. The use of advanced visualization techniques shows how GPR data interpretation is enhanced through the use of high-resolution, quasi-three-dimensional images of the subsurface. The GPR results provided additional insight into the nature and distribution of various subsurface targets including buried metallic and non-metallic objects, fill areas and some utility piping. The results of the EM and GPR surveys may be used by FEMP to help guide future site exploration and remediation efforts and will help determine where these geophysical methods may have value at other areas on site.

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1.0 Project Overview

Fluor-Fernald is engaged in a variety of environmental site investigation and remedial activities at the Fernald Environmental Management Project (FEMP) located outside of Cincinnati, Ohio. Many of the activities at FEMP require general or detailed knowledge of the subsurface before invasive subsurface work tasks can be performed. Because of the costs and inherent hazards associated with some of these site activities, various non-destructive subsurface exploration tools can play a valuable role in helping to remotely characterize shallow subsurface. Two non-destructive geophysical tools were selected for demonstration purposes in four task areas at the FEMP site, and included:

- Electromagnetic Terrain Conductivity Profiling (EM), and
- Ground-Penetrating Radar (GPR)

The four Task areas are noted on Figure 1 and summarized on Table 1. The survey areas were chosen in part to demonstrate and evaluate the performance of these methods in a variety of survey settings and to explore potential subsurface targets of real interest at the FEMP site (e.g., anomalous buried objects and fill areas, piping and structures, etc.).

Survey Task Area	Method(s) Used, Location and Task Description (Figures)
I	**EM**; Selected Transects; Wooded area, variable topography, East of Paddys Run (Figures 2-4)
II	**EM, GPR**; Gridded survey areas; Partially wooded to grassy and open, Northeast of Paddys Run (A2P1 area, Figures 5-18)
III	**GPR**; Gridded Survey area; Utility Corridor, gravel roadway and vicinity (Figures 19-22)
IV	**EM**; Gridded Survey area; Active Flyash Pile perimeter, open and grassy (Figures 23-26)

Table 1. Geophysical Demonstration Survey Areas

The ground surface conditions varied between open, grassy regions (Tasks II and IV) to densely overgrown and wooded areas (Tasks I and II [partial]). The topography within most of the survey areas was fairly level along with some low earth mounds, ridges and slopes. The exceptions were in the Task I area where steep slopes and dense vegetation were present along some transects. The densely wooded areas in particular presented the most problems for the performance of both methods and particularly for GPR. The shallow soil conditions are reportedly glacial silts and clays and mixed alluvial materials overlying the deeper sand and gravel aquifer. The shallow water table in the various task areas ranges from a few feet to several tens of feet below the ground surface. During the January survey, several inches of snow was present throughout the Task II area.

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2.0 Methodology

The two geophysical methods demonstrated and evaluated at the FEMP site were:

- Electromagnetic Terrain Conductivity Profiling (EM), and
- Ground-Penetrating Radar (GPR)

The following paragraphs provide only a very brief overview of these methods, their applications and limitations. More in-depth information is available through the technical references listed in Section 7.0 and in Appendices A and B for EM and GPR, respectively.

Electromagnetic Terrain Conductivity Profiling

The EM terrain conductivity profiling instrumentation make two measurements useful for environmental site investigations: (1) soil electrical conductivity (quadrature phase) and (2) in-phase (metallic sensitive). Terrain conductivity is a useful measurement for mapping spatial variations in soil and fill types based on contrasts in electrical conductivity. The in-phase measurement is most sensitive to buried metallic objects and can be used to locate and map buried reinforced steel structures, barrels, underground storage tanks, pipes and utility lines, and other buried metallic structures or highly conductive debris.

EM conductivity surveys are widely used as reconnaissance level site screening tools and for more detailed buried object detection and mapping. The method works well over large areas where potentially large conductive targets or variations in conductivity are of interest. The amount of coverage will depend on the survey parameters used including the line and station spacing, although a few acres to several tens of acres per day are not uncommon productivity rates. The maximum depth of exploration is considerably deeper than that for GPR. The exploration depth was probably on the order of 15-ft to 25-ft at the FEMP site. The actual exploration depth is difficult to determine and depends on several factors as noted in Appendix A.

Most EM systems, including the GSSI GEM-300 that was used on this project, are lightweight and portable and require one field operator. The EM response can be monitored in the field continuously and recorded electronically. The GEM-300 provides a real-time graphical and numerical display of the data. The data are easily downloaded to a PC and both data channels (conductivity and in-phase) can be contoured using commercially available contouring programs.

Limitations to the use of EM arise from a variety of electrical interference sources that include: ambient electrical noise such as occurs in urban or densely developed areas, thunderstorms and nearby metallic objects at or above the ground surface such as fences, debris piles, overhead power lines, parked cars, reinforced concrete structures, buried foundation walls, etc. The presence of various metallic surface obstructions can limit or even preclude any interpretation of the EM data in the vicinity of these obstructions. EM surveys are less effective or impossible in steep, unstable, flooded, densely vegetated, overgrown or otherwise obstructed areas. Specific targets of interest can be obscured by some of the factors noted above. Older models of the GEM-300 are known to suffer from some thermal instability and the readings may drift slowly in response to daily temperature variations and instrument warm-up.

Ground-Penetrating Radar

Ground-Penetrating Radar (GPR) has been used as a site investigation tool for diverse applications for several decades. The 3-D GPR approach is not so much a new geophysical technique as it is an interpretation enhancement to conventional GPR procedures. Aspects of both conventional GPR and 3-D GPR surveys were demonstrated at FEMP on this project.

Ground-Penetrating Radar (GPR) operates by transmitting and receiving microwave electromagnetic impulses. By moving a broadband, dipole antenna across the ground surface, an qausi-two-dimensional cross-section of the subsurface can be displayed on the GPR system unit in real-time. GPR is sometimes described as a kind of pulse-echo device, not unlike sonar or an acoustic fish finder. In contrast to these acoustic devices, however, GPR operates by using electromagnetic signals that are governed by the principles of electromagnetic wave propagation through the subsurface. Transmitted GPR impulses propagate downward through the subsurface, reflect off buried target boundaries and return to the receiver antenna. Contrasts in the electrical properties of a target will cause some of the GPR signal to reflect back toward the ground surface. Interfaces between electrically distinctive materials such as sand and clay, backfill and steel, concrete and soil, and the water table can be detected using GPR under favorable survey conditions. The technical basis for GPR is described in Daniels (1989), Davis and Annan (1989), Powers (1995), and Conyers and Goodman (1997). A comprehensive review of GPR is also available on the Internet at www.g-p-r.com.

3-D visualization of GPR data is a recently developed approach that allows the interpreter to use high-resolution three-dimensional images of the shallow subsurface. The goal of 3-D GPR is to help visualize and interpret complicated subsurface features and their spatial relationships using conventional GPR field data.

3.0 Field Procedures

Grumman Exploration, Inc. conducted EM surveys at FEMP in Task areas I, II and IV on January 25 and 27, and March 2, 2000. GPR surveys were conducted in the Task II and III areas on February 16 and 17, 2000. Table 1 identifies the Figures associated with each task area survey.

Survey Grids

Survey grids and transect lines was established by Fluor-Fernald land surveyors and Grumman Exploration, Inc. prior to each survey. Pin-flags or paint marks were placed at measured, fixed intervals. The field coordinate systems used for geophysical surveys differed from the true site coordinate system. Fluor-Fernald accurately surveyed selected field grid coordinate positions. Using these survey data, various mathematical corrections were applied to the field grid coordinates to convert the field data coordinates to the true site coordinate system. Engineering drawings of each survey area were provided by Fluor-Fernald and were used as overlays on various Figures in this report. Both the field and true coordinate systems are indicated on some of the survey diagrams.

EM Conductivity Surveys

The instrumentation used for the various task area surveys consisted of a GSSI (Geophysical Survey Systems, Inc.) GEM-300 multi-frequency electromagnetic profiling system. Vertical dipole quadrature phase (proportional to terrain conductivity) and in-phase (metal sensitive) measurements using a single, in-line coil alignment at three frequencies (2,070 Hz, 4,350 Hz and 9,810 Hz) were recorded electronically at each measurement location (9,810 Hz approximates the frequency used by the Geonics, Ltd. EM-31 system). Table 2 summarizes the various survey statistics for each survey area. A "continuous survey" mode was used over the gridded survey areas. In this survey mode, data are acquired at a fixed time interval while the operator moves along a survey line at a steady walking pace. Reference marks at flagged locations are incorporated into the data during acquisition to fix the measurement locations. The reference flags were spaced every 50-ft in Task areas II and IV and at irregular intervals in Task area I. Subsequently a computer program is used to adjust the station positions with respect to the coordinate system being used.

The conductivity readings are reported in relative units of milli-Siemens per meter (mS/m) and the in-phase in parts-per-million (ppm). The GEM-300 conductivity readings are considered relative since no absolute conductivity calibration/reference locations were available on site and the instrument experienced some thermal drift effects (the Task II EM survey was performed under very cold, snow covered conditions). The in-phase results are also considered relative and only large deviations (positive or negative) should be considered meaningful for interpreting the presence of metal objects. The in-phase response in the absence of conductive or metallic conditions should be centered around zero ppm. In general, buried conductive objects appear as strong positive conductivity or in-phase anomalies (orange and red on contour diagrams) and above-ground metallic objects appear to cause strong negative conductivity and in-phase deviations (blue and purple on contour diagrams).

	EM Survey Area		
EM Survey Parameter	**Task I**	**Task II**	**Task IV**
Area of coverage - approx. (acres or linear ft)	5,725 ft[1]	2.3 a	0.24 a
Line Spacing (ft)	N/A	5	2
Station Spacing (ft)	~1.6 - 1.7[1]	~1.6 - 1.7	~1.6 -1.7
Meas. Stations (#)	4,580	11,947	3,070
Duration of Survey (hrs, m)[2]	4.5 h	4.75 h	35 min

[1]Approximate footage - over rough terrain
[2]First reading to last reading based on time-stamp, includes intervening breaks, down-time, etc.

Table 2. EM Survey Area Parameters and Statistics

Following each task area survey, the data were downloaded onto a laptop computer and prepared for contouring. The Task I and II area data appear to show some thermal drift effects possibly because of the extreme cold temperatures encountered during the surveys. A computer program was developed and used to help correct some of the drift effects. Portions of the final contoured data show slight artificial biases created by the drift correction program and these appear to occur in the vicinity of the anomalous conductivity and in-phase responses noted on Figure 4. The EM data were contoured using a commercially available program (Surfer, Golden Software, Inc.). For the Task I results, the quadrature (conductivity) and in-phase measurements are presented as X-Y profile plots on Figures 2 through 4. Only the 9,810 Hz survey frequency is presented because of the similarity of the data for the three survey frequencies. The Task II and IV results are presented as color contour diagrams.

Ground-Penetrating Radar

The Task II and Task III areas were surveyed using GPR in the locations indicated on Figures 13 and 19. Table 3 summarizes the various GPR data acquisition parameters.

The GPR system used was a Geophysical Survey Systems, Inc. SIR-2 in conjunction with a 200 MHz dipole antenna for Task II. A higher resolution, shallower sensing 400 MHz antenna was used for Task III. The GPR system used requires only minimal system calibration and check-out procedures. The initial survey set-up consisted of performing simple system checks (power, connections, etc.) followed by running several test scans. During the performance of the test lines, some of the data acquisition parameters were adjusted. A survey wheel was used to acquire distance-based data at the density of approximately 10.1 GPR traces per foot (~1 trace every inch).

GPR Survey Parameter	GPR Survey Area Task I	GPR Survey Area Task II
Antenna(s) Used	200 MHz	400, 200 MHz
Range (time window in ns)	150 ns	60 ns
Line Spacing	2-ft and selected scan lines	2-ft
No. of scan lines (data storage size MB)	64 (59.9 MB)	122 (32.9 MB)
Linear Feet of coverage	5843-ft	3200-ft
Duration	~4 h	~5 h

Table 3. GPR Survey Parameters and Statistics

Time windows (ranges) of 60 nanoseconds (ns) and 150 ns were used for the 400 MHz and 200 MHz antennas, respectively. Different time-variable gain functions and broad bandpass filters were used for the 400 and 200 MHz antennas. The filters were applied during acquisition to reduce extraneous interference. The field records were displayed in real time and observed in the field during acquisition. All data were recorded electronically on the internal hard disk in the field and later transferred to a desktop or laptop PC computer and *Silicon Graphics, Inc. Indy* workstation for subsequent processing, display and analysis.

While many of the significant GPR features were apparent on the raw GPR field records, supplemental data processing was performed to enhance the interpretation and presentation of these features. Figure A.3 illustrates the effects of these digital data processing procedures. An overview of GPR principles, including data processing and analysis, is provided in Appendix A. The data processing consisted of bandpass filtering, and spatial filtering (f-k) to suppress horizontal banding (antenna coupling) within the GPR records. Using the processed GPR records, three-dimensional (3-D) representations of the GPR data were developed to help visualize and interpret the data. Some subsurface features can be interpreted on the basis of recognizing various characteristic GPR reflection response patterns and their spatial configuration. Many reflection responses apparent on the 2-D records in Task II could not be categorized and are identified as significant but anomalous.

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4.0 Analysis and Interpretations

The following paragraphs summarize the significant geophysical survey findings from the FEMP site. A general summary of the EM and GPR findings from the four task areas are presented first. Next the results for the individual task areas are summarized in order of the specific EM and then the GPR findings for each area. The Figures illustrating these results are noted below and summarized in Table 1.

General EM Survey Findings

Based on the EM surveys performed at the FEMP site, the following general findings were noted:

- Reconnaissance-Level Survey Tool Large gridded areas can be surveyed relatively quickly. Several acres per day using a fairly dense grid line and station density can be expected in relatively open and unobstructed areas. Lower rates of coverage can be expected in more obstructed, overgrown or ungridded areas.
- Performance The EM system used at the FEMP site is portable, relatively simple to operate and requires a single operator. The EM instrument does not come in contact with the ground and single or multiple-frequency data can be acquired at a normal walking pace. The data are displayed in real-time, recorded digitally and are easily transferable to a PC for further analysis and presentation using widely available software.
- Operating Environment The EM surveys were performed in a wide range of settings under differing weather conditions (open, wooded, snow covered, wet, cold). The EM surveys were most effective over the more open and gridded survey areas where two-dimensional survey coverage could be obtained. The EM survey also yielded useful, albeit more general subsurface information along the more densely wooded and overgrown Task I transects.
- Buried Object and Feature Exploration Elevated to anomalous conductivity and in-phase readings were noted in several areas and appear to indicate the presence of buried metallic objects and variations in soil or fill types or geologic conditions. Further exploration would be required to determine the cause of these anomalous targets and conductivity variations. Both large and small but shallow conductive objects appear to have been detected.
- Exploration Depth The effective exploration depth for the various frequencies used was probably on the order of 15-ft to 25 ft according to depth response nomograms provided by the manufacturer. However, most of the observed response is believed to derive from the upper 3-ft to 15-ft of the subsurface based on theoretical response equations (Keller and Frischnecht [1966] , McNeill [1980a, 1980b]). The general similarity of the responses across survey frequencies suggests that the many of the

conductivity/in-phase variations and anomalies occur at fairly shallow depths, perhaps within the upper 10-ft.

- Buried vs. Above Ground Targets The EM results generally indicate that positive (increased) conductivity and in-phase responses occur over or in the vicinity of conductive buried objects. In contrast, strongly negative conductivity and in-phase responses were noted over some ground-level or very shallow (<1-ft) conductive objects (e.g. rebar and metal scrap, reinforced concrete pads, wells).
- Interference The EM response was affected by nearby conductive objects such buildings, fences, guard rails, etc. The approximate area of influence from these objects is on the order of 5-ft to 15-ft and appears to depend on the size and orientation of the metallic object and its position with respect to the actual EM measurement station. Buried objects or conditions in the vicinity of these interference sources may be obscured. The EM readings did not appear to be affected by the overhead power lines located along the northern edge of the survey area.

General GPR Survey Findings

The GPR survey findings for all survey areas are summarized as follows:

- Buried Object Exploration The GPR results appear to have detected numerous shallow reflective objects within the detailed task II survey area. Some of these objects appear to be concrete, stone and/or metallic objects based on the observed reflection responses. A buried former ground surface in the Task II survey area also appears present in this area. One or more piping runs were noted in the Task III area, although not as many pipes could be clearly resolved on the GPR records as are reportedly present in this area. The depth to the tops of these targets can be estimated provided one or more valid calibration locations are available.
- Focussed Exploration Tool GPR performs best when working in smaller, more targeted areas where detailed, higher resolution subsurface information is desired. GPR does not appear to be as effective as EM for use as a general site-screening tool.
- Depth of Exploration The depth of exploration in most of the areas surveyed was probably on the order of 4 to 6-ft. The exploration depth may have been greater within the detailed 3-D GPR survey area within Task II. The presence of moist silty-clay in many of the survey areas probably contributed to the apparent moderate to high signal attenuation effects and the resultant shallow exploration depth. GPR will probably not be effective at FEMP in silty-clay covered areas where exploration depths of over 5-ft to 10-ft are desired. The actual effective exploration depth may vary depending on the survey area conditions and antenna used.
- Operating Environment GPR data acquisition is fastest and easiest over smooth, relatively open and level areas such as mowed grassy fields and gravel or asphalt paved areas. GPR is not restricted in the vicinity of nearby metallic objects or structures except when certain lower frequency, unshielded antennas area used. The

GPR antenna requires close, consistent contact with the ground surface. Consequently, data acquisition becomes slower, more difficult and even impossible in the presence of more dense vegetation, rough, steep or variable, topography, and/or wet, snow covered or flooded areas.

- Performance GPR records were acquired by hand-towing the antenna at a normal walking pace and resulted in up several thousand linear feet of coverage per hour. 3-D GPR surveys with dense survey line coverage can typically cover up to 1/2 to 1 acres per day under favorable conditions. The ruggedized, battery operated and somewhat portable field equipment allows acquisition over some areas of rough, less accessible or wet terrain. The GPR system is built on a PC platform and thus the data are readily transferable to other PC systems for analysis and display.
- Resolution The resolution of specific reflective targets using GPR is on the order of a few inches and is considerably higher than that for EM. A trace acquisition rate of ~1 trace/ft and high sample rates result in high lateral and vertical data resolution displayed as quasi-2D cross-sections. A survey wheel helps maintain greater positional accuracy along each gridded survey line. Selected scans in the Task III area using the 200 MHz antenna achieved poorer resolution of the pipe(s) and did not appear to attain significantly greater depth.
- 3-D Visualization of the Subsurface - 3-D GPR images provided useful representations of the spatial positions and extent of various buried objects. The position of some of the Task III utility piping were readily apparent in the 3-D images although were more difficult to discern on the 2-D GPR records. One to two hours of data processing were required for the preparation of the 3-D data volumes.

Task Area Survey Results and Interpretations

Task I - EM Conductivity Profiling Transects (Figures 2, 3 & 4)

The EM results from the Task I transects showed only minor variability and no significant strong conductivity or in-phase anomalies. The variations in conductivity generally appear as gradual changes that seem related to variations in topographic elevation along each transect. In general, topographically lower elevation areas (closer to Paddys Run) exhibited lower conductivity readings while higher areas showed higher conductivity readings. This may be the result of geologic or soil stratigraphy changes between the high and lower elevations. For example the lower elevation soil and shallow geology may contain greater amounts of sand and gravel (lower conductivity), while the higher elevation areas may be underlain by more silt and clay rich materials (higher conductivity). Some of the smaller scale variations in conductivity could be related to the presence of local concentrations of fill or other disturbed material with conductivity levels that differ from the surrounding background areas. Examples of local conductivity variations are noted on Transects A, C and F (Figures 2, 3 and 4 respectively). More detailed gridded surveys of these areas would be required to map the spatial extent of the large and small-scale variations in conductivity levels. No anomalously strong conductivity or in-phase readings were noted. The slight variations in in-phase readings may be related to system noise or the irregular movement of the instrument along the transects, particularly over the steep slopes or in overgrown areas. The dense vegetation, trees and topographic variations made the EM data acquisition slower and more difficult.

<u>Task II - EM Conductivity Profiling Survey</u> (Figures 5 through 12)
Figure 5 illustrates the EM survey area, site features and the approximate positions of the nearly 12,000 measurement stations. Figure 6 is a site diagram illustrating the general EM survey interpretations. Figures 7 through 12 present the color contoured EM conductivity and in-phase results for the three survey frequencies. The lowest frequency measurements (2,070 Hz) theoretically represent the deepest sensing readings while the highest frequency readings (9,810 Hz) represent a shallower region of the subsurface. The noteworthy findings were as follows:

- A strong, coincident conductivity and in-phase anomaly on all frequencies was observed in the east-central sector of the survey area (around 1348195 E, 476940 N). This EM anomaly is approximately 25-ft across, nearly circular shaped and is centered near the peak of the larger earth mound in this area. The strength and presence of coincident anomalies indicate that the cause of this anomaly is a large metallic object or concentration of metallic objects. Based on this finding, a 100-ft square area centered over this anomaly was chosen for a detailed GPR survey.
- Larger areas of slightly elevated conductivity readings in the north central, east central and southeast sectors may be associated with the low earth mounds, ridges and other topographic variability noted in these areas. The elevated conductivity could represent the response from different soil, stratigraphic or fill materials in these locations. Some of these earth mounds and ridges were also scanned using GPR.
- Moderately elevated to locally anomalous high conductivity readings were observed in the north-central area (east of the well house and southeast of the air monitoring station, Figure 7). This zone is most prominent on the low frequency diagrams and this suggests that the cause of this conductivity high zone may derive from a deeper region of the subsurface. No corresponding in-phase anomalies were noted in this area which appears to indicate that this anomaly is not cause by buried metallic objects.
- Most of the small, isolated conductivity and in-phase anomalies noted throughout the survey area appear to be attributable to above ground metallic objects and structures including: buildings, concrete pads, wells, guard rails, rebar and reinforced concrete fragments, sign posts and other metallic objects visible at or above the ground surface. Many of the visible objects are noted on the site diagram overlay. Most of the visible metallic objects appear to be identifiable based on strong negative conductivity and in-phase responses. Locations with both positive and negative anomalies may represent buried conductive or metallic objects that are

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also partially exposed at the ground surface (e.g. near station 1348245 E, 477000 N, Figures 6 and 7).

- The prominent east-west banding on the in-phase and to a lesser degree on the conductivity contour diagrams is believed to be a data processing artifact associated with thermal drift corrections that were applied to the raw data (see Figures 7 and 8). This banding does not appear to represent any real subsurface condition.

<u>Task II - Ground-Penetrating Radar Survey</u> (Figures 13 through 18)
Figure 13 indicates the GPR survey areas within Task II including the focussed 3-D GPR survey area and the selected transect lines. Figure 14 illustrates the locations of subsurface objects and conditions interpreted from the 3-D GPR data. The time required for processing this data set was approximately 2.5-hours, and included applying various digital filters to all the GPR records and developing 3-D data volumes to assist with the interpretation process. The results of the Task II GPR surveys are summarized as follows:

- A large cluster of reflective objects was observed in the same position as the strong EM anomalies described previously. The strong reflection response is consistent with the presence metal in these objects. Possible interpretations of these objects include reinforced concrete fragments, metallic debris, barrels, or other metallic objects. Figures 15 and 16 show selected 2-D GPR records that illustrate the GPR response over these objects. Figure 17 presents 3-D GPR diagrams that illustrate the object cluster as well as other objects and conditions. Further exploration would be required to determine the nature of this object cluster.
- Although a precise depth to these objects cannot be determined, it believed that these objects are located approximately 2-ft to 4-ft below the ground surface.
- Isolated small reflective objects were noted on many GPR records from within the area below the earth mound. The approximate locations of many of these objects are noted on Figure 14. The apparent lack of EM response over these targets suggests that either the objects are too small or possess too little conductivity contrast to be detected using EM. Possible interpretations of these objects include large stones, boulders, concrete fragments, wood debris, etc. In general these objects appear relatively shallow and probably reside in the 2-ft to 5-ft depth range.
- A deeper reflective surface was noted on some of the survey lines. This surface is believed to be a former ground surface or stratigraphic interface. This surface is believed to be level and continuous with the ground surface in the areas surrounding the earth mound. The apparent slope of this surface noted on some of the GPR records (e.g. Figures 15a, 16a and c) corresponds to the change in elevation of the GPR antenna while moving up over the earth mound (increased travel time through greater depth). Topographic elevation data from this area could be used to derive an approximate pulse velocity estimate for the materials within the earth mound.
- The more irregular and chaotic reflection response observed in the upper 0-ns to 50-ns on the GPR records over the earth mound is believed to indicate the presence of fill material, non-native soil or highly disturbed soil conditions. The more chaotic

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reflection response is believed to be caused by a heterogeneous mix of soil and fill materials as well as by variations in soil moisture and compaction.

- The overall depth of exploration is believed to be on the order of 5-ft to 7-ft within the mound and probably less, 3-ft to 4-ft, in the lower areas surrounding the mound.
- High levels of apparent signal attenuation, system noise and antenna ringing were more prominent on records from areas surrounding the earth mound. This may be an indication of higher amounts of soil moisture and/or silty-clay in the topographically lower areas surrounding the mound. The low to moderate signal attenuation effects noted over the mound itself may indicate lower and silt and clay content (possibly more sand and gravel) and/or lower soil moisture (better drainage).
- No obvious anomalous buried objects or conditions were observed on the selected transect lines performed in the Task II area. Most of the GPR transect records showed high levels of signal attenuation and antenna ringing, indicating elevated levels of soil moisture and silty clay. Somewhat chaotic, shallow reflections were noted on a few of these records and may indicate the presence of fill of disturbed soil conditions. In general, the ground surface conditions within the transect areas (topographic variability, overgrown and/ or wooded) were not considered favorable for GPR data acquisition.

Task III - Ground-Penetrating Radar (Figures 19 through 22)
A ground-penetrating radar survey was performed over a section of the asphalt and gravel roadway northeast of Task II where several , known buried utilities are located. Figure 19 illustrates the survey area and significant interpretations. Figure 20 illustrates various perspectives of the entire GPR data set using a 3-D visualization methodology. Finally, Figures 21 and 22 illustrate selected GPR records at regular intervals across the survey area. The survey line naming refers to the field grid coordinate system. The results of the Task II GPR surveys showed the following:

- The 3-D GPR diagrams show the interpreted position of one or two pipes within a trench below the roadway. The piping appears to follow the center of the roadway in the south and shifts to the west side of the road in the northern sector of the survey area.
- The main piping run appears as a single linear reflection on the 3-D GPR sections and multiple pipes within the trench cannot be clearly resolved. Up to two possible pipes are apparent on some of the individual GPR records as strong inverted-parabola shaped reflections. The close proximity of pipes, both vertically and laterally, within the trench would cause multiple pipes to appear as one, stronger and wider apparent pipe reflection on the GPR records. Some of the records appear to resolve a smaller and shallower pipe above the main pipe(s). The pipe response(s) are not clearly or consistently apparent on all records.

- Indications of a buried culvert that reportedly crosses below the roadway could not be discerned on any of the GPR records or 3-D images. It is likely that the depth to the top of the culvert and the effects of high signal attenuation prevented the detection of this target.
- High signal attenuation and system noise levels in the areas on either side of the trench suggests the presence of moist silty-clay in these areas. Clearer, less attenuated signal responses from within the trench area appear to indicate more granular trench backfill materials (e.g., sand and gravel).
- The depth of exploration over the trench may have been on the order of 3-ft to 5-ft, while the effective exploration depth appears to be less in areas surrounding the trench (2-ft to 4-ft). The actual exploration depth in an area may vary over short distances depending on the actual electrical properties of different soil or fill materials distributed through an area.
- The lateral resolution appears to be on the order of a few inches, although the resolution may vary locally depending on the ground surface conditions (e.g. surface roughness and variability).

Task IV - EM Conductivity Survey - Fly-Ash Landfill Area (Figures 23 through 26)
A site diagram with the general EM survey interpretations is presented on Figure 23. EM conductivity and in-phase color contour diagrams are shown on Figures 24 through 26 for the three survey frequencies.

The results of the EM survey in the strip of land northeast of the Active Flyash Pile showed minor but consistent variations in the EM conductivity readings across the survey area. The overall range of conductivity variation was moderate to low, on the order of 20 to 30 mS/m across the survey area. A broad region of higher conductivity was observed over the western half of the survey area. This region of higher conductivity gradually tapers into a zone of lower conductivity in the eastern and northeastern survey areas. The higher conductivity region suggests the presence of more conductive materials in this area and could indicate one or more circumstances including: more clay, conductive fill (e.g. fly ash), higher soil moisture, saturation, or more electrically conductive groundwater conditions. In contrast, the lower conductivity region suggests the opposite effects, including possibly higher amounts of sand or gravel, lower amounts of conductive clay or fill, or better drained, lower moisture or less saturated soil. The lowest conductivity levels observed along the northeastern fringe of the survey area may be associated in part with the steep drainage ditch sidewall and stone present in this area. The elevated conductivity readings noted along the southern and portions of the northern edges of the survey area represent the effects of the nearby fence and steel fence posts.

The in-phase levels are generally unremarkable throughout the survey area and appear to indicate that no highly conductive materials (e.g. metal) are present in the subsurface. The apparent banding in the -in-phase contours appears to be an instrument drift or stability problem exaggerated in part by the relatively small in-phase contour interval. Large, buried metal objects would be expected to cause in-phase anomalies an order of magnitude larger than the low data variations shown on these contour diagrams. It is also possible that this banding is caused by some buried linear structure win this area although additional site information would be required to verify this possibility (particularly the response shown near the northwest-southeast mid-line on Figure 26). The in-phase responses from the south fence and north fence posts are readily apparent.

5.0 Conclusions and Recommendations

The results of the Electromagnetic conductivity profiling and Ground-Penetrating Radar surveys demonstrated several valuable applications of these techniques at the FEMP site. EM conductivity mapping appears to be an effective and rapid site-screening tool at the FEMP site. EM works well over large, open areas where various buried targets or conditions within the upper 20-ft of the subsurface can be detected and mapped based on variations in electrical conductivity. Effective EM applications include mapping fill boundaries and locating buried conductive objects such as waste debris and fill, metal, tanks and piping. GPR is an effective tool for focussed surveys of the shallow subsurface where detailed, high resolution information is required. Examples of potentially useful GPR applications at the FEMP site include some utility surveys, delineating fill boundaries and conducting buried object or structure mapping and characterization. 3-D visualization methods can help speed-up and strengthen the interpretation of GPR data, particularly in more complicated settings. In general, GPR appears to be less effective for deeper applications (>5-ft to 7-ft) at the FEMP site, mainly because of the presence of moist silty-clay in much of the shallow subsurface. Although GPR appears to be less useful as a general site-screening tool, a valuable site exploration strategy is to survey larger areas using EM and then use GPR to spot check or focus on anomalous locations detected by the EM survey.

Although EM and GPR are among the most popular and widely used environmental site investigation tools, FEMP should consider the use of other, alternative geophysical tools as appropriate for those applications when GPR or EM may be less effective. Examples of other geophysical methods that are also useful for applications similar to those evaluated for this project include time-domain metal detection (e.g., EM-61) and magnetometry. Other geophysical tools that also find use on environmental and civil engineering applications include electrical resisitivity, borehole logging and various seismic methods. The use of any geophysical tool in other areas at the FEMP should only be implemented after a careful consideration of project specific factors including: site conditions, survey objectives and expectations, survey method(s) and instrument(s) used, and the experience and qualifications of the field staff and data interpreter.

6.0 Limitations

The use of geophysical exploration methods, such as those described herein, should not be considered a substitute for invasive subsurface exploration such as drilling, digging or excavation. The EM and GPR data are interpreted. No warranty or statement of fact regarding actual subsurface conditions is contained herein. The contoured EM results should not be construed to imply that EM measurements were obtained at locations other than the actual measurement stations using the gridded coordinate system established by Fluor-Fernald. The geophysical data acquired are time and location specific. If questions or uncertainties exist regarding the interpreted presence or absence of subsurface conditions based on the geophysical data obtained from this site, it is recommended that supplemental subsurface explorations, such as drilling, test-pit explorations or hand-digging, be conducted if possible to further characterize and document actual subsurface conditions.

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7.0 Technical References

Electromagnetic Conductivity Profiling

GSSI, 1998, GEM-300 Multi-frequency Electromagnetic Profiler, System Manual, Operating System Version 1.10, Geophysical Survey Systems, Inc., North Salem, NH, 67 p.

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Internet Sites

www.g-p-r.com
www.geophysical.com
www.geonics.com
www.sensoft.on.ca
www.ldeo.columbia.edu/eeg/gpr.links/gpr.links.html

FIGURES

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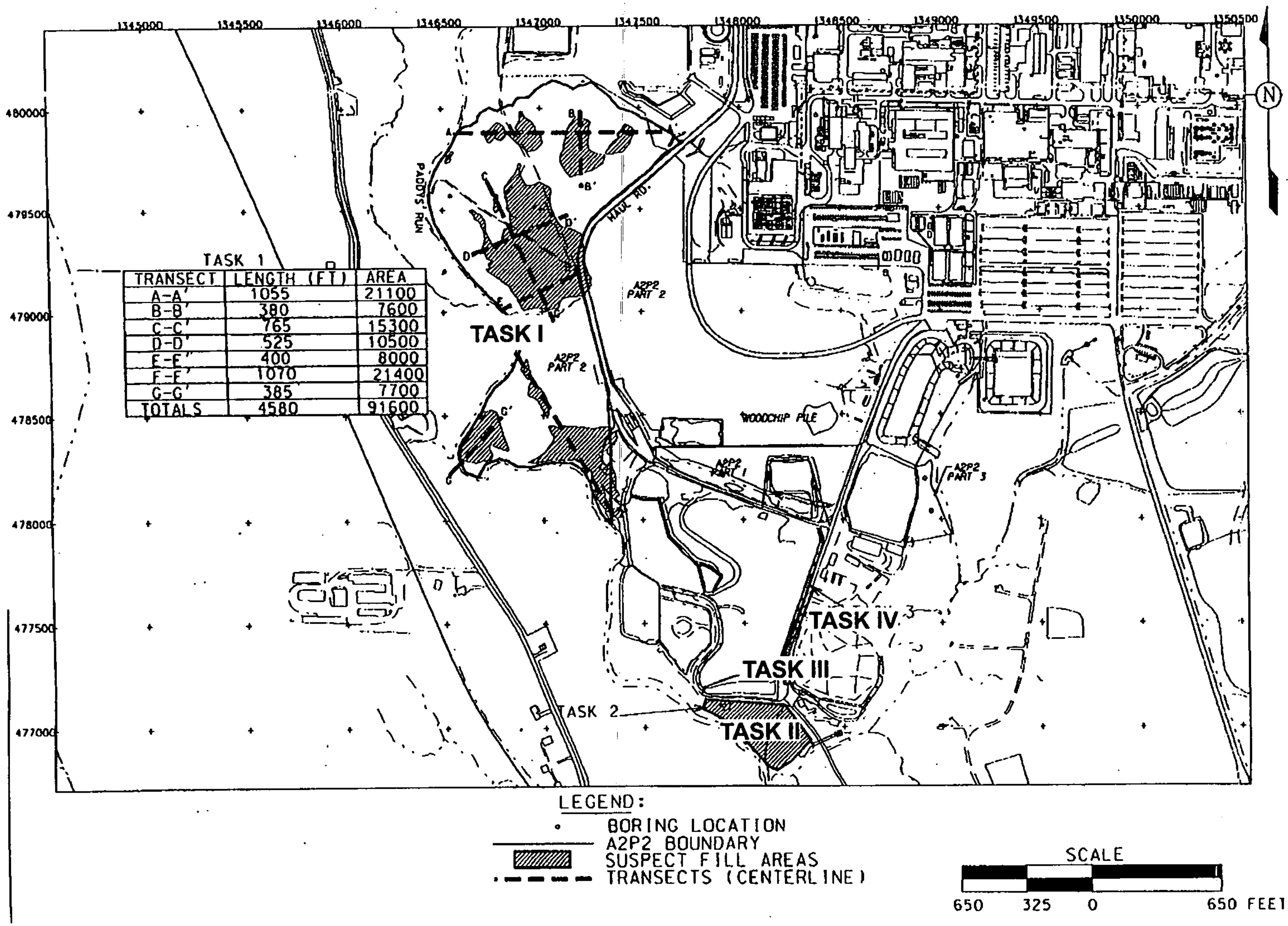

TRANSECT	LENGTH (FT)	AREA
A-A'	1055	21100
B-B'	380	7600
C-C'	765	15300
D-D'	525	10500
E-E'	400	8000
F-F'	1070	21400
G-G'	385	7700
TOTALS	4580	91600

Notes:
AutoCAD overlay provided by Fluor-Fernald

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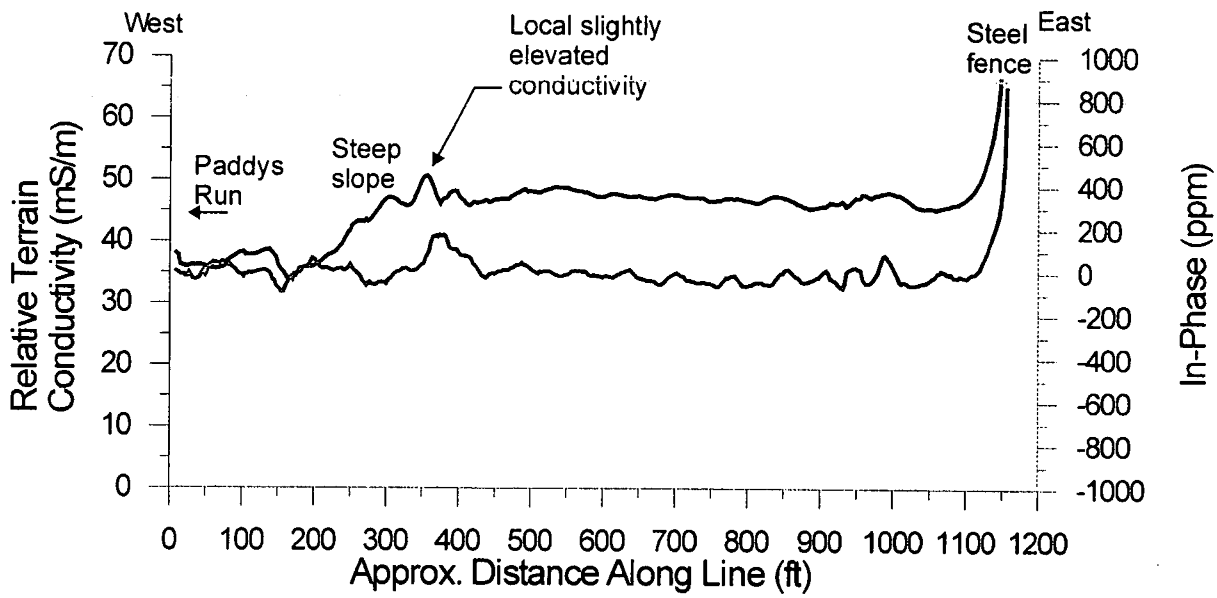
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor/Daniel Fernald	By: dlg	Date: 02/15/00	
Project No. 01-20002	Checked	Scale: as shown	

Figure 1 Title: Geophysical Demonstration Project Task Areas

000028

3077

Transect A



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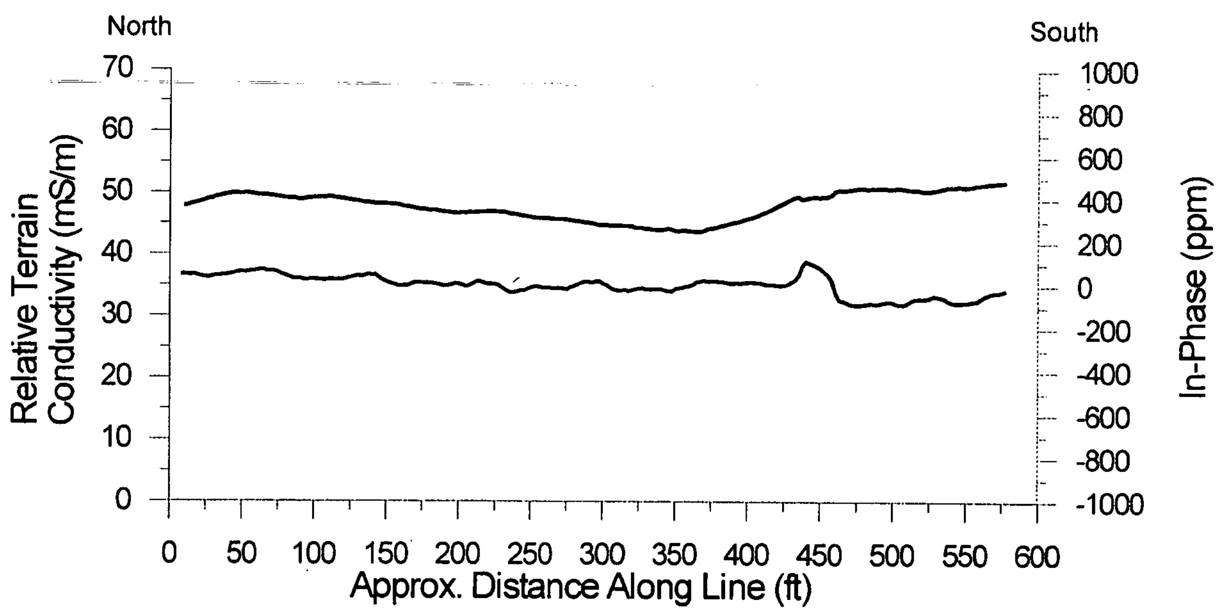

000029

Notes:
GSSI GEM-300 Multi-frequency Terrain
Profiling Instrumentation
Vertical dipole, single coil orientation,
Selected transects, ~2-ft station spacing, no stacking
Survey frequency shown: 9810 Hz
Survey date: January 27, 2000

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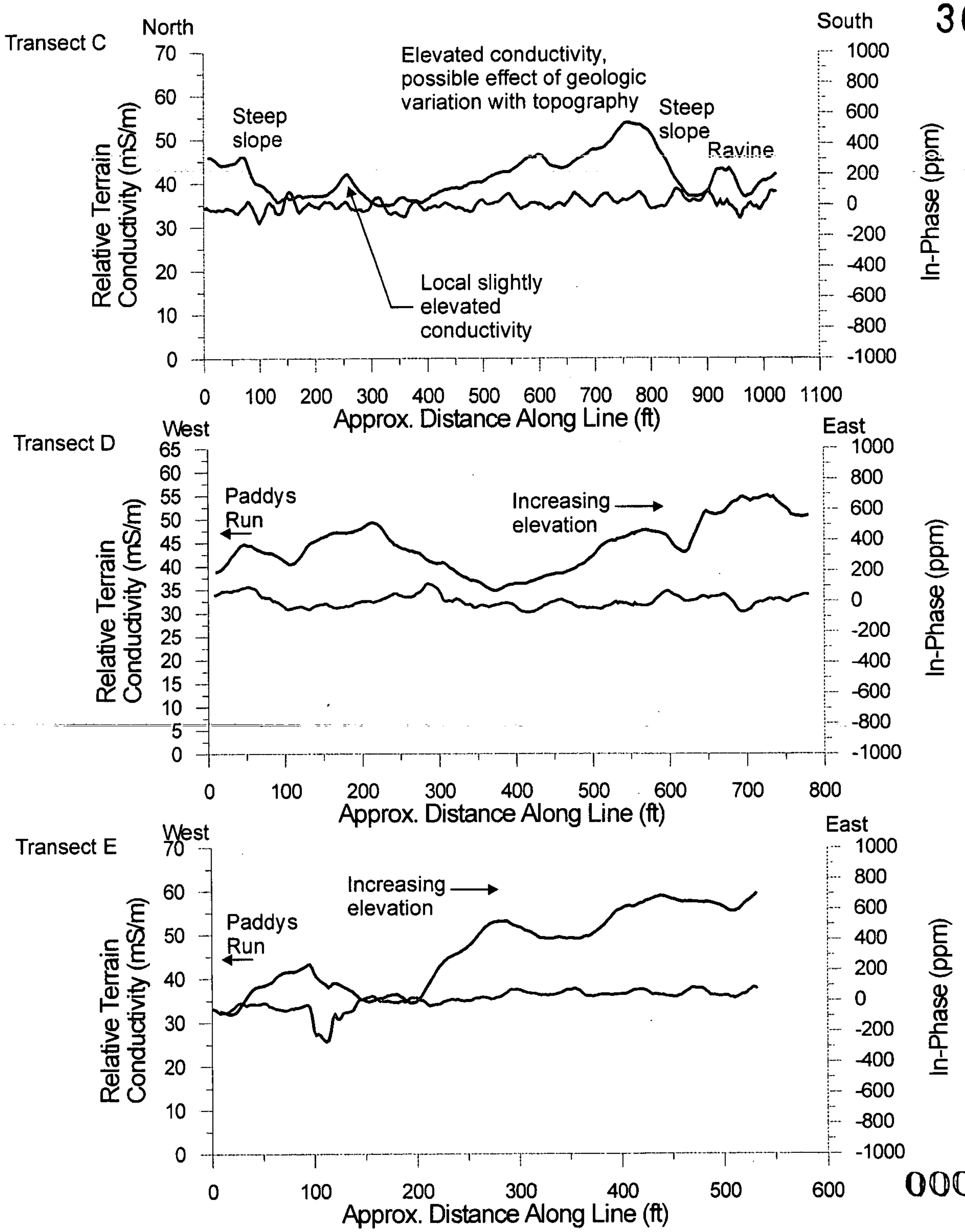
Project	Report of Geophysical Demonstration		
Location	Fernald Environmental Management Project		
Client	Fluor-Fernald	By dlg	Date 02/15/00
Project No.	01-20002	Checked	Scale as shown

Figure 2 | Title EM Transects A and B - Task I Survey Area

3077



000030

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
Selected transects, ~2-ft station spacing, no stacking
Survey frequency shown: 9810 Hz
Survey date: January 27, 2000

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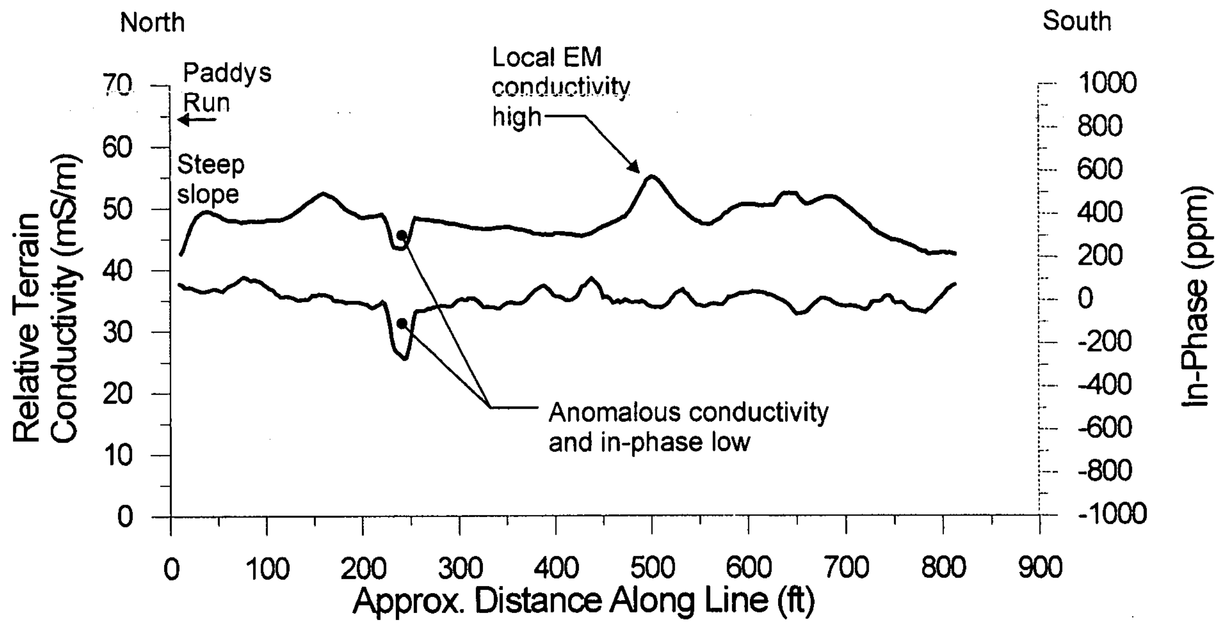
Project	Report of Geophysical Demonstration		
Location	Fernald Environmental Management Project		
Client	Fluor-Fernald	By dlg	Date 02/15/00
Project No.	01-20002	Checked	Scale as shown

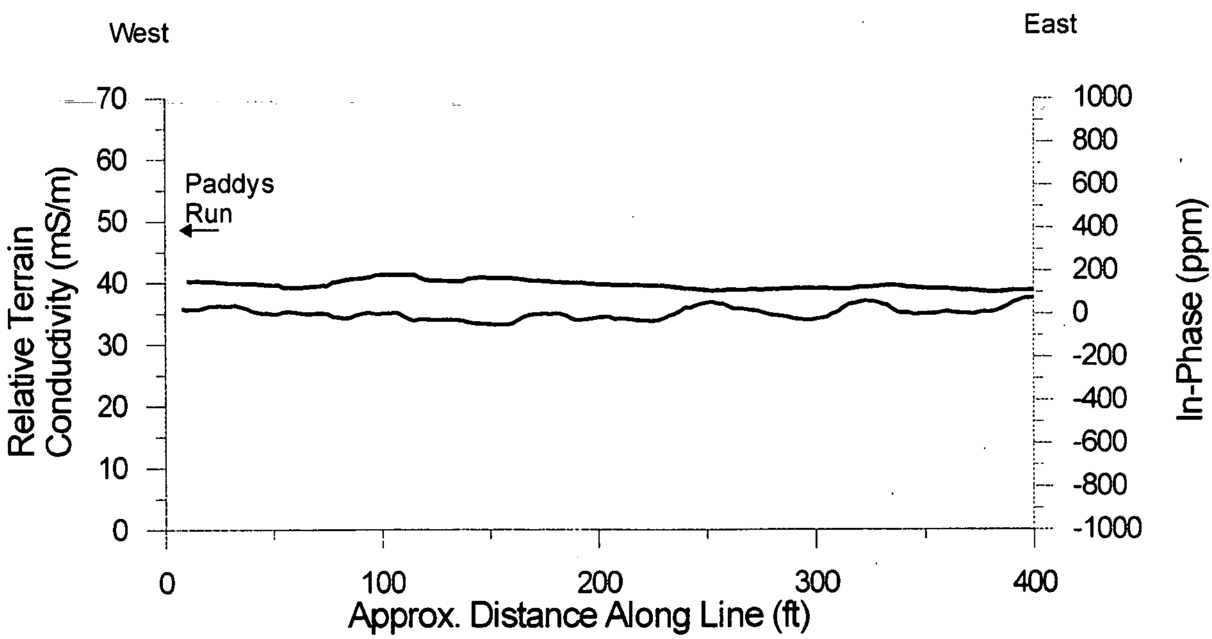
Figure 3 | Title EM Transects C, D and E - Task I Survey Area

3077

Transect F



Transect G



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Notes:
GSSI GEM-300 Multi-frequency Terrain
Profiling Instrumentation
Vertical dipole, single coil orientation,
Selected transects, ~2-ft station spacing, no stacking
Survey frequency shown: 9810 Hz
Survey date: January 27, 2000

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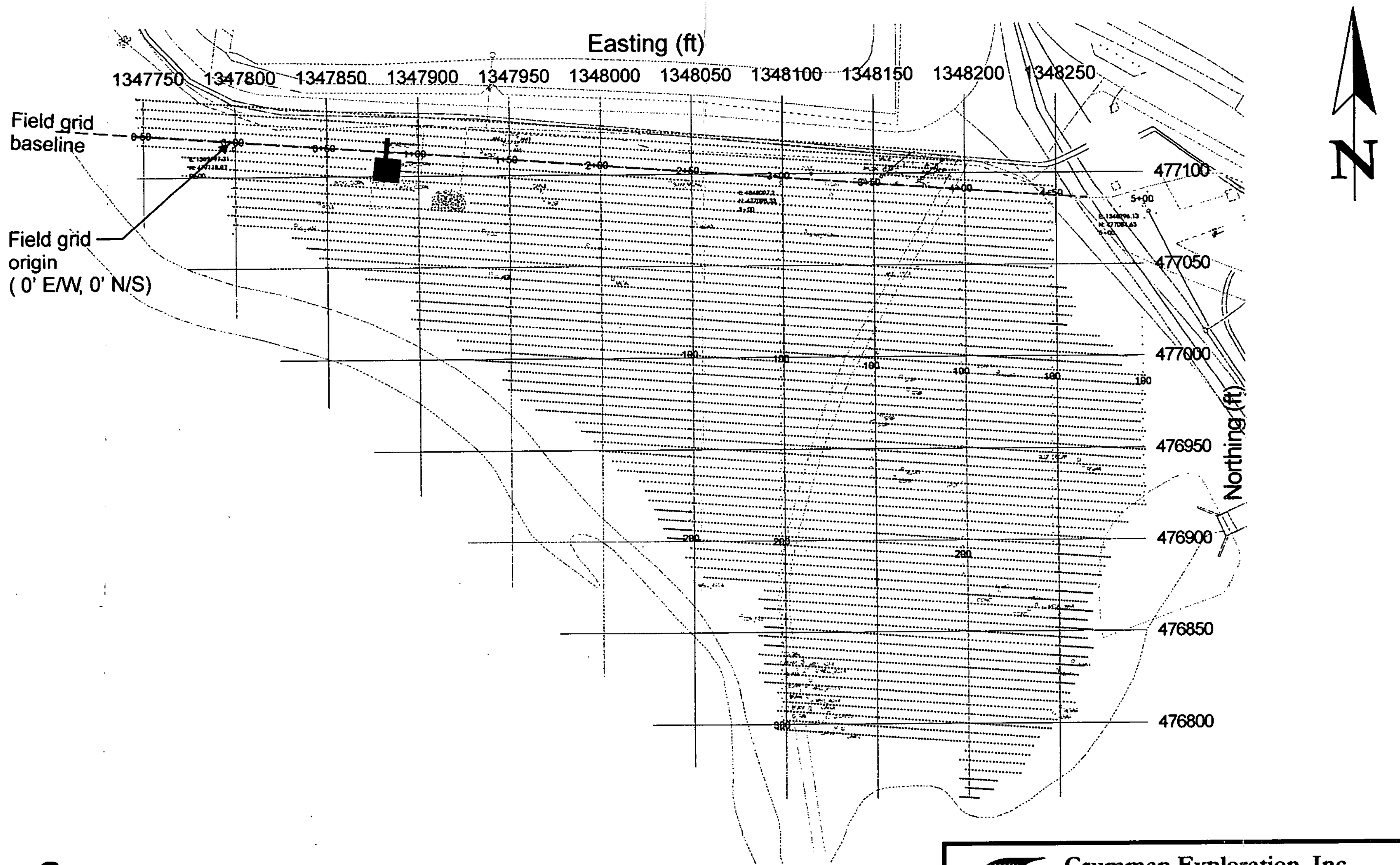
Location	Fernald Environmental Management Project		
Client: Fluor-Fernald		By: dlg	Date: 02/15/00
Project No.: 01-20002		Checked	Scale: as shown

Figure 4	Title: EM Transects F and G - Task I Survey Area



Scale (ft)

0 25 50 75 100

(1"=80')

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

000032

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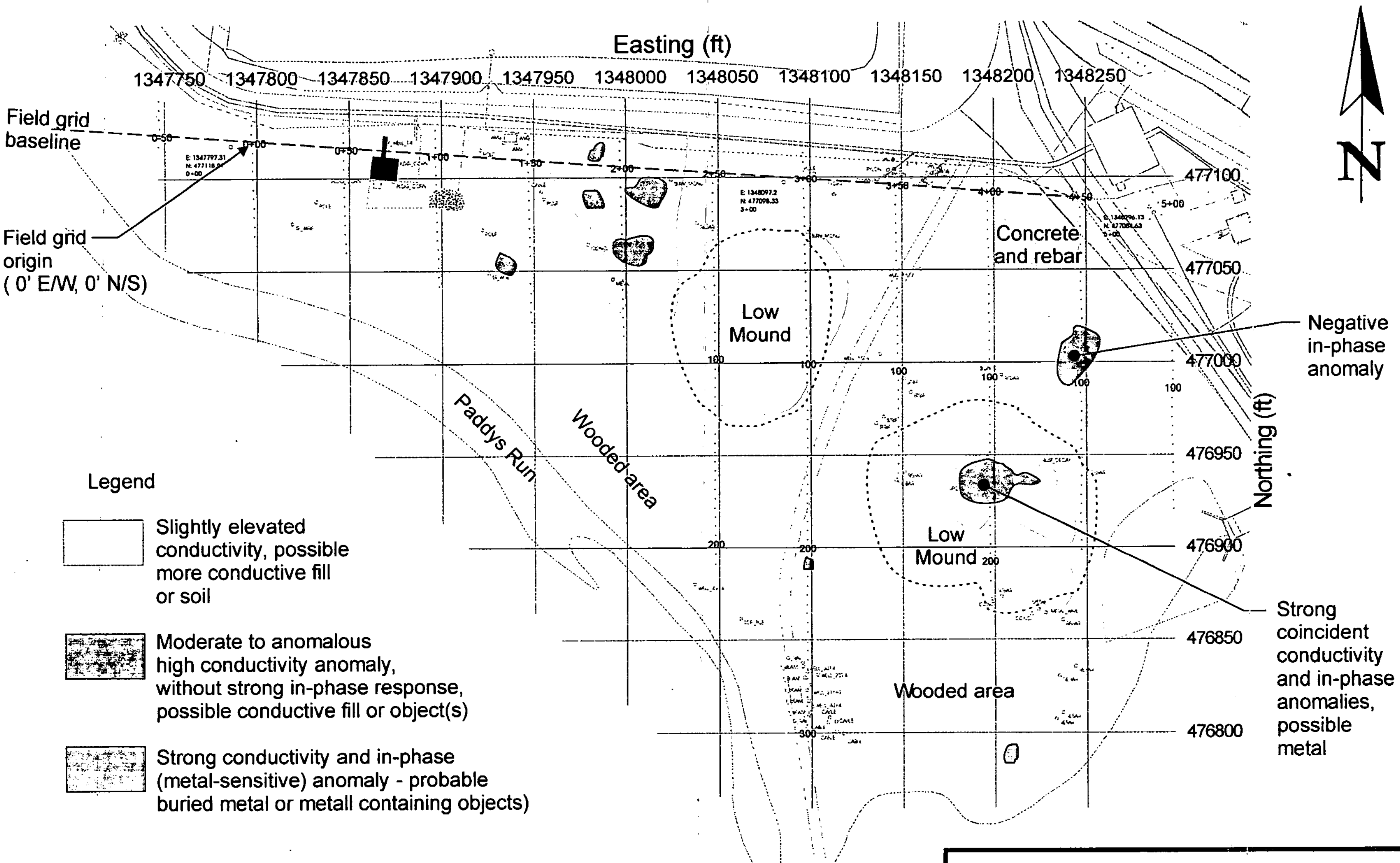
Project	Report of Geophysical Demonstration		
Location	Fernald Environmental Management Project		
Client/Owner: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: 1"=80'	

3077

Figure 5 | Title: Task II Area EM Survey Grid and Measurement Stations



000033

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000
AutoCAD overlay provided by Fluor-Daniel

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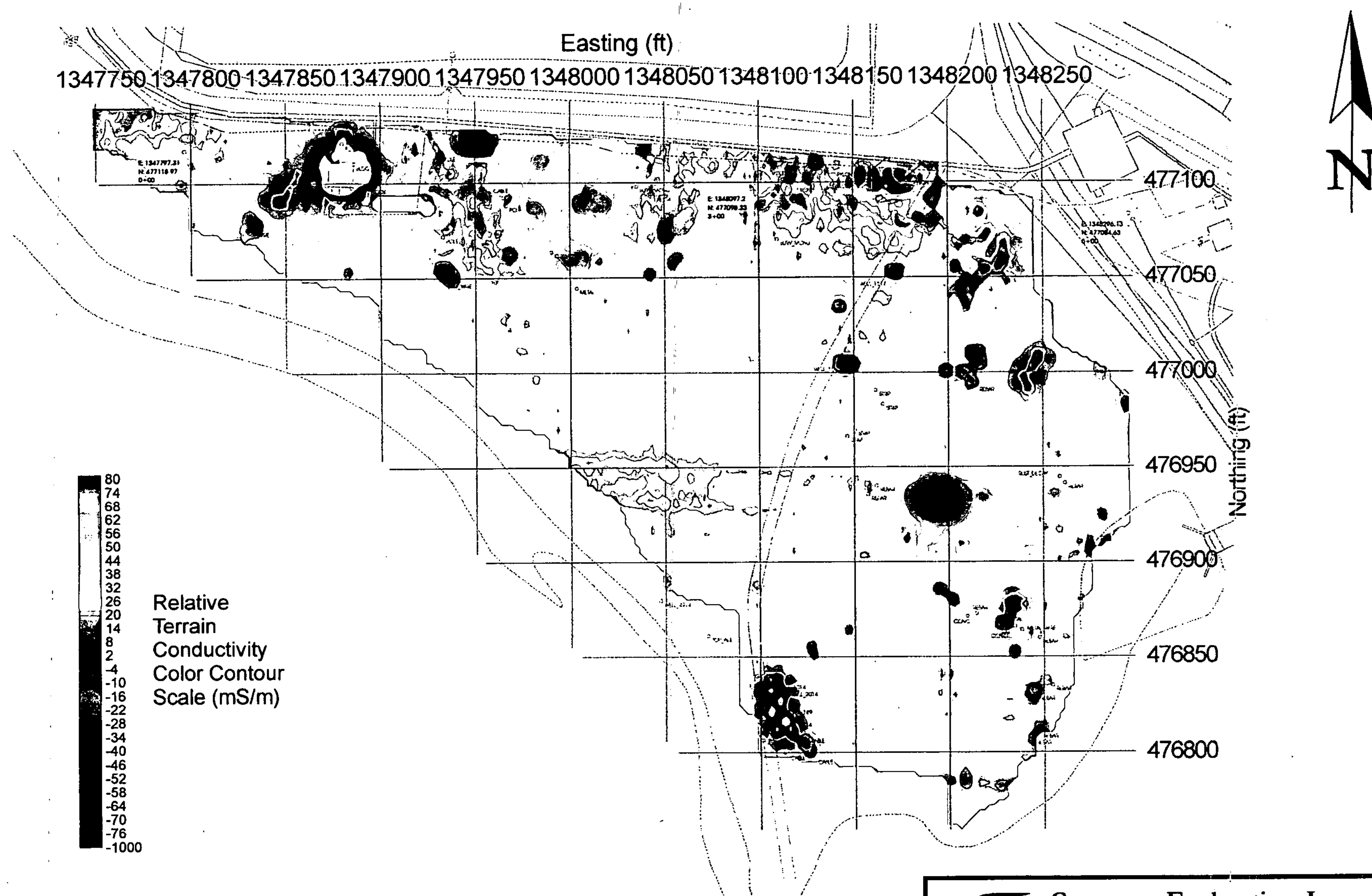
Client/Owner	Fluor-Fernald
By	dlg
Date	02/15/00
Project No.	01-20002
Checked	
Scale	1"=80'
Figure	6
Title	Task II Area EM Survey Results and Interpretation Summary

3077



Scale (ft)
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(1"=80')

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

000034

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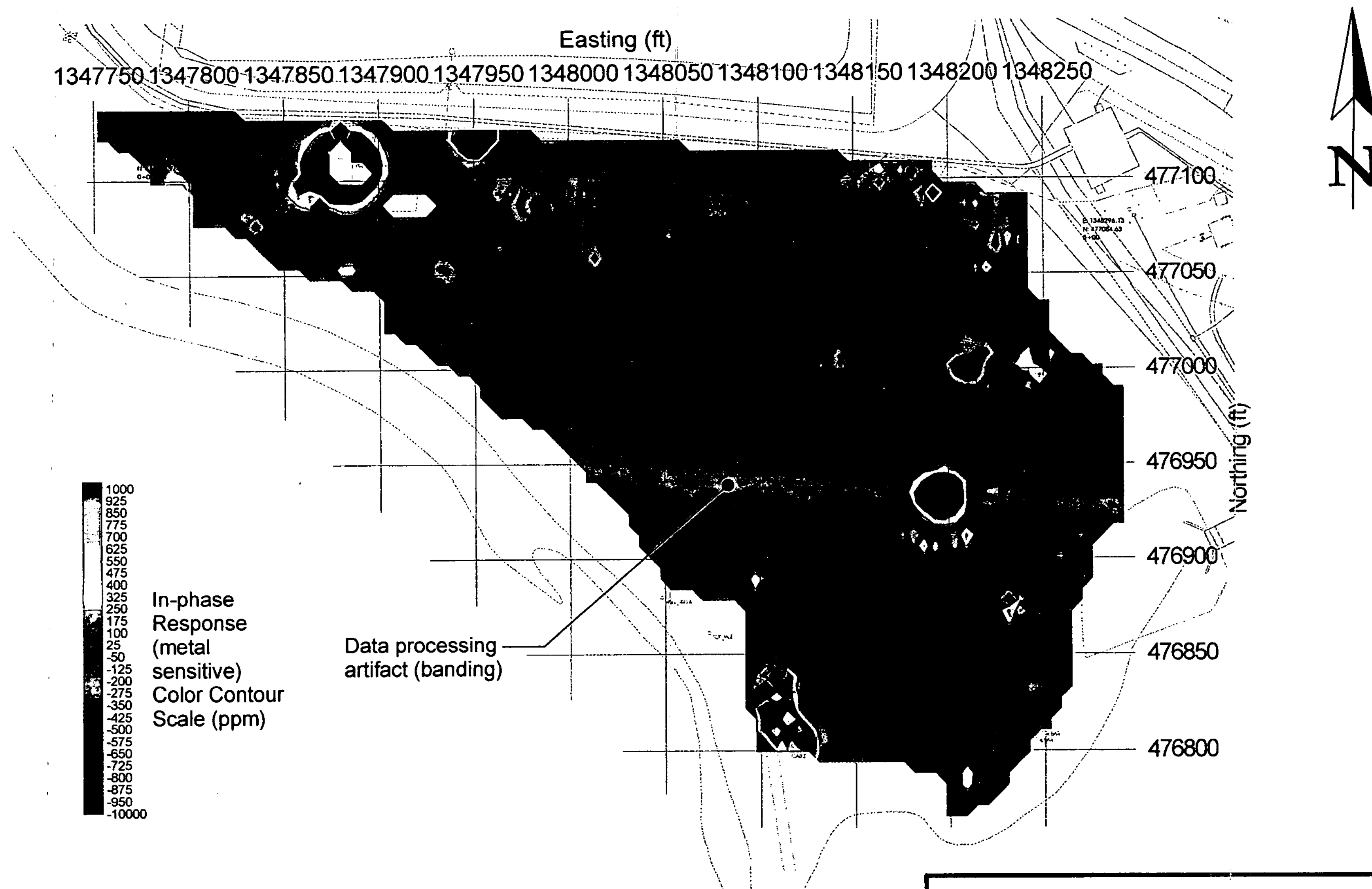
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: 1"=80'	

3077

Figure 7 Title: 2070 Hz - Relative Terrain Conductivity Contour Diagram - Task II Survey Area



Scale (ft)
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(1"=80')

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

000035

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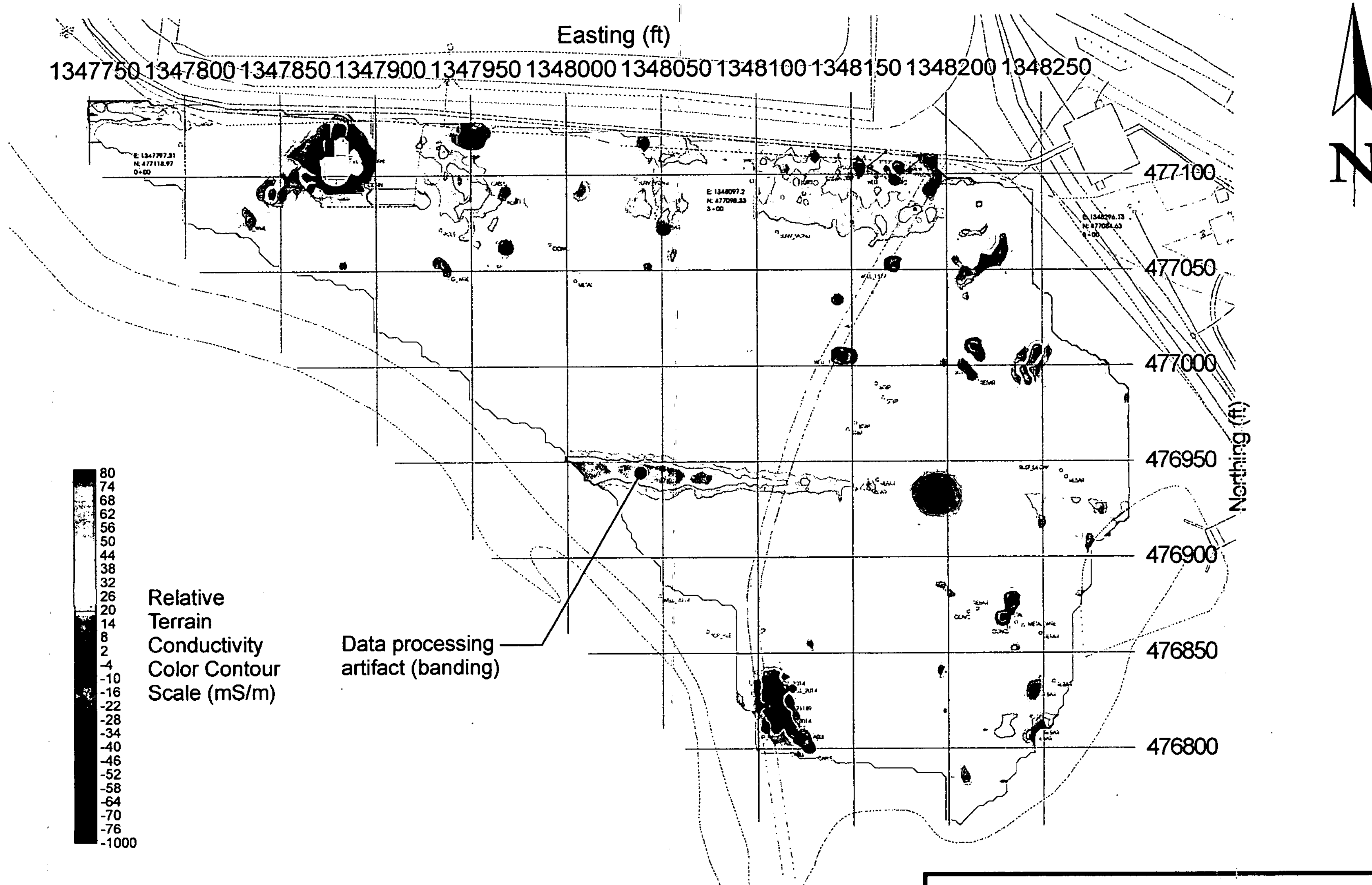
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: 1"=80'	

Figure 8 | Title: 2070 Hz - In-phase (metal sensitive) Response Contour Diagram - Task II Survey Area

3077



Scale (ft)

0 25 50 75 100

(1"=80')

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

000036

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Location	Fernald Environmental Management Project		
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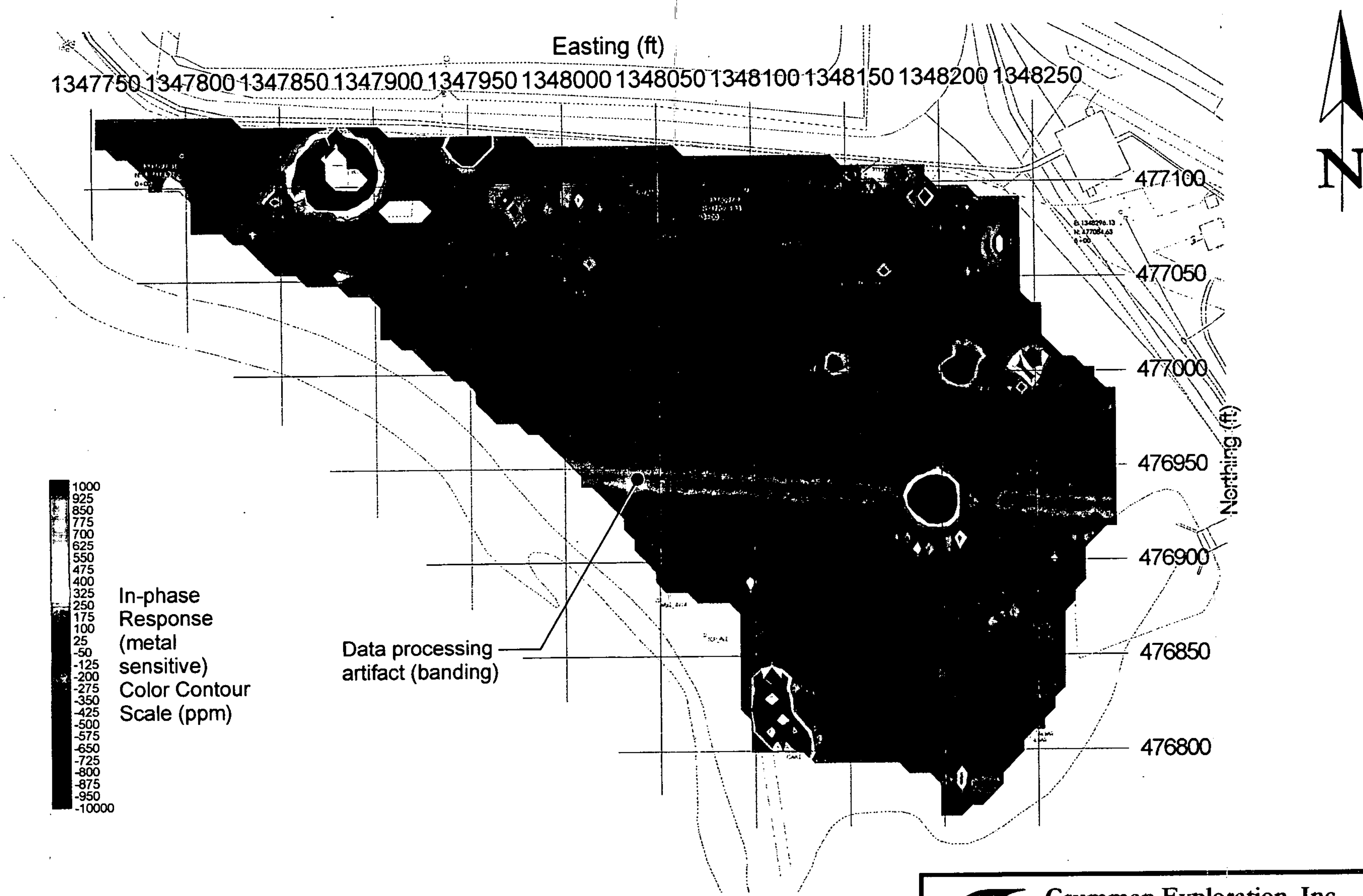
Project No.: 01-20002	Checked:	Scale: 1"=80'	

3077

Figure 9 | Title: 4530 Hz - Relative Terrain Conductivity Contour Diagram - Task II Survey Area



Scale (ft)

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(1"=80')

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

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Project	Report of Geophysical Demonstration
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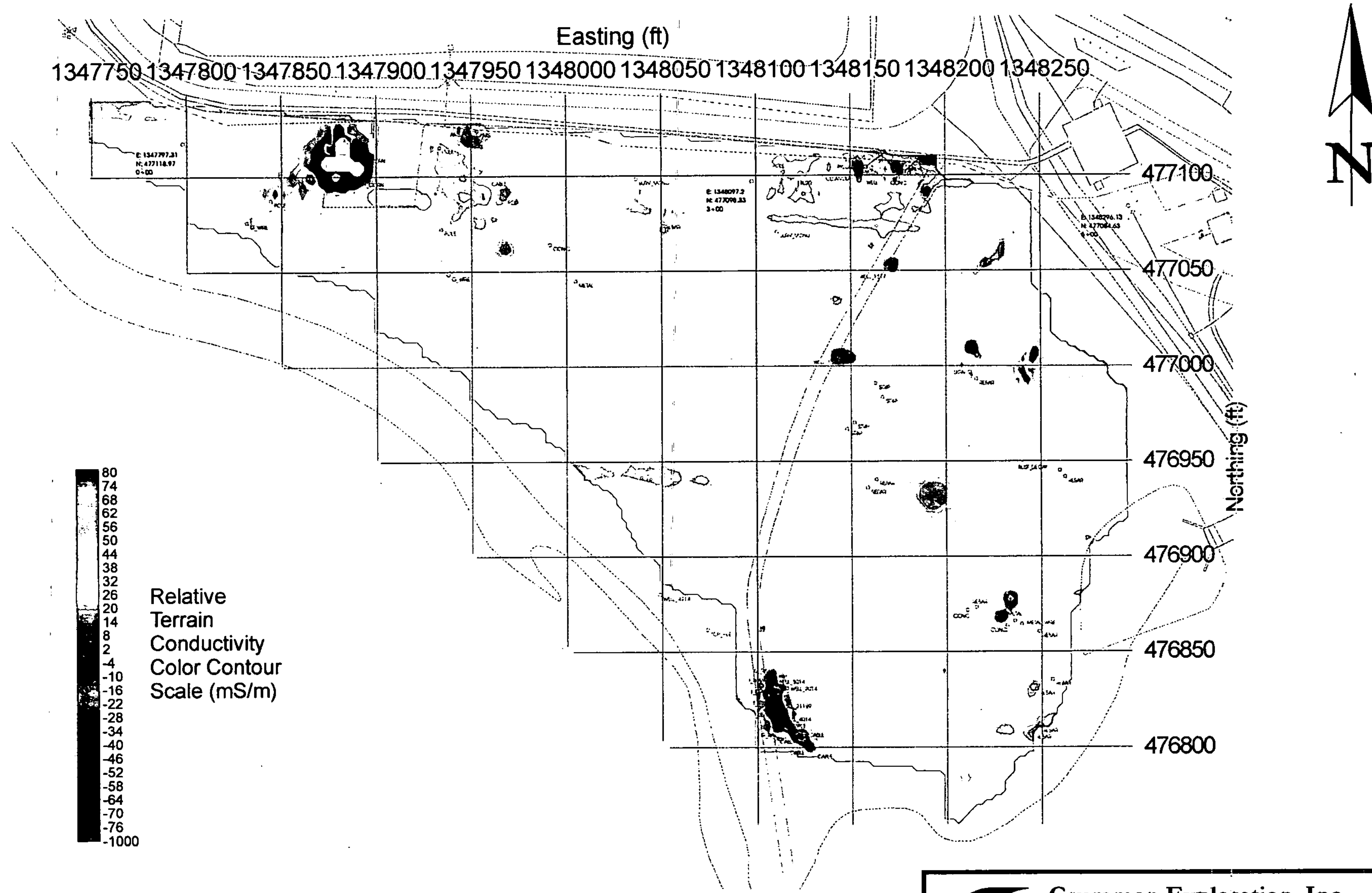
Client/Owner	Fluor-Fernald
By	dlg
Date	02/15/00
Project No.	01-20002
Checked	
Scale	1"=80'

Figure 10 Title 4530 Hz - In-phase (metal sensitive) Response Contour Diagram - Task II Survey Area



Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

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Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: 1"=80'	

Figure 11 — Title: 9810 Hz - Relative Terrain Conductivity Contour Diagram - Task II Survey Area

000038

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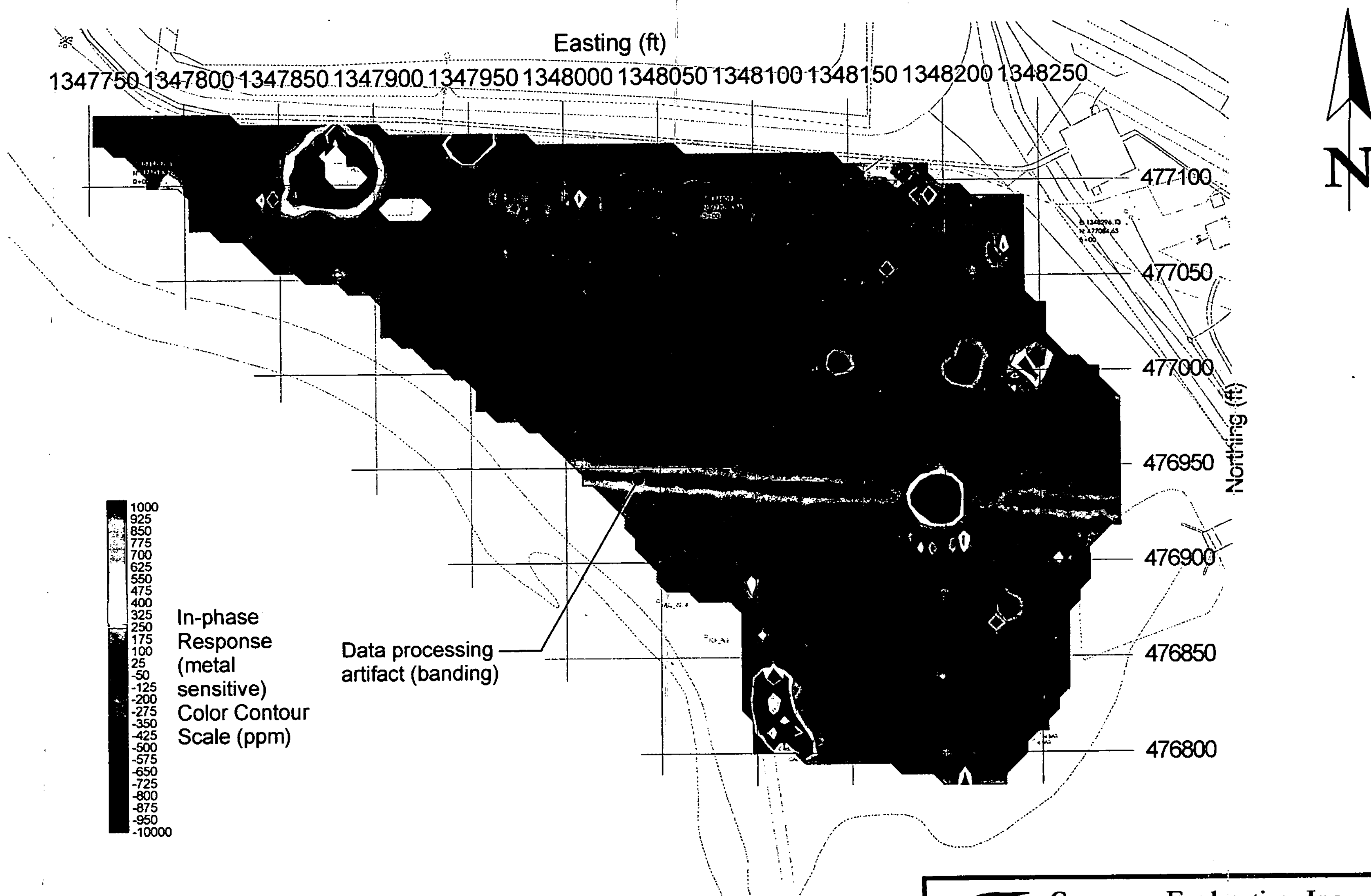

Scale (ft)
0 25 50 75 100
(1"=80')

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
5-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: January 25, 2000

000039

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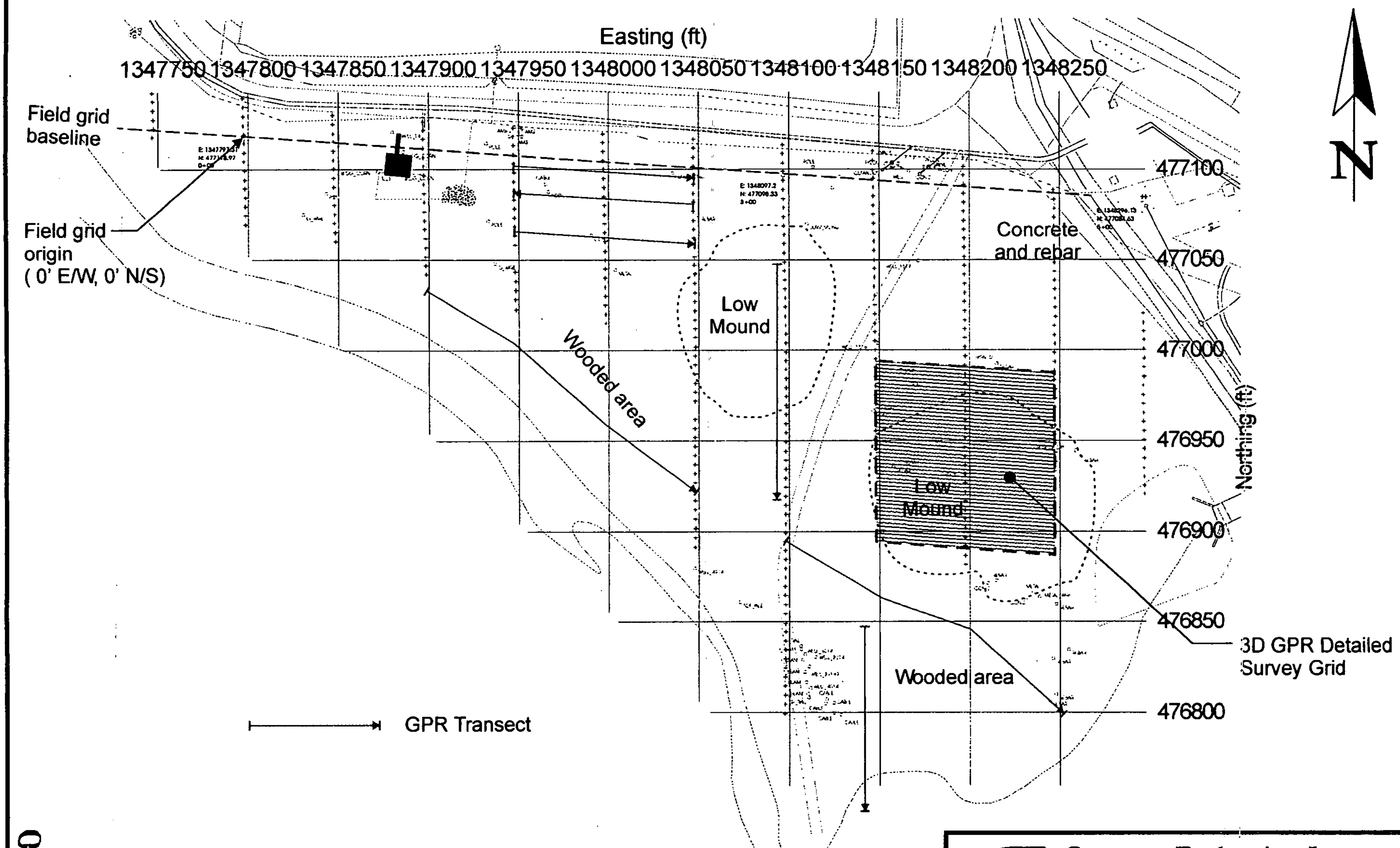
Client/Owner	Fluor-Fernald
By	dlg
Date	02/15/00
Project No.	01-20002
Checked	
Scale	1"=80'

3077

Figure 12 — Title: 9810 Hz - In-phase (metal sensitive) Response Contour Diagram - Task II Survey Area



Scale (ft)
0 25 50 75 100
(1"=80')

Notes:
GSSI SIR-2 GPR System
200 MHz antrnna, 200 ns range
512 samples/trace, ~10.1 traces/ft
2-ft line spacing in3-D survey grid
Survey date: February 16, 2000

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By	dlg
Date	02/15/00
Project No.	01-20002
Checked	
Scale	1"=80'

Figure 13 Title Task II GPR Survey Areas

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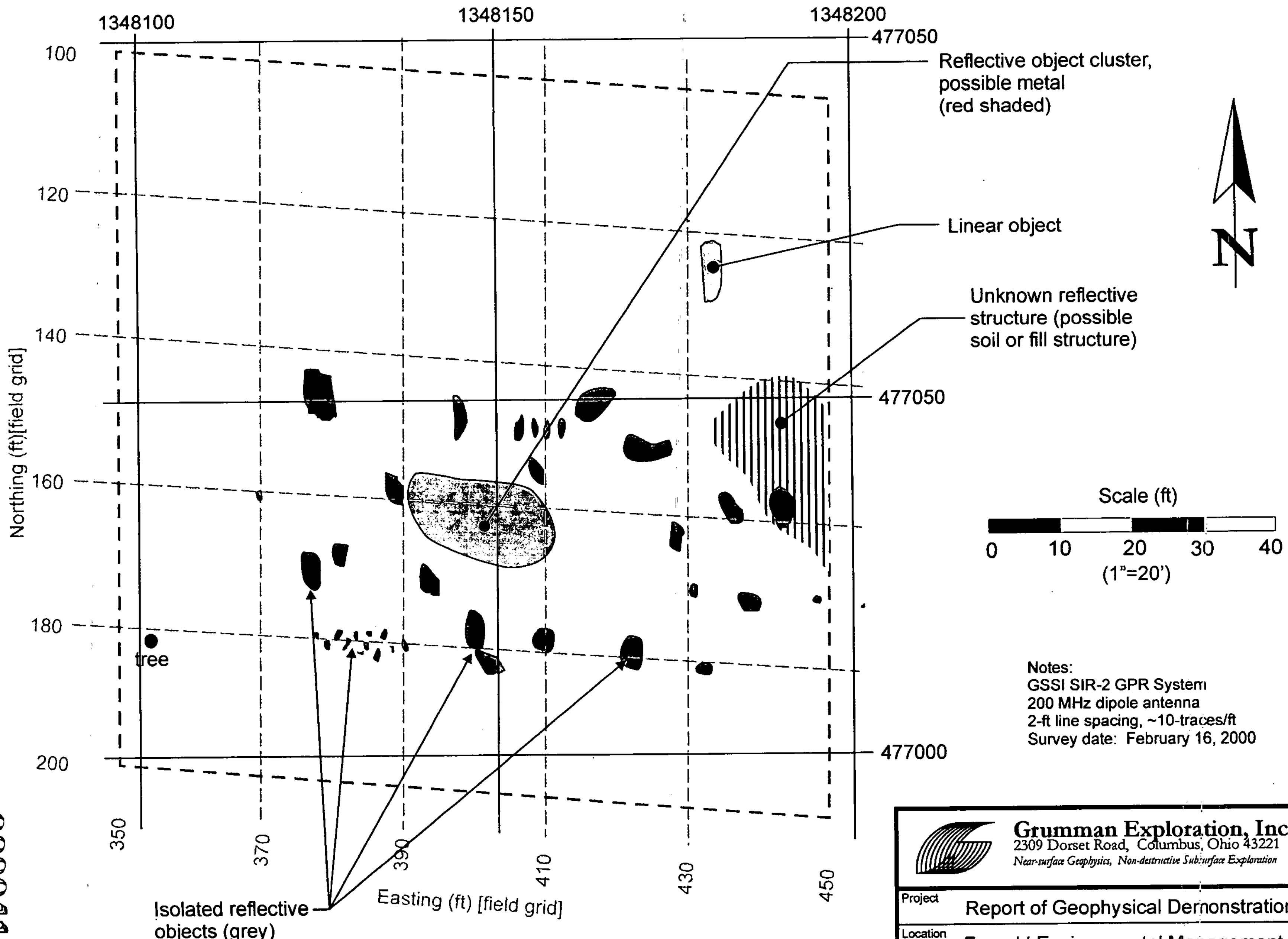

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Project	Report of Geophysical Demonstration		
Location	Fernald Environmental Management Project		
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Project No.: 01-20002	Checked:	Scale: 1"=20'	

Figure 14 Title: Task II 3-D GPR Survey Area Interpretations

000041

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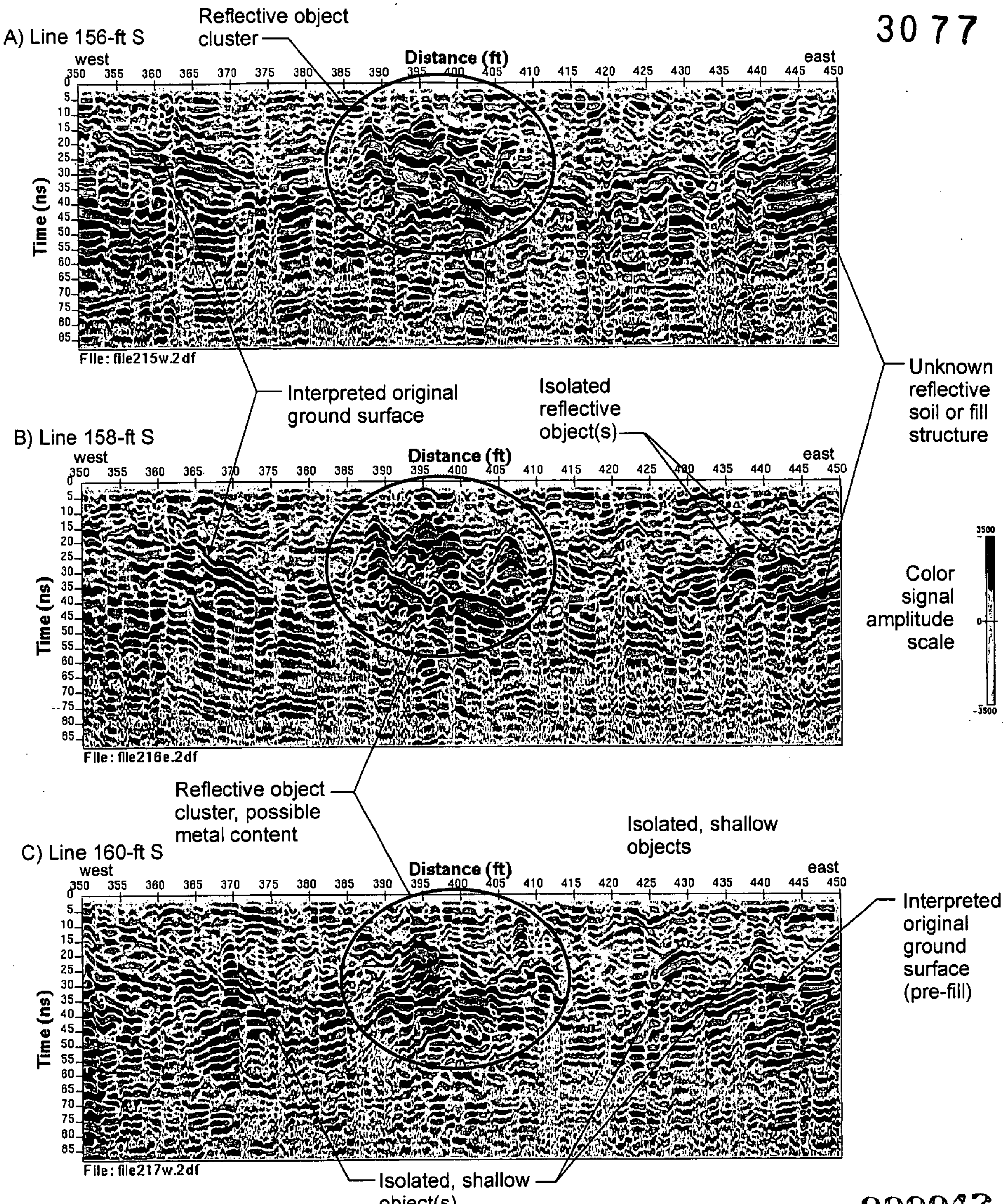

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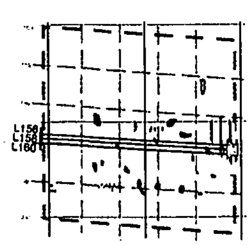

Notes:
GSSI SIR-2 GPR System
200 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 16, 2000

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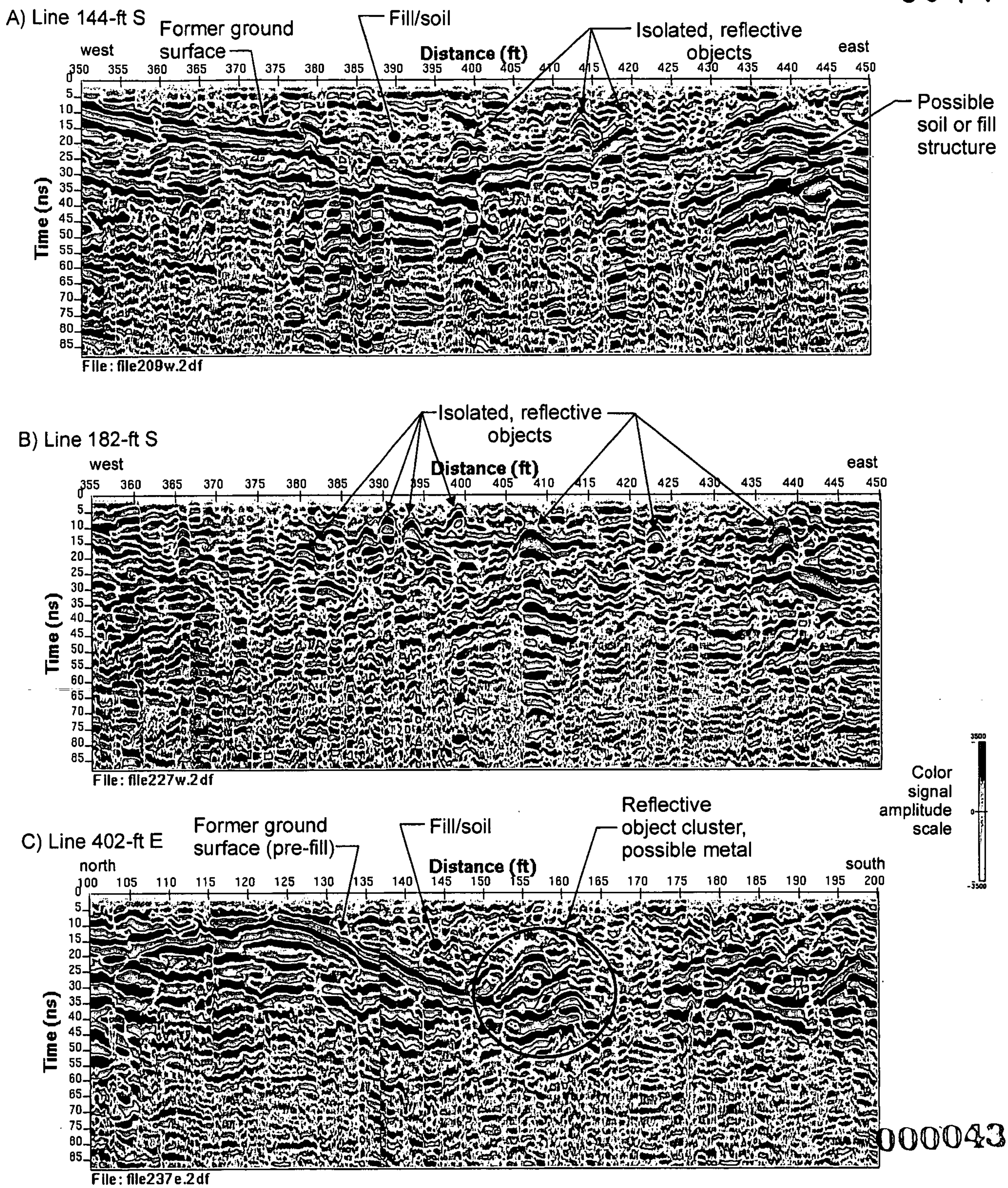
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald	By: dlg		Date: 02/15/00
Project No.: 01-20002	Checked:		Scale: nts

Figure 15 — Title: Selected GPR Records - Task II Area



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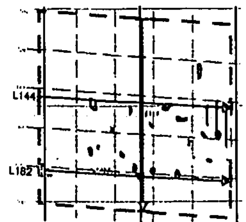

Notes:
GSSI SIR-2 GPR System
200 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 16, 2000

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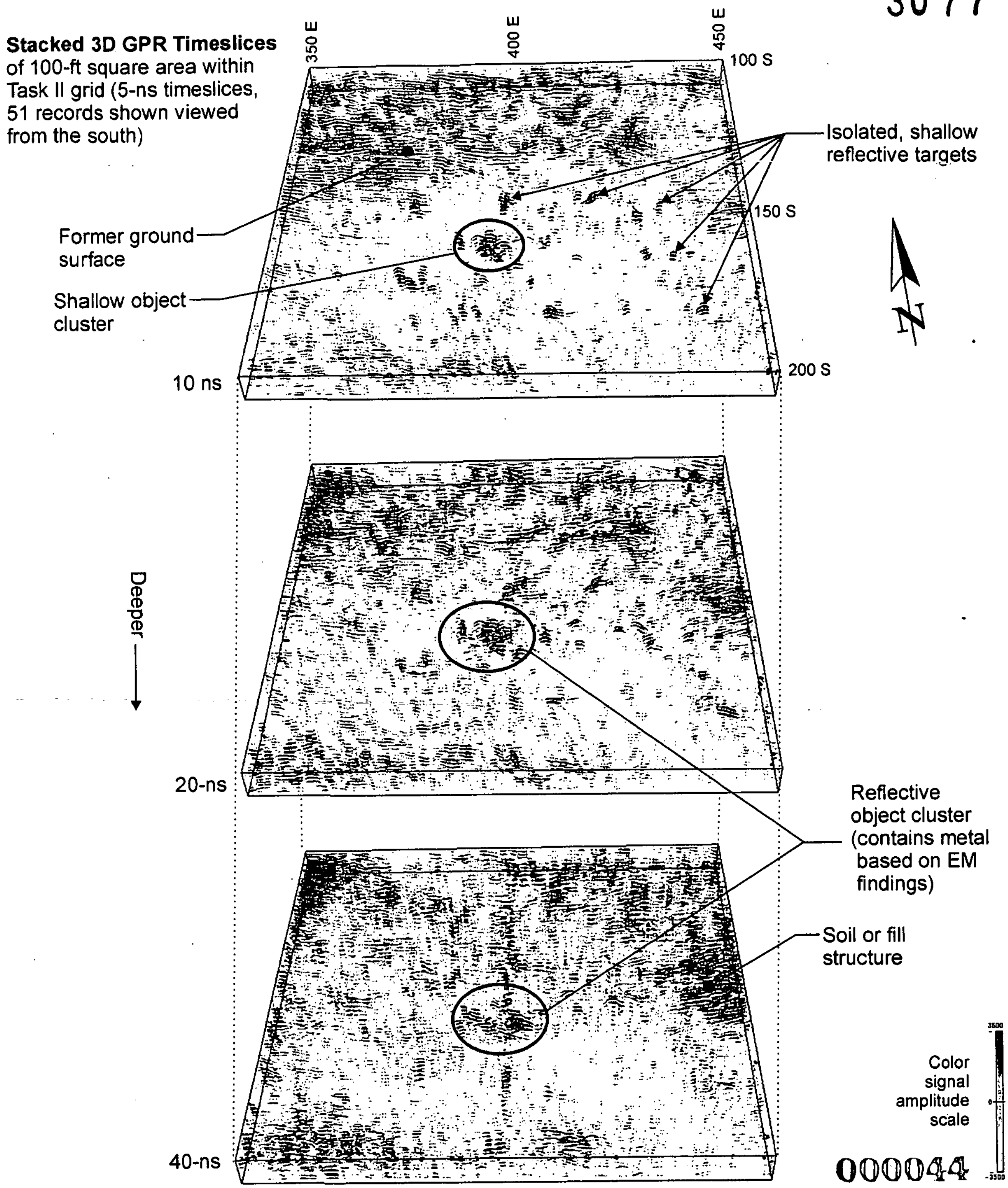
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald	By: dlg	Date: 02/15/00	
Figure: 16	Title: Selected GPR Records - Task II Area	Project No.: 01-20002	Checked:	Scale: nts



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Notes:
GSSI SIR-2 GPR System
200 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 16, 2000

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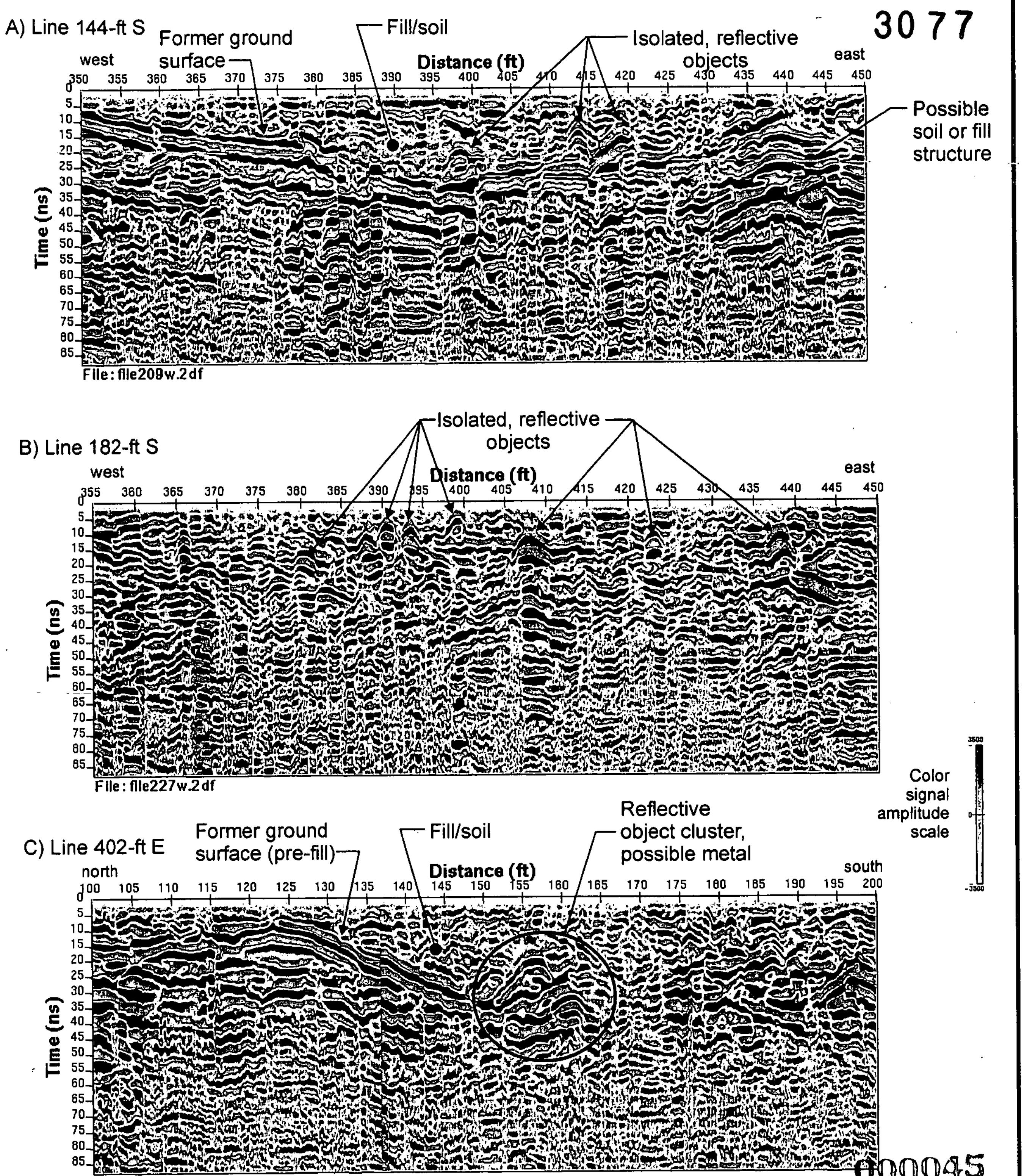
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: nts	

Figure 17 — Title: 3-D GPR Diagram - Task II Survey Area



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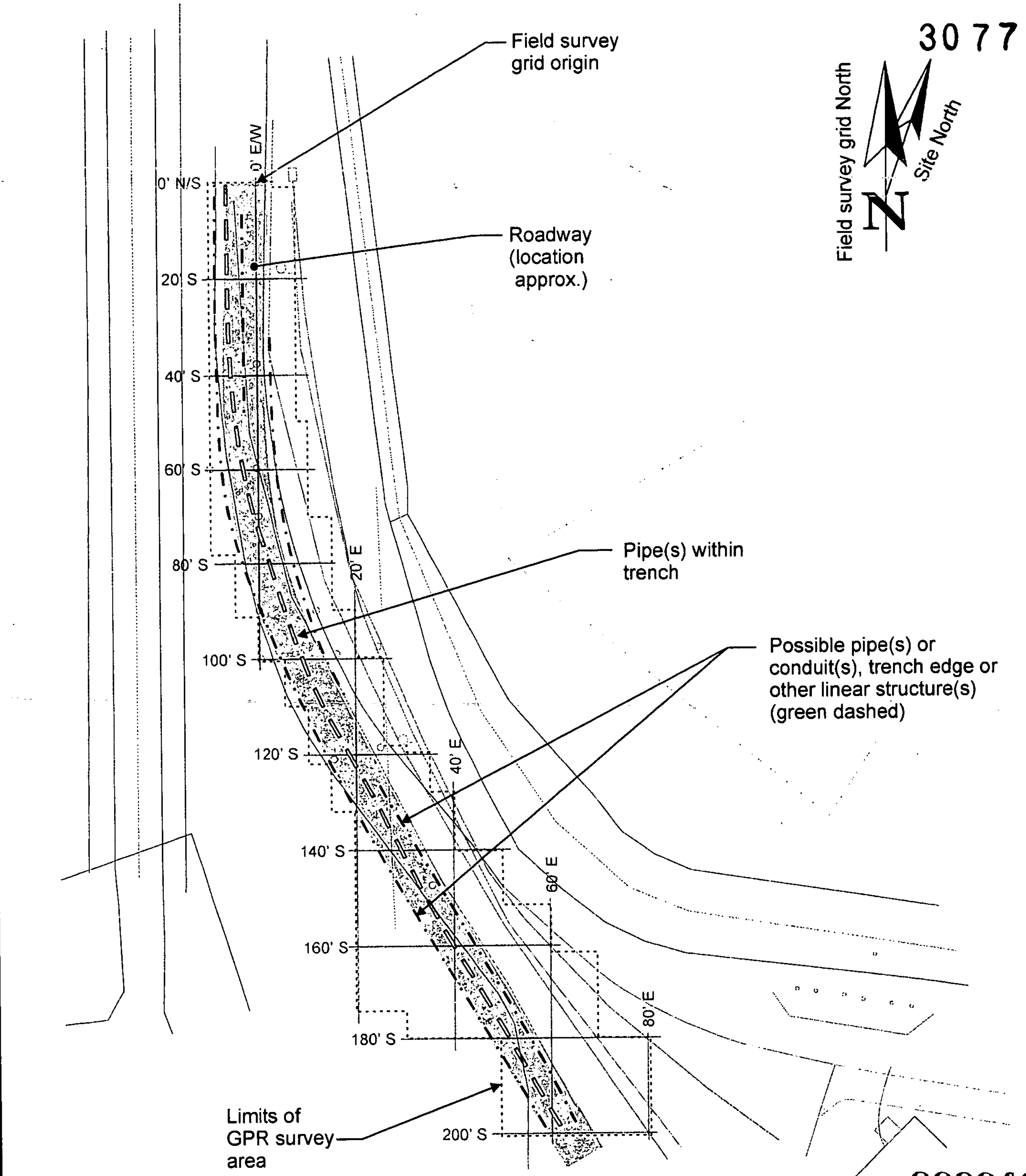
Near-surface Geophysics, Non-destructive Subsurface Exploration

Notes:
GSSI SIR-2 GPR System
200 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 16, 2000

Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: nts	

Figure 18 — Title: Selected GPR Records - Task II Area Transects

3077



000046

Notes:
GSSI SIR-2 GPR System
400 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 17, 2000
AutoCad overlay by Fluor-Fernald

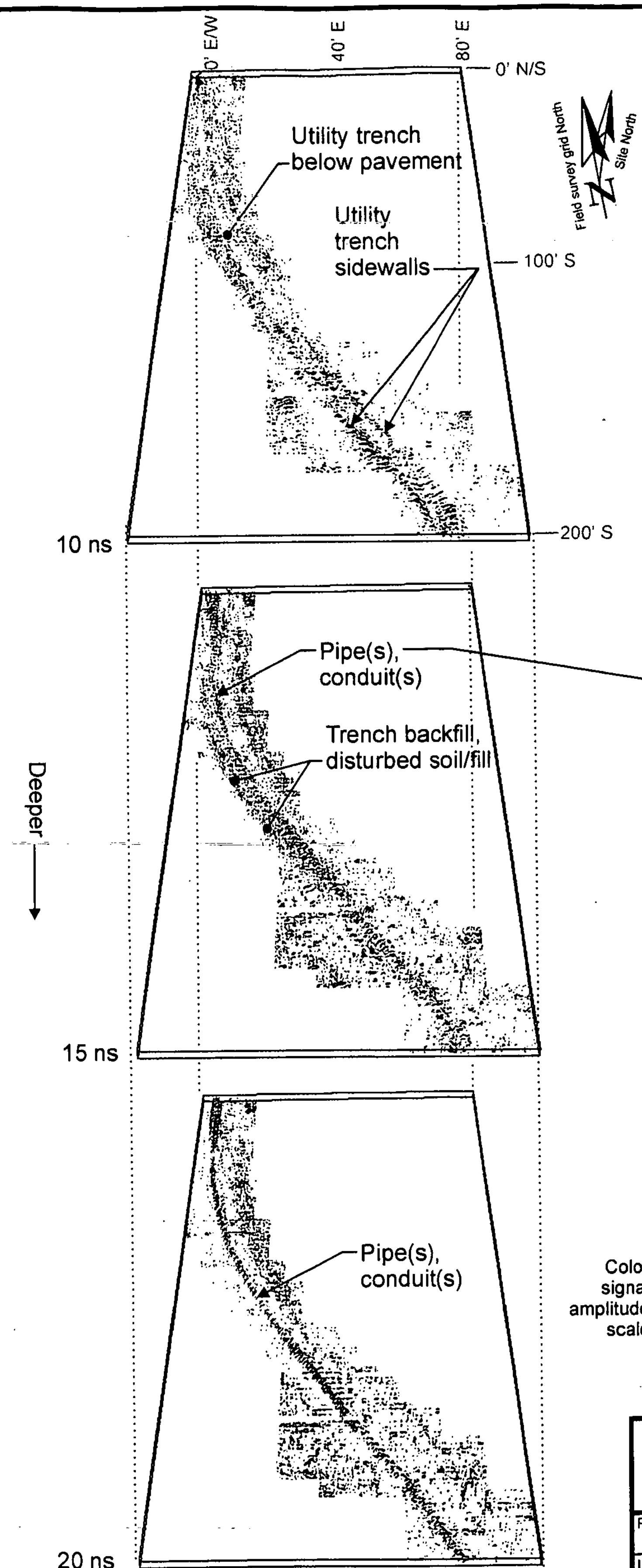
Grumman Exploration, Inc.
2309 Dorset Road, Columbus, Ohio 43221
Near-surface Geophysics, Non-destructive Subsurface Exploration

Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald	By: dlg	Date: 02/15/00	
Project No.: 01-20002	Checked:	Scale: 1"=30'	

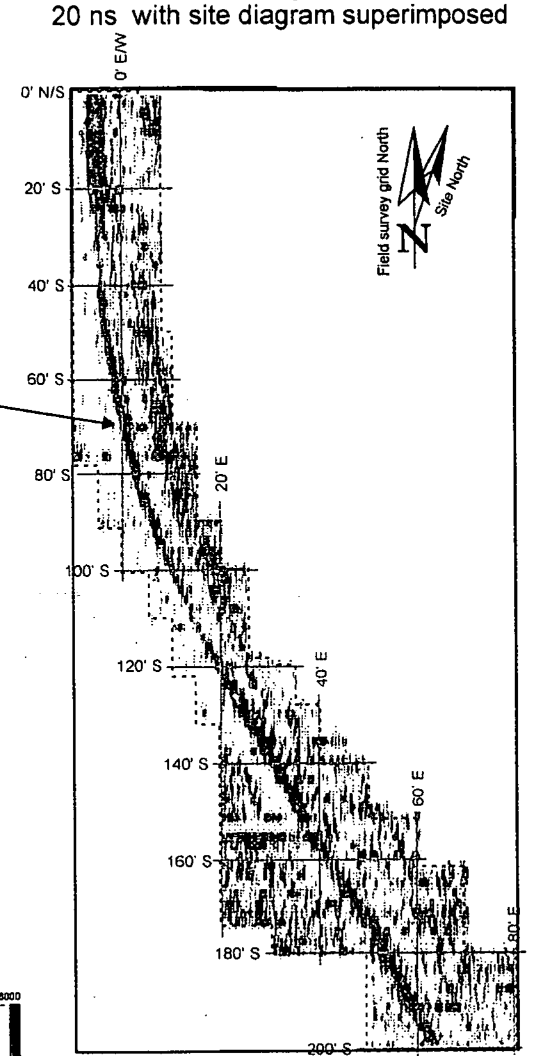
Figure 19 — Title: Utility Corridor GPR Survey Area - Task III

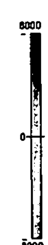
3077

Stacked 3D GPR Timeslices [left] of utility corridor survey area (5-ns timeslices,101 records shown viewed from the south)



Planview timeslice [below] centered at 20 ns with site diagram superimposed





Color signal amplitude scale

000047

Notes:
GSSI SIR-2 GPR System
400 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 17, 2000

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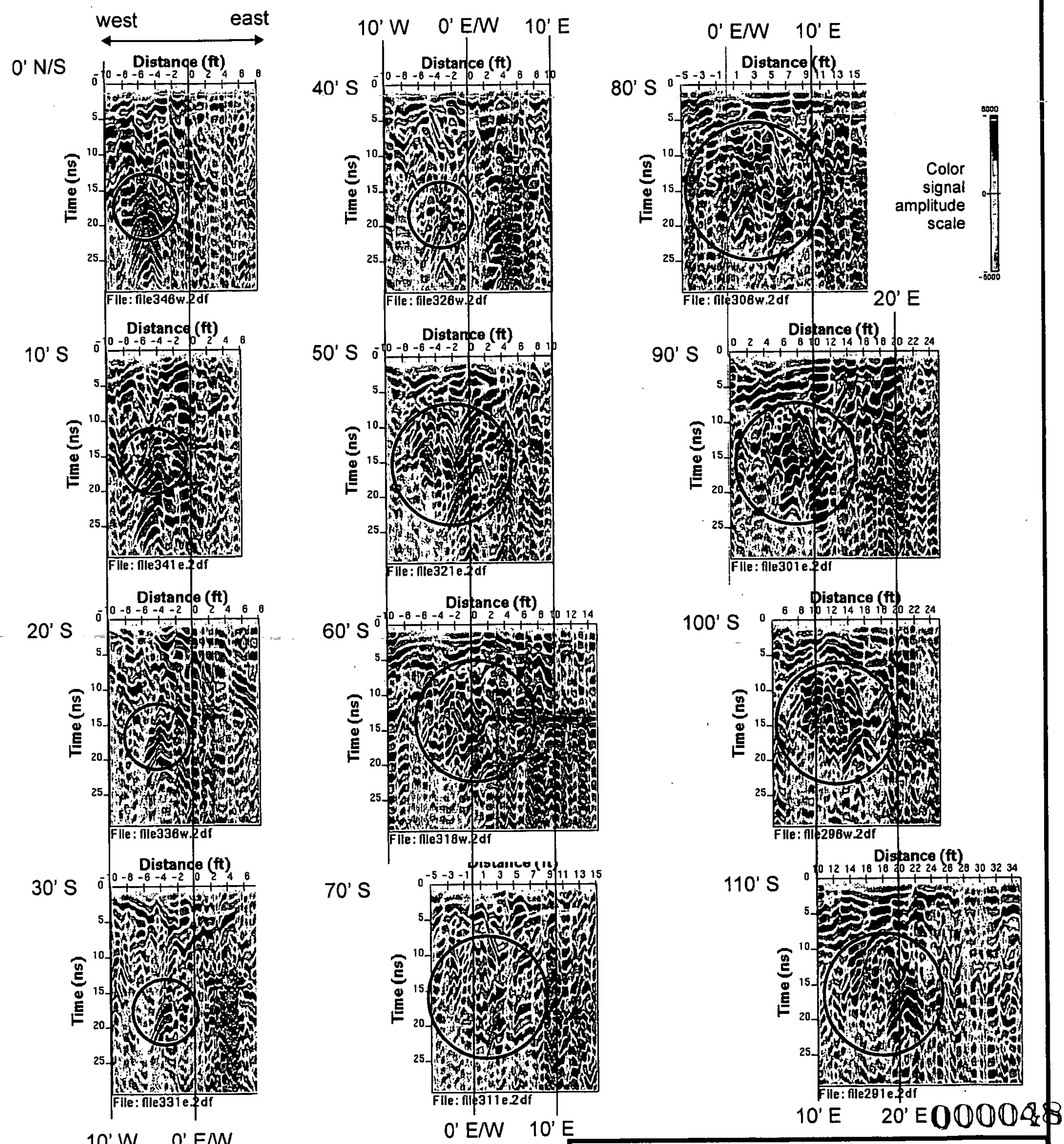
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald	By: dlg		Date: 02/15/00
Project No.: 01-20002	Checked:		Scale: 1"=30'

Figure 20 Title 3-D GPR Diagram - Task III Utility Corridor

Selected GPR Records from 10-ft intervals - Task III Utility Corridor (northern three fifths)



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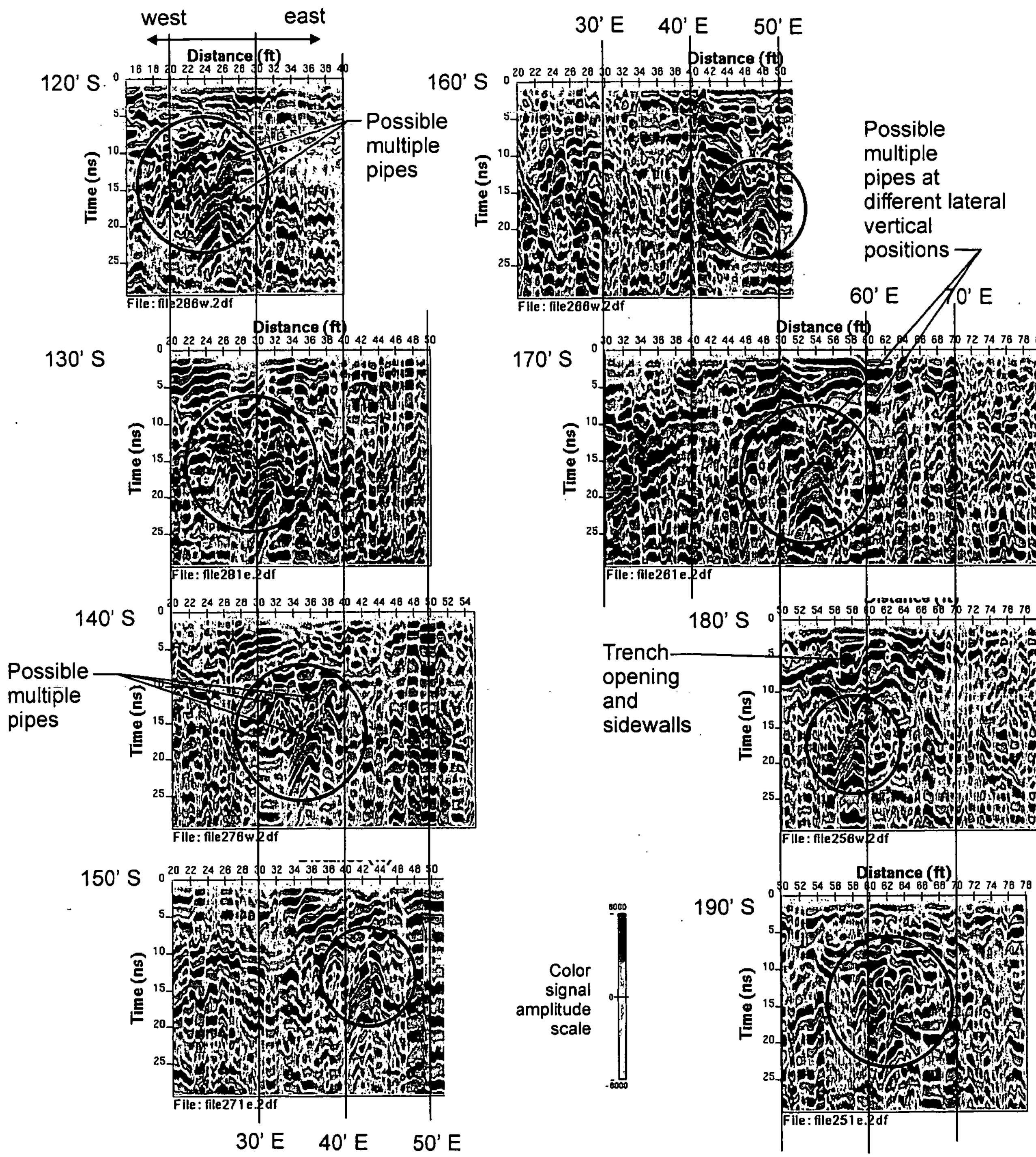
Notes:
GSSI SIR-2 GPR System
200 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 17, 2000

Project	Report of Geophysical Demonstration		
Location	Fernald Environmental Management Project		
Client	Fluor-Fernald	By dlg	Date 02/15/00
Project No.	01-20002	Checked	Scale nts

Figure 21 — Title: Selected GPR Records - Task III Utility Corridor

Selected GPR Records from 10-ft intervals - Task III Utility Corridor (southern two fifths) 3077



000049

Notes:
GSSI SIR-2 GPR System
200 MHz dipole antenna
2-ft line spacing, ~10-traces/ft
Coordinates refer to field survey grid
Survey date: February 17, 2000

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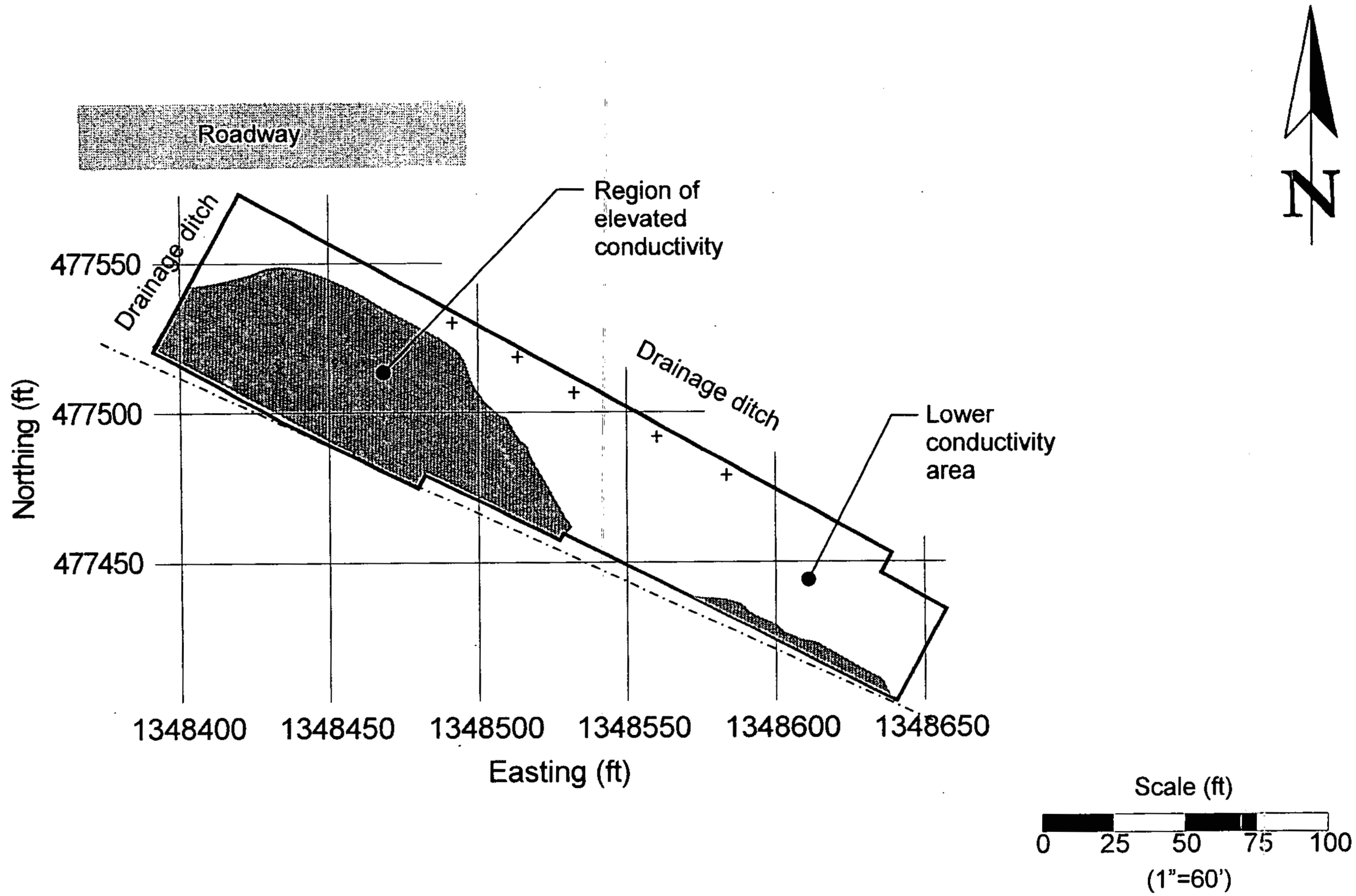
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client: Fluor-Fernald		By: dlg	Date: 02/15/00
Project No.: 01-20002		Checked:	Scale: nts

Figure 22 Title: Selected GPR Records - Task III Utility Corridor



Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
2-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: March 2, 2000

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Near-surface Geophysics, Non-destructive Subsurface Exploration

Project	Report of Geophysical Demonstration
Location	Fernald Environmental Management Project
Client/Owner	Fluor-Fernald
By	dlg
Date	03/14/00
Project No.	01-20002
Checked	
Scale	1"=60'

Figure 23 Title Task IV Active Flyash Pile Area - Conductivity and In-phase Interpretations

000050

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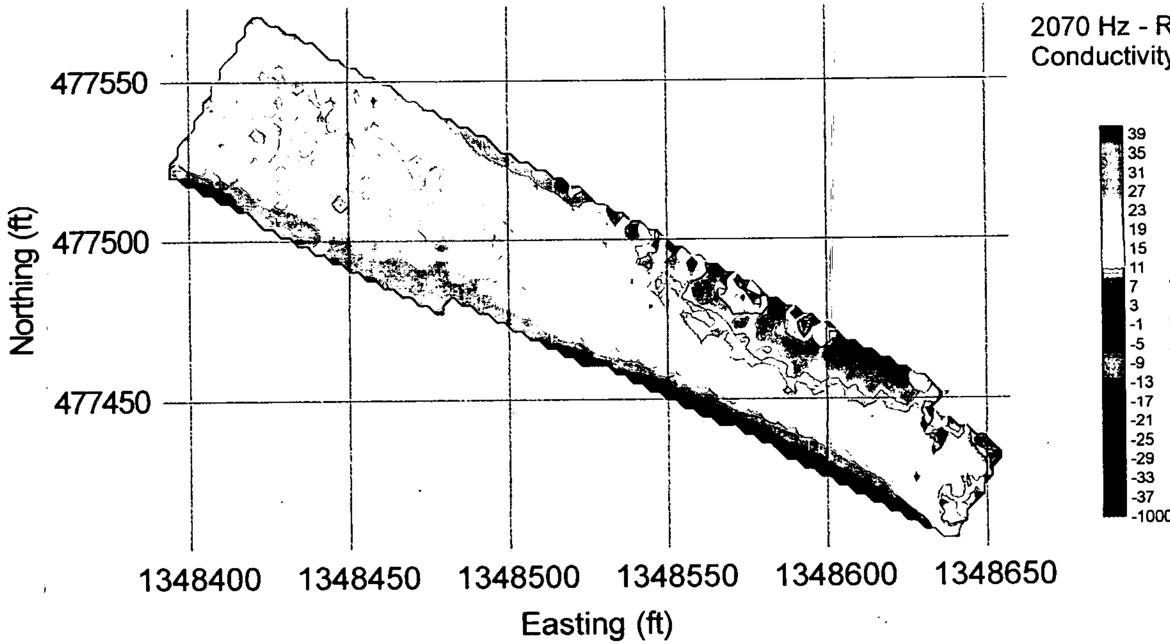
2070 Hz - Relative Terrain Conductivity Contour Diagram

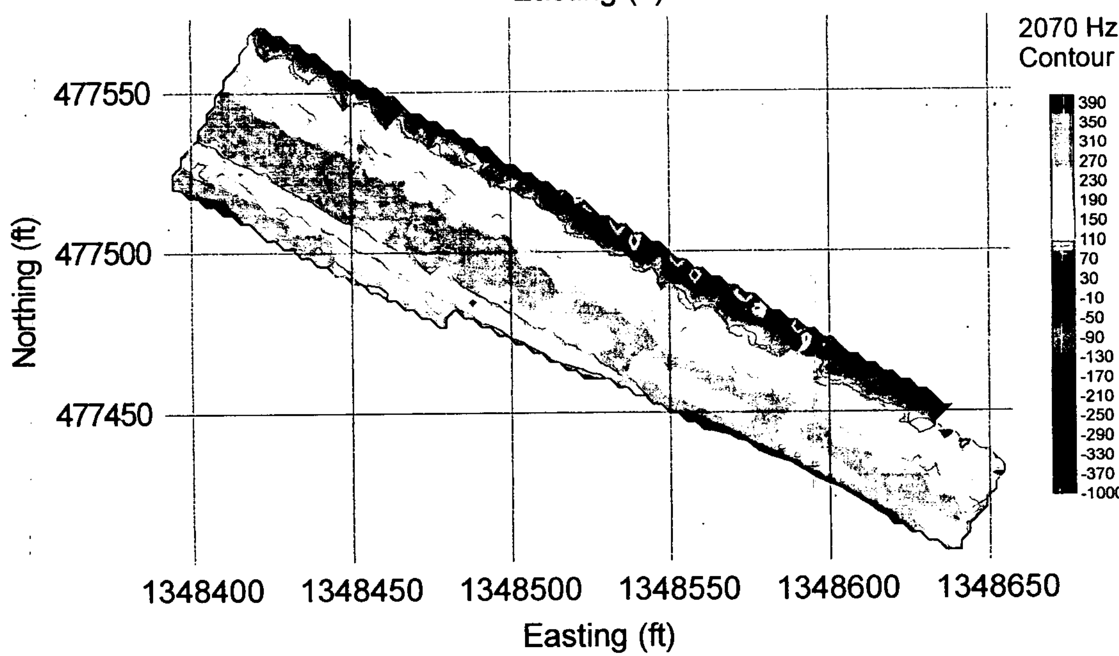


Relative Terrain Conductivity Color Contour Scale (mS/m)

N

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
2-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: March 2, 2000

2070 Hz - In-phase (metal sensitive) Contour Diagram



In-phase Response (metal sensitive) Color Contour Scale (ppm)

Scale (ft)
0 25 50 75 100
(1"=60')

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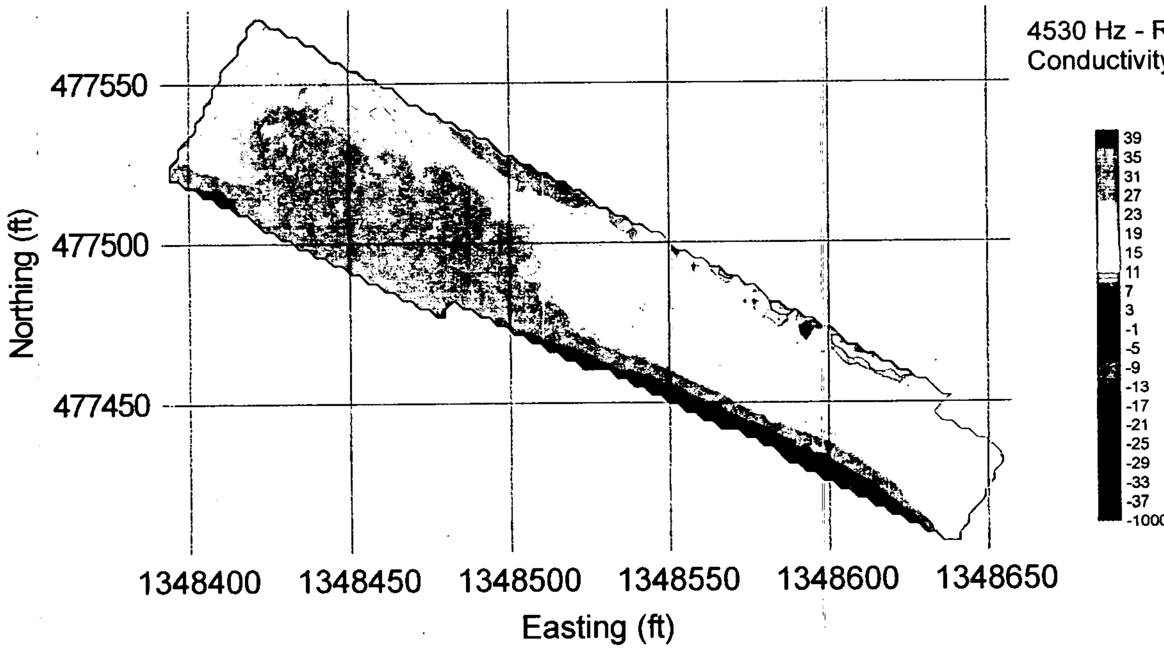
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor-Fernald	By: dlg		Date: 03/14/00
Project No.: 01-20002	Checked:		Scale: 1"=60'

Figure 24 | Title: 2070 Hz - Conductivity and In-phase Contour Diagrams - Task IV Active Flyash Pile

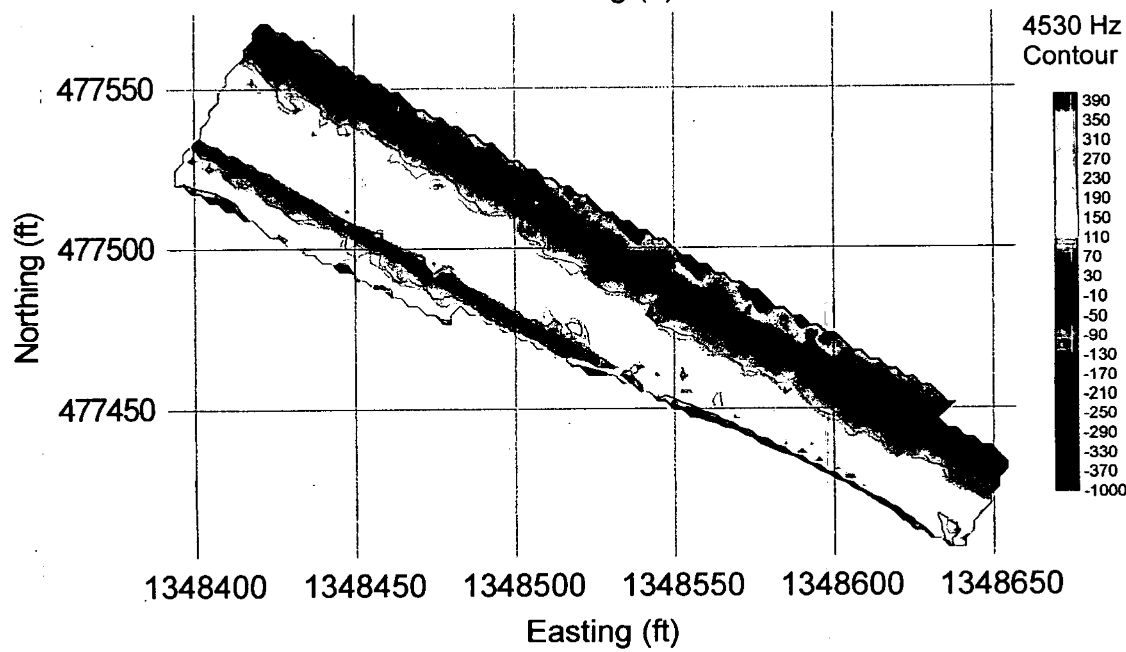
000051

3077



Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
2-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: March 2, 2000

N



Scale (ft)
0 25 50 75 100
(1"=60')

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2309 Dorset Road, Columbus, Ohio 43221
Near-surface Geophysics, Non-destructive Subsurface Exploration

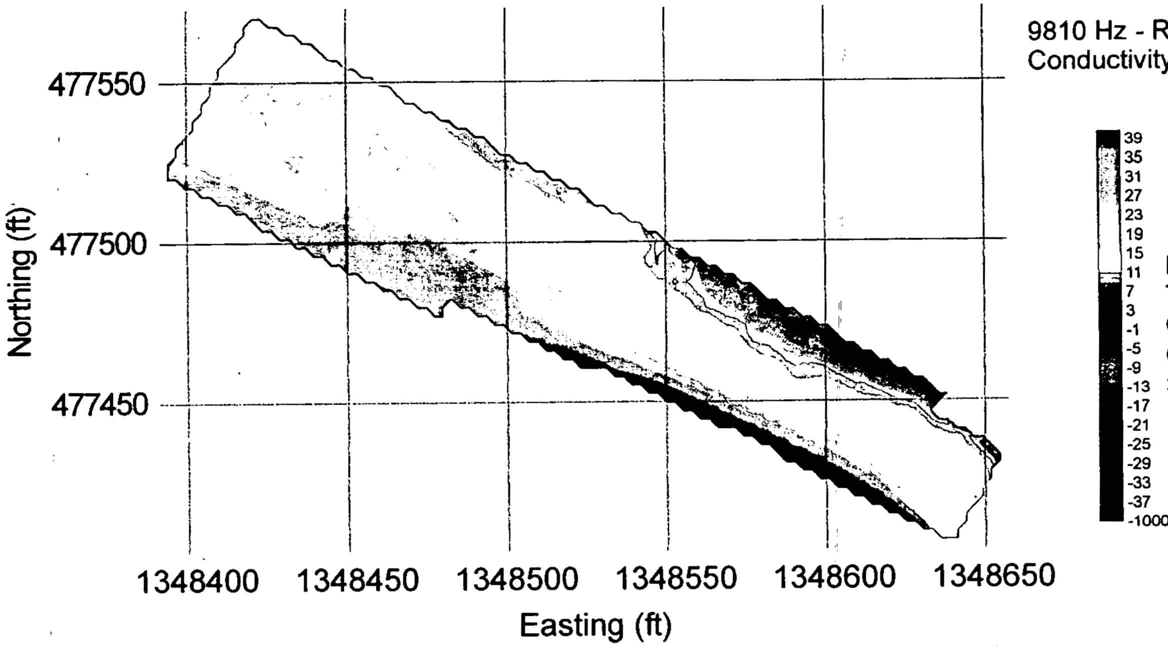
Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor-Fernald	By: dlg	Date: 03/14/00	
Project No.: 01-20002	Checked:	Scale: 1"=60'	

Figure 25 Title 4530 Hz - Conductivity and In-phase Contour Diagrams - Task IV Active Flyash Pile

000052

3077

9810 Hz - Relative Terrain Conductivity Contour Diagram

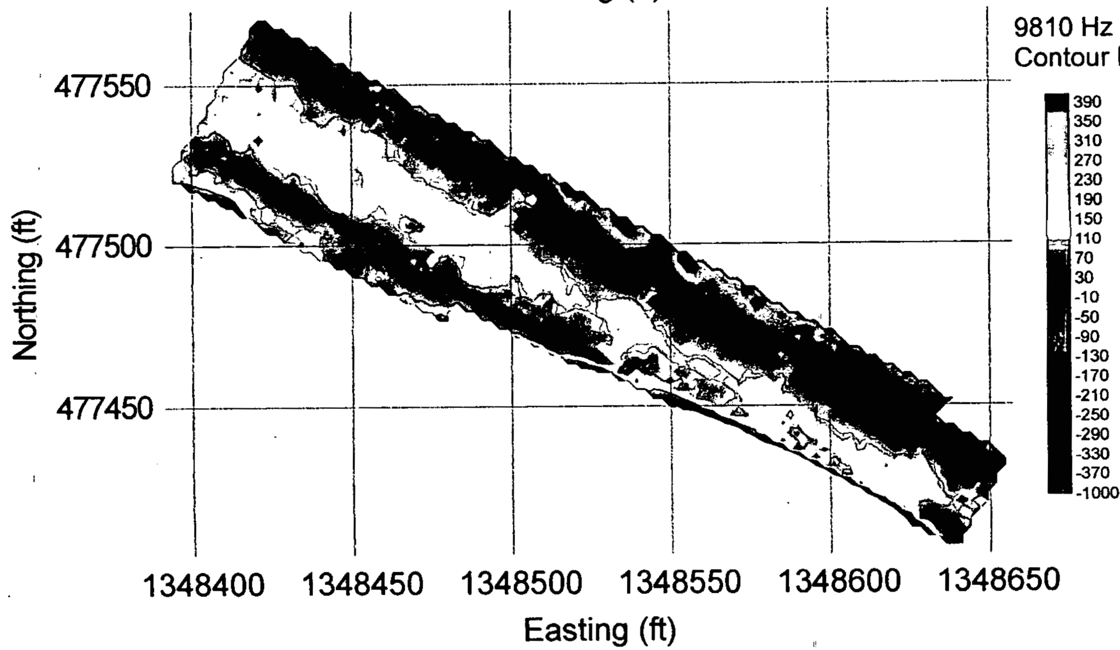


Relative Terrain Conductivity Color Contour Scale (mS/m)

N

Notes:
GSSI GEM-300 Multi-frequency Terrain Profiling Instrumentation
Vertical dipole, single coil orientation,
2-ft line spacing, ~2.5-ft station spacing, no stacking
Survey frequencies: 2070, 4530 & 9810 Hz
Survey date: March 2, 2000

9810 Hz - In-phase (metal sensitive) Contour Diagram



In-phase Response (metal sensitive) Color Contour Scale (ppm)

Scale (ft)
0 25 50 75 100
(1"=60')

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Project: Report of Geophysical Demonstration			
Location: Fernald Environmental Management Project			
Client/Owner: Fluor-Fernald	By: dlg		Date: 03/14/00
Project No. 01-20002	Checked		Scale: 1"=60'

Figure 26 | Title: 9810 Hz - Conductivity and In-phase Contour Diagram - Task IV Active Flyash Pile

000053

3077

APPENDICIES

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APPENDIX A

Overview of Electromagnetic Terrain Conductivity Profiling

A.1 Introduction and Applications

The EM terrain conductivity profiling instrumentation make two measurements useful for environmental site investigations: (1) soil electrical conductivity (quadrature phase) and (2) in-phase (metallic sensitive). Terrain conductivity is a useful measurement for mapping spatial variations in soil and fill types based on contrasts in electrical conductivity. Low conductivity (σ) earth materials, such as a sand and gravel ($\sigma \cong$ 5-20 mS/m typical), can often be distinguished from higher conductivity silts or clays ($\sigma \cong$ 20-60 mS/m). Moisture or water saturation also enhances a material's conductivity. EM conductivity surveys are commonly used to help locate and map buried fill, objects and ground water plumes based on differences in electrical conductivity between impacted or non-native areas and natural, undisturbed areas. The presence of conductive fill or debris or electrolytic fluids in the shallow subsurface can raise the terrain conductivity above background levels enough to be detectable using these systems. The in-phase measurement is most sensitive to buried metallic objects and can be used to locate and map buried reinforced steel structures, well casings, pipes and utility lines, and other buried metallic structures or highly conductive debris.

A.2 EM Technical Background

The EM terrain conductivity instrumentation operates using specially configured transmitting and receiving coils. A receiving coil measures the subsurface response to EM eddy currents that are induced in the subsurface by the transmitting coils. The induced EM response provides an estimate of the bulk electrical conductivity of a subsurface region centered below the EM instrument. As a consequence, these EM systems are often referred to as induced field or frequency domain systems. Figure A.1 schematically illustrates the EM system and Figure A.2 shows the GEM-300 system in use at the FEMP site. Background descriptions of the EM method can be found in Keller and Frischknecht [1966], McNeill [1980a] and McNeill [1980b]. The multi-frequency GEM system is reviewed in Won [1996] and GSSI [1998].

A.3 Depth of Exploration and Resolution

The depth of exploration depends on the coil orientation and spacing, operating frequency, target size and configuration, and the electrical properties of the host material and target. Lower frequencies will penetrate deeper into the subsurface and the *skin-depth* is often used as a guide to the actual penetration distance. According to the manufacturer, the exploration depth for the EM-31 is approximately 18-ft. The exploration depth for the GEM-300 can vary and depends in part on the frequency(ies) used (selectable between 325 Hz up to 19 KHz). Consequently the exploration depth for the GEM-300 can range from a few feet to several tens of feet depending on the frequency(ies) selected. In general, the bulk of the response for both instruments derives from the 3-ft to 15-ft depth range. More precise exploration depth estimates typically involve complicated mathematical inversion procedures along with some prior knowledge of the subsurface electrical properties and their distribution. Similar to vertical resolution, the lateral resolution of the EM instrumentation will depend in part on the coil configuration and design, survey station and line spacing, target size, depth and the electrical conductivity of the target and surrounding media.

A.4 Commercial EM Systems and Operation

Commercially available EM conductivity instruments include the popular Geonics, Ltd. EM-31 and EM-34 and several newer multi-frequency EM instruments such as the GEM-300 (Geophysical Survey Systems, Inc.[GSSI]) and the GEM-2 (Geophex, Inc.) as well as others. Most EM systems, including the EM-31, GEM-300 and GEM-2, are lightweight and portable and require one field operator. The EM response can be monitored in the field continuously and recorded electronically. The GEM-300 provides a real-time graphical and numerical display of the data. The data are easily downloaded to a PC and both data channels (conductivity and in-phase) can be contoured using commercially available contouring programs.

A.5 Limitations

Limitations to the use of EM arise from a variety of electrical interference sources that include: ambient electrical noise such as occurs in urban or densely developed areas, thunderstorms and nearby metallic objects at or above the ground surface such as fences, debris piles, overhead power lines, parked cars, reinforced concrete structures, buried foundation walls, etc. The presence of various metallic surface obstructions can limit or even preclude any interpretation of the EM data in the vicinity of these obstructions. EM surveys cannot be performed in steep, unstable, flooded, densely vegetated, overgrown or otherwise obstructed areas. Specific targets of interest can be obscured by some of the factors noted above. Older models of the GEM-300 are known to suffer from some thermal instability and the readings may drift slowly in response to daily temperature variations and instrument warm-up.

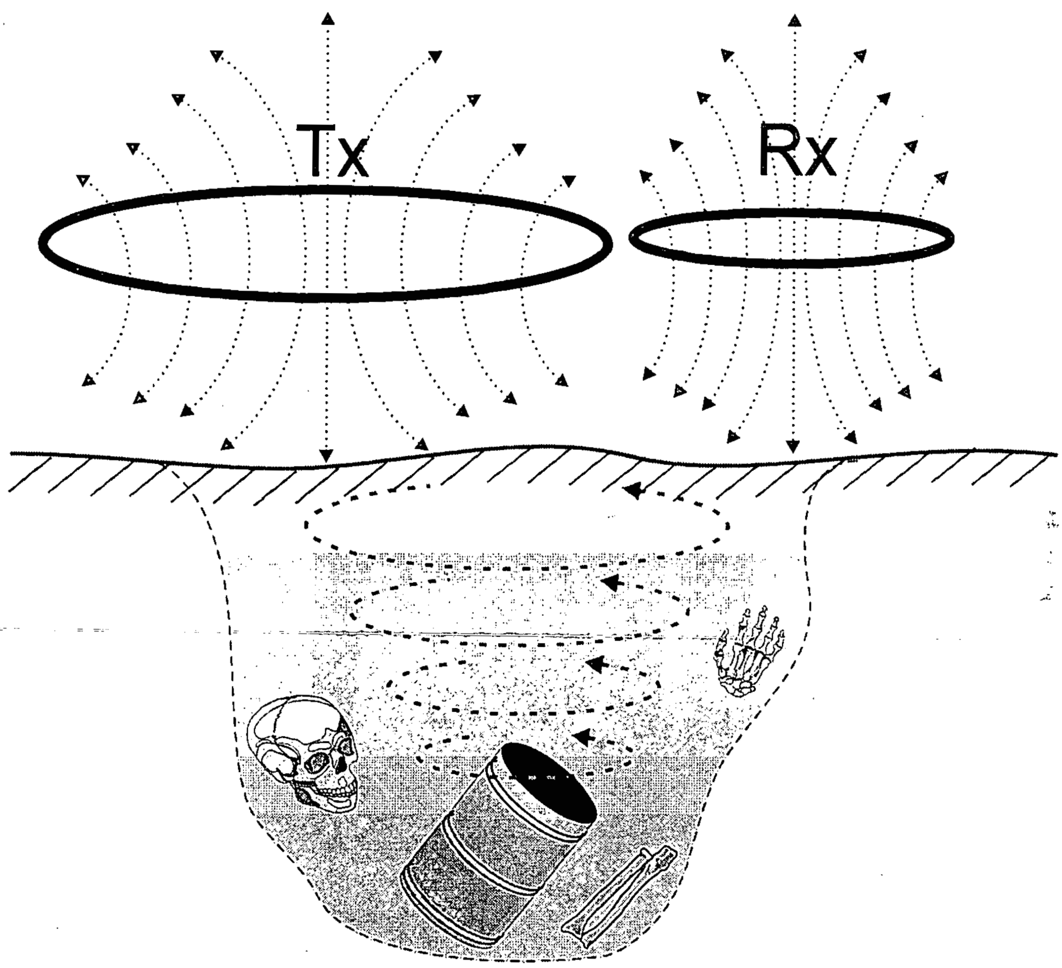

Figure A.1 Schematic diagram of EM terrain conductivity instrumentation. Transmitter coil (Tx) induces an EM field in the subsurface. The subsurface response is detected by the receiver coil (Rx). Both quadrature phase (proportional to conductivity) and in-phase (metal sensitive) responses are measured.

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Figure A.2 Photos of the GEM-300 EM survey instrumentation at the FEMP site. The orange casing houses both transmit and receiver coils. A small screen allows the operator to monitor the received conductivity or in-phase response either numerically or graphically in real-time. Photos illustrate use of EM in a variety of seasonal settings and terrains. Photos provided by Fluor-Fernald.

APPENDIX B

Overview of Ground-Penetrating Radar

B.1 Introduction

Ground-Penetrating Radar (GPR) operates by transmitting and receiving microwave electromagnetic impulses through the subsurface. By moving a broadband, dipole antenna across the ground surface, an approximate (quasi) two-dimensional cross-section of the subsurface can be displayed on the GPR system unit. GPR is sometimes described as a kind of pulse-echo device, not unlike sonar or an acoustic fish finder. In contrast to these acoustic devices, however, GPR operates by using electromagnetic signals that are governed by the principles of electromagnetic wave propagation through the subsurface. Transmitted GPR impulses propagate downward through the subsurface, reflect off buried target boundaries and return to the receiver antenna. Contrasts in the electrical properties of a target will cause some of the GPR signal to reflect back toward the ground surface. Interfaces between electrically distinctive materials such as sand and clay, backfill and steel, concrete and soil, and the water table can be detected using GPR under favorable survey conditions. The technical basis for GPR is described in Daniels (1989), Davis and Annan (1989), Powers (1995), and Conyers and Goodman (1997). A comprehensive review of GPR is also available on the Internet at www.g-p-r.com.

The preceding simplified description belies much of the complexity of GPR. Among the interdependent variables that affect GPR performance include: the electrical properties of the subsurface and targets, the spatial configuration of the subsurface and targets, the GPR system hardware and performance, above ground and below ground conditions, and electrical interference. Also important are subjective variables such as exploration objectives, expectations and the experience of the person(s) conducting the survey and interpreting the results. As an electrical method, the basis for understanding GPR lies in the principles of electromagnetic wave propagation (e.g., Maxwell's Equations, Radar Equation, etc). The references noted above summarize the theoretical basis for GPR more completely. The following paragraphs provide a simplified summary of some of the basic concepts useful for understanding GPR.

B.2 Applications

GPR is credited with successfully exploring a wide variety of buried targets and subsurface conditions. Popular applications of GPR span the fields of environmental, geologic and civil engineering and generally involve buried target characterization, detection and mapping. Published examples of the application of GPR for environmental site characterization include: Daniels and others (1992), Grumman and others (1995), Maxwell & Schmock (1995), and Olhoeft (1992).

B.3 GPR System Components and Operation

A basic GPR system consists of a system control unit and recording instrumentation connected to transmitter and receiver antennas (see Figures B.1 and B.2). The transmit and receive antennas may be separate components or housed together in a single container or antenna box. Both antenna elements are placed in close proximity to the ground surface to efficiently transmit and receive the GPR signal. Several different GPR antenna designs are used, although most commercial systems use a dual dipole antenna configuration. High-frequency, short duration impulses that originate on the transmit antenna radiate outward in a pattern determined by the impulse characteristics, antenna design and near surface electrical properties. At the moment the transmit pulse begins, the second receiver antenna 'listens for' (measures) the returning signal. The received waveforms are displayed on the system unit and may be recorded digitally. By moving the antennas across the ground surface, the series of recorded impulses responding to horizontal and vertical changes in the subsurface create the impression of a two-dimensional cross-section of the subsurface. The recording is actually a quasi 2-D representation of the configuration of electrically different materials within the subsurface (Figure B.1).

Several GPR systems are commercially available from manufacturers worldwide. The general configuration of these systems tends to be similar with a few important distinctions in design, portability, field-ruggedness, technical performance and cost. The GPR system output can range from a paper strip-chart print-out to real-time color video displays. Recently developed systems allow the data to be displayed and recorded digitally in real-time in the field. Various GPR software programs are available for simple and advanced data analysis and display.

B.4 Electrical Properties, Signal Reflection and Attenuation

The electrical properties that affect GPR signal propagation and reflection are: conductivity (charge transport), permittivity (dielectric, related to charge storage), and permeability (related to magnetic properties). Electrical conductivity strongly affects the attenuation of the GPR signal, with higher electrical conductivity causing higher levels of signal loss. Higher conductivity clay soils tend to severely reduce signal penetration, sometimes to as little as a few feet. In contrast, low conductivity sand often results in low signal loss and deeper penetration, often on the order of 15-ft to 30-ft. Permittivity is also a source of signal loss similar to the effect of conductivity. However, it is the contrast in permittivity between materials that is responsible for causing reflections, and permittivity can be used to estimate the depth of exploration. Permittivity is sometimes referred to as the dielectric characteristic of a material and is often termed the 'dielectric constant'. Magnetic permeability tends to have a minimal influence on GPR except in materials with elevated iron or magnetic mineral content. Other signal loss mechanisms are described in the references noted previously.

In order for reflection to occur, there must be a sufficient permittivity contrast across the reflecting interface, and the interface must be spatially well defined (i.e., sharp, not gradational). A buried concrete surface or the water table in a coarse grained soil (e.g., sand

and gravel) are often good reflecting surfaces. A gradational boundary, such as a thick capillary fringe above the water table in a finer grained soil (e.g., silt or clay) may not be sufficiently distinct to produce any reflection. The larger the permittivity contrast between materials, the stronger the reflected energy will be. Many conductive metals, being nearly perfect reflectors, generate strong reflections and often a distinctive 'ringing' response on the GPR record. A general lack of reflections or reflecting interfaces from an area may occur because of: (a) high signal attenuation caused by conductive soil conditions, and/or (b) no detectable targets or reflecting surfaces.

How efficiently an antenna radiates energy into the subsurface (termed antenna-ground coupling) depends in part on the similarity of the electrical characteristics of the antenna and the subsurface. The greatest transfer of energy into the subsurface occurs when the electrical impedance of the antenna closely matches that of the ground. When a mismatch occurs (such as over conductive or clay-rich soils), some of the radiated energy remains and resonates within the antenna and causes a distinctive 'ringing' pattern on the GPR record. Antenna ringing (poor antenna-ground coupling) is often apparent as a series of moderate to strong horizontal bands that extend across the record (see Figure B.3). A similar ringing effect can occur in response to some reflective targets or interfaces whereby electrical currents resonate within a target or antenna. In this case, targets often appear with a series of strong, parallel bands that appear to shadow the target farther down the record ('ringdown'). Buried reinforced pavement, steel pipes and other metal objects often show this response.

B.5 Depth of Exploration

Each GPR trace is a measure of the amount of time required for a transmitted impulse to propagate down through the subsurface, reflect off an interface, and travel back to the receiver antenna. Consequently, the recorded time is a two-way travel time – down and back. Travel time is recorded in units of nanoseconds (ns: 1 ns = 1 billionth of a second). The travel time of a reflected impulse is related to the depth of the reflector by the permittivity of the subsurface through which the pulse travels. Specifically, the velocity (v) of a GPR signal through some homogeneous medium is the speed of light (c) divided by the square root of the medium's permittivity (ε).

$$v = \frac{c}{\sqrt{\varepsilon}}$$

Using the 'pulse' velocity of a subsurface medium and the observed two-way travel time to a reflector, one can calculate depth to the reflecting interface. The derivation of reliable depth estimates tends to be more complicated in practice. The effective depth of exploration may actually vary across a site as a function of the spatial variation in the electrical properties of the subsurface.

Electrical permittivity is not a commonly reported field parameter. However, there are several methods to derive the velocity of a material and subsequently depth or permittivity.

One simple 'depth calibration' method involves measuring the travel time required to reflect off a target or interface (e.g., a pipe or stratigraphic surface) at a known depth and then calculate a velocity. Another procedure (walk-away test) involves using transmit and receive antennas separated by fixed distances to reflect off a horizontal subsurface interface (e.g., water table or stratigraphic layer). The change in observed reflector travel times can be used to derive a composite velocity estimate for that region of the subsurface. These methods are valid provided the electrical properties of the subsurface across the rest of the site are approximately the same as at the 'calibration' locations. Unfortunately, assumptions regarding homogeneous subsurface conditions are not always valid or known ahead of time, particularly at many urban and industrial sites with complex subsurface conditions. Consequently, some GPR practitioners only convert GPR records to a depth scale when favorable conditions or prior knowledge of subsurface electrical properties are available. Alternatively, it is possible to derive a plausible range of target depths using reasonable estimates of permittivity or pulse velocity through materials known or suspected to be present at a site.

Table B.1 summarizes estimated two-way travel times for GPR signals using very general estimates of velocity and permittivity for materials similar to those that may be present on site. Table A.1 indicates that a reflector buried in a till (silt and clay) at 6-ft would appear at approximately 40 ns, while the same reflector in dry sand would appear at 30 ns.

			Depth (ft)				
Earth Material	Relative Dielectric Permittivity	2-way Pulse Velocity (ns/ft)	2	4	6	8	10
Clay - wet	27	10.5	21	42	63	84	105
Clay - dry	4	4	8	16	24	32	48
Till (clay and silt)	11	6.7	13	27	40	54	67
Sand – wet	25	10	20	40	60	80	100
Sand – dry	6	5	10	20	30	40	50
Fresh water	81	18	36	72	108	144	180

Table B.1 – Estimated two-way travel times (ns) for targets buried at various depths within various earth materials – material values are very generalized and are based on a table available from *Geophysical Survey Systems, Inc.*

B.6 Antenna Frequency and Resolution

The depth of exploration and target resolution of GPR systems is determined by the frequency of the signal used. Typical dipole antennas used for GPR operate in the 50 MHz to 1,000 MHz frequency range. These antennas transmit an impulse consisting of a broad range of frequencies and the antennas are usually identified by their approximate highest power frequency of operation (e.g., 400 MHz, 200 MHz). The trade-off between depth of exploration and vertical resolution is a function of the antenna frequency. In general, lower frequency signals (longer wavelength, larger antenna size) penetrate deeper into the subsurface but result in lower resolution (poorer detection of small targets). Conversely, higher target resolution is achieved by using a higher frequency antenna although with reduced signal penetration. One rule of thumb regarding vertical resolution and target detectability is that the size of a target must be on the order of one-half the wavelength of the signal within the subsurface. The choice of antenna is site- and target-specific. In general, lower frequency antennas provide only minimal additional depth penetration at sites where unfavorable, conductive near surface conditions are present, and they have the added disadvantage of poorer vertical resolution.

Lateral (horizontal) resolution is controlled by the trace and line spacing, with the in-line resolution usually being considerably higher than the cross-line resolution. As a rule of thumb, the horizontal resolution is approximately two times the trace or line spacing (e.g., 1-ft line spacing => ~2-ft cross-line resolution, 1-inch trace spacing => ~2-inch in-line resolution). This asymmetry in lateral resolution emphasizes the importance of conducting perpendicular crossing scans when possible.

B.7 Data Analysis and Interpretation

The advent of powerful and affordable GPR recording systems, computers and software has led to the increased use of advanced digital data processing of GPR data. Many GPR data analysis procedures were borrowed from the fields of petroleum exploration (seismic) and electrical engineering. The objectives of these methods in general are to improve the appearance of targets or features of interest while simultaneously suppressing undesirable aspects within the data such as noise and clutter. The use and application of various data analysis tools depends on factors including applicability, effectiveness, complexity, software availability, cost, turn-around time, and interpreter experience. Commonly applied data processing routines include: bandpass frequency filtering, spatial filtering, time-variable amplitude gain adjustment, average trace subtraction, and trace averaging. A wide variety of other more advanced processing algorithms may also be appropriate under favorable circumstances. Undesirable interference sources include ambient microwave noise, internal system noise and antenna-ground coupling artifacts (e.g., ringing).

GPR records are usually displayed using various shading or color assignments to correspond to different signal amplitudes. The top, horizontal axis of a GPR record typically corresponds to distance along the ground surface while the vertical axis corresponds to two-way travel time or depth if the appropriate depth conversion is made.

GPR data analysis is highly interpretive and depends on the quality of the field data, data processing methods and interpreter knowledge and experience.

B.8 3-D GPR Data Visualization

The 3-D GPR approach is not so much a new geophysical technique as it is an interpretation enhancement to conventional GPR procedures. The goal of 3-D GPR is to help visualize and interpret complicated subsurface features and their spatial relationships using conventional GPR field data. By taking advantage of recent technological innovations, such as through the use of advanced data processing techniques and 3-D visualization methods, 3-D GPR can be an effective tool for developing high-resolution images of the shallow subsurface. The three critical components of a GPR survey that uses 3-D imaging include:

- Field Data Acquisition procedures,
- Data Processing (enhancement) methods, and
- Computerized Data Visualization using powerful graphics computers and software.

The following paragraphs briefly summarize 3-D visualization of GPR data.

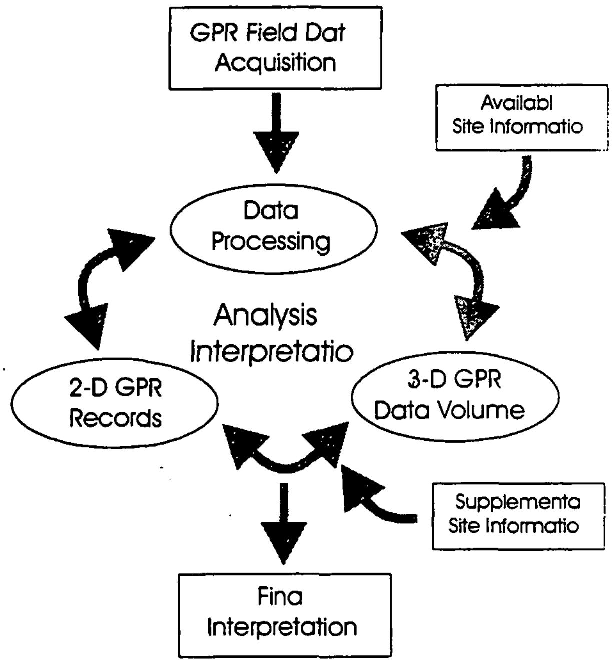

Figure B.5 Schematic Sequence of a 3-D GPR Survey

3-D GPR is a relatively new advancement that is described in Annan and Daniels (1998) and mentioned in Conyers and Goodman (1997), both of which include references to other published examples of 3-D GPR. Daniels and others (1998) present examples of the recent effective use of 3-D GPR for environmental site characterization. Because the 3-D GPR technique is relatively new, there exist several valid approaches and no generally accepted standards of practice have been established. The 3-D GPR methodology described herein is one possible approach and is described in Daniels and Grumman (1996). Figures B.4 and B.5 illustrate the basic sequence of steps used in 3-D GPR.

3-D GPR uses conventional GPR data acquired across a gridded, two-dimensional ground surface to create a three-dimensional (3-D) data volume representing the subsurface. The time (depth) axis is used to represent the third dimension. In most cases the field survey consists of surveying a site along closely spaced parallel survey lines, thereby acquiring a dense sequence of 2-D GPR records that span the site. The process of creating the 3-D volume consists of combining the series of 2-D records or 'slices' into a larger data set. To be efficient and economical, all the field data must be acquired digitally. Additionally, powerful computers and software are required to create and view the resultant 3-D data volume. Most 3-D visualization software programs allow the interpreter to view the entire data volume, sub-volumes or slices from any angle using any amplitude color scheme.

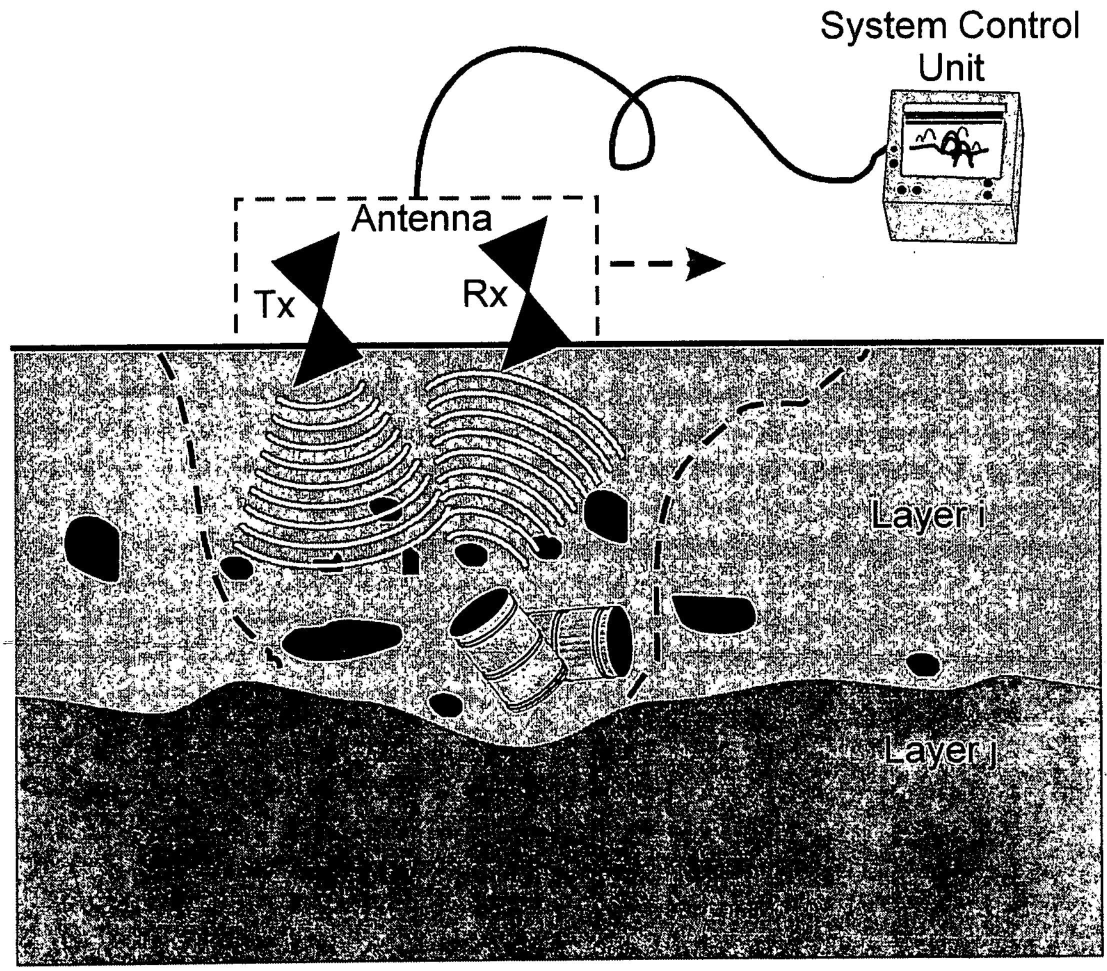

Figure B.1 Schematic diagram of a ground-penetrating radar system. High-frequency EM impulses propagate downward through the subsurface and reflect off interfaces between electrically dissimilar materials. Transmitter and receiver antennae are moved across the ground surface and the received signals are displayed on the system control unit in real-time.

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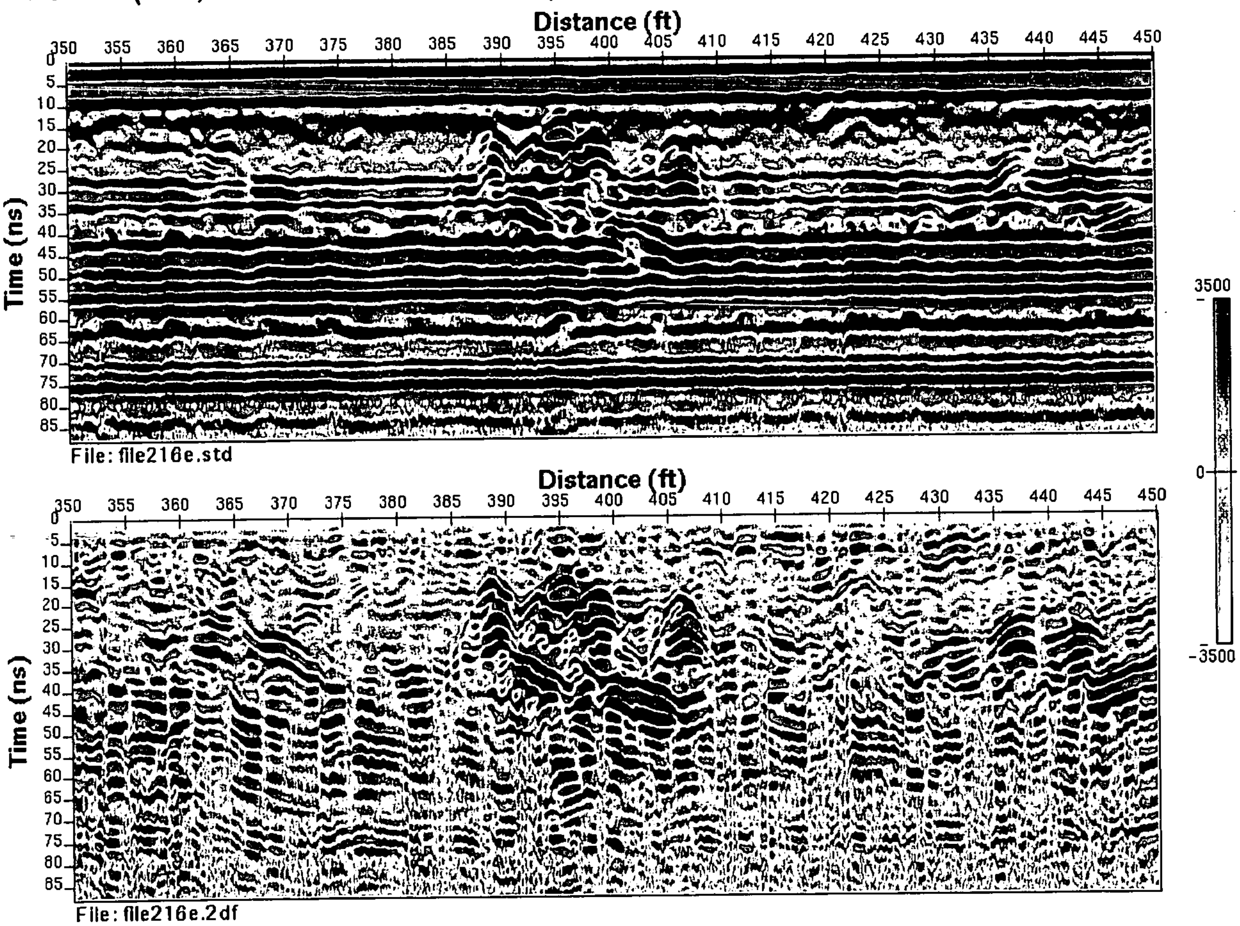
Figure B.2 Photos of the GPR system used at the FEMP site. The ruggedized orange box houses both transmitter and receiver antennas. A cable connects the antenna with the digital system control unit (not shown). A survey wheel controls the scan acquisition rate according to actual distance traveled. Different antennas may be used depending on exploration depth and resolution objectives.
Photos provided by Fluor-Fernald.

Before (raw, unfiltered GPR record)



After (Processed, filtered GPR record)

Figure B.3 Example of effects of digital data enhancement - Processing included bandpass and spatial (f-k) filtering. Record of field line 158-ft S, Task II (A2P1) survey area.

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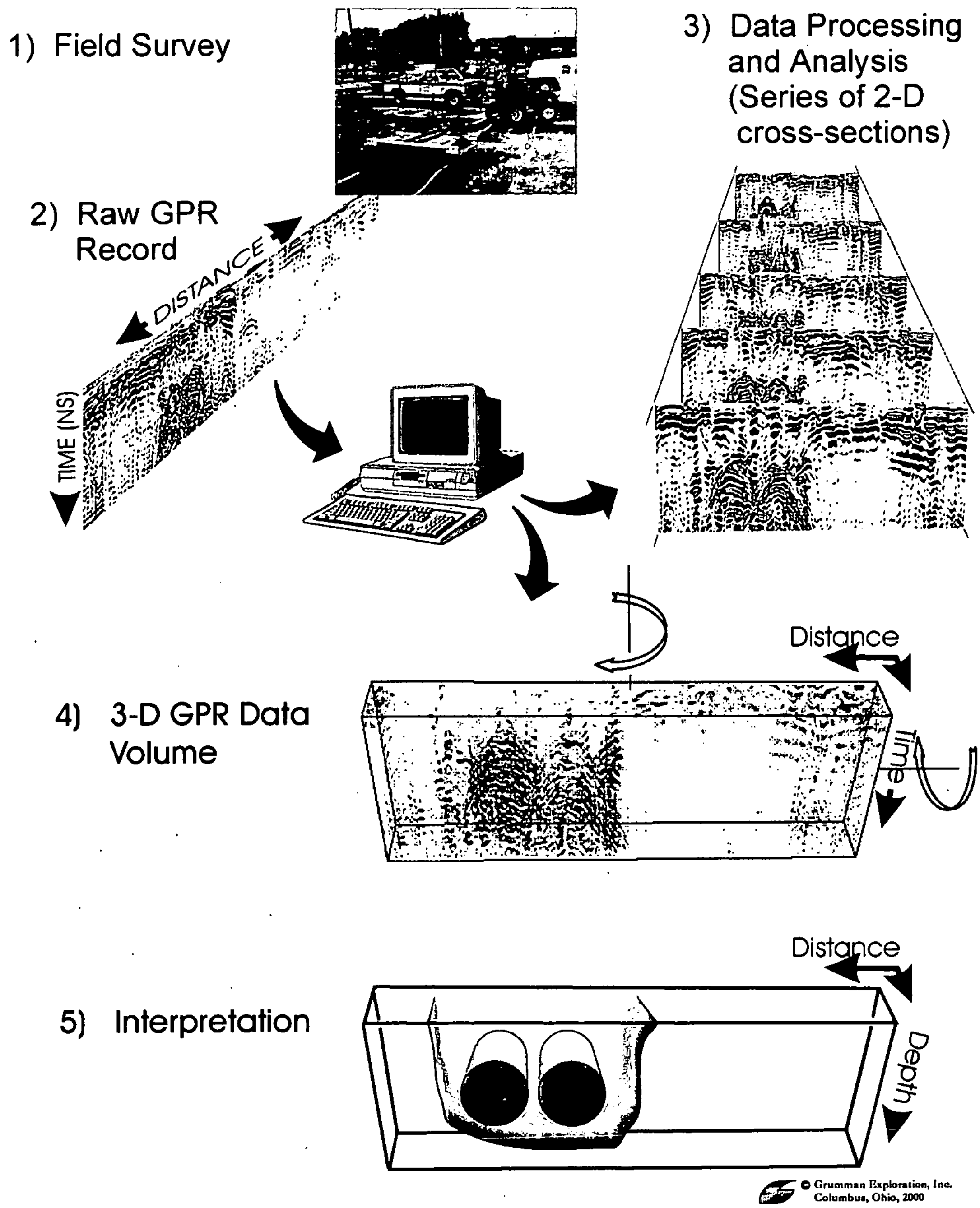

Figure B.4 Graphical Illustration of the 3-D GPR Process. Steps used to develop 2-D and 3-D GPR images.

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