Report of
Electromagnetic Terrain Conductivity Surveys
Area 1 Phase III Investigations
Fernald Environmental Management Project
Cincinnati, Ohio

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Prepared for

Fluor-Fernald

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Executive Summary

EM conductivity surveys were performed in two areas within the Area 1 Phase III investigation area at the Fernald Environmental Management Project. The two survey areas are referred to as the Southwest and Northeast Fill areas. The objectives of the EM surveys were to explore and map various suspected subsurface conditions and targets in these areas where possible and within the limitations of the EM survey method. Among the subsurface features of interest included the exploring for the presence of fill, trenches, filled excavations, buried metallic and non-metallic objects. The results of the surveys are presented as color contour diagrams with site diagram and survey grid overlays. Low to moderate variation in conductivity levels were noted in several of the survey areas and suggests different soil or fill conditions within these areas. Numerous, spatially small in-phase (metal sensitive) anomalies were noted scattered in portions of each survey area. It is suspected that most of these anomalies represent small isolated pieces of metallic debris or objects containing metal. These observed in-phase anomalies were strongest on the high-frequency data, which suggests that these targets are concentrated in the upper few feet of the subsurface including at or just below the ground surface. Follow-up investigations at these locations would be required to observe and document the actual causes of these variations in the conductivity and in-phase responses. It is unlikely that additional non-destructive geophysical explorations (e.g. ground-penetrating radar) would provide significantly improved target characterization.

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1.0 Project Overview

Non-destructive investigations within Area 1 Phase III (AIP3) using Electromagnetic Terrain Conductivity Profiling (EM) was performed by Grumman Exploration, Inc. with assistance from Fernald Environmental Management Project (FEMP) staff during September 2000. The objectives of these investigations were to non-destructively assess subsurface conditions in the Southwest and Northeast Fill areas as designated by FEMP. The potential targets of interest included possible fill areas, trenches, excavations, buried objects. FEMP staff established the survey grids and provided field assistance.

The two EM surveys are identified and summarized on Table 1. The ground surface conditions varied between open, grassy regions to densely overgrown and wooded areas. The topography within most of the Southwest Fill area was uneven earth ridges and hummocks. The Northeast area topography consisted of both moderate slopes and level areas. The densely overgrown and wooded areas in particular presented the most problems for the performance of the EM surveys. Consequently, several small but densely vegetated sub-areas could not be scanned using EM. 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 two survey areas is believed to range from a few feet to several tens of feet below the ground surface. The actual survey coverage differs slightly from what was originally planned because of additions and modifications to the area boundaries by FEMP staff or because of dense vegetation (brush, fallen trees, etc.) in a few areas which restricted access.

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2.0 Methodology

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 exploration depth was probably on the order of the upper 15-ft to 25-ft of the subsurface at the FEMP site. Most of the observed target responses are believed to be within the upper 5-ft of the subsurface based on the observed frequency response. The actual exploration depth is difficult to determine and depends on several factors that are reviewed in a previous EM survey report for work conducted at FEMP during January 2000 (Document No. 20400-RP-0003).

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. Electrical interference may be introduced and some targets of interest can be obscured by some of the factors noted above.

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3.0 Field Procedures

Grumman Exploration, Inc. conducted EM surveys at FEMP in the Southwest and Northeast Fill areas within Area 1 Phase III on September 13 and 22, 2000, respectively. The Southwest Fill area consisted of a large and a small sub-area.

Survey Grids

Survey grids and transect lines was established by Fluor-Fernald land surveyors prior to each survey. Pin-flags or paint marks were placed at carefully measured intervals by FEMP staff. The field coordinate systems used for geophysical surveys differed from the true site coordinate system, and Fluor-Fernald surveyed selected field grid coordinate positions so that the field coordinate system could be converted to the state-plane system. Engineering drawings of each survey area were provided by Fluor-Fernald and were used as overlays on the Figures presented in this report. Both the field and true coordinate systems are indicated on 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 1 summarizes the various survey statistics for the survey areas. The survey line spacing was 5-ft and the station spacing was approximately 1.75-ft to 2-ft. A portion of the Northeast Fill area was surveyed using a 10-ft line spacing because of dense vegetation and trees. 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. Lines of 5-ft spaced reference flags were spaced every 50-ft. 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. 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. A calibrated in-phase response in the absence of conductive or metallic conditions should be centered around zero ppm. However, a constant positive or negative offset in the in-phase response is not uncommon and the data may be adjusted by simply

adding or subtracting this constant offset from the data. In general, buried conductive objects appear as strong positive conductivity or in-phase anomalies (orange and red on contour diagrams) and above-ground or very shallow metallic objects appear to cause strong negative conductivity and in-phase deviations (blue and purple on contour diagrams).

EM Survey Area	EM Survey Parameter			
	Survey Date	**Report Figures**	**Meas. stations** (#)	**Duration of Survey** (hrs:min)[1]
Southwest Fill - Large Grid	9/13/00	1, 2	3,513	1:02
Southwest Fill - Small Grid	9/13/00	1, 2	656	0:10
Northeast Fill	9/22/00	3, 4	3,364	1:14

[1]First reading to last reading based on time-stamp, includes intervening breaks, down-time, etc.

Table 1. Area 1 Phase III EM Survey Area Parameters and Statistics

Following each task area survey, the data were downloaded onto a laptop computer and prepared for contouring. The EM data were contoured using a commercially available program (Surfer, Golden Software, Inc.). The contoured 9,810 Hz survey frequency results are presented herein, and the results for the two other frequencies are presented in the Appendix as explained in Section 4.0.

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4.0 Analysis and Interpretations

The following paragraphs summarize the EM terrain conductivity profiling survey findings from the two Area 1 Phase III investigation locations at the FEMP site. Figures 1 and 2 correspond to the conductivity and in-phase results for the Southwest Fill area, respectively. Figures 3 and 4 illustrate the contoured Northeast Fill area results. Note that the in-phase color contour scales differ between survey areas to help bring out important contrasts in the in-phase response. The contoured results for the lower survey frequencies (4,470 and 2,010 Hz) are generally very similar to the 9,810 Hz data and are included in the Appendix. The site topography diagrams were provided by Fluor-Fernald.

General Findings Across Survey Areas

Several general conductivity and in-phase responses were noted in many of the Area 1 Phase III EM survey areas. Among the observations are:

- Coincident, small conductivity and in-phase anomalies were observed in both isolated and clustered locations in both areas surveyed. This overall response type was similar to what was observed in the EM surveys performed in Area 2 Phase II. Of the anomaly types, there tended to be a larger number of in-phase anomalies and fewer of the locally small 'negative' conductivity responses. Most of these anomalies were present in the Southwest fill area, which compares with fewer and weaker anomalies in the Northeast Fill area. Most of these anomalies are generally weak to moderate in strength and which suggests small and/or shallow metallic targets. The number, strength and aerial extent of the in-phase and conductivity anomalies decreases on the lower frequency data. This appears to indicate that the targets responsible for these anomalies are concentrated in the range of 0-ft to 5-ft below the ground subsurface.
- The size of the observed anomalies tended to be relatively small and may indicate that the targets are similarly small (smaller than the spatial extent of the contoured anomalies) and probably on the order of a couple square feet or considerably less in most instances.
- The magnitudes of the observed in-phase anomalies tended to be significantly lower compared to the prominent in-phase anomalies observed in the "Carolina area" (Area 2, Phase I, Document No. 20400-RP-0003) south of Basin 2. This may indicate that the metallic targets seen in these survey areas are probably smaller and possibly shallower than some of those observed in A2PI area. The contoured in-phase response may have been low enough to be close or within the instrument's background noise-level for some areas.
- Moderate variations in terrain conductivity were observed in the Northeast Fill area which may indicate different soil or fill types, changes in stratigraphy, and/or variations in soil moisture content, saturation or the presence of groundwater. Further invasive exploration in these areas would be required to document the cause of some of these variations. There

was a distinct lack of spatial variation within the contoured Southwest fill conductivity results.

- The rough, densely vegetated terrain in several of the survey areas could be responsible for some of smaller EM anomalies. The unsteady movement of the EM instrumentation has been known to introduce occasional, short duration data spikes. Follow-up spot-checks at some of the isolated EM anomalies noted in area G1 in Area II phase appeared to indicate real subsurface targets at most of the locations checked (Document No. 20400-RP-0003).

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Southwest Fill Area (Figures 1 and 2)

The contoured conductivity results for both areas show a general lack of large spatial variations in conductivity levels. Most of the conductivity readings appear to be concentrated in the 20 to 30 mS/m range which is fairly representative for silty clay soil or fill with some sand and gravel content. Irregular shaped and spatially small low to negative conductivity zones were present throughout the larger survey area. Possible causes for these low conductivity 'pockets' include zones of sand, gravel, concrete or other lower conductivity fill. It is also possible that these areas could also be affected by the hummocky topography across the site and the unsteady movement of the EM instrument over this terrain. The small survey grid showed little variation in conductivity levels, including over the low earth mound near the middle of this grid.

Coincident, small in-phase peaks, and to a lesser extent, conductivity lows were observed scattered throughout the larger western survey grid. These anomalies appear both isolated and in possible clusters as indicate on Figure 1. This response may indicate a soil fill matrix with minor amounts of miscellaneous metallic and non-metallic debris. The anomaly clusters suggest several small metallic targets (e.g. scrap, rebar, reinforced concrete fragments, etc.) in close proximity to one another. Most of these anomalies are generally weak to moderate in strength, which suggests small and/or shallow metallic targets. The strongest in-phase (metal) anomaly clusters are located near the west end and northwest corner of the survey area. The number and strength of the in-phase and conductivity anomalies decreases on the lower frequency data which appears to indicate that the targets responsible for these anomalies are concentrated in the upper 0-ft to 4-ft of the subsurface. A negative conductivity response is often observed over metallic targets at or very close to the ground surface. The contouring program can exaggerate the apparent size of the target, and rough movement through dense vegetation occasionally produces erroneous, negative conductivity responses. Only one small in-phase anomaly was observed in the smaller eastern survey grid.

Northeast Fill (Figures 3 and 4)

The EM survey results from the Northeast Fill area showed several broad regions of elevated conductivity which are noted on Figure 3. One region of elevated conductivity is located in the northern quarter of the survey area. Conductivity levels consistently increase moving from east to west or to topographically lower areas. There appears to be a strong correlation between the topographic contours and the conductivity levels. Possible explanations for this response include topographically controlled changes in soil or bedrock stratigraphy, moisture or saturation levels moving from higher to lower terrain. A small pond is present directly north of the northwest corner of the survey area and it is considered likely that the elevated conductivity readings in the northwest corner are influenced by increased soil moisture or saturation in this area. Small concrete fragments and other scattered construction debris was observed on the ground surface in this area.

The second and larger region of elevated conductivity is centered in the east-southeast central region of the survey area. The conductivity levels are highest in the region closest to the fence and appear to diminish moving to the southwest. The overall size and configuration of this elevated conductivity region could indicate a broad zone of more conductive soil and/or earth fill extending from the fence down slope to the west and south. It is possible that the observed conductivity variations simply represent natural variations in the shallow soil, geologic and/or hydrogeologic conditions. The general lack of small-scale conductivity variations may indicate that the material in this area contains in this containing higher clay and/or moisture levels.

In contrast to the Southwest Fill area, very few small coincident conductivity and in-phase anomalies were observed. The largest cluster of in-phase anomalies was located approximately 40-ft southwest of the fenced area. This may indicate a small concentration of small metal objects of metallic debris. Further exploration at this location would be required to document the cause of these anomalies. A larger number of widely scattered, smaller and weaker in-phase anomalies was observed across the northern half of the site. Most of these anomalies are generally weak in strength and which suggests small and/or shallow metallic targets or possibly system noise effects from the movement through the rough terrain in this area. As with the Southwest Fill area, the number and strength of the in-phase and conductivity anomalies decreases on the lower frequency data. This may indicate that the targets responsible for these anomalies are small and are concentrated in the upper 0-ft to 5-ft of the subsurface. Small concrete fragments and other scattered debris was observed on the ground surface in this area.

5.0 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 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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6.0 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.

Keller, G.V. and Frischknecht, F.C, 1966, Electromagnetic Methods in Geophysical Prospecting, Pergammon Press, New York, NY.

McNeill, J.D., 1980a, Electrical Conductivity of Soil and Rocks, Technical Note TN-5, Geonics, Ltd., Mississauga, Ontario, Canada, 22 p.

McNeill, J.D., 1980b, Electromagnetic Terrain Conductivity Measurements at Low Induction Numbers, Technical Note TN-6, Geonics, Ltd., Mississauga, Ontario, Canada, 15 p.

Won, I.J., Keiswetter, D., Fields, G.R.A., and Sutton, L., 1996, GEM-2: A New Multi-frequency Electromagnetic Sensor, JEEG, Aug 1996, v.1, No. 2, pp 129-137

FIGURES

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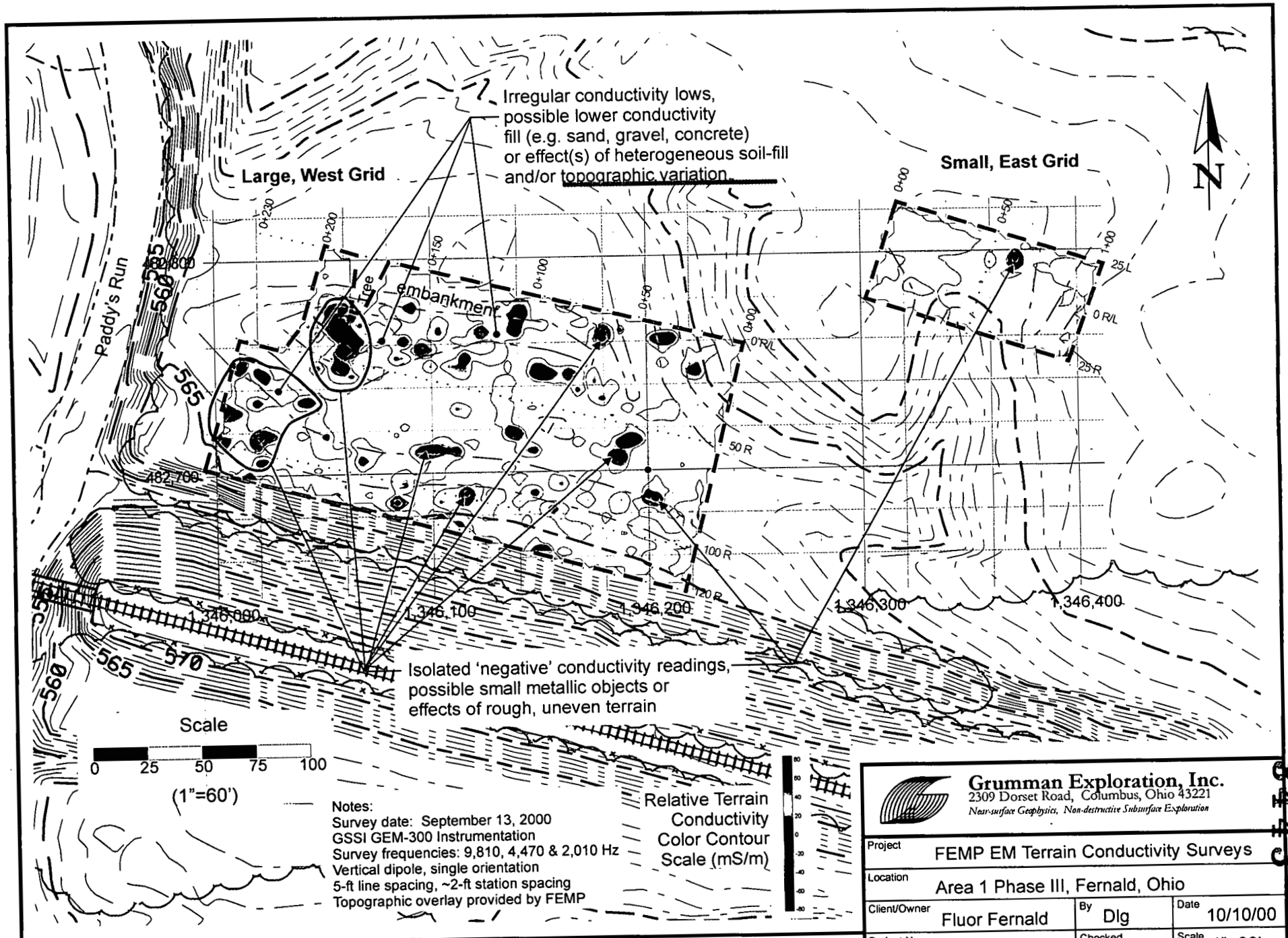

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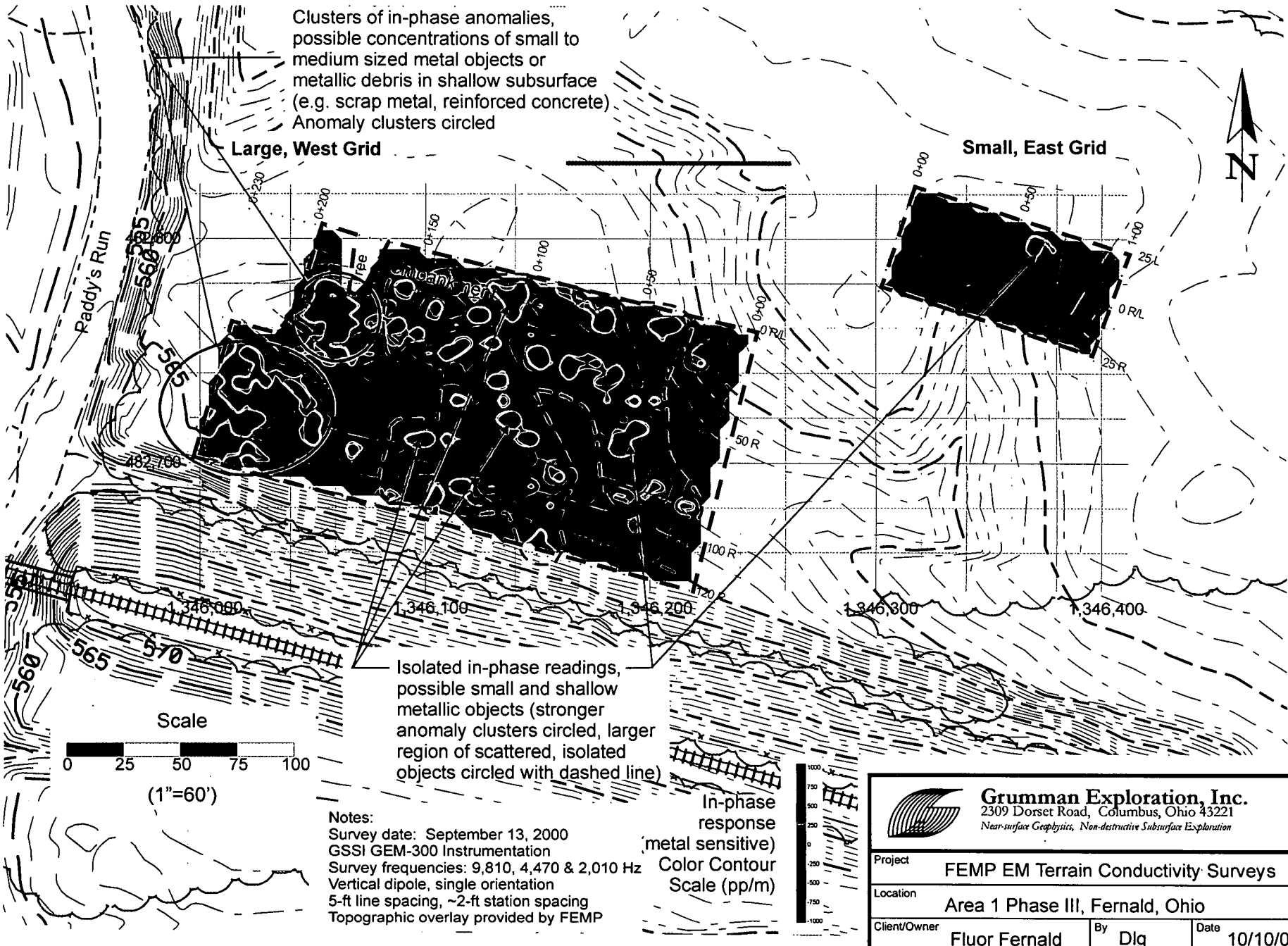

Notes:
Survey date: September 13, 2000
GSSI GEM-300 Instrumentation
Survey frequencies: 9,810, 4,470 & 2,010 Hz
Vertical dipole, single orientation
5-ft line spacing, ~2-ft station spacing
Topographic overlay provided by FEMP

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Project	FEMP EM Terrain Conductivity Surveys		
Location	Area 1 Phase III, Fernald, Ohio		
Client/Owner	Fluor Fernald	By Dlg	Date 10/10/00
Project No.	01-20044	Checked	Scale 1"=60'

Figure 2 | Title **Southwest Fill**, A1PIII EM In-phase (metal sensitive) Contour Diagrams - 9,810 Hz

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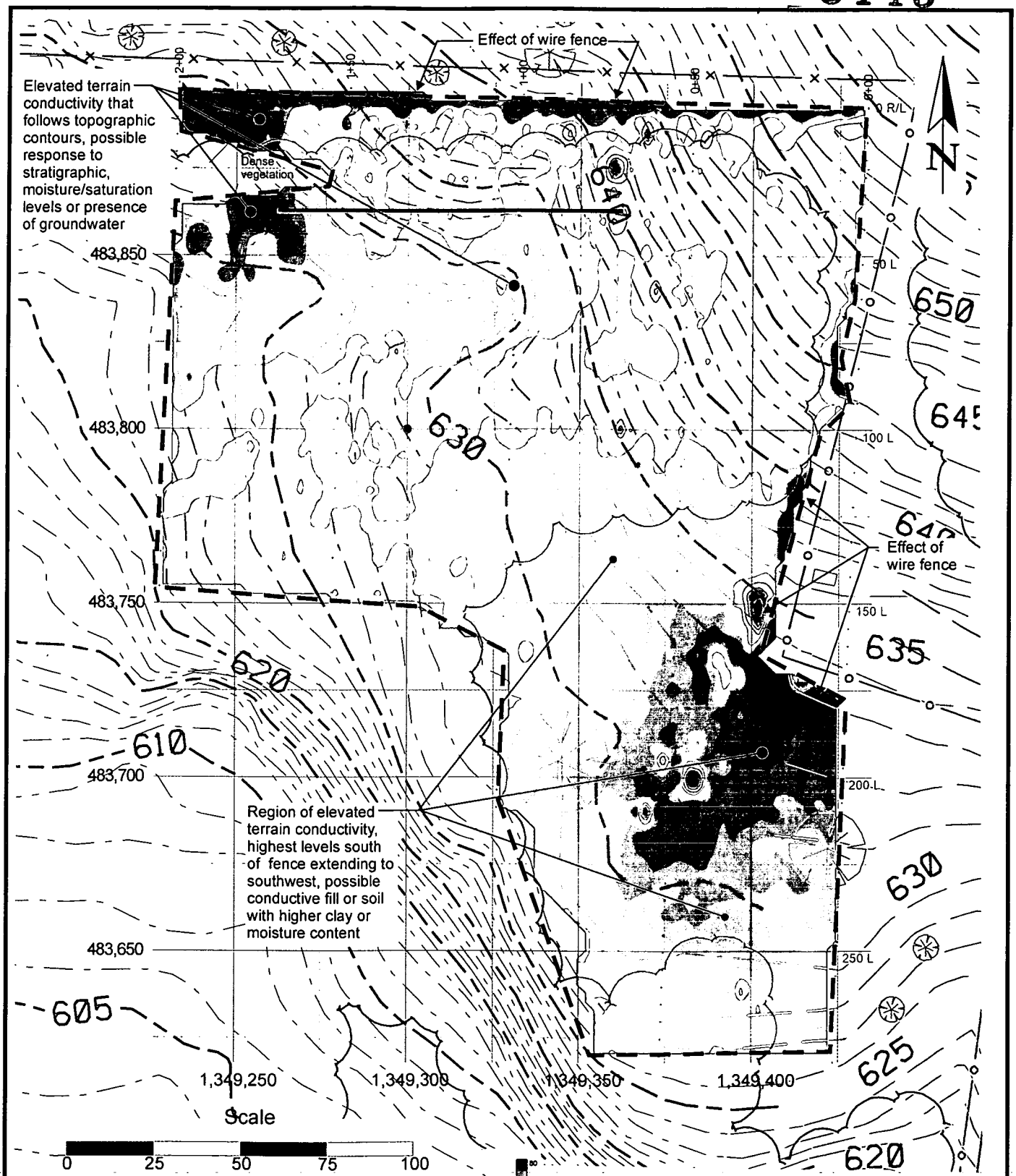

Notes:
- Survey date: September 22, 2000
- GSSI GEM-300 Instrumentation
- Survey frequencies: 9,810, 4,470 & 2,010 Hz
- Vertical dipole, single orientation
- 5-ft line spacing, ~2-ft station spacing
- Topographic overlay provided by FEMP

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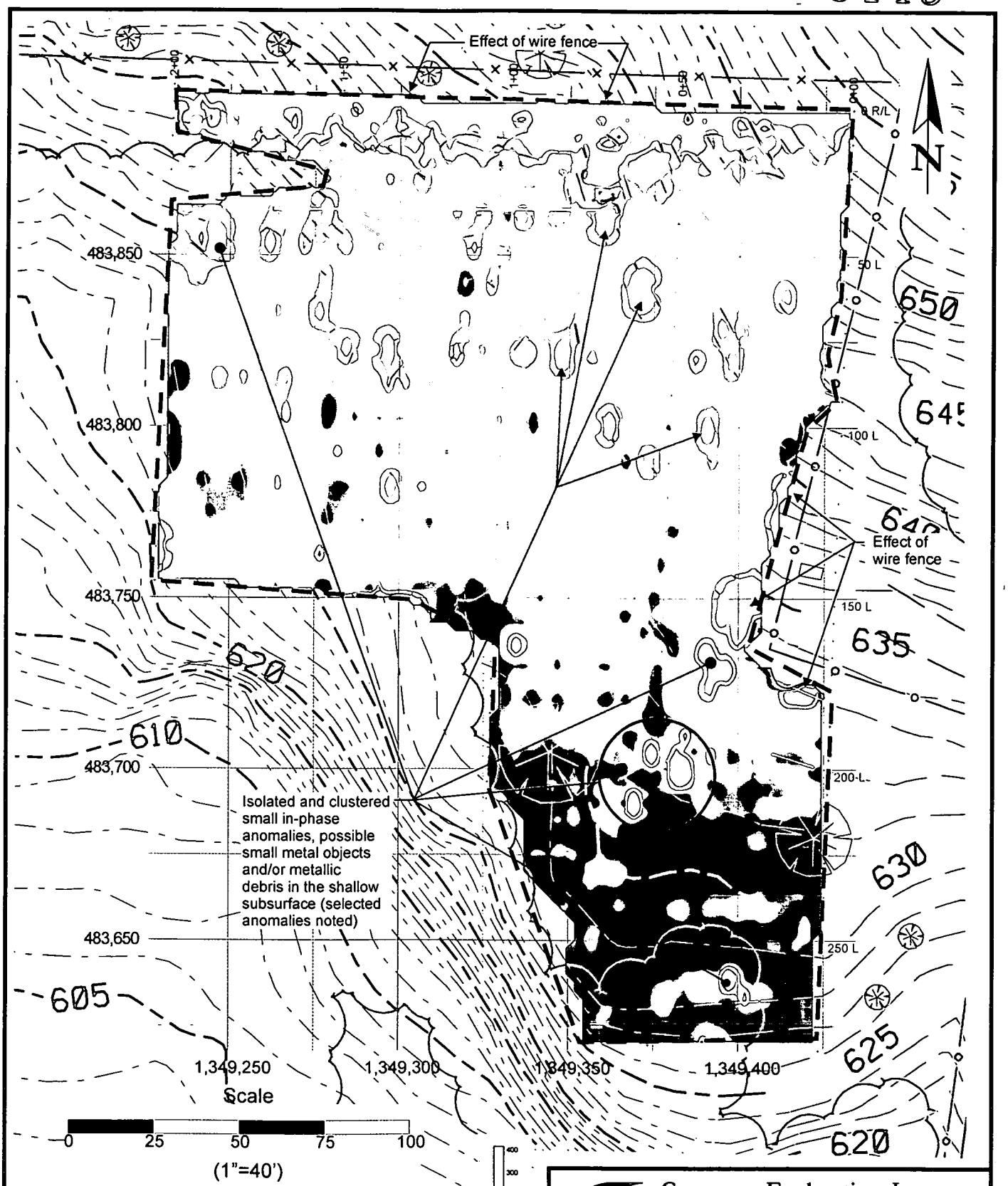
Project	FEMP EM Terrain Conductivity Surveys		
Location	Area 1 Phase III, Fernald, Ohio		
Client	Fluor Fernald	By Dlg	Date 10/10/00
Project No. 01-20044		Checked	Scale 1"=40'

Figure 3	Title Northeast Fill, Conductivity Contour Diagram



Notes:
- Survey date: September 22, 2000
- GSSI GEM-300 Instrumentation
- Survey frequencies: 9,810, 4,470 & 2,010 Hz
- Vertical dipole, single orientation
- 5-ft line spacing, ~2-ft station spacing
- Topographic overlay provided by FEMP

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

400, 300, 200, 100, 0, -100, -200, -300, -400

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Location	Area 1 Phase III, Fernald, Ohio		
Client	Fluor Fernald	By: Dlg	Date: 10/10/00
Project No.	01-20044	Checked	Scale: 1"=40'

Figure	Title
4	Northeast Fill, In-phase Contour Diagram

APPENDIX

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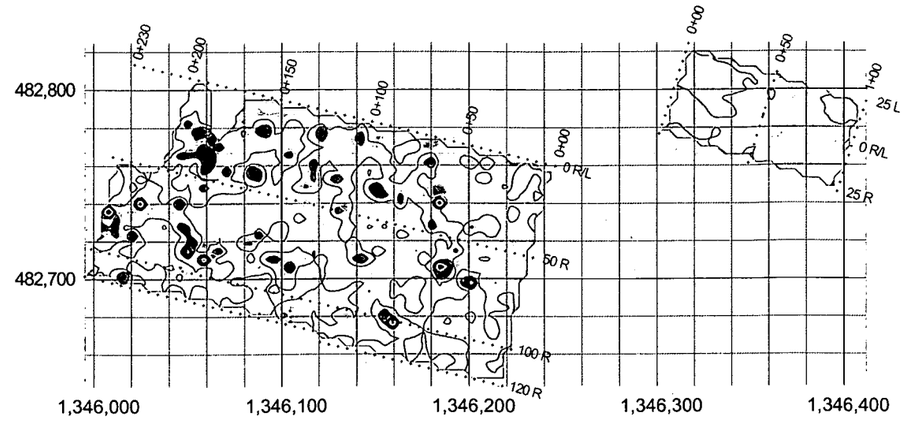
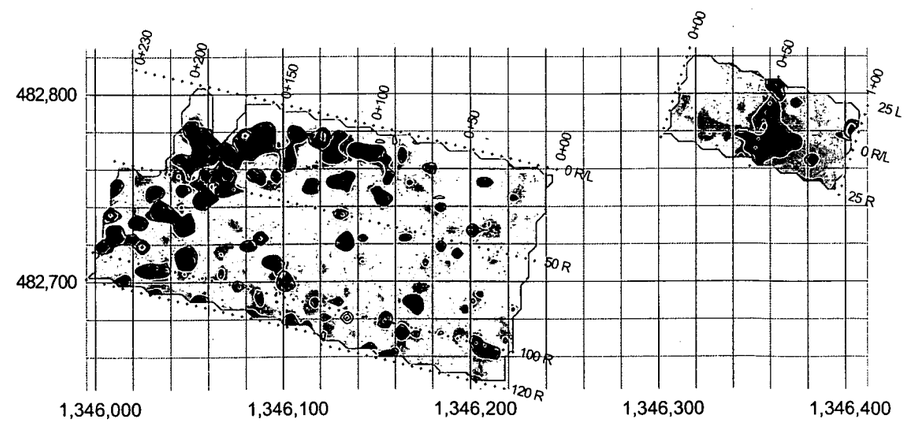
Terrain Conductivity Contour Diagrams

4,470 Hz



2,010 Hz



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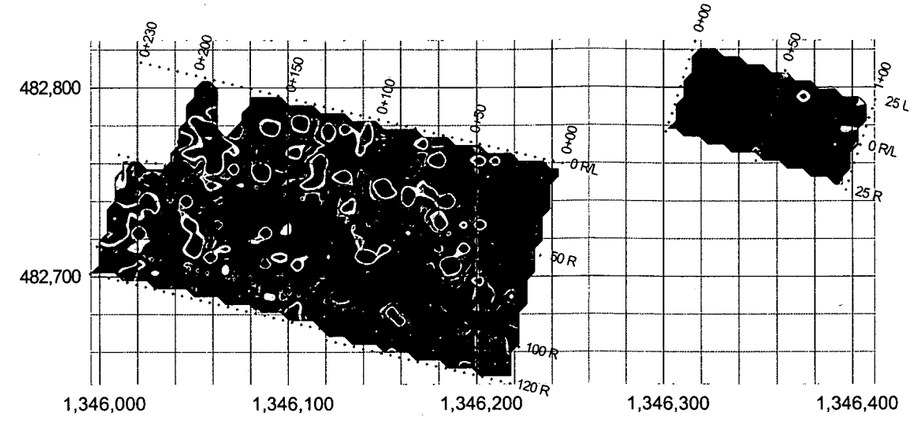
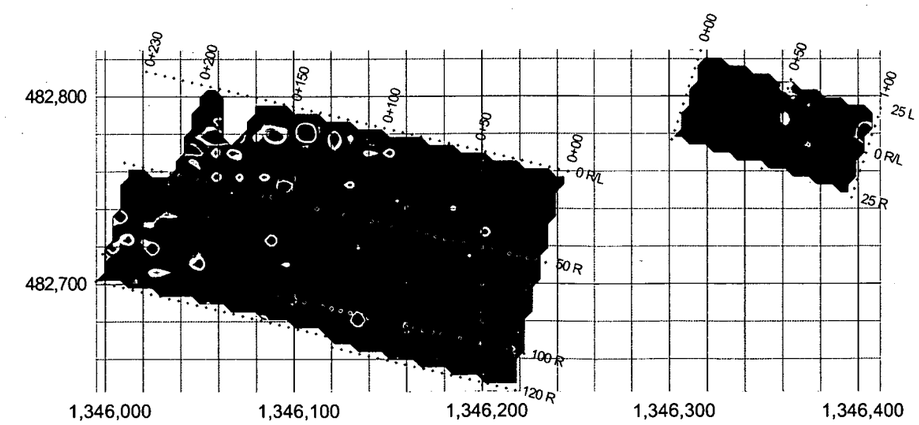
In-Phase (Metal-sensitive) Contour Diagram

4,470 Hz



2,010 Hz



Relative Terrain Conductivity Color Contour Scale (mS/m)

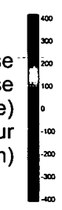
Scale

0 20 40 60 80 100

(1"=80')

Notes:
Survey date: September 13, 2000
GSSI GEM-300 Instrumentation
Survey frequencies: 9,810, 4,470 & 2,010 Hz
Vertical dipole, single orientation
5-ft line spacing, ~2-ft station spacing
Refer to Figures 1 and 2 for 9,810 Hz results
Note different in-phase scale from Figure 2

In-phase response (metal sensitive) Color Contour Scale (pp/m)



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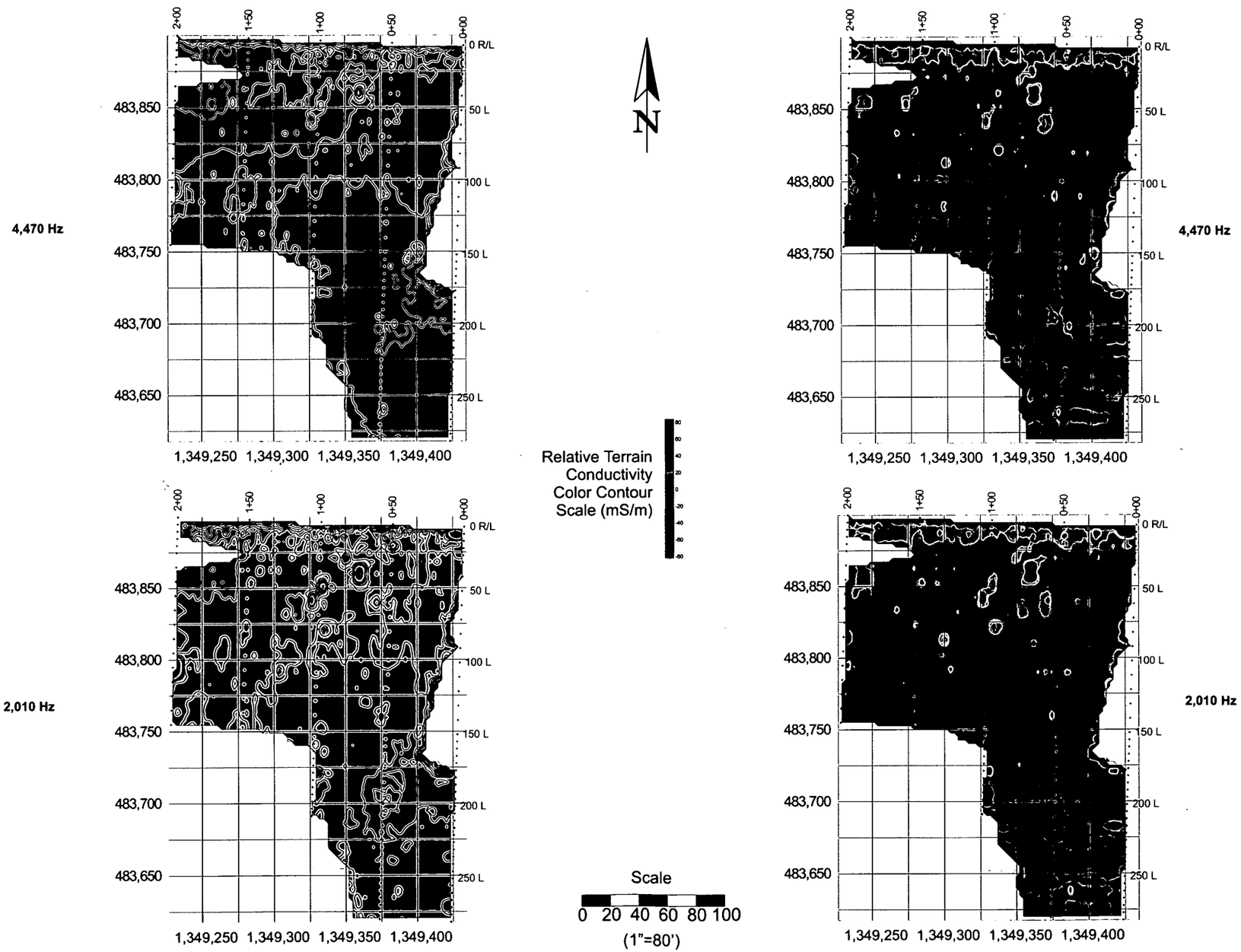
Project	FEMP EM Terrain Conductivity Surveys		
Location	Area 1 Phase III, Fernald, Ohio		
Client	Fluor Fernald	By Dlg	Date 10/10/00
Project No.	01-20044	Checked	Scale 1"=80'

Figure	Title
A.1	**Southwest Fill**, Area 1 Phase 3 EM Terrain Conductivity and In-phase (metal sensitive) Contour Diagrams - 4,470 and 2,010 Hz

Terrain Conductivity Contour Diagrams

In-Phase (Metal-sensitive) Contour Diagram



Notes:
Survey date: September 13, 2000
GSSI GEM-300 Instrumentation
Survey frequencies: 9,810, 4,470 & 2,010 Hz
Vertical dipole, single orientation
5-ft line spacing, ~2-ft station spacing
Refer to Figures 3 and 4 for 9,810 Hz results
Note different in-phase scale from Figure 4

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Project	FEMP EM Terrain Conductivity Surveys		
Location	Area 1 Phase III, Fernald, Ohio		
Client	Fluor Fernald	By Dlg	Date 10/10/00
Project No. 01-20044		Checked	Scale 1"=80'

Figure	Title
A.2	**Northeast Fill**, Area 1 Phase 3 EM Terrain Conductivity and In-phase (metal sensitive) Contour Diagrams - 4,470 and 2,010 Hz