Countywide Recycling & Disposal Facility
Division of Republic Waste Services of Ohio
3619 Gracemont Street S.W.
East Sparta, Ohio 44626
Phone: 330-874-3855
Fax: 330-874-2426

March 3, 2008

Ohio Environmental Protection Agency
Northeast Region Office
2110 East Aurora Rd.
Twinsburg, Ohio 44087

Attn: Mr. Joshua D. Adams
Environmental Specialist

RE: SOUTH SLOPE INVESTIGATION
PRELIMINARY GEOPHYSICAL SURVEY RESULTS AND
WORK PLAN FOR PHASE II INVESTIGATION
COUNTYWIDE RECYCLING AND DISPOSAL FACILITY

Dear Mr. Adams:

Countywide has completed Phase I of study at the South Slope of the Countywide Recycling and Disposal Facility (Countywide). This study was performed because drilling of gas monitoring probe SGP-6, on December 7, 2007, suggested presence of waste material and leachate outside the permitted limit of waste. Based on that finding, Countywide contracted a firm to do a geophysical survey to further assess the conditions.

Your letter of February 11, 2008, and our subsequent site meeting on February 26, 2008, acknowledged that Countywide had undertaken the geophysical investigation and outlined a phased approach as such:

- Phase I – Geophysical Investigation.
- Phase II –Evaluation of the Geophysical Study and Soil Boring Installation.
- Phase III – Final Data Report and Conclusions

The final result of these three phases will be an understanding of the limits of solid waste, identification of the mode of movement of the waste (e.g. shallow or deep), and the extent, if any, of impacted materials outside the permitted limits of waste. That understanding will then be used to determine appropriate remedial measures.

<u>Geophysical Investigation</u>
Hager GeoScience. Inc. (Hager), based in Woburn, Massachusetts, was selected for this work based on their extensive experience and wide-ranging geophysical capabilities. Hager performed a low-frequency ground penetrating radar (GPR) survey from January 15 to January 18, 2008. A thorough technical discussion and presentation of results is contained in their report in Attachment A. The GPR results presented and discussed herein are considered "preliminary." The results will be finalized after completion of the Phase II boring investigation that is further described in this Work Plan.

Hager believes that they were successful in identifying the limits of waste (reflector W1) at the South Slope area. It should be noted that we are currently describing this based on the supposition that this reflector represents waste material. Subsequent work conducted during the investigation may result in assigning a different interpretation to the W1 reflector. The limits of their investigation are shown with a tick-mark grid on Figure 1. Cross sections superposing as-built liner locations, permitted limits of waste, and two previous surveyed surfaces are shown on Figure 3.

Significant preliminary findings of the geophysical study and conclusions drawn by Countywide as a result of the study are:

- Throughout most of the length of the study area, waste appears, typically, to have moved about 10 feet outside (south) of the permitted limit of waste.
- The extent of largest movement was between Hager Profile 200W and 520W (see Figure 1).
- Between Hager Profiles 200W and 520W, waste is located typically 12 to 16 feet above the crest of the as-constructed liner.
- The geophysical investigation was not able to discern the presence or absence of liquid outside the permitted limits of waste disposal.

Since the as-constructed HDPE liner "runout" extends 12-20 feet beyond (south) of the permitted limit of waste, most, if not all, of the displaced waste is still underlain by HDPE and compacted clay material (HDPE runout limits shown on Figures 3). This would mean that about 0.1 acres of waste has moved beyond the permitted limit of waste, but that the movement may be wholly contained on the "runout" of the constructed liner system.

<u>Proposed Boring Program Objectives</u>
Countywide proposes a drilling program to meet the following objectives:

1. Physically locate the limit of waste so that Hager can verify/calibrate their geophysical models.
2. Determine the displacement, if any, of HDPE liner or geocomposite material (to assess whether slope movement has affected the integrity of the liner system).
3. Determine where liquid is present within the waste, soil, and buttress material in the South Slope area.
4. Characterize liquid found in the borings.
5. Preliminarily determine if liquid is migrating down and away from the permitted limit of waste disposal.

Proposed Boring Program Components

The program will consist of 15 borings, 7 of which will be converted to observation wells for liquid level and/or quality determination. See Figure 1 for the proposed locations of the borings. A discussion of the components of this phase of the investigation is presented below.

Boring Locations and Depths
Test borings will be advanced using hollow stem drilling techniques. Oversized split spoon samples (2.5 inch ID) will be used with either a standard hammer or 300 lb hammer depending on the driving difficulty. Use of this procedure was successful in obtaining representative samples during drilling of the shallow INC-series holes.

Two lines of borings, SS-1 to SS-4 and SS-5 to SS-8, will be drilled at Hager 400 W (E 43000) and Hager 200W (E 43200). The GPR survey indicates that these locations are near areas of maximum waste movement. Further, the movement measured at the ground surface during the period from August 2006 and September 20, 2006 was a maximum near these locations. Four (4) borings will be drilled to form cross sections at these locations beginning 5 feet north of the permitted solid waste boundary and progressing at 10 foot intervals to 25 feet south of the permitted solid waste boundary. Borings will be drilled to within one foot of the as-built top of FML and/or the April 2006 topo grades.

In addition to the eight borings discussed above, additional borings will be drilled to document conditions near the limit of solid waste boundary at other locations. Specific offsets for the additional borings would be determined after the first two sections of 4 holes are finished. At present, it is assumed they would be offset 3 and 13 feet south of the solid waste boundary. These would likely include:

- Two borings, SS-9 and SS-10, at Hager 320W (E 43080) to explore the apparent override feature shown in the GPR interpretation.
- One boring, SS-11, near Hager 80W (E 43320), where the lateral measured displacement was nearly as great (400W) and the GPR interpretation indicates an override feature.
- Two borings, SS-12 and SS-13, near Hager 480W (E 42920) where the interpretation of the location of the W1 reflector was unclear.

Again, the purpose of these borings is to physically locate the limit of waste outside the permitted limit of waste disposal so that Hager can verify/calibrate their geophysical models and to determine the displacement, if any, of HDPE liner or geocomposite material (if HDPE liner or geocomposite material is encountered, the boring will be immediately backfilled with a low-permeability, quick-set grout to maintain containment).

Observation Wells
To allow sampling and characterization of liquid, and measurement of in situ permeability of displaced waste (if encountered), an observation well will be constructed in SS-2 and SS-6. In addition, observation wells will be installed in SS-4, -8, -10, -11, and -13 to determine if liquid is present in the soil material outside the expected zone of displaced waste. These observation wells will consist of a 2" diameter PVC well casing with a 2 foot long screen installed within the lower five feet of the boring as depicted on Exhibit 1.

In addition to the borings near the permitted solid waste boundary, two shallow observation wells will be drilled between the toe drain at the limit of the temporary cap and the drainage system installed in July of 2006 south of the solid waste boundary. These drains are depicted on Figure 2. The observation wells in these holes will have 2 foot screens installed just above the April 2006 topo grade. The sand pack in these wells will be extended upward 5 feet above the top of the screen. These wells are indicated as SS-14 and SS-15 on Figure 1 and Figure 2.

Vibrating Wire Piezometers
Vibrating wire piezometers (VPW) in test borings between observation wells will allow determination of the gradients between the borings. VPW(s) will be placed in SS-3 and SS-7 near the bottom of the boring and at locations of significant seepage horizons (as observed during drilling). A single VPW will be installed in waste material (if encountered) in SS-1 and SS-5.

Liquid Sampling
At his time, it is proposed that liquid samples be obtained from SS-2, -4, -6, and -8 and also from previously-installed SGP-5 (all other soil gas probe borings in the area of interest are dry). These samples will be analyzed for the parameters indicated in Order 4.A.9 of the March 28, 2007 F&Os (leachate indicator parameters).

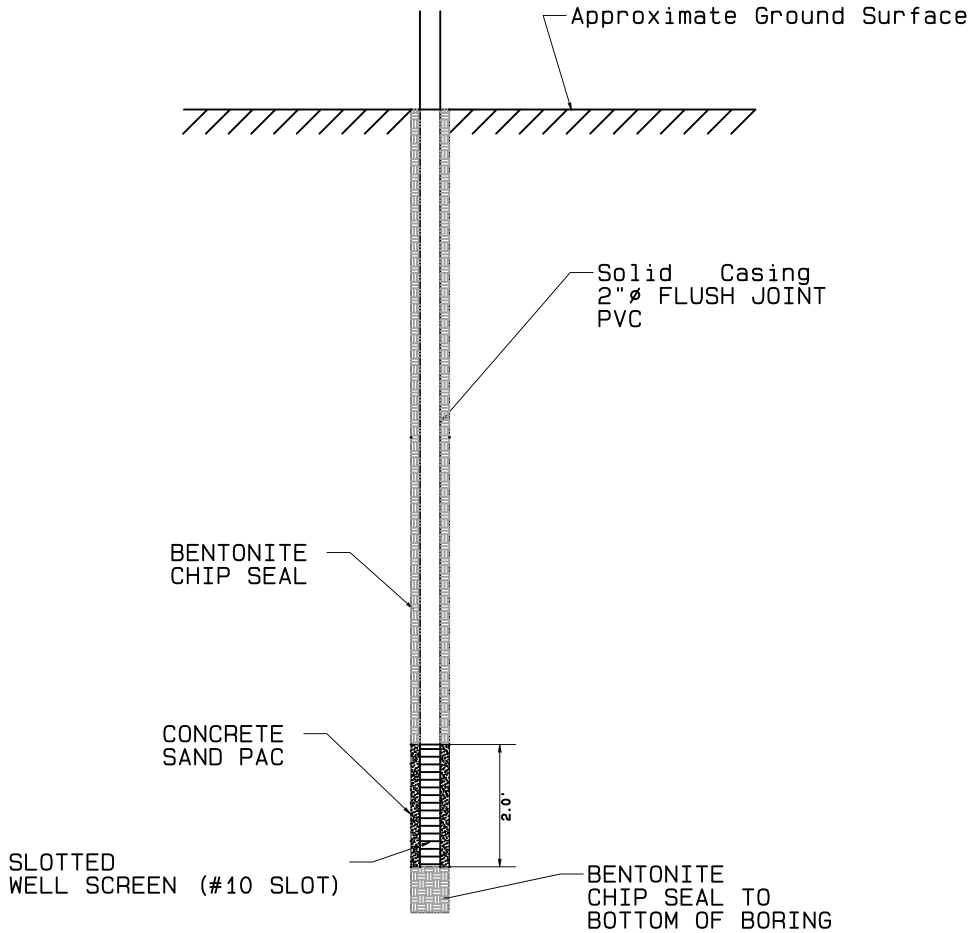
Schedule and Reporting
Countywide intends to start the boring program before the end of March. The investigation may take about three weeks to perform. Then, another two weeks will be needed to receive the laboratory analytical data. Within two weeks of receiving the analytical data, Countywide will submit a report of findings. In all, it is expected that the Phase II report should be completed by the end of May.

It is anticipated that this Phase II investigation will help further the understanding of conditions at, and the nature of movement that, occurred at the South Slope; but may not allow firm conclusions. Therefore, additional investigation may be proposed as a Phase II(A) investigation so that more conclusive findings can be presented in the report that comprises Phase III of this work.

Please feel free to call me should you have any questions.

Tim Vandersall, P.E.
General Manager

ec: Jeff Rizzo, OEPA-NEDO
Eric Adams, OEPA-NEDO
Karen Naples, OEPA-NEDO
Ed Gortner, OEPA-CO
Clarke Lundell, Republic
Todd Hamilton, CWRDF
Mike Beaudoin, Earth Tech
Peter Carey, PJC Associates



NOTES:
1) WELLS INSTALLED IN COMPLETED BORINGS AT DEPTH DETERMINED BASED ON BORING RESULTS
2) WELL SCREEN TO BE 2' LONG

P. J. Carey & Associates, P.C.

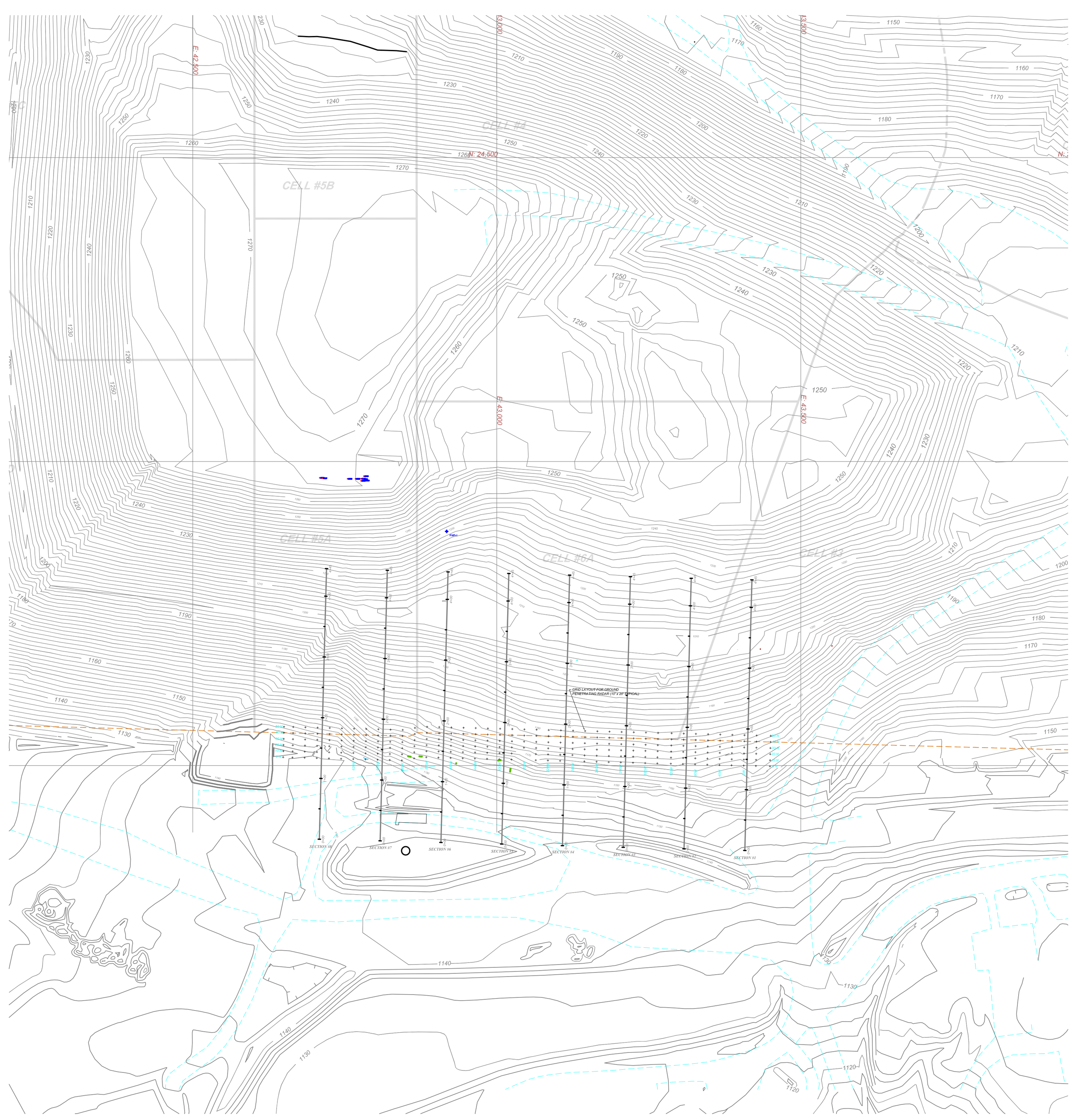
COUNTYWIDE RDF STARK COUNTY,OH			
COUNTYWIDE SOUTH SLOPE INVESTIGATION OBSERVATION WELL DETAIL			
DESIGNED BY	PJC	CHECKED BY	PJC
DRAWN BY	KLCH	DATE	3/3/2008
SCALE: NTS	Drawing No.	SHEET No. EXHIBIT 1	Revision No. 0

REPUBLIC
SERVICES OF OHIO II, LLC
Stark County, Ohio

COUNTYWIDE
RECYCLING & DISPOSAL FACILITY

3619 GRACEMONT STREET S.W., East Sparta, OH 44626
Phone: (330) 874-3855   Fax: (330) 874-2426

GROUND RADAR PENETRATION



SITE MAP
SCALE: 1"=200'

INDEX OF SHEETS

PREPARED MARCH, 2008 BY

DIVERSIFIED ENGINEERING INC.
Phone: (330) 364-1631
Fax: (330) 364-4031
e-mail: dei@div-eng.com
225 Fair Avenue, NE
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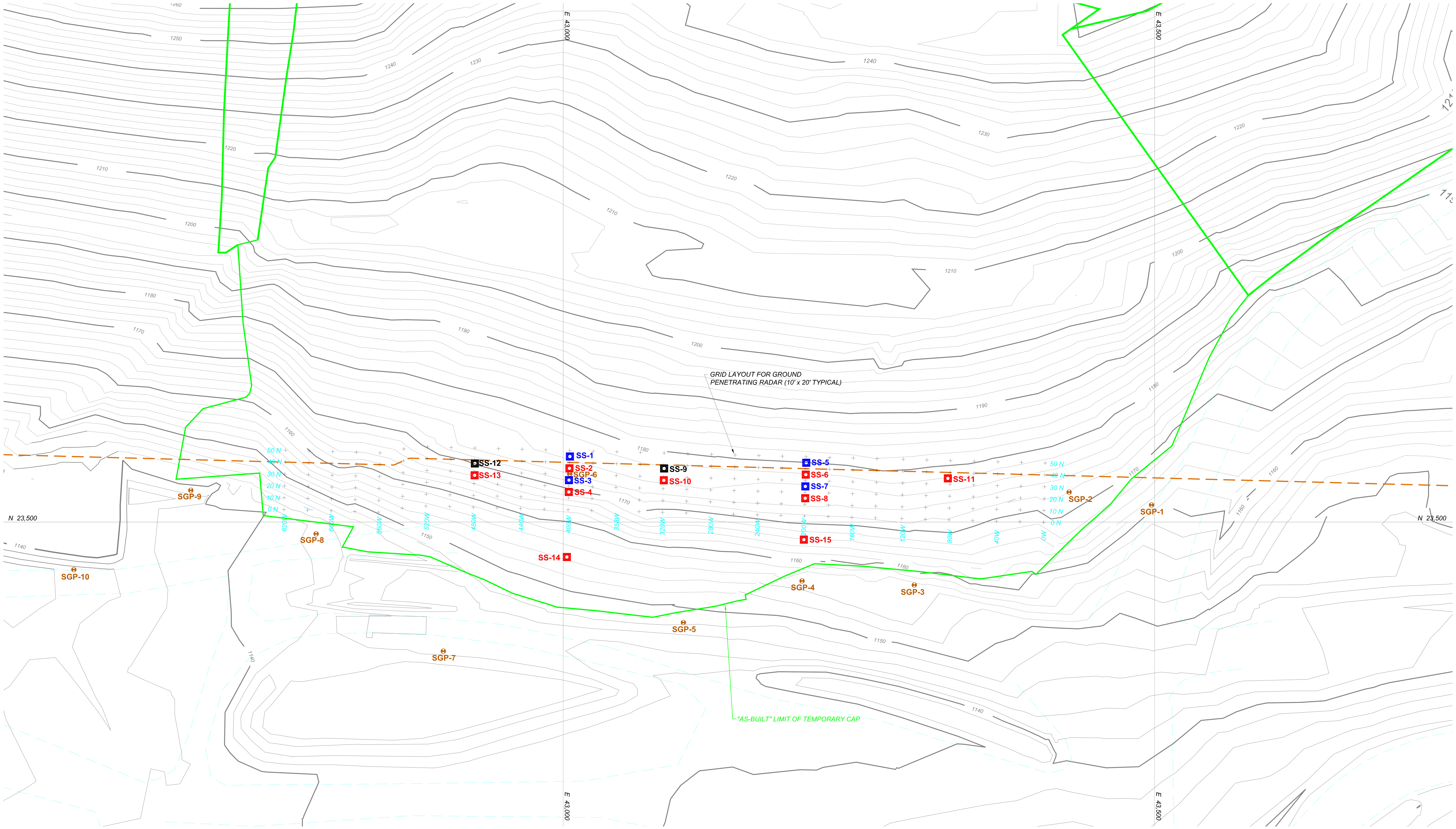
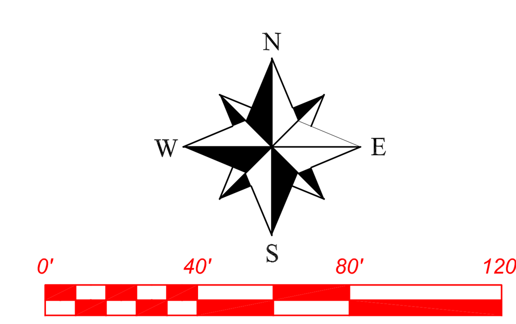


LEGEND

(orange dashed line)	EXISTING SOLID WASTE BOUNDARY
(grey line)	EXISTING CELL BOUNDARY
—1150—	2' CONTOUR - EXISTING GROUND
(green outline)	"AS-BUILT" LIMIT OF TEMPORARY CAP
SGP-3	SOIL GAS PROBE "AS-BUILT" LOCATION
SS-9	PROPOSED TEST BORING LOCATIONS
SS-2	PROPOSED TEST BORING LOCATIONS WITH OBSERVATION WELLS
SS-1	PROPOSED TEST BORING LOCATIONS WITH VIBRATING WIRE PIEZOMETERS



COUNTYWIDE RDF

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CHECKED: CCV	03-03-08	
REVISED DATE:		

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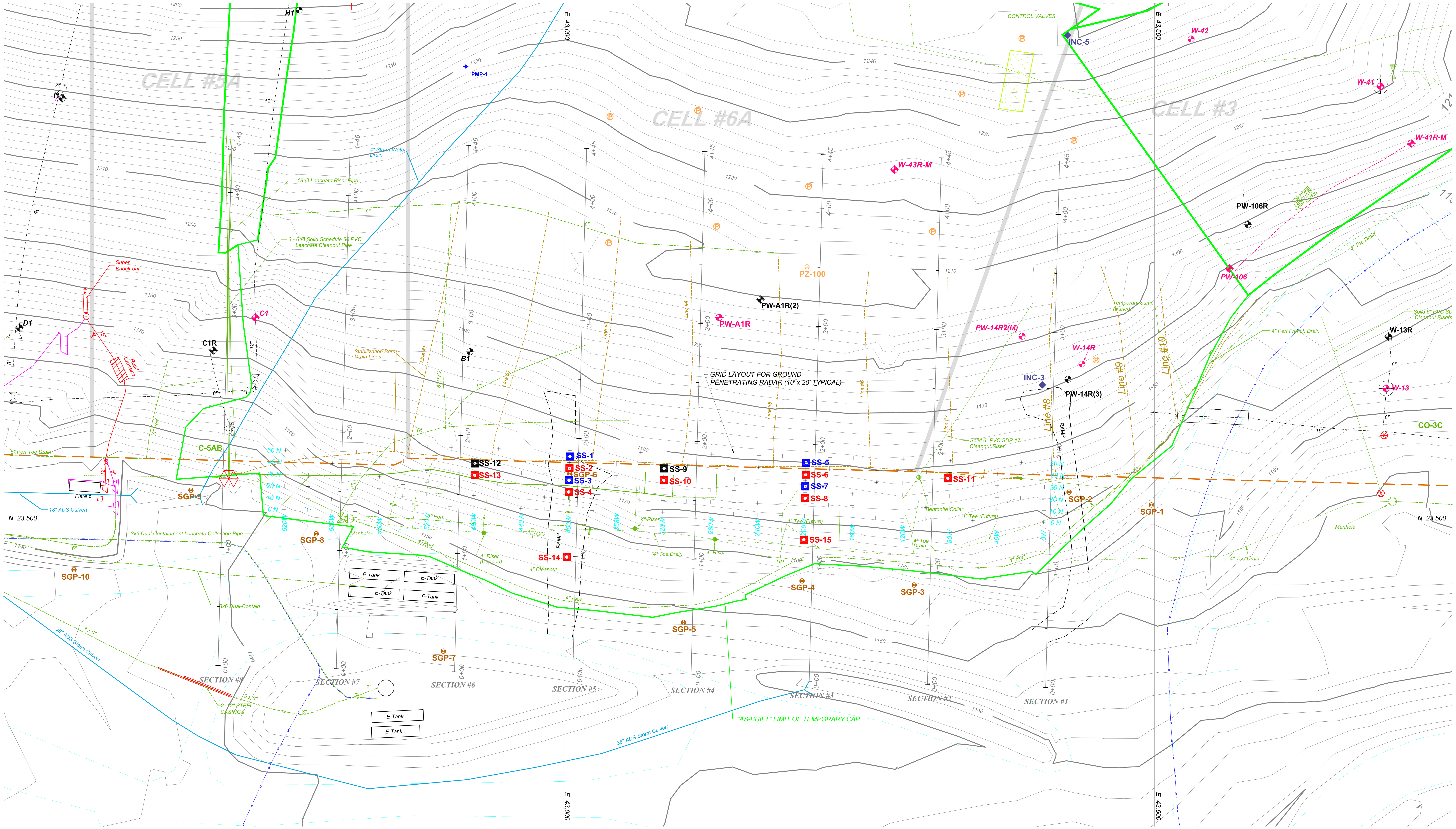
PROJECT:
GROUND RADAR PENETRATION

SHEET TITLE:
SITE PLAN

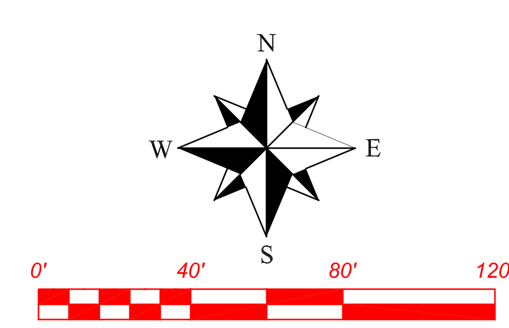
FILE ID:
Ground Radar Penetration

FIGURE 1



LEGEND

	EXISTING SOLID WASTE BOUNDARY
	EXISTING CELL BOUNDARY
1150	2' CONTOUR - EXISTING GROUND
	LEACHATE CLEANOUT RISER
(SIZE)	LFG HEADER/LATERAL (BELOW GROUND)
(SIZE)	LFG HEADER/LATERAL (ABOVE GROUND)
(SIZE)	LEACHATE CONDENSATE PIPE (ABOVE GROUND)
(SIZE)	LEACHATE COLLECTION PIPE (BELOW GROUND)
(SIZE)	LEACHATE COLLECTION PIPE (ABOVE GROUND)
(SIZE)	AIRLINE (ABOVE GROUND)
	CONDENSATE DRIPLEG
	FLANGE
	LEACHATE CLEANOUT RISER
	CMP CASING
W-4	VERTICAL EXTRACTION WELL
	REDUCER FITTING
N1	REMOTE WELLHEAD
	REMOTE VALVE
	HEADER ACCESS RISER
	CONTROL VALVE
	BLIND FLANGE
	FLANGE CONNECTION
	HORIZONTAL COLLECTOR
	ROAD CROSSING
	ASBESTOS PLACEMENT AREA
	"AS-BUILT" LIMIT OF TEMPORARY CAP
PMP-3	"AS-BUILT" PRESSURE MONITORING PROBE
DB #1	DROSS BORING PROBE
W-4	ABANDONED VERTICAL EXTRACTION WELL
N1	ABANDONED REMOTE WELLHEAD
(SIZE)	ABANDONED LANDFILL GAS HEADER/LATERAL
	CLEANOUT MONITORING LOCATIONS
PZ-100	PIEZOMETER
INC-1	INCLINOMETER
LW-29	LEACHATE RECOVERY WELL
SGP-3	SOIL GAS PROBE "AS-BUILT" LOCATION
SS-9	PROPOSED TEST BORING LOCATIONS
SS-2	PROPOSED TEST BORING LOCATIONS WITH OBSERVATION WELLS
SS-1	PROPOSED TEST BORING LOCATIONS WITH VIBRATING WIRE PIEZOMETERS



COUNTYWIDE RDF

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CHECKED:	CCV	03-03-08	
REVISED DATE:			

PROJECT: GROUND RADAR PENETRATION

SHEET TITLE: UTILITY SITE PLAN

FILE ID: Ground Radar Penetration

FIGURE 2

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Phone: (330) 364-1631
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225 Fair Avenue, NE
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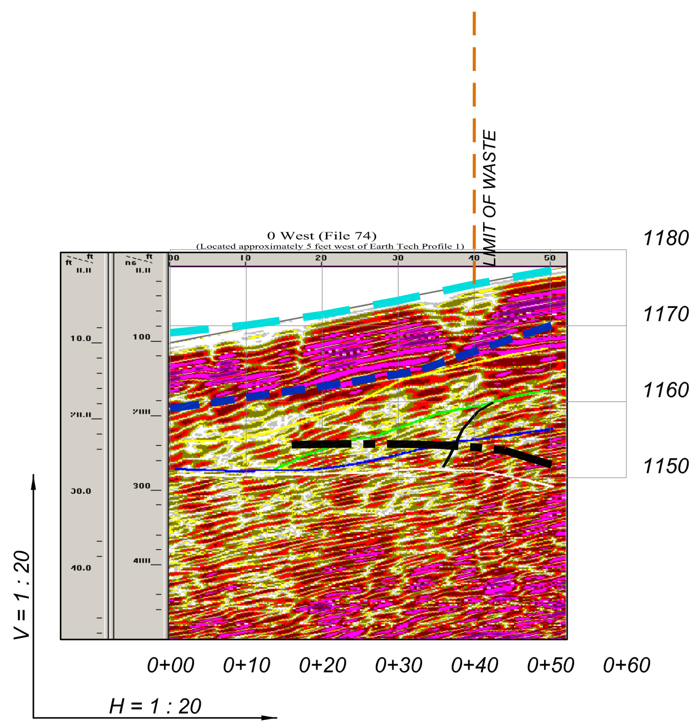

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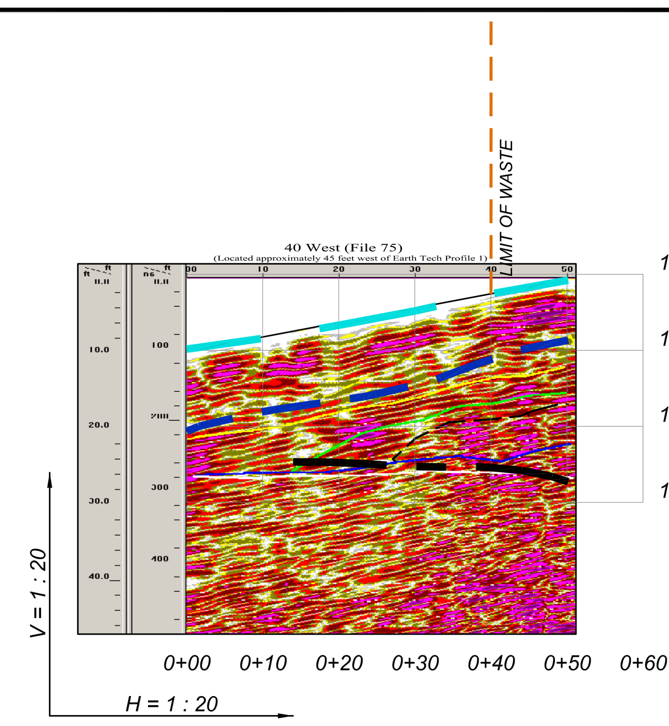

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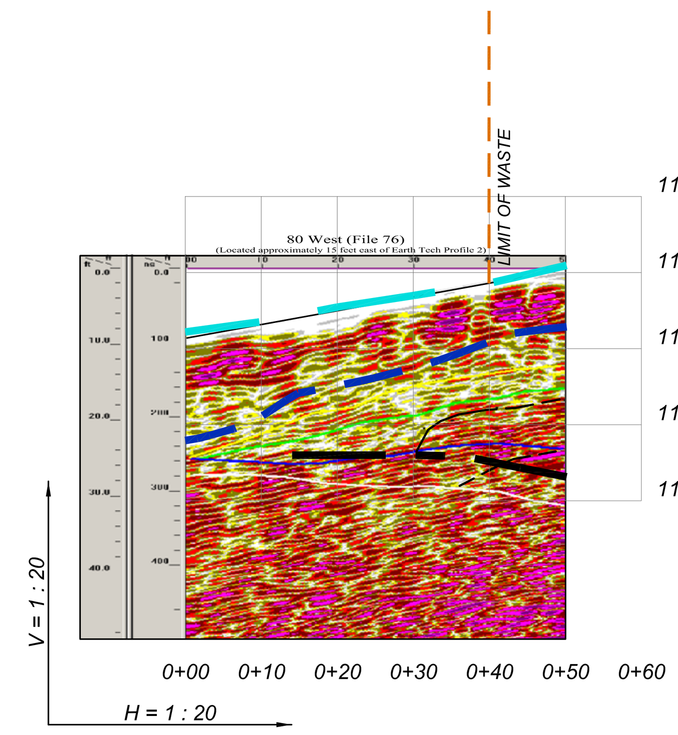

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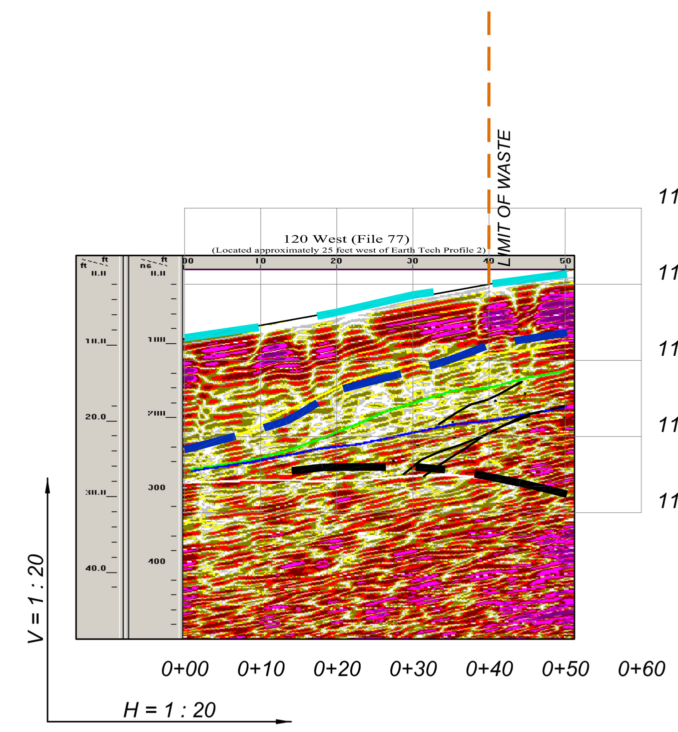

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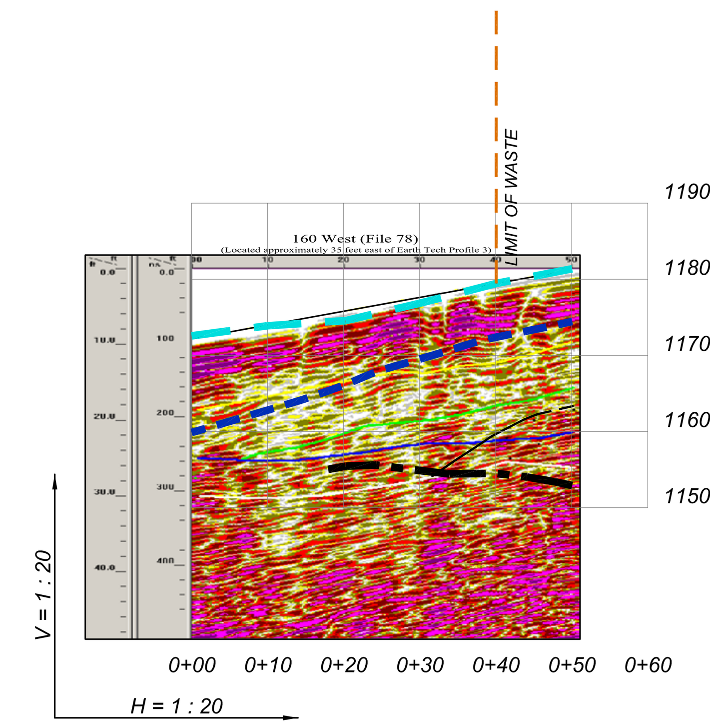

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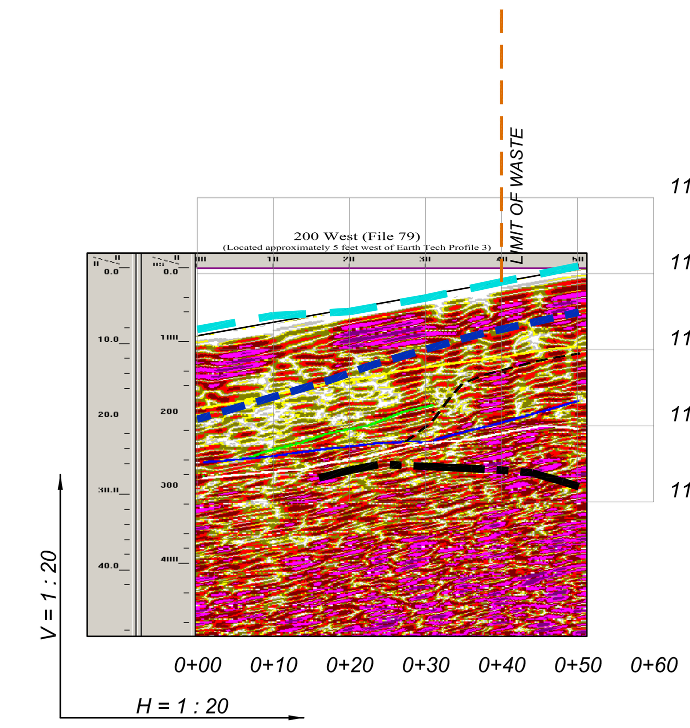

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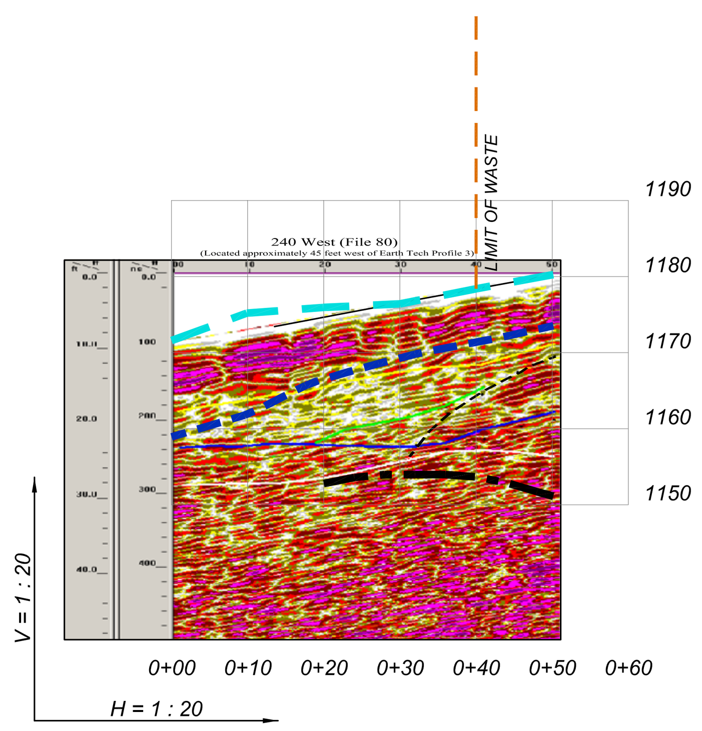

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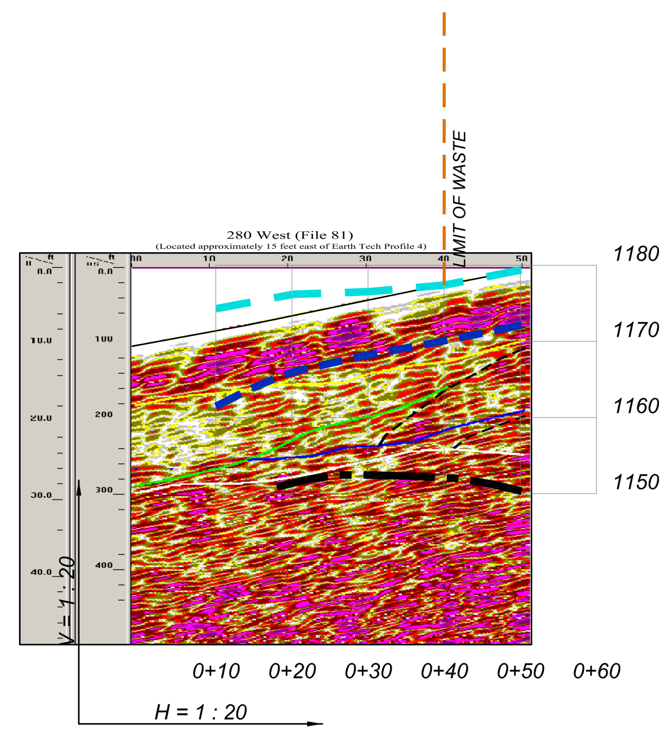

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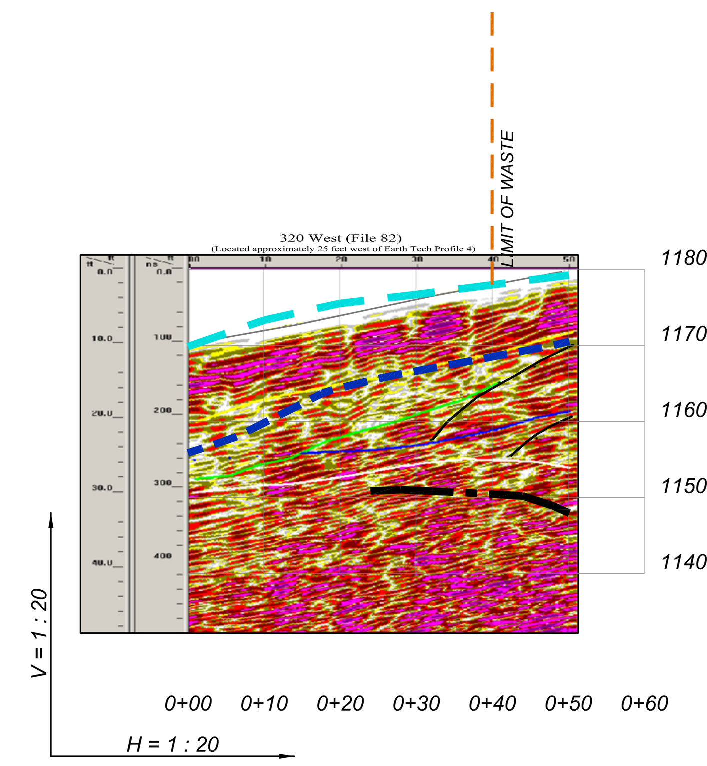

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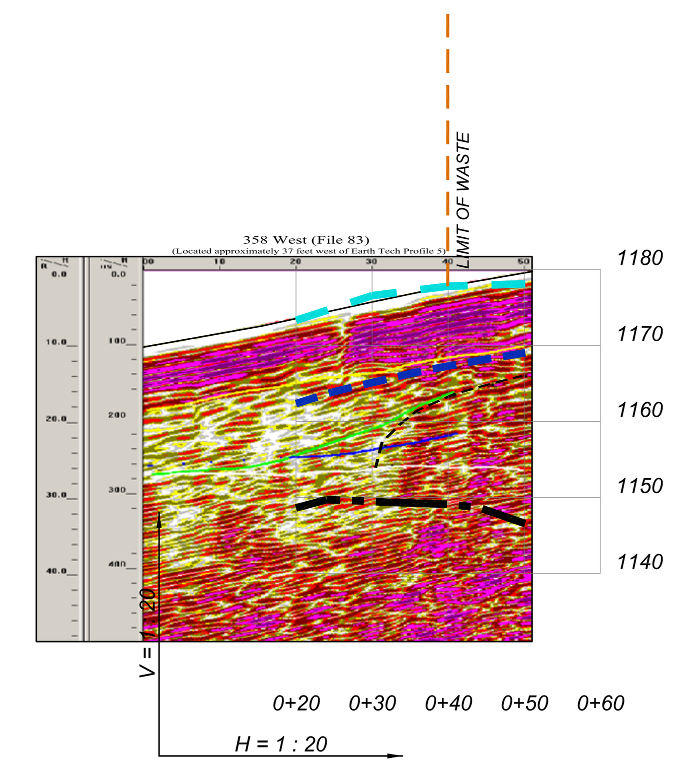

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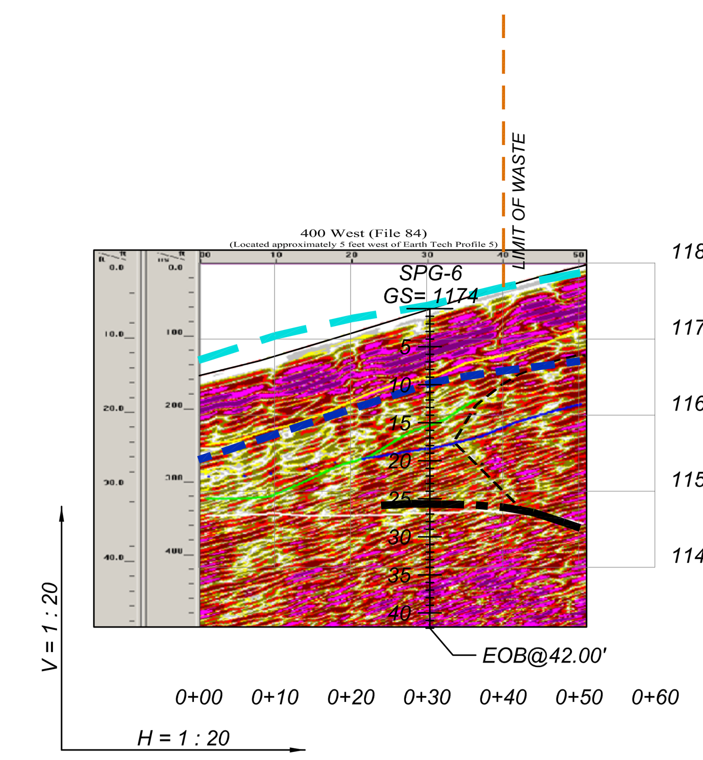

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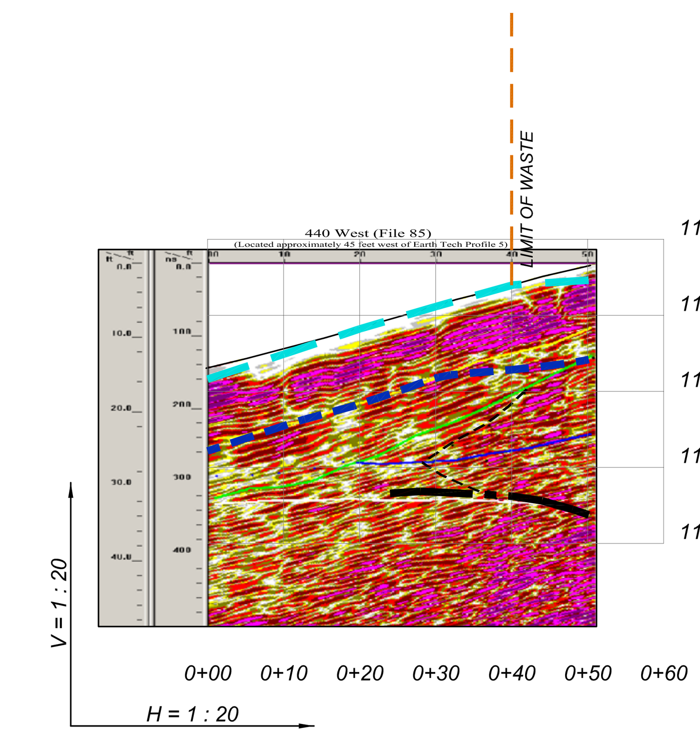

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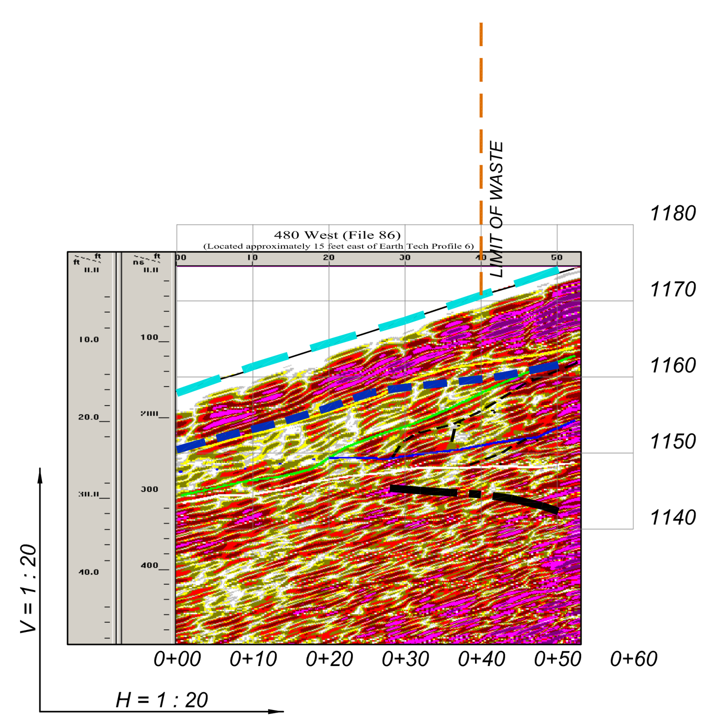

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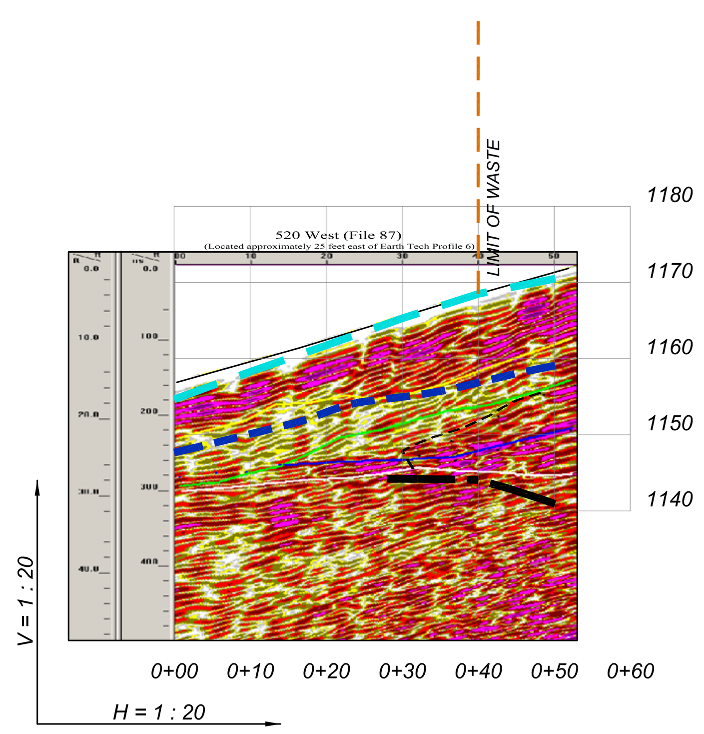

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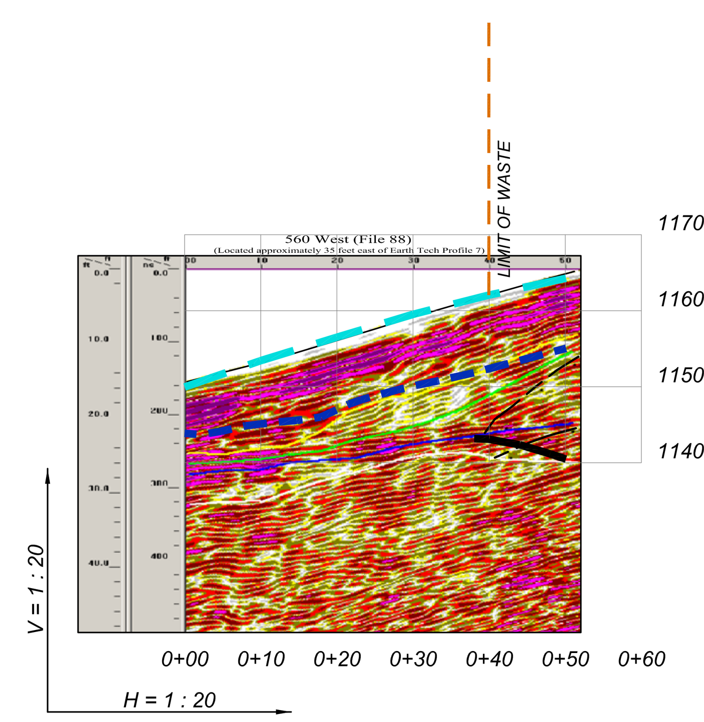

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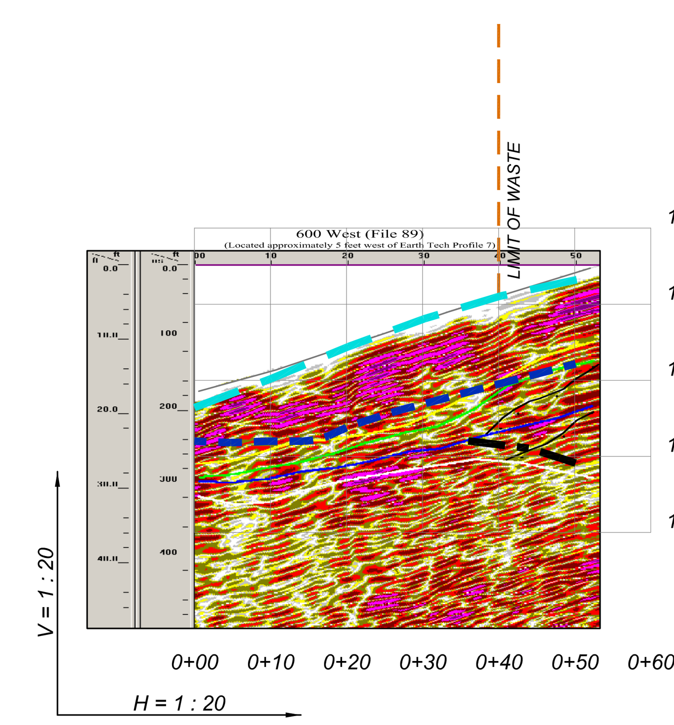

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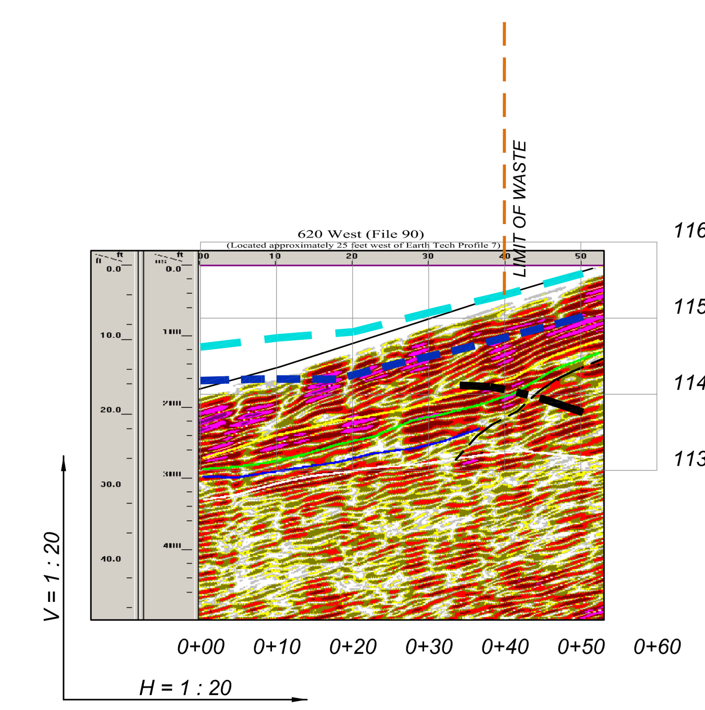

SECTION 620 WEST

Hager GeoScience, Inc. Legend

- H1 Reflector (base of buttress)
- H2 Reflector
- H3 Reflector
- H4 Reflector (Bottom of Landfill (white)
- W1 Reflector (Interpreted Limit of Waste or Waste Effects)
- Slope Adjustment Grid 10'Hx10'V Grid

Shift-direction and magnitude for correcting effect of sloping surface on GPR raypaths. Use to more accurately locate the subsurface position of features below the landfill slopes.

DIVERSIFIED ENGINEERING'S LEGEND

- WEEKLY SURFACE TOPO (01-07-08)
- SOUTH SLOPE GRADE (09-20-06)
- TOP OF LINER GRADE

NOTES:
1) RADAR IMAGES AND CROSS SECTIONAL DATA PROVIDED BY HAGER GEOSCIENCE, INC.

2) CROSS SECTION DATA SHOWN BY DIVERSIFIED ENGINEERING, INC. IS FROM COMPLIED SURVEY DATA AND CELL CONSTRUCTION RECORD DRAWINGS.

COUNTYWIDE RDF

SCALE: 1" = 20'H, 1"=20' V.		REVISIONS	PROJECT: GROUND RADAR PENETRATION
DRAWN: LDB	03-03-08		SHEET TITLE: CROSS SECTIONS
CHECKED: CCV	03-03-08		FILE ID: Ground Radar Penetration
REVISED DATE:			FIGURE 3

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Fax: (330) 364-4011
e-mail: dei@dei-eng.com

ATTACHMENT A

HAGER GEOSCIENCES, INC.
GEOPHYSICAL STUDY

FEBRUARY 2008

GEOPHYSICAL INVESTIGATION FOR
LANDFILL CHARACTERISTICS
COUNTYWIDE RFD
EAST SPARTA, OHIO

Prepared for:

Earth Tech, Inc.
36133 Schoolcraft Road
Livonia, Michigan 48150

Prepared by:

Hager GeoScience, Inc.
596 Main Street
Woburn, Massachusetts 01801

File 2008005
February 2008

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PLATE 1. GPR Traverse Locations

PLATE 2. GPR Anomalies

APPENDIX: GPR PROFILES

South to North

- Profile 0W
- Profile 40W
- Profile 80W
- Profile 120W
- Profile 160W
- Profile 200W
- Profile 240W
- Profile 280W
- Profile 320W
- Profile 358W
- Profile 400W
- Profile 440W
- Profile 480W
- Profile 520W
- Profile 560W
- Profile 600W
- Profile 620W

West to East

- Profile 10N
- Profile 30N
- Profile 50N

EXECUTIVE SUMMARY

In January of 2008, Hager GeoScience, Inc. (HGI) was contracted by Earth Tech, Inc. (Earth Tech) to perform a geophysical investigation at the Countywide Landfill in East Sparta, Ohio. The primary objective of the investigation was to confirm the limit of waste (LOW) on the south side of the landfill and to delineate the base liner. A secondary objective was to identify possible anomalous leachate saturation zones in the same area. The work was performed under the direction of Earth Tech.

Geophysical data were collected along traverses at the landfill between January 15th and 18th, 2008. Two low frequency high-powered GPR systems (100-MHz and 40-MHz) were used to provide the best opportunity for depth penetration and target resolution within a subsurface environment inhospitable to GPR signals. The 40-MHz antenna system required more data collection time, but provided the best overall signal quality and was used for the landfill analysis.

The survey area extended 640 feet in the east-west direction (parallel to the landfill slope) and 50 feet in the south-north direction (perpendicular to the landfill slope). Twenty (20) profiles were prepared within the surveyed area, 17 in the south-to-north direction and 3 in the west-to-east direction.

The interpretive results of the investigation indicate:

- The presence of subsurface electromagnetic boundaries H1, H2, H3, H4, and W1 that can be mapped across the survey area.
- Disruption of the mapped H2 electromagnetic boundary and shift in the W1 boundary to the south between 200W and 400W, north of approximately the 40N grid line.
- An anomalous high-amplitude reflector between 445W and 600W coinciding with a mapped radar reflector boundary may indicate a more saturated leachate horizon, or it may be an engineered structure.

Other conclusions of the investigation include:

- Low frequency GPR methods can be successfully used in landfill environments to investigate subsurface features to depths of at least 50 feet.
- The 40-MHz antenna system operated in discreet point data collection mode provides the best data quality, but requires additional time for data collection.
- The 100-MHz antenna system could also provide useful data for attenuation studies.
- Additional closely spaced 40-MHz south-to-north survey traverses extending farther north of the LOW line would enhance the subsurface details and provide better context for waste vs. non-waste GPR signal response.
- Further analysis would be necessary to investigate leachate saturation.

Hager GeoScience, Inc.

1.0 INTRODUCTION

In January of 2008, Hager GeoScience, Inc. (HGI) was contracted by Earth Tech, Inc. (Earth Tech) to perform a geophysical investigation at the Countywide Landfill in East Sparta, Ohio. The primary objective of the investigation was to confirm the limit of waste (LOW) on the south side of the landfill and to delineate the base liner. A secondary objective was to identify possible leachate saturation zones in the same area.

Geophysical techniques that could achieve the stated objectives were explored during several discussions with P.J. Carey and Associates. Minimally intrusive methods that could image 60 feet below ground surface and resolve waste and leachate saturation targets within existing surface and subsurface landfill conditions were evaluated. The ground-penetrating radar (GPR) method was determined to be the most likely to meet the objectives. Although higher frequency radar antennas are commonly used to evaluate landfill margins, low frequency radar systems are less common. The application of low frequency radar methods for deeper landfill investigations is problematic and not routinely done. When attempted at landfills, low frequency radar antenna configurations are tested to evaluate the adaptability of the systems to site conditions and the quality of the test data.

Field investigations were performed at the landfill under the direction of Earth Tech between January 15th and 18th, 2008.

2.0 TECHNICAL APPROACH

The geophysical study at the Countywide landfill was designed to test the efficacy of the lower frequency GPR techniques to distinguish and resolve variations of buried waste materials, berm materials, and saturation effects to depths of up to 50 feet beneath landfill slopes of up to 3:1 containing multiple surface utilities. Two high-powered bi-static antenna systems, with center frequencies of 100-MHz and 40-MHz, were chosen for the investigation. The next section provides a brief description of the method. Section 7.0 provides more detailed information about the GPR technique and its limitations.

The strategy behind the multi-frequency approach was to achieve the highest resolution and depth penetration possible in a subsurface environment inhospitable to GPR signals. HGI anticipated that the conductive leachate, waste materials, clay soils, and carbonaceous shale buttress would significantly attenuate GPR signals. Based on our previous experience, we know that data from our high-powered 100-MHz antenna system can be significantly attenuated and still provide sufficient signals to resolve deeper subsurface targets. We also know that stacked signals using our high-powered MLF system in discreet point collection mode produce superior signal quality with reduced resolution capability.

The basic geometry of the survey traverses consisted of traverses perpendicular and parallel to the landfill slope. Survey control is of paramount importance for accurately locating delineated subsurface features. In cooperation with Countywide surveyors, the LOW was marked on the landfill slope and used as the baseline for the survey. Countywide established a predetermined survey area that extended 10 feet north and 40 feet south of the LOW. Countywide surveyors established 10-foot markings 10 feet north and 30 feet south of the LOW baseline and 20-foot markings in the west-east direction. The grid stretched 750 feet in the east-to-west direction and 50 feet in the north-to-south direction (Plate 1). HGI provided a field crew of 3 geophysicists for the field program.

3.0 DATA ACQUISITION

Following the morning briefing session on January 15th, the HGI field crew collected GPR data from January 15th through 18th, 2008. The survey area (described in Section 2.0) was located on the south-facing slope of the landfill. Most of the surface within the surveyed area was covered with a liner and a network of surface piping of varying sizes. The slopes were variable and ranged from a minimum of approximately 2:1 to more than 3:1 (Figures 1 and 2). The slope and utilities create surface coupling issues that affect GPR data quality. These effects are minimized by data processing techniques, but can never be totally eliminated.

The HGI grid coordinate system used for the survey is based on the survey grid provided by the Countywide surveyors. Due to surface conditions, eastern and western portions of the Countywide grid were inaccessible and could not be surveyed. Plate 1 illustrates the relationship of the HGI and Countywide grid systems and shows where the traverses were performed. Forty feet of the eastern Countywide grid were inaccessible due to steep slopes. Approximately 90 feet of surface at the western end of the Countywide grid were covered with cohesive wet clay (Figures 3 and 4). The 100-MHz antenna survey was performed in this area with great difficulty. To avoid damage to survey equipment, the 40-MHz antenna survey was not performed in this area.

The HGI grid origin (0W, 0N) is equivalent to the Countywide survey grid point 2302; i.e. the HGI grid begins 40 feet west of the beginning of the Countywide grid.

GPR. The GPR method is amenable to the interrogation and mapping of discontinuous subsurface interfaces, such as changes in stratigraphy. GPR data were collected as two-way travel time, in which the measurements are made of the time for the input radar wave pulse to travel to a subsurface discontinuity and reflect back to the antenna at the ground surface. Depths to discontinuous interfaces are recovered from the recorded travel-time data using radar propagation velocities. At the Countywide Landfill, site-specific velocities were estimated through calibration with profiles provided by Earth Tech and from velocity analyses of data obtained from a CDP survey performed at the site.

Ground penetrating radar data were collected using a Geophysical Survey Systems, Inc. (GSSI) SIR System 2 digital ground penetrating radar system. The GPR data were displayed on a color monitor for immediate visual inspection and quality control and simultaneously recorded on the system's hard drive for later processing and interpretation.

As stated earlier, the GPR field program was designed to test the ability of low frequency antennas to resolve the desired targets at the desired depths. A 100-MHz high-powered bi-static antenna in survey wheel data collection mode was used to collect data on 20-foot centers perpendicular to the slope and 10-foot centers parallel to the slope (Figure 5). A high-powered Multiple Low Frequency (MLF) bi-static antenna system, operated in discrete point mode at a center frequency of 40-MHz, was used to collect data on 40-foot centers perpendicular to the slope and 20-foot centers parallel to the slope (Figure 6). Plate 1 illustrates the locations of both surveys.

Landfill surface conditions prohibited the use of a survey wheel with the 40-MHz antenna system. Consequently, the 40-MHz survey data were collected using discrete, stacked measurements at 1-foot intervals. Sixty-four (64) stacks per station were used for the point mode survey. The benefit of stacking signals in the point collection mode includes an increase in the signal-to-noise ratio and cleaner records than can be produced in the survey wheel mode. However, such a method requires more time for collecting data; hence, fewer traverses could be made in the survey area within the allotted schedule.

Surveys using the 100-MHz antenna system were conducted exclusively in the survey wheel collection mode. The time acquisition window for both the 100-MHz and 40-MHz data collection was 500 nanoseconds (ns).

4.0 DATA REDUCTION AND ANALYSIS

Following the field data collection, the geophysical data were downloaded to a PC at the HGI office. The data were archived, processed, and analyzed using the following proprietary software:

- GPR: GSSI's RADAN for Windows NT™ with Structural and Stratigraphic Interactive Interpretation Module®
- Profile Modeling: Surfer® 8.0
- Data Calculations: Excel®
- Graphic Presentations: AutoCAD® 2000

Radargrams were analyzed using GSSI's RADAN for Windows NT™. Before the data could be analyzed, significant processing was required to reduce the detrimental effects of noise associated with radio frequency signals, reflections from surface structures, buried debris, conductive fluids, and the geometric distortions of tilted antennas. Several processing algorithms are available for correcting data and improving data quality. It is important not only to select the optimal processing regimen for the 100-MHz and 40-MHz data sets, but also to apply the processes in the order that enhances the targeted features.

For practical reasons, the final basic processing regimen selected for these data provided the best overall data quality for examining the subsurface features. The processing schemes could be altered or refined to evaluate other specific aspects of the subsurface, such as saturation effects. The regimen included band-pass filters, horizontal smoothing, background removal, gain adjustments, surface and distance normalization, data differentiation, wavelet deconvolution, and color table and transform adjustments. Migration processing was applied to specific 100-MHz records in certain circumstances to assist in data analysis. Data stretching was used in processing the 40-MHz data. Figure 7 illustrates the pre- and post processing conditions of 100-MHz radargrams. Figure 8 shows a 40-MHz raw radargram as collected in wiggle trace form. Figure 9 illustrates the results of the 40-MHz data processing regimen as applied to the same record shown in Figure 8.

After careful evaluation of the quality of processed 100-MHz and 40-MHz data, HGI concluded that the signal quality was significantly better with the 40-MHz data. Consequently, the subsurface analysis was performed using only the 40-MHz data.

The 100-MHz data were highly attenuated but still capable of resolving targets in some areas. However, these data were highly susceptible in several areas to signal multiples produced at the surface and within the loosely packed buttress material that could not be overcome to HGI's satisfaction with signal processing. Conversely, the 40-MHz data were not as susceptible to the signal multiples and provided suitable boundary resolution. Valuable information could still be extracted from attenuation characteristics and other aspects of the 100-MHz data; however, within the allotted schedule, the immediate objectives of the project would have to be met using the 40-MHz data.

Two-way travel times to the top of the interpreted reflectors were picked and entered into an ASCII file according to file number and traverse offset. A database of landfill reflector depth points was created. The reflector depths were calculated from two-way travel-times measured to the top of the interpreted reflector. A site-specific velocity was estimated through calibration with profiles provided by Earth Tech, from velocity analyses of data obtained from a CDP survey performed at the site, and experience from previous surveys. GPR travel-time data were mapped into the depth domain using this velocity estimate.

Significant parameters associated with calculating radar propagation velocities at this landfill site are the lateral and vertical variations of:

- composition and thickness of buried media
- media porosity, and
- leachate content.

Among other factors, these parameters determine the electromagnetic permittivity of radar signals and, therefore, their velocity. In the natural environment, such changes are normally associated with trends in subsurface soils and can therefore be mapped. However, at landfills, changes are unpredictable and are prohibitively expensive to map and incorporate into depth calculations. If depth is a critical and sensitive issue, velocity variations can be isolated for small areas of the landfill by conducting frequent velocity analyses or obtaining several calibration points. However, in context with this study's objectives and on the basis of our evaluation of the effects of velocity variations at this landfill, HGI has applied one estimated velocity value to all depth calculations used to construct the report profiles.

Another important factor considered when analyzing data from the landfill was the spatial distortion produced by the variable landfill slope on the data collected from a tilted radar antenna. Both surface normalization and slope vector adjustment corrections have been made to the radargrams. Surface normalization adjusts the depth of reflected signals relative to the topographic relief along the traverse. This adjustment is necessary because the radar traces are collected with time zero as the datum. The datum for each trace must be reset on slopes to place the time zero for each trace at the correct relative topographic position along the slope. Elevations used for normalizing the radargram surfaces were obtained from surface elevations interpolated from the topography included in the base plan provided by Earth Tech.

Although the relative vertical (Z) positions of the traces on the radargram have been adjusted by the surface normalization technique, the trace position in XZ space must also be adjusted. This is necessary because the radar traces represent sampling perpendicular to the bottom of the antenna. Since the antenna is tilted on the landfill slope, the position of the trace must be rotated by the tilt angle.

The ability to perform both the surface normalization and slope adjustments on the same radargram is not readily available in one processing program. Therefore, a simple slope vector adjustment indicator is provided on the profiles to indicate the magnitude and direction of adjustment that should be made for subsurface features to place them in correct XZ space.

A linear interpolation between interpreted depth points was used to delineate the reflectors. These mapped boundaries represent natural or man-made changes in subsurface electromagnetic properties that cause reflection of radar signals.

The reflectors mapped at the subject site may represent a single boundary or a single reflective zone consisting of a system of boundaries that, together, are below the resolution capability of the investigative wavelet. The resolution of subsurface objects and their dimensions is primarily governed by the size of an object or thickness of a layer relative to the wavelength of the investigative signals. The wavelength, in turn, is dependent on the propagation velocity of the subsurface medium and the predominant frequency of the investigative signal.

For most materials, the ability to *resolve* the thickness of thin layers requires that the thickness be on the order of one wavelength of the radar signal. This relationship allows for the measured response of reflected waves from the top and bottom of the thin layer and of the dampened reverberation characteristics of signals from within the layer. The detection of a thin layer with wavelengths greater than the layer thickness only requires that the reflection amplitude from the layer interface be higher than the background noise level.

Based on signal characteristics typical for the surveyed area, the resolution limit for data collected with the 40-MHz radar antenna system is estimated to be approximately 5 feet. Several subsurface boundaries produced radar signal reflections that were mapped. Laterally continuous reflectors were correlated from one south-to-north profile to the next and interpolated continuously in the west-to-east profiles.

5.0 DATA SYNTHESIS

As discussed in Section 4.0, only the 40-MHz data were used to perform the subsurface evaluation. The data signal-to-noise ratio and resolution capability achieved with the 40-MHz antenna system proved to be better than anticipated.

Seventeen south-to-north and three west-to-east profiles were constructed to depict the subsurface characteristics. With a few exceptions, the south-to-north profiles are spaced 40 feet apart from 0W to 620W. The west-to-east profiles are spaced 20 feet apart from 10N to 50N.

The profiles illustrate that subsurface electromagnetic boundaries, representing changes in soil/fill characteristics, are laterally continuous and can be mapped across the surveyed area. It may be possible to associate these boundaries with engineered structures and waste margins. Any discrepancies between the GPR profile delineations and the locations/elevations of engineered features could be attributed to survey limitations, depth calculations, resolution limitations, or other aspects of geophysical interpretation.

Three categories of radar reflectors or boundaries can be discerned from the data. One category includes strong (high-amplitude) reflections from the interface between the boulder/clayey soil buttress overlying the entire area and the underlying soils. This reflector has been identified as H1 in the Appendix profiles. A second category includes a complex set of lower (but observable) amplitude reflections from sub-vertical and sub-horizontal interfaces representing lateral and vertical changes in electromagnetic properties of materials. We interpret these materials to include waste and other units of variable fill material. Reflectors or boundaries in this category have been identified as H2, H3, and W1. A third category includes the lowest discernable boundary, below which significant signal attenuation occurs and from which the reflected signals fail to define any geometric patterns. The reflection and attenuation pattern of this lower zone can be characteristic of a soil/clay interface or an interface containing very conductive fluids. Although this interface is distinct and may be the base of the landfill, the resolution of this interface is not sufficient to identify its specific nature or design. This boundary is identified as H4.

Conditions anomalous to the survey area as a whole appear between 200W and 400W (Plate 2 and Appendix south-to-north profiles from 200W through 400W). Within the interval from 200W and 400W, the H2 reflector is missing and the W1 boundary is located farther south than in the surrounding areas, albeit by 5 to 10 feet (see Profiles 200W to 400W, 30N, and 50N). The definition of the W1 boundary in the south-to-north profiles is variable depending on the location of the profiles. This is partly because of the limited waste and non-waste context provided within a 10-foot area surveyed north of the LOW.

The west-to-east profiles (10N, 30N, and 50N) show an anomalous high-amplitude reflector between 445W and 600W. The reflector appears to become stronger toward the north, is interpreted to coincide with the H3 boundary, and is in close vertical proximity to the basal H4 boundary. This zone may be more saturated with leachate, or it may be an engineered structure.

Definitive GPR anomalies attributable to zones of saturation were not obvious in the GPR data. Noted in Section 4.0 is that the processed data were designed to provide the best overall data quality. Although these data may show the effects of leachate saturation, they were not optimized for this purpose. Attenuation studies could provide better indications of variation in leachate saturation. Additional effort would be required for this analysis.

6.0 CONCLUSIONS

This study provides a basis to further investigate areas of concern in the landfill. Drilling or other methods should be used to investigate the two areas delineated in Plate 2 in order to evaluate the geophysical interpretations made in this study.

The following are specific conclusions from our geophysical study results at the Countywide landfill:

- Subsurface electromagnetic boundaries designated H1, H2, H3, H4, and W1 can be mapped across the survey area.
- Disruption of the mapped H2 electromagnetic boundary is evident between 200W and 400W, north of approximately the 40N grid line.
- Low frequency GPR methods can be used in landfill environments to investigate subsurface features to depths of at least 50 feet.
- The 40-MHz antenna system operated in discreet point data collection mode provides the best data quality, but requires additional time for data collection.
- The 100-MHz antenna system could also provide useful data for attenuation studies.
- Additional closely spaced 40-MHz south-to-north survey traverses extending farther north of the LOW line would enhance the subsurface details and provide better context for waste vs. non-waste GPR signal response.
- Further analysis would be necessary to investigate leachate saturation.

7.0 THE GROUND PENETRATING RADAR TECHNIQUE

General Description of the Method - The principle of ground penetrating radar (GPR) is the same as that of weather or police radar, except that GPR transmits electromagnetic energy into the ground, which is reflected back to the surface from interfaces between materials with contrasting electrical (dielectric and conductivity) properties. The greater the contrast between two materials in the subsurface, the stronger the reflection observed on the GPR record. The depth of GPR signal penetration depends on the properties of the subsurface materials and the frequency of the antenna used to collect radar data. The lower the antenna frequency used, the deeper the signal penetration, but the lower the signal resolution.

We collect GPR data using a Geophysical Survey Systems SIR System 2, 2000, or 3000 digital ground penetrating radar unit, which consists of a computer connected to a transmit/receive antenna. Radar data are collected in point, continuous, or survey wheel mode while moving the antenna across the ground. Data are displayed in color on the computer monitor and simultaneously recorded on the unit's hard drive for later processing and interpretation using proprietary RADAN for Windows® software.

Data Analysis and Interpretation. The horizontal scale of the GPR record shows distance along the survey traverse. In the continuous data collection mode, the horizontal scale on each GPR record is determined by the antenna speed. When a survey wheel is used, as at this site, the GPR record is automatically marked at specified intervals along the survey line. The vertical scale of the radar records is determined by the recording time range or interval. The recording interval represents the maximum recording time allotted to capture reflected radar signal. The conversion of two-way travel time to depth depends on the propagation velocity of the GPR signal, which is site specific. In the absence of site-specific subsurface information about stratigraphy, we estimate propagation velocities from handbook values and experience at similar sites.

The size, shape, and amplitude of GPR reflections are used to interpret GPR data. Metal objects such as USTs and utilities produce reflections with high amplitude and distinctive hyperbolic shapes in GPR records when traverses are made perpendicular to their long axes. Clay or concrete pipes and boulders may produce radar signatures of similar shape but lower amplitude. The boundaries between saturated and unsaturated materials, sand and clay, and bedrock and overburden, generally also produce strong reflections.

General Limitations of the Method - GPR signal penetration is site specific, determined by the dielectric properties of local soil and fill materials. GPR signals propagate well in resistive materials such as sand and gravel; however, soils containing clay, ash- or cinder-laden fill, or fill saturated with brackish or otherwise conductive groundwater cause GPR signal attenuation and loss of target resolution (i.e., limited detection of small objects). Concrete containing rebar or mesh also inhibits signal penetration.

Interpreted depths of objects detected using GPR are based on on-site calibration, handbook values, and/or estimated GPR signal propagation velocities from similar sites. GPR velocities and depth estimates may vary if the medium of investigation or soil water content is not uniform throughout the site. (Electromagnetic waves do not travel as fast through water as air, so the distance to a reflector below the water table may appear farther than in actuality.)

Utilities are interpreted on the basis of reflectors of similar size and depth that show a linear trend, but GPR cannot unambiguously determine that all such reflectors are related. Fiberglass USTs or utilities composed of plastic or clay may be difficult to detect, as well as objects underneath reinforced concrete pads.

Changes in the speed at which the GPR antenna is moved between stations causes slight variations in distance interpolations, and hence in interpreted object positions.

The GPR antenna produces a cone-shaped signal pattern that emanates approximately 45 degrees from horizontal fore and aft of the antenna. Therefore, buried objects may be detected before the antenna is located directly over them, and GPR anomalies may appear larger than actual target dimensions.

GPR is an interpretive method, based on the subjective identification of reflection patterns that may not uniquely identify a subsurface target. Borings, test pits, or site utility plans must verify the results.

Figure 1. Countywide Landfill showing slope and surface pipes at west end.

Figure 2. Countywide Landfill showing slope and surface pipes at east end.

Figure 3. Wet clay and end of temporary cap in west area of GPR grid, Countywide Landfill.

Figure 4. Data collection with the 100-MHz bi-static antenna and survey wheel in wet clay at west end of GPR grid, Countywide Landfill.

Figure 5. Data collection with the 100-MHz bi-static GPR antenna perpendicular to the slope, Countywide Landfill.

Figure 6. Data collection with the 40-MHz bi-static GPR antenna perpendicular to the slope, Countywide Landfill.

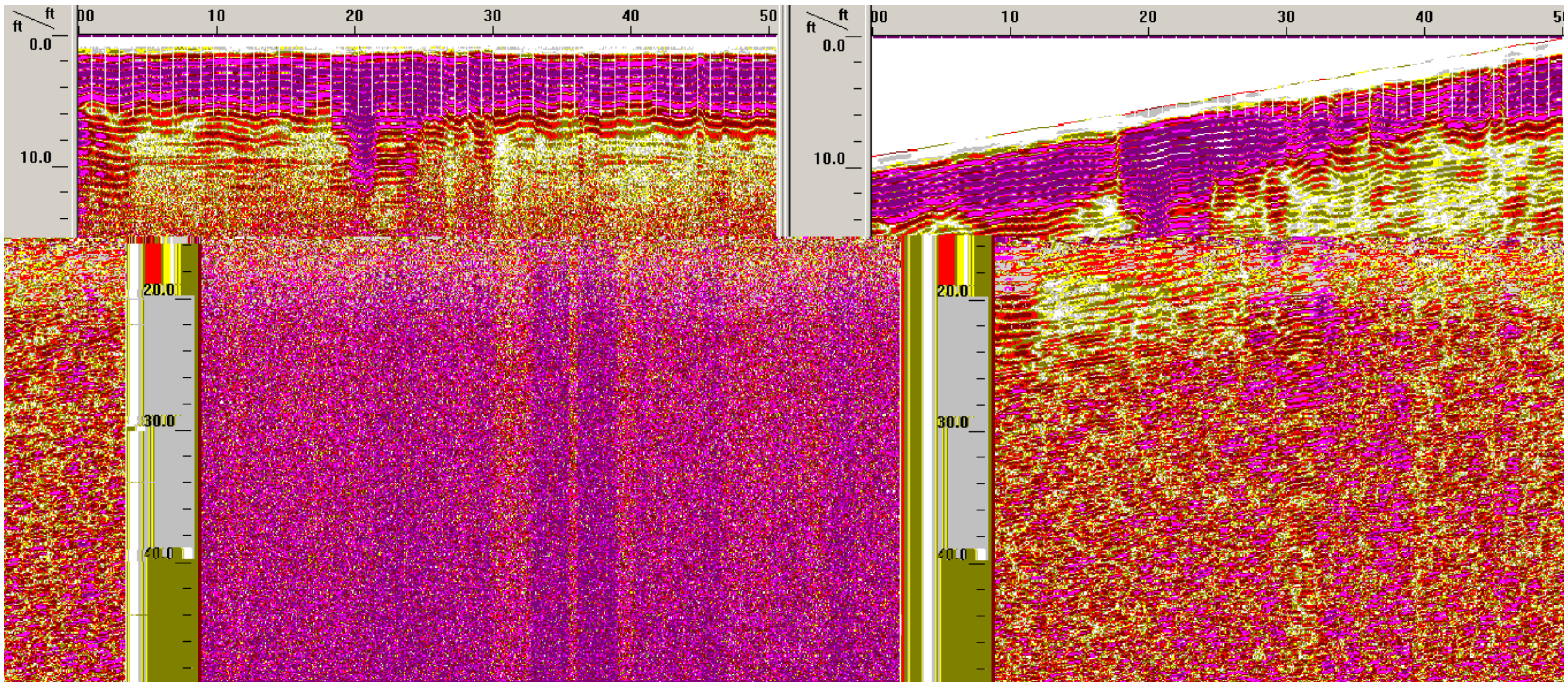


Figure 7. Example of 100-MHz GPR radargrams for south-to-north profile. Raw record is on left and processed record on right.

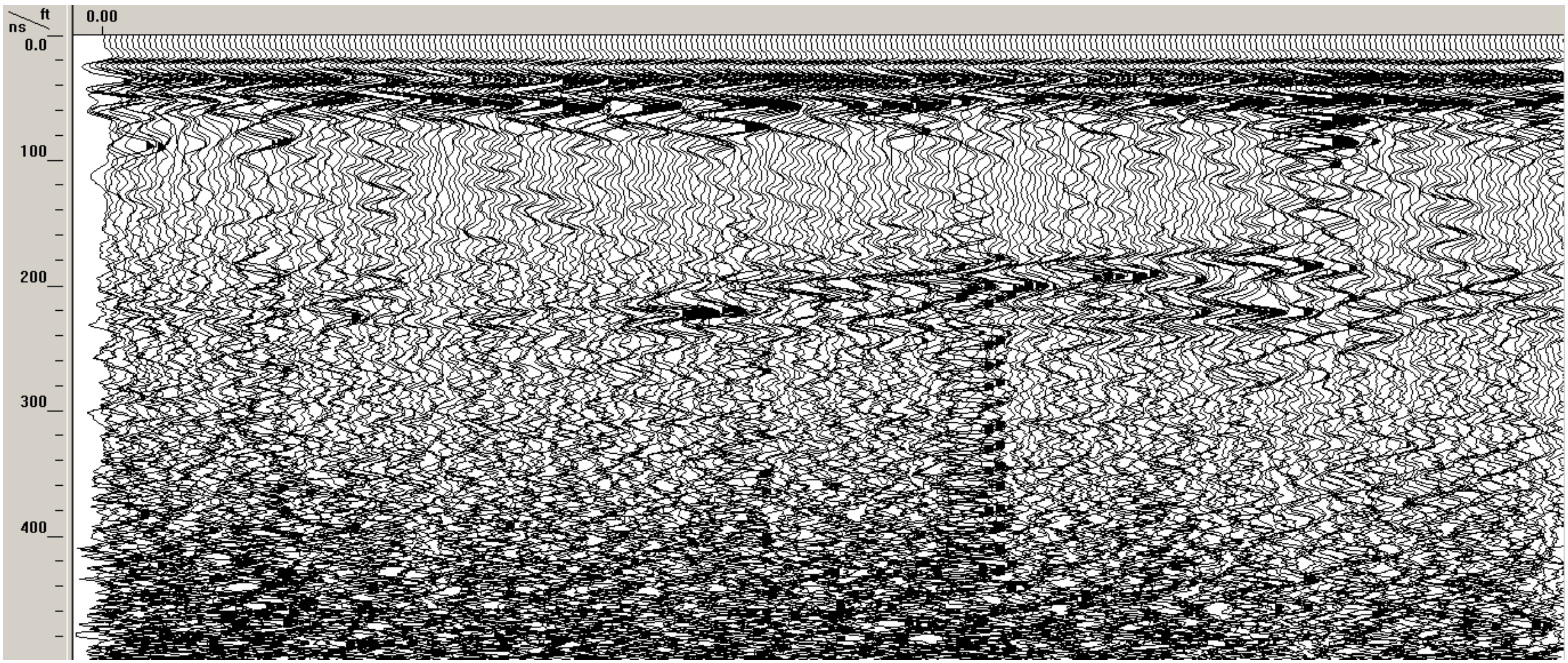


Figure 8. Example of raw 40-MHz GPR radargram for west-to-east profile. Wiggle-trace data collected in point mode.

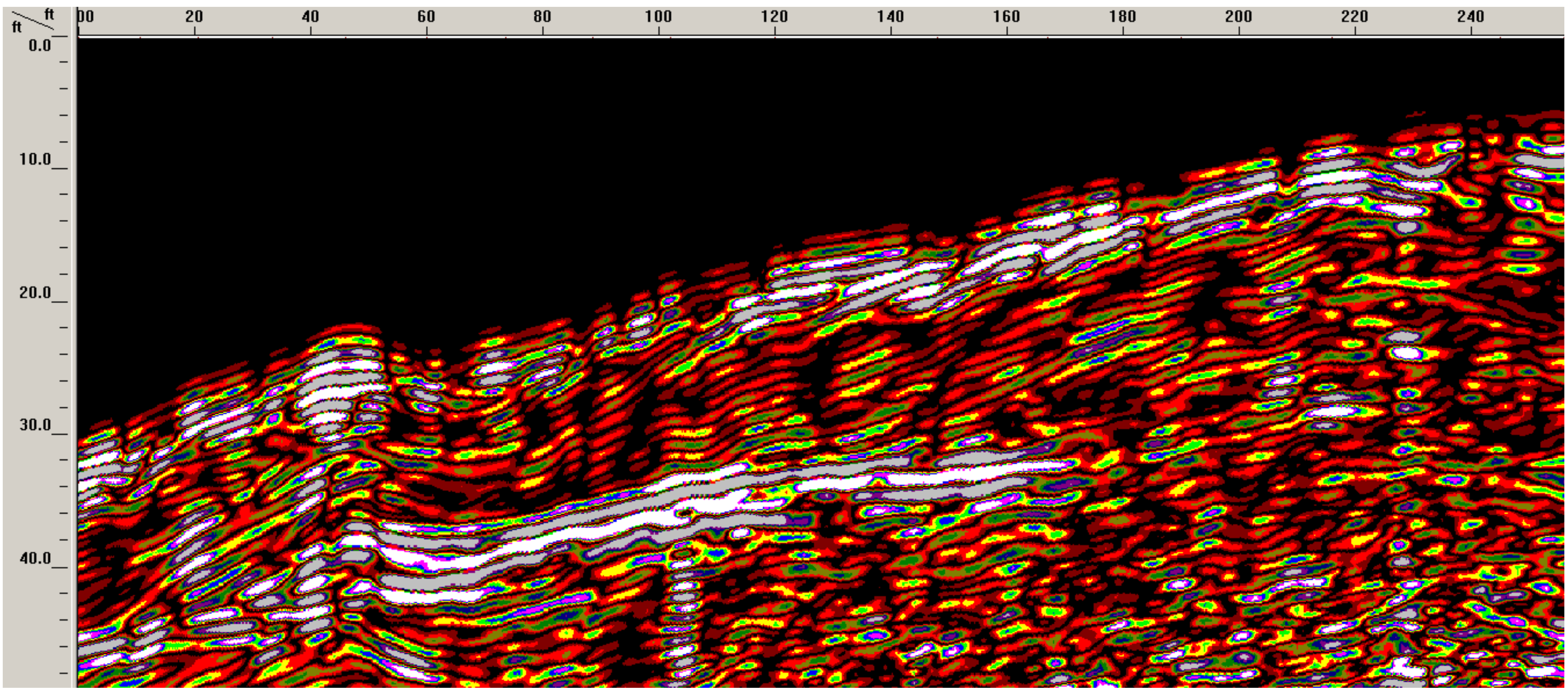
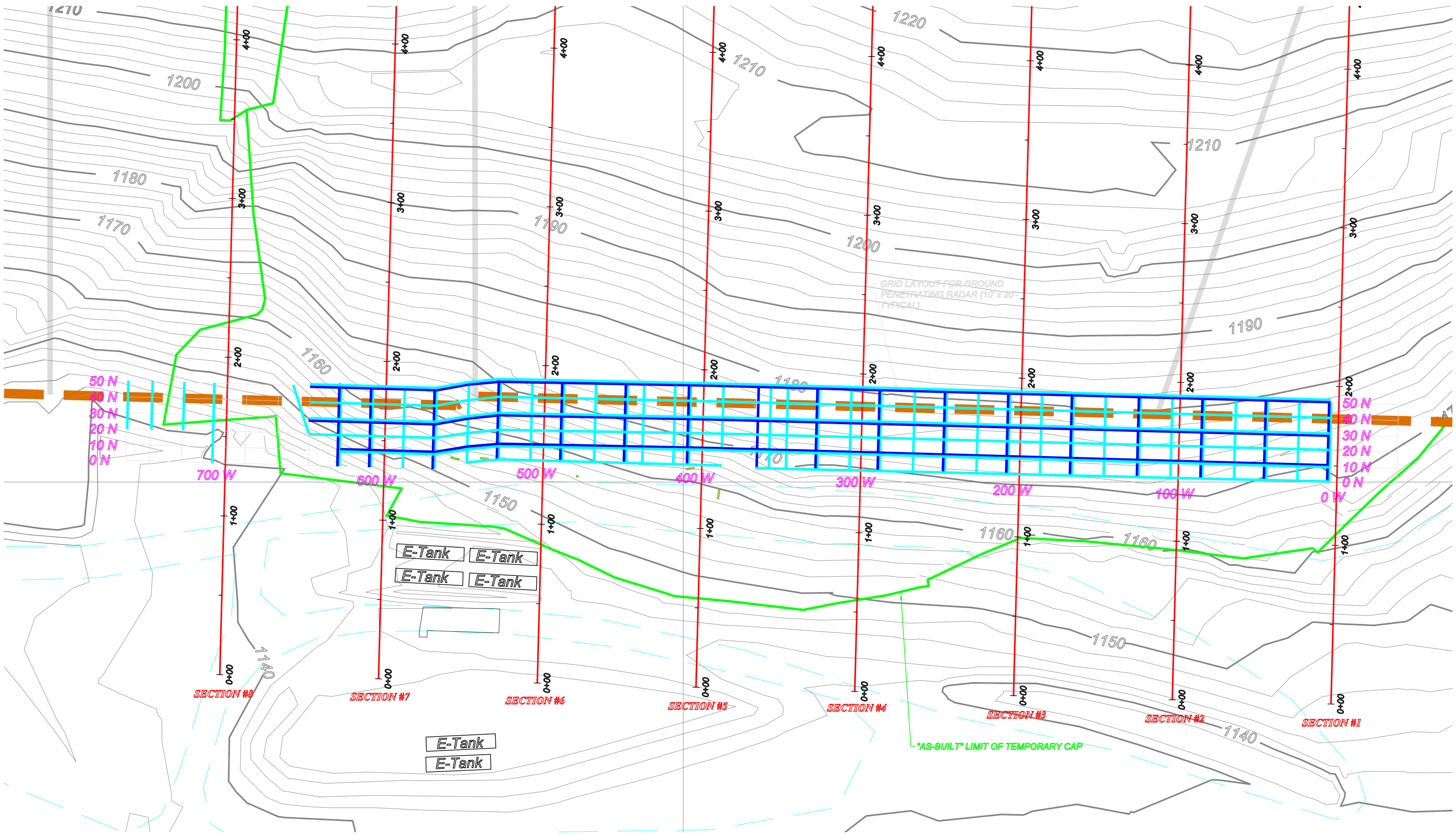


Figure 9. 40-MHz GPR radargram after data processing regimen was applied to the same record shown in Figure 8.



NOTES:

1) Base drawing supplied by Earth Tech, Inc.

Legend

40 MHz GPR Traverse (blue line)	
100 MHz GPR Traverse (cyan line)	
100 W	HGI Grid Coordinate

0 30 60 120

SCALE in FEET

PLATE 1

FEBRUARY 2008	FILE NO. 2008005

Location Plot
GPR Traverse Locations
Countywide RDF
East Sparta, Ohio

Hager GeoScience, Inc.
596 Main Street, Woburn, MA 01801
(781) 935-8111 hgi@hagergeoscience.com

NOTES:

1) Base drawing supplied by Earth Tech, Inc.

Legend

General Area of GPR Anomaly

0 60 120

SCALE in FEET