RETTEW ENVIROSCAN

3020 Columbia Avenue, Lancaster, PA 17603 ● Phone: (800) 738-8395
E-mail: rettew@rettew.com ● Website: rettew.com

Engineers
Environmental Consultants
Surveyors
Landscape Architects
Safety Consultants
Geophysicists

October 22, 2019

Mr. Larry J. Gremminger
Sunoco Pipeline, LP
535 Fritztown Road
Sinking Spring, PA 19608

RE: Geophysical Survey
Sunoco Pipeline, LP Pipeline Project
S3-0460 Boot Road GPR Survey at Wilson Drive
East Goshen Township, Chester County, PA
RETTEW Project No. 096303003

Dear Mr. Gremminger:

RETTEW Associates, Inc. completed a Ground Penetrating Radar (GPR) geophysical survey along a 980-foot section of the S3-0460, Greenhill Road horizontal directional drill (HDD) site. The purpose of the survey was to detect and delineate subsurface voids or low-density zones adjacent to an HDD path where a recent inadvertent return (IR) occurred through a saw-cut in the roadway. A multi-technique geophysical survey along a 250-foot section of the Greenhill Road HDD was completed on June 22, 2019. A copy of the report of the June 22nd survey is included as **Attachment 1**. This survey is an expansion and repeat of the GPR survey with integrated Global Positioning Systems (GPS). The following report, figures, and attachments describe the method and results of the investigation.

EXECUTIVE SUMMARY

The expanded survey was completed on October 8 and 9, 2019. GPR scanning detected several underground utilities (previously marked by others on the surface) as well as four anomalous areas of high-amplitude GPR reflectors characteristic of disturbed soils and possible soil settlement or subsidence, possibly from movement of material in the shallow utility trenches. Three areas are located around multiple water lines and valves, and the other, a larger area, away from any known utilities. These anomalous features do not appear to represent open voids.

SITE DESCRIPTION

The S3-0460, Greenhill Road HDD is located at the intersection of East Boot Road and both Wilson Drive and Carriage Drive in Chester County, Pennsylvania (see **Figure 1**). A geophysical survey was conducted along a 980-foot section of the east- and west-bound lanes of Boot Road, which parallels the HDD alignment (see **Figure 2**). Portions of each lane of Boot Road were closed for approximately 4 to 6 hours each to complete the survey.

GPR SURVEY

The GPR survey was completed using a GSSI GPR digital controller and dual-frequency 300/800 MegaHertz (MHz) scanning antenna. GPR systems produce cross-sectional images of subsurface features and layers by continuously emitting pulses of radar-frequency energy from a scanning antenna as it is towed along a survey profile. The radar pulses are reflected by interfaces between materials with differing dielectric

properties. The reflections return to the antenna are displayed on a video monitor as a continuous cross section in real time. Since the electrical properties of air and clay mud are distinctly different from undisturbed soils, such features produce characteristic reflections. In particular, air and mud typically produce very high-amplitude, characteristically reverberating reflections.

GPR scanning was performed along survey profiles spaced approximately 2 feet apart, as well as several additional diagonal transects (see **Figure 2**, red lines). The GPR data were integrated with a Topcon Hiper Lite Plus DGPS GNSS system. The profiles were recorded for post-processing with both Radan by GSSI and GPR-Slice by Geophysical Archaeometry Laboratory, Inc. GPR-Slice was used to filter the individual profiles before combining them into a three-dimensional model of the subsurface. Seven horizontal slices were then extracted between 0 and 6 feet below grade. **Figure 3** shows three of the seven horizontal slices and a composite of the seven slices combined. The shades of red represent the relative amplitude of the GPR signal increasing from white (minimum) to red (maximum).

Figure 4 summarizes the results of the GPR survey with an annotated slice and two vertical GPR profiles showing samples of the anomalous features identified in the 3D model. The vertical profile colors represent relative amplitude of the GPR signal. Shades of white indicate the highest amplitude signal, while black and red represent the lowest amplitudes.

RESULTS

The GPR results show multiple high-amplitude reflectors across the survey area. Most of the reflections are associated with the numerous underground utility lines beneath the survey area as well as related surface features such as valves, manholes, and inlets. Three adjacent anomalous areas are located beneath the west-bound lane (near 15318+00), between several suspected water lines and multiple water valves (hatched in **Figure 4**). These areas show high-amplitude GPR reflectors, including downward-dipping reflectors. The two westernmost areas were identified in the June 2019 GPR survey by RETTEW. The third is coincident with a backfilled excavation area. This GPR reflection pattern is characteristic of settlement or subsidence, as opposed to most of the GPR reflectors across the site that are associated directly with utility lines or disturbed soils around and above the buried utilities. The three anomalous areas (near 15318+00) are located between water lines and water valves and therefore may be related to settlement of the water line trench materials or associated with other past events not related to the recent IR. A larger area of high-amplitude reflectors (near 15320+00) was observed in the eastbound lane, southeast of the Carriage Drive intersection (**Figure 4**). These GPR reflectors also show characteristics of settlement or subsidence, but do not appear to be associated with observed underground utility lines. Note that these reflectors may be related to pre-road construction or pre-road land use and do not appear to have had an impact the current road conditions.

LIMITATIONS

The survey described above was completed using standard and/or routinely accepted practices of the geophysical industry, and the equipment employed represents, in RETTEW's professional opinion, the best available technology. RETTEW does not accept responsibility for survey limitations due to inherent technological limitations or unforeseen site-specific conditions. We will notify you of such limitations or conditions, when they are identifiable.

Please also note that the survey is based on observation of current subsurface conditions. Therefore, while the results of this survey can be used to guide further investigations, RETTEW cannot make any warranties concerning future subsidence occurrence — particularly under the influence of altered surface and subsurface drainage patterns due to grading and construction activities.

We have enjoyed and appreciated the opportunity to have worked with you. If you have any questions, please do not hesitate to contact the undersigned.

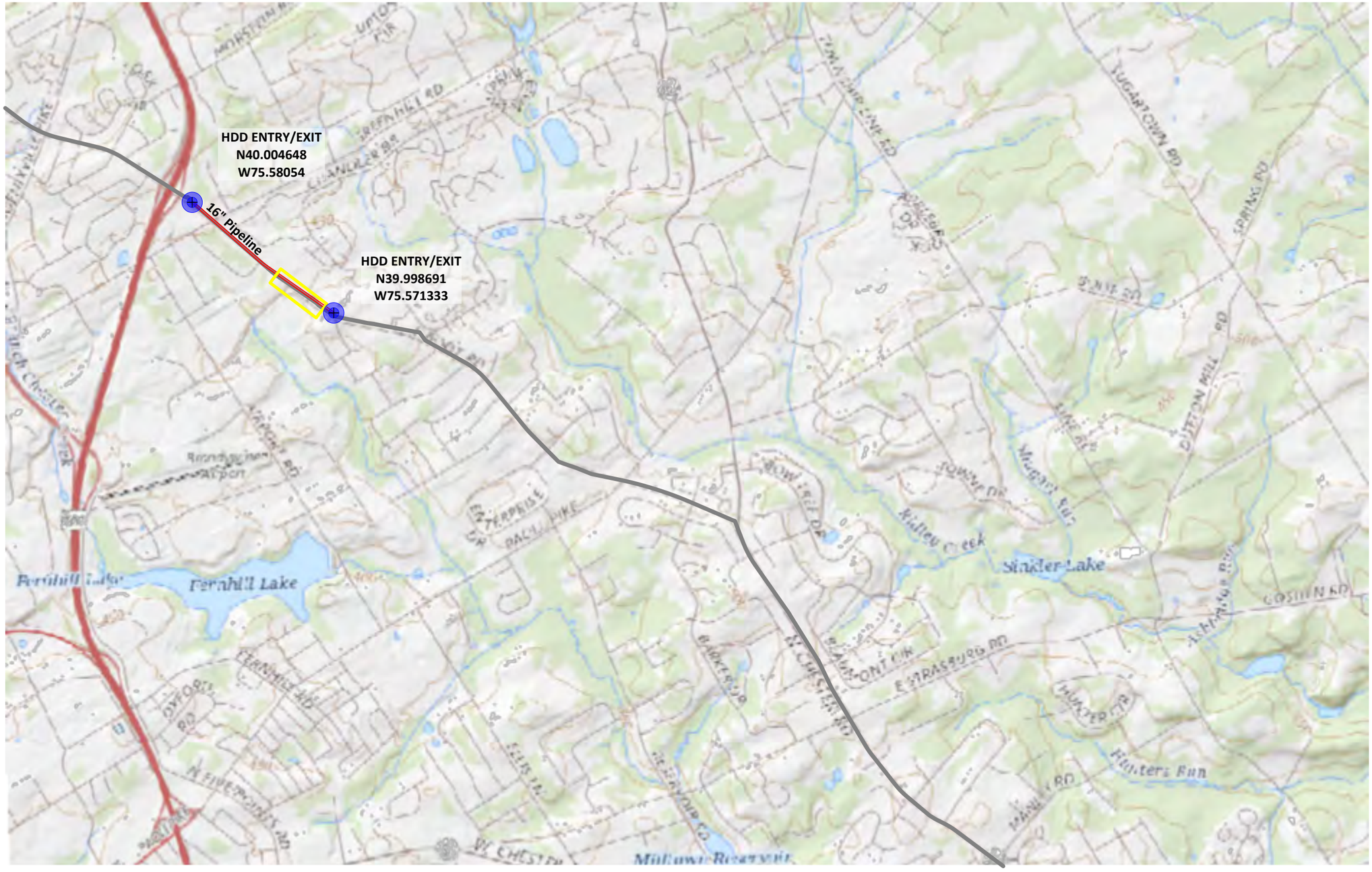
Charles H. Rhine, MSc, PG
Senior Project Manager

Felicia Kegel Bechtel, MSc, PG
Director of Geophysics

Enclosures
Figure 1: Topographic Basemap
Figure 2: Data Coverage Map
Figure 3: GPR Horizontal Slice Maps
Figure 4: Data Summary Map
Attachment 1 – June 2019 S3-0460 Boot Road GPR Survey at Wilson Drive Report

Z:\Shared\Projects\09630\096303003 - SL - Greenhill Road Geophysics\GP - Boot Road GPR\REPORT PIECES\S3-0460 Greenhill Rd Final 2019-10-22.docx

ENCLOSURES



Geophysical Survey Legend

- Proposed 16" HDD Alignment
- Geophysical Survey Area
- HDD Entry/Exit Point

Scale (ft)

0 1000 2000 3000 4000

Notes:

Basemap extracted from USGS US Topographic WMS Server, extracted 01/2019.

SURVEY DATE:	09/25/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	10/17/2019
SCALE:	1" = 2000'
FIGURE NO.	1 of 4

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Phone 1-800-738-8395

Figure 1: Topographic Basemap

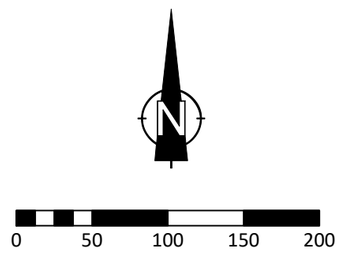
East Boot Road/Greenhill Road
S3-0460

CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP

Legend

- GPR Profile
- Gas Line (observed with GPR)
- Water Line (observed with GPR)
- Manhole - Water
- Manhole - Storm
- Manhole - Unknown
- Water Valve
- Stormwater Inlet
- 16" Pipeline
- 20" Pipeline



Notes:

Basemap image from Nearmap, extracted 8/2019.

Coordinates in PA South State Plane, NAD83.

SURVEY DATE: 09/25/2019
RETTEW No.: 096303003
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 10/18/2019
SCALE: 1" = 100'
FIGURE NO. 2 of 4

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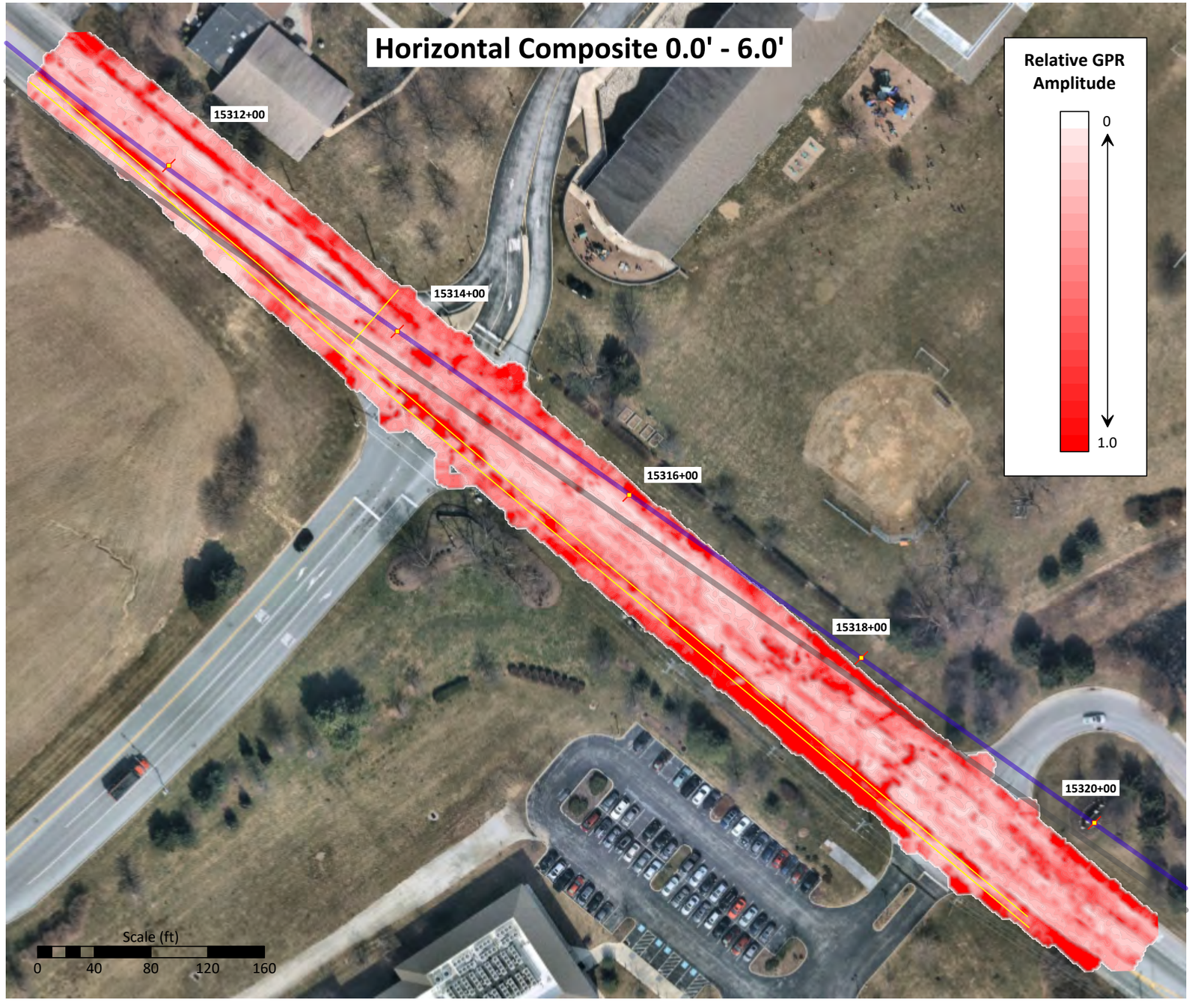
Figure 2: Data Coverage Map

East Boot Road/Greenhill Road
S3-0460

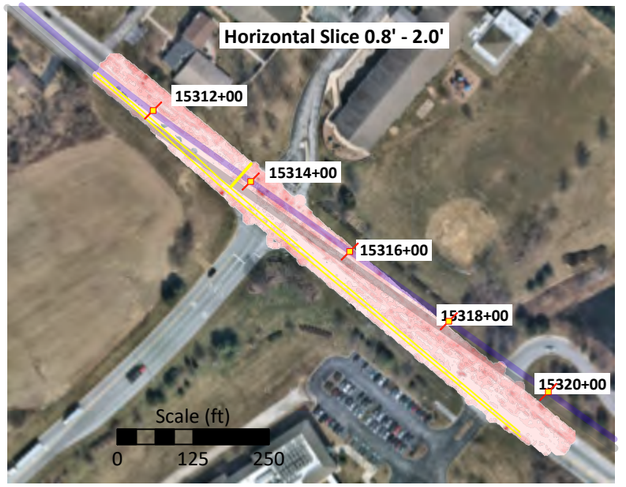
CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP

Horizontal Composite 0.0' - 6.0'

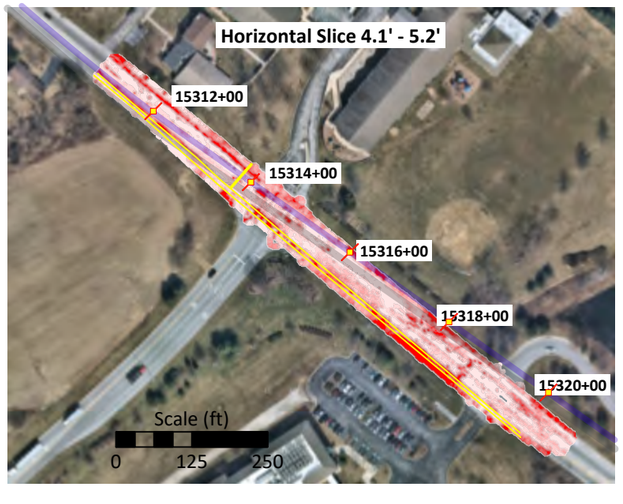


Horizontal Slice 0.8' - 2.0'



Horizontal Slice 2.4' - 3.6'

Horizontal Slice 4.1' - 5.2'



Legend

- Gas Line (observed with GPR)
- 16" Pipeline
- 20" Pipeline

Notes:

Basemap image from Nearmap, extracted 8/2019.

Vertical GPR slices from GPR-Slice v7, by Geophysical Archaeometry Laboratory, Inc.

SURVEY DATE:	09/25/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	10/18/2019
SCALE:	see inserts
FIGURE NO.	3 of 4

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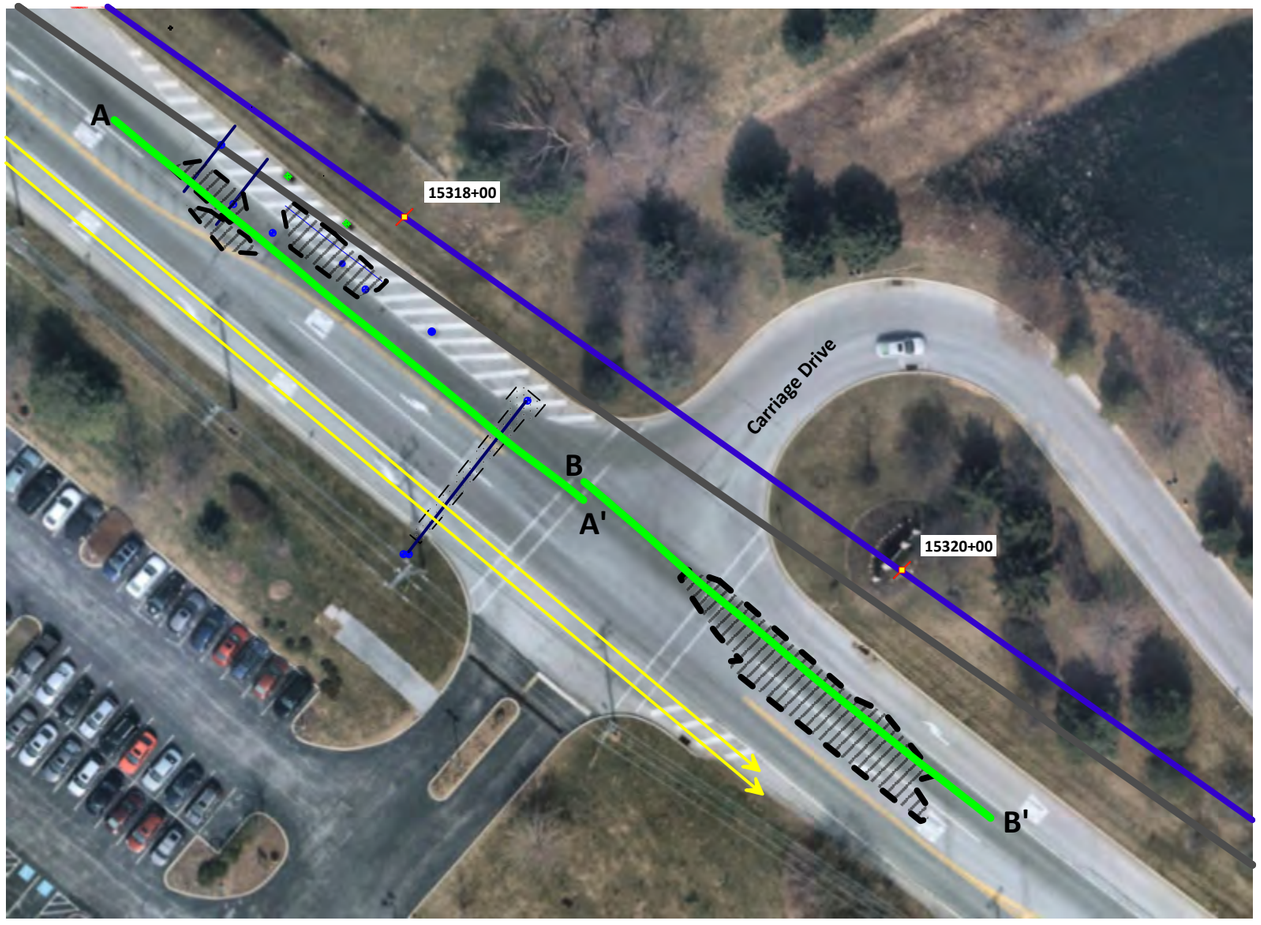
Figure 3: GPR Horizontal Slice Maps

East Boot Road/Greenhill Road
S3-0460

CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP



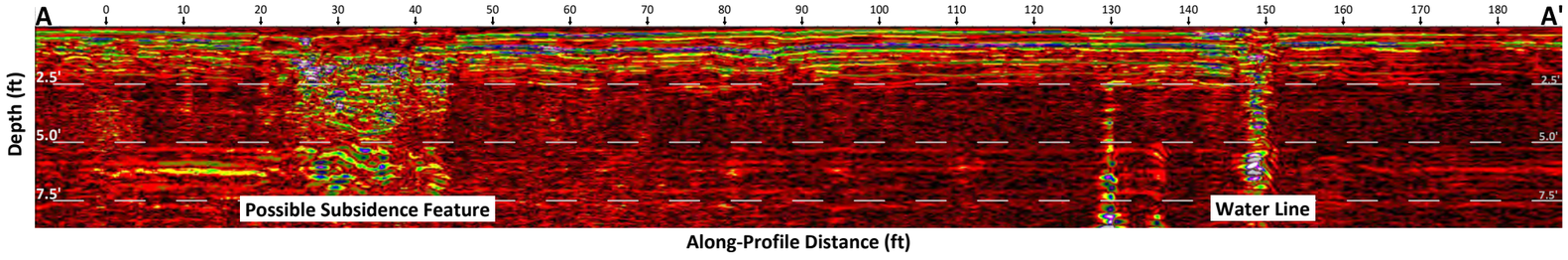
Plan View Scale (ft)

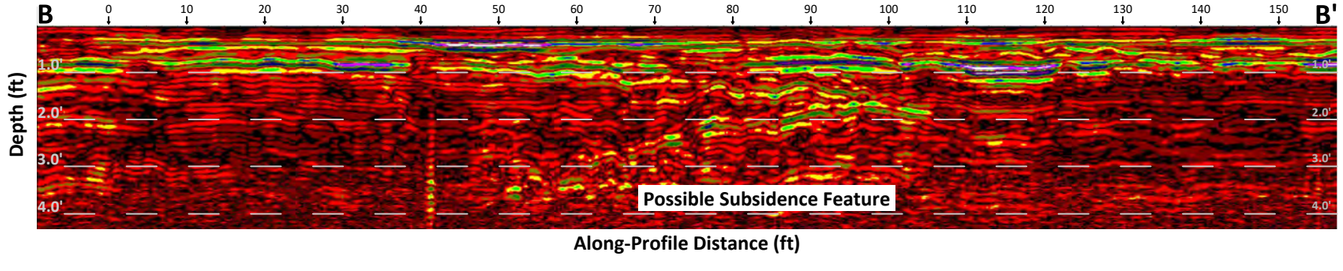
0 25 50 75 100

Legend

- GPR Anomalous Features (Possible Subsidence)
- High-Amplitude GPR Signal
- Gas Line (observed with GPR)
- Water Line (observed with GPR)
- Manhole - Water
- Manhole - Storm
- Manhole - Unknown
- Water Valve
- Stormwater Inlet
- 16" Pipeline
- 20" Pipeline

N





Notes:

Basemap image from Nearmap, extracted 8/2019.

GPR data from GSSI System, 300/800 MHz antenna with RTK-GPS.

Vertical profiles from Radan by GSSI. Hoizontal slice from GPR-Slice by Geophysical Archaeometry Laboratory, Inc.

SURVEY DATE:	09/25/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	10/18/2019
SCALE:	1" = 50'
FIGURE NO.	4 of 4

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Figure 4: Data Summary Map

East Boot Road/Greenhill Road
S3-0460

CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP

ATTACHMENT 1

June 2019 S3-0460 Boot Road GPR Survey at Wilson Drive Report

RETTEW ENVIROSCAN

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Engineers
Environmental Consultants
Surveyors
Landscape Architects
Safety Consultants
Geophysicists

July 29, 2019

Mr. Larry J. Gremminger
Sunoco Pipeline, LP
535 Fritztown Road
Sinking Spring, PA 19608

RE: Geophysical Survey
Sunoco Pipeline, LP Pipeline Project
250-Foot Section of Boot Road Centered on 460 HDD Saw-cut Location
East Goshen Township, Chester County, PA
RETTEW Project No. 096303003

Dear Mr. Gremminger:

RETTEW Field Services, Inc. completed a multi-technique geophysical survey along a 250-foot section of the S3-0460, Greenhill Road horizontal directional drill (HDD) site. The purpose of the survey was to detect and delineate subsurface voids or low-density zones adjacent to an HDD path where a recent inadvertent return (IR) occurred through a saw-cut in the asphalt. The following report, figures, and attachments describe the methods and results of the investigation.

EXECUTIVE SUMMARY

The multi-technique geophysical survey was completed on June 22, 2019. Three different geophysical techniques were utilized to detect and delineate subsurface voids or low-density zones beneath the roadway. The survey identified features characteristic of low-density soils and possible bedrock fractures which are described below:

- Microgravity delineated subsurface low-density zones in several areas. These zones could represent air-, water-, or mud-filled voids, or locally deeper rock/thicker soils.
- Seismic Refraction and Multi-spectral Analysis of Surface Waves (MASW) techniques confirmed the presence of bedrock low-velocity zones that are characteristic of fracture zones.
- Ground Penetrating Radar (GPR) scanning detected several underground utilities (previously marked by others on the surface) as well as an anomalous area of high-amplitude GPR reflectors characteristic of disturbed soils between two water lines, and another adjacent to the water line in the saw-cut area.

Results from the survey techniques are consistent with each other, suggesting that the local bedrock may be fractured. In addition, there is evidence of movement of material in the shallow utility trenches.

SITE DESCRIPTION

The S3-0460, Greenhill Road HDD is located at the intersection of East Boot Road and Carriage Drive in Chester County, Pennsylvania (see **Figure 1**). A geophysical survey was conducted within the 250-foot accessible portions of the east- and west-bound lanes of Boot Road, which parallels the HDD alignment (see **Figure 2**). The west-bound lane portion of the geophysical survey could not be centered on the

saw-cut location due to its proximity to the Carriage Drive intersection, which could not be shut down for the geophysical survey. Portions of each lane of Boot Road were closed for approximately four hours.

The site bedrock geology consists of the Glenarm Wissahickon Formation, with the contact between ultramafic rocks (serpentinite) a few hundred yards to the southeast (see **Figure 2**, inset). This unit, formerly mapped as part of the Wissahickon Formation, is a metamorphic mica-schist that is probably lower Paleozoic in age (Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, compilers, 1980).

MICROGRAVITY SURVEY

Microgravity meters are capable of detecting and measuring very small local variations in gravity. Several factors can locally affect the force of gravity. One factor is the local density or mass distribution of the bedrock or soils beneath the meter. Gravity highs (mass excesses) commonly represent locally shallow bedrock pinnacles or float blocks in the soil profile or zones of particularly massive bedrock. Gravity lows (mass deficiencies) may represent locally deep bedrock cutters or clay seams where soil displaces bedrock; air-, water- or mud-filled voids within bedrock; stoping voids in the soil above bedrock; or zones where soils have been made less dense by removal of fines. Specific microgravity survey parameters are listed in **Appendix A**.

The resulting residual microgravity data are shown on **Figure 3**. The values depict the general plan-view shallow mass distribution beneath the survey area. Lower values (red) represent local mass deficiencies (air- or clay-filled voids or deeper soils), and higher values (blue) represent local mass excesses (bedrock highs or float blocks).

SEISMIC MASW AND REFRACTION SURVEY

Seismic MASW and refraction methods utilize the speed of seismic waves through various geologic layers and features to characterize subsurface conditions. The methods enable determination of the approximate depth to bedrock or rock profile, and variations in soils and rock stiffness. MASW can detect low velocities below the top of rock that might be associated with fracture zones. The principles of seismic refraction are summarized in **Appendix B**.

The seismic survey consisted of two profiles along the microgravity profiles (see blue triangles representing each geophone, **Figure 2**). Color-contour velocity models of the seismic velocity for refraction and MASW are presented on **Figure 4;** refraction on the upper profiles and MASW on the lower profiles. On each, the vertical scale represents relative elevation in feet, and the horizontal axis represents an along-profile distance in feet. The color contours represent variations for compressional or primary (P) wave velocities for refraction, and shear or secondary (S) wave velocities for MASW. Increasing velocities grade from blue to yellow to orange to brown (refraction), and purple to grey to tan to brown (MASW). Please note that high- and low-velocity data along the first and last fifteen feet of any profile have higher uncertainty. Specific seismic refraction and MASW survey parameters are listed in **Appendix A.**

GPR SURVEY

A GPR survey was completed using a GSSI GPR digital controller and dual frequency 300/800 MegaHertz (MHz) scanning antenna. GPR systems produce cross-sectional images of subsurface features and layers by continuously emitting pulses of radar-frequency energy from a scanning antenna as it is towed along a survey profile. The radar pulses are reflected by interfaces between materials with differing dielectric properties. The reflections return to the antenna are displayed on a video monitor as a continuous cross

section in real time. Since the electrical properties of air and clay mud are distinctly different from undisturbed soils, such features produce characteristic reflections. In particular, air and mud typically produce very high-amplitude, characteristically reverberating reflections.

GPR scanning was performed along the microgravity/seismic survey profiles, as well as several additional parallel transects (see **Figure 2**, red lines). The long parallel profiles were recorded for post-processing and are presented on **Figure 5**. The vertical scale represents approximate depth in feet below grade while the horizontal scale is along-profile distance in feet as measured by a high-precision (sub-millimeter) survey wheel that also triggered the GPR pulses. The colors represent relative amplitude of the GPR signal. Shades of white indicate the highest amplitude. During set-up and calibration, and following scanning of the profiles in **Figures 5** and **6**, additional variously-oriented radar profiles were examined in real time (but not recorded) to identify and delineate high-amplitude reverberating anomalies of the type commonly associated with suspected air- or mud-filled voids. Specific GPR survey parameters are listed in **Appendix A.**

RESULTS

The microgravity data are depicted on **Figure 3** as colored dots representing the relative density of the subsurface, with blue for high-density, green for "site normal," and red for locally low-density areas. The microgravity results delineated several low-density areas beneath the survey grid. Low density (red) represents low-density soils or possible "missing" rock and soils, while blue represents intact bedrock or float material, or compacted soils. A minor low-density reading was detected around the location of the IR; however, it is very laterally restricted, indicating that it is not extensive.

The seismic refraction data are presented as cross-sectional profiles on **Figure 4** and indicate a general two-layer stratigraphy consisting of residual soil mantle over bedrock. The uppermost layer has average P-wave velocities generally less than 5,000 feet per second (fps) with a thickness of approximately 25-35 feet. This is consistent with the residual clay soil mantle or deeply weathered bedrock (shaded blue to yellow). The deepest layers have velocities over 10,000 fps (shaded orange to brown) consistent with competent crystalline bedrock (Carmichael, R. S., 1989). The area between roughly the 5,000 and 10,000 fps contours represents a suspected weathered bedrock zone or saprolite transitioning from soil to bedrock.

The seismic refraction results show several locations where the competent bedrock surface is depressed, possibly indicative of deeper weathering along fractures. The suspected fracture zones are highlighted in magenta on the seismic profiles.

The MASW seismic cross sections are presented on **Figure 4,** lower profiles. The MASW velocity models show velocity changes within the bedrock layer across the profiles that are relatively consistent with the seismic refraction. Velocity lows below the bedrock surface could indicate fractures; these zones are highlighted on the cross sections.

The GPR results show multiple high-amplitude reflectors across the survey area. Most of the reflections are associated with the numerous underground utility lines beneath the survey area. An area beneath the west-bound lane, between two suspected water lines, shows high-amplitude reflectors, including downward-dipping reflectors. This reflection pattern (circled on Profiles 7, 8 and 9, in **Figure 5**) is characteristic of settlement or subsidence. These anomalies are between two water lines. A smaller area of high-amplitude reflectors observed in the eastbound lane along Profile 12 is also adjacent to a water

line in the saw-cut area (**Figure 5**). These results suggest that there has been some settlement of the water line trench materials, and possibly infiltration of the trench materials by outside material; i.e. water from precipitation or the lines themselves, or possibly drilling fluids.

CONCLUSIONS

The geophysical techniques display anomalies indicative of potential fracture zones within the underlying bedrock. **Figure 7** summarizes the geophysical survey results in plan view. The GPR survey indicated two significant anomalous zones, both above seismic anomalous zones and underground utilities, that may be associated with saturated soils (possibly from the nearby utilities). These two areas do not show significant microgravity lows, and neither the microgravity nor GPR data show open voids along the asphalt cut.

Although RETTEW sees no evidence the IR caused any subsurface impacts or subsidence, there are identified anomalies beneath the roadway which may be related to leaks in existing water lines. For safety considerations these anomalies warrant further investigation. RETTEW recommends Sunoco investigate the two GPR anomalous areas identified on **Figures 5, 6,** and **7** by drilling or test pitting to further characterize these anomalous conditions to ensure the anomalies are not resulting from drilling activities.

LIMITATIONS

The survey described above was completed using standard and/or routinely accepted practices of the geophysical industry, and the equipment employed represents, in RETTEW's professional opinion, the best available technology. RETTEW does not accept responsibility for survey limitations due to inherent technological limitations or unforeseen site-specific conditions. We will notify you of such limitations or conditions, when they are identifiable.

Please also note that the survey is based on observation of current subsurface conditions. Therefore, while the results of this survey can be used to guide further investigations, RETTEW cannot make any warranties concerning future subsidence occurrence — particularly under the influence of altered surface and subsurface drainage patterns due to grading and construction activities.

We have enjoyed and appreciated the opportunity to have worked with you. If you have any questions, please do not hesitate to contact the undersigned.

Charles H. Rhine, MSc, PG
Senior Project Manager

Timothy D. Bechtel, PhD, PG
Senior Project Manager

Felicia Kegel Bechtel, MSc, PG
Director of Geophysics

Enclosures

Figure 1: Topographic Basemap
Figure 2: Data Coverage Map and Geologic Setting
Figure 3: Residual Microgravity Results
Figure 4: Seismic Survey Results
Figure 5: GPR Profiles
Figure 6: GPR Profiles with Anomalies
Figure 7: Geophysical Survey Summary
Appendix A: Geophysical Survey Parameters
Appendix B: Introduction to Seismic Refraction

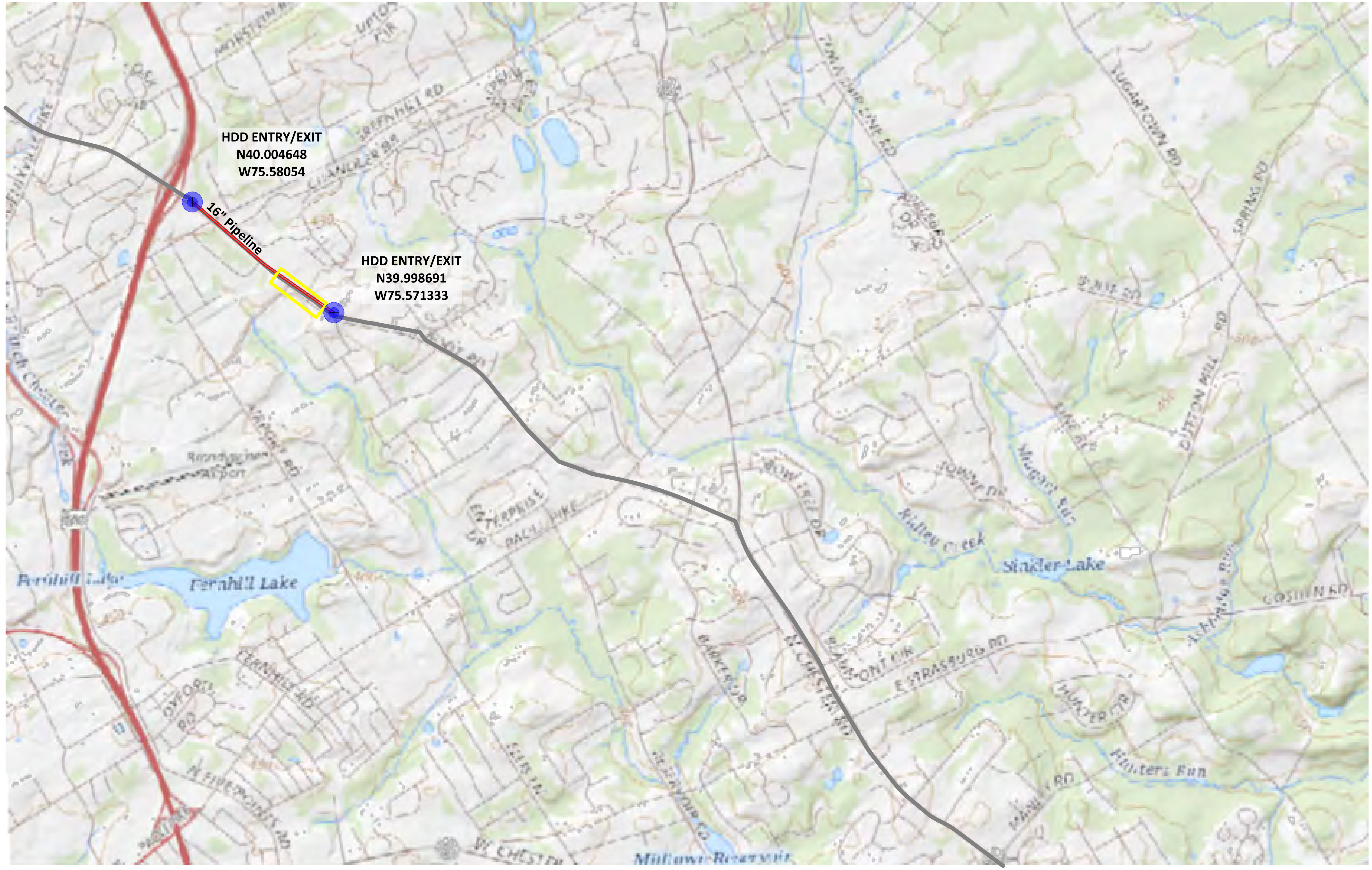
References

Berg, T.M., Edmunds, W.E., Geyer, A.R., and others, 1980, Geologic Map of Pennsylvania, PA Geological Survey, 4th series.

Carmichael, R. S. (1989), Physical Properties of Rocks and Minerals, CRC Press.

Wood, C. R. (1980). Groundwater resources of the Gettysburg and Hammer Creek formations, southeastern Pennsylvania: Pennsylvania Geological Survey, 4th ser. Water Resource Report, 49, 87.

ENCLOSURES



Geophysical Survey Legend

- Proposed 16" HDD Alignment
- Geophysical Survey Area
- HDD Entry/Exit Point

Scale (ft)

0 1000 2000 3000 4000

Notes:

Basemap extracted from USGS US Topographic WMS Server, extracted 01/2019.

SURVEY DATE:	06/22/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	07/18/2019
SCALE:	1" = 2000'
FIGURE NO.	**1 of 7**

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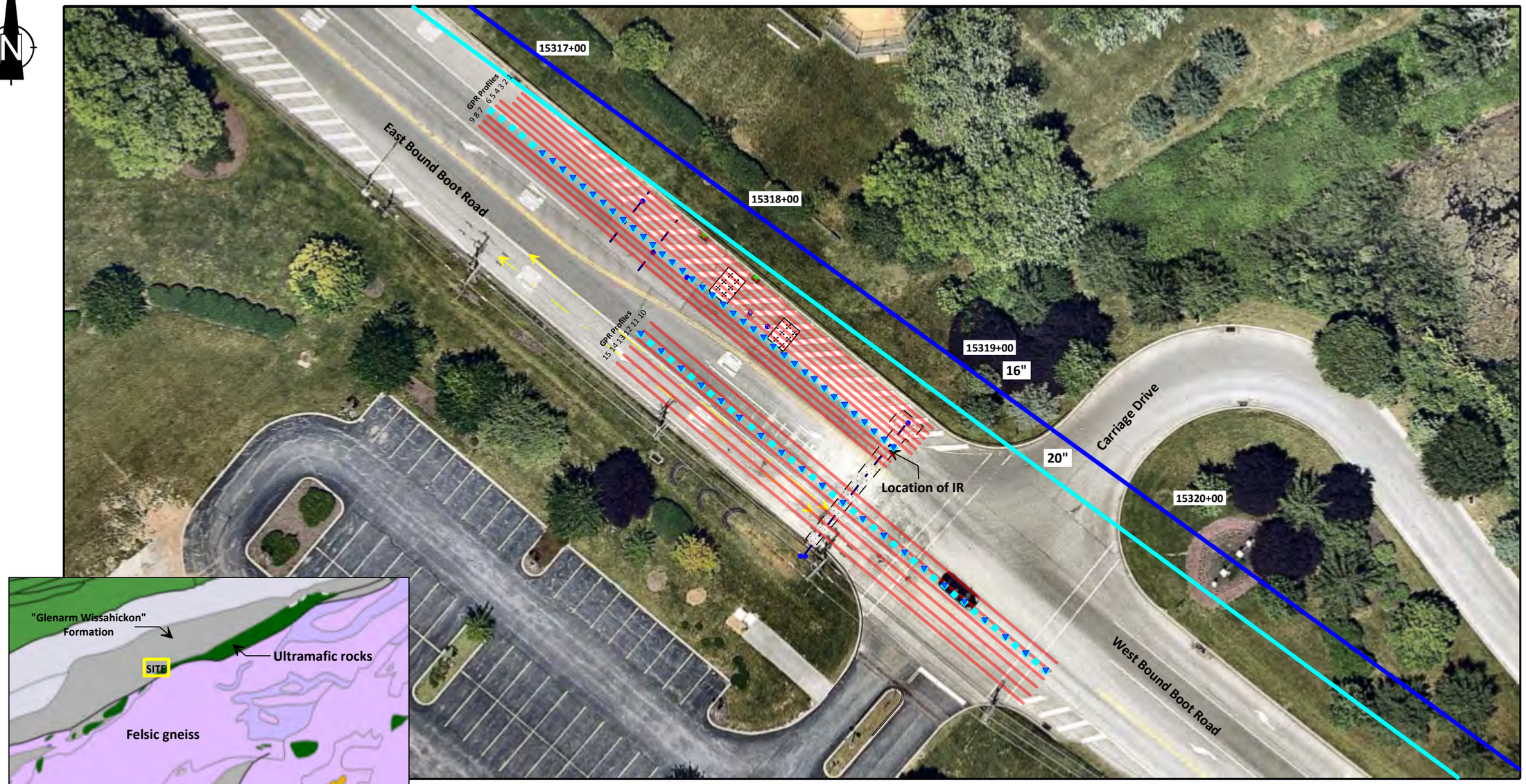
3020 Columbia Avenue, Lancaster, PA 17603
Phone 1-800-738-8395

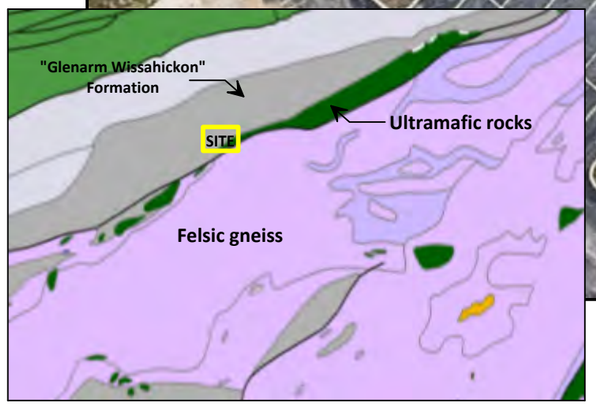
Figure 1: Topographic Basemap

East Boot Road/Greenhill Road
S3-0460

EAST GOSHEN TOWNSHIP
CHESTER COUNTY, PA

Data Coverage Map





Geologic Setting

Geophysical Survey Legend

- GPR Profile Line
- Microgravity Survey Station
- Seismic Geophone Location
- Proposed 16" Alignment
- Proposed 20" Alignment
- Gas Lines (marked by others)
- Excavation Pits (Metal Covers)
- Water Valves
- Saw-cut Area
- Water Lines

Scale (ft): 0 20 40 60 80

Notes:

Basemap from Nearmap on June 9, 2019.

Survey profiles/stations from DGPS survey by RETTEW.

Geologic information from DCNR WMS Server, extracted 11/2018, and Wood (1980).

SURVEY DATE:	06/22/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	07/18/2019
SCALE:	1" = 40'
FIGURE NO.	2 of 7

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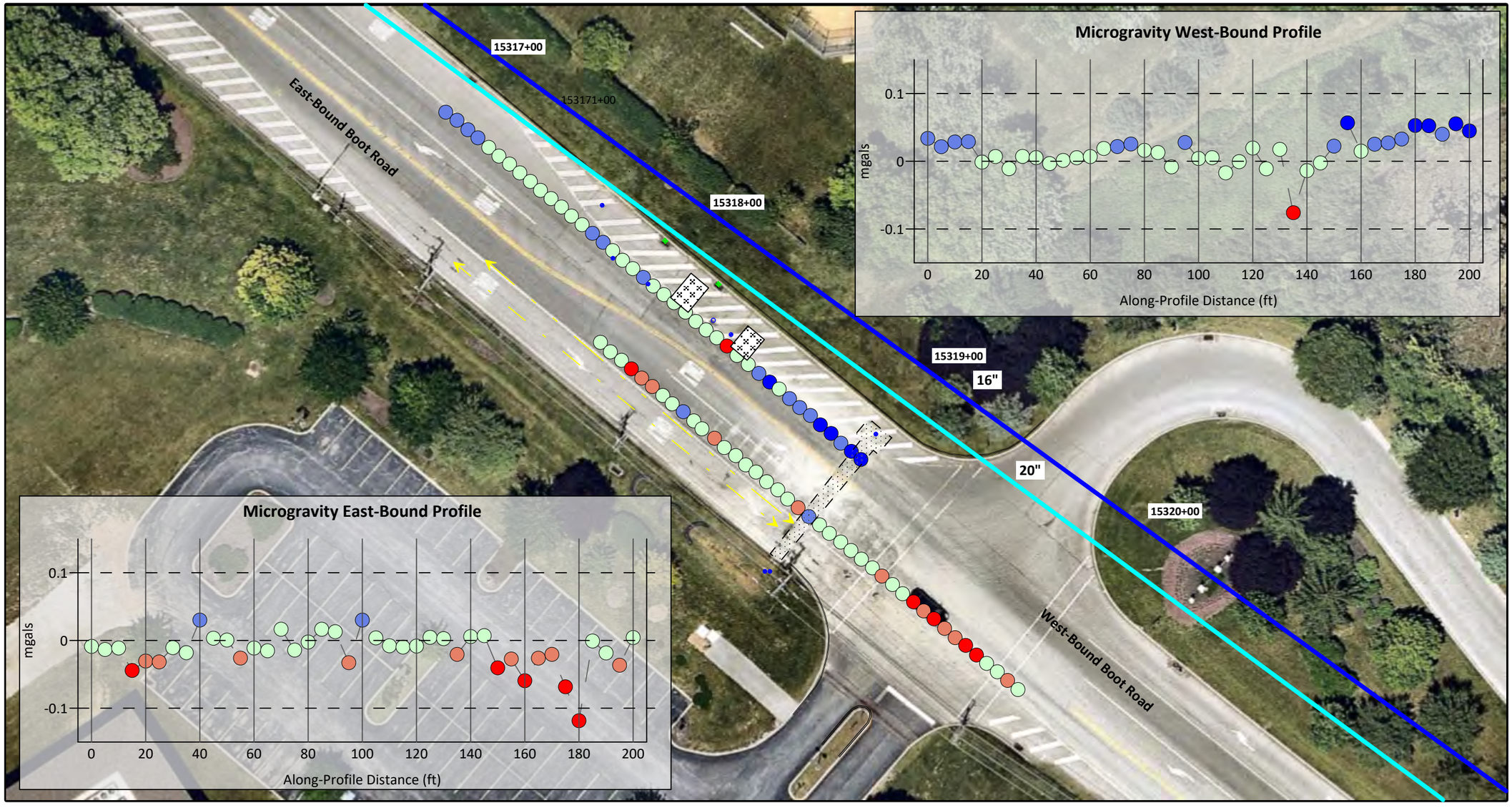
Figure 2: Data Coverage Map and Geologic Setting

East Boot Road/Greenhill Road
S3-0460

CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP

Residual Gravity Results



Classed Post-Microgravity
- -0.12 mgals to -0.04 mgals
- -0.04 mgals to -0.02 mgals
- -0.02 mgals to 0.02 mgals
- 0.02 mgals to 0.04 mgals
- 0.04 mgals to 0.12 mgals

Geophysical Survey Legend

- Microgravity Survey Station (color-coded)
- Proposed 16" Alignment
- Proposed 20" Alignment
- Gas Lines (marked by others)

Scale (ft)
0 20 40 60 80

Notes:

Basemap from Nearmap on June 9, 2019.

Microgravity data from Scintrex CG-5 gravimeter, with Bouguer correction.

SURVEY DATE:	06/22/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	07/18/2019
SCALE:	1" = 40'
FIGURE NO.	3 of 7

RETTEW ENVIROSCAN
RETTEW Field Services, Inc.
3020 Columbia Avenue, Lancaster, PA 17603
Phone 1-800-738-8395

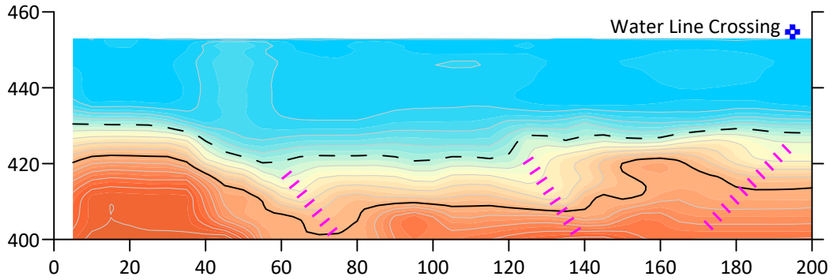
Figure 3: Residual Microgravity Results

East Boot Road/Greenhill Road
S3-0460

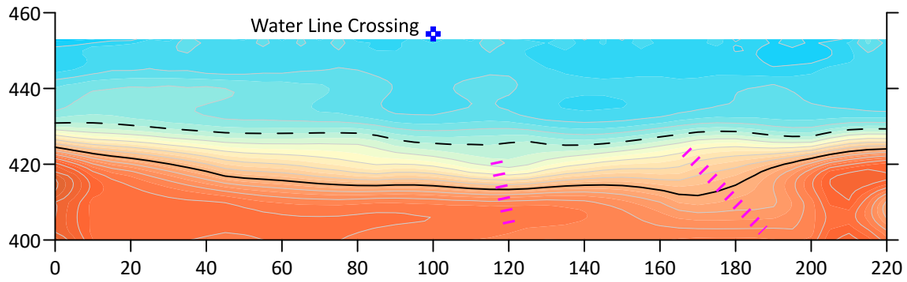
CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP

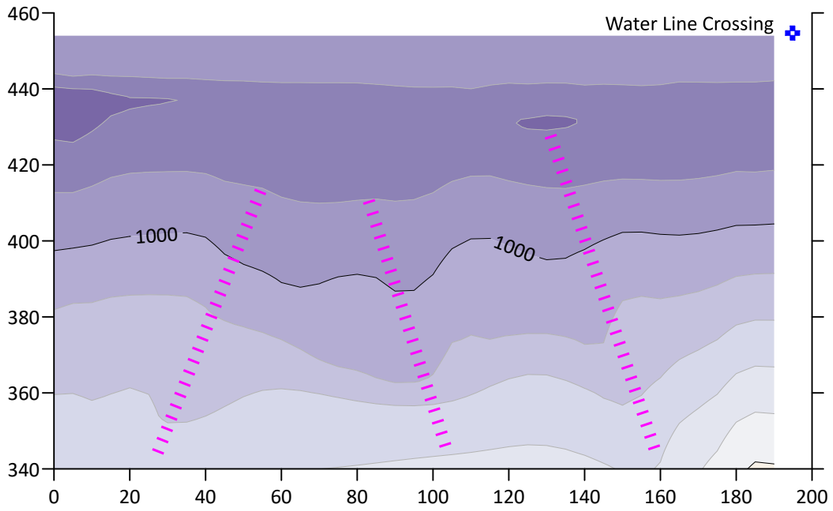
Seismic Refraction West-Bound Profile



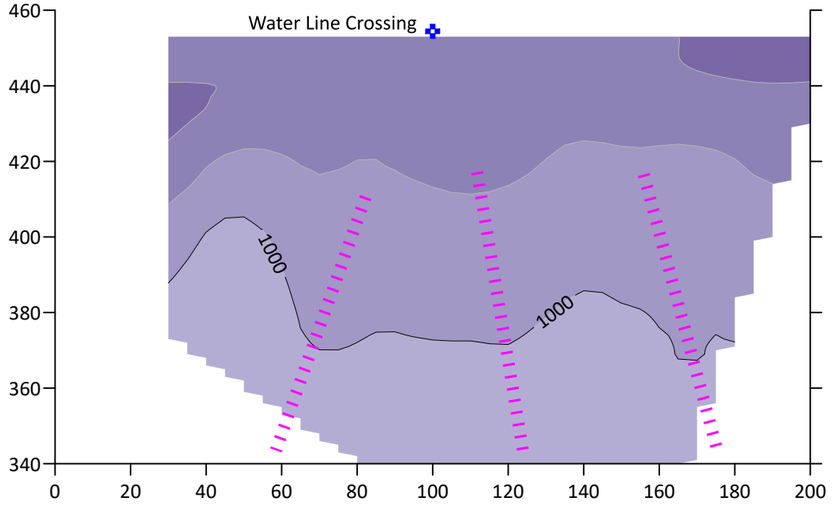
Seismic Refraction East-Bound Profile



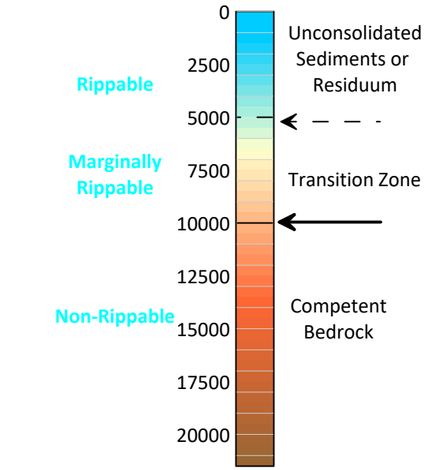
Seismic MASW West-Bound Profile



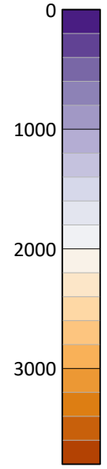
Seismic MASW East-Bound Profile



Relative P-Wave Velocity (fps)



Relative S-Wave Velocity (fps)



Weighted Average Velocity
(Trg)

V_1 = 1,939 fps

V_2 = 9,429 fps

Geophysical Survey Legend

Possible Fracture Zone

Proposed 16" HDD

11627+00 Station Number

Notes:

Seismic data from Geometrics 24-channel Geode with 4.0 Hz geophones.

Relative seismic velocity models from SeisImager (by Oyo Corporation) tomographic and ReMi inversions.

SURVEY DATE: 06/22/2019
RETTEW No.: 096303003
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 07/18/2019
SCALE: 1" = 2000'
FIGURE NO. 4 of 7

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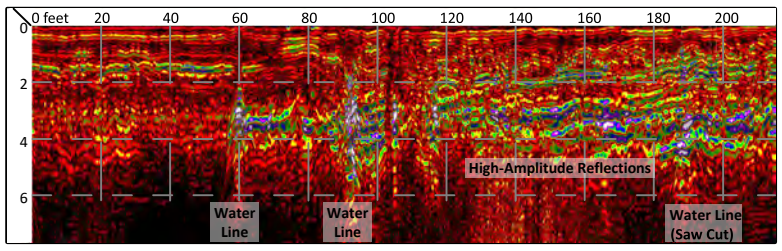
Figure 4: Seismic Survey Results

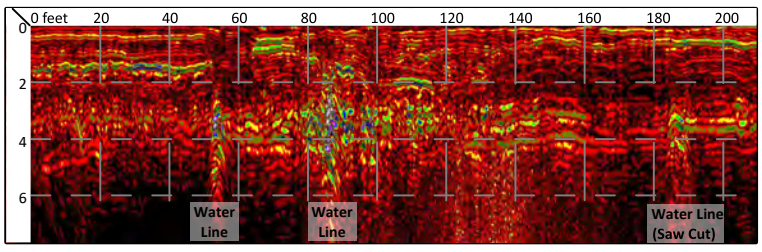
East Boot Road/Greenhill Road
S3-0460

CHESTER COUNTY, PA
EAST GOSHEN TOWNSHIP

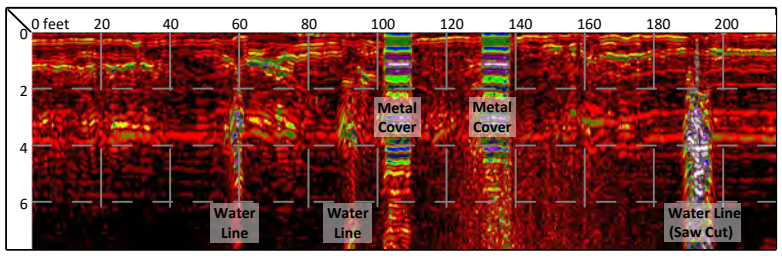
Westbound Lane - Profile 1



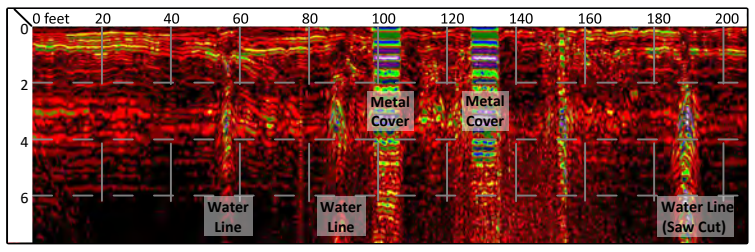
Westbound Lane - Profile 2



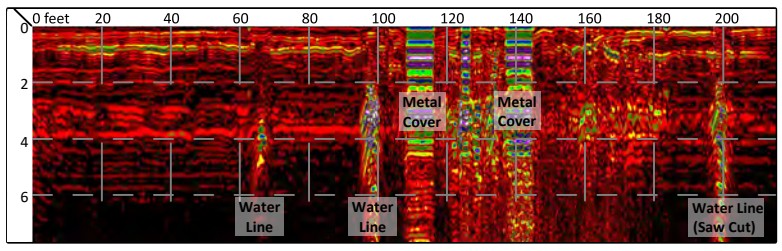
Westbound Lane - Profile 3



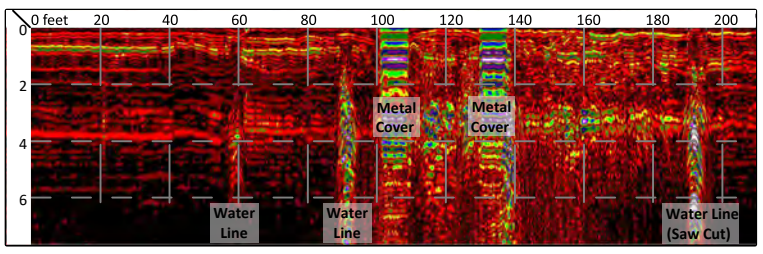
Westbound Lane - Profile 4



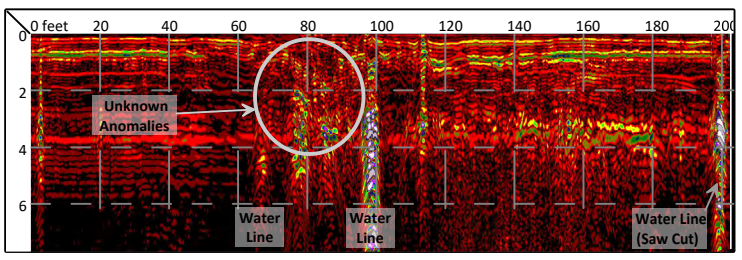
Westbound Lane - Profile 5



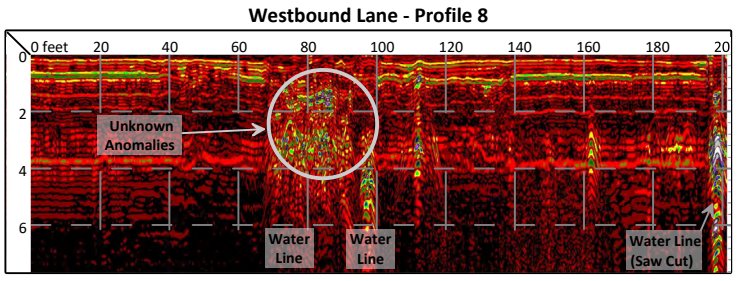
Westbound Lane - Profile 6



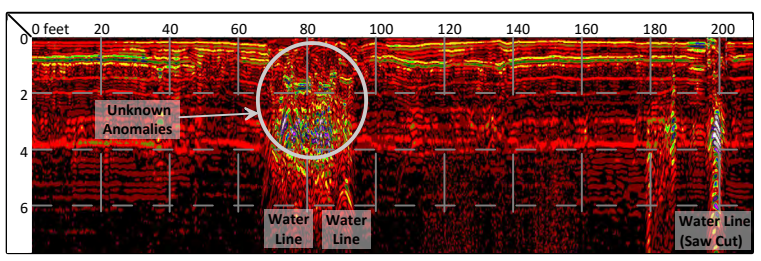
Westbound Lane - Profile 7



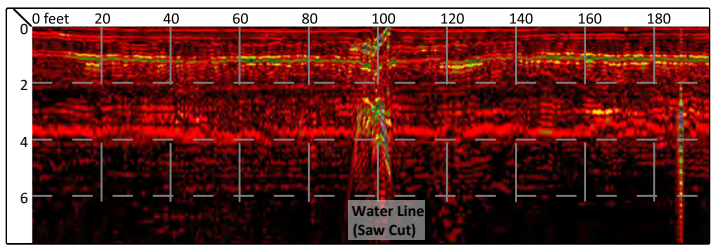
Westbound Lane - Profile 8



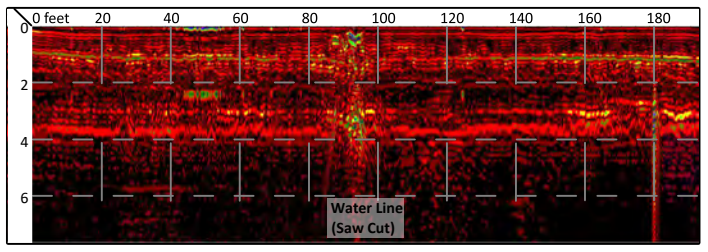
Westbound Lane - Profile 9



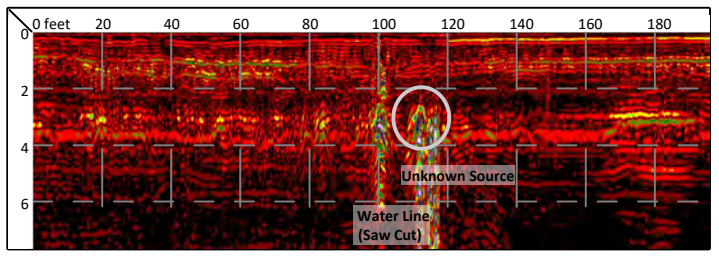
Eastbound Lane - Profile 10



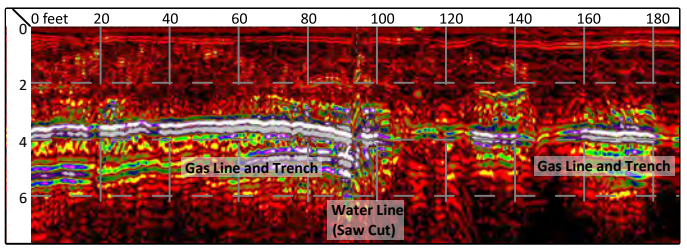
Eastbound Lane - Profile 11



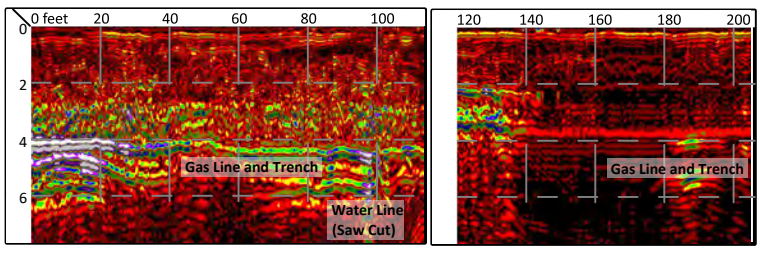
Eastbound Lane - Profile 12



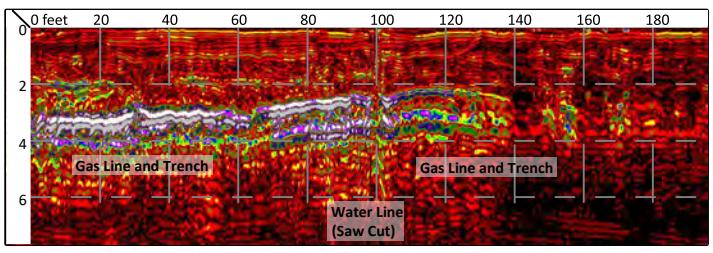
Eastbound Lane - Profile 13



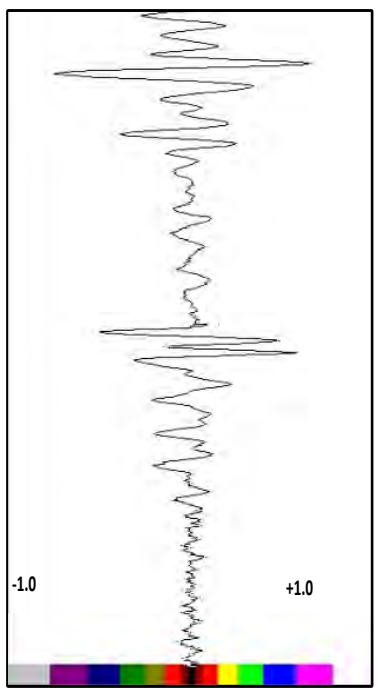
Eastbound Lane - Profile 14



Eastbound Lane - Profile 15



Relative GPR Signal Amplitude



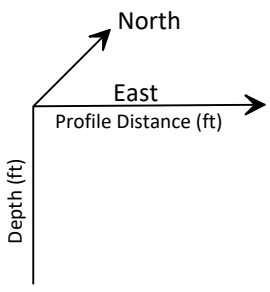


Figure 5: GPR Profiles

East Boot Road/Greenhill Road
S3-0460

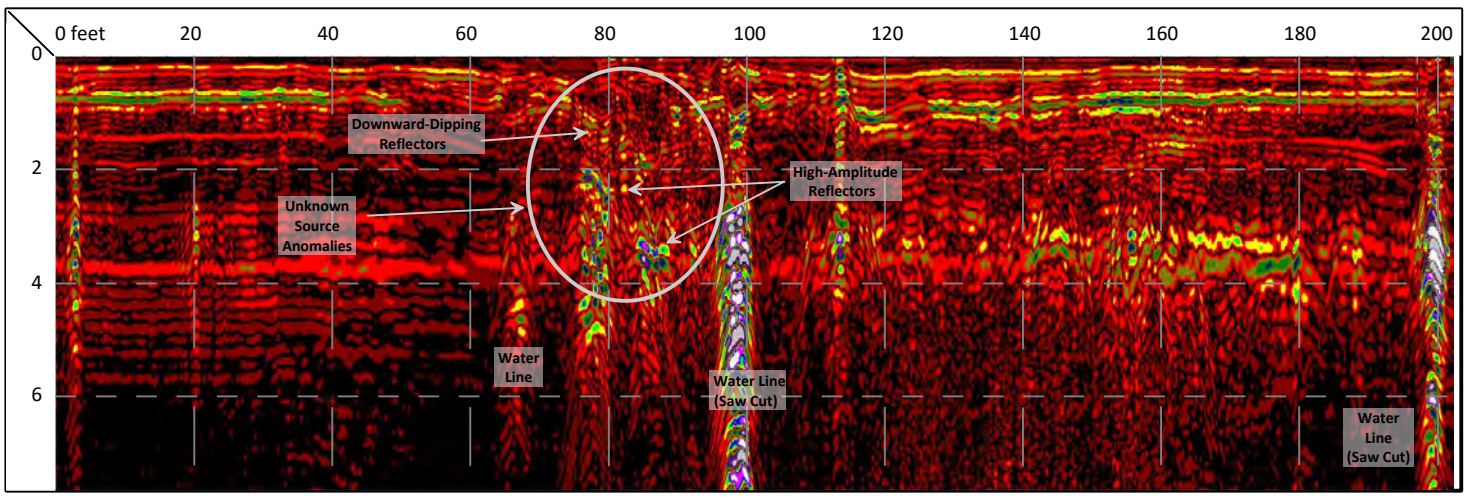
EAST GOSHEN TOWNSHIP

CHESTER COUNTY, PA

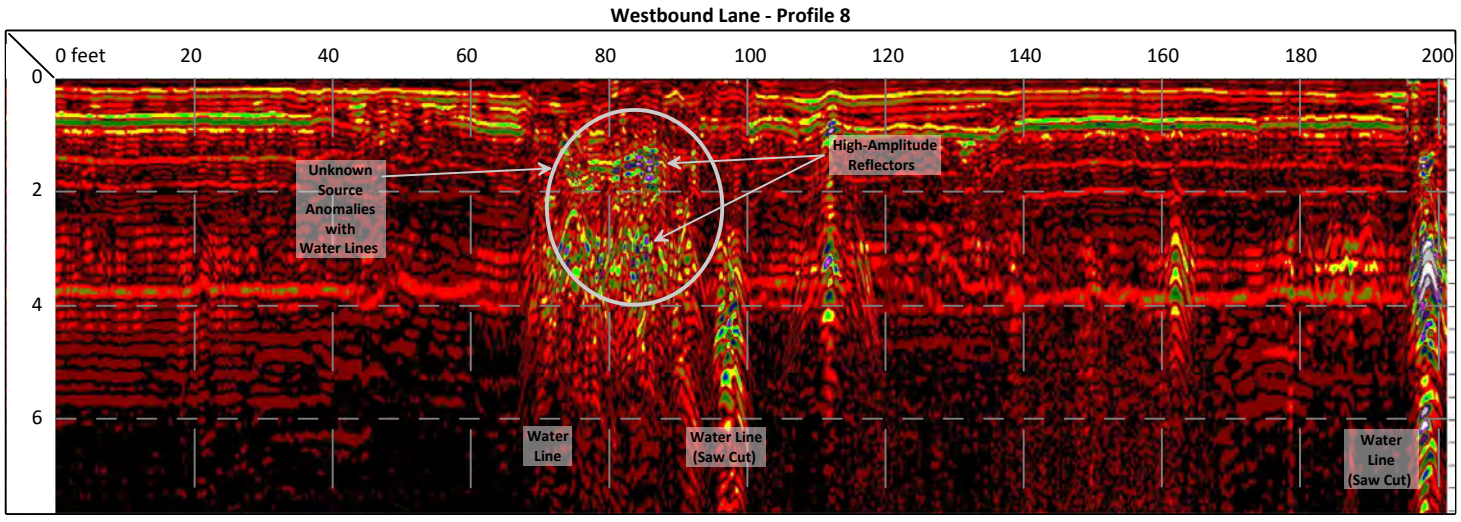
RETTEW Field Services, Inc.
3020 Columbia Avenue, Lancaster, PA 17603
Phone 1-800-738-8395

SURVEY DATE:	06/22/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	07/18/2019
SCALE:	see profiles
FIGURE NO.	5 of 7

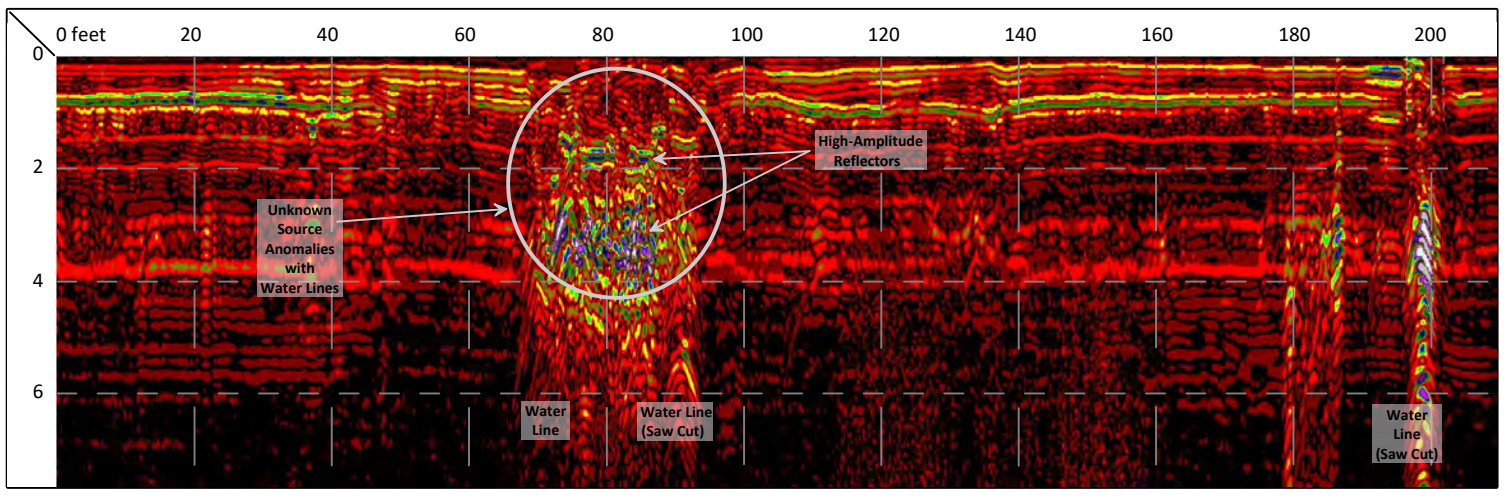
Westbound Lane - Profile 7



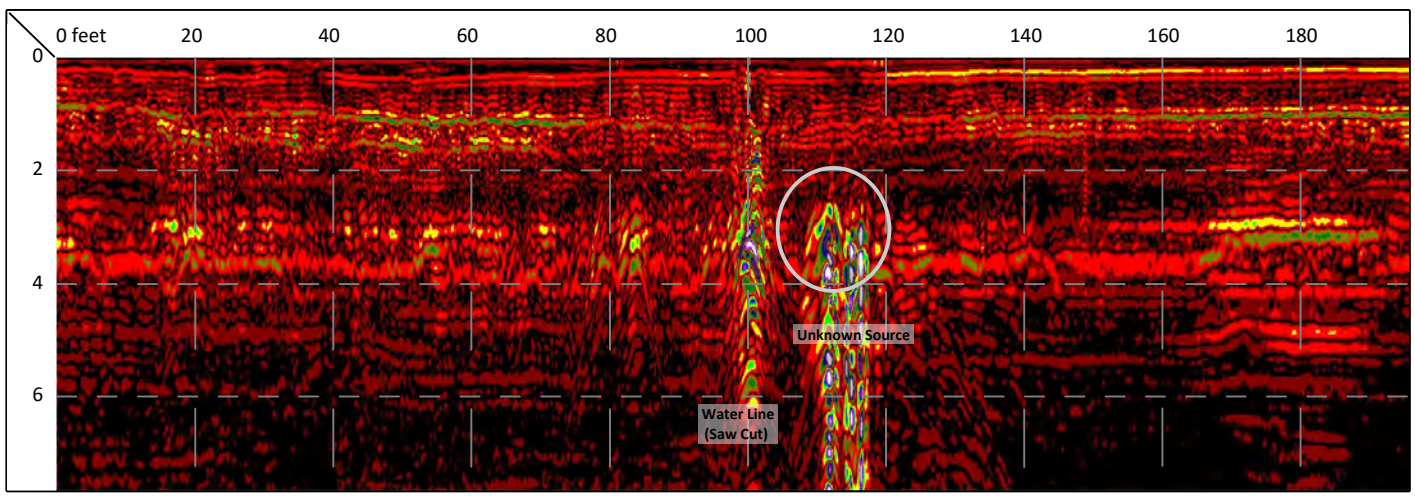
Westbound Lane - Profile 8



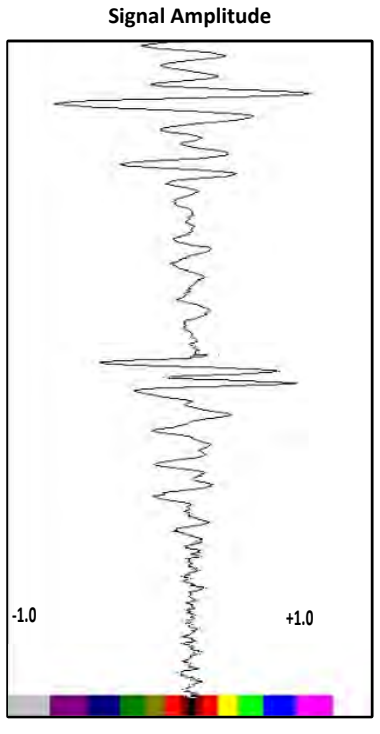
Westbound Lane - Profile 9



Eastbound Lane - Profile 12



Relative GPR Signal Amplitude



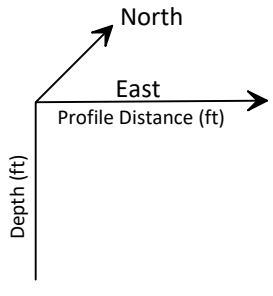


Figure 6: GPR Profiles with Anomalies

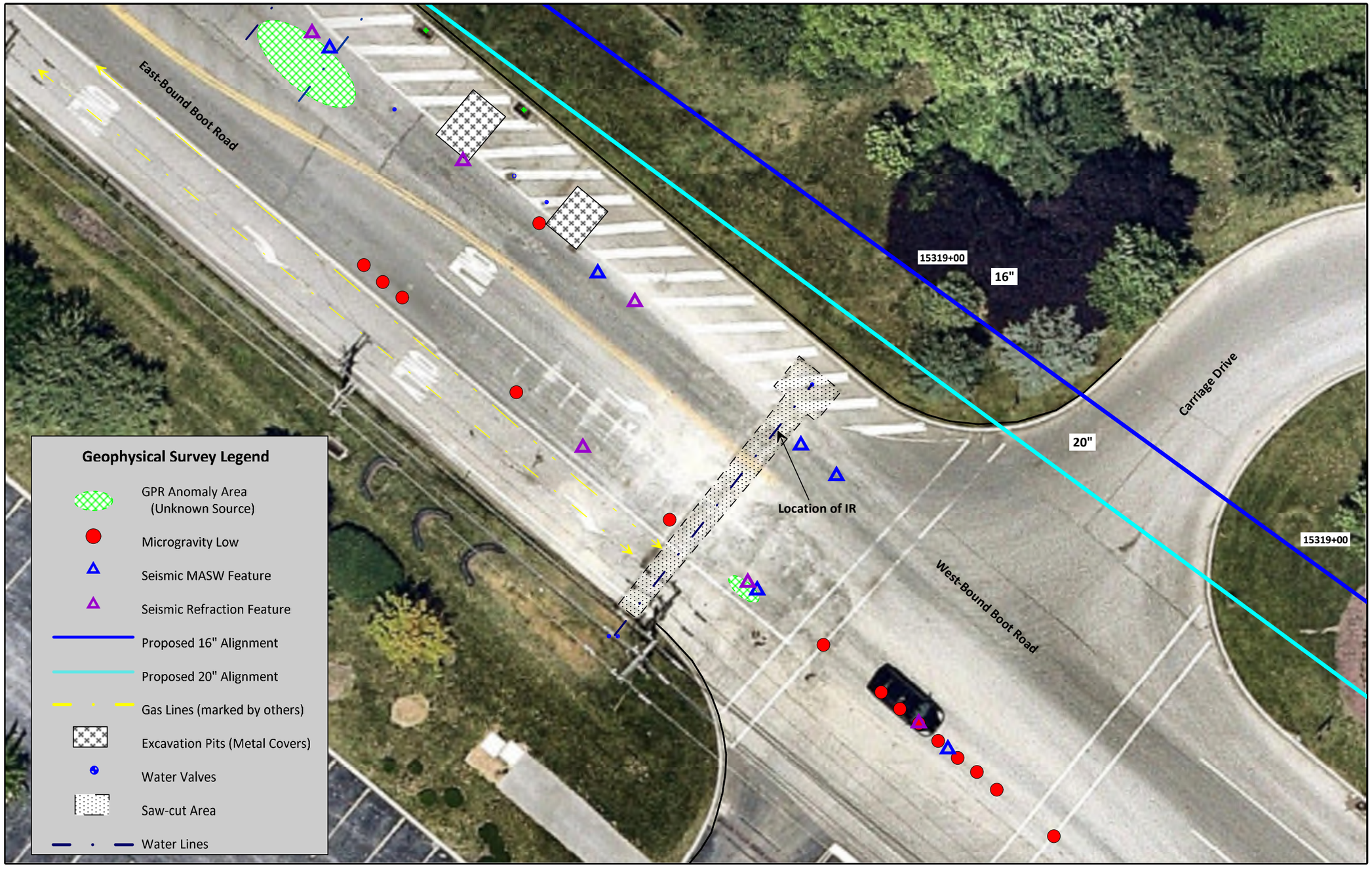
East Boot Road/Greenhill Road
S3-0460

EAST GOSHEN TOWNSHIP

CHESTER COUNTY, PA

RETTEW Field Services, Inc.
3020 Columbia Avenue, Lancaster, PA 17603
Phone 1-800-738-8395

SURVEY DATE:	06/22/2019
RETTEW No.:	096303003
REVIEWED BY:	FKB
DRAWN BY:	CHR
DATE:	07/18/2019
SCALE:	see profiles
FIGURE NO.	6 of 7



Notes:

Basemap from Nearmap on June 9, 2019.

Anomalous features based on geophysical survey; see RETTEW report for details.

Scale (ft)

0 10 20 30 40

SURVEY DATE: 06/22/2019
RETTEW No.: 096303003
REVIEWED BY: FKB
DRAWN BY: CHR
DATE: 07/25/2019
SCALE: 1" = 20'
FIGURE NO. 7 of 7

ENVIROSCAN

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Figure 7: Geophysical Survey Summary

East Boot Road/Greenhill Road
S3-0460

CHESTER COUNTY, PA

EAST GOSHEN TOWNSHIP

APPENDIX A

Geophysical Survey Parameters

Geophysical Survey Parameters -- Greenhill Road

	Spacing[1] (feet)	Shot Interval[2] (feet)	Offset[3] (feet)	Spread Length[4] (feet)	Array Type	Effective Depth[5] (feet)	Lateral Resolution[5] (feet)	Vertical Resolution[5] (percent)	System
Seismic Refraction	5/10	20/40	20	200		40	5/10	15	**Geometrics Geode**
Seismic MASW	5/10	5	20	200		60	5/10	25	**Geometrics Geode**
GPR	continuous		3		300/800	depends on soil	depends on depth	5	**GSSI SIR-4000**
MicroGravity	5		20			size-depth trade-off	depends on depth	depends on depth	**Scintrex CG-5**

[1] geophone, electrode, or station

[2] Seis (27-lb slidehammer source)

[3] distance between parallel profiles

[4] Seis

[5] rule-of-thumb only (most depend on site-specific soil properties, sampling interval, depth, and target dimensions)

APPENDIX B

Introduction to Seismic Refraction

RETTEW
3020 Columbia Avenue, Lancaster, PA 17603 ● Phone: (800) 738-8395
E-mail: rettew@rettew.com ● Website: rettew.com

INTRODUCTION TO SEISMIC REFRACTION

BY TIMOTHY D. BECHTEL, PHD, PG

ENERGY

Mechanical elastic (seismic) waves generated by a hammer blow, weight drop, or explosion.

SENSITIVITY

Sensitive to elastic properties or moduli – generally strongly correlated with density.

BASIC EQUIPMENT

Recording Seismograph (generally 24 or more channels); Geophones (one for each channel); Geophone cable; Hammer or weight plus strike plate or explosives; Trigger switch.

COMMON APPLICATIONS

Determination of the depth and dip of soil horizons and bedrock surfaces. Recent processing advances allow some detection and delineation of discrete targets.

PRINCIPLES

In a uniform isotropic earth, the shock wave from a blow or explosion at the surface travels outward and downward in a hemispherical wave front like a three-dimensional ripple from a pebble in a still pond. At any point on the wave front, a straight line from the shock source to the wave front depicts the path of the seismic wave and is called a ray path (see **Figure SR-1**). In reality, there are several independent shock waves; the fast-moving primary, compressional or P wave front; the slower moving secondary, shear or S wave (both of which form hemispherical wavefronts); and several disk-like wave fronts that travel only along the surface of the earth (called surface waves or ground roll). For the purposes of most seismic refraction surveys, only the fastest moving wave front — the P wave — is considered. S-wave refraction is used in selected circumstances where complete determination of elastic moduli is desired – particularly when it may be desirable to eliminate the effects of water saturation.

In a layered earth, the hemispherical P shock wave defined by the radially distributed P ray paths are deflected according to the laws of optics (Snell's Law) at interfaces between materials with differing seismic velocities (i.e. densities or elastic properties). Figure SR-2 depicts the deflection of ray paths due to an increase in P velocity at a bedding plane. The type of deflection that a ray path will undergo is dependent upon the angle at which it strikes the interface, and falls into one of four categories:

Some direct rays (green in **Figures SR-2** and **SR-3**) travel parallel to the ground surface at the seismic velocity of the upper layer, do not strike the underlying interface, and consequently are not deflected.

Reflected rays (purple in **Figures SR-2** and **SR-3**) arise where direct rays strike the interface, and a portion of the energy is reflected symmetrically back towards the surface.

The portion of the energy of the incident direct wave that is not reflected upward is refracted or bent as it crosses the interface – making refracted waves in the lower layer (red in **Figures SR-2** and **SR-3**).

At a precise angle called the critical angle, the incident ray is refracted directly along the interface, and travels at the higher seismic velocity of the lower layer (see Critically Refracted Wave in **Figure SR-3**). As this critically refracted or head wave races along beneath the interface, it generates a secondary elastic disturbance that travels back to the surface along ray paths that define a wave front analogous to the bow wake of a ship. These returning rays again travel at the slower velocity of the upper layer.

To perform a refraction survey, a linear array of ground motion sensors or geophones is spaced out from the seismic source or shot point, forming a geophone spread. Each geophone is connected to a separate channel in a seismograph which records a wiggle trace representing the ground motion resulting from the passage of the various seismic rays.

As depicted in the time-distance (T-X) curve in Figure SR-4, the layered earth structure can be determined by analyzing the seismographic wiggle traces. At distances close to the seismic source, the first wiggle or ground motion (the first arrival after the shot) is due to passage of the direct wave travelling at the velocity of the upper layer. Reflected waves arrive later since they have by definition traveled a greater distance at the same velocity (additional later wiggles are caused by passage of the more slowly travelling S and surface waves). Beyond a distance dictated by the critical angle, the first arrival of seismic energy represents the head wave of the critically refracted ray. These refracted rays also by definition travel a greater distance than the direct wave. However, along part of their path, they have traveled at the higher velocity of the underlying more consolidated layer. At greater distances from the shot point, where the path length in the higher velocity layer becomes significant, the head wave arrivals actually race past the direct wave and become the first arrival (see labeled crossover in **Figure SR-4**). By extension, it can be shown that if a third layer with even greater velocity lies at greater depth, the head wave from this layer will become the first arrival at a sufficient distance from the shot point.

In conventional seismic refraction, only the first P wave arrivals can be reliably selected on a wiggle trace record. The later reflected P wave arrivals are generally obscured by the slower-travelling S and surface waves, and the very slow air blast or sound wave from the shot. To interpret a seismic refraction record, the first arrival travel times are measured for each wiggle trace and plotted at the appropriate point on a time-distance (T-X) curve (see Figure SR-4). In a plane-layered earth, these first arrivals define a series of line segments, each representing a discrete layer. The seismic velocity of each layer is simply the reciprocal of the slope of the associated line segment. The thickness of each layer can be calculated from the distances where the line segments intersect. The mathematics for these calculations are easily derived, and can be found in any introductory geophysics text.

True geologic strata are rarely perfectly horizontal. The effect of a dipping interface on a travel time curve cannot be recognized using a single shot point. Calculations based on a T-X curve from a single shot point should always be considered as producing apparent depths to interfaces and apparent seismic velocities for all but the uppermost layer. To determine the true depths and dips of interfaces and the true seismic velocities, it is necessary to reverse the seismic line; that is, move the shot point to a location at or beyond the farthest geophone in the spread, and repeat the shot. The calculation of true depths, dips and velocities from reversed seismic lines is also readily performed.

CAPABILITIES

Conventional seismic refraction can yield accurate measurements of depths and attitudes of soil horizons, groundwater tables, and other relatively distinct and planar strata. Modern computer analysis of multi-fold seismic refraction data (i.e. with many and overlapping shot points) can provide delineation of undulating or even irregular (as opposed to simply planar) interfaces. The latest generation of computer processing techniques require very high-fold data, but in favorable conditions, are capable of resolving even discrete targets such as foundation elements, tunnels or cavities, and can resolve gradational boundaries as well as distinct interfaces. The seismic P-wave velocities of materials are generally an indication of relative density or compaction. S-wave refraction data (collected using specialized geophones, shock sources and field procedures) can provide S-wave velocities that bear a well-constrained empirical relationship to standard penetration test (SPT) N values and therefore bearing capacity. For surveys where matching P- and S-wave velocities are determined, the dynamic elastic moduli of subsurface materials can be calculated (including Poisson's Ration, Young's or Bulk Modulus, and Shear Modulus or Rigidity).

LIMITATIONS

Seismic data is collected at spaced geophones, and therefore does not provide continuous profile data. If geophones are spaced too widely, thin layers can be missed entirely.

Conventional refraction interpretations are only accurate where the velocity of strata increase with depth. Velocity inversions not only alter the data, but are particularly insidious since the presence of a low velocity zone at depth is not apparent in first arrival data. The latest generation of computer processing techniques do allow detection and delineation of laterally restricted low velocity zones (e.g. tunnels, cavities, gravel lenses, etc.).

Sharp or dramatic interface relief such as limestone pinnacles cannot always be resolved even with very tight geophone spacing. Therefore, refraction profiles of expectedly irregular interfaces should be assumed to represent somewhat smoothed versions of actual relief (see e.g. Figure **SR-5**).

Seismic records can contain noise due to heavy machinery vibrations, vehicular traffic, and sometimes even wind or distant earthquakes. Care must be taken to identify potential sources of seismic noise prior to beginning a survey.

The effective survey depth is limited to approximately 1/5 of the greatest shotpoint to geophone distance. Therefore, very deep surveys may require impractically long lines (requiring consideration of other geophysical techniques such as seismic reflection).

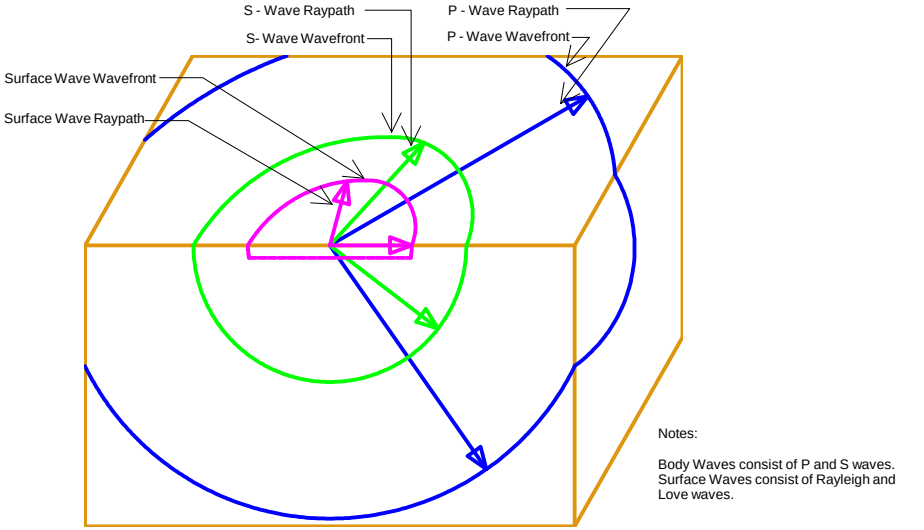

Figure SR-1 Seismic Wave Types Rev. 04/2018 RETTEW

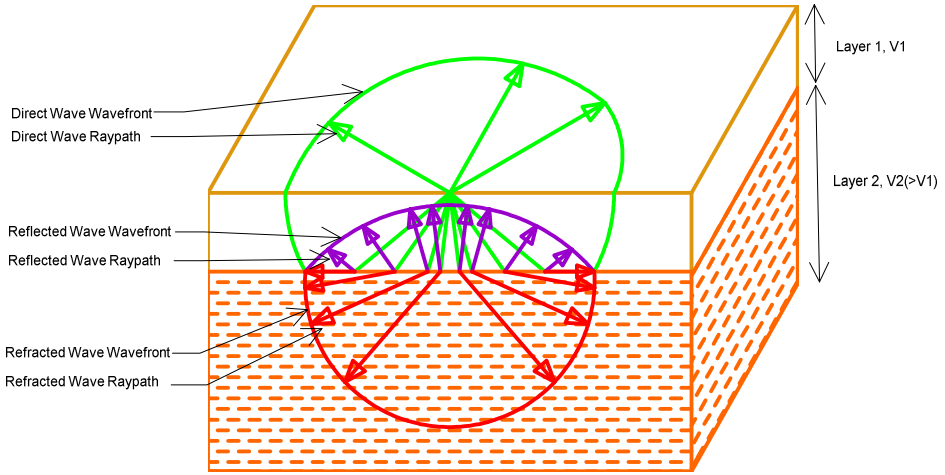

Figure SR-2 Effect of Layering on Body Wave Raypath Rev. 04/2018 RETTEW

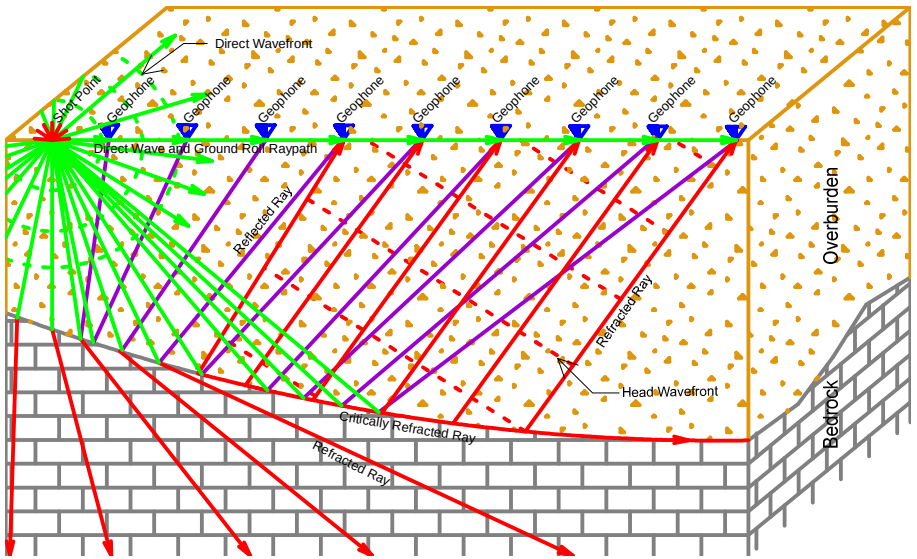

Figure SR-3 Seismic Ray Path Geometry Rev. 04/2018 RETTEW

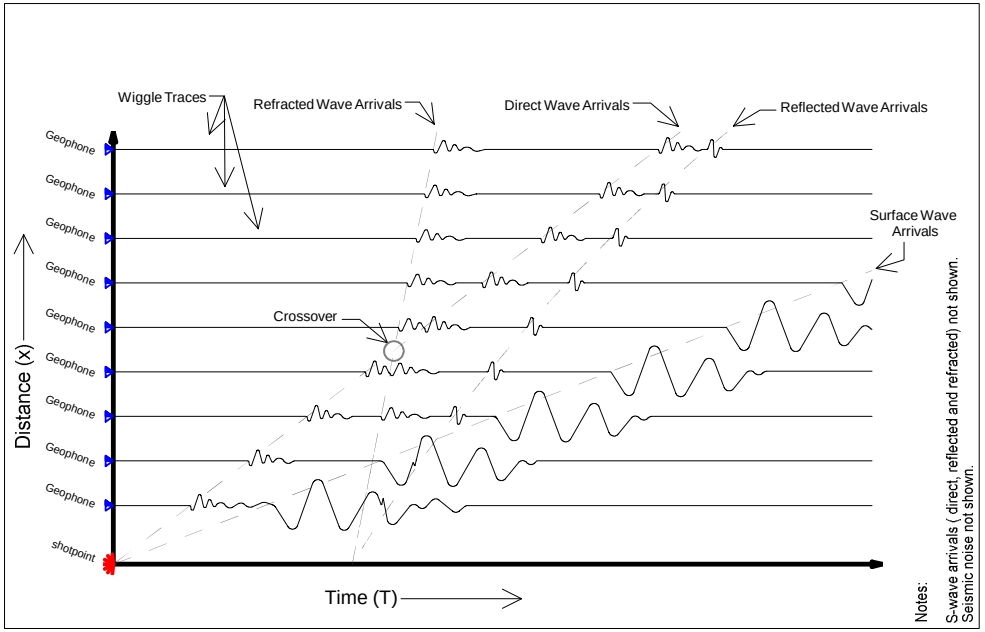

Figure SR-4 Idealized Seismic Record and T- X Graph Rev. 04/2018 RETTEW

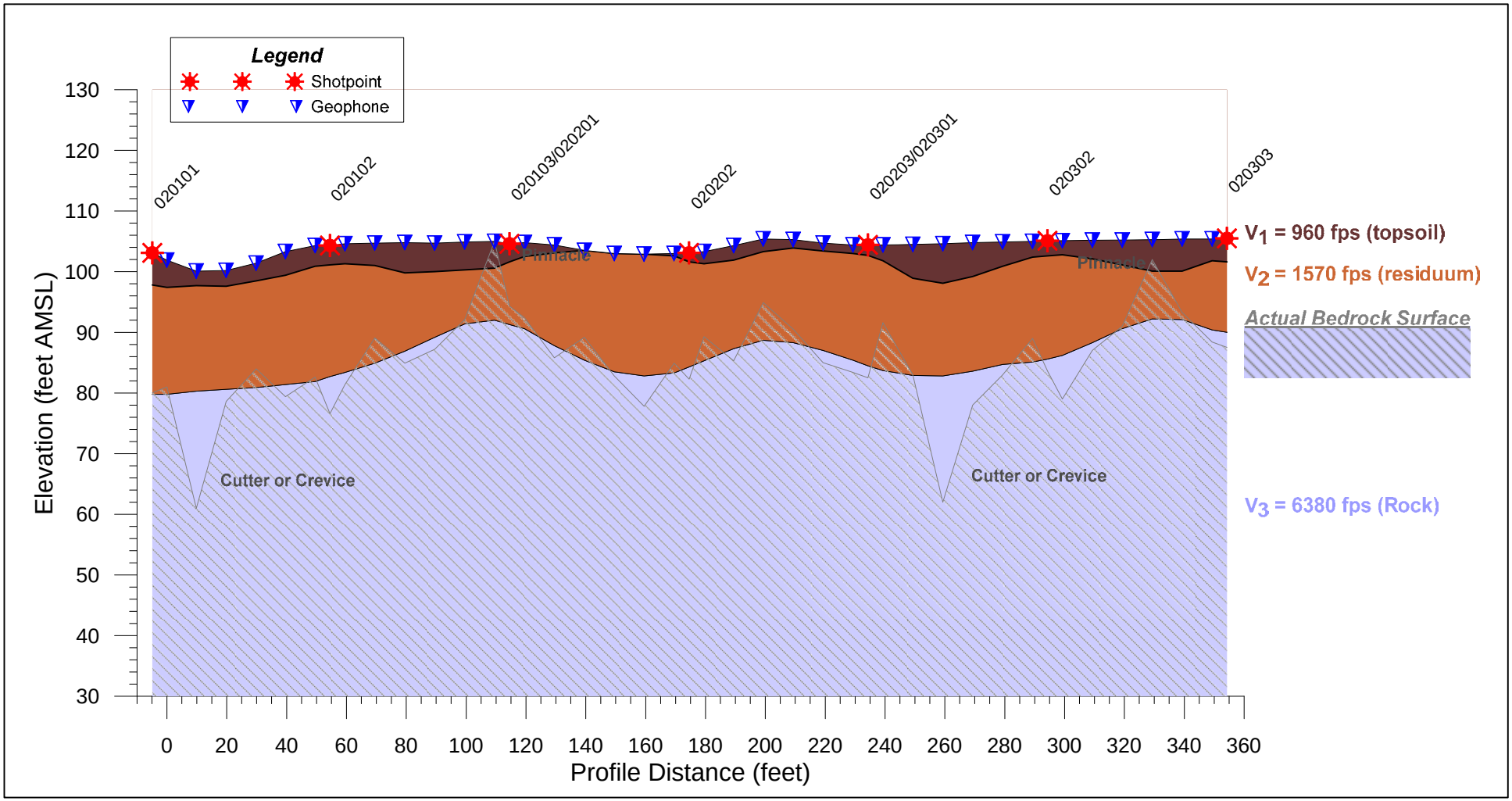

Figure SR-5 **Example Karst Terrane Seismic Profile** Revised 04/2018 RETTEW