SHRP 2 Renewal Project R01B and R01C

Field Evaluation of Tools Developed in the SHRP 2 R01B and R01C Projects

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Field Evaluation of Tools Developed in the SHRP 2 R01B and R01C Projects

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Manassas Park, Virginia

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CHAPTER 1
Introduction

About So-Deep

So-Deep, Inc., was selected as the subsurface utility engineering observation firm for the geophysical tools produced by the second Strategic Highway Research Program (SHRP 2) Project R01B, Utility Locating Technologies, and R01C, Innovations in Locating Deep Utilities. So-Deep has been performing utility mapping since 1981 and has a history of utility tool detection beta testing in field conditions. All of So-Deep's mapping work is performed under the direct responsible charge of appropriately registered professionals. So-Deep's equipment inventory and experience include the wide range of frequencies and accessories of traditional RF pipe and cable locators, magnetic gradiometers, active and passive acoustic devices, terrain conductivity meters, single channel ground penetrating radar (GPR), and television camera and sonde insertion to facilitate utility detection. Standard operating procedures include inspecting and entering if necessary all vaults, hand holes, cabinets, and pedestals in order to identify all pipes and cables and conduits; employing direct conductive connections, passive frequency sweeps, and inductive methods for all identified utilities and throughout the entire project limits for unknown utilities; correlating discovered utility signatures to a comprehensive utility records research for utility identification; and searching beyond the project limits for utility identification structures. As such, So-Deep routinely identifies the vast majority of existing utilities. These field data, when surveyed to applicable tolerances and to the clients' survey control, represent the field activities necessary to obtain American Society of Civil Engineers (ASCE) *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data* (38-02) utility quality level (QL) B data. Other activities required to prepare ASCE 38-02 QL B data include a comprehensive records review prior to fieldwork, computer-assisted design and drafting (CADD) processing, field check of preliminary mapping, multiple reviews to check records for proper utility ownership, plotting of ASCE 38-02 QL C and QL D data, and professional reviews. So-Deep readily adopts new technology when it can to add to its existing tools capabilities.

About the Selected Projects

Virginia DOT (VDOT) and Georgia DOT (GDOT) projects were selected as test sites. Both VDOT and GDOT are long-term clients of So-Deep, and as such, So-Deep is thoroughly familiar with soil types, project logistics, utility types and characteristics, and typical utility engineering and construction methods in these geographic regions. So-Deep had recently performed utility mapping on both project sites, allowing a comprehensive comparison of tool capabilities and logistical considerations. A significant consideration for the selection of these particular projects was that the soils on the two projects were quite different. Based on the data that is found on the U.S. Department of Agriculture GPR suitability map, the VDOT site was expected to be a challenge for successful GPR responses while the GDOT site was expected to be more favorable. A secondary consideration was that existing traffic, topography, and other site conditions represented a broad range of logistical issues for evaluation. (See Appendix D—Photographs)

About the Evaluation Process

The review process included observing the ease of operations of the new tools, the field data collection activities, and the CADD processing of collected data. These activities are only part of the process necessary to create ASCE QL B data.

Highly experienced So-Deep personnel observed the two SHRP 2 R01B tools [Terra Vision II and time domain electromagnetic induction (TDEMI)] for two days on the VDOT site and three days on the GDOT site. The SHRP 2 R01B tools were demonstrated in the field by technicians and geophysicists from Underground Imaging Technologies (UIT). The SHRP 2 R01C tools were only observed on the GDOT site. The acoustic locator was demonstrated by the Gas Technology Institute (GTI) and the radio frequency identification (RFID) tag reader by Visible Assets, Inc. An evaluation and processing of the SHRP 2 R01B data were observed in UIT's office in Albany, New York.

Project limits in the field were selected to maximize project coverage in the shortest amount of possible field time. This resulted in the tools being deployed mostly on paved areas, although a few level grassy areas were also covered in spot locations. It should also be noted that the usability of these new tools over an entire project site was not attempted due to time constraints.

This evaluation compared the results of utilities found by the new tools with those utilities documented by So-Deep within the limits. The limits used for the evaluation are those depicted where the UIT and So-Deep limits overlapped at both the Virginia and Georgia sites. Test holes were selected at the Georgia site to investigate differences between the UIT and So-Deep utility plots and to compare depths. Test holes were also selected to investigate potential non-utility anomalies found by the new tools.

CHAPTER 2
Selected Projects

Stringfellow Road Project (VDOT)

The Stringfellow Road project was a typical commercial suburban widening and road realignment project. The project required utility mapping both on and off the existing right-of-way. Significant portions of the project involved cut and fill at the edges of the existing paving/shoulder. The new tools at this point in development are primarily best suited for level terrain within the project. The project limits, as developed by VDOT, include private fenced areas, deep ditches, large numbers of utility poles, ongoing parallel construction activities, heavy traffic, signalized intersections, and heavy tree and brush growth—in other words, a quite standard DOT project within a heavily urbanized population center. For the purposes of SHRP 2 R01B tool evaluation, portions of the project area were selected that minimized terrain challenges in order to get the maximum amount of tool coverage within the two-day time limit. Due to the traffic volume affecting the safety of the TerraVision II and TDEMI crews, *Manual of Uniform Traffic Control Devices* (MUTCD) rules, and the need to completely stop traffic during the TDEMI operation (sensor interference with moving metal cars), a third-party firm (FlagStaffers, LLC) specializing in DOT traffic control was required.

The covered project area utilities included natural gas, petroleum, water, electric, telephone, cable TV, storm, sanitary, and traffic control. Depths for these utilities ranged from less than 1 foot (surface-embedded traffic control sensor loops) to almost 14 feet. Standard So-Deep tools and techniques were capable of designating 93.5% of these utilities, including petroleum lines up to 14 feet deep. VDOT specifically excludes residential services, traffic control, and irrigation lines from its utility mapping scopes. Survey companies pick up gravity sanitary and storm sewers, which are depicted only at ASCE 38-02 QL C during the initial project survey phase. These scope restrictions are in place in order to minimize costs for utility mapping where risks are extremely low for project impacts. The total percentage of achieved ASCE 38-02 utility QLs (excluding scope-dependent ones, such as gravity sewers) that So-Deep depicted was as follows: 93.5% QL B, 6.5% QL C, and 0% QL D. All QL A data requested by the DOT were found within the 8-inch × 8-inch test holes that had been set up horizontally from the QL B data.

Stringfellow Road GPR and TDEMI Results

The SHRP 2 R01B GPR tool (TerraVision II) was ineffective in the Virginia clay soils and was unable to image utilities, and therefore no depth readings were obtained. This mirrors So-Deep's 25-year experience in northern Virginia from evaluating utility-focused GPR hardware over the years. The TDEMI tool was considerably more effective and was able to detect 43% (see Appendix A—Table A.1) of the utilities found by So-Deep in the covered project area. The TDEMI tool found a majority of the metallic water pipes (93%) (see Appendix B—Figure B.1), and one-third of the metallic gas lines (33%) in the areas covered in this test. Only about 10% of underground communication systems were detected (see Appendix B—Figure B.2). None of the electric facilities were found by the TDEMI unit. However, the TDEMI tool also triggered responses on the in-paving traffic control sensor loops, which in turn required considerable time and effort in unnecessary data interpretation for utilities out of scope. The TDEMI also found 210 feet of unknown utilities. Additional review determined that these included a water line installed after So-Deep performed its mapping and storm drainage that was out of So-Deep's scope of work. Due to terrain issues, only about 50% of the total project area would have been capable of utilizing the SHRP 2 R01B tools, given their size and towing restrictions.

Talbotton Road Project (GDOT)

The Talbotton Road project was a typical commercial urban and suburban widening and road realignment project. This required utility mapping both on and off the existing right-of-way, although a significant portion of the project that was off right-of-way consisted of commercial parking lots. This project is a highly congested utility infrastructure with poor records, heavy traffic, signalized intersections, limited line-of-sight due to road elevation changes, and some heavy tree and brush growth in a few places. Again, because of the limitations of the tools (size and towing restrictions), the team selected only level, unobstructed portions of the project area that maximized the amount of tool coverage within the two-day time limit.

The covered project area utilities included natural gas, water, electric, telephone, cable, storm, sanitary, traffic control, and several unknown function lines. Depths for these utilities were mostly unknown, but from a combination of records, measurements in vaults and valve boxes, and pipe and cable locating depth functions, they were anticipated to range from less than 1 foot (surface-embedded traffic control sensor loops) to 6 feet for the vast majority of utilities other than gravity storm and sanitary systems. Drainage culverts, road and sidewalk underdrains, and residential services beyond meters are out of So-Deep's scope of work.

GDOT specifies a significant amount of additional utility information on its subsurface utility engineering (SUE) deliverables. Examples of this include the number and type of cables and conduits, cable pair sizes of cables leaving/entering pedestals and cabinets, sewer flow direction, and empty conduits. This information must be gathered through field investigation, records review, and designating of individual cables as accessed at structures. Utility types must be investigated by tracking utilities through and/or off project limits, within reason, until identifying structures are found, unless records are unambiguous.

The total percentage of achieved ASCE 38-02 utility QLs by So-Deep was as follows: 81% QL B, 13.5% QL C (mostly long runs of sewers), and 5.5% QL D. Unknown utilities (detectable but with no records or physical structures/connections to identify them) at QL B came in at 14% of the total QL B data.

Talbotton Road TerraVision II and TDEMI Results

Both the TDEMI and GPR (TerraVision II) tools were effective in the project soils. The TerraVision II imaged utilities to an effective depth of about 5 feet. Metallic utilities were responsive to both the TDEMI and TerraVision II in most cases, providing a good correlation to the ASCE 38-02 QL B results.

Both tools found a majority of the metallic water and metallic gas lines in the areas covered. TerraVision II had some success on the nonmetallic sewer lines. Neither tool had great success on the communication systems, although bits and pieces were able to be imaged. There is some question whether the small bits and pieces could be interpreted and identified without the benefit of a completed level “B” plan set at hand. Where the tools did identify utilities, there was good correlation with the existing So-Deep’s QL B data. Overall, within the covered project areas, the SHRP 2 R01B tools found 47% (see Appendix A—Table A.2) of the QL B utilities in scope that were not identified by So-Deep as unknowns. They also found an additional 12% of utilities. Approximately half of that 12% consisted of drainage culverts that were out of scope and easily visually identified. The SHRP 2 R01B tools also found remnants of what appears to be a previously undesignated utility “ghost” system in one side street for which there were no utility records or structures—a true unknown (see Appendix B—Figure B.3). Due to the location, configuration, and fragmented nature of this utility, and as a result of the test holes, it is believed to be an abandoned water or gas distribution system. There were also several locations where the original QL B investigation showed an “end of geophysical information (EOI)” where the SHRP 2 R01B tools detected a signal somewhat further.

Perhaps the greatest advantage of the TerraVision II tool is that of a continuous depth profile of an imaged utility (see Appendix A—Table A.3)

So-Deep dug 13 test holes to correlate the TerraVision II depths with actual field-excavated measured depths. The agreement in depth ranged from 0.03 foot to 2.05 feet. However, most depths were in agreement by approximately one-half foot. There does not appear to be any correlation between type of utility, actual depth, or material type to explain the variation in TerraVision II depths to the actual exposed measured depth. It should be noted that the test hole depths ranged from 0.33 foot to 4.24 feet.

A second significant feature of both the TerraVision II and TDEMI tools was the ability to image geotechnical anomalies and actually see some amount of structure within those anomalies. For a 300-foot stretch of Talbotton Road, an area of both very high conductivity and reflected impedance was discovered. This large area has some significant and repeating 7-foot × 7-foot structures (anomalies) that could represent conductive concrete slabs, as determined by test holes. (See Appendix B—Figure B.4.)

After the TerraVision II and TDEMI tools were fielded and the results analyzed and plotted, test hole locations (described below) were selected.

The test hole locations were selected to

1. Verify the presence of utilities imaged by the SHRP 2 R01B tools not identified and mapped by So-Deep.
2. Qualify the accuracy of the TerraVision II depth readings versus actual test hole depth measurements.

3. Verify the existence and function of the “ghost” system imaged by the SHRP 2 R01B tools.
4. Identify the nature of the anomalous area within which 7-foot × 7-foot footprints were found by the SHRP 2 R01B tools.

Test Hole #2

This test hole was excavated on a random water line during the field-testing of the SHRP 2 R01B tools. This line had been previously detected and mapped by So-Deep.

Test Hole #150

This test hole was selected at an extension to a water line that So-Deep has mapped. The extension was identified by the SHRP 2 R01B tools but could not be detected by So-Deep. Excavation revealed the extension to be a small diameter (1 inch) pipe that extended about 20 feet from the main line.

Test Hole #151

This test hole was selected at the crossing of two unknown type utilities imaged by the SHRP 2 R01B tools that So-Deep did not detect. These lines are part of the “ghost” system. Test hole excavation revealed a 2¾-foot metallic line crossing a 2-foot metallic line. Both lines were badly corroded and were determined to be either abandoned gas or water.

Test Hole #152

This test hole was selected at the crossing of two unknown type utility lines imaged by the SHRP 2 R01B tools but not found by So-Deep. Test hole excavation revealed a 3½-inch metallic line crossing a 2 ½-inch metallic line. Both lines were badly corroded and were determined to be abandoned water or gas lines.

Test Hole #153

This test hole was selected to verify if a 14-inch clay sanitary sewer line extended beyond the point of So-Deep mapping EOI and continued as imaged by the SHRP 2 R01B tools. The test hole proved the line extended past the EOI but did not continue all the way to the following manhole as imaged by the SHRP 2 R01B tools (line not present in the manhole).

Test Hole #154

This location was selected to determine the presence and nature of an unknown type/function line mapped by So-Deep but not imaged by the SHRP 2 R01B tools within the anomalous area that encompassed the 7-foot × 7-foot footprints found by the SHRP 2 R01 B tools. This test hole revealed a 2-inch layer of asphalt covering 5 inches of steel mesh reinforced concrete. The unknown was determined to be a 1¼-inch metallic line.

Test Hole #155

This test hole was selected on a water line imaged by the SHRP 2 R01B tools and detected and mapped by So-Deep at the edge of the anomalous area. An 8¾-inch outside diameter (OD) ductile iron pipe was found beneath 4 inches of concrete (no wire or rebar).

Test Hole #156

This test hole was selected on an unknown utility imaged by the SHRP 2 R01 B tools that was not identified during the So-Deep mapping. The unknown was determined to be a badly corroded 2¾-inch metallic pipe thought to be abandoned water or gas.

Test Hole # 157

This test hole was selected to determine the presence and nature of a utility imaged by the SHRP 2 R01B tools but not detected by So-Deep within the anomalous area. The unknown was determined to be a 1¼-inch OD copper water line covered with 6 inches of wire reinforced concrete and 2 inches of asphalt.

Test Hole #158

This test hole was selected on a gas line imaged by the SHRP 2 R01B tools and identified and mapped by So-Deep.

Test Hole #159

This test hole was selected at the point where a gas line mapped by So-Deep and imaged by the SHRP 2 R01B tools crossed an unknown line only imaged by the SHRP 2 R01B tools. A 4½-inch plastic gas line was documented, and the unknown was determined to be a ¾-inch copper water line that was out of So-Deep's scope of work.

Test Hole #160

This test hole was selected on a telephone duct imaged by the SHRP 2 R01B tools and identified and mapped by So-Deep.

Test Hole #161

This test hole was selected at the location of an unknown line imaged by the SHRP 2 R01B tools. The unknown was determined to be a badly corroded 2½-inch OD metallic line thought to be an abandoned water or gas line.

The results of the test hole excavation were as follows:

1. The utilities imaged by the SHRP 2 R01B tools, and not mapped by So-Deep were found in the selected test holes.

2. The accuracy of the TerraVision II depths ranged from a differential of only 0.03 foot (Test Hole #2) to 2.05 feet (Test Hole #152). Note also that on this project, the utility depths are relatively shallow when compared with DOT projects in other locations.
3. The “ghost” system does exist and appears to be an abandoned gas or water distribution system consisting of corroded metallic lines in the 2- to 3-foot range.
4. The anomalous area imaged by the new tools was found to be an asphalt-covered, reinforced concrete roadway.

(See the results of the depth correlations from the TerraVision II to the So-Deep actual measurements taken at the test holes presented in Appendix A—Table A.3.)

Talbotton Road SHRP 2 R01C Tool Results

Two tools from the SHRP 2 R01C program were field-tested: RFID tags and an acoustic locator (AL). The AL failed to find two relatively shallow sanitary laterals for which it should have been well-suited. The AL gave a false indication of a found utility where none existed. It was determined that there was either a hardware or software problem that could not be fixed in the field. After So-Deep excavated a test hole on the target utility at its actual location, recalibration of the AL was attempted. The AL was not able to locate the line after it was recalibrated, and no further tests on the AL were conducted.

Regardless of the science behind the AL, So-Deep believes this tool to be highly impractical for field operations. It is very time-consuming and needs an empty non-liquid-filled pipe as the utility to be designated. Usually such empty pipes can readily be designated through cameras and/or sonde insertion (for deep utilities) and composite core wire insertions (for pipes up to 20 feet deep) with sufficient reliable horizontal accuracy. Additionally, the AL sound inducer at this stage of development must be coupled to a vertical standpipe and is limited to specific pipe sizes. A major problem for the AL device is caused by water in the pipe (a typical scenario for empty deep conduits), because the acoustic signal will be completely attenuated. The AL requires placement of five sensors in a straight line with relatively short spacing; if you don’t know the direction of the pipe leaving the sound introduction point, it is quite time-consuming to identify and get your first signal because it might originate in any of 360 degrees from the vertical pipe introduction point. Furthermore, the sensors require about five minutes to receive and calculate a signal, making the placement of sensors in traveled roadways impossible without stopping traffic for long periods of time. At this time, So-Deep sees very limited commercial application.

The RFID tag tool has two main components: the buried tag itself and the handheld reader/locator. The tags are a polyvinyl chloride tube (6 inches long by ¾ inch diameter with a 1 inch × 1 inch square head) and therefore unsuitable for most pipe attachment applications during pipe installation, other than for open trench methods. The tags were disappointing in their manufacturing; in one case, during installation the cap of the tag came off. The tags were essentially hollow, making them susceptible to floating in any kind of high water table scenario.

However, these manufacturing problems are probably easily addressed during commercialization.

A somewhat more difficult problem is that of antenna orientation. While data can be read from the tag when buried, the tag itself cannot be used for accurate location purposes unless the antenna orientation is exactly parallel or perpendicular to the tag reader. The horizontal error in surface location becomes larger as the angle of deviation increases and as the tag depth increases. Installation of this exact orientation proved very challenging through a typical vacuum-excavated test hole. Tag installation during construction will require great care to achieve useful data in the future.

The reader itself was an iPod inserted into an antenna device. The iPod screen was small and difficult to read due to both size and sunlight interference. More work on this reader interface is necessary before commercialization. The reader locates and identifies the tag number. A separate database to access stored utility information is necessary.

The RFID tags worked, and the reader for the tags worked. So-Deep believes there are other commercial tags already available and in common reader use that are more user friendly and accurate for the bulk of RFID needs. However, the RFID tags may have an application in deep utilities where it is known that the soil above them will be disturbed. Installation of these tags will remain challenging. Additionally, the fact that there is a battery life aspect is troubling, since utilities can be in the ground for many years beyond the expected battery life of the RFID tags. In summary, So-Deep does not see much use for these tags given the limitations of installation issues associated with orientation, battery life, and limited field data provided by the reader. (Refer to Appendix D—Photographs.)

CHAPTER 3
Summary and Conclusions

Evaluation and Processing of Data

The data collected by these sophisticated SHRP 2 R01B tools cannot currently be interpreted in the field in real time. The geophysical data must be analyzed in an office environment using customized software. The processing and analysis of the data by UIT took about four weeks before So-Deep received AutoCAD files depicting utilities for both sites; however, So-Deep does not know how many hours the processing actually required. Utility types in UIT's AutoCAD files were identified by referencing So-Deep's previous QL B subsurface utility investigation into UIT's data. UIT was not required to identify utilities from utility records or utility structures.

The TerraVision II multi-channel three-dimensional (3D) GPR collects data from a fixed array of 14 GPR antennas on a towed trailer that covers a 5-foot-wide swath. The trailer also contains a GPS unit to enable the tool to obtain 3D data. UIT's field technicians collected the field data with UIT's data acquisition shell software. The GPR data sets were then filtered, processed, and merged by a UIT geophysicist using Geophysical Survey Systems, Inc., RADAN software. Subsequent analysis and interpretation were performed by a UIT geophysicist using UIT's SPADE software. The SPADE software allowed the UIT geophysicist to slice the 3D data into two-dimensional planes for better analysis. Utilities, appearing as hyperboles in different slices, were connected and given depth attributes. UIT then created a DXF file to transfer the generic utilities into AutoCAD for comparison and identification with So-Deep's utility file.

The TDEMI system, commonly referred to as transmitting electromagnetic systems (or TEMS), collects data from five coils mounted on a fiberglass trailer. The system sends a time varying electromagnetic pulse into the ground that causes metallic objects in the subsurface to be charged. The coils then measure electrical decay over time. The TDEMI data were collected by UIT's technicians using G&G Sciences Inc. EM3D software. GPS was integrated with the geophysical data collection that is two dimensional in nature; no depth information on utilities is obtained. The TDEMI data sets are then processed, merged, analyzed, and interpreted by a UIT geophysicist using Geosoft's Oasis montaj software. Generic utilities the UIT geophysicists identified in Oasis montaj were exported as a DXF file to AutoCAD. The utilities were then compared in AutoCAD with a So-Deep existing utility file to identify utility types.

So-Deep believes that the data generated by the SHRP 2 R01B tools can be incorporated with the traditional data sources that lead to QL B mapping. Furthermore, some portion of the data may lead to additional advances such as geotechnical feature detection and continuous utility depth profiles.

More About the TDEMI and GPR Tools

So-Deep believes that with future refinement and development, and on the right project with the right soils, the addition of the TDEMI and TerraVision II tools for the purposes of supplementing ASCE 38-02 QL B data on a project have merit. However, DOTs need to understand that the costs of implementing the use of these new tools will be significant and might not result in any additional targeted utilities being mapped. The SHRP 2 R01B tools imaged some abandoned sections of utilities that required additional test holes to determine their existence so they could be discounted. So-Deep believes that in its current stage of development, TDEMI and TerraVision II are not adequate for stand-alone QL B mapping; they should only be considered as a supplement to existing tools and not a replacement. The ability to calculate more reliable depths with the TerraVision II system than with other typical mapping tools is a great advantage, but that advantage is only realized when a GPR signal can penetrate to local utility depths verified with QL A data (test holes).

Some of the purported advantages may be the interpretation of data that comes from non-utility structures. Although little additional data were gathered other than unknown underground utilities during the testing, both the TerraVision II and TDEMI tools seem capable of providing additional data sets. This might include showing geometry, location, intensity, and depths (from GPR data) of either areas of anomalies or of known structures such as paving thickness, substrate thickness, voids, water table, soil lenses, boulders, bedrock, and so forth. The Talbotton Road project had a great example of this. The tools were used as a guide to select test holes that verified this area to have an asphalt and wire–reinforced concrete base, which could be an old roadway. Given the rather long time for data processing and interpretation, it might make sense to deploy TDEMI and TerraVision II very early in a project's life cycle, when design functions can incorporate the conditions that are found.

Because data are processed and interpreted in the office after field collection, identification of a given utilities' type can only be done by correlation to existing records or surveyed utility information. Because existing records are often incomplete and locationally inaccurate, TDEMI and TerraVision II have shortcomings over traditional "in-the-field" contemporaneous determinations of utility types.

The results of data gathered by the new tools are not known to the field data collection team, and there will be some difficulties merging this technology into current QL B fieldwork. The data collected by these tools need to be tied by survey to surface features that would give a more positive identification of individual utility type and configuration. Conventionally surveyed utility surface features would need to be included into the field work in an attempt to correlate the data sets. The new tools do add some data to the overall utility investigation, but it appears the amount of utilities added to the project to be a fairly small percentage. In some instances both TerraVision II and TDEMI responded; however, the depiction of those utilities did not always agree with one another. When reviewing the data, one must decide to pick one data set over another or perhaps average the data to establish the "best fit." As no marks are placed on the ground during the data collection process, no option for field review to make final check corrections are possible.

DOTs (and all potential clients) will need to understand that in order to perform the TDEMI and TerraVision II surveys on traveled roadways, significant traffic control and disruptions will occur. So, in addition to increased mapping costs and time of processing and correlating results, there will also be an impact on the traveling public.

There were several locations at both the Virginia and Georgia sites where telephone manholes existed within TerraVision II and TDEMI project limits. The final interpretation of collected data did not indicate these structures.

The following lists outline the advantages of and challenges to adding the SHRP 2 R01B TDEMI and TerraVision II tools to an SUE consultant's toolbox. So-Deep considers these tools as a complementary pair; where it is clear that the comments relate only to one tool, it is so indicated.

Advantages

- Broad areas of flat unobstructed right-of-way can be covered quickly in the field.
- Depth profiles anywhere there is an interpretable image (TerraVision II).
- Features other than utilities can be interpreted (both tools) with depths (TerraVision II).
- Good at picking up pieces of interrupted/broken utilities.
- Can find some additional unknown utilities.
- Has appearance to the public of a "higher technology" in use.
- Can go beyond some "ends of geophysical Information" points when EOI is caused by obstruction or material change (TerraVision II).
- Serves as confirmation of other interpretations, increasing reliability of mapping results.
- The data can be reanalyzed with more sophisticated computer systems/software as they are developed in the future.

Conceptual Challenges

- Highly trained data interpreters needed.
- Specialized data interpretation software needed.
- Traffic control can be extensive on traveled roadways; usually requires flagging and possible attenuator vehicles due to MUTCD requirements, and police presence may be required at controlled intersections.
- No utility type identification possible other than correlation to other sources.
- Savvy field operators needed to follow strict quality assurance procedures for survey and equipment function since geophysics and survey are combined.
- Costs for adding to more complete "traditional" mapping methods are large.
- TerraVision II and TDEMI tools by themselves are insufficient for complete data collection required to develop ASCE QL B deliverables expected from most DOTs.

Practical Challenges

- Only suitable for open areas.
- Cart and trailer (especially with the TDEMI unit) can be awkward to maneuver in and around any surface other than flat ROW roadways.
- These tools have trouble with virtually all small-sized lines. Direct buried electric and telephone lines, especially fiber optic cables, were not found during this test.
- Increased number of temporary traffic control devices and manpower are required.
- Cannot traverse uneven terrain.
- Cannot traverse wooded or brush terrain.
- No real time feedback to technicians.
- Unable to identify utility type/function.
- The tools could not adequately approach utility poles, cabinets, or pedestals to accurately trace ownership of utilities.

Questionnaire (See Appendix C)

So-Deep has utilized the questionnaire developed by the SHRP 2 research team with input from the User Group and Technical Expert Task Group. So-Deep did not fill out one for each tool at each site; rather, the project team combined the tools and sites and made observations when there were differences. Many of the questions are answered in the individual SHRP 2 R01B and R01C reports and in the above sections of this report and may not necessarily be duplicated in this report.

Conclusions

TerraVision II and TDEMI appear to be good tools for certain projects that may enhance but not replace traditional utility mapping methods. A significant amount of further testing through a comprehensive test hole program would be beneficial going forward, especially for determination of unknowns, reliability of depths, and identification of areas of anomalies. It may be difficult to convince DOTs to increase their utility mapping budgets to accommodate the costs associated with the new tools. As such, So-Deep believes a beneficial path forward is to offset some of the utility mapping costs of the new tools with a budget from other DOT departments that will benefit from the additional data. These might include but are not limited to paving and maintenance functions, archeological surveys, environmental surveys, geotechnical base-lining and bore hole placement development, arborist (for historical tree root determinations), septic field mapping, limits of cemeteries, and reduction of unknown or differing site conditions for construction departments. So-Deep does not believe the SHRP 2 R01C tools will be of enough benefit for further commercial development at this time.

APPENDIX A
Tables

Table A.1. So-Deep QL B versus SHRP 2 R01B Tool Utility Footage, Stringfellow Road, Virginia Utility Results

Utility	W	G	T	E	CATV	SAN	STORM	UNK*
So-Deep QL B Footage	1,860 ft	2,795 ft	1695 ft	75 ft				
SHRP 2 R01B Footage	1,740 ft	825 ft	205 ft	0 ft				210 ft
% Footage Found by SHRP 2 R01B	93%	33%	12%	0%				

Note: W = water, G = gas, T = telephone, E = electric, CATV = cable TV, SAN = sanitary, UNK=unknown.
* Out of So-Deep scope or newly installed lines.

Table A.2. So-Deep QL B vs. SHRP 2 R01B Tool Utility Footage, Talbotton Road, Georgia Utility Results

Utility	W	G	T	E	CATV	SAN	STORM	UNK*
So-Deep QL B Footage	2,635 ft	1,655 ft	1,405 ft	90 ft	85 ft	1,815 ft	220 ft	880 ft
SHRP 2 R01B Footage	1,855 ft	860 ft	135 ft	0 ft	0 ft	610 ft	290 ft	775 ft
% Footage Found by SHRP 2 R01B	70%	51%	9%	0%	0%	33%	100%+	na

Note: na = not applicable.
* Data for UNK (unknown utility or instrument response) is shown for comparison purposes here. The UNK lines found by So-Deep do not necessary coincide with the UNK lines found by the new tools; therefore, percentages of lines found do not apply.

Table A.3. So-Deep QL A (Test Hole) Data, Talbotton Road, Georgia Utility Results

Test Hole #	Sheet #	Expecting	Found	So-Deep Actual	TerraVision II Depth	Differential*
2	24-14	10 in. Water line 6-way telephone duct	11 in. Water line RPC telephone duct	1.67	1.70	+0.03 ft
150	24-05	12 in. Water line unknown	12¾ in. Water line 1 in. Metallic	3.85 3.43	— 2.488	— +0.94 ft
151	24-05	Unknown parallel unknown crossing	2¾ in. Metallic 2 in. Metallic	1.93 2.26	— 1.543	— +.0.72 ft
152	24-05	Unknown parallel unknown crossing	2½ in. Metallic 3½ in. Metallic	1.92 3.12	2.13 to 3.971 1.569 to 1.367	–0.21 to –2.05 +1.55 to +1.75
153	24-05	Unknown	14 in. Clay pipe	2.22	—	—
154	24-09	Unknown	1¼ in. Metallic	2.62	1.947	+0.67 ft
155	24-11	8 in. Water line	8¾ in. Water line	2.83	2.331	+0.50 ft
156	24-31	Unknown	2¾ in. Metallic	2.66	1.996	+0.66 ft
157	24-10	Unknown	1¼ in. Copper water line	1.45	0.833	+0.61 ft
158	24-05	6 in. Gas line	7 in. Gas line	3.83	4.158	–0.33 ft
159	24-31	2 in. Gas line unknown	4½ in. Plastic gas line ¾ in. Copper water line	4.24 0.33	3.892 0.537	+0.35 ft –0.21 ft
160	24-10	6-way MTD F.O. telephone	RPC Telephone duct	3.90	4.081	–0.18 ft
161	24-10	Unknown	2½ in. Metallic	3.29	2.891	+0.40 ft

* A plus (+) sign in front of the differential figure indicates that the TerraVision II depth estimate was shallower than the actual field measured depth, and the minus (–) sign indicates that the TerraVision II estimate was deeper.

APPENDIX B
Figures

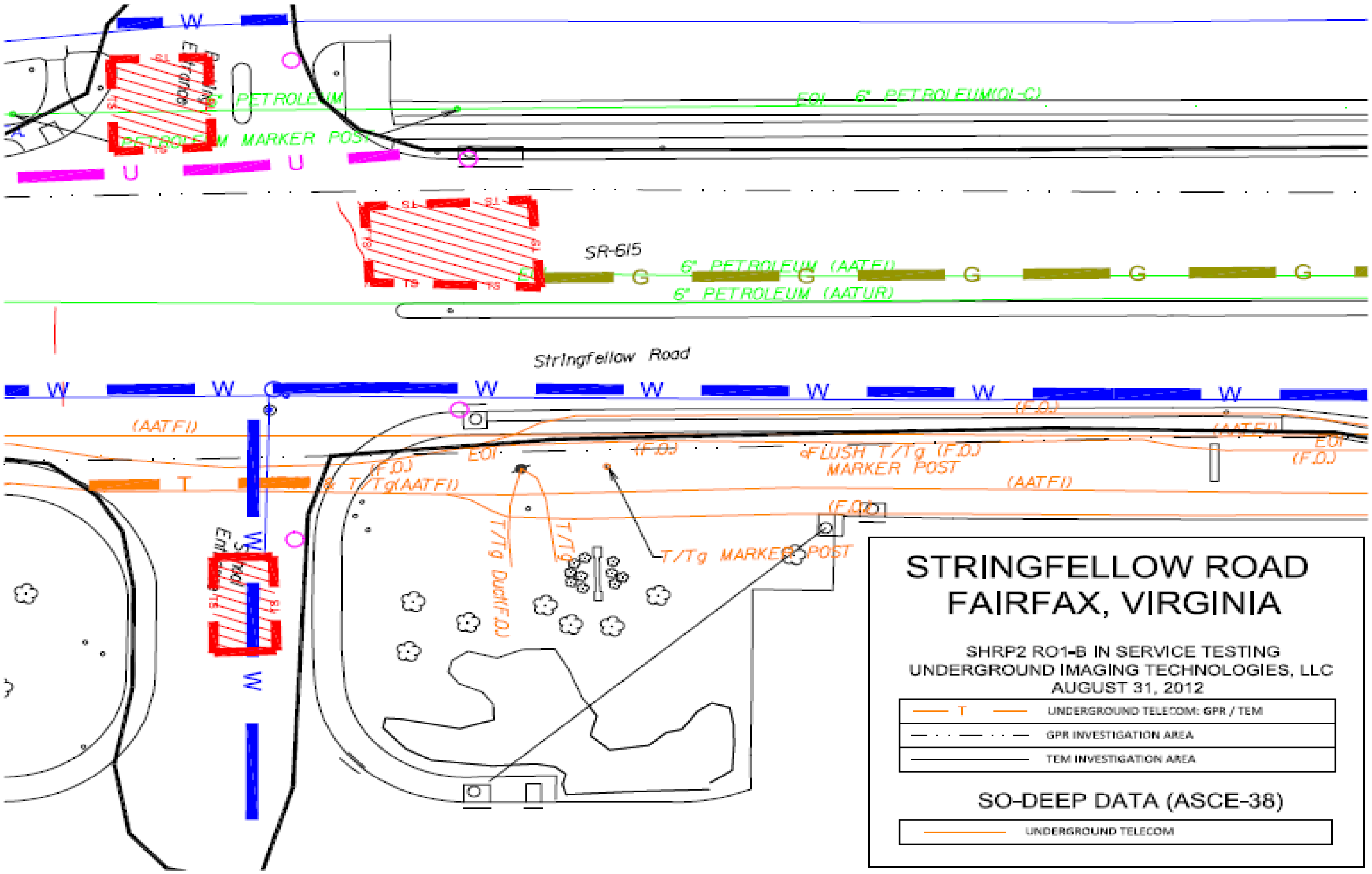

Figure B.1. Water lines: The thick lines represent SHRP 2 R01B tools, and the thin lines represent So-Deep.

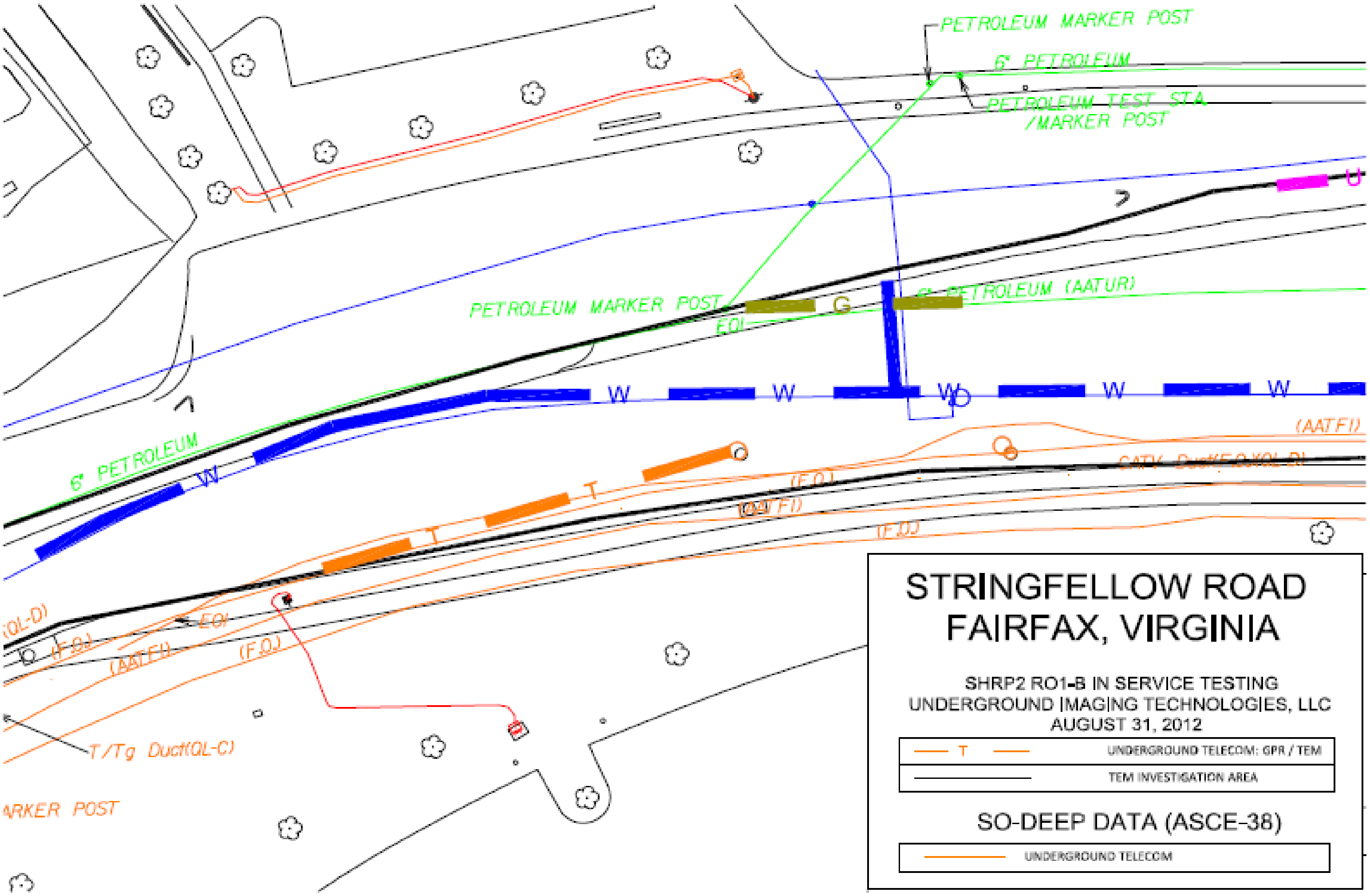

Figure B.2. Communications lines: The thick lines represent SHRP 2 R01B tools, and the thin lines represent So-Deep.

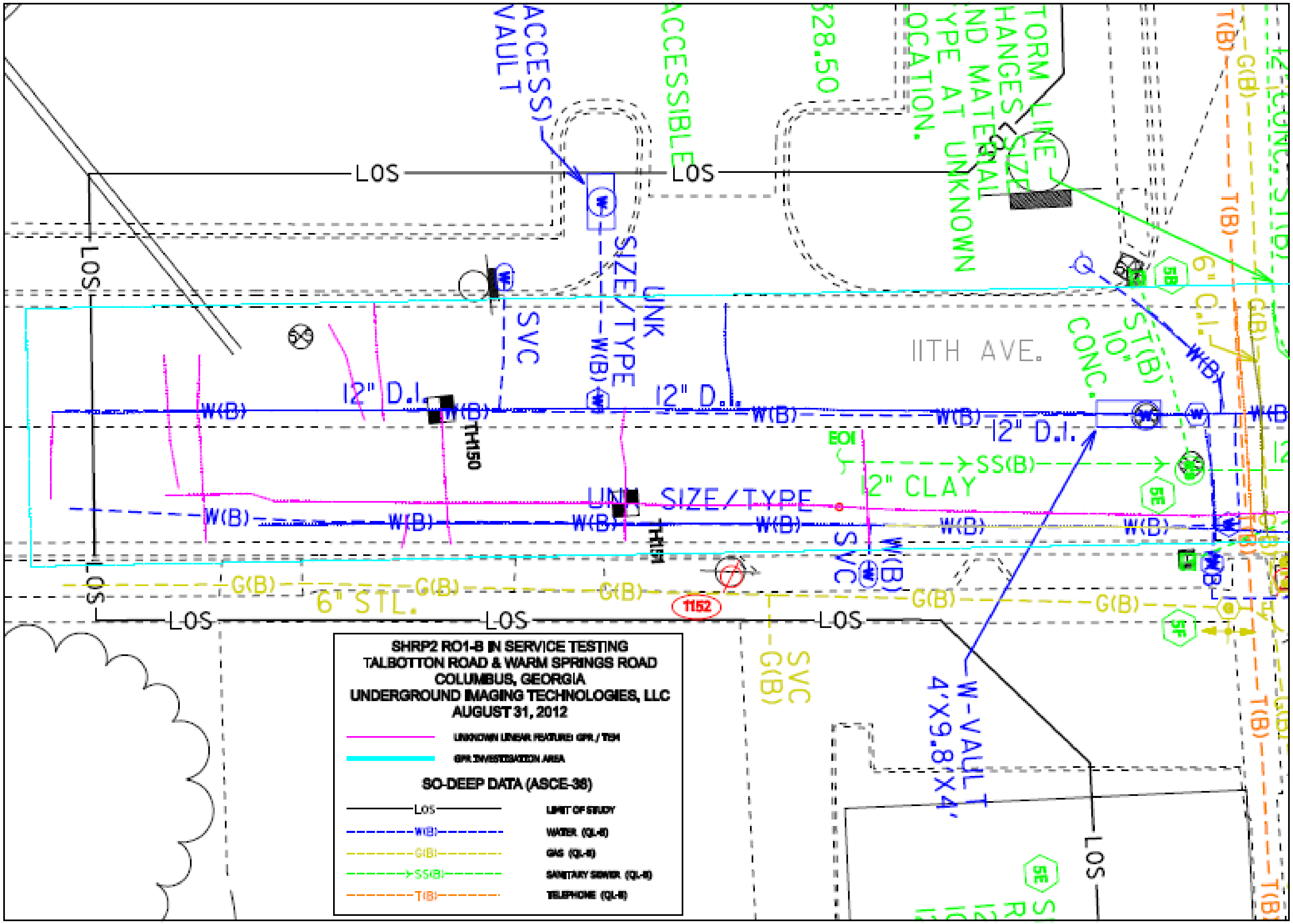

Figure B.3. Unknown “ghost” utility system (purple lines).

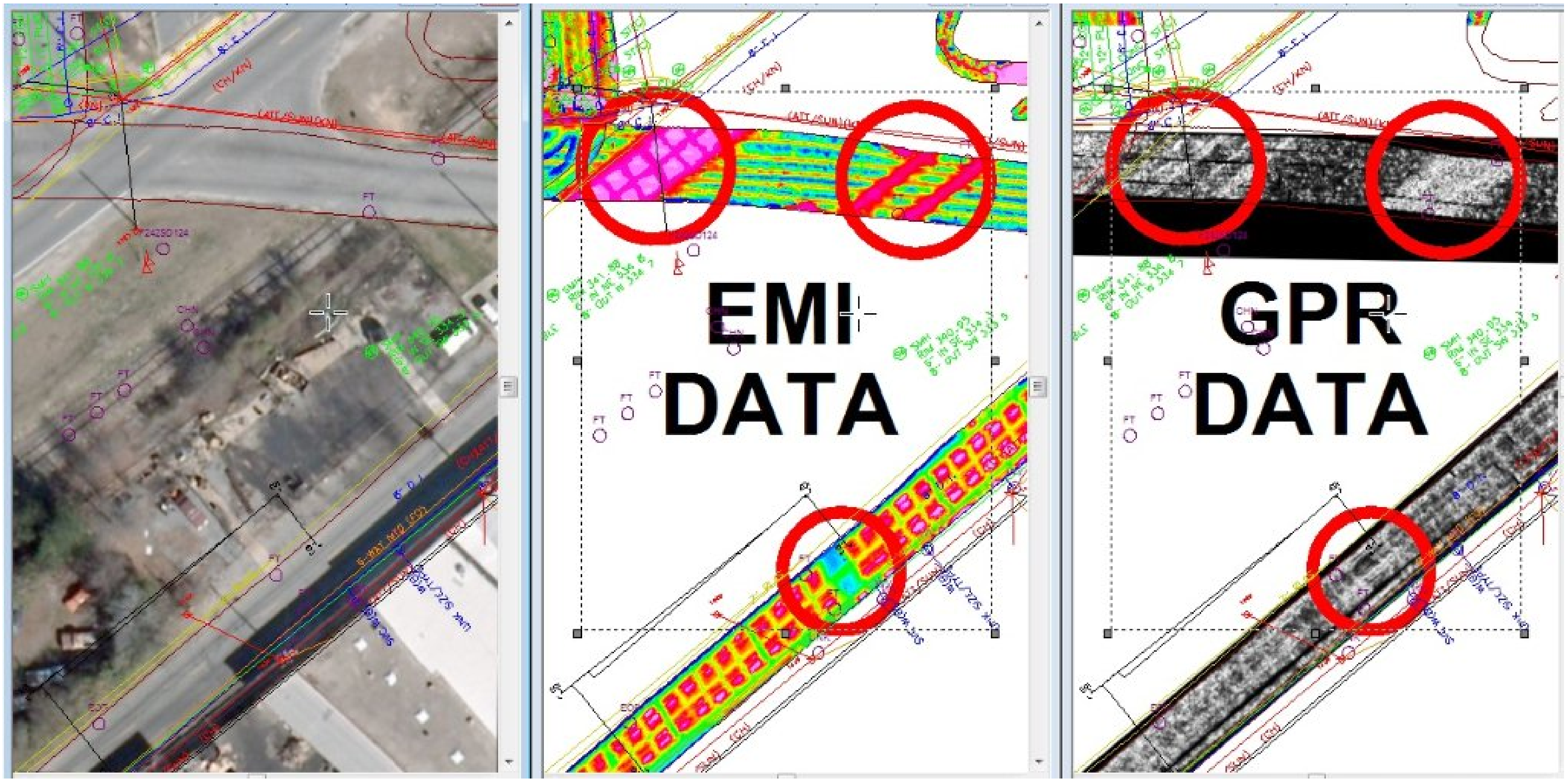

Figure B.4. Anomalous area. EMI = TDEMIS; GPR = TerraVision II.

APPENDIX C
Questions

1. Describe the site environment:
   a. Soil classification (if known)
      Unknown
   b. Ground water table and tidal influence (if known)
      Unknown
   c. Presence of salt water (if known)
      Unknown
   d. Presence of and type of contamination to include debris (if known)
      Unknown
   e. Complexity of subsurface facilities (multiple utilities, development history, etc.)
      Typical suburban roadway utility congestion
   f. Presence of stray current producing facilities (light rail, street car, active cathotic protection, etc.)
      None
   g. Ground temperature (if known)
      Unknown
   h. Weather conditions during the test
      Hot

2. Did the prototype tool find a utility that other tools did not find?
   a. Storm, TC loops, UNKs, and sanitary lines were found (VA site).
   b. Storm and TC loops that are out of scope, unknown lines at the VA site (later identified as water and storm lines (TDEMI) installed after the So-Deep investigation was completed (VA site).
   c. Abandoned gas or water distribution system.

3. Did the tool not find a utility that other tools did find?
   a. TerraVision II was ineffective at finding utilities at the VA site.
   b. TDEMI did find and match lines at the VA site.
   c. The TerraVision II and TDEMI had a much better response at the GA site, though judged still ineffective on cable type electric, CATV and telephone lines.

4. Did the data from the tool provide more comprehensive information than other tools, for example, viable depth, information on substrate, image of other structures, etc.?
   a. Refer to Appendix A—Table A.3.

5. Did the tool require new or additional traffic control versus common practice now?
    a. *Additional traffic control required for work in the roadways. Flagging crew needed to escort the cart and trailer in traffic, guide traffic around the unit, and assist with turning around.*
    b. *Signalized intersections may require police to manage traffic.*
    c. *High traffic or speed limit project sights might require a truck-mounted attenuator to ensure the safety of the data collection crew.*

6. Do our technicians require special training? How much training?
    a. *Difficult to judge in the prototype stage, envision once system and operational checks are in place, a less skilled team could operate the new tools.*
    b. *UIT's data acquisition team is highly trained.*

7. How portable is the equipment?
    a. *Movement from site to site requires a box truck and trailer followed by on-site assembly.*
    b. *Movement on site; physical obstacles frequently prevent complete project coverage.*

8. Can we ship it or transport it easily?
    a. *Typically the box truck and trailer are driven to the job site.*
    b. *Could be shipped (trucked) and local tow vehicle obtained.*

9. Are there site restrictions in its use, for example only on pavement, not able to work around obstructions, wet or marshy areas, extreme heat or cold, etc.?

    a. *Tow vehicle needs traction.*
    b. *Uneven terrain could potentially cause issues with plotted positions of data collected. The GPS antenna is mounted fairly high above the antenna array (6 feet ±) and if tilted off center due to sloping terrain, would not be directly over the utilities below.*
    c. *Also, again if the terrain is sloped the antenna array would not be pointing down, but at an angle to horizontal, thus compounding the error of the high GPS antenna mounting point.*
    d. *New tools are best suited for flat ROWs and roadways.*
    e. *Brush, wooded areas, ditches, tall curbs along with every item sticking straight up on project, (signs, UPs, FHs, guy wires, trees, bushes, etc.) are common on road widening projects and prevent full coverage with the new tools.*

10. Do we need special survey equipment?

    a. *GPS base and rover system with RTK capabilities*

b. *Calibration strips and utility features should be surveyed conventionally for QA purposes. The more surveyed the better for latency checks.*

11. Do we need special survey software?
    a. *No, though (proprietary) software needed to account for "rover" position relative to the antenna array position.*

12. How will this alter our quality assurance processes?
    a. *QA process will need to be reviewed and revised.*
    b. *In these test cases, the field work previously completed by So-Deep was the guide to identity the responses detected by the new tools.*
    c. *Current field work techniques for these new tools prevent current QA processes from being followed:*

    - *No paint marks to check.*
    - *No utilities are identified during data acquisition phase; at the time of collection, the tools are run over the site in a structured manner to ensure coverage is complete. The effectiveness of the field work is discovered in the office as the data are processed.*
    - *This data acquisition process does not allow the field crew to differentiate between in and out of scope utility lines (for example, residential service lines and storm and traffic control systems are typically all out of scope lines).*
    - *Records review and second trip to the field using conventional designating techniques and equipment will be needed after data is processed to ensure a thorough QL B investigation is complete.*

13. Is there a method in which to accomplish final checks?
    a. *Final check as we currently define it (physically returning to the field to ensure that all surveyed lines are depicted, and a last chance to resolve discrepancies with lines indicated on record) would not be possible as no surface marks nor utility identification information was obtained while using these tools.*
    b. *If supplemental survey of utility appurtenances had been completed, field checking of those points could be done.*

14. Do we need special permission from utility owners?
    a. *No special permission is anticipated.*

15. Can the tool damage a utility?
    a. *Neither the TDEMI nor TerraVision II shows cause for concern.*

16. What are the maintenance requirements of the tools?
    a. *No maintenance procedures observed in the field.*

17. How do we calibrate the tools? Is it easy to do so?
    a. *Daily calibration throughout the data collection process is needed by way of collecting data on known surveyed landmarks spaced throughout the project.*
    b. *Calibration steps are taken in the field prior to data collection to ensure proper operation and instrument response.*
    c. *Metal strips (tape or chains) are placed at convenient, regularly spaced points in the field and the location surveyed to check and allow shifting data back into alignment.*

18. Do we know when we're getting good data while in the field or do we need to wait until we get to the office and see the results?
    a. *It appears some level of information is available during the collection process. The operators can confirm that the data is being collected but no visualization of utilities is possible at that time.*

19. How many field people do we realistically need to operate these tools?
    a. *Beyond the prototype phase, it appears as though a well-trained 2-man data acquisition crew plus 2 or more traffic control people. Consideration will also be needed for traffic conditions that would trigger the need for a truck-mounted attenuator and/or policemen on site to control traffic at signalized intersections at a given project location.*

20. How much ground can we cover per hour?
    a. *The tow vehicle can move at 3–5 mph and cover a 4-foot–5-foot swath per pass. This is a good pace if the job site is wide open. However, it appears the greater concern is whether the new tools can cover enough of the site to get a complete picture of the project.*

21. Was the tool more accurate for certain utility configurations?
    a. *The collected data are probably easiest to interpret when looking at long, mostly straight lines. Details such as reverse taps on water lines did not show on the final interpretation.*
    b. *Most lines (water and gas) that were linear in configuration had reasonably good agreement with the surveyed So-Deep information.*

22. What types of utilities can the Terra Vision II and TDEMI units detect?
    a. *The tools, in combination did see:*
        1. *Gas lines*
        2. *Water lines*
        3. *Storm lines*
        4. *Sanitary lines*

5. *Telephone lines*
6. *Traffic control loops*

23. What size of utilities can it see?
    a. *The smallest diameter line found by the new tools was 1 inch. There were locations with smaller diameter cables (electric, telephone, and CATV) that were not found by the new tools. Traffic control loops embedded in the asphalt roadway were imaged at some locations.*

24. Can the tool detect utilities that are stacked one on top of another?
    a. *No, the line or trench might be detected, but no separation of stacked lines is expected.*

25. Is the tool affected by reinforced concrete, steel plates, guide rails, railroad tracks, etc.?
    a. *Yes, Talbotton Road near 29th Street: Instrument responses indicated a large regularly shaped pattern (7 feet × 7 feet) possibly reinforced concrete under the roadway. Limited utilities in the area, so the tools' abilities to detect utility lines lying under the detected structure not thoroughly tested.*

26. What types of materials can be detected?
    a. *Steel*
    b. *Concrete*
    c. *Ductile iron (& presumably cast iron)*
    d. *Clay*
    e. *Plastic*

27. Was the tool able to discriminate between nearby utilities?
    a. *Buried jointly electric and telephone ducts depicted as one line (VA site).*
    b. *So-Deep found (2) 6-inch gas lines running parallel and separated by 8 feet (±), the tools only found (1) of the (2) lines (VA site).*
    c. *Found "unknown" distribution system adjacent to active water distribution system (GA site). (Refer to Appendix B—Figure B.3.)*
    d. *Tools seem to have difficulty separating utility lines closer than 18 inches.*

28. Do you trust the tool enough to call the result quality level B?
    a. *Not as the sole source of field collected data:*
        1. *Though the tools do "see" utilities, direct correlation between the depicted lines and appurtenances does not exist.*
        2. *No field final check of the plotted utilities is possible, as no utility marks are placed to "final check."*

   3. *The tools provide reliable, reproducible though generic utility lines. These generic responses must somehow be correlated to the utility records and base map. This could be a difficult and time-consuming task without the benefit of a completed QL B survey at hand.*

29. Was the new tool quicker than older tools?
    a. *This is difficult to determine. It appears that the tools can cover an open area in a shorter amount of time. However, the additional time SUE technicians spend yields considerable more utility information within the scope of work (no unnecessary utilities traced/depicted). Also, SUE technicians "work" the areas inaccessible to the tools.*
    b. *Office time to process and analyze the data is much longer (weeks vs. days).*

30. Will the new tool help reduce the number of test holes?
    a. *Some test holes might not be necessary due to the data collected by the new tools. However, the limitation of the tools, such as penetration depth, inaccessible areas and incomplete detection of lines would indicate a minimal reduction of test holes at this time.*

31. Did the tool help validate other tools?
    a. *Yes and No. There were multiple locations where the utility lines "found" by the new tools closely matched the information provided by So-Deep. On the GA site, the new tools found lines not detected by conventional means nor indicated on records. Though there were several locations where the new tools merely "found" lines that were out of scope, or lines installed since the So-Deep survey.*

32. Is it easy to decide when to use this tool?
    a. *The additional cost associated with utilizing the TerraVision II and the TDEMI tools on a typical DOT project would not be cost-effective for the additional utilities found. High risk locations and areas with poor utility records should consider these tools for a more complete utility investigation.*

33. Can you convince a client to pay for the use of this tool?
    a. *Not at this point on transportation projects.*

34. How will this tool be integrated into practice?
    a. *These tools would add another layer to the procedures necessary to perform a typical quality level "B" site investigation. There are always advantages to adding tools and data for compiling a complete SUE picture. However, the use of these tools does not integrate readily into conventional SUE techniques and would start out as being a separate, independently run project. Comparisons could be made between the data sets*

from the conventional SUE project to the TDEMI and TerraVision II results; much like what was done in this field trial.

b. *These tools alone cannot provide data with enough certainty as to utility identity to achieve the QL B standard.*

35. What are the limitations on how deep the utility lines can be detected?
    a. *Limitations are determined by local soil conditions. In every instance though, conventional designating techniques yield a more comprehensive map with lines at all depths encountered on these projects.*
    b. *The TerraVision II did not reliably image any utility lines at the VA site due to clay soils prevalent in that region. At the GA site, depths in the 5 foot range were possible.*
    c. *Generally, the TerraVision II will find pipes that are larger in diameter (inches) than the depth in feet. For example: a 3-inch gas line will be found at a depth of 2 feet but not at a depth of 4 feet.*

APPENDIX D
Photographs

Figure D.1. Data collection at Virginia site in temporary traffic-controlled space, TerraVision II.

Figure D.2. Data collection at the Virginia site with traffic control vehicle following data collection with TerraVision II.

Figure D.3. UITs TerraVision II during data collection at the Georgia site.

Figure D.4. RFID tag and reader, supplied by Visible Assets, Inc., field-tested prior to tag placement.

Figure D.5. UITs TerraVision II during data collection on the Georgia site.

Figure D.6. GTI acoustic locator consisting of five receiving antennas, one sound-inducing speaker, an acoustic transmitter, and an operator with laptop.

Figure D.7. Staging area with TDEMI unit.

Figure D.8. TDEMI data collection at Virginia site.