EFCOG Best Practice #84

Best Practice Title: Subsurface Investigations

Facility: Idaho National Laboratory

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Brief Description of Best Practice: Subsurface investigation survey processes (see Best Practice for Subsurface Investigations)

Why the Best Practice was used: In 2004 the INL Environmental Safety and Health (ES&H) organization made a request to provide better information on the subsurface investigation process prior to excavations.

What are the benefits of the Best Practice: Improvement of the designation of interferences in the subsurface investigation processes, to minimize unplanned interruption of utilities, to mitigate project delays due to repair of damaged utilities and to promote greater safety working conditions for INL employees and subcontractor employees.

What problems/issues were associated with the Best Practice: Additional associated costs due to providing an enhanced subsurface investigation.

How the success of the Best Practice was measured: Trending of excavation "hits" has shown there have been fewer unexpected findings, less damage to utilities and overall worker safety has improved significantly.

Description of process experience using the Best Practice:

The INL regularly uses this process to improve the designation of interferences in the subsurface investigation process, to minimize unplanned interruption of utilities, and to mitigate project delays due to repair of damaged utilities. The method also inherently supplies information for remarking purposes, versus re-surveying, as well as developing institutional memory and incident forensic capabilities.

The process has improved worker safety through a better understanding of the subsurface prior to excavation/penetration as well as better hazard communication between workers, safety personnel and management. The process has improved savings from unplanned costs to projects due to utility strikes and has aided greatly in the design and work control development stage of a project through improved information in the contracting and bid process.

White Paper Attachment for Best Practice #84
Subsurface Investigations
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Introduction

This best practice covers subsurface survey processes developed at the Idaho National Laboratory (INL) for designating interferences prior to excavation (and penetration) planning and operations. These processes were first shared at a Department of Energy (DOE) workshop for hidden electrical hazards at the Savannah River National Laboratory in Early 2008. The results of this meeting was a proposal to form a sub-committee, under the Electrical Safety Committee, this concept was presented at the fall meeting for the Energy Facility Contractors Group (EFCOG). During 2009 the sub-committee was organized and a workshop conducted at the Fall EFCOG meeting at the Hanford site. The best practices for the survey process presented here are the direct result of modifications and clarifications developed at that workshop. Two other best practices concerning Subsurface Utility Engineering (SUE) were finalized at his workshop including Training and Qualification Systems (Savannah River National Laboratory) and Subsurface Requesting and Permitting.

The INL first began developing this survey process as the response to a request in 2004 from the INL Environmental Safety and Health organization (ES&H) to provide better information on the subsurface prior to excavation. While initially focused on detection tools, it quickly became apparent that improvements were needed at many levels and we began changing the emphasis from locating tools to the overall detection process. During the next several years the process itself was refined on projects including surveys performed around INL's reactors for decommissioning as well a large effort survey for a new major utility corridor in one of INL's facilities.

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The purpose of this short paper is to share a best practice developed at the INL and reviewed through several meetings and one workshop involving SUE professionals from around the DOE complex. The underlying goal was to develop a process that a facility should be able to incorporate into an acceptable existing program without drastic internal modifications or to help guide a site in the process of building it's own subsurface capability. The approach is to provide recommendations that are both general and precise. The paper includes several sections, a description of the basic process, a discussion on current standards, the three-tiered description of geophysical efforts, and recommendations for survey approach and tool application.

Process Description

Excavation

At the INL the improved process starts when a request for a subsurface investigation is submitted. After the request is processed an initial walk-down is scheduled with the requestor, any relevant sub-contractors and facility subject matter experts (SME's) to define the area of interest.

The survey layout is generally dependent on the requestor's stated needs but should include enough area to account for later design changes and the inevitable excavation creep. This happens often enough that we regularly expand beyond the requestor's area by at least several meters in all possible directions. The survey will also have a defined origin and boundaries that can be easily related to a map-able feature such as a well surveyed building or bench mark. If there is no nearby reference then the corners are surveyed so that the investigation area and survey results can be accurately placed on the relevant drawing or GIS layer (geographical information system) .

Generally a rectangular area is laid out with clearly marked corners and dots painted on the ground with white paint (layout color). The dots are painted on one meter intervals and serve several purposes. First they clearly delineate the area cleared for excavation to all involved. They also help with the geophysical mapping surveys by serving as spacing guides when running the geophysical survey equipment. They allow for recording of properly referenced results obtained from non-mapping surveys such as radio-frequency (RF) tracing. Finally they permit the results to be easily and accurately painted on the ground prior to the excavation.

For the geophysical mapping we employ multiple geophysical methods within the defined area. Usually this includes parallel ground penetrating radar (GPR) profiles collected on 1/4 to 1/3 meter spacing (making use of the one meter dot spacing) in each of the two principle directions. In addition an electromagnetic induction survey (EMI), using a Geonics EM-61, at ½ meter spacing is performed to locate deeper interferences, utility risers and isolated metal debris. Finally a thorough RF survey is performed to locate interferences the other methods may have missed. During the field survey the RF results are recorded relative to the marked grid so they can be included in the final electronic results (maps).

Following the field surveys, the geophysical mapping data is processed and interpreted for interferences. The results are painted on the existing ground grid as well as placed in a scaled drawing, such as a verified facility AutoCAD drawing or GIS database at the INL.

Finally when the results (drawing, photographs, interference list, etc.) are sent back to the requestor, a final walk-down is performed with the requestor and any relevant subs to communicate the findings and to insure all requirements are met for work to move forward.

Penetrations

Wall and floor (structural) penetrations begin and proceed in the same manner as the excavations with the request and initial walk down. The survey area is of course much smaller and instead of white paint, a black permanent marker is used to define the survey boundary. As with the excavation approach, a mapping approach is still employed with a high frequency GPR (Mala CX System) as well as a Hilte Ferroscan. The GPR includes on-board processing of the gridded data so an image of the result is immediately available and marked on the existing grid with a large red or blue permanent marker. The main difference is in the results supplied to the requestor as a formal scaled drawing is usually not available so a scaled sketch, with local corners as reference, is substituted along with the images from the scanning equipment. A final walk down is of course performed.

Standards and Due Diligence in SUE

There are few standards with respect to what defines a SUE process and none that define an adequate geophysical survey relative to the few standards that do exist. There are various ASTM standards for the geophysical methods but they are general descriptions of method application with no focus or guidance on what to do specifically in the SUE environment.

There is one specific standard related to SUE. The ASCE standard 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data,* gives guidance in two main areas, the quality of the information that you have on the area you are planning on excavating, and a standardized terminology useful when dealing with multiple disciplines as well as regional lexicons. This standard divides information quality into four main grades (ASCE38-02, 2002);

- Quality Level D
  - *"Information derived from existing records or oral recollections".*
- Quality Level C
  - *"Information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to quality level D information".*
- Quality Level B
  - *"Information obtained through the application of appropriate surface geophysical methods to determine the existence and approximate horizontal position of subsurface utilities".*
- Quality Level A
  - *"Precise horizontal and vertical location of utilities obtained by the actual exposure (or verification of previously exposed and surveyed utilities) and subsequent measurement of subsurface utilities, usually at a specific point".*

While this qualitative scale is useful in understanding the overall quality of the subsurface information prior to breaking ground, for quality Level B there is no description of what constitutes an adequate or appropriate geophysical effort. INL addressed this internally by developing a three-tiered description of the geophysical effort relating to the SUE environment (Figure 1).

The lowest tier (Tier I) can be considered the industry standard. This is the level of effort that necessitated the INL developing a new process. It mainly employs RF instruments for the purpose of line tracing, or RF 'Designating' using the new lexicon. GPR instruments may be employed in isolated profiling to support the RF work but no mapping is performed. There is little to no knowledge retained beyond the markings on the ground and maybe some photographs of the marked-up ground after the completed survey. It can be adequate in an environment where a level of medium to high risk in hitting an unmarked utility is acceptable.

The Tier II survey or enhanced survey is the outcome of the developmental work at the INL. It takes the main portion of a Tier I survey, the RF designating, and adds a geophysical mapping component and the development of a simple bounding reference grid that allows institutional retention of the RF results. At this level multiple tools are employed (GPR, EMI, Magnetics) and all data and processed results are preserved for later use. Final results are still painted on the ground as with the Tier I survey but they are also placed on properly scaled drawings to preserve institutional knowledge. This approach is used by the INL in the low acceptable risk environment within the DOE complex.

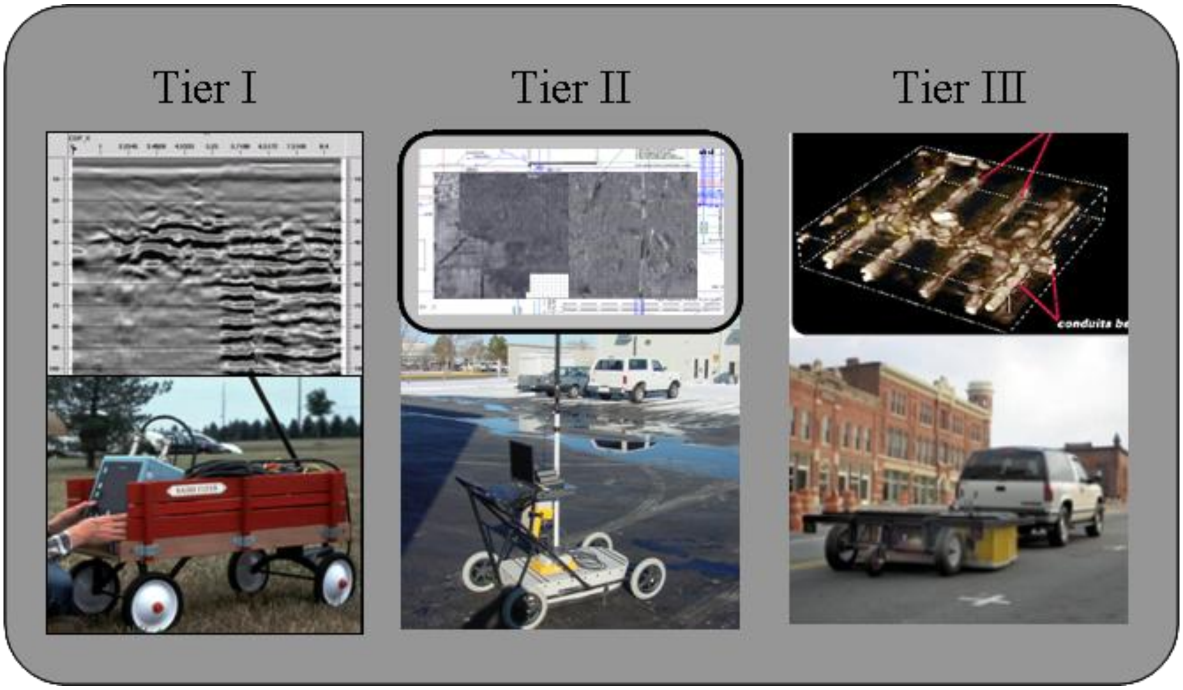

Figure 1. Graphical depictions of the three tiers defined in the INL process. Tier I (left) can be considered as the industry standard and mainly uses radio frequency (RF) tracing with some isolated GPR profiling. Little to no knowledge is retained beyond the markings on the ground. Tier II (center) or enhanced survey takes the RF work of a Tier I survey, the RF designating, and adds geophysical mapping with multiple methods and a more formalized and complete record and reporting approach. This is the most practical approach to be used in a low or zero risk environment. Tier III (right) is the level of large municipal surveys using linked arrays of sensors, and of research and development projects for developing new tools.

The Tier III level is that of the large (multiple city blocks) surveys that employ arrays of geophysical instruments (GPR, EM, Magnetics) in massive mapping projects. Also included in this group are the university research projects for improving technologies such as the step-frequency GPR's, or the research into characterizing utilities rather than just finding (designating) them. This level of effort is effective given enough time and money but is not usually available or affordable for normal DOE site operations.

Geophysical Due Diligence

With the ASCE 38-02 Quality level B better defined through this tiered description, question of due diligence and risk assessment enters in the geophysical surveying side of SUE. In an environment of acceptable medium to high risk a properly performed industry standard approach (Tier I) may serve adequately to satisfy the level of required geophysical surveying. However, in an environment of low risk acceptability such as seen in the DOE complex nuclear sites, the Tier I approach is no longer adequate and due diligence and minimization of risk requires a multi-method Geophysical Tier II approach whenever possible. That being said, even at the INL, Tier I surveys are commonly performed as adequate and appropriate subsurface investigations. However, a process (procedure) should be developed to define when the Tier I is actually acceptable. From INL experience with clarification provided at the Hanford workshop, a Tier I level of effort is acceptable only in the following cases;

- Exceptionally good institutional knowledge.
- Site authorities have developed programmatic or procedural instruction for allowing Tier I surveys.

- As verification of a repainted Tier II survey.
- Under SME and/or ES&H written discretion

Tier II and the need for multiple methods

The requirement for multiple methods in subsurface surveying is due to an inherent limitation in any single technology. This is often discussed and debated among industry professionals but the following statistics, derived from a set of 23 Tier II surveys at the INL, under different investigators and in different conditions, clearly show that any given method only finds a subset of the possible interferences (Figures 2 and 3).

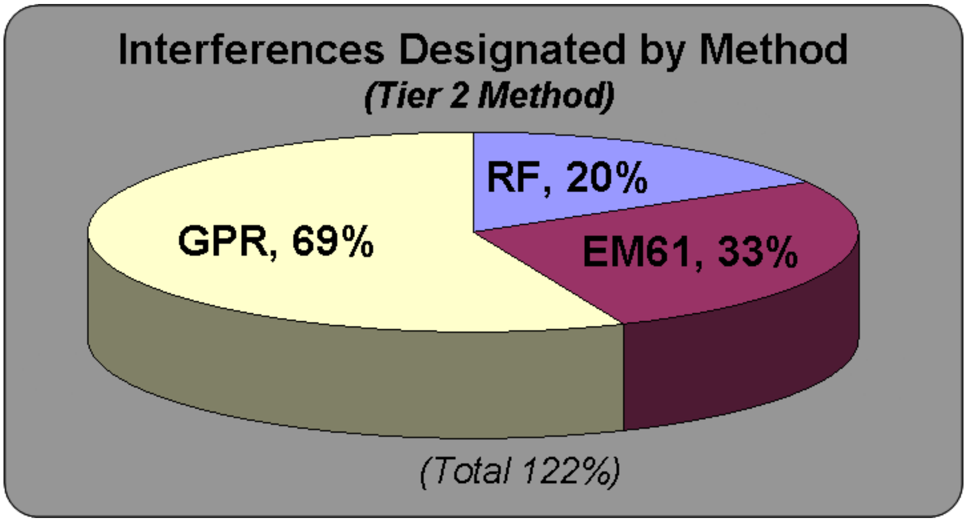

Figure 2. Pie chart showing the percentage of interferences designated by a given geophysical method for 23 Tier II surveys at the INL. Note the sum of percentages is equal to 122 % since a number of interferences were designated by more than one of the methods. This result shows that ground penetrating radar (GPR) designated almost 70% of the interferences with electromagnetic induction (EM) designating 33% and "RF Designating" finding 20% of the surface designated interferences.

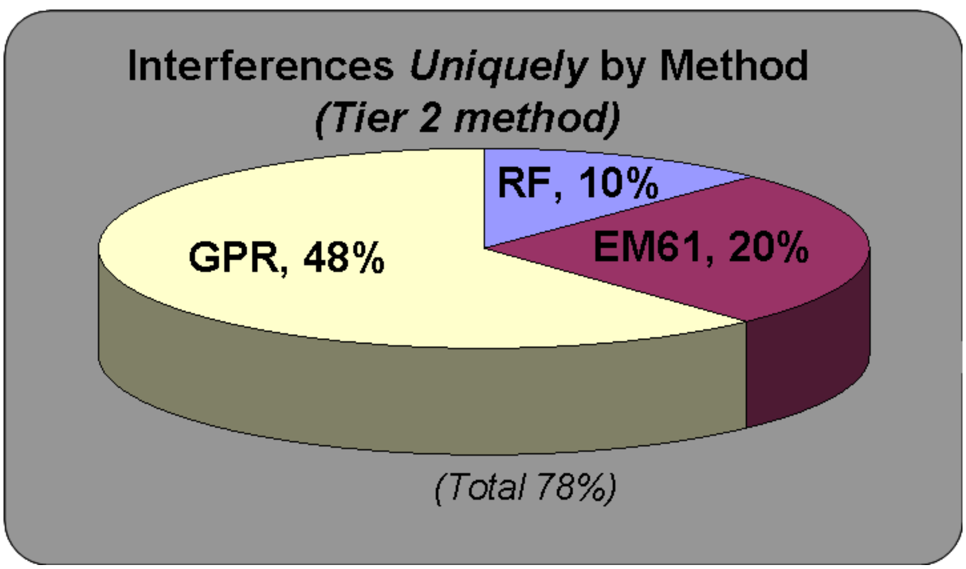

Figure 3. Pie chart showing the percentage of interferences *uniquely* designated by a given geophysical method for the same 23 Tier II surveys at the INL as shown in Figure 2. Note the sum of percentages here is only 78% as the interferences designated by more than one method were excluded. This result is worth noting in that it indicates that without the GPR

mapping approach almost half the interferences would be missed by the survey. If only the GPR mapping were to be used, 30% of the interferences would have been missed (RF and EMI). This figure graphically illustrates the requirement for multiple methods to be used in subsurface surveying.

Geophysical tools for the possible mix

With the realization that site specific conditions may adversely impact the effectiveness of any given method or tool, a minimum set of tools for a sufficiently equipped site may include:

- Ground penetrating radar cart with 250 and 500 MHz antenna for excavations.
- Radio Frequency Detection (RF) w/ 50/60 Hz detection for excavations.
- Induction Electromagnetic tool for excavations.
- Magnetometer for excavations.
- High frequency Concrete system Radar (1.6 Ghz w/ 60 Hz detect) for penetrations.
- Rebar Locator for penetrations.
- Institutional knowledge, inherent intuition, situational awareness for both excavations and penetrations.

Tier II and Method Application

Almost all SUE relevant methods can be used in several different ways. To illustrate a GPR may be used to collect isolated profiles or used to collect closely spaced profiles that are then processed and rendered in an amplitude vs. depth map (mapping). In general for Tier II surveying, a method should be applied with a high level of data density, geophysical mapping approach, rather than isolated profiling. The following lists the desired application for the different methods.

Radio Frequency Locators (RF) *(Excavation)*

- Any direct connects and induction tracing should include as much of the surrounding area (beyond the grid) as possible. At the INL this includes any nearby buildings whether they are directly affected by the excavation or not.
- The RF survey must include a 50/60 Hz power sweep in both directions covering the entire survey area and surrounding areas.
- Two Man induction Sweeps are required for large areas with no direct connects. This should include sweeps in at least two directions and in any direction normal to expected interferences.

Ground Penetrating Radar (MHz) *(Excavation)*

- GPR should be employed with a mapping approach where closely spaced profiles (1/4 to ½ meter) are acquired in each principle direction to allow for effective interpretation of time/depth sliced data and to ensure adequate overlap and coverage of the survey area. At the INL a 1/3 meter spacing is most common with 1/4 meter used for smaller areas or rougher surfaces, and 1/2 meter spacing for large (>30 m sides) smooth areas.
- Distance based data collection (counter wheel vs. timed collection) should be used and trace spacing along the profile should be small enough to adequately sample the shallowest interferences. At the INL a trace spacing of 2-4 cm is usually used.
- Depth estimations must be calculated based on data derived velocity estimations using migration analysis or hyperbola curve matching

- Antenna choice is based on expected depth of interferences or excavation and on the complexity of the survey area and expected interferences. Choices are usually between the 200-250 MHz antennas, for maximum depth penetration, and the 400-500 MHz antennas for high resolution shallow sensing.

EM Induction and magnetic surveying *(Excavation)*

- These methods should be employed with a mapping approach where closely spaced profiles are acquired to provide a densely populated dataset for interpretation.
- Profiling should be designed so there is adequate overlap of the sensing volumes between each profile. At the INL an EM-61 Mk2 (1 meter square coils) is used to collect EMI profiles at ½ meter spacing to provide an adequate overlap of the sampled data set.

Floor & wall GPR Systems (GHz range with 60 Hz option) *(Penetration)*

- Used in mapping mode (gridded) with time/depth sliced processing and imaging. At the INL a Mala CX radar system is used to collect a gridded data set and to produce time sliced radar data for interpretation.
- Include 60 Hz Scanning

Tier II and Survey Design (layout)

Tier II surveying requires a fully marked and well designed survey area that is necessary to clearly delineate the approved cleared excavation limits and to assist in the data collection process. Figure 4 shows a cartoon sketch of a typical boundary setup. The design of the survey area should be done with thought given to the following;

- Basic excavation area is defined based on the initial walk down with requestor and surveyor.
- Survey team should routinely “over-survey”, or expand the survey boundary, to account for unanticipated expansion and aide in mapping of subtle subsurface objects. At the INL we routinely expand the boundary several meters or more to account for excavation creep and future operations in the area.
- The survey should account for how existing structures and environmental conditions (e.g. gravel vs. asphalt surfaces) will affect survey boundary and grid spacing. For example, if a boundary occurs at the edge of a road, the survey may extend out to the middle of the road to better image the surface transition and to account for any interferences at the edge of the road.
- The survey grid boundary must be able to be related to a permanent physical surface object for recording the position. *(surveying)*

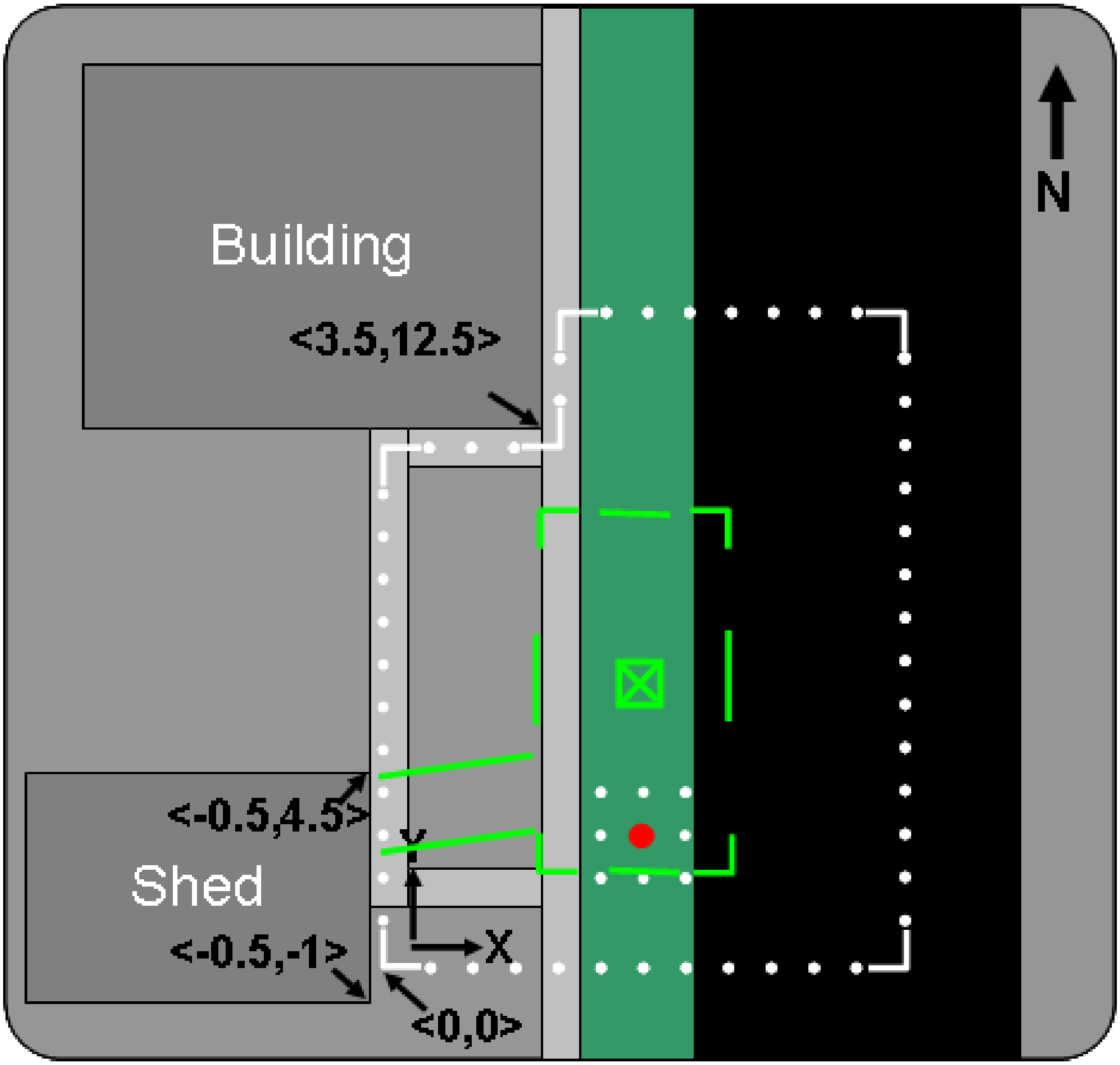

Figure 4. This sketch shows a map view of a typical 12 meter by 15 meter survey area near a building and a shed. Note this includes a cutout section around the building and what will be a 'hole' in the mapped data around a fire hydrant (red). The green outlined area (from the initial walk down) is the expected area of excavation for running a water line, tapped from the fire line, into the shed. The sketch mimics what we would do in the field with the survey area defined by painted white corner marks and painted white dots on 1 meter spacing. The origin of the survey area is defined here as the lower left (SW) corner and the mapped building corners are measured, with respect to the survey grid, for placement on a map that accurately depicts these existing buildings. The two principle directions for the survey are defined relative to the origin, and dense data collection would proceed by making use of this origin and the meter spaced dots. Later the interpreted results from processing the data would be painted on the ground using the established grid as reference. The survey area was expanded to allow for excavation creep and to better image interferences that may be running down the edge of the road.

Tier II and Reporting Details

Probably the greatest variance across the industry is the level of reporting of subsurface results. The process developed at the INL not only improved the surveying but also better defined how the results should be presented and reported. This section covers the tools used in reporting results as well as the required parts of a complete report.

At the INL a completed subsurface report prepared for the client will have used several different software tools including a word processor, a scaled drawing program (AutoCAD or ARC-GIS), geophysical data processing and imaging software (Geosoft, Surfer, GPR-Slice, etc.), and finally an electronic document management system (database). A sub-surface investigator needs to be familiar with all these programs.

Scaled Drawing

A completed report must include a properly scaled map or drawing of the designated interferences (utilities). This must be an accurate formalized drawing, either by CAD or similar software, that includes survey grid reference points, designated interferences, or nearby physical references (buildings, sidewalk, etc.). This will serve the purpose of preserving institutional memory so that the grid and interferences can be restored later if needed (remarking). Un-scaled and hastily sketched "field maps" are not sufficient and should never be included in a report.

List of Interferences

A list of the designated interferences should accompany the drawing so that the requestor has an understanding of the interferences found and of which and how many of the methods located any given interference. This list should be in the form of a spread-sheet or delimited ASCII file and should include all information needed to redraw the interference, if needed. An example of a drawing and list is given in Figure 5.

		RTC	Corr	Perch	Area EF							
Area AB												
Feature	Depth (ft)	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)	Method(s)
Line 1	2.0	4.5	-5.5	4.5	2	6.5	6.5					GPR/EM61
Line 2	3.0	0	1.5	20	-5.5							GPR/EM61/RF
Line 3	3.0	0	1.5	25	1.5	41	1	43	-1	43	-5.5	GPR/EM61
Line 4	4.0	0	6	14	5.5	20	5.5	22.5	6.5			RF
Line 5	unk	19.5	-5.5	19.5	6.5							EM61
Line 6												
Line 7	5.5	0	5.25	25	5.25	36.5	5	36.5	-5.5			GPR/EM61/RF
Line 8	2.0	29.5	0.5	29.5	6.5							EM61
Line 9	2.0	3.5	-5.5	3	-1							GPR/RF
Line 10	2.0	17	-5.5	17.5	6.5							GPR/EM61
Line 11	2.0	14.8	6.5	14.8	4							GPR/EM61/RF
Line 12	3.0	12.5	6.5	12	-5.5							GPR
Line 13	2.5	25	6	44	6							GPR
Line 14	1.5	45.1	-5.5	45.5	6.5							GPR
Line 15	1.5	46.6	-5.5	46.8	6.5							GPR
Line 16	2.5	41.2	-5.5	41.2	6.5							GPR
Line 17	2.5	42.5	-5.5	42.5	-1	43.5	6.5					GPR/EM61
Line 18	3.0	36.5	-5.5	36.5	4.5	33	6.5					GPR/EM61

Figure 5. An example of a Subsurface Survey result in drawing form and a listing of the interferences designated in one survey area from the drawing. Note the drawing includes

nearby buildings and structures for reference, survey areas are marked in yellow and interferences in pink, the color used at the INL to designate unknown interferences.

Photographs

Digital images of the results painted on the ground, when allowed by security and procedures, are an acceptable part of the record to be delivered to the client and stored in the database but are <u>NOT</u> to be used as a substitute for a properly scaled drawing.

Areas of Concern (AOC)

While most interferences are properly designated through Tier II surveying, there may still be areas in the survey where either soil condition prevents a clear "picture" of the subsurface, or surface condition prevent surveying in small areas within the survey limits (holes and cutouts). These areas are to be termed "Areas of Concern". Avoid the use of misleading or overly broad terminology such as *Neutral Zone, unknown, anomalous,* etc. as these terms are used with different meanings in the SUE related fields of engineering, health & safety and geophysics. Areas of Concern are to be clearly delineated on the ground, in the drawing, and in the report. They are to be communicated to project personnel (Project Managers, Supervisors, and Field Workers). Any unknown subsurface anomalies and un-surveyed areas should be clearly delineated as an area of concern (AOC). At the INL these areas are marked by enclosed boxes or circles that are hatched, both on the ground and in the drawing, and marked with the letters 'AOC'. These are areas at the INL where mechanical excavation cannot occur.

Depths and Type Identification

A large area of difference, even within the INL, is in the reporting of utility type and depth. There are national standards for the painting of identified designated interferences on the ground (blue for water lines, yellow for gas lines etc.) but in many cases the surveyor is not comfortable uniquely identifying the type of interference. In fact at the INL some investigators refuse to identify the lines and mark all as unknown. If the interference is well known and can be positively identified the national color code are used as specified in the national standards. If the utility is unknown or the surveyor is uncomfortable, mark as unknown according to conventional local practice and detail this preference, including color used, in the report and final walk down to all relevant parties.

Another area dependent on the surveyor's comfort level is reporting the depth of an interference. Some surveyors using Tier II methods with adequate GPR processing have little concern in reporting a depth while others have little confidence, especially if they are only performing a Tier I RF survey. Like utility type, interference depths should be reported only if accurately known but the surveyor must also report the tolerances of that depth (e.g. 2 feet ± 6 inches) to insure the client has a realistic understanding of the limitations in the measurement or interpretation.

Time limit before SI Redo

With the advent of the Tier II process, the natural time limit for the acceptance of a subsurface survey has been greatly extended. Prior to the recording of all data and results, the natural time limit of a survey was reflected by the durability of the painted results. Now with records from a Tier II survey, the time limit can be extended so long as;

- The survey area conditions and environment has not changed (e.g. new construction, excavation, removal of survey references, etc.)
- And the Tier II results can be accurately reconstructed

Marking Interferences

The main issue in how interferences are marked is to insure that all relevant parties, such as sub-contractors, are aware of the marking conventions and that the marking conventions are consistent across the site or complex. In all cases follow the DoE/Contractor contract language or national codes (APWA 2001) when possible. In situations where these are not well defined or developed, or a situation arises where they are not applicable, the following conventions are commonly used at the INL

- Survey areas are painted as dots in white (layout color)
- Linear interferences should be marked (designated) as hidden lines, both on the ground and in the drawing, with a close spaced dashed line (1 to 1 spacing) over the entire length of the interference inside the survey area.
- Avoid marking interference outside the survey area as contractors commonly assume that area was adequately surveyed as well.
- Areas of Concern should be hashed enclosed areas and clear labeled as "Area of Concern (AOC)."

Conclusions

These best practices for Subsurface Survey processes were developed at the Idaho National Laboratory (INL) and later shared and formalized by a sub-committee, under the Electrical Safety Committee of EFCOG. The developed best practice is best characterized as a Tier II (enhanced) survey process for subsurface investigations. A result of this process has been an increase in the safety and lowering of overall cost, when utility hits and their related costs are factored in. The process involves improving the methodology and thoroughness of the survey and reporting processes; or improvement in tool use rather than in the tools themselves.

It is hoped that the process described here can be implemented at other sites seeking to improve their Subsurface Investigation results with little upheaval to their existing system.

Acknowledgements

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References

ASCE38-02, 2002: Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data, American Society of Civil Engineers.

APWA, 2001: Recommended Marking Guidelines For Underground Utilities, American Public Works Association

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