REPORT S2-R01-RW-2

Development of the Selection Assistant for Utility Locating Technologies

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STRATEGIC HIGHWAY RESEARCH PROGRAM

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Development of the Selection Assistant for Utility Locating Technologies

R.L. STERLING, E.N. ALLOUCHE, J. ANSPACH, J. MATTHEWS, J. BERCHMANS, J. SIMICEVIC
Trenchless Technology Center, Louisiana Tech University
So-Deep, Inc.

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The authors of this report would like to acknowledge the contributions made by other members of the project team. Thanks go to Monica Starnes, who has helped us in many aspects of the project, participating in major team meetings, reviewing the research documents, and providing contacts for appropriate organizations and companies. Thanks also to the Technical Expert Task Group, which has followed the project from the start to the preparation of the project report and the presentation of its conclusions.

The Selection Assistant for Utility Locating Technologies (SAULT) website also contains searchable databases of utility-locating equipment, utility-damage case studies, and applications of Subsurface Utility Engineering (SUE) approaches. The information for these databases has been gathered from the literature and company websites, as well as through personal contact with many professionals in companies and research organizations. Their help and support are greatly appreciated.

FOREWORD

Monica A. Starnes, PhD, *SHRP 2 Senior Program Officer*

This is the second report published from SHRP 2 Renewal Project R01: Encouraging Innovation in Locating and Characterizing Underground Utilities. While the first publication focused on reporting existing and emerging technologies and recommending subsequent research work in this area, this report presents the development of the Selection Assistant for Utility Locating Technologies (SAULT). SAULT is a web-based software tool that serves as decision support for identifying effective utility-locating methods for particular site and project environments.

As part of Phase 1 of SHRP 2 Renewal Project R01, the Trenchless Technology Center at Louisiana Tech University developed an extensive database designed to serve as a quick technical reference tool for existing and emerging utility-locating and characterization methods. For each locating technology, the reference database provided a short description, a comprehensive list of performance characteristics, typical applications, and an image. The database was originally developed to serve as a stand-alone application.

After reviewing the database, the SHRP 2 Technical Coordinating Committee for Renewal Research recommended further development of this electronic database into a software tool for decision support. The committee noted that the new tool should help support the day-to-day activities of designers and other decision makers in transportation agencies. This recommendation was the genesis for SAULT.

To deal with the complexity and multi-attribute nature of subsurface utility engineering and geophysical tools, the team from the Trenchless Technology Center developed SAULT as an expert-based system. Any expert-based system attempts to reproduce the performance of one or more human experts in a particular field. With SAULT, the user operates the expert system through an interactive dialogue that guides the user through a series of choices to solicit the needed input. At the end of the analysis, the user receives a summary report listing all the utility-locating methods deemed suitable for the project under consideration and any condition improvements that may facilitate the locating activities. This decision-support tool, as well as three other databases (utility locator equipment, case studies, and utility strikes), can be accessed at http://138.47.78.37/sault/home.asp. Welcome to SAULT!

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Executive Summary

This report outlines the software development tasks associated with SHRP 2 Renewal Project R01, Encouraging Innovation in Locating and Characterizing Underground Utilities. The software has been implemented in a web-based application that includes a decision-support system to assist users with limited expertise in understanding the types of utility-locating equipment that are most appropriate to different utility-locating problems. This Selection Assistant for Utility Locating Technologies (SAULT) is combined in the web application with the following three databases that were also created during the R01 project: a database containing real-world examples of utility damage, their causes and impacts; a success-stories database containing examples of the successful application of the Subsurface Utility Engineering (SUE) approach to utility-locating activities; and a utility locator technology database that provides a database of specific utility-locating equipment organized by classes of locating technology.

Chapter 1 provides the background to the R01 project and the timeline for the database and software development tasks. Chapter 2 outlines why the decision-support system was selected from the various alternatives available and describes the structure and components involved in creating the web-based selection assistant. The expert system approach uses the Jess Expert System Shell, which is embedded in a Java applet. A brief description of each of the three associated databases is also provided in Chapter 2. The appendices provide a user's manual for the website and selection assistant, as well as the expert system logic flowcharts used to build the software.

By providing this decision-support tool and reference information in a readily accessible format, it is hoped that this web application can be a valuable source of information and guidance for professionals who would like to understand how to approach utility-locating activities but do not have the technical knowledge or experience to make informed decisions just by reading the relevant literature and equipment information. This decision-support aid is not intended to replace the experience and expertise of a utility-locating professional. It is not practical to capture all of the nuances of specific site circumstances and equipment performance in a software application, and two experts may have different opinions on the efficacy of alternate approaches for a particular project. Nevertheless, being able to follow the general guidance of an experienced utility-locating professional represents an excellent starting point for understanding and questioning the expected success rate of utility-locating activities.

CHAPTER 1

Introduction

Background to the Study

This report has been prepared as part of a study funded by the second Strategic Highway Research Program (SHRP 2), funded by Congress to provide a targeted, short-term research program addressing key issues in highway transportation. The SHRP 2 program addresses four strategic focus areas: the role of human behavior in highway safety (Safety); rapid highway renewal (Renewal); congestion reduction through improved travel time reliability (Reliability); and transportation planning that better integrates community, economic, and environmental considerations into new highway capacity (Capacity). The overall goal of the SHRP 2 Renewal program is to develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities. The renewal scope applies to all classes of roads.

This is the second report prepared as a part of the SHRP 2 Renewal Project R01. The first report, *Encouraging Innovation in Locating and Characterizing Underground Utilities* (Sterling et al. 2009), examined how to encourage innovation in developing technologies and procedures that will help reduce the time and cost risk on transportation projects due to utility issues. These approaches include improving surface geophysical techniques, using existing techniques more effectively, and integrating these techniques with better record-keeping practices. The first report resulted in recommendations for funding of three follow-on research projects that were started in 2009.

The purpose of this additional report is to document the development of a SHRP 2-funded website that provides decision-support software and supporting information databases for the selection of utility-locating approaches for transportation projects.

Project Timeline

The SHRP 2 R01 project began on February 12, 2007. The draft Phase 1 report was completed in November 2007, together with databases for examples of utility damage causes and implications, applications of the Subsurface Utility Engineering (SUE) process in transportation projects, and locating equipment capabilities. After the SHRP 2 committee review, the Phase 1 report was edited, and it was confirmed on April 18, 2008, that the Phase 1 findings were accepted and that the team could proceed to Phase 2 of the project. Work on Phase 2 of the project (turning the Phase 1 recommendations into draft requests for proposal) was carried out from June to September 2008. The draft Phase 2 report was integrated with the Phase 1 report in September 2008, and the draft final report was submitted on September 30, 2008. The integrated report was approved in March 2009 and published on the SHRP 2 website in October 2009.

CHAPTER 2

Methodology

Choice of Decision-Support System

The approach to developing decision-support aids for transportation professionals was developed with the following issues in mind:

- The capability limits of individual utility-locating technologies are poorly defined and may vary from one equipment manufacturer to another even within the same basic class of equipment.
- There is little independent testing of utility-locating equipment and technologies to provide quantitative information to users or purchasers of the equipment and hence the principal information available on the range of application of different equipment comes from the manufacturers of that equipment. Some manufacturers are more optimistic than others.
- The ability of specific technologies to find utilities is highly dependent on ground conditions and site-related, error-producing conditions. These problems are described in more detail in the main R01 report (Sterling et al. 2009). This means that if the site or ground conditions can be improved, the success of the utility-locating method can be improved for the same material type, content, diameter, and depth of utility.

The issues listed have a strong influence on the type of decision-support system that can be used to provide guidance to the appropriate types of utility equipment. The following are the basic options for decision-support software:

a. Deterministic decision-support systems (e.g., the value of each attribute is compared with an acceptable range for each method alternative) (see Matthews et al. 2005).
b. Decision support based on fuzzy logic where degrees of membership of a given attribute value for a given method alternative can be expressed as a linguistic description (e.g., highly probable, probable, neutral, unlikely, highly unlikely) (see Flintsch and Chen 2004).
c. Selection based on a case-based selection approach involving comparing equipment capabilities with the characteristics of a particular locating problem (e.g., depth of utility, depth-to-diameter ratio, utility material) based on the best fit with historical cases stored in the software database (see Morcous et al. 2002).
d. Expert system analysis based on coding the questions and decisions that an experienced professional would ask and take based on the purpose of the search and the site and utility conditions (see Amirkhanian and Baker 1992).
e. Decision support provided by synthesis of the choices or preferences that an experienced group of professionals express. These can be analyzed in several ways, including, for example, the Analytical Hierarchy Process l (AHP) (see Al-Barqawi and Zayed 2008).
f. Learning-based algorithms using Artificial Neural Network (ANN), generic algorithm (GA), or another classification approach. Site and utility parameters would represent the input variable, and the likelihood of success for each approach could be the output (see Flintsch and Chen 2004).

The research team reviewed the possible directions for the decision support for utility-locating technologies and made the following conclusions:

a. Insufficient data is available in the public domain on the characteristics of specific equipment or even classes of technologies to make firm selections across all the potential variability of soil and site conditions (thus excluding deterministic methods).
b. It is not considered feasible at the current time to assemble a sufficient number of cases of successful and unsuccessful applications of utility-locating technologies under different site and utility conditions to train an artificial neural network. The large number of input variables and

possible technologies make ANN a non-optimal approach for the task at hand.

c. Many aspects of site and utility conditions are unknown when planning a utility-locating exercise. The process often becomes a series of progressively refined technological approaches—starting with the simplest and cheapest methods that are likely to work and progressing to more expensive approaches only as necessary.
d. Technological approaches are usually combined with off-site and on-site detective work to help define utility location and characteristics (user knowledge increases as part of the solution convergence process).
e. The range of potential utility types and site conditions that would affect the choice of a locating technology makes the creation of a limited set of questions that could reasonably be answered by an expert panel impractical for the type of comparisons used in the AHP process (comparisons made pair-by-pair among all the alternatives available).
f. The most feasible way to create a decision-support system at the present time is to build an expert system that follows the decision logic of a highly experienced utility-locating professional.
g. The use of fuzzy logic in making decisions would be helpful but not essential in developing expert system logic for the decision-support process.
h. The expert system will only provide guidance based on the range of conditions considered and is not a substitute for direct experience with specific equipment under specific site conditions.

Expert System Platform

The programming of the logic of expert systems is independent of the specific domain of expertise involved (i.e., the underlying logic can be used to provide decision support in many application areas). This has led since the 1980s to the development of a variety of general purpose expert system software platforms (often referred to as expert system "shells"). Some are in the public domain, while others are offered for sale as software development platforms. Expert systems are often based on crisp decision logic (definitive answers to yes-or-no questions or values of decision parameters). A smaller subset of expert system shells provides the ability to use fuzzy parameters and decision logic in the applications.

After a broad survey of the systems available, the suitability for the utility-locating application and licensing costs and conditions, the team selected Jess, the rule engine for the Java platform, version 7.1p2.

Jess is an expert system shell written in Java and uses a version of the Rete algorithm. An academic license for its usage is available free of cost and a commercial license at negotiable and reasonable prices. The software can be downloaded and installed on a web server; it is small (about 7 MB) and fast. Client computers do not need an installation of Jess. A Java-enabled Internet browser is adequate for executing Jess programs; Jess programs can be compiled and encapsulated within Java applets, which then can be embedded in a web page. This approach has been adopted for the implementation of the expert system shell in the SAULT framework (refer to the next section on software delivery approach). Such an approach eliminates the need to distribute CD-ROMs and makes software updates at a later date much easier. If desired, access to the Jess program could be controlled by constructing a user-authenticated website.

Jess programs can be edited using any text editor. Syntax definition files, which highlight keywords, are available for common text editors. Jess easily interfaces with Java. Jess objects could be used in Java programs, and Java objects could be invoked in Jess programs. This feature renders Jess easily used in conjunction with Java's wide-ranging applications.

Jess supports both forward- and backward-chaining of rules. Fuzzy logic can be implemented using Jess by downloading the FuzzyJess extension available at National Research Council Canada's website (NRC Canada 2010). A Jess demo is available at the Jess website (Sandia National Laboratories 2010).

Software Delivery Approach

An important decision in making the software available to the user community is whether the software will be distributed to each user via CD-ROM or web access (download) and then be run locally, or whether the software will be accessed directly via the Internet from a central server. The following are the advantages and disadvantages of each approach:

- Software distribution approach
  - Advantages
    - Distribution followed by local use of the software does not require Internet access for software operation and using the application does not depend on Internet access speed.
  - Disadvantages
    - Software distribution and local installation can create a need for higher levels of user support than simply accessing an application on a central server.
- Web access approach
  - Advantages
    - Software updates and "bug" fixes can be accomplished more quickly and easily when the software is centrally located.
    - Software enhancements, such as additional data, case histories, and data corrections to be added to the application databases, can also be readily accomplished when installed on a central server.
    - The use of a centralized application greatly simplifies licensing and usage issues and reduces costs.

- With free access to the decision-support website, accessing and using the software and databases is easy and quick to accomplish.
- Disadvantages
  - Some firewall-related access problems may occur.

For the reasons listed, it was decided that the software should be made available over the Internet from a central server. This server is housed at the Trenchless Technology Center (TTC), Louisiana Tech University, and the software is to be supported by the TTC on behalf of the SHRP 2 program at least through January 15, 2012. Rights to the domain-specific information and logic used by the software are in the public domain. Software development and availability of the SAULT console requires commercial software licenses for the web server. Such licenses need to be available for Jess, Microsoft Access, Java, and others. A diagram of the software architecture is shown in Figure 2.1.

Knowledge Capture

The basis for the expert system is the career-long utility-locating experience of James Anspach (see Appendix C). In preparation for the knowledge capture sessions, a list of the expected influencing parameters for utility-locating technology choices was created. However, during the preliminary discussions session with Anspach, it was difficult to generate a decision logic starting from the effect of parameters on equipment and procedural decisions. The most effective way to capture the decision process was determined to be to follow a job-related decision process in which the nature of the utility-locating task was first identified (e.g., finding a cable or pipe), and then the series of questions that the expert would pose to help define the locating approach required would be captured. The answer to each of these questions triggers a different series of questions concerning items such as the nature of the utility material, the conductivity of the soil, and the accessibility of the utility for direct connection of an impressed signal. Because of the iterative nature of many utility-locating exercises, it was found necessary in the decision logic to include questions as to whether a particular method had previously been tried. If it had not, then this method could be suggested as the first alternative; if it had previously been tried, then an alternate method would be explored with an additional set of questions. The expected depth of the utility being sought is an important parameter; however, many decisions about the potential of various types of utility-locating approaches can be

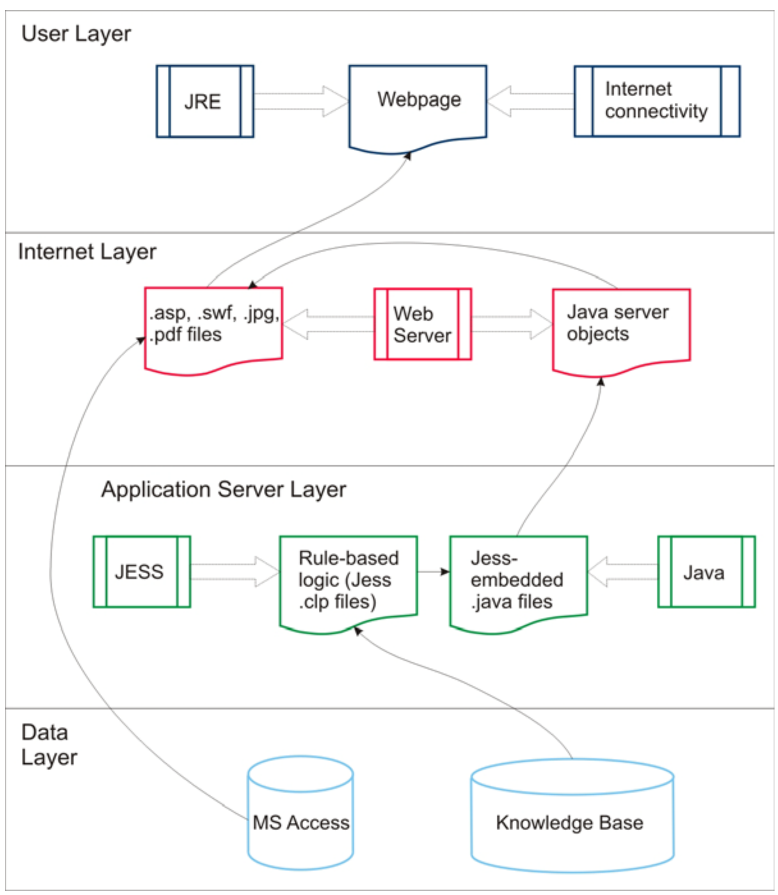

Figure 2.1. SAULT expert systems software architecture.

made with only a rough estimate of the utility's depth of cover. The flowcharts created were grouped into six individual flowcharts for ease of presentation. These flowcharts are provided in Appendix B. The decision logic may shift from one flowchart to another based on the input parameters requested, and, eventually, the decision process will result in one or more recommendations as to suitable utility-locating approaches. When none of the standard choices for utility-locating technologies are expected to be successful, the software will return the answer "Exploratory Test Holes/Prototype Systems." Otherwise, the technology choices will be one or more of the following technologies:

- Magnetic locator;
- Metal detector;
- Pipe/cable locator (low-frequency conductive mode);
- Pipe/cable locator (medium-frequency conductive mode);
- Pipe/cable locator (high-frequency conductive mode);
- Pipe/cable locator (medium-frequency inductive mode);
- Pipe/cable locator (high-frequency inductive mode);
- Pipe/cable locator (radio mode);
- Pipe/cable locator (60-Hz power mode);
- EM sonde and walkover locator;
- Noise emission device and receiver (geophone);
- Inductive array;
- Ground-penetrating radar (GPR);
- GPR (multichannel, multifrequency);
- Infrared thermography;
- Terrain conductivity meter; and
- Elastic wave-based techniques.

The success of some approaches can be increased by improving the site conditions. These condition improvements are provided as suggestions in connection with the various technology recommendations. The six condition-improvement categories are as follows:

- Remove metallic surface obstacles;
- Control ambient noise;
- Increase thermal difference between ground and utility;
- Create a new access point;
- Remove snow or leaves from the surface; and
- Isolate EM noise/optimize signal.

Software Development

With the preferred expert system shell identified, the software architecture outlined, and the knowledge capture process initiated, the software development work could commence. This consisted of a series of development stages in which a simple trial application was first tested to ensure that there were no major implementation hurdles to overcome, and then the full application was programmed. Table 2.1 gives the major software development tasks. Some of these tasks could be undertaken as parallel activities.

Three electronic databases related to utility-locating had already been developed as part of Phase 1 of the R01 project. These databases were integrated with the website presenting the SAULT application and are described in the "Related Searchable Databases" section.

Related Searchable Databases

Phase 1 of the R01 project included the development of three databases related to utility-locating issues. These databases provide the following:

- Examples of utility damage and associated cause(s);
- Examples of case studies where the SUE approach had been used for utility mapping together with assessment of its benefit, where available; and
- The characteristics of many commonly available utility-locating technologies and equipment based mostly on information from the manufacturers' literature.

Table 2.1. Major Software Development Tasks

Task
Selection of an expert system as the decision-support approach
Capture of the decision logic in a series of extended sessions with the "expert" (Jim Anspach)
Selection of the expert system shell
Design of the software delivery architecture
Preliminary testing of the expert system approach and software architecture
Development of detailed flowcharts covering all the various utility-locating parameters and site conditions based on the decision logic captured above
Customization of Jess console applet: Changing the graphic interface and printout options
Development of the Java applet integrating input and output for a pilot Jess program
Embedding the Java applet in the web page for a sample portion of the expert system to ensure functionality
Integrating the three associated databases into the website
Full development of the Jess console and Java applets
Testing and validation of the Jess program for all utility-locating modules in accordance with the flowchart logic

In conjunction with the provision of the SAULT over the Internet, it was decided to integrate the three databases with the expert system in a coordinated application. A summary of each database and its searchability via the web application follows. A user's guide to the website is provided in Appendix A.

It is recognized that none of the databases are exhaustive and that many case histories and equipment manufacturers may not be directly represented in the database. An advantage of the web-based application, however, is that additional database entries can readily be added and immediately be made available when new information is provided.

Utility Strikes Database

Utility strikes are frequent events, with a utility strike occurring nearly every minute somewhere in the country. Although most utility strikes result in minimal local damages, many others can result in fatalities, injuries, or significant collateral damage. The cost of repairing the damaged utility is often overshadowed by costs associated with disruption of services, traffic, and normal life patterns; project delays; contractor claims; and litigation.

The 60 case studies currently included are presented in a standard format. Focus is given to the characteristics of the events, a short description, and causes and lessons learned if such were reported. The utility strike incidents represent a small sample of the thousands of utility strikes that occur in the United States each year and have been summarized primarily from incidents reported in the *Underground Focus* magazine (Planet Underground Media 2010). The incidents selected provide real-world examples of utility damage incidents, their causes, and the resulting disruption and financial impact.

Utility damage incidents are collected by numerous state agencies responsible for utility safety, and a national repository has been created by the Common Ground Alliance (CGA 2010). The Planet Underground website provided in the reference also has an accident file archive.

Review of the cases included in the utility strikes database suggests that the circumstances of the strike and adequacy of the response could play an equal or greater role than the criticality of the utility in determining the degree of damage and losses incurred due to the accident.

SUE Case History Database

The SUE Case History database presents selected case histories of subsurface utility engineering success stories associated with transportation projects. The SUE process and associated quality level designations for utility information can be found in *CI/ASCE 38-02 Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data* (ASCE 2002). The database currently contains 59 cases. The case studies were obtained through discussion with practicing professionals, literature search, a survey of SUE projects conducted by the TBE Group Inc., and a research report released by the University of Toronto (Osman and El-Diraby 2005; Purdue University 1999; Sinha et al. 2007). These cases represent successful applications of SUE technologies and practices in a variety of transportation-related projects. In addition, several non-transportation related projects for which data is available as to the relative cost of the SUE effort or the estimated benefit-cost ratio, or both, for this effort are also briefly described.

From a review of the database, SUE mapping surveys seem to consistently have a positive effect when performed early during the design phase of construction projects. It is not uncommon that agencies are driven to undertake SUE investigations following one or more projects that went bad because of multiple utility conflicts or serious utility-related accidents, or both. The benefit-cost ratio to project owners in the cases documented ranged between 2 and 6.6, while the cost of the SUE studies ranged between 0.125% and 2% of the total project budget. The benefit-cost ratios in all cases considered only savings in terms of construction costs and schedule delays; costs associated with possible utility strikes were not considered due to uncertainness associated with the parameters involved. The older and more developed the area where construction is scheduled to take place, the greater is the benefit-cost potential; also, the larger the scope of the project the greater the benefit-cost ratio, and the smaller the investment in SUE in terms of percentage of total budget. It can also be noted that a study by Penn State University for PENNDOT showed a 22:1 cost ratio when it looked at 10 randomly selected PENNDOT projects (Sinha et al. 2007).

Utility-Locating Technologies Database

The electronic database of the characteristics of utility-locating technologies was assembled primarily using manufacturer data. The information available and the ranges of suggested applicability varied significantly from manufacturer to manufacturer even for similar classes of equipment.

The web presentation of the database has several areas that either provide information or can be used to refine the selection within the database. The operation of these is described in Appendix A. The utility-locating equipment is divided into various classes of locating technologies. An image illustrating the equipment used is provided for each method class together with a general description of this method class. A list of locating equipment that falls within the method class allows information on specific equipment to be accessed. This information includes performance indicators and other descriptive information, such as the following:

- Whether the equipment is expected to find ferrous or nonferrous objects, or both;
- Equipment applicability to four broad classes of soil type;
- Minimum and maximum frequency of operation when applicable;
- Effort or training required for data interpretation;
- Relative cost indication;
- Maximum depth of effectiveness anticipated; and
- General application summary and more detailed method description.

Conclusion

SAULT, though not a replacement for the experiences and expertise of a utility-locating professional, is a valuable source of information and guidance. The software's expert-system-based decision-support system assists novice users in understanding the types of utility-locating equipment and their ideal applications. Through its large databases and accessible format, SAULT will aid professionals in understanding and implementing the process of locating underground utilities.

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APPENDIX A

SAULT Website User's Guide

Introduction

This appendix is intended to serve as a user's guide for the Selection Assistant for Utility Locating Technologies (SAULT) database. The website navigation is straightforward and, hence, the operation of the website is described using a series of screenshots from the website.

The selection assistant and the three databases accessible from the website are all updatable. Corrections or additions can be sent to the following e-mail address for consideration for inclusion. The message header must include the following text: "SAULT website information update." If additional equipment or case studies are proposed for inclusion, the information must be complete and prepared in the same format as the existing database entries. The e-mail address for information submission is ttc@coes.latech.edu. In case of problems with the above e-mail address provided, please contact the Trenchless Technology Center (TTC) at 318-257-4072.

Website Access and Background Information

To access the website, use the following URL: http://138.47.78.37/sault/home.asp.

Depending on your screen size and resolution, you will see the SAULT website home page as shown in Figure A.1. The red boxes and circles superimposed on the screenshot are shown to assist in the website guidance. This home page, together with the adjacent section "About This Tool," provides background information on the SAULT software and explains the limitations of the selection assistant process for complex utility-locating problems. Information on the SHRP 2 program and a website disclaimer also are provided. The five headings across the website can be accessed from any of the individual web pages. The selection assistant software can be accessed from the home page by either clicking "SAULT Console" on the header bar or clicking "Go to the SAULT Console" at the bottom of the home page (Figure A.2).

SAULT Console

Once at the SAULT Console page, you will see the upper part of the selection assistant dialogue layout. When you arrive at this page, the JAVA applet containing the selection assistant software should begin to load. This may take several minutes when using a slow Internet connection but, once loaded, the applet should provide rapid responses to the user input independent of connection speed. Once the applet is loaded, the top portion of the page should appear as shown in Figure A.3.

If you scroll down the web page, you will see question and answer boxes (Figure A.4). This is where the selection assistant will request information from you and where you will provide the answer or selection. The first question asks you to name the analysis test case. In the web page shown, the user has entered "Test 1" as the test case name.

The next question begins a series of interactive questions in which the subsequent questions and options depend on the answers given previously. The answers involve selecting one of the options given in the question. Each option is given a number, and the user simply types in the appropriate number in the answer box. In the example shown in Figure A.5, from the choices of [1] Cable or [2] Pipe, the user has entered "2" to choose the option "pipe."

In the next screen shown (Figure A.6), the user has entered "1" to select water as the contents of the pipe from a menu of five options: [1] Water, [2] Sanitary Sewer, [3] Storm Sewer, [4] Steam, and [5] Gas.

In Figure A.7, this analysis continues with the question regarding whether the pipe is metallic. Entering "2" selects the choice [2] No and indicates that the pipe is nonmetallic.

Continuing this particular example, the next question is about the conductivity of the soil above the utility and a nonconductive soil is chosen. In Figure A.8, attention is also drawn to the history of choices that can be seen building in the box below the Question and Answer boxes. The user can scroll within this box to trace the analysis path taken to this point.

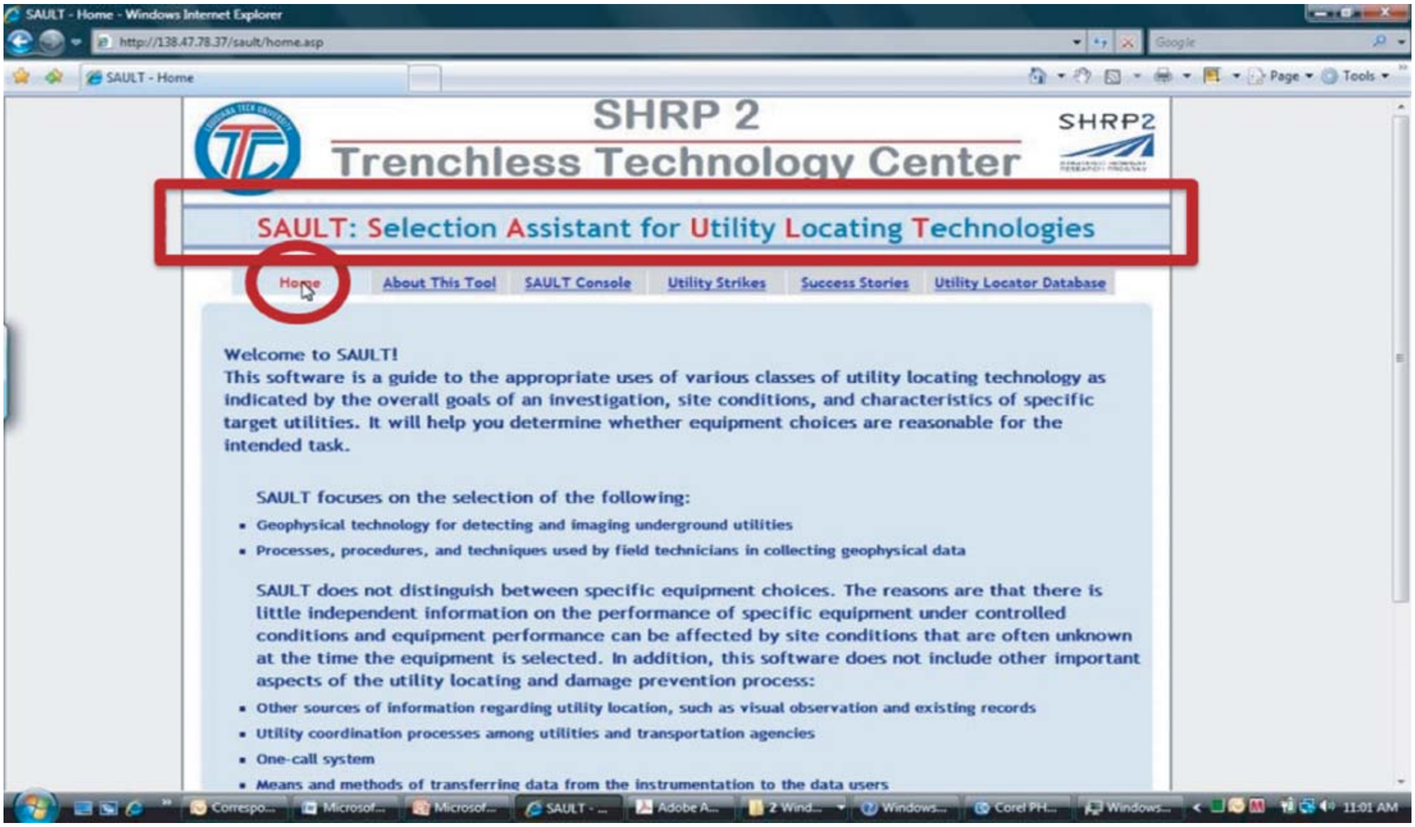

Figure A.1. SAULT website home page.

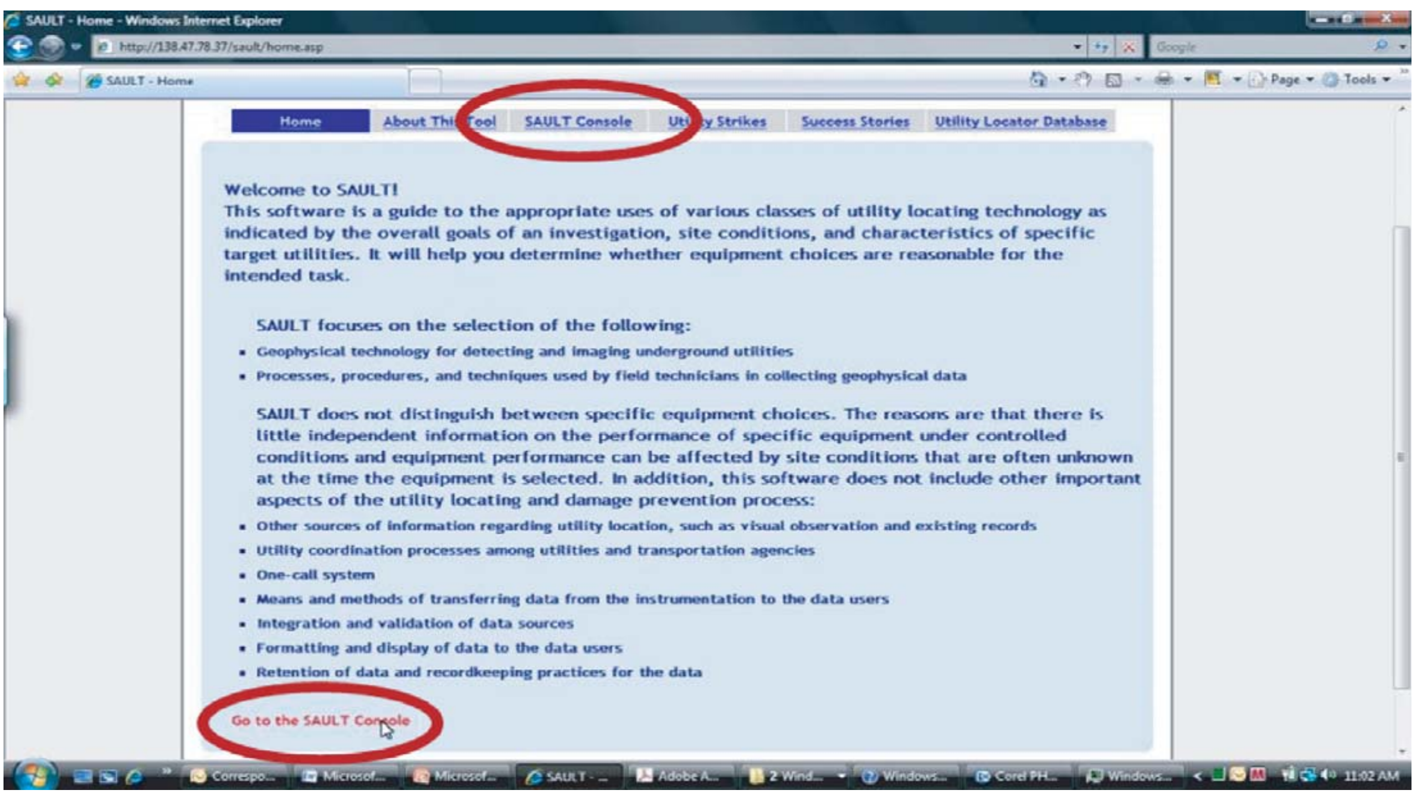

Figure A.2. The "SAULT Console" links on the home page.

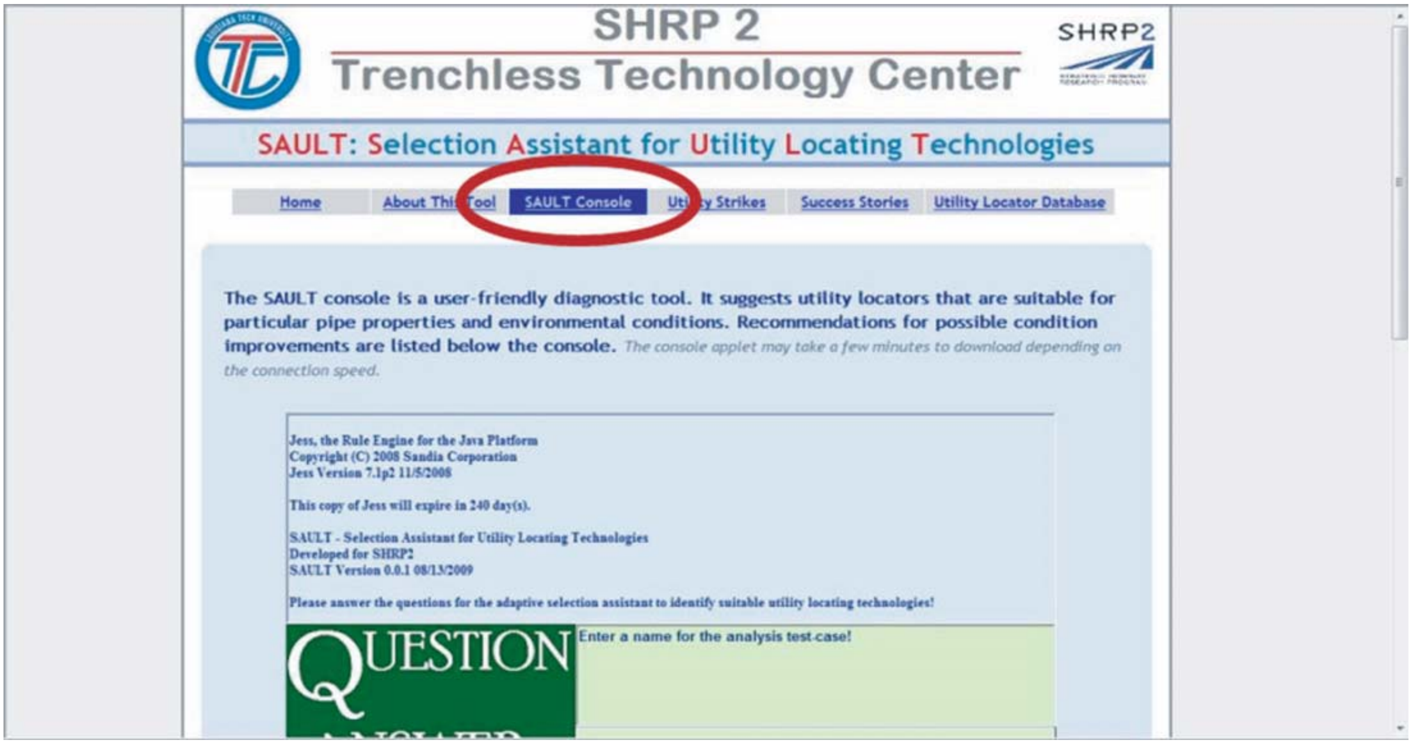

Figure A.3. The SAULT Console page.

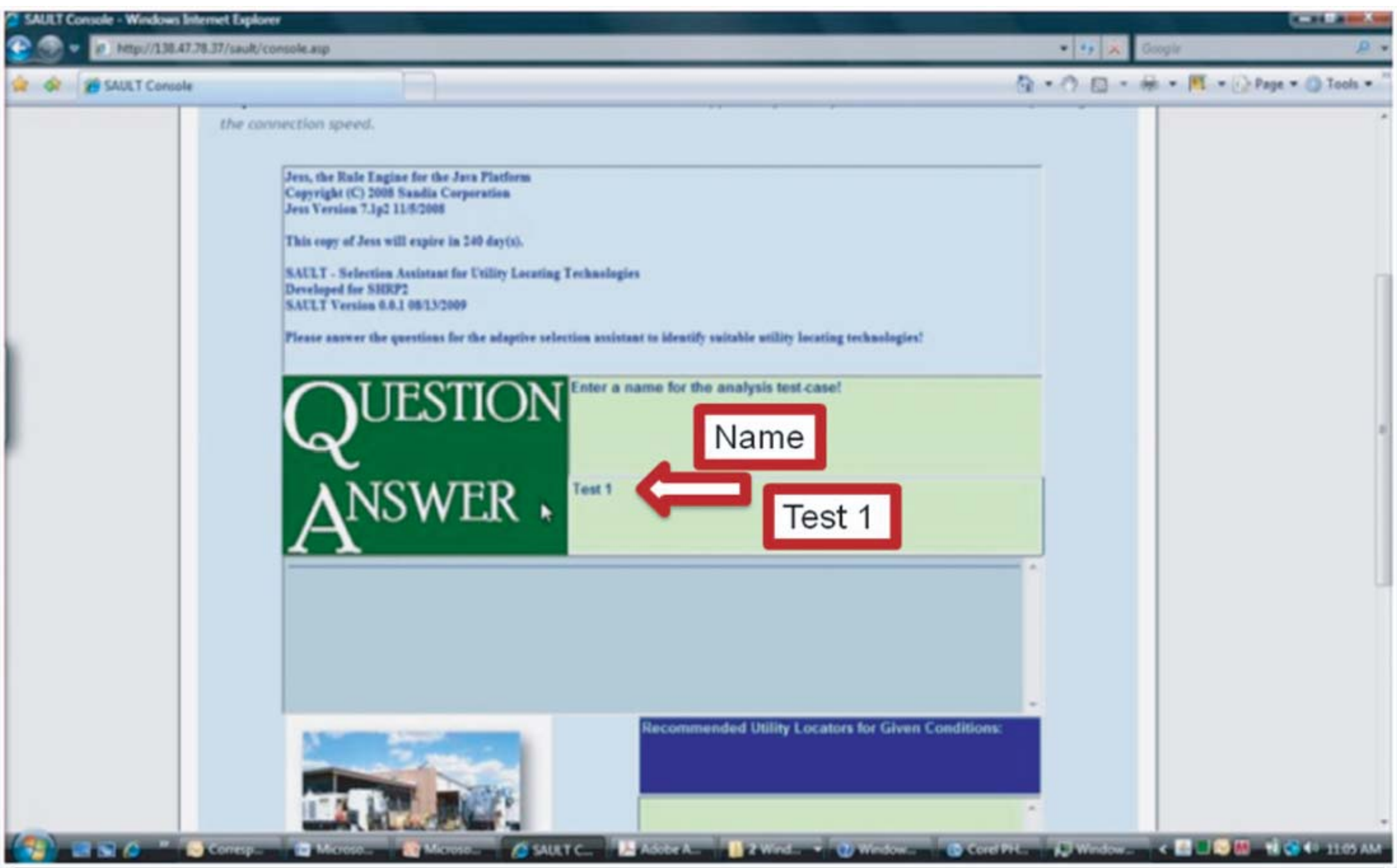

Figure A.4. Entering the test case name on the SAULT Console.

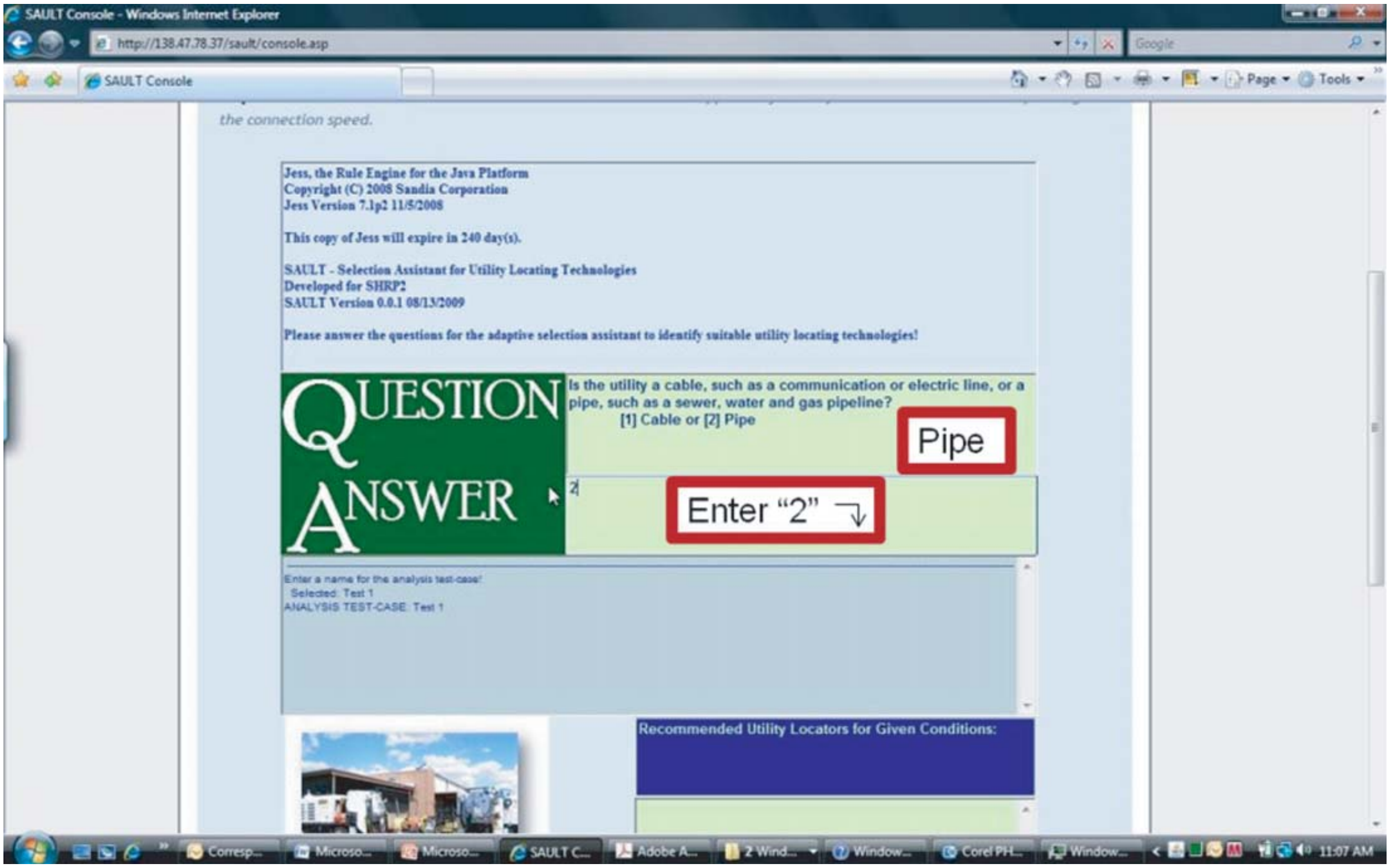

Figure A.5. Selecting an option in the SAULT Console.

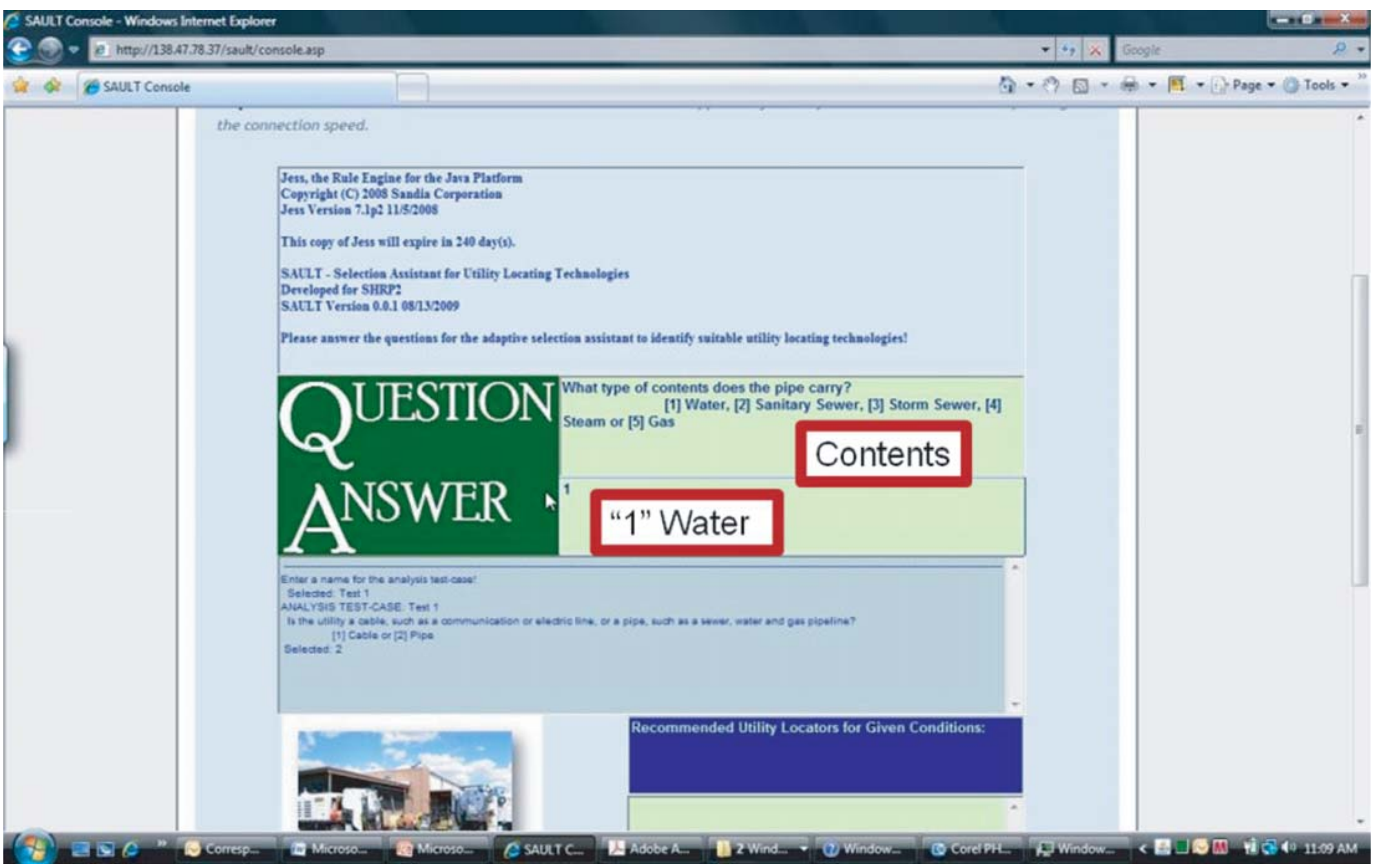

Figure A.6. Specifying pipe content.

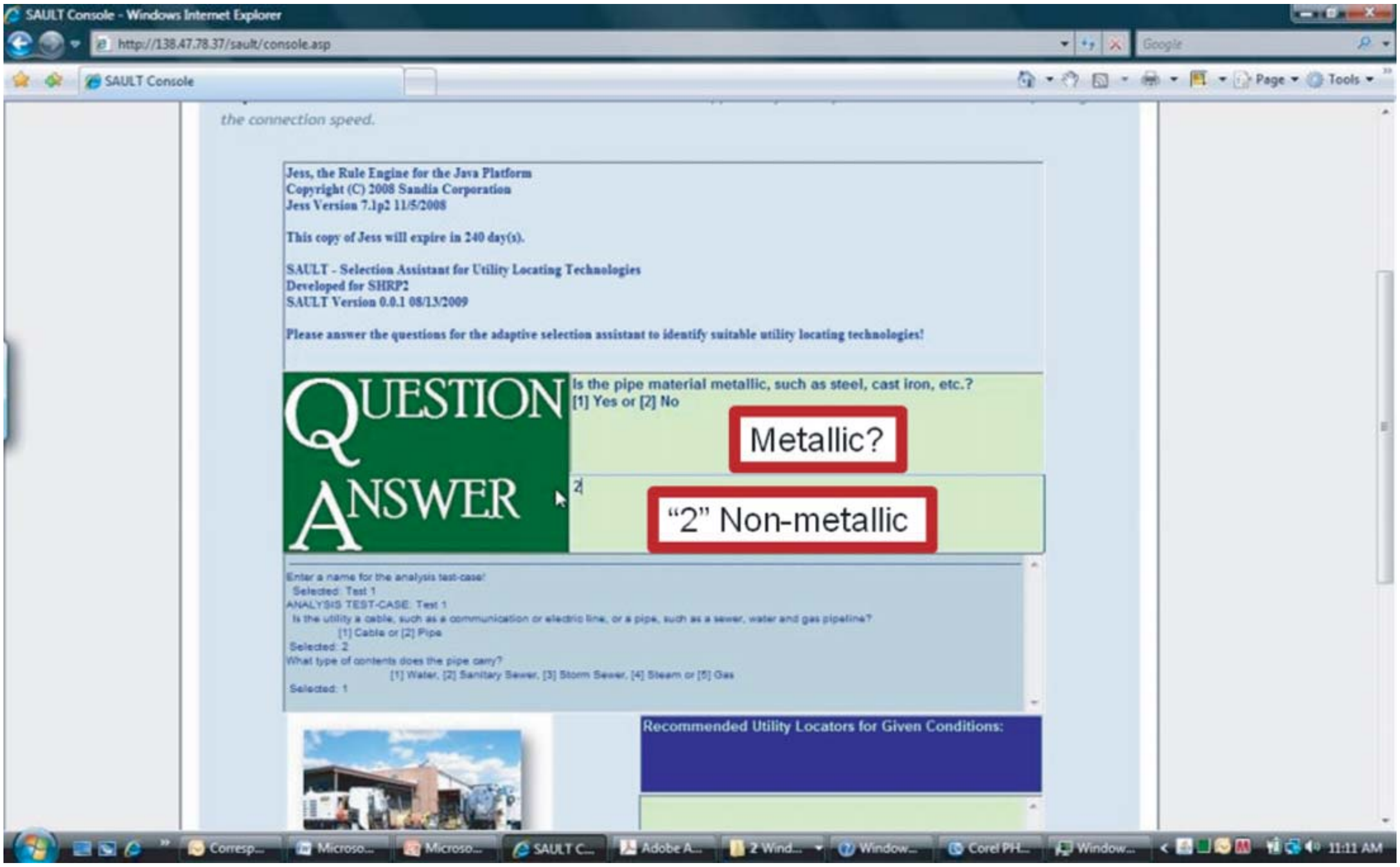

Figure A.7. Specifying pipe material.

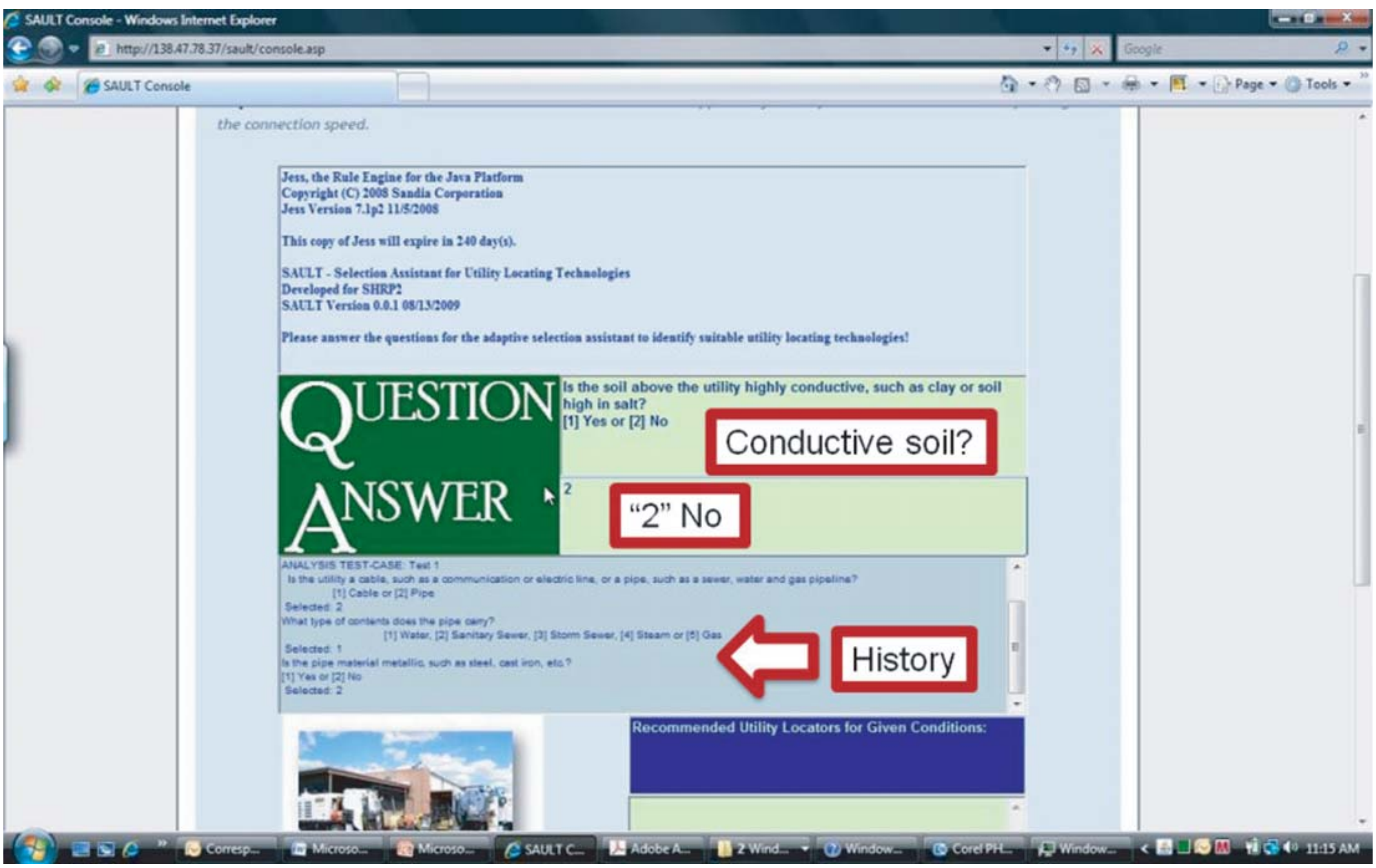

Figure A.8. Specifying the conductivity of the soil. The history of choices is also shown.

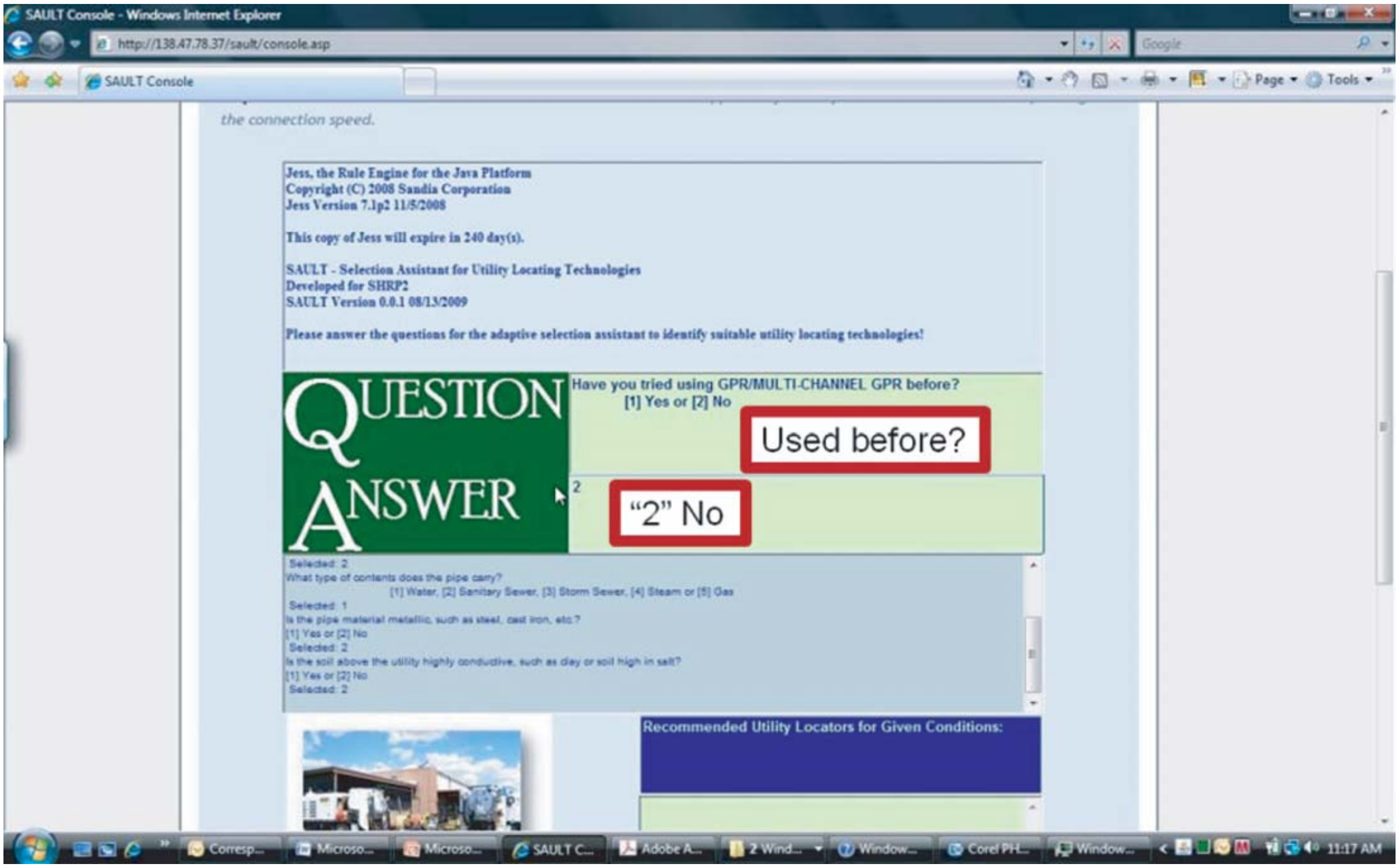

Figure A.9. Providing information about the use of GPR/multi-channel GPR.

In Figure A.9, the decision assistant requests information on whether a particular method has been tried before. This allows the assistant to suggest the most likely methods first and also to ask additional questions to help define other approaches if this option has already been attempted. In this case, the user has indicated that "GPR/multi-channel GPR" has not been used before.

In Figure A.10, a depth range for the utility is requested. These depth ranges vary according to the type of method being evaluated and the impact of depth on variations in the method selection. In this case, three depth ranges are offered, and the range "7–12 ft" has been selected.

The final question in this test case (Figure A.11) concerns the depth–diameter ratio for the utility. The choice of a depth–diameter ratio less than 6 has been made.

The final screen for this test case is the recommendation from the selection assistant. This appears in the box highlighted in Figure A.12. If there are several alternatives recommended, you may need to scroll within the box to see the full list.

Information on potential condition improvements is included with the recommendations for all answers except "Exploratory Test Holes/Prototype Systems." These suggested condition improvements indicate actions that may be taken to improve the effectiveness of the recommended technology. The condition-improvement information is shown in the lowest box as illustrated in Figure A.13. Additional information can be shown for each condition improvement by clicking the "more/less" hyperlink next to each listed improvement.

Utility Strikes Database

The Utility Strikes database is accessed by clicking on the fourth tab across the top of the website (Figure A.14). The information in the database comes primarily from accounts of utility strikes provided in the *Underground Focus* magazine (Planet Underground Media 2010). There are 60 case histories included in the database at the time of writing of this report. The case histories can be accessed either by scrolling down the database and clicking an individual record or by clicking on the search button.

A search can be conducted using any of the fields shown on the search screen or using keywords associated with each case history. To search by keywords, click on the keywords hyperlink (Figure A.15).

After clicking one or more keywords and selecting "any" or "all" keywords, click on the link "FIND utility strikes" (Figure A.16). In the example shown, the condition that the "locating/marking" was inaccurate was chosen.

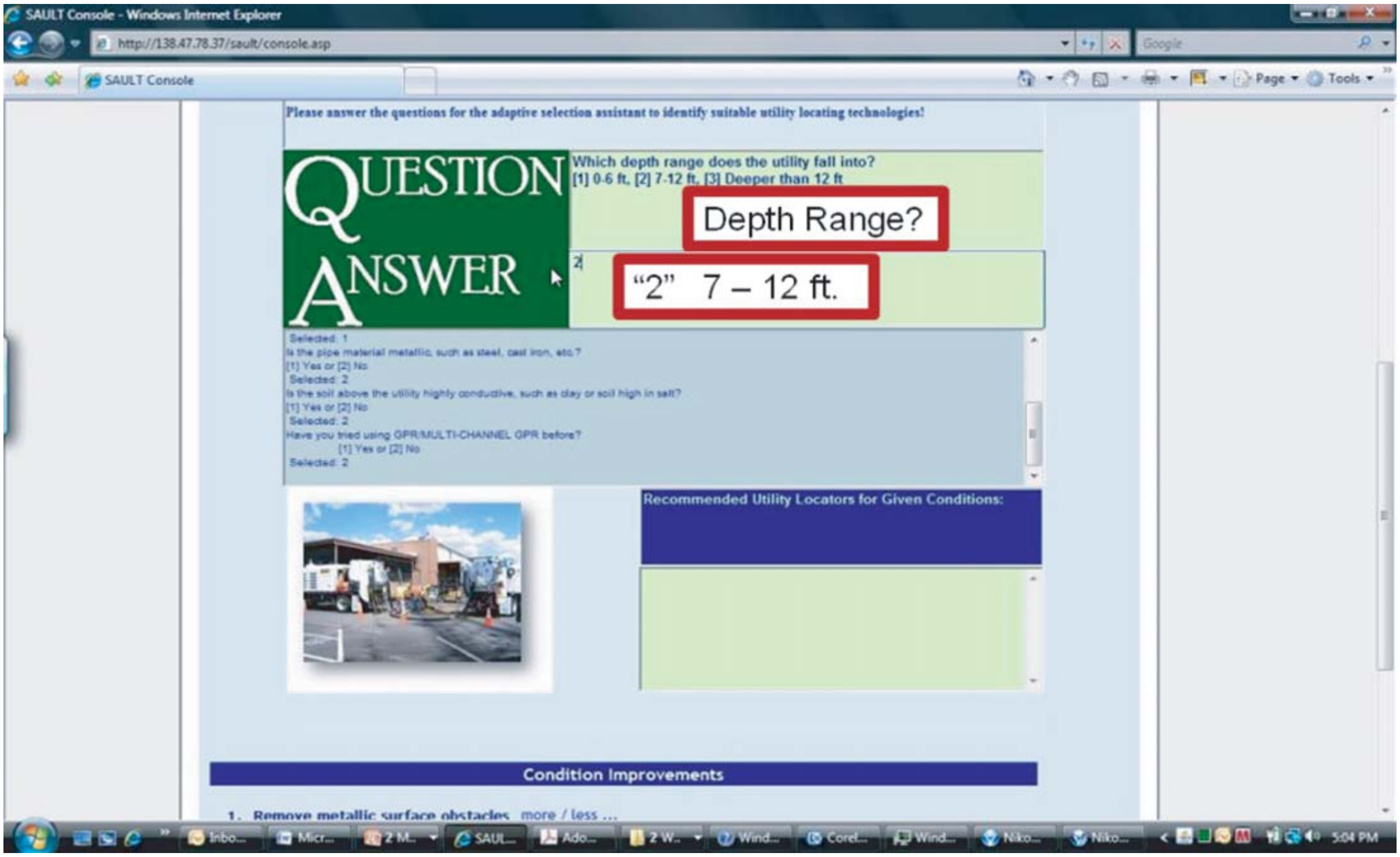

Figure A.10. Selecting depth range.

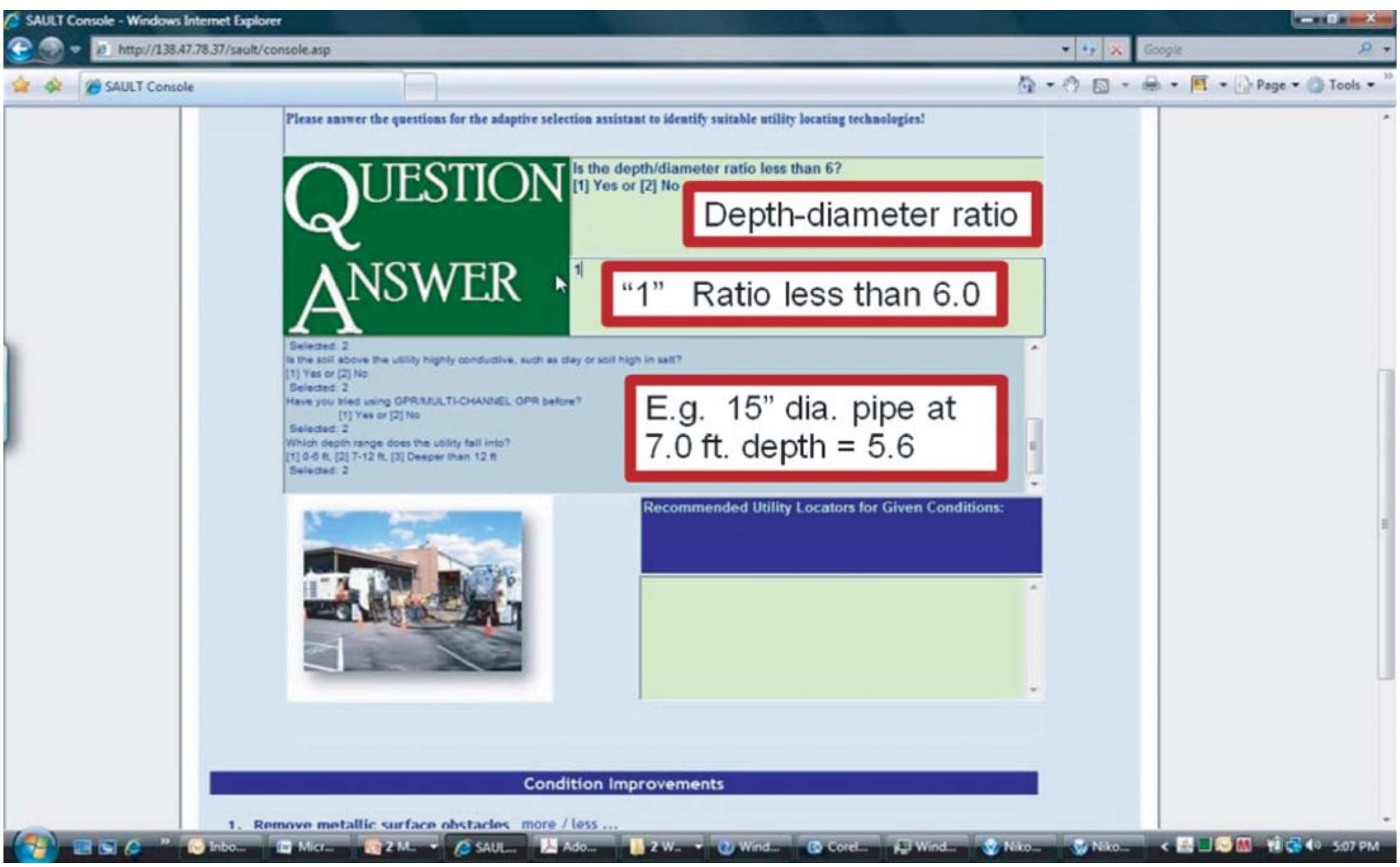

Figure A.11. Specifying depth–diameter ratio.

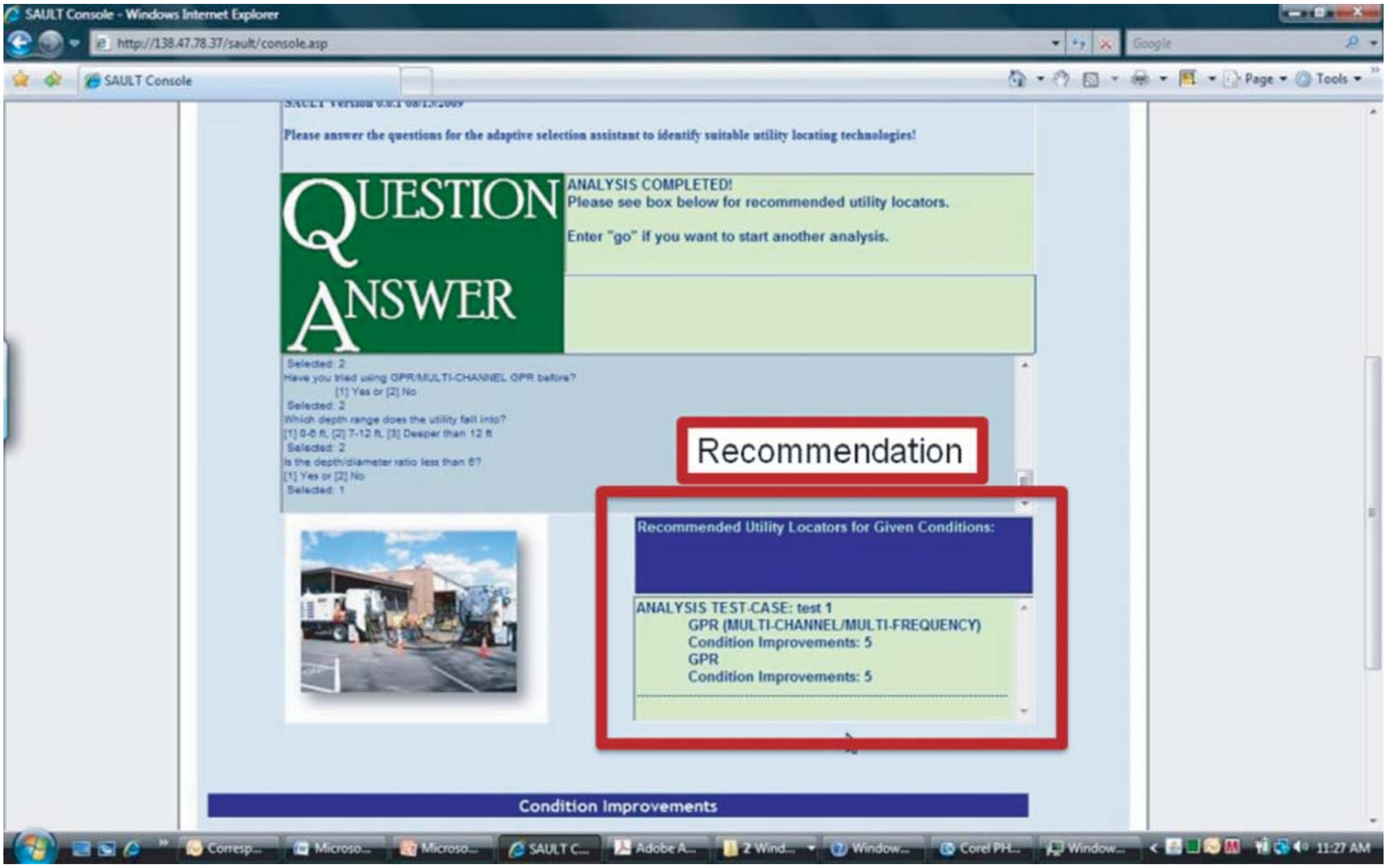

Figure A.12. SAULT recommendation.

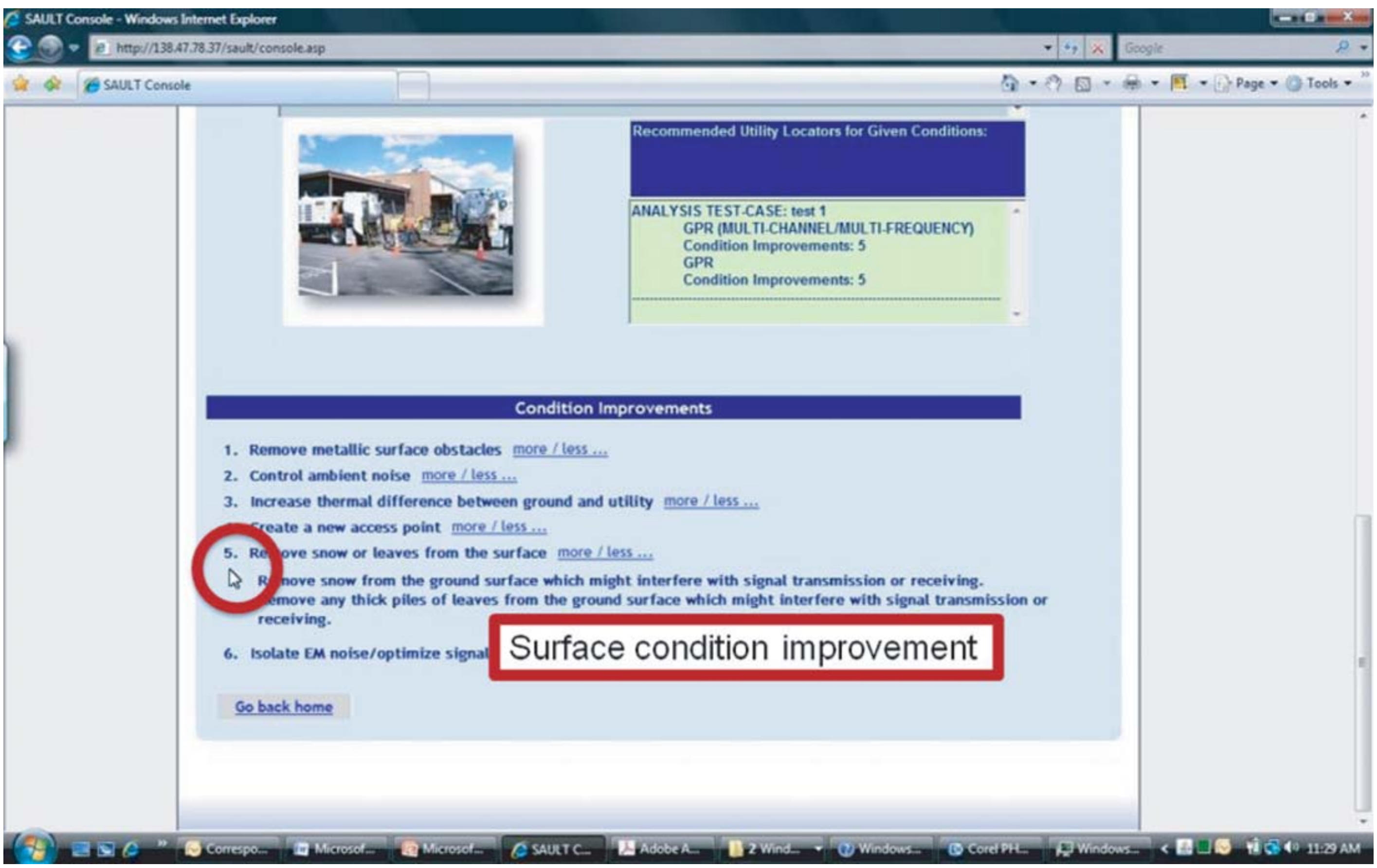

Figure A.13. SAULT condition-improvement information.

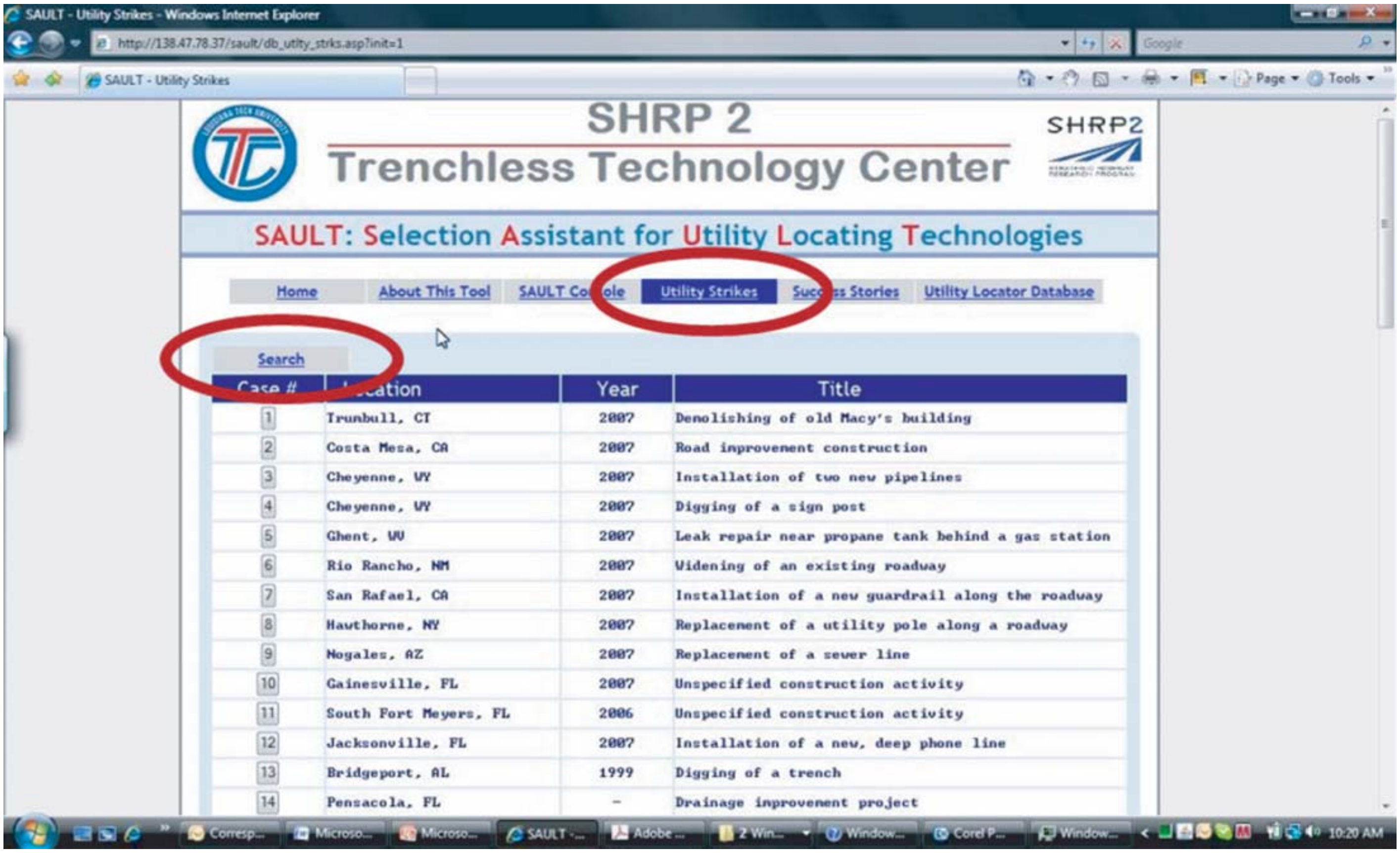

Figure A.14. SAULT Utility Strikes database.

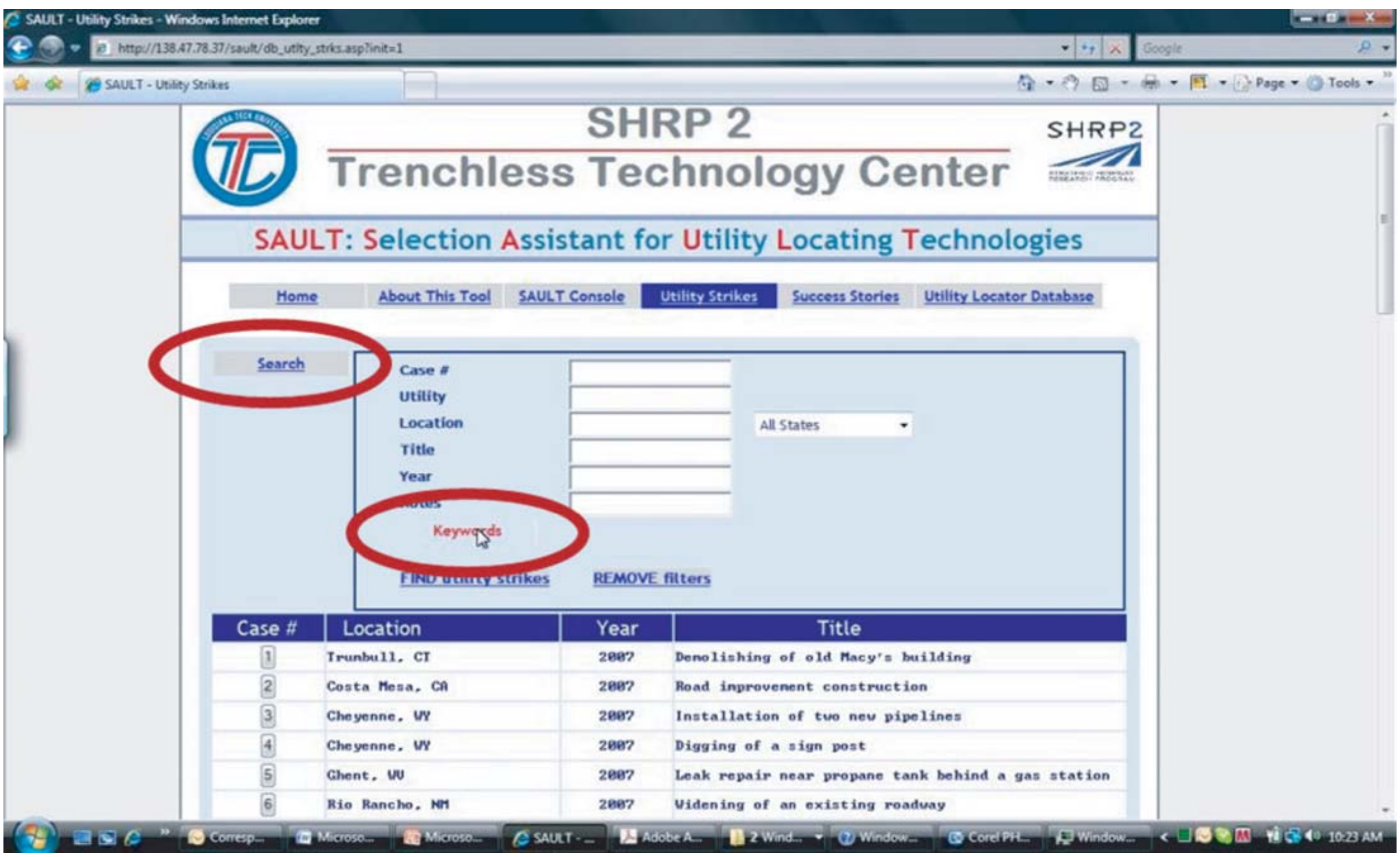

Figure A.15. Searching the SAULT Utility Strikes database.

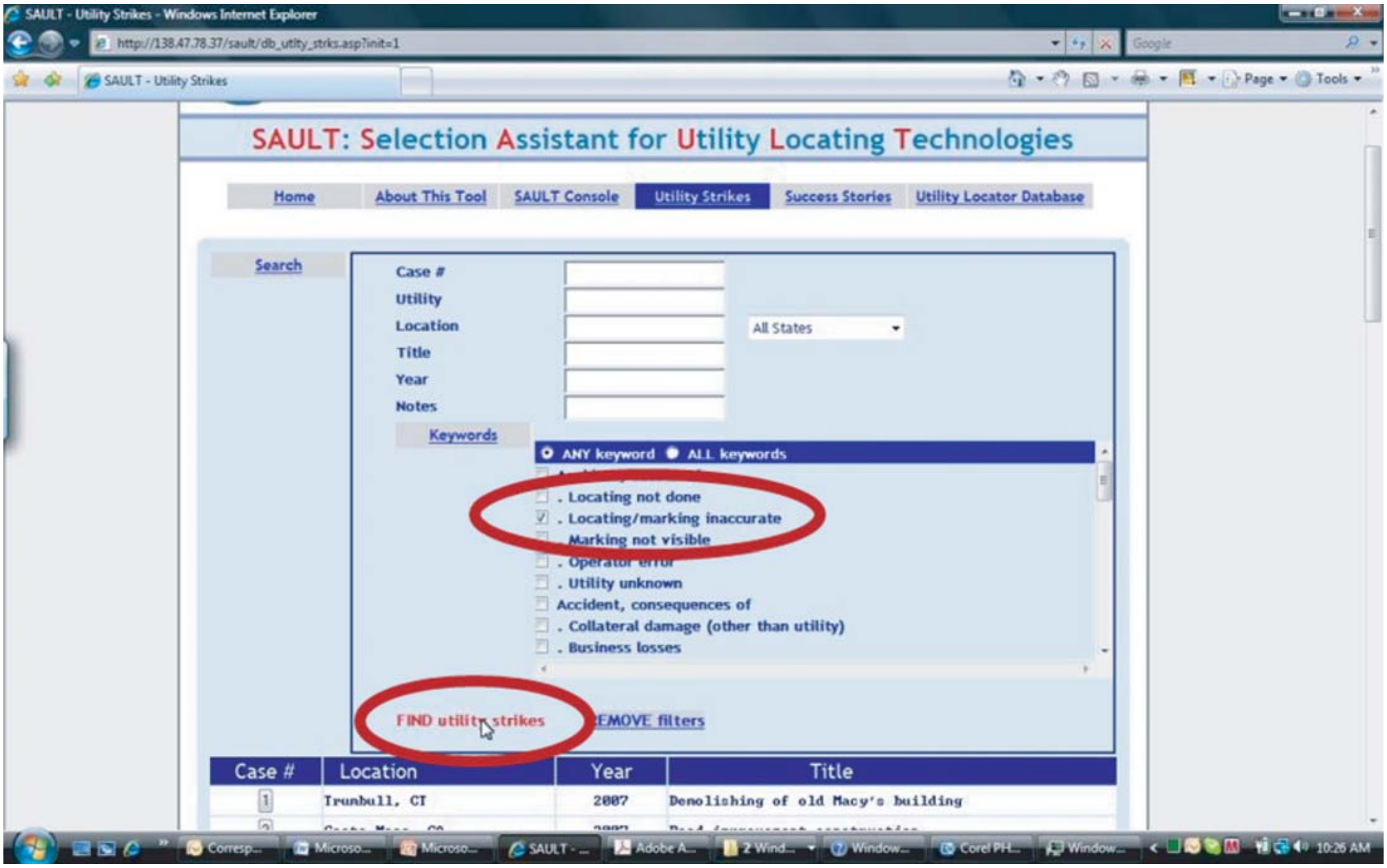

Figure A.16. Searching by keyword.

For the specified selection, 12 cases are found (Figure A.17), and any of these case histories can be opened by clicking on the individual case.

When clicking on an individual case, the case history summary opens (Figure A.18).

Success Stories Database

The fifth tab across the top of the website opens the Success Stories database. The case studies in this database were obtained through discussion with practicing professionals, literature search, a survey of SUE projects conducted by the TBE Group Inc., and a research report released by the University of Toronto. These cases represent successful applications of SUE technologies and practices in a variety of transportation-related projects. Accessing the database works in the same way as described for the Utility Strikes database. The database can provide valuable information on successful utility-locating strategies used in specific circumstances, such as deep-buried utilities and utilities around airport facilities. In Figure A.19, the initial screen for this database is shown. Fifty-nine case histories are in the database at the time of writing of this report; Case 6 is highlighted.

When Case 6 is clicked, the case history is opened (Figure A.20).

Utility Locator Database

The final database included on the website is the Utility Locator database, which is accessed by clicking on the rightmost tab across the top of the web page. This web page has several areas that either provide information or can be used to refine the selection within the database (Figure A.21). A horizontal scrolling box immediately below the web page tabs provides access to various classes of locating technologies or equipment. In the case shown, the method class "medium frequency conductive pipe/cable locator" is selected. A small picture illustrating the selected equipment is provided for each method class and, at the bottom of the screen, a general description of this method class is provided. The box highlighted on the left side of the screen provides a vertical scrolling box that lists the specific equipment currently included in the database for this method class.

Figure A.22 shows the method class "GPR" highlighted. The left-hand box provides more information about equipment.

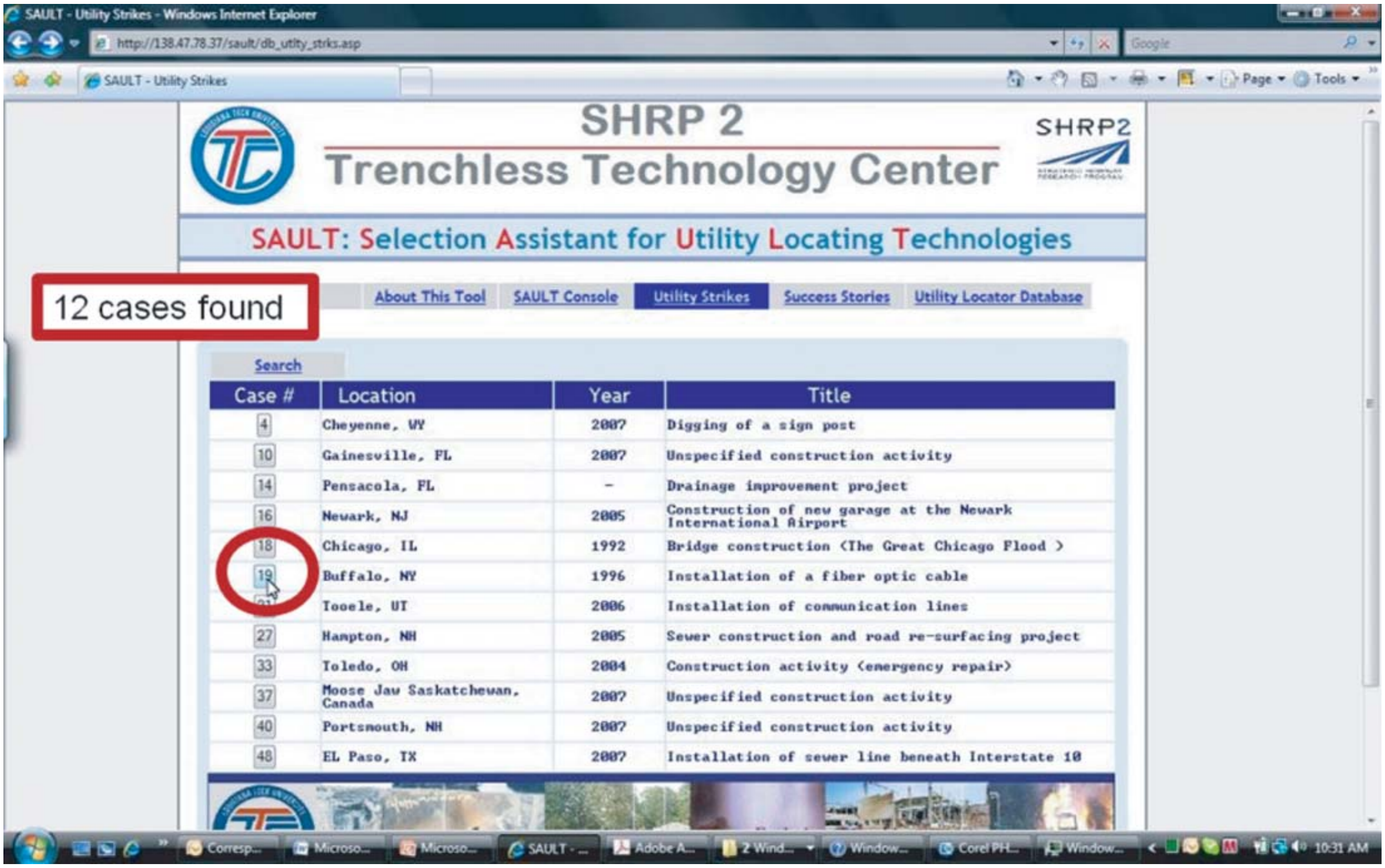

Figure A.17. Keyword search results.

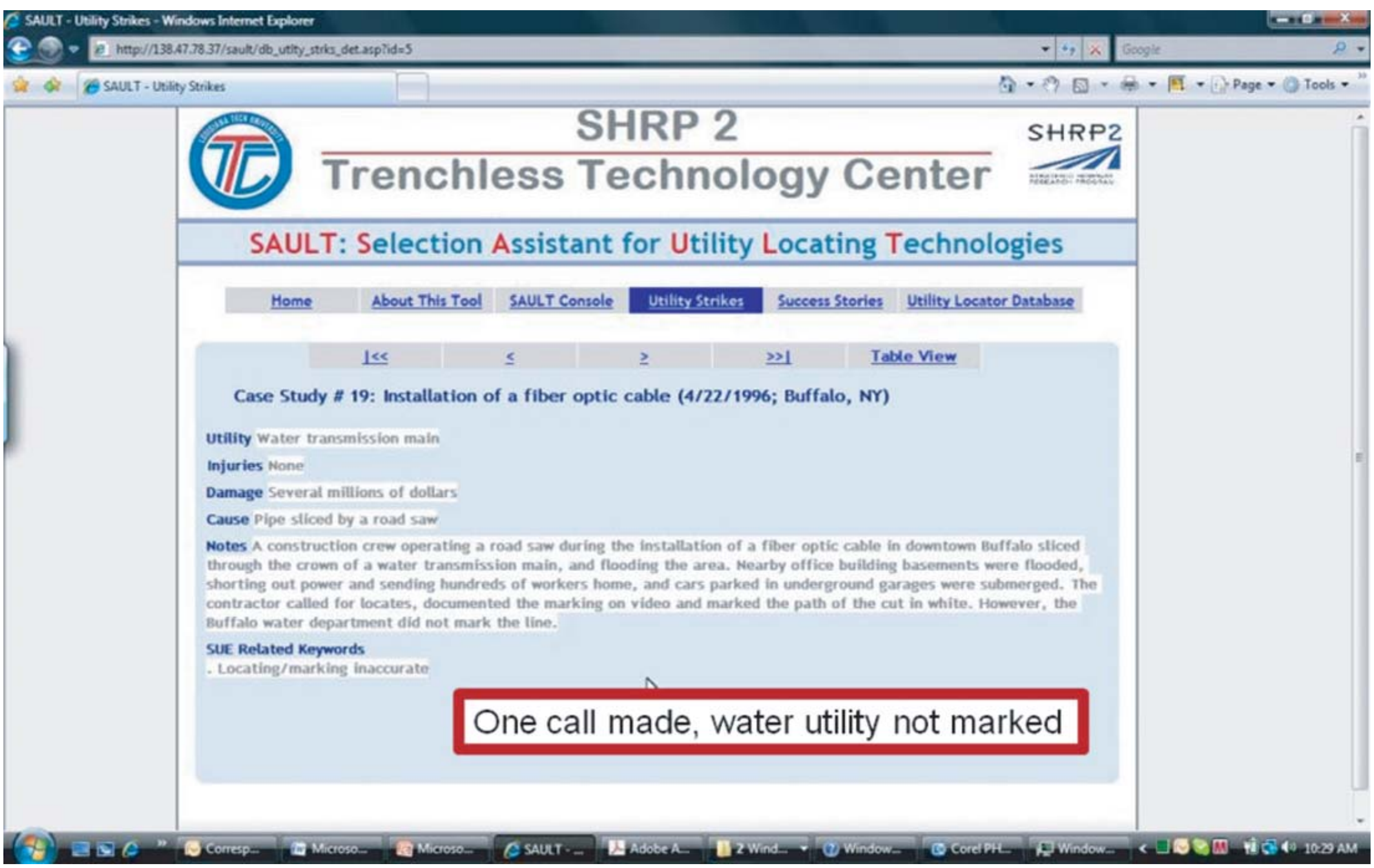

Figure A.18. Case history summary.

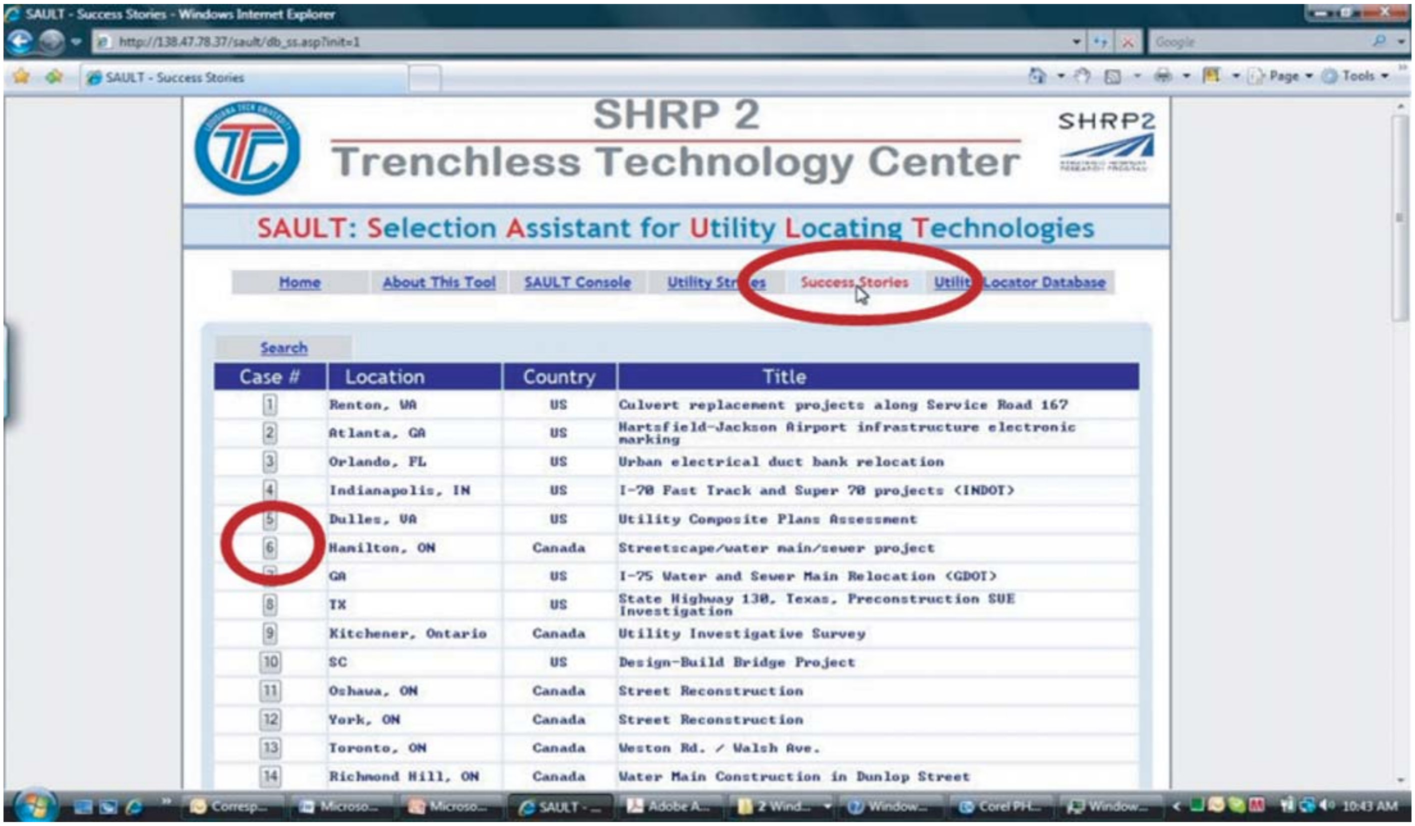

Figure A.19. The Success Stories page.

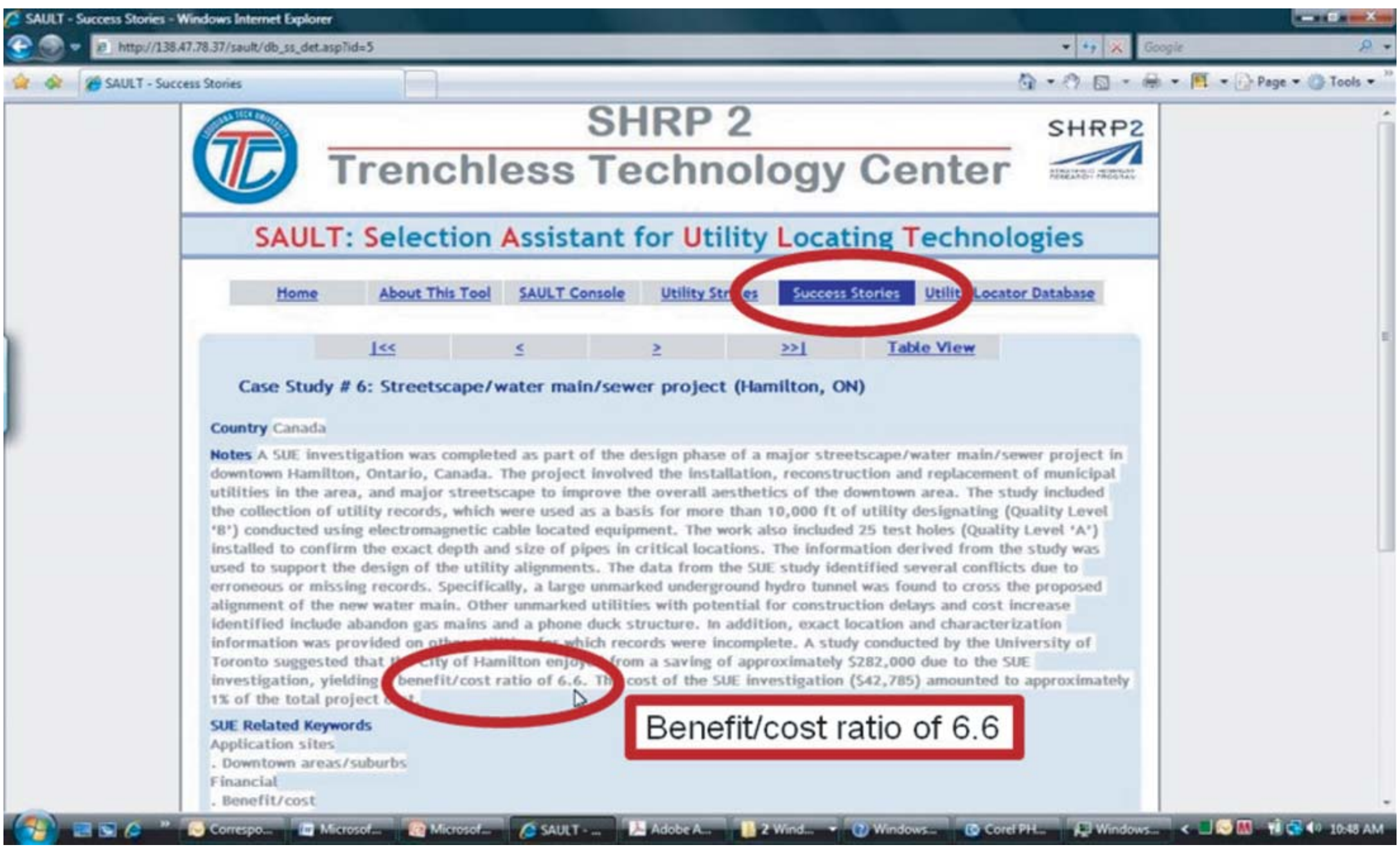

Figure A.20. Case 6 in SAULT Success Stories.

Figure A.21. The Utility Locator database.

Figure A.22. Method class "GPR" on SAULT Utility Locator database.

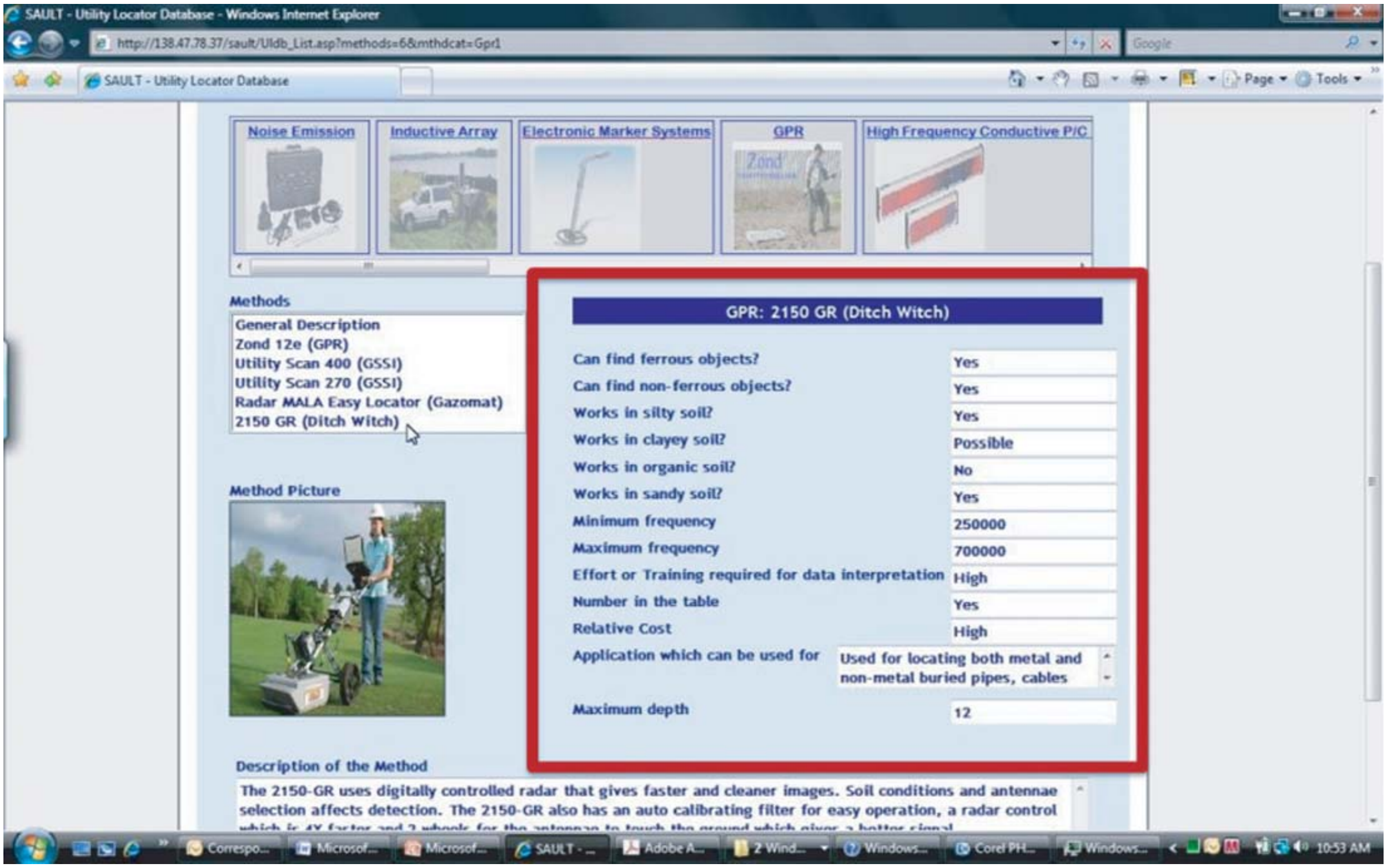

Figure A.23. Example of GPR equipment details.

When a specific piece of equipment is clicked, details on the equipment appear (Figure A.23). In most cases, the information will include an image of the equipment and a set of detailed performance-related parameters that have been collected from the manufacturer's literature, website, and so forth. These performance parameters have not been independently verified.

This completes the tour of the website and the instructions for how to access the data provided and to use the decision assistant software. To provide additional information or suggested corrections to the database information or decision-support logic, please contact the Trenchless Technology Center through their e-mail address, ttc@coes.latech.edu, or telephone 318-257-4072.

APPENDIX B

Decision Logic Flowcharts

The flowcharts that resulted from the expert knowledge capture using James Anspach as the utility-locating expert are shown in Figure B.1 in the pages that follow.

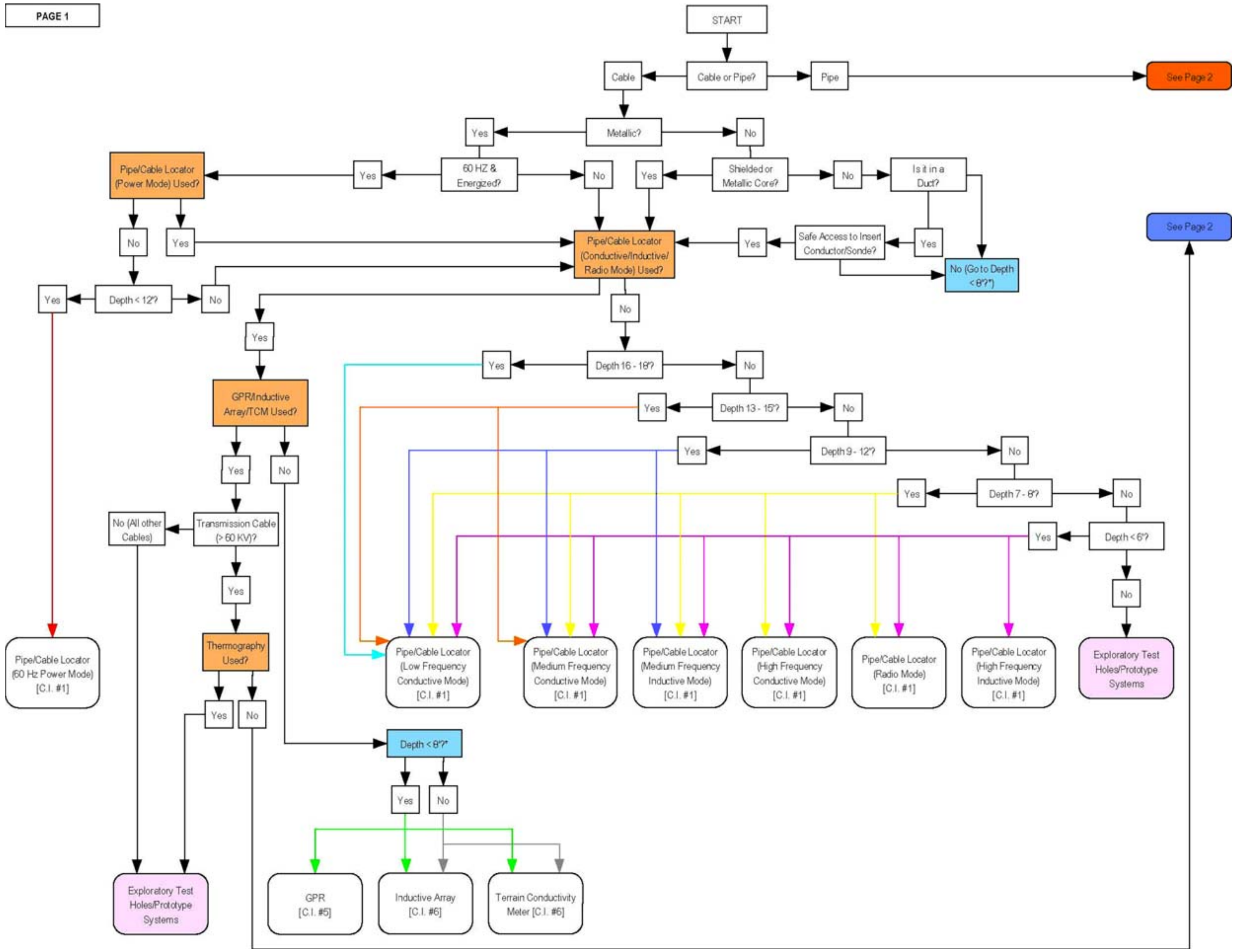

Figure B.1. SAULT decision logic flowcharts.

(continued on next page)

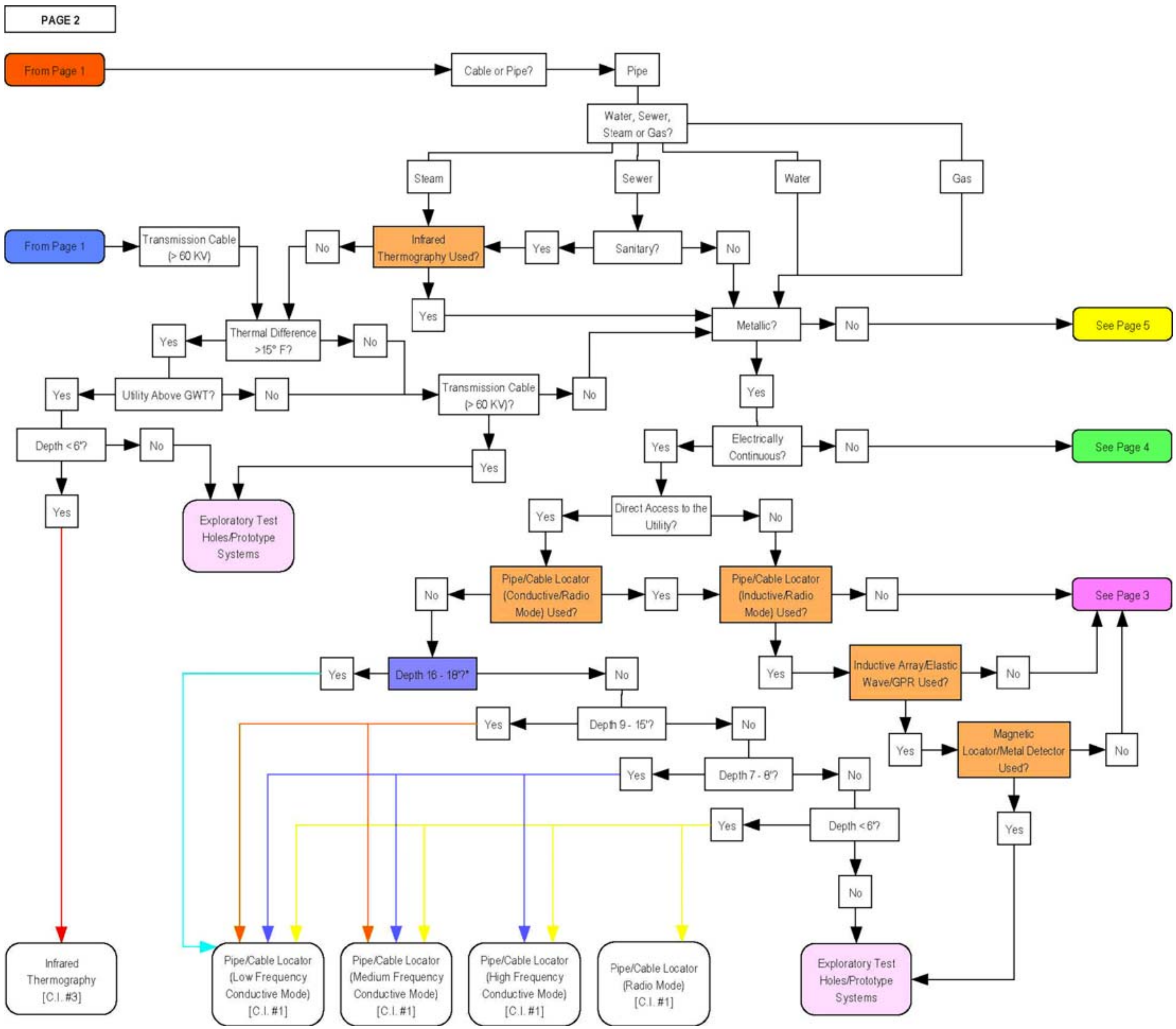

Figure B.1. SAULT decision logic flowcharts (continued).

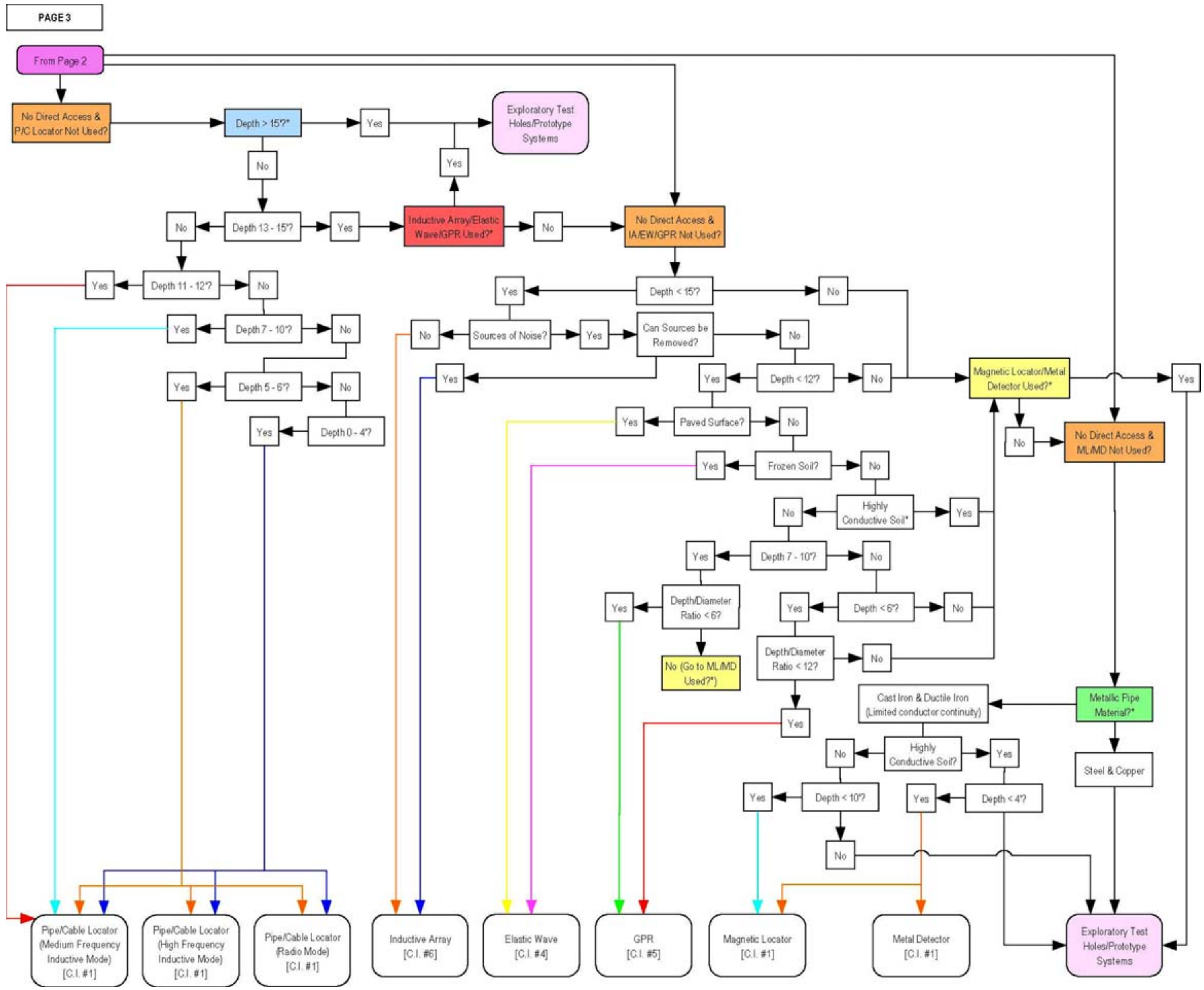

Figure B.1. SAULT decision logic flowcharts (continued).

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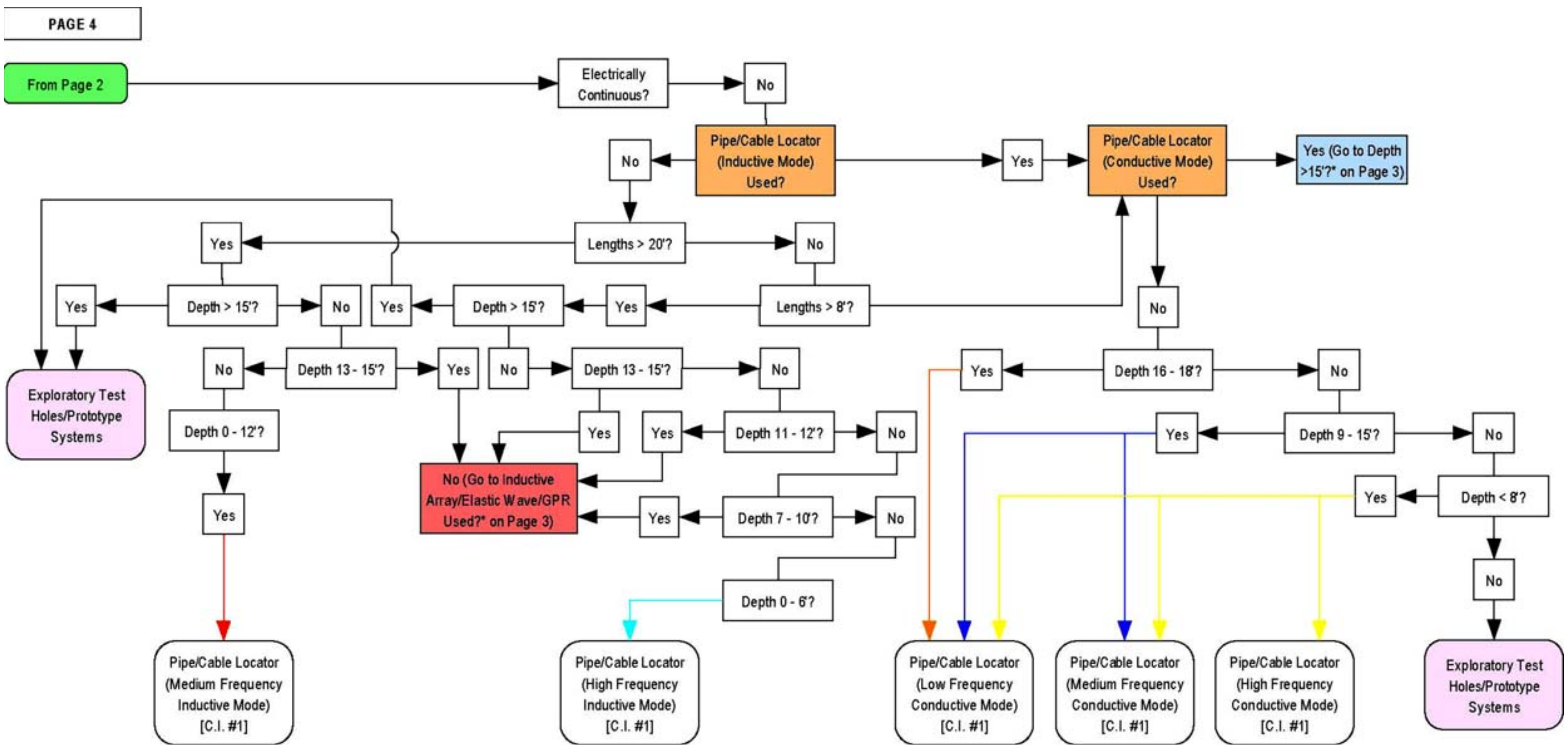

Figure B.1. SAULT decision logic flowcharts (continued).

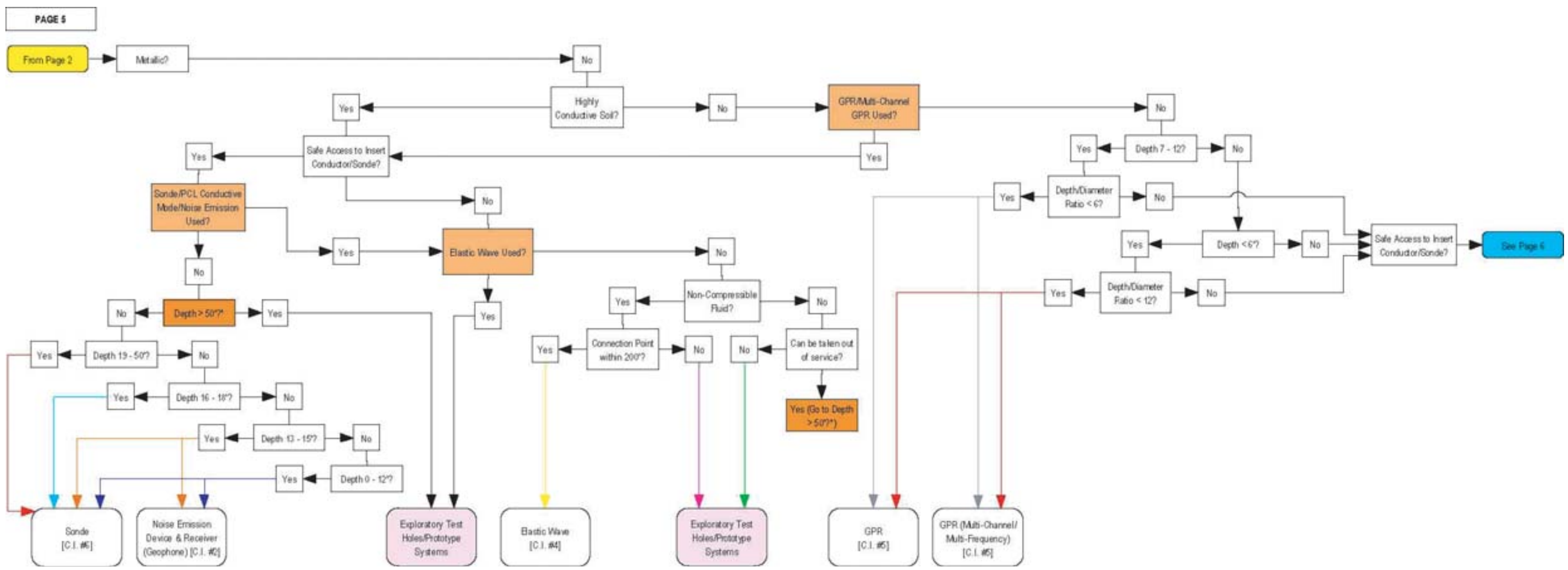

Figure B.1. SAULT decision logic flowcharts (continued).

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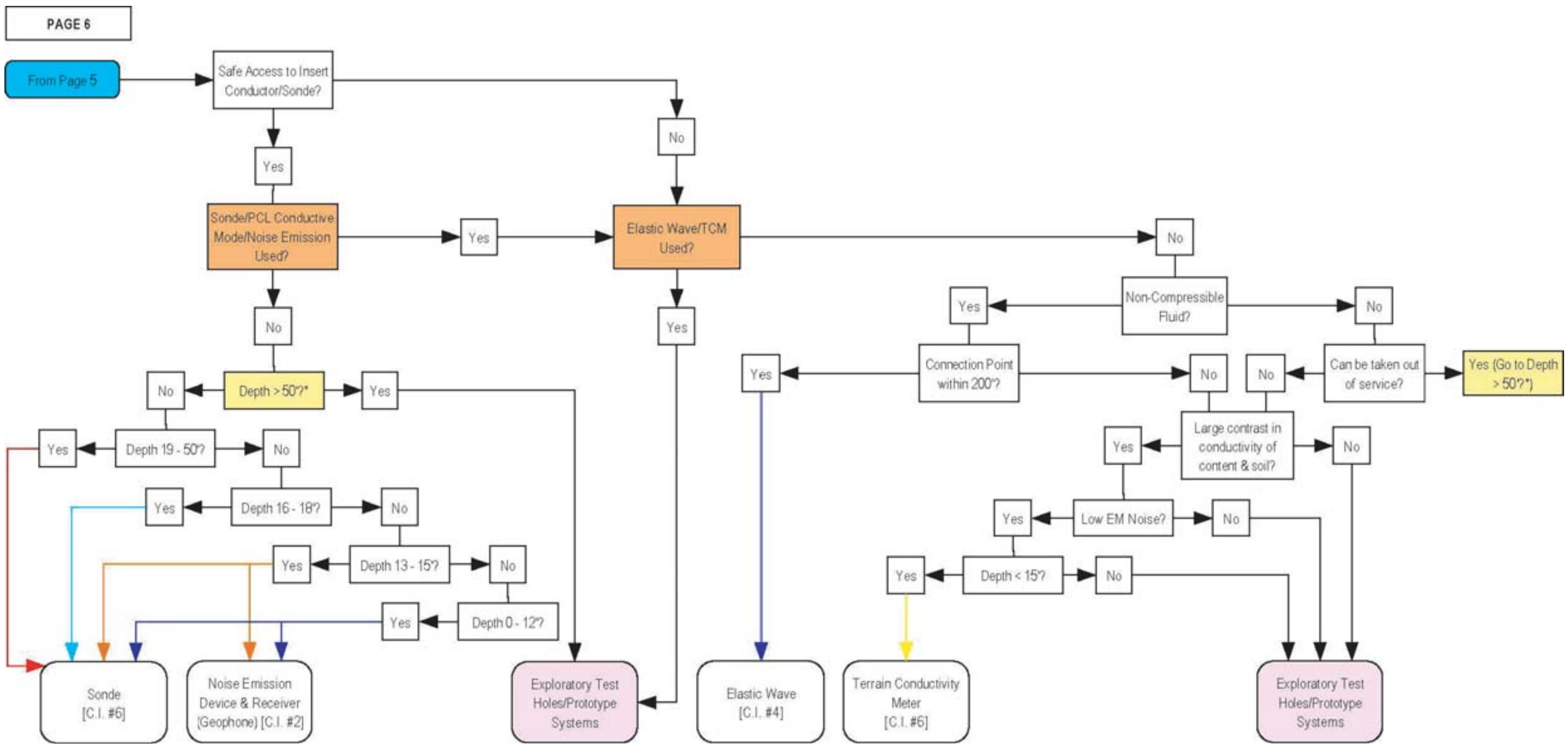

Figure B.1. SAULT decision logic flowcharts (continued).

APPENDIX C

Biography of James Anspach

James Anspach has more than three decades of experience in the utility-locating industry. Until 2009, he was a principal in the subsurface utility engineering company So-Deep, Inc., and was the project manager for utility mapping of major highway projects, such as the Woodrow Wilson Bridge (Maryland and Virginia), Alaska Way Viaduct, and Military Highway (Norfolk, Va.). He was a key creator and chair of the American Society of Civil Engineer's national standards activity *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data.* He is the author of many technical papers, research reports, and articles on surface geophysics applicable to detecting and tracing utilities and is the ASCE's sole instructor for subsurface utility engineering and utility locating. He is a technical editor or reviewer for many federal guidelines regarding utilities, including FAA Cable Cut Study, FHWA/Purdue Cost Savings Study for Projects Utilizing SUE, NTSB Damage Prevention Workshop, Common Ground Study, DOE Technical Report on Identification of Utilities, and FAA Safety Study on Preventing Utility Damages. He is currently an independent consultant.

Related SHRP 2 Research

Technologies to Support Storage, Retrieval, and Utilization of 3-D Utility Location Data (R01A)

Utility Locating Technology Development Utilizing Multi-Sensor Platforms (R01B)

Innovation in Location of Deep Utility Pipes and Tunnels (R01C)

NDT for Concrete Bridge Decks (R06A)

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