Selection Assistant for Utility Locating Technologies (SAULT): Web Tool Report
SHRP 2 Renewal Project R01

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Web Tool Report

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The authors of this report would like to acknowledge the contributions made by other members of the project team in developing decision support logic and web-based decision support software (now obsolete) for the selection of utility locating methods. Thanks go to Dr. Monica Starnes, the contract administrator with the Transportation Research Board, who has helped 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 Project Advisory Committee who have followed the project from the creation of the Request for Proposal to its completion.

This report also contains databases of utility locating equipment, utility damage case studies, and applications of Subsurface Utility Engineering (SUE) approaches. The information for these databases has been taken from the literature, from company websites and by personal contact with many professionals in companies and research organizations. Their help and support is greatly appreciated.
EXECUTIVE SUMMARY

This report presents the Selection Assistant for Utility Locating Technologies (SAULT) developed with the SHRP2-R01 project entitled Encouraging Innovation in Locating and Characterizing Underground Utilities.

The SAULT was originally implemented in a web-based application that included 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 and three databases also created during the SHRP2-R01 project. The databases contain real-world examples of utility damage with causes and consequences; examples of the successful application of the Subsurface Utility Engineering (SUE) approach to utility locating activities; and utility locating equipment organized by classes of locating technology.

This report replaces the SAULT web pages as of January 2015. The change was prompted by the fact that web technologies originally used to build SAULT (Java applets) became outdated in time and the web pages posing potential security threats are no longer supported by most Internet browsers. The report documents the decision logic built into the software and the contents of the databases.

Chapter 1 provides the background to the SHRP2-R01 project. Chapter 2 describes the flowcharts for the selection of appropriate utility locating methods for different utility locating problems. Chapter 3 provides a brief description of each of the three associated databases.

Appendices provide decision support flowcharts, list condition improvements which can help improve the performance of utility locating technologies, and include the complete contents of the related databases.

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 different 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.
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1. INTRODUCTION

SHRP 2 is a focused, time-constrained, management-driven program designed to complement existing highway research programs. It focuses on applied research in four areas: Safety, to prevent or reduce the severity of highway crashes by understanding driver behavior; Renewal, to address the aging infrastructure through rapid design and construction methods that cause minimal disruptions and produce lasting facilities; Reliability, to reduce congestion through incident reduction, management, response, and mitigation; and Capacity, to integrate mobility, economic, environmental, and community needs in the planning and designing of new transportation capacity.

SHRP 2 was authorized by Congress in August 2005 as part of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The 9-year program began in 2006. SHRP 2 was conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Sciences, parent organization of TRB and NRC. The program provided for competitive, merit-based selection of research contractors; independent research project oversight; and dissemination of research results.

The SHRP2-R01 project began on February 12, 2007. The draft Phase 1 report was completed during 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. Following the SHRP 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 during 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 SHRP2 website in October 2009.

As part of Phase 2, a web-based software application, Selection Assistant for Utility Locating Technologies (SAULT), was developed which offered an expert-system-based decision-support system to assist users with limited understanding of the various types of utility locating equipment to select the appropriate different equipment for locating utility problems. SAULT was combined in the web application with the three databases created during the SHRP2-R01 project: Utility Strikes Database; SUE Case Histories Database and Utility Locating Technologies Database. The software was housed on a central server at the Trenchless Technology Center (TTC), Louisiana Tech University, from January 2010 through December 31, 2014.

This report replaces the SAULT web pages as of January 2015. The change was prompted by the fact that web technologies used originally to build SAULT (Java applets) became outdated in time. The web pages posing potential security threats are no longer supported by most Internet browsers. The report presents the decision logic built into the software by using decision support flowcharts and the contents of the databases.

The decision logic developed in SHRP2-R01 and presented in this report 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 decision logic as two different experts may have different opinions on the efficacy of alternate approaches for the same problem. 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.

2. DECISION SUPPORT FLOWCHARTS

The basis for the decision support flowcharts is the career-long utility locating experience of James Anspach for whom a brief biosketch is provided below.

Jim Anspach has more than three decades of experience in the utility locating industry. He was until 2009, a principal in the Subsurface Utility Engineering company So-Deep, Inc. and was the Project Manager for utility mapping of major highway projects including as example: Woodrow Wilson Bridge, Alaskan Way Viaduct, 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 the Director of Utility Market and Practice Development for Cardno, Inc.

In preparation of the decision support flowcharts, a list of the expected influencing parameters for utility locating technology choices was created. However, during the preliminary discussions session with Anspach, it was found 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 was asked. 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, the accessibility of the utility for direct connection of an impressed signal, etc.

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 been tried before. If not, then this method could be suggested as the first alternative; if yes, 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 made with only a rough estimate of the utility’s depth of cover. The flow charts created were grouped into 6 individual flow charts for ease of presentation. These flow charts are provided in Appendix A.

The decision logic may shift from one flow chart 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 as mentioned in the Flow Chart Pages 1 through 6 in Appendix A (Report Pages 8 through 13):
• C.I. #1 Magnetic Locator (Appendix A: Flow Chart Page 2,3)
  o Metal detector (Appendix A: Flow Chart Page 2,3)
  o Pipe/Cable Locator (Appendix A: Flow Chart Page 1,2,4)
    ▪ Low frequency conductive mode (Appendix A: Flow Chart Page 1,2,4)
    ▪ Medium frequency conductive mode (Appendix A: Flow Chart Page 1,2,4)
    ▪ High frequency conductive mode (Appendix A: Flow Chart Page 1,2,4)
    ▪ Radio mode (Appendix A: Flow Chart Page 1,2,3)
    ▪ Low frequency inductive mode (Appendix A: Flow Chart Page 2)
    ▪ Medium frequency inductive mode (Appendix A: Flow Chart Page 1,3,4)
    ▪ High frequency inductive mode (Appendix A: Flow Chart Page 1,3,4)
    ▪ 60 Hz power mode (Appendix A: Flow Chart Page 1)
• C.I. #2 Noise Emission Device and Receiver (geophone) (Appendix A: Flow Chart Page 5)
• C.I. #3 Infrared Thermography (Appendix A: Flow Chart Page 2)
• C.I. #4 Elastic Wave (Appendix A: Flow Chart Page 2,3,5,6)
• C.I. #5 GPR (Appendix A: Flow Chart Page 1,3,4,5)
  o GPR (multi-channel/multi-frequency) (Appendix A: Flow Chart Page 1,3,4,5)
• C.I. #6
  o Inductive Array (Appendix A: Flow Chart Page 1,2,3)
  o Sonde (Appendix A: Flow Chart Page 5,6)
  o Terrain conductivity meter (Appendix A: Flow Chart Page 1,6)

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 as mentioned in Appendix B. The six condition improvement categories are:

• 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
• Isolate EM noise / optimize signal

3. DATABASES

Phase 1 of the SHRP2-R01 project included the development of three databases related to utility locating issues. These databases provide:

• Utility Strikes Database - examples of utility damage and associated cause(s)
• SUE Case History Database - examples of case studies where the SUE approach had been used for utility mapping together with assessment of its benefit where available
• Utility Locating Technologies Database - utility locating technologies and equipment (compiled information based mostly on the manufacturers’ literature).

A summary of each database is provided below and the complete contents of databases are included in appendices C, D and E. 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.

Utility Strikes Database

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

The Utility Strikes Database includes 60 case studies presented in a standard format. Focus is given to the characteristics of the events, a short description and causes/lessons learned if such were reported. The utility strike incidents represent a small sample of the thousands of utility strikes that take place in the U.S. 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 a number of 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.

In this database, 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. 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 above for the Utility Strikes database. The database can provide valuable information for successful utility locating strategies used in specific circumstances such as deep buried utilities and locating of utilities around airport facilities.

SUE Case Histories Database

The SUE Case History Database presents 59 case histories of subsurface utility engineering success stories. Of these, most are associated with transportation projects representing successful applications of SUE technologies and practices. These case studies can provides valuable information for successful utility locating strategies used in specific circumstances such as deep buried utilities and locating of utilities around airport facilities. Several projects are non-transportation related projects for which relative cost of the SUE effort and/or the estimated benefit/cost ratio for this effort is available.

The SUE process and associated quality level designations for utility information can be found in CI/ASCE 38-02. 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 (Sterling et al 2011, SHRP 2nd Report).
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 due to multiple utility conflicts and/or serious utility related accidents. 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 uncertainty 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 ten randomly selected PENNDOT projects (Sinha et al 2007).

Utility Locating Technologies Database

The Utility Locating Technologies Database 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 technologies are presented using performance indicators and other descriptive information as follows:

- Whether the equipment is expected to find ferrous and/or non-ferrous objects,
- Equipment applicability to 4 broad classes of soil type
- Minimum and maximum frequency of operation when applicable,
- Effort, training for data interpretation
- Relative cost indication
- Maximum depth of effectiveness anticipated
- General application summary and more detailed method description
REFERENCES


SHRP2, 2010. Strategic Highway Research Program 2 active research projects SHRP 2 R-01(A), SHRP 2 R-01(B) and SHRP 2 R-01(C) http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Public/Pages/Renewal_Projects_303.aspx


APPENDIX A. DECISION SUPPORT FLOWCHARTS

The flow charts that resulted from the expert knowledge capture using James Anspach as the utility locating expert are provided on the following six pages.
APPENDIX B. CONDITION IMPROVEMENTS

The following measures represent condition improvements which can help improve the performance of utility locating technologies:

[1] Remove metallic surface obstacles: remove large metallic articles (e.g., trash bins, automobiles, metallic grates, manhole covers), which might interfere with the receiving a clear signal, from the zone of interest.

[2] Control ambient noise: Wait until traffic and/or construction noises subside before attempting to locate.

[3] Increase thermal difference between ground and utility: Wait for the ground to freeze or cool to a point when ground temperature is 15 °F lower than the pipes contents (i.e. reschedule work to the fall/winter; perform work during nighttime). Alternatively, if possible, heat the contents in the pipe to 15 °F above average the ground temperature.

[4] Create a new access point: Access the utility through another manhole or basement reducing the distance the signal has to travel. Alternatively, one can excavate down to the utility for the purpose of tying in.

[5] Remove snow or leaves from the surface: Remove snow from the ground surface which might interfere with signal transmission or receiving. Remove any thick piles of leaves from the ground surface which might interfere with signal transmission or receiving.

[6] Isolate EM noise/optimize signal: Discontinue the use of other electrical and/or electromagnetic devices near the utility location such as generators. In the case of critical facilities (e.g., power substations), consult facility owner as to dates of scheduled shutdown of the facility for routine maintenance.
APPENDIX C. UTILITY STRIKES DATABASE

KEYWORDS USED

**Accident, causes of**
- Locating not done
- Locating/marking inaccurate
- Marking not visible
- Operator error
- Utility unknown

**Accident, consequences of**
- Area evacuated (homes, buildings, etc.)
- Business losses
- Collateral damage (other than utility)
- Explosion/fire
- Fatalities
- Flooding
- Injuries
- Loss of service
- Spills (environmental pollution)
- Traffic/flight delays

**Accident, response to**
- Adequate response (damage limited to initial event)
- Inadequate response (subsequent damages/losses)

**Excavation equipment**
- Auger
- Backhoe
- Drill
- Hand excavating tools
- Pavement saw
- Pile driver
- Skid loader
- Trench box

**Utilities damaged, type**
- Communication cables
- Electric cables
- Fiber optics
- Natural gas lines
- Petroleum/gasoline pipelines
- Propane gas tank
- Sewer pipelines
- Steam lines
- Underground Storage Tanks (UST)
- Utility vaults
- Utility tunnel
- Water pipelines

CASE STUDIES

1. **Demolishing of Old Macy’s Building in Trumbull, CT (2007)**

** Cause:** Excavation induced damage

** Damage:** None

** Injuries:** Worker injured from gas pressure

While demolishing the old Macy’s building in Trumbull, CT, to build a new Target store, construction workers punctured a gas main. The shopping center was evacuated and closed for two hours while the gas leak was being repaired. The pressure released from the broken 4-in. natural gas line caused one construction worker minor injuries. Shoppers were not allowed access to their cars parked near the shopping center until the repair was completed.

**Keywords:** Natural gas lines; Area evacuated (homes, buildings, etc.); Business losses; Injuries
2 Road Improvement Construction in Costa Mesa, CA (2007)

Cause: Punctured via auger
Damage: None
Injuries: None

In Costa Mesa, CA, a 4-in. diameter gas line was punctured during road improvement construction work in the vicinity of a new shopping center. Southern California gas company officials said that the accident was caused by an auger, which struck the plastic main close to the intersection, resulting in a gas leak. The gas company officials said that the contractor did not obtain the right permit for construction in that area. Over 35 people were evacuated from the area. There was a low income housing neighborhood located close to the construction site and firefighters assisted the evacuation of 10 residents from their homes. The gas company had to dig down to the line on both sides of the road in order to isolate the damaged pipe section. The ventilation systems in the area were monitored by the county hazardous materials team to make sure that the level of gas in the air did not reach an unsafe level in surrounding buildings.

Keywords: Adequate response (damage limited to initial event); Auger; Natural gas lines; Area evacuated (homes, buildings, etc.)

3 Installation of Two New Pipelines in Cheyenne, WY (2007)

Cause: Pipe rupture via steel trench box
Damage: None
Injuries: None

An oil spill of about 126,000 gallons occurred when construction workers ruptured a 24-in. pipeline. They were installing two new pipelines six miles south of Exeland, Wisconsin. The oil that spilled flowed into a pit that was dug for the construction project. The pipe ruptured when the workers were getting ready to drill under the road. A trench box made of steel, which was put into a 15-ft. deep ditch to prevent it from collapsing, hit the pipeline and formed a large hole. According to the officials, groundwater and soil were not affected by the spill.

Keywords: Petroleum/gasoline pipelines; Spills (environmental pollution); Trench box

4 Digging of a Sign Post in Cheyenne, WY (2007)

Cause: Cable damaged by an auger
Damage: 1,600 ft. of fiber optic; phone service
Injuries: None

In the town of Cheyenne, WY, construction workers were digging a sign post using an auger, and caused the loss of long distance telephone service when the auger ripped through the fiber optic cable. Representatives from both Qwest and WYDOT confirmed that the line was mis-located by the locating service. Technicians were sent to the site to repair the damage, and to replace the 1,600 ft cable that was destroyed.

Keywords: Fiber optics; Communication cables; Locating/marking inaccurate; Auger; Loss of service
5 Leak Repair near Propane Tank Behind a Gas Station in Ghent, WV (2007)

Cause: Excavation induced damage
Damage: Gas station, school, several vehicles
Injuries: Four fatalities, five injuries

In Ghent, WV, workers were repairing a leak near one of the 500-gallon propane tanks located behind a gas station, and the workers possibly hit the tank. Following a 911 call, a fire truck was dispatched. An explosion occurred as the fire truck was pulling in and the fire truck, an ambulance, and many other vehicles were overturned. Among the fatalities were two workers, a paramedic, and a fire fighter. Five people were hospitalized and their condition was serious. According to the authorities, propane is heavier than air, and had therefore spread along the ground into a building where it came into contact with an ignition source and resulted in a fire. The gas station was destroyed and the explosion sent debris flying into a school located one mile away, causing minor damage to the school’s property. No one was injured at the school.

Keywords: Propane gas tank; Fatalities; Injuries; Explosion/fire; Business losses; Collateral damage (other than utility)

6 Widening of an Existing Roadway in Rio Rancho, NM (2007)

Cause: Unspecified puncture of gas main
Damage: Not specified
Injuries: None

In Rio Rancho, NM, a 16-in. high pressure gas line was punctured as a contractor was working on a project to widen an existing roadway. Nearby residents were informed of the incident and the roads leading to the area were closed by police. The concentration of the gas in the surrounding air was determined to be high, forcing the evacuation of residents from 32 nearby homes for a 24-hour period.

Keywords: Natural gas lines; Area evacuated (homes, buildings, etc.)

7 Installation of a New Guardrail along the Roadway in San Rafael, CA (2007)

Cause: Puncture due to drilling operation
Damage: 5,000 -10,000 USD, spill of raw sewage
Injuries: None

A 30-in. sewer main that conveys wastewater from Tamalpais Valley to the south Sausalito-Marin city sanitary district treatment plant was punctured while the road contractors were installing a new guardrail along the roadway. As a result, thousands of gallons of raw sewage were spilled into an adjacent wetland. Following the incident, traffic was stopped for several miles. Earlier that week, contractors working on the same stretch of highway punctured the same sewer pipe twice with a boring unit as they were drilling holes for new posts. During the pipe repair and cleanup, a traffic lane was closed. Officials estimated direct costs to be around 10,000 USD.

Keywords: Sewer pipelines; Spills (environmental pollution); Traffic/flight delays; Drill
8 Replacement of a Utility Pole along a Roadway in Hawthorne, NY (2007)

Cause: Excavation induced damage
Damage: Not specified
Injuries: None

In Hawthorne, NY, a 12-in. water main and a gas service line were damaged when power company workers were replacing a utility pole along a roadway. The water and gas lines were marked, but the marks were covered by fresh snow and the workers did not see them. The street was flooded and the traffic was stopped for several hours. No loss of property or injuries were reported.

Keywords: Sewer pipelines; Water pipelines; Marking not visible; Flooding, Traffic/flight delay

9 Replacement of a Sewer Line in Nogales, AZ (2007)

Cause: Excavation related damage
Damage: 11 homes affected
Injuries: None

In Nogales, AZ, city workers replacing a sewer line accidentally hit and ruptured a gas line. A total of 11 homes were damaged. The city paid hotel accommodation for seven families until the damage was repaired; the remaining four families were allowed to return home two hours after the accident.

Keywords: Natural gas lines; Collateral damage (other than utility); Area evacuated (homes, buildings, etc.)

10 Unspecified construction activity in Gainesville, FL (2007)

Cause: Repeated damage by HDD work
Damage: Highway and businesses shut down
Injuries: None

One of the busiest highways in North Central Florida was shut down and many businesses were evacuated when a contractor using Horizontal Directional Drills (HDD) damaged a gas line. After damaging the gas line, the contractor reported the incident and relocated away from the location of the strike, but later, struck the line again. The gas line was mismarked, but the contractor was blamed for continuing the work in the same location after the first accident. A gas company official said that the contractor should have terminated all construction activities following the first accident until the accident was investigated and the exact location of the gas line found. The company claimed that according to the Florida’s regulations, an excavator who comes in contact with an underground facility must stop digging. The marking was reported to be about 15 ft. away from the gas line's actual location.

Keywords: Natural gas lines; Locating/marking inaccurate

11 Unspecified Construction Activity in South Fort Meyers, FL (2006)

Cause: Excavation related damage
Damage: Highway shut down
Injuries: None

In South Fort Meyers, FL, a construction crew excavating across the roadway hit a water main. A large volume of water leaked from the damaged pipeline that was under high pressure, causing erosion of the road base and the formation of a large sink hole measuring 15 ft. across and several feet deep. Another sink hole, discovered nearby, was also attributed to the water flowing from the damaged line. The report did not elaborate on the extent of the damage or if the utility was properly marked. The busy highway was shut down for several days due to the accident.

Keywords: Water pipelines; Flooding

12 Installation of a new, deep phone line in Jacksonville, FL (2007)

Cause: Directional boring related damage
Damage: Damage to utility
Injuries: None

While installing a deep underground telephone utility (over 10 ft. deep) in Jacksonville, FL, a directional boring contractor working for Bell South damaged an existing electric utility that was also deeply buried. Bell South contacted a local engineering firm requesting assistance in designing a repair. After reviewing the technical details, the engineering firm informed Bell South that it was unfamiliar with a feasible technical solution for repairing the damaged line.

Keywords: Electric cables; Drill

13 Digging of a Trench in Bridgeport, AL (1999)

Cause: Pipe rupture by a backhoe
Damage: 1.4 million USD
Injuries: Three fatalities and six injuries

While digging a trench in Bridgeport, AL, a backhoe operator damaged a 0.75-in. steel natural gas service line and a 1-in. water service line. The natural gas line, operating at 35 psi, had two leaks as a result of the backhoe bucket hitting and pulling the natural gas line. The escaping gas entered into a nearby building, ignited, and resulted in a large explosion that destroyed the building and two adjacent buildings. Other buildings in the area sustained damages of various degrees. The damaged utilities were not located prior to the excavation.

Keywords: Natural gas lines; Water pipelines; Locating not done; Backhoe; Collateral damage (other than utility); Explosion/fire

14 Drainage Improvement Project in Pensacola, FL

Cause: Pipe damaged during excavation
Damage: 100,000 USD
Injuries: None

Escambia County, FL sought location information for utilities in and around an HDR Drainage Improvement project in Pensacola. The County was unwilling to pay for Quality Level “A” work. During
construction, a mismarked 12-in AC water main was hit. It was assumed that 400 ft. of the pipe had to be relocated. However, when construction began, it was discovered that only 40 ft. of a 12-in. AC water main required relocation. The added cost for Escambia County was over $100,000.

Keywords: Water pipelines; Locating/marking inaccurate


Cause: Cable damaged during excavation
Damage: Not available
Injuries: None

In St. Paul, MN, Northwest Airline’s data communication was brought down for three hours after a construction crew damaged a fiber optic cable on March 21, 2000, and the back-up system failed. Consequently, the airline was forced to issue boarding passes manually, which slowed down normal procedures, and compromised their ability to ensure that the weight of the passengers was equally distributed in the aircraft. Flight delays and cancellations occurred throughout the USA on many of the company’s 1,700 daily flights.

Keywords: Communication cables; Fiber optics; Traffic/flight delays

16 Construction of New Garage at the Newark International Airport in Newark, NJ (2005)

Cause: Cable damaged during pile driving
Damage: Not available
Injuries: None

In Newark, NJ, three high voltage electrical cables (26,000-V) that serve the Newark Airport’s passenger terminals were accidentally damaged when a pile driver sliced into an underground concrete vault while driving piles for a new garage. The back-up system was unable to compensate for the power loss and escalators, automatic doors, ticket computers, luggage conveyors, and fuel pumps ceased. Consequently, the airport was shut down and air travel was disrupted. About 1,000 passenger flights were canceled, tens of thousands of travelers were impacted, and air travel in the eastern half of the country was disrupted. The airport was shut down for 24-hours as emergency crews were installing a 100-ft. loop to bypass the three damaged lines so that power could be restored to the terminals. Three construction companies were cited by the New Jersey Board of Public Utilities for failing to guarantee that the routes of buried electrical cables were clearly marked before construction crews began digging.

Keywords: Electric cables; Locating/marking inaccurate; Pile driver; Traffic/flight delays

17 Natural Gas Pipeline Explosion in Edison, NJ (1994)

Cause: By an excavator (previous undetected pipe damage)
Damage: 65 million USD
Injuries: One death and 2,000 tenants displaced

In Edison, NJ, a 36-in. natural gas pipeline broke and exploded into flames next to the Durham Woods apartment complex, New Durham Road. The resulting fire completely destroyed or severely damaged 14
apartment buildings. In response to the fire, New Jersey passed regulations requiring excavators to call a telephone hotline prior to digging so that pipeline companies can mark the precise locations of their pipes on the dig site.

Keywords: Natural gas lines; Area evacuated (homes, buildings, etc.); Explosion/fire

18 Bridge Construction (The Great Chicago Flood) in Chicago, IL (1992)

Cause: Damage to tunnel wall due to pile driving
Damage: $1.95 billion
Injuries: None
In Chicago, IL, a barge driving piles as part of the construction of the Kinzie Street Bridge caused the constructor to punch a hole through the Chicago riverbed and damaged the wall of a long forgotten, mismarked utility tunnel used nearly a century ago for transporting coal and goods. Several weeks following the damage, a leak was formed. A repairman inspecting a cable running through the tunnel issued a warning and forwarded a videotape to the city, but no repair action was taken. Eventually the leak grew sufficiently large and caused the river to pour in and flood basements and underground facilities throughout much of the Chicago business district and the underground shopping district. This forced an evacuation of the Chicago Loop and the financial district, and a termination of electrical power and natural gas services to the area. The water started flowing into subway

Keywords: Utility tunnel; Locating/marking inaccurate; Inadequate (subsequent damages/losses); Flooding; Business losses; Collateral damage (other than utility). Pile driver

19 Installation of a Fiber Optic Cable in Buffalo, NY (1996)

Cause: Pipe sliced by a road saw
Damage: Several millions of USD
Injuries: None
In downtown Buffalo, NY, a construction crew operating a roadsaw during the installation of a fiber optic cable sliced through the crown of a water transmission main and flooded the area. Nearby office building basements were flooded, causing a power shootout. Hundreds of workers were sent home, and cars parked in underground garages were submerged. The contractor called for locators to document the marking on video and mark the path of the cut in white. However, the Buffalo Water Department did not mark the line.

Keywords: Water pipelines; Locating/marking inaccurate; Flooding; Collateral damage (other than utility); Pavement saw

20 Installation of a new water pipeline in Walnut, CA (2004)

Cause: Pipe sliced by a road saw
Damage: Several millions of USD
Injuries: Five deaths and four serious injuries
In Walnut, CA, an excavator excavating a trench for the installation of a new water pipeline hit a jet fuel
and gas pipeline that run parallel to the line of excavation. The jet fuel line ruptured and exploded. Four people died in the explosion and another worker succumbed a day later due to third-degree burns. Four others were hospitalized with moderate to severe burns. Safety concerns about residual gas vapors hindered the work of rescue teams that attempted to recover the dead and injured.

Keywords: Natural gas lines; Pavement saw; Collateral damage (other than utility); Explosion/fire; Injuries; Fatalities

21 Installation of Communication Lines in Walnut, CA (2006)

Cause: Backhoe
Damage: Flood in two county offices
Injuries: None

In Walnut, CA, construction workers who were installing communication lines between the new county building and the courthouse hit an unmarked water main. An investigation revealed that there were two water mains adjacent to each other, but only one of them was marked by the one call service. Following the accident, two county offices and eight homes were flooded and suffered extensive water damage. Water service was discontinued for six hours.

Keywords: Water pipelines; Backhoe; Locating/marking inaccurate; Loss of service; Flooding; Collateral damage (other than utility)

22 Repair of Leaking Gas Line in the Road in Puyallup, WA (2006)

Cause: Backhoe
Damage: Structural Damage
Injuries: None

In Puyallup, WA, a construction crew excavating the roadway to expose and fix a leaking gas line hit a water service and an electric conduit. According to the city official, the construction company did not ask for the utility map of the area from the city office, nor did they call for a locating service. Thus, they were not aware of the fact that the gas line they were looking for was placed underneath the curb and not in the street. The city office took a legal action against the construction company involved.

Keywords: Water pipelines; Electric cables; Backhoe; Locating not done

23 Road Construction Project in Searcy, AR (2005)

Cause: Backhoe
Damage: Disruption of commercial activities
Injuries: None

During a road construction project in Searcy, AR, a crew assigned with utility relocation hit and damaged a fiber optic cable while trying to expose and relocate another utility. Consequently, the entire town lost internet service, and merchants were unable to process credit card charges for three hours.

Keywords: Communication cables; Fiber optics; Backhoe; Loss of service; Business losses
24 Road Widening Project in Macon, GA (2005)

Cause: Skid loader
Damage: Homes evacuated and business shut down
Injuries: None

In Macon, GA, a skid loader pushing over a tree during a road widening project ruptured a 6-in. gas main. The resulting explosion sent flames 15-ft. into the air. Five homes in the vicinity of the explosion were evacuated and two restaurants shutdown. Fire fighters worked for seven hours to get the fire under control and allowed repair activities to take place. Inspection of the pipe revealed a 2-in. hole in the pipe’s wall.

Keywords: Natural gas lines; Skid loader; Area evacuated (homes, buildings, etc.); Business losses; Explosion/fire

25 Road construction in Topeka, KS (2005)

Cause: Excavator
Damage: 1,000 customers without power
Injuries: None

In Topeka, KS, a construction crew conducting excavation activities on a road construction site hit and damaged an underground power line. The power line was not located before the excavation started. One thousand customers, including an elementary school, were left without power for several hours.

Keywords: Electric cables; Locating not done; Loss of service

26 Unspecified Construction Activity in Gloucester, MA (2005)

Cause: Backhoe
Damage: Loss of water supply / property damage
Injuries: None

In Gloucester, MA, a backhoe operator hit and ruptured a 20-in. water transmission line. Water gushing out of the pipe flooded several homes in the vicinity, and in some basements, water was knee deep. The accident led to the loss of potable water service to half of the town. Boil water orders were issued to the entire town due to pressure loss in the entire water distribution system, and many pipes had to be re-chlorinated. According to the mayor, the city experienced four major water breaks in the same area within a four year period. There was no report on whether the utility was marked or not.

Keywords: Water pipelines; Backhoe; Collateral damage (other than utility); Loss of service; Flooding

27 Sewer Construction and Road Resurfacing Project in Hampton, NH (2005)

Cause: Pavement grinding machine
Damage: 500,000 USD machine destroyed, business losses
Injuries: One worker

During a 12-million USD sewer construction and road resurfacing project in Hampton, NH, the pavement grinding machine hit a 6-in. gas main, causing an explosion. The resulting 30 ft. diameter fireball engulfed the 500,000 USD pavement grinding machine in flames, injuring the operator. Twenty minutes later, a second explosion took place, which was sufficiently strong to blow heavy cast-iron manhole covers 1-ft into the air. The line was marked but it was reported that the operator expected it to be at a greater depth. It took seven hours for fire fighting crews and the gas company emergency team to bring the situation under control and restore gas service. According to the reports, this was the third time that a utility strike accident occurred on this construction project. The first two accidents, occurring within a week of each other, involved inadvertent strikes of water mains, and resulted in the loss of potable water service to the residential neighborhood.

Keywords: Natural gas lines; Pavement saw; Locating/marking inaccurate; Injuries; Explosion/fire

28 Soil Sampling for Environmental Monitoring Program in Middletown, NJ (2005)

Cause: Auger
Damage: Highway closed, environmental spill
Injuries: None

In Middletown, NJ, a drilling crew operating an auger-based system to collect soil samples as part of an environmental monitoring program punctured a gas line. The resulting explosion and fire forced authorities to shut down one lane of the highway for several hours. The fire department's special services put the fire out.

Keywords: Natural gas lines; Auger; Traffic/flight delays; Explosion/fire

29 Construction Activity Involving a Utility Relocating in Yonkers, NY (2005)

Cause: Backhoe
Damage: 1,000 apartments lost water supply
Injuries: None

While digging to expose and relocate another utility in Yonkers, NY, a construction crew hit and broke a water main. Consequently, residents in 1,000 apartments lost water and heat service for several hours. This was the third time that an accident related to the utility strike occurred during this particular project. The project involved the construction of 22 new apartment units.

Keywords: Water pipelines; Backhoe; Loss of service

30 Construction Activity at Major Downtown Intersection in Houston, TX (2005)

Cause: Construction
Damage: Major traffic delays
Injuries: None

In Houston, TX, the functionality of traffic signals on a major downtown intersection were disabled when a construction crew accidentally cut a buried power cable, resulting in a power outage. A large traffic
jam was formed, causing traffic delays throughout the downtown area. Residents and businesses in the area were without power for several hours.

Keywords: Electric cables; Traffic/flight delays; Loss of service

31 Unspecified Construction Activity in Asheville, NC (2005)

Cause: Excavator
Damage: Highway closed, environmental spill
Injuries: None

In Asheville, NC, an excavator ruptured a 16-in. water main. Water escaping from the main began to erode and destabilize the soil around it. Consequently, a part of the adjacent building's foundation settled, causing large cracks to form in the external walls.

Keywords: Water pipelines; Backhoe; Collateral damage (other than utility)

32 Unspecified Construction Activity in Chico, CA (2005)

Cause: Backhoe
Damage: Loss of service, damaged utilities
Injuries: None

In Chico, CA, a backhoe operator hit and ruptured a natural gas line, which ignited and sent flames 20 ft. into the air for about two hours. A construction barricade was set on fire and some television cables were damaged by heat. Seventeen homes were without gas service until the repairs were completed. The gas line was marked with spray paint, but the spray paint markings were erased during ongoing construction activities.

Keywords: Natural gas lines; Marking not visible; Backhoe; Explosion/fire; Loss of service


Cause: Backhoe
Damage: Evacuation of a shopping center
Injuries: None

In Toledo, OH, a city crew working on an emergency repair accidentally punctured a 6-in. gas line, which resulted in the evacuation of a nearby shopping center. The gas company admitted that they did not mark the gas line correctly. The operator of the backhoe said that they surveyed the area before digging, and confirmed that the gas line was not marked properly.

Keywords: Natural gas lines; Locating/marking inaccurate; Backhoe; Area evacuated (homes, buildings, etc.)

34 Unspecified Construction Activity in Eurora, Australia (2005)

Cause: Jackhammer
Damage: Evacuation of 15 businesses
Injuries: One worker injured

In Eurora, Australia, construction workers hit a gas line with a jackhammer. The resulting explosion and fire forced the evacuation of 15 adjacent businesses. One store caught on fire and was partly damaged. One of the workers suffered facial burns and was taken to the hospital for treatment. High gas concentrations were measured in adjacent structures, slowing down fire fighting operations.

Keywords: Hand excavating tools; Explosion/fire; Area evacuated (homes, buildings, etc); Injuries

35 Unspecified Construction Activity in Trois-Rivers, Canada (2005)

Cause: Jackhammer
Damage: Seven buildings destroyed
Injuries: One death and six injured

In Trois-Rivieres, QC, Canada, one person died and six people were injured as natural gas from a previously damaged line got into several homes through the sewer system before igniting. Seven homes were destroyed and a blaze raged for five hours. It took 150 fire fighters to get the fire under control. A total of 30 homes were evacuated.

Keywords: Sewer pipelines; Natural gas lines; Hand excavating tools; Area evacuated (homes, buildings, etc.); Collateral damage (other than utility); Explosion/fire; Injuries; Fatalities

36 Road Improvement Project in Coquitlam, BC Canada (2007)

Cause: Backhoe
Damage: Evacuation of a police headquarter
Injuries: None

In Coquitlam, BC, Canada, a backhoe operator working on a road improvement project struck a gas main located in front of the Royal Canadian Mounted Police office. The incident led to the evacuation of the facility and an additional 500 people were evacuated from a nearby building. The backhoe operator was arrested and charged in failing to take the needed step to determine the location of underground utilities before starting an excavation, as required by the law.

Keywords: Natural gas lines; Backhoe; Locating not done; Area evacuated (homes, buildings, etc.)

37 Unspecified Construction Activity in Moose Jaw Saskatchewan, Canada (2007)

Cause: Excavation
Damage: 6,000 CAD and environmental spill
Injuries: None

The city of Moose Jaw, SK, Canada, agreed to pay 6,000 CAD to a landowner because its engineering department mismarked a water and sewer line near a decommissioned gas station where the construction work was carried out. The mismarked utilities were damaged during the excavation and resulted in a severe sewage leakage.
38 Unspecified Construction Activity in Darlington, UK (2007)

Cause: Excavator
Damage: 2 million USD
Injuries: None

In Darlington, UK, an excavator working for a gas company damaged a gas main, resulting in the interruption of gas services to 6,500 homes and businesses. The gas company was ordered to pay 2 million USD in compensation.

Keywords: Natural gas lines; Loss of service

39 Installation of a New Waterline in Annapolis, MD (2007)

Cause: Excavator
Damage: Hospital evacuated
Injuries: None

In Annapolis, MD, a backhoe excavating a trench hit a natural gas line while installing a new waterline. No casualties were reported but the Anne Arunde Medical Center had to be evacuated.

Keywords: Natural gas lines; Backhoe; Area evacuated (homes, buildings, etc.)

40 Unspecified Construction Activity in Portsmouth, NH (2007)

Cause: Backhoe
Damage: 6 residents evacuated
Injuries: None

In Portsmouth, NH, a natural gas main was damaged by a public works construction crew working on the replacement of a water main. According to officials, the utility line records were inaccurate. The records showed that the line ran perpendicular to the street, while in actuality, it was running diagonally to the street.

Keywords: Natural gas lines; Locating/marking inaccurate; Backhoe

41 Soil Testing Near a Gas Station in Cherry Hill, NJ (2007)

Cause: Auger
Damage: Loss of phone services
Injuries: None

In Cherry Hill, NJ, more than 2,000 customers lost their telephone service for two days when a contractor conducting a soil testing near a local gas station bore into the town’s main fiber optics line.
According to Verizon, the utility marked its lines in the requested area, but the contractor chose to drill in a different area. Nearly 1,800 telephone lines were damaged, and an additional 1,800 lines were adversely affected. A local police station lost phone and fax services for two days, and had to rely on wireless communication.

Keywords: Communication cables; Auger; Loss of service

42 New Water Pipe Installation in Wycoff, NJ (2007)

Cause: Backhoe
Damage: 12 Residents evacuated
Injuries: None
In Wycoff, NJ, about one dozen homes were evacuated and a street was closed down when a contractor excavating the street to install a new water pipe damaged a 4-in. gas main. No injuries were reported.

Keywords: Natural gas lines; Backhoe; Area evacuated (homes, buildings, etc.)

43 Unspecified Construction Activity in Rensselaer, NY (2007)

Cause: Backhoe
Damage: Residents evacuated, road closed
Injuries: None
In Rensselaer, NY, a 6-in. natural gas line was damaged by a backhoe operator working for the city. According to the workers, the spray paint that was used by the gas company subcontractor ran off and the workers were unable to see marks. Several residents were evacuated while repair activities took place. A similar incident happened one hour later in a nearby school where construction crews were working.

Keywords: Natural gas lines; marking not visible; Backhoe; Area evacuated (homes, buildings, etc.)

44 Unspecified Construction Activity in Akron, OH (2007)

Cause: Backhoe
Damage: Street collapse
Injuries: None
In Akron, OH, a 200-ft. long and 16-in. dia. cast-iron water main, 80 years old, broke when the already corroded pipe was hit by excavating equipment. Water gushing out of the ruptured water main washed the road foundation, causing the pavement above the ruptured line to collapse along a 700 ft. long strip. This accident resulted in a reduced water pressure for the entire town, adversely impacting activities at St. Thomas Hospital.

Keywords: Water pipelines; Backhoe; Flooding; Loss of service

45 Unspecified Construction Activity in Columbus, OH (2007)

Cause: Auger
In Columbus, OH, construction workers hit a gas line with an auger, causing a leak. One thousand people occupying an adjacent 10-story building were evacuated. The building housed the offices of the School Employee’s retirement system of Ohio. No information was provided as to if the pipeline was marked or not.

Keywords: Natural gas lines; Auger; Area evacuated (homes, buildings, etc.)

46 Unspecified Construction Activity in Cleburne, TX (2007)

Cause: Not specified
Damage: Not mentioned
Injuries: One fatality and four injuries

In Cleburne, TX, a gas leak resulted in gas migrating through the sewer system into a house where it accumulated. When a resident lit a cigarette, an explosion occurred, killing one person and injuring four others. The house was destroyed.

Keywords: Natural gas lines; Injuries; Fatalities; Explosion/fire; Collateral damage (other than utility)

47 Light Rail Extension Project in Salt Lake City, UT (2007)

Cause: Backhoe
Damage: None
Injuries: Resident’s health affected

In Salt Lake City, UT, a backhoe operator ruptured a 6-in. methane gas line while working on the light rail extension project. Most of the gas leaked into a nearby mall, resulting in the evacuation of the mall and adjacent retail facilities.

Keywords: Natural gas lines; Backhoe; Area evacuated (homes, buildings, etc.); Injuries

48 Installation of Sewer Line beneath Interstate I-10 in EL Paso, TX (2007)

Cause: Backhoe
Damage: 100,000 USD, interruption of water supply
Injuries: None

In EL Paso, TX, a construction crew installing a sewer line beneath I-10 damaged a 16-in. water transmission line, resulting in the formation of a massive sink hole, and interrupted water supply to about 2,000 homes. The damage was fixed within 15 hours at a cost of 100,000 USD. According to the water district spokesman, records did not show that there was a water main in that area.

Keywords: Water pipelines; Locating/marking inaccurate; Backhoe; Collateral damage (other than utility); Loss of service
49  **Road Widening Project in Jonesboro, GA (2007)**

**Cause:** Backhoe  
**Damage:** Residents evacuated  
**Injuries:** None

In Jonesboro, GA, a backhoe working on a road widening project struck an 8-in. high pressure (300 psi) natural gas line, ripping a 3-in. long gash into the pipe. All traffic on nearby roads was shutdown, and residents of adjacent homes were evacuated until the repairs were completed.

**Keywords:** Natural gas lines; Backhoe; Area evacuated (homes, buildings, etc.); Traffic/flight delays

50  **Highway Improvement Project in Boise, ID (2007)**

**Cause:** Backhoe  
**Damage:** 600 customers lost phone services  
**Injuries:** None

In Lava Hot Spring, ID, telephone service to 600 customers, including a 911 service, was disconnected when a construction crew working on a highway improvement project accidentally cut the underground telephone line.

**Keywords:** Communication cables; Backhoe; Loss of service

51  **Removal of an Old Gas Main in San Francisco, CA (2007)**

**Cause:** Backhoe  
**Damage:** Thousands of homes lost water services  
**Injuries:** None

In San Francisco, CA, a backhoe operator working on the removal of an old gas main broke a 12 in. water main, causing loss of water services to thousands of businesses and homes. Fire alarms in 25 nearby schools were ringing continuously due to the pressure drop in the system. No mention was made as to whether or not the water main was marked.

**Keywords:** Water pipelines; Backhoe; Loss of service

52  **Construction Activity in Woodland, CA (2007)**

**Cause:** Backhoe  
**Damage:** 300 people evacuated  
**Injuries:** None

In Woodland, CA, a gas line at the entrance to a mall was damaged by a backhoe. The mall was evacuated for several hours. According to officials, the contractor did not contact the One-Call center before commencing the excavation activity.

**Keywords:** Natural gas lines; Backhoe; Operator error; Area evacuated (homes, buildings, etc.)
53 Installation of a Utility Pole in Lawrenceville, GA (2007)

Cause: Auger
Damage: Road closed down
Injuries: None

In Lawrenceville, GA, construction workers hit a 2-in. gas line while using an auger to install a utility pole. Firefighters from the department’s HazMat team worked to monitor the gas from the leak and residents were asked to come back when the level of the gas was safe.

Keywords: Natural gas lines; Auger; Traffic/flight delays

54 Road Project in Gorham, ME (2007)

Cause: Backhoe
Damage: Hundreds of residents evacuated
Injuries: None

In Gorham, ME, a highway construction company ruptured a 6-in. natural gas line while working on a road project. Residents, along with students from two of the University of Southern Maine’s dorms, were evacuated as a result of the gas leak. Some residents and students from a nearby high school complained of headache as the gas entered various buildings.

Keywords: Natural gas lines; Backhoe; Area evacuated (homes, buildings, etc.)

55 Unspecified Construction Activity in Reno, NV (2007)

Cause: Backhoe
Damage: Downtown city block evacuated
Injuries: None

In Reno, NV, the county hall and an entire downtown city block were evacuated after a backhoe operator struck a 4-in. natural gas line, which resulted in a severe gas leak. Two construction workers were left stranded on a six-story high beam until the gas company employee shut off the gas leak, as fire officials were concerned that starting the internal combustion engine could ignite the gas.

Keywords: Natural gas lines; Backhoe; Area evacuated (homes, buildings, etc.)

56 Unspecified Construction Activity in Syracuse, NY (2007)

Cause: Backhoe
Damage: Road closed
Injuries: None

In Syracuse, NY, construction workers excavating outside of the War Memorial building hit a natural gas line, causing a leak. The area was closed to traffic. Also, the ventilation system of the War Memorial building was shut down to prevent gas from entering the building.
Keywords: Natural gas lines; Backhoe; Traffic/flight delays

57 Street Reconstruction Project in Norman, OK (2007)

Cause: Pavement saw
Damage: 60 homes evacuated
Injuries: None

In Norman, OK, a medium-pressure 4-in. gas line was hit by construction workers operating a pavement saw during a street reconstruction project. About 60 homes were evacuated by emergency response crews.

Keywords: Natural gas lines; Pavement saw; Area evacuated (homes, buildings, etc.)

58 Electrical Work at Point State Park in Pittsburgh, PA (2007)

Cause: Ram hoe
Damage: Hotel and several office buildings evacuated
Injuries: None

In Pittsburgh, PA, an operator working on a 2.5 Million USD state contract for electrical work at Point State park damaged a 20-in. medium-pressure gas line by a ram hoe that was used to break up the asphalt cement pavement. The gas line was immediately shut off. A hotel and a nearby newspaper building were evacuated by the emergency response crews. The line was marked by the utility locating service; however, the construction company claimed that rain and snow made it difficult to see the marks. A spokesman for the utility said that the construction company should have called for a relocator if the marks were faded or invisible.

Keywords: Natural gas lines; Marking not visible; Operator error; Business losses; Area evacuated (homes, buildings, etc.)

59 Street Improvement Project in De Soto, TX (2007)

Cause: Backhoe
Damage: City without water
Injuries: None

While working on a street improvement project in De Soto, TX, a backhoe ruptured one of the two parallel underground water lines serving the city. Both pipelines where shut down, and a repair crew had to excavate the street to the level of the pipes to determine which of the two parallel water lines was hit before they could carry out the needed repairs. Nearly half of the city was without water for hours while the repair process was going on. Authorities said the line was marked, but the construction workers were excavating too close to the line.

Keywords: Water pipelines; Backhoe; Operator error; Loss of service; Area evacuated (homes, buildings, etc.)
Landscape Construction in Half Moon Bay, CA (2007)

Cause: Construction activity
Damage: 25 residents evacuated
Injuries: None

In Half Moon Bay, CA, about 25 residents were evacuated when the gas main leaking natural gas was discovered. All the roads leading to the area were shut down until repair work was completed. An investigation concluded that landscape construction workers at a nearby park, who worked in the area two months before the leak was noticed, were responsible for the damage. Gas company officials claimed that the landscape company did not call for utilities locating before they conducted their work.

Keywords: Natural gas lines; Operator error; Area evacuated (homes, buildings, etc.)
APPENDIX D. SUE CASE HISTORIES DATABASE

KEYWORDS USED

Application sites:
. Airports
. Downtown areas/suburbs
. Highways/roads/intersections
. Railways
. Rivers
. Swamps

Challenges:
. Confined entry
. Deep utilities
. Dewatering (utility vaults)
. Local conditions: pipes set in concrete
. Local conditions: few surface structures
. Local conditions: coal fields
. Pipes, non-metallic
. Pipes, asbestos
. ROW (Right-of-way), access to
. Scheduling
. Traffic control

Consequences:
. Design/redesign
. Relocation of existing utilities
. ROW (Right-of-way) acquisition
. Eliminated need for utility relocation

Financial:
. Benefit/cost
. Cost, direct
. ROI (Return on investment)
. Savings

Methods, locating:
. Acoustics
. CART (Computer Aided Radar Tomography)
. Composite core
. Coupling techniques
. Electrical wave techniques
. EM (Electromagnetic) induction
. Excavating
. Gamma rays
. GPR (Ground Penetrating Radar)
. Magnetic tools/magnetometers
. Pipe/cable locators (EM)
. Radar tomography (RT)
. Seismic waves
. Terrain conductivity

Methods, condition assessment:
. CCTV

Methods, marking:
. Ball markers
. Concrete markers
. GIS (Geographic Information system)
. GPS (Global Positioning System)
. RFID (Radio frequency identifier)
. Utility markers

Tools/equipment, locating

Utilities previously unknown/inaccurately identified, types:
. Electric lines
. Fiber optics cables
. Gas lines
. Petroleum lines
. Sewer pipelines
. Septic systems
. Steam lines
. Utility vaults
. Underground storage tanks
. Water pipelines
. Wells

Utilities located, lengths quoted

Utility records, identified shortcomings:
. Incomplete (utilities not in records)
. Inaccurate (wrong location/depth of shown utilities)
. Non-existing (utilities never located)

Locating levels (utility quality levels):
. Test holes (QL-A)
CASE STUDIES

1       Culvert Replacement Project along Service Road 167 in Renton, WA (1998)

In the late 1990s, the Washington Department of Transportation undertook a series of new culvert installations and replacement projects in Renton, WA. The objective of the work was to support the migration of salmon fish upstream of local tributaries for conservation purposes. The projects were conducted along Service Road 167, which is a four lane highway road parallel to the Pacific coastline. This project called for the installation of a 6-ft (1.8 m) diameter, 200-ft. (65 m) long culvert using a trenchless technology method. The crossing was to take place where the elevated highway traversed a flood plain.

A similar project was conducted a year earlier near Everett, WA, utilizing a microtunneling method. However, the microtunneling boring machine (TBM) used on that project encountered various obstacles immediately below the road surface such as tree trunks, boulders, concrete blocks, and old rail cars, which the contractor used with locally available materials as fill materials when the highway was originally built. This resulted in significant construction delays, cost overruns, and claims. The TBM got jammed and required the initiation of a costly recovery operation using a pipe jacking technique.

In an attempt to avoid the repeating of such difficulties, an innovative subsurface utility engineering investigation was developed and executed. The investigation consisted of three bores directionally drilled across the highway. One of these bores was located along the proposed centerline of the new culvert, while the other two were placed 6-ft north and south of it. A 4-in. polyethylene conduit was installed in each of the bores. A suite of geophysical tools, including borehole ground penetrating radar, induction, gamma, and seismic were used to conduct cross-bore studies.

The results from the different studies were correlated with each other, as well as with observations made during the HDD drilling (i.e. locations along the bores where obstacles were encountered). Twenty one possible targets were identified along the proposed centerline. However, the alignment 6-ft. south of the proposed centerline had only six obstacles identified. Thus, the culvert alignment was moved 6-ft south, and the project was completed successfully using pipe ramming.

Keywords: Highways/roads/intersections; Electric lines; Design/redesign; EM (Electromagnetic) induction; Gamma rays; GPR (Ground Penetrating Radar); Seismic waves; Crossbores, drilled (QL-B)

2        Hartsfield-Jackson Airport infrastructure Electronic Marking in Atlanta, GA (2006)

Hartsfield-Jackson Atlanta is the world’s busiest passenger airport, serving more than 89 million passengers in 2005. To expand the capacity of the airport, a new 9,000-ft runway was officially commissioned in May of 2006. As new cables were buried parallel to the new runway, approximately 1,000 discrete locations were electronically marked to support routine maintenance activities and future construction work. Typically, buried utilities at airports are marked using 2-ft. x 2-ft. x 6-in. concrete markers flush with the ground, which are placed immediately above marked features. Such physical markers are costly (about $100 each), and require ongoing maintenance such as painting and grass removal. Also, they can be accidentally displaced by moving equipment and soil erosion, which can compromise excavation accuracy. Locating the buried utilities is accomplished using multi-frequency electromagnetic cable locators. While effective for tracing an individual metallic cable, ambiguous results could arise when there are multiple utilities in close proximity.

To overcome these shortcomings, the FAA decided to adopt an innovative Radio Frequency Identifiers (RFID) buried marker technology that has low vulnerability to moving equipment, requires no
maintenance, and provides precise locating information. The RFID sensors act as passive antennas, reflecting back the query signal from the locator without the need for an internal power source. An inspection is accomplished from the surface using a locating device. The information pre-encoded in the markers can range from their exact coordinates to the diameter and material of the buried utility/utilities beneath it. Another advantage of RFID buried marker technology is the relative ease of distinguishing among multiple adjacent buried utilities.

The marking system selected for the project consisted of 4-in. round ball markers (3M™ Dynatel™ 2200MiD Series), each containing a unique and remotely readable identification number. Each marker can be programmed with custom ‘script’ that includes information such as the purpose and composition of the buried utility, its coordinates, and the depth below grade. An operator scripts each ball using a portable locating device, and places it in the trench as utility installation progresses. In the Atlanta project, markers were placed at 200-ft. intervals for straight sections, and at shorter intervals at turn points, and in congested areas. Each utility was marked on either side of all road crossings. The marker locator used a GPS feature that allowed for automatically collecting GPS coordinates for markers as they were buried. GPS information was then transferred to the mapping database, along with marker identification number and other relevant information, thus creating an electronic as-built map in a GIS format that would be used easily in the future construction planning and maintenance operations.

Keywords: Airports; EM (Electromagnetic) induction; Pipe/cable locators (EM); Ball markers; GPS (Global Positioning System); RFID (Radio frequency identifier); Utility markers

3 Urban Electrical Duct Bank Relocation in Orlando, FL

The Orlando Utilities Commission wanted to redesign the electrical duct bank system in downtown Orlando, but the redesign was very complex because of the urban nature of the region and the Interstate 4 and the State Road 408 Interchange, two major limited access highways in central Florida. The task of locating and identifying underground facilities was assigned to a SUE consultant. The investigation successfully identified not only known facilities but several utilities for which records were not provided. The design and construction processes were performed and executed smoothly.

Keywords: Downtown areas/suburbs; Incomplete (utilities not in records)

4 I-70 Fast Track and Super 70 projects (INDOT) in Indianapolis, IN

Indiana DOT (INDOT) regularly uses SUE to identify and coordinate utility impacts and relocations to avoid utility delays that risk schedule demands. Examples of this practice are the I-70 Fast Track and Super 70 projects in Indianapolis, and the I-74/US 421 roadway improvements for a new Honda plant in Greensburg. The INDOT I-70 Fast Track project involved reconstructions to accommodate the expansion of the Indianapolis Airport, and included the relocation and the lowering of a 2.3-mile section of interstate I-70 by 20-ft. To meet tight scheduling demands, test holes and utility designations were made within the first month. In addition, proactive utility coordination efforts were initiated to support the aggressive fast-track schedule. The project was completed with minimal utility disturbances related issues.

Keywords: Highways/roads/intersections; Scheduling; Excavating; Test holes (QL-A)

5 Utility Composite Plans Assessment in Dulles, VA

Dulles Transit Partners hired a SUE firm to assess utility composite plans compiled using as-built data for the Dulles Metrorail Extension Project in the Tysons Corner area of Fairfax County, VA. Records used
included one-call marks, as-built drawings, facility maps, and design plans. The SUE investigation employed electromagnetic equipment to confirm the records, discovering many misreported or unknown utilities. Consequently, the owner decided to expand the SUE investigation to the entire project area.

Findings from the SUE investigation helped avoiding significant construction related impacts associated with unmarked/mis-marked utilities, and the project was completed without a serious incident. Fairfax County started using SUE in 1980 in an effort to reduce construction expenses caused by unexpected utility hits, redesign costs, and contractor claims. Utilizing SUE during the design of projects has dramatically reduced the extent of the problems.

Keywords: EM (Electromagnetic) induction; Incomplete (utilities not in records); Inaccurate (wrong location/depth of shown utilities)

6 Streetscape/water main/sewer project in Hamilton, ON, Canada (2002)

A SUE investigation was completed as part of the design phase of a major streetscape/water main/sewer project in downtown Hamilton, Ontario, Canada. The project involved the installation, reconstruction, and replacement of municipal utilities in the area, and a major streetscape to improve the overall aesthetics of the downtown area. The study included the collection of utility records, which were used as a basis for more than 10,000-ft. of utility designating (QL-B), conducted using electromagnetic cable located equipment.

The work also included 25 test holes (QL-A) for confirming the exact depth and size of pipes in critical locations. The information derived from the study was used to support the design of the utility alignments. The data from the SUE study identified several conflicts due to erroneous or missing records. Specifically, a large unmarked underground hydro tunnel was found to cross the proposed alignment of the new water main. Other identified unmarked utilities that would have caused construction delays and cost increase included abandon gas mains and a phone duct structure. In addition, exact location and characterization information were provided for other utilities for which records were incomplete.

A subsequent study conducted by the University of Toronto suggested that the City of Hamilton saved approximately $282,000 due to the SUE investigation, yielding a benefit/cost ratio of 6.6. The cost of the SUE investigation ($42,785) amounted to approximately 1% of the total project cost.

Keywords: Downtown areas/suburbs; Benefit/cost; Cost, direct; Savings; EM (Electromagnetic) induction; Excavating; Pipe/cable locators (EM); Incomplete (utilities not in records); Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A); Surface geophysical techniques (QL-B)

7 I-75 Water and Sewer Main Relocation in GA

The Georgia Department of Transportation (GDOT) was preparing to relocate water and sewer mains coming from a rest area and paralleling I-75. GDOT suspected that there were conflicts between newly proposed utility services and the existing utility lines in the right-of-way, and they hired a SUE consultant to provide utility information for the project.

A QL-B study and a subsequent QL-A investigation (excavation of test holes) revealed, however, that no conflict existed at the critical sections. The utilities were not relocated, resulting in a savings of thousands of dollars.
8 State Highway 130, TX, Preconstruction SUE Investigation in TX

A SUE investigation was undertaken as part of the pre-construction phase of State Highway 130, a major Design-Build transportation project involving a four-lane highway, toll facilities, and major interchanges. The design called for the relocation of many utilities, as well as the construction of new utilities, to support the toll roadway.

The SUE firm designated approximately 1.5 million linear feet of utilities, and excavated more than 600 test holes. Based on the SUE information, the road designers revised their plans, shifting the right-of-way by approximately 300-ft., to avoid the relocation of several high-pressure pipelines. This change prevented project delays and resulted in savings estimated at $3 million.

Keywords: Highways/roads/intersections; Design/redesign; Savings; Excavating; Test holes (QL-A); Surface geophysical techniques (QL-B)

9 Utility Investigative Survey in Kitchener, ON, Canada

The first SUE pilot project initiated by the Ontario Ministry of Transportation (MTO) took place in the City of Kitchener-Waterloo, Canada, at the Homer Watson Boulevard and Highway 410 interchange. The project involved the reconstruction of the Homer Watson interchange with the 401 highway and included the following activities: bridge reconstruction, lane widening, modifications to alignments of existing ramps, and the construction of new ramps.

At the time of data collection, design was about 30% completed. Utility records information was collected and served as the basis for utility designation (QL-B), which was performed using multi-frequency electromagnetic cable locating equipment in zones where the new ramps would be constructed.

A number of potential conflicts were identified and 16 test holes (QL-A) were made to confirm the vertical depth and characteristics of selected utilities at critical locations. A number of unmarked, underground utilities were located, including a fiber optics line located at the same location where the formation of the bridge was to be installed.

Based on data provided by the SUE investigation, designers decided to lower several utilities that were in grade conflict with the excavations for the proposed ramp. The cost of the SUE investigation was $25,000. A study by the University of Toronto suggested that MTO saved over $62,000 due to the subsurface investigation, which translated into a return on investment of $2.48 for each dollar spent. The cost of the SUE investigation amounted to 0.125% of the overall project budget.

Keywords: Highways/roads/intersections; Design/redesign; Cost, direct; ROI (Return on investment); Savings; EM (Electromagnetic) induction; Excavating; Incomplete (utilities not in records); Test holes (QL-A); Surface geophysical techniques (QL-B)

10 Design-Build Bridge Project in SC

A contractor on a Design/Build bridge project needed to determine the exact locations of a water main and a sewer main serving a local educational facility that were located deep beneath a local swamp and river. An innovative SUE approach was used to locate the exact position of the mains beneath the water surface. The consultant shut down the mains on a national holiday and dewatered them, so that an
electromagnetic sonde could be pulled through the pipes. Using a receiver on the surface, the exact location of the deep utilities was determined. Based on the information provided, the contractor was then able to complete the design and construction of the bridge pilings while avoiding the utilities.

Keywords: Rivers; Swamps; Deep utilities; EM (Electromagnetic) induction; Surface geophysical techniques (QL-B)

11 Street Reconstruction in Oshawa, ON, Canada

In Oshawa, ON, Canada, the Regional Municipality of Durham sought to engage in a full-depth reconstruction of the 4-lane Ritson Road due to deteriorating pavement conditions. The municipality elected to use the opportunity to renew an existing water main and construct a separate storm-water collection system. Due to previous incidents involving inaccurate information about underground utilities and the age of the area’s infrastructure, which increased a likelihood of inaccurate/incomplete utility records, a comprehensive SUE investigation was conducted.

QL-B designation was completed along the proposed alignment for designating gas, electrical, and telecommunications utilities. A total of 43 test holes were made to confirm the designation and provide the exact depth of utilities at critical locations.

The information collected by the SUE investigation was compared to the information provided by owners of various utilities. The most important discrepancy that was identified involved a gas main, which was believed to be in conflict with planned waterline but was found to be 8-ft. away from the location indicated by the utility’s records. Consequently, the relocation of the gas main was canceled.

In addition, several other inaccuracies in the as-built drawings were detected and corrected, thus eliminating potentials conflicts and subsequent claims.

The cost of the SUE investigation was $91,000, which was approximately 2% of the project’s total cost. The University of Toronto’s research team estimated the return on investment for the investigation to be 2.1.

Keywords: Downtown areas/suburbs; Eliminated need for utility relocation; Cost, direct; ROI (Return on investment); Savings; Excavating; Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A); Surface geophysical techniques (QL-B)

12 Street Reconstruction in York, ON, Canada

A utility project involved the construction of a three mile long, 42-in./30-in. diameter, pre-cast concrete feeder main along Major Mackenzie Drive in York, Ontario, at a projected cost of $8 million.

Funding for the SUE investigation was justified by claims in previous projects, which were caused by inaccurate utility information, as well as for the nature of the project that called for pre-cast concrete pipe. This pipe type lead to limited flexibility, as all bends and chambers are pre-fabricated in the plant and shipped to site. Thus, field modifications would be costly as elements would have to be re-ordered with new dimensions and configurations, resulting in extra construction costs and delays.

SUE was utilized when approximately 30% of the design was completed. At this time, a preliminary route had been selected based on known data. The SUE investigation revealed several unmarked abundant utilities and several potential conflicts with poorly marked traffic control and electrical utilities.

The added accuracy in terms of location of existing utilities, as well as the identification of several unmarked pipes and conduits, resulted in changes in the route and the grade of the new pipe to avoid
these conflicts. Namely, because of the information provided, the new pipe was not placed beneath an 18-ft. deep sewer force main, which would have been costly and risky considering the deteriorated structural condition of the force main.

The investigation included approximately 30,000 linear ft. of utility designation and five test holes, at a cost of $20,000, or about 0.25% of the project total cost. A study by the University of Toronto calculated a benefit/cost ratio of approximately 3.9 for the SUE component of the project.

**Keywords:** Highways/roads/intersections; Design/redesign; Benefit/cost; Cost, direct; Excavating; Incomplete (utilities not in records); Test holes (QL-A)

### 13 Weston Rd. / Walsh Ave. in Toronto, ON, Canada

In Toronto, ON, Canada, a new 16-in. PVC water main was to be constructed to replace an existing 6-in. steel main that was nearing the end of its service life.

A SUE investigation was initiated when the design was about 60% completed. The study included QL-C verification of maps and records and 6,000-ft. of QL-B designation. A total of 13 test holes were excavated along the proposed alignment at critical locations. The main findings of the SUE investigation were a 12-in. steel gas main that was found to be nearly 2-ft. off its marked location along the north side of Weston Road, and an unmarked 12-in. steel gas main branch serving properties on the south side of the street that was in a direct conflict with the proposed alignment.

Based on data provided by the SUE investigation, the route of the water main was moved from the south to the north side of the street, resulting in significant savings in terms of shorter service connections and reduced pavement restoration requirements.

In addition, several unmarked electrical ducts and a storm sewer were located, and their location incorporated in the design.

The cost of the SUE investigation was $31,000 while the savings from eliminating construction delays and reduced pavement restoration cost were estimated by a University of Toronto to be just over $100,000, thus yielding a benefit-to-cost ratio of approximately 3.25.

**Keywords:** Downtown areas/suburbs; Design/redesign; Benefit/cost; Cost, direct; Savings; Excavating; Incomplete (utilities not in records); Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A); Surface geophysical techniques (QL-B); Above ground objects, surveying of (QL-C)

### 14 Water Main Construction in Dunlop Street in Richmond Hill, ON, Canada

In the town of Richmond Hill, ON, Canada, a 12-in. diameter, 2,000-ft. long water main was to be constructed along Dunlop Street. The town requested an SUE investigation late into the design process, after other projects brought to light utility misinformation in its records, and their potential adverse impacts in terms of contractor claims and schedule delays (e.g., a similar water main replacement project in which a $55,000 cost overrun was incurred on a $675,000 project).

The SUE investigation included nearly 10,000-ft. of utility designation and three test holes. The main finding of the investigation was that telecommunication cables shown under the sidewalk in the plans were found to be 7.5-ft. into the roadway.

Because SUE investigation was conducted when design was 90% completed, substantial redesigning was required to accommodate the findings of the investigation. Specifically, the city required to owner of the telecommunication cables to relocate them at the expense of the utility, thus saving the city $50,000.
The expected cost of relocating 150-ft. of the 12-in. gas main called for the original design. The cost of the SUE investigation added approximately 2% to the total project cost.

Keywords: Downtown areas/suburbs; Design/redesign; Relocation of existing utilities; Cost, direct; Savings; Excavating; Utilities located, lengths quoted; Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A); Surface geophysical techniques (QL-B)

15 Combined Sanitary/Storm Sewer in King Street in London, ON, Canada

In downtown London, ON, Canada, a new sanitary sewer system was planned to replace a 60-year old combined sanitary/storm system placed beneath King Street.

The city's records in this area were very old and relied mainly on utility information compiled in 1966. An earlier project conducted in the mid 1990s in the same part of the downtown core was abandoned after numerous conflicts with existing utilities were encountered during the construction, resulting in no return for an investment of $80,000.

To avoid a similar situation, the City decided to conduct an extensive SUE investigation early in the design process (when it was approximately 30% completed). The SUE investigation included designating 6,600-ft. of telecommunication, gas, electrical, water, sewer, steam utilities, and 19 test holes.

The SUE provider supplied the design team with detailed drawings of the location and width of existing utilities, some of which were known to exist but their location was unknown, while records for others were missing altogether (particularly service connections). Also, the status of the utilities (i.e., in-service vs. abandoned) was determined, easing the process of getting utility owners to remove/re-locate their lines.

The main finding was that steam pipes used for heating city facilities were in direct conflict with the proposed sewer line. Neither the city nor the steam company had records of the location of these pipes.

Based on data provided by the SUE investigation, it was determined that the preliminary design was not feasible, and a complete redesign was needed. Consequently, the construction was postponed for two years due to the restrictions in the downtown core, which permitted excavation work every other year.

The cost of the SUE study was $40,000, while a conservative estimate of the resulted savings to the city conducted by the University of Toronto came at just below $80,000, a return on investment of about 2.0.

Keywords: Downtown areas/suburbs; Design/redesign; Cost, direct; ROI (Return on investment); Savings; Excavating; Incomplete (utilities not in records); Non-existing (utilities never located); Test holes (QL-A); Surface geophysical techniques (QL-B)

16 Street Reconstruction in Richmond Hill, ON, Canada

Richmond Hill is a fast growing community near Toronto, Ontario. To support rapid residential development in the area, it was decided to convert Hall Street, a rural roadway with drainage ditches, into a curb-and-gutter cross-section. The plan also called for the removal of the drainage ditches.

Due to previous successes with SUE technology, the town decided to consider the use of SUE on all projects where significant potential for conflict with existing utilities existed. The SUE study revealed that a gas main marked to be 6-ft. off the curb was actually located inside the roadway, and thus, required relocation prior to the commencement of the transportation project. The cost of the SUE study was $11,000, and the estimated return on the investment associated with the SUE investigation was 3.0.
17  **Construction of Bypass Sanitary Sewer in York, ON, Canada**

The York Durham Trunk Sanitary Sewer (YDSS) was reaching its design capacity, and it was decided, as a short term solution, to construct a bypass sanitary sewer that will parallel the existing line, tying into the North Don Collector Trunk. The area is highly developed and served by a dense network of buried utilities. Furthermore, the design team enjoyed little flexibility due to the need to accommodate the existing inverts of the upstream and downstream connections and several known crossings by other on-grade sewer lines.

The consultant performed SUE levels ‘D’ and ‘C’ investigations, and hired a specialized subcontractor to perform QL-B and QL-A studies at critical locations.

The SUE investigation was conducted when the design was 30% completed. All utilities within the right-of-way of the proposed sewer bypass were designated along with 39 test holes constructed to confirm the accurate depth of utility at locations of potential conflicts.

The main finding was that a 16-in. sewer crossing the proposed line was 8-in. deeper than originally indicated by the records, eliminating the need for its relocation. The SUE study cost $62,000, and resulted in an estimated saving of $123,000 (University of Toronto estimate), or a benefit-cost of approximately 2.

**Keywords:** Downtown areas/suburbs; Eliminated need for utility relocation; Benefit/cost; Cost, direct; Savings; Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A); Surface geophysical techniques (QL-B); Above ground objects, surveying of (QL-C); Existing records, review of (QL-D)

18  **Locating of a 69 kV electric power line underneath the St. John’s River in Jacksonville, FL**

Jacksonville Electric Authority (JEA) owns a 69 kV electric power distribution line, which crosses underneath the riverbed floor of the St. John’s River in Jacksonville, FL. Along the shore of the river, waterfront rehabilitation work was being performed. As part of this work, a new seawall was to be constructed. The engineering firm performing the construction hired a SUE company to locate the depth and position of the high voltage line along the north shore, so that they could avoid hitting the line when placing the metal sheet piling into the riverbank.

Electromagnetic measurements were performed using Witten Technologies’ prototype Array of Induction Receivers (AIR) system. The AIR system is based on electromagnetic induction measurement techniques and operates on the same basic principles as traditional handheld radio- detection devices. An electric current is induced in a subsurface utility line. The induced current produces a magnetic field that is detected at the surface. The AIR system provides 48 simultaneous magnetic field measurements over an 8-ft. swath. Magnetic field data is typically collected on a 1-ft.x1-ft. grid spacing over the entire survey area. The position of AIR system is tracked using an accurate positioning system, such as a robotic laser tracking system, which provides centimeter position accuracies. The data is processed using advanced electromagnetic modeling techniques. The combination of the sensitive, broadband, three-component sensors, the volume and density of the data collected, the advanced data processing, and interpretation techniques used, enabled detection of deep pipes in complicated environments.

In the JEA project, the AIR system determined the utility line to be approximately 7-ft. deep at the shallowest point on shore and approximately 35-ft. deep at the deepest point on shore.
Additionally, waterborne measurements were performed at various points on the river and were able to
detect the utility line crossing the river, at a depth in excess of 50-ft.

Keywords: Rivers; Deep utilities; EM (Electromagnetic) induction; Electric lines; Surface geophysical
   techniques (QL-B)

19 Alaskan Way Viaduct and Sea Wall Utility Mapping Project in Seattle, WA

To a large degree, this project incorporated many of the techniques, equipment, and concepts
developed over the past half century for utility mapping. The utility mapping scope of work for the
Viaduct project was robust, and included characterization data not normally obtained for transportation
projects. This extra characterization was necessary due to the tight corridor for utility relocations, cost,
time estimating for utility owners, and continuity of utility service. It also provided enough data for a
preliminary 3-D model. This characterization included: quality levels, ownership, size, inverts on all
cables/conduits leaving all vaults, vault depth and outside dimensions, depictions of every cable/conduit
between vaults or its terminating point, utility depths at all valves, utility depths from records
interpretations, pole/circuit riser numbers, and basement wall termination points. Vault diagramming
forms were included for each vault on the project.

GPR, five different pipe and cable locators, magnetic tools, active and passive acoustics, terrain
conductivity, and many differing coupling and insertion techniques were used to detect and trace
utilities. A vast majority of utilities from record were able to be mapped at QL-B, and many additional
utilities not on record were found and mapped. The project environment presented many challenges.
These included ROW access issues and scheduling, heavy high speed traffic on the southern portion,
heavy pedestrian and vehicle traffic through the downtown portion, security issues with the
homeless/panhandlers, and an extremely congested and complex underground utility environment.
Underground basements, corridors, and parking garages routinely extended beyond building walls and
needed investigative access. The coordination of sports and other special events was required. Over 500
vaults were entered; roughly 100 needed de-watering. Approximately 200 test holes for QL-A data were
constructed. Project hydraulic designers needed to know the elevations, size, shape, material, and type
of footings for three large diameter sewer lines. One of these sewers, in the middle of S. Royal
Brougham, was a 112-in. diameter RCP, set in a concrete cradle on wood piers. The entire structure was
13-ft. across, and over 13-ft. deep. The bottom of the cradle was below groundwater. The pipe was
cracked, and sewage was evident in the excavation.

Keywords: Dewatering (utility vaults); Local conditions: pipes set in concrete; ROW (Right-of-way),
   access to; Scheduling; Traffic control; Acoustics; EM (Electromagnetic) induction; Excavating; GPR
   (Ground Penetrating Radar); Pipe/cable locators (EM); Test holes (QL-A); Surface geophysical techniques
   (QL-B)

20 Prairie Parkway SR-71 (IDOT Distr 3) in Kendall County, IL

A SUE company performed QL-B and QL-A mapping in a limited area. The scope of work was to
designate various gas, petroleum, and crude oil pipelines ranging in size from 10-in. to 36-in. in
diameter. The SUE consultant utilized a variety of pipe and cable locators, with differing connection
methods. GPR was found to be ineffective due to the conductive nature of the local soil conditions. Test
holes were excavated at several points of conflict with the proposed interchange.
After reviewing the results, IDOT elected to change the location of the interchange. Utilizing the SUE deliverables early in the design process permitted IDOT to adjust which properties were to be purchased.

Keywords: Highways/roads/intersections; Design/redesign; Excavating; GPR (Ground Penetrating Radar); Incomplete (utilities not in records); Test holes (QL-A)

21 ILL 159 Road Improvements (IDOT Distr 8) in Collinsville, IL

A SUE consultant designated over 178,000-ft. of underground utilities, as well as overhead utilities, mobilizing six field designating teams, providing a continuous input to the client to keep this high profile project on schedule. Sewer mapping required manhole access and the insertion of composite core reels. This project was unique in that all QL-B services were performed before background mapping was developed. A total of 56 test holes were excavated at potential conflict zones for precise depth and elevation (QL-A data).

Keywords: Highways/roads/intersections; Design/redesign; Excavating; Utility markers; Test holes (QL-A); Surface geophysical techniques (QL-B)

22 New Mississippi River Bridge Crossing (IDOT Distr 8) in St. Louis, IL

A SUE consultant mapped approximately 23,000-ft. of underground utilities. This included a large unimproved area of a landfill, with no available utility records. A variety of utility search and trace techniques were used to identify metallic and non-metallic utilities. This project was exceptional due to the necessary coordination with several railroads that crisscrossed the area.

Keywords: Highways/roads/intersections; Railways; Pipes, non-metallic; Non-existing (utilities never located)

23 IL Route 157 (IDOT District 8) in St. Clair County, IL

A SUE consultant performed designating, surveying, and utility mapping at QL-B of approximately 46,000-ft. of utilities, as well as excavated a total of 44 test holes for precise depth and elevation. One test hole on a sanitary line was in excess of 15-ft. deep.

Keywords: Highways/roads/intersections; Excavating; Test holes (QL-A); Surface geophysical techniques (QL-B)

24 I-35/I-670 Improvement (MoDOT Distr 4) in Kansas City, MO

A SUE consultant performed QL-B mapping, and discovered an extensive amount of fiber optic facilities that had a direct link into and out of an AT&T building in the northeastern portion of the project. Due to inadequate utility records and confidence of utility ownership, it became imperative to gain access to the large quantity of fiber optic splice chambers present within and outside our project limits. After extensive research and discussions with the numerous fiber optic utility owners, access to the splice chambers was granted, enabling them to successfully designate the fiber optic facilities within the project’s limits. This required toroid clamps and composite core insertion coupling techniques, combined with low frequency pipe and cable locators to distinguish individual cables.

Keywords: Highways/roads/intersections; Coupling techniques; Pipe/cable locators (EM); Fiber optics cables; Incomplete (utilities not in records); Inaccurate (wrong location/depth of shown utilities)
25 Raleigh Durham Intl Airport, North Ramp General Aviation Redevelopment in Morrisville, NC

A SUE company completed a “Level B” investigation of 71+ acres of airport property, including public access roads and the General Aviation Area. During this work, 67,437-ft. of underground utilities were designated using QL-B. A wide variety of pipe and cable locators, magnetic locating tools, and GPR were used. The breakdown by utility and owner systems is as follows: Water (RDU) 6,926-ft., Power (Progress Energy, RDU, FAA) 10,200-ft., Communication (BellSouth, FAA) 29,108-ft., Gas (PSNC) 5,825-feet, FSS (RDU) 1,1960-ft., and Unknown utilities 13,419-ft. The designation process included accessing and inspecting 15+ utility vaults housing facilities owned by BellSouth, Progress Energy, FAA, and RDU. This mapping was supplied in AutoCAD and incorporated into the airport’s GIS system.

Keywords: Airports; GPR (Ground Penetrating Radar); Magnetic tools/magnetometers; Pipe/cable locators (EM); GIS (Geographic Information system); Utility vaults; Surface geophysical techniques (QL-B)

26 Honolulu Intl Airport in Honolulu, HI

A SUE subcontractor was hired by M-K International for the terminal upgrade and other improvements at Honolulu International Airport. The scope of the work included collecting and depicting all utility information in the affected areas. This airport included a large military shared presence, and existing records were of very dubious quality. The SUE consultant evaluated the veracity and origin of the existing records, upgraded their quality through field surface geophysical imaging, and where necessary, through excavation. Over 250,000-ft. of existing utilities of all types were subsequently depicted at QL-B. A wide variety of pipe and cable locators, coupling techniques, magnetic tools, and elastic wave techniques were used to detect and trace utilities.

Confined space entry with vault dewatering was extensive.

Keywords: Airports; Confined entry; Dewatering (utility vaults); Coupling techniques; Electrical wave techniques; Magnetic tools/magnetometers; Pipe/cable locators (EM); Utilities located, lengths quoted; Incomplete (utilities not in records); Surface geophysical techniques (QL-B)

27 Dulles Intl Airport & Reagan National Airport in Washington, DC

PMC, a consortium of firms that operate as construction manager for WMAA’s upgrades at Dulles International Airport and National Airport, hired a SUE contractor to provide utility mapping services on an on-call basis. One of the projects involved verifying and upgrading the airport’s existing GIS utility data for a design involving the parking deck at National Airport. Approximately 30% error and/or omission rate was found to exist between the airport-supplied utility GIS data (shown at QL-D) and the field investigation data (QLB). The finding of these discrepancies resulted in a significant project savings to WMAA. Additionally, this data served as an important catalyst for many recommendations found in the FAA’s ASA-500 Final Report “Cable Cuts: Causes, Impacts, and Preventive Measures”.

Keywords: Airports; Savings; GIS (Geographic Information system); Inaccurate (wrong location/depth of shown utilities); Surface geophysical techniques (QL-B)

28 Lambert Field in St. Louis, MO

This was the nation’s first project utilizing the FAA’s 2003 policy on subsurface utility engineering as a design and damage prevention tool. Portions of the project were on the Air National Guard base. Pipe and cable locating equipment frequencies and power were tightly controlled and coordinated with the base munitions officer. Specific pipe and cable locators with acceptable frequencies, magnetic tools,
insertion techniques, terrain conductivity, and elastic wave techniques were used, along with specific discrete area coupling methods. GPR was not utilized due to potential interference with FAA communications. A security benefit was realized when an unsecured large diameter sewer was discovered running from off base to under the munitions storage area.

Keywords: Airports; Coupling techniques; Electrical wave techniques; Magnetic tools/magnetometers; Pipe/cable locators (EM); Terrain conductivity; Sewer pipelines; Incomplete (utilities not in records)

29 VA DOT in Richmond, VA

VDOT used subsurface utility engineering in a major highway project in the City of Richmond, including the designation and the surveying of the route to determine “as-built” utility positions. One hundred and fifty-six (156) test holes were excavated, and nearly half (75 sites) of the utilities verified via test holes were in conflict with the proposed utility facilities. As a result, design changes were made and 61 of the potential conflicts were eliminated. By making these changes, $731,425 worth of utility adjustments were avoided; whereas, the cost of digging the test holes was only $93,553, resulting in a savings of $637,872 (benefit/cost ratio of 6.82). In the words of Mr. Richard Bennett, former State Utilities Engineer, “We feel like we eliminated over $700,000 worth of utility conflicts, and the cost was less than $100,000. We can’t imagine going back and doing a project without having this information available to us.” Overall, Virginia DOT credits SUE with helping to reduce the time needed to design highways from five years to four years, a 20% reduction in time.

Keywords: Highways/roads/intersections; Design/redesign; Benefit/cost; Excavating; Test holes (QL-A)

30 VA DOT Route 29 By-Pass in Warrenton, WA

VDOT was interested in obtaining the elevation on a telephone duct run in Warrenton. The duct run made a turn between the manholes that were about 600-ft. apart. Snaking the ducts to obtain an adequate designating signal proved ineffective due to the extreme depth of the facility (deep utility). Numerous test holes were excavated to get an alignment on the facility at the point where VDOT needed data. That facility was deep, and large debris in the backfill thwarted vacuum excavation. Finally, a track loader was used to remove the top 8-ft. of cover. This method was still not enough to obtain the information. Working with VDOT, a large track excavator was used to cut the top 17-ft., and a trench box emplaced. Designating technology was then used to refine the horizontal location, and vacuum excavation within the trench box was utilized to expose the utility.

Keywords: Highways/roads/intersections; Deep utilities; Excavating; Test holes (QL-A)

31 VA DOT, Route 620 in Crystal City, VA

During the planning of major highway upgrades in a highly congested area, the SUE study found major relocation problems. In one case, an access ramp was designed to be placed directly over an underground shopping mall. This one relocation alone saved over $1 million. Utilities were difficult to designate since, in some cases, utility conduits were integral with the underground structures. Trenchless technology methods were planned to emplace a storm drain over an existing electric duct that was a main power circuit for the Pentagon and National Airport. The SUE company recommended QL-A data on the duct, even though the profile depicted on the plans (through invert measurements in adjoining vaults) showed no conflicts. It was found that the electric duct, which was bowed upward
between the vaults, was directly in conflict with the proposed micro-tunneling, a finding that averted a major utility damage.

Keywords: Highways/roads/intersections; Design/redesign; Excavating; Electric lines; Test holes (QL-A)

32 VA DOT, Route 620 (VA DOT) in Fairfax County, VA

A utility coordination services (UCS) effort revealed numerous conflicts between the proposed road alignment, the high voltage transmission lines, and the buried petroleum pipelines. The SUE study yielded a preliminary utility relocation cost estimate in order to quantify costs and to compare alternatives, such as a redesign of the roadway alignment. As a result, the plans were sent back to design for realignment. The savings to VDOT were very significant.

Keywords: Highways/roads/intersections; Design/redesign; Electric lines; Petroleum lines; Inaccurate (wrong location/depth of shown utilities)

33 VA DOT Project in Covington, VA

On a subsurface utility engineering project in Covington, VA, a SUE study was able to locate and map an old terra-cotta sewer dating back from 1925. There were no access points, and records were sketchy. Using a combination of sondes and exploratory vacuum excavation, the SUE Company was able to accurately map the horizontal and vertical locations of utility conflicted with the proposed road construction.

Keywords: Highways/roads/intersections; Excavating; Incomplete (utilities not in records); Test holes (QL-A)

34 Capital Boulevard (NC DOT) in Wake County, NC

NCDOT requested sixty (60) test holes based upon previously furnished designating information. Many of the test-hole locations were in pavement along with this heavily congested primary roadway. Traffic control requirements were significant, and that whenever possible, several utilities were documented in a single test hole. This resulted in considerable cost savings. An evaluation of the information showed that the location of a non-designated sanitary line differed from existing plan depictions, which conflicted with proposed features. Other services included terrain conductivity and magnetic searches for anomalies, with subsequent air/vacuum excavation methods. This approach was successful in identifying the exact location and condition of a buried sanitary structure, which was in conflict with a proposed retaining wall and temporary sheeting/pile operations. Had this main interceptor sewer been damaged, environmental consequences would have been severe. Services were provided within the project’s tight time schedule.

Keywords: Highways/roads/intersections; Traffic control; Excavating; Magnetic tools/magnetometers; Terrain conductivity; Sewer pipelines; Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A)

35 I-40 Rest Area (NC DOT) in Haywood County, NC

The study included designating and TV (e.g., pipeline video inspection for TV) inspection services on water and sanitary facilities crossing I-40. Designating identified the location of the existing water line and enabled NCDOT personnel to confirm the existence of a useable casing pipe crossing I-40. TV
inspection services revealed that the existing sanitary line under I-40 was structurally sound, and identified several conditions contributing to flow problems.

Keywords: Highways/roads/intersections; CCTV; Water pipelines

36  Caldwell County (NC DOT) in Lenoir, NC

SUE was used early in the development of a project on the Southwest Loop Extension in Lenoir to identify utilities that needed to be relocated. Approximately 58 test holes were selected at points of potential conflict. In addition, a geophysical investigation was conducted in 11 sites to search for unrecorded, underground storage tanks. Based on the SUE data, the location of 16 storm drain boxes were changed to eliminate utility conflicts. The SUE contractor also detected underground storage tanks near the proposed right-of-way limits, and constructed test holes to determine the precise position of the previously unrecorded storage tank locations.

Keywords: Highways/roads/intersections; Relocation of existing utilities; Excavating; Underground storage tanks; Incomplete (utilities not in records); Test holes (QL-A); Surface geophysical techniques (QL-B)

37  Wake County (NC DOT) in Raleigh Beltline, NC

Many of the facilities on this site were made out of thermoplastic materials, and thus, required extensive record interpretation and correlation with field data. Additionally, some water and sanitary force mains were privately owned with no available records. The SUE consultant detected the presence of these facilities through sweeping procedures and by personal interviews with local residents to identify the private facility owners.

Keywords: Highways/roads/intersections; Pipes, non-metallic; Incomplete (utilities not in records)

38  NC 138 (NC DOT) in Currituck County, NC

SUE was used on a highway project in North Carolina to locate a PVC water line along 18 miles of NC 168 in Currituck County. The location of the line was critical to determine conflicts with proposed pavement widening and shoulder excavation work. Using vacuum excavation, 40 holes were dug at a cost of less than $10,000. Using the resulting QL-A information, it was determined that approximately 21,280-ft. of the water line could remain in place. The resulting savings to NCDOT was estimated at $500,000, a benefit/cost ratio of 50 to 1.

Keywords: Highways/roads/intersections; Pipes, non-metallic; Eliminated need for utility relocation; Savings; Excavating; Water pipelines; Test holes (QL-A)

39  (PA DOT) in Erie, PA

A SUE consultant was asked to designate and map some active and abandoned steam lines near the waterfront area Erie, Pennsylvania. The city was undergoing a major redevelopment of the waterfront area, and was gradually phasing out a Pennsylvania Electric plant in the vicinity. In addition to providing electricity, the plant also provided steam for heating. The records on the location of the steam pipes were extremely poor. In addition, the pipes were insulated in asbestos, and there was a concern that disturbing the pipes would create an environmental hazard. The SUE consultant was able to map the entire system (live and abandoned). It was found that the asbestos was encased in concrete or double...
piping and posed a minimal environmental hazard. The SUE firm performed designating services (approximately 65,000-ft.) and excavated 40 test holes.

Keywords: Downtown areas/suburbs; Pipes, asbestos; Excavating; Steam lines; Incomplete (utilities not in records)

40 Lackawanna Industrial Highway (PA DOT) in Lackawanna County, PA

The SUE consultant performed designating and locating services on the “fast-track” basis for Lackawanna Industrial Highway. The SUE consultant coordinated with five (5) different consultants to provide Penn DOT accurate design information. These projects presented substantial technical difficulties. The terrain provided obstacles for our crews since the utility ran cross-country through coal fields. Existing survey control was sporadic throughout the project, and very few surface structures existed. Consequently, considerable survey work was necessary to document utility information.

Keywords: Highways/roads/intersections; Local conditions: few surface structures; Local conditions: coal fields

41 S. Madison Street Connector (DE DOT) in Wilmington, DE

This project was to provide access to the proposed development of the Christiana Riverfront. The site was a former industrial park dating back to the early 1900s. While providing subsurface utility engineering services on this project, the SUE consultant found significant discrepancies between utilities indicated on records, and those actually existing. Approximately 15,500-ft. of underground utilities were designated and seventy-two (72) test holes excavated.

Keywords: Downtown areas/suburbs; Excavating; Utilities located, lengths quoted; Inaccurate (wrong location/depth of shown utilities); Test holes (QL-A)

42 MD State Highway Administration in Columbia, MD

A highway project in Columbia, Maryland, involved the realignment and widening of the roadway from two to six lanes. Maryland State Highway Administration (MSHA) contracted a SUE study to support the relocation of water, sewer, gas, telephone, electric, and CATV facilities along Route 29 in Columbia, Maryland. This project involved both arterial/collector road and interstate/expressway requirement options for both overhead and underground utilities. MSHA engaged the SUE consultant in the relocation design for a gravity sanitary sewer that was in conflict with a proposed storm retention pond. The use of SUE enabled MSHA to redesign the hydraulics system to minimize conflicts with utilities. Instead of impacting about 5,000-ft. of each utility (gas, water, and sanitary), conflicts were reduced to about 400-ft. of each. The cost for SUE was $56,000. Cost savings to MSHA and the utilities amounted to $1,340,000 (benefit/cost ratio = 23.9 to 1).

Keywords: Highways/roads/intersections; Design/redesign; Benefit/cost; Savings

43 MD State Highway Administration in Montgomery County, MD

Maryland State Highway Administration (MSHA) hired a SUE consultant to perform an estimate of utility congestion and a dollar estimate for utility relocation on a project in Montgomery County on MD Route 355. The consultant designated approximately 80,000-ft. of utilities, located 125 utilities and points of conflict, and provided a determination of septic systems and wells and underground storage tanks that might affect right-of-way acquisition, highway design, and construction.
44 MD State Highway Administration, New Hampshire Ave in MD

Approximately sixty (60) homes and businesses along a ten mile stretch of this urban/rural stretch had no records of their septic systems, wells, or underground storage tanks (USTs). Previous construction on a different section of the road was delayed, property was purchased at a premium price, temporary housing and clean-up costs were incurred, and extra orders promulgated when the excavator discovered such buried structures within the construction zone. The SUE study included a review of septic system/well/UST installation practices as well as surface geophysics and non-destructive testing techniques to identify the drainage fields/wells/USTs.

Keywords: Downtown areas/suburbs; Septic systems; Underground storage tanks; Wells; Non-existing (utilities never located); Surface geophysical techniques (QL-B)

45 MD State Highway Administration Project

On another project in Maryland, involving widening an interstate highway from four to six lanes with full shoulders, retaining walls, and barriers, the use of SUE enabled MSHA to redesign the barriers and change the grading and ditches to minimize conflicts with utilities (gas, water, and telephone). The cost for SUE was $5,000. The cost savings to MSHA and the utilities amounted to $300,000, and the relocation time was reduced by 46 months.

Keywords: Highways/roads/intersections; Design/redesign; Cost, direct; Savings

46 Chagrin Boulevard (OH DOT) in Cleveland, OH

ODOT acquired designating and locating services to assist in the design of the widening of Chagrin Boulevard. The study revealed many discrepancies between the utility records and the actual utility positions. In one case, a sewer line that was recorded as being on the south side of Chagrin Boulevard was actually on the north side. In another case, a pipe that was recorded as carrying telephone lines was actually a gas line. An ODOT representative stated to the Chagrin Herald Sun, “This should help us avoid any delays once the project begins. We are spending more money up-front, but saving time and money in the long run.”

Keywords: Highways/roads/intersections; Gas lines; Sewer pipelines; Inaccurate (wrong location/depth of shown utilities)

47 Mapping Requirements for Permit Applications in Greenwood Village, CO (2002)

In 2002, Greenwood Village, Colorado, instituted new mapping requirements for its permit applications for companies seeking to install new lines within its boundaries. Applicants are required to determine the location – both vertical and horizontal – of all existing utilities within the permit area, and provide the city with a map in a GIS format of their findings. This information is available to all underground utility owners and contractors. The city mandated two levels of permits. For a project less than 500-ft., the applicants are required to pothole every 100-ft. on either side of the proposed new utility as well as at line crossing. For projects longer than 500-ft., the entire right-of-way must be mapped.

Keywords: Downtown areas/suburbs; Excavating; GIS (Geographic Information system); Non-existing (utilities never located)
In the late fall of 2003, the West Palm Beach Operations Center of District Four, Florida Department of Transportation, decided to undertake a test of Computer Aided Radar Tomography (RT). Radar Tomography is a technology that employs the use of a radar array to penetrate soil to locate subsurface structures or other anomalies. In the set up used, signal strength of 200 MHz was transmitted by arrays of nine transmitting and eight receiving antennae. The objective of the study was to determine if RT technology was capable of giving better information regarding subsoil conflicts for buried utilities and foreign anomalies (buried rock or concrete, building pads and walls) compared to traditional SUE methods. The technology was tested on two FDOT projects in the West Palm Beach area. For the Olive Avenue project, it was found that RT technology was able to locate about 50% the existing utilities drawn and identified by the designers. Recommendations from the FDOT report included: a) radar data interpreters should be more cognizant of the specific needs and procedures of the FDOT; and, b) better communication was needed between the service provider and the DOT as to expectations and abilities. While this particular evaluation of Computer Aided Radar Tomography technology was not as successful as initially hoped for, overall Florida has a good experience with SUE technology. For example, Florida DOT analyzed the use of SUE on two major projects in Tallahassee and Miami and concluded that it saved $3 in contractor construction delay claims for every $1 spent for subsurface utility engineering.

Keywords: Savings; Radar tomography (RT); Incomplete (utilities not in records)

On a utility project in Columbus, Ohio, the Columbus Southern Power Company designed and installed almost 2 km of underground 138 kV electric line through the downtown area at a lower cost, a reduced risk, and ahead of schedule by including SUE in its design. The increased quality of the utility information presented at the pre-bid meeting increased the bidder's confidence in the construction plans, resulting in a bid, which was $400,000 less than anticipated. The cost of SUE was less than $100,000 (benefit/cost ratio of 4.00 to 1). Additionally, there were no change orders as a result of utilities not correctly depicted on the plans, no utility relocations, no utility damages on the project, and no contractor claims.

Keywords: Downtown areas/suburbs; Benefit/cost; Cost, direct; Inaccurate (wrong location/depth of shown utilities)

The project took place in an urban area and involved replacing an existing bridge, widening traffic lanes, and constructing new bridge approaches. The bridge crossed over Norfolk Southern main railroad tracks, and led directly to the area hospital. A large underground phone system had been relocated near the project site two years prior to the project. The project length was approximately ½ mile. Available information revealed a 16-in. gas line, 12-in. water and sewer line, three underground fiber-optic lines in different conduit runs, a buried telephone and vault, as well as some unknown lines in the project area. However, the exact location and direction of the existing lines was unknown. For the QL-B SUE investigation, electromagnetic equipment was used together with a field meeting between the SUE firm and the utilities, and the coordination with the utilities, to carry “beacon” into pipelines. For QL-A, the vacuum excavation method was conducted at 44 different locations. As a result of the SUE investigation, the roadway drainage facilities were successfully designed to save time and relocation expenses; the potential impact of bridge pier construction on the existing lines was avoided. The culvert was tied onto the existing pipes.
51 3rd Ave. Bridge, SR 0022-024 in Blair County, PA

The project was a replacement of an entire existing bridge located at an urban area with high traffic volume. There were three water authorities that crossed at this bridge, one around and two under. The two lines were 12-in. in diameter. There was also a telephone conduit system and a vault near the bridge with 10 conduits attached to the existing bridge. Homes and businesses were adjacent to the bridge and allowed little or no room to relocate the facilities. The project length was approximately ¼ mile. The bridge had to be fully open to traffic by a certain date, so it was a time-sensitive project. The initial SUE information was incorrect. The SUE firm found that the utility marked plans were wrong. The utility had depicted the facilities, assuming the top of the page was north. In fact, on this plan, the top of the page was south. The QL-B SUE investigation was conducted using electro-magnetic equipment along with close coordination with the utilities. For QL-A, the vacuum excavation method was performed at nine different locations. As a result of the SUE investigation, it was possible to design shoring around existing telephone conduits, design the bridge to accommodate telephone facilities, positively identify the gas line, and determine that it was not impacted.

Keywords: Downtown areas/suburbs; EM (Electromagnetic) induction; Incomplete (utilities not in records); Test holes (QL-A); Surface geophysical techniques (QL-B)

52 18th St. Culvert, SR 0036-25M in Blair County, PA

The project was to add drainage to an existing road and to lower the roadways as much as possible to provide additional overhead clearance for trucks to go freely under a railway overpass. The available information revealed that there was a complex existing utility network at the project site. This included a 12-in. – diameter gas line, a 16-in. – diameter water pipeline, a large buried telephone system, an underground electric system, and an abandoned 36-in. sewer culvert along with a 72-in. sewer pipe, all within a 22-ft. wide roadway. For the SUE QL-B investigation, electro-magnetic equipment was used along with close coordination with the utilities. For the QL-A investigation, the vacuum excavation method was performed at 15 different locations. Results of the SUE investigation indicated that many of those facilities were abandoned, and that the proposed gas line relocation would not work. Also, SUE provided proper location for inlet and drainage facility. Time was the most valuable savings for this project. An additional benefit was that based on the SUE results, the water authority was convinced to replace a 24-in. waterline while the road was open, and to prevent the road from being torn up by water in the event of a break in the 100- year-old waterline.

Keywords: Downtown areas/suburbs; Design/redesign; EM (Electromagnetic) induction; Excavating; Test holes (QL-A); Surface geophysical techniques (QL-B)

53 Cresson Culvert, SR 2014-04M in Cambria County, PA

The project was to rebuild a roadway under a railway overpass. Work involved the complete reconstruction of a portion of the roadway and the installation of the drainage facilities. Preliminary information revealed a gas line parallel to the roadway plus underground telephone line and water pipeline within the project site. However, the exact location and depth of the pipelines were unknown. SUE investigation was conducted by means of electro-magnetic equipment and close coordination with utilities for QL-B. For QL-A, the vacuum excavation method was performed at 15 different locations. Based on the results of the SUE investigation, the drainage facilities were designed to avoid utilities at
various locations. Meanwhile, the results of SUE allowed the gas company to map a better plan for relocation.

Keywords: Railways; EM (Electromagnetic) induction; Excavating; Incomplete (utilities not in records); Test holes (QL-A); Surface geophysical techniques (QL-B)

54 Towanda River Road, SR 6006 – 001/002 in Bradford County, PA

The project was to construct a roadway bypassing the center of Towanda to relieve traffic congestion. Preliminary information revealed many undocumented underground obstacles at the project site. The underground obstacles included an unknown location of sanitary sewer, water, gas, telephone, TV, and electric lines. There were also abandoned water and sewer lines throughout the project site, but no one knew their exact locations. In the SUE investigation, pipe and cable locators, together with existing maps and guidance by surface features, were used to determine QL-B. For QL-A, the vacuum excavation method was performed at approximately 150 locations. Based on the results of the SUE investigation, a decision was made to place the drainage facilities at the site without interference with the existing underground utilities.

Keywords: Downtown areas/suburbs; Excavating; Pipe/cable locators (EM); Incomplete (utilities not in records); Test holes (QL-A); Surface geophysical techniques (QL-B)

55 Market St. River, Williamsport, SR 0015-77 in Williamsport, PA

The project involved replacing a bridge into the city of Williamsport, installing traffic circles, and reconstructing state route SR 15. The main purpose of the project was to relieve traffic congestion and to replace an old bridge that had a weight limit and was inefficient. The project site had a very complex network of existing underground utilities involving unknown locations of sanitary sewer, water, gas, telephone, TV cable, and electric lines. Existing maps, surface features, and pipe and cable locators were used to determine SUE QL-B. Approximately 110 vacuum excavation tests were performed to determine QL-A. The results of the SUE investigation provided locations for drainage facilities that had little interference with the existing underground utilities. Also, the utility companies were given an accurate location of their underground facilities in this area.

Keywords: Downtown areas/suburbs; Excavating; Incomplete (utilities not in records); Test holes (QL-A)

56 Danville River Bridge, SR 0054-014 in Montoursville, PA

The project was to replace an inefficient bridge and to improve traffic conditions as well as a railroad crossing in the Borough of Danville. At the project site, there were unknown locations of sanitary sewer, water, gas, telephone, TV cable, and electric lines. Very few maps of the existing pipelines were available. Pipes and cable locators guided with surface features were used to determine SUE QL-B. Approximately 25 vacuum excavation tests were performed to determine QL-A. Based on the results of the SUE investigation, a decision was made to place the drainage facilities at locations that were least affected by existing underground utilities. Also, the utility companies now have an accurate location of their underground facilities in this area.

Keywords: Rivers; Excavating; Incomplete (utilities not in records); Test holes (QL-A)
57  Cameron Bridge, Shamokin, SR 0061-079 in Shamokin, PA

The project was to replace an inefficient bridge and to relieve traffic congestion in the city of Shamokin. At the project site, there existed a very complex, undocumented, underground network of pipelines including sanitary sewer, water, gas, telephone, TV cable, and electric lines. Also, there were over five existing water lines that needed to be temporarily and then permanently relocated. To determine SUE QL-B, pipe and cable locators, guided with surface features, were used. For QL-A, approximately 30 vacuum excavation tests were conducted. The results of the SUE investigation provided locations for drainage facilities that were least affected by the existing underground utilities at the project site, and are now documented.

Keywords: Downtown areas/suburbs; Excavating; Incomplete (utilities not in records); Test holes (QL-A)

58  Reconstruct Main St. in Elkland, SR 0049-50M in Elkland, PA

To improve drainage and to alleviate traffic congestion, this project involved the reconstruction of SR 49 as well as the replacement of sanitary and storm sewers, sidewalks, and curbs. Preliminary information revealed sanitary sewer, water, and gas lines at the project site without knowledge of their locations. Because very few maps of existing underground pipelines were available, pipe and cable locators, guided with surface features, were used to determine SUE QL-B. QL-A was determined by conducting vacuum excavation tests at approximately 75 different locations throughout the project site. From the results of the SUE investigation, the roadway drainage facilities were located at places with least interference with the existing underground utilities. The results of the SUE investigation also provided the utility companies with an accurate location of their underground pipelines.

Keywords: Downtown areas/suburbs; Excavating; Pipe/cable locators (EM); Incomplete (utilities not in records); Test holes (QL-A); Surface geophysical techniques (QL-B)

59  Bellwood Road and Bridge, SR 0865-002 in Blair County, PA

The project involved the relocation of a roadway and the reconstruction of a bridge in the rural area of Bellwood. The SUE was used on the roadway portion to design drainage facilities. In the early project stage, there was some information on a gas line on one side of the existing road, and a waterline on the other side at the project site. The technology used for SUE QL-B included basic electro-magnetic equipment, such as the pipe and cable locator and metal detector. For SUE QL-A, the vacuum excavation method was used at 15 different locations. Based on the results of SUE investigation, the decision was made to place drainage facilities on the side of the road where the waterline was located. On that side of the road, there was less impact length and more room for relocation; additionally, the work could be done by the department of transportation contractor.

Keywords: Downtown areas/suburbs; Design/redesign; Excavating; Gas lines; Water pipelines; Test holes (QL-A)
APPENDIX E. UTILITY LOCATING TECHNOLOGIES DATABASE

METHODS USED

Pipe and Cable (P/C) Locators
1. High Frequency Conductive P/C Locator
2. Medium Frequency Conductive P/C Locator
3. Low Frequency Conductive P/C Locator
4. Inductive P/C Locator
5. Radio Mode P/C Locators
6. Sonde Mode P/C Locators
7. Inductive Array

Other:
8. Magnetic Methods
9. Metal Detectors
10. Electronic Marker Systems
11. Ground Penetrating Radar (GPR)
12. Multichannel GPR
13. Noise Emission
14. Infrared (IR) Thermography
15. Elastic Wave
16. Terrain Conductivity Meter

METHODS DESCRIPTION

1 – 7. Pipe and Cable (P/C) Locators

Electromagnetic methods using pipe and cable locators are the most frequently used techniques for detecting and tracing metallic underground utilities. Non-metallic utilities such as plastic pipes can also be located if tracer wires are laid with them. In addition, non-metallic powered utilities which radiate their own electromagnetic field can be detected with this method. Electromagnetic techniques can operate in three modes: active, passive and sonde mode.

Active Mode. In active mode, the equipment has both transmitting antenna(s) and receiving antenna(s). A transmitter emits electromagnetic waves (radio frequency) and a magnetic field is generated. If a metal pipe or cable is laid within the magnetic field, induced current is produced. The current is carried by the utility along its length generating a magnetic field which is detected above ground with a receiving antenna.
There are three ways of getting a signal onto pipes and cables in active mode: conductive, inductive and inductive clamp methods.

In **conductive mode**, a transmitter is directly connected to one end of pipe or cable being located using crocodile clips. For a strong signal over a long distance, and for minimal coupling to other conductors, low frequencies are best. Proper grounding is important when using the conductive method: in general, the better the ground, the stronger the signal.

In **inductive mode**, a transmitter is placed on the ground over the buried pipe or cable. If the transmitter is not within five feet or so of the line, signal is likely to be very weak. The inductive method tends not to work where the utility is deep. One method of increasing effective operating depth is using a sonde which is pulled through the utility. Effective depth of detection without sonde is 20 feet or often less, and with sonde 50 feet or more. Drifting of the peak signal at the surface from the true alignment of the utility will occur with increased depth. In inductive clamp mode, utility locating coupling clamps are used. When the clamp's jaws are closed around a pipe or cable, a signal can be induced into a particular line, reducing the chance of other conductors picking up signal. The clamp must close fully, and the conductor must be well grounded on the near and as well as the far end.

The size, shape, and type of antenna are directly related to its efficiency in receiving a signal of a certain shape and frequency. Lower-frequency locators can penetrate deeper into the ground, but more power is needed to do so. Less-conductive utilities need higher frequency to propagate over distance. However, with higher frequency, the signal will travel less distance. A larger homogenous conductor can be more difficult to detect and trace than a smaller one, since the radio waves spread out and travel on the pipe surface. A larger surface means more signal attenuation. Under ideal conditions (a single utility in a relatively homogeneous soil with a recently calibrated instrument), locating can be quite precise and accurate. Some manufacturer specifications state 2.5% to 5% accuracy up to 10 feet of depth. In the congested utility arena of an urban or suburban street, depth estimations are frequently in error by a significant amount. Frequencies used by Pipe and Cable (P/C) Locators can be grouped into three classes:

- High (between 300 KHz and 3 MHz).
- Medium (between 30 and 300 kHz), and
- Low (less than 30 kHz),

**Passive Mode.** In passive mode, the equipment has only receiving antenna(s). Some buried utilities, e.g., electrical and telephone, radiate their own electromagnetic field which can be detected using the radio frequency (RF) receiver without inducing a current. There are two types of passive mode: the **60Hz Power Mode** for locating utilities such as high-voltage AC power transmission lines which operate at and emit frequencies of 50 or 60 Hz, and the **radio mode** for locating utilities carrying frequencies used to transmit television and radio programs.

**Sonde Mode.** In **sonde mode**, self-contained signal transmitters are used. A standard sonde combines compact size with a strong signal that is detectable up to 20 feet in the air and 10 feet in cast iron. A sewer sonde incorporates a very strong housing and makes the sonde suitable for use in municipal sewer systems. For tracing small diameter utilities (as small as 0.5 inch internal diameter), a traceable plastic covered fiberglass rods incorporating wire conductors can be used.

**Inductive Array** operates on the same basic principles as traditional pipe and cable locators in inductive mode. In this method, multiple transmitters are used to induce electric current in a subsurface and an array consisting of multiple triaxial broadband electromagnetic sensors is used to record different reflected frequencies simultaneously, allowing detection of multiple utilities. In one
8. Magnetic Methods

Magnetic methods are based on the magnetic properties of iron and nickel to detect and trace iron and steel pipes. For detecting utilities, the gradient survey method is used.

Magnetic gradiometers are pairs of magnetometers with their sensors separated, usually horizontally, by a fixed distance. Two field sensors separated approximately 9 to 20 inches apart, are used to cancel the effects of the magnetic field sources in the area. In the absence of nearby iron or steel object, these sensors are in balance. As the detector moves closer to the magnetic object, the shape and intensity of magnetic field creates imbalance in the sensors which can generate a readable output. It is generally easier to detect a vertical object than the horizontal round pipe. Depth estimation is not possible with this method.

9. Metal Detectors

Walk-through metal detectors are the most frequently used metal detectors for detecting the presence of metallic objects. They have portals bracketed with two large coils or loop-type antennae, one a source and the other a detector. Electromagnetic waves (low-frequency radio waves) are emitted by the source coil into the detection space. When the electromagnetic field of the transmitted wave impinges on a conducting object, it induces transient currents on the surface of the object; these currents, in turn, radiate electromagnetic waves. These secondary waves are sensed by the detector coil.

10. Electronic Markers and Detectors

There is a growing trend towards the placement of permanent Electronic Markers around buried utilities for marking utilities, particularly in critical facilities. They include tracer wires and buried magnets, and more sophisticated passive electromagnetic (EM) balls and radio-frequency ID tags (balls). Passive EM balls act as passive antennas, reflecting back the query signal from the locator without need for an internal power source. Some balls feature unique frequencies so that only a particular utility would be indicated by signal reception. These are generally in the high frequency (HF) or ultra-high frequency (UHF) range. Passive radio-frequency ID tag (RFID) are similar in concept to passive EM balls, but are also capable of transmitting back data embedded in them such as information about the characteristics of the utility, year of construction and exact spatial coordinates.
11. Ground penetrating radar (GPR)

Ground penetrating radar (GPR) can locate both metallic and non-metallic utilities. GPR is a wave propagation technique which uses high-frequency electromagnetic waves, usually in the range 50 MHz to 1 GHz. A GPR transmission antenna transmits the waves into the ground. When the waves encounter a buried object or a boundary between materials having different dielectric constants, they are reflected or refracted or scattered back to the surface. A receiving antenna then records the variations in the return signal. Overall propagation into the ground is a factor of frequency, power, and soil resistivity. Frequencies around 400 MHz are typically used for utility locating. Utility detection occurs when the boundary of the utility is different than the surrounding soil. A very different boundary produces the best reflection (i.e., metallic utility buried in dry sand). The smaller the utility, the higher the frequency is needed to detect it. However, the higher the frequency, the quicker the signal dissipates with depth and the smaller the depth of penetration. A general rule of thumb for current technology in practice is a depth to diameter ratio of 12 to 1 under ideal conditions (i.e. a 1 inch utility at a 1 ft foot depth).

The more conductive is the surface (steel reinforcement, de-icing salts, saline water, and soil with high organic or iron contents) the less effective are GPR systems. Ideal conditions for GPR include dry sand while least optimal conditions are represented by marine clays and similar highly conductive soils.

GPR can determine relatively accurately depth of a utility. In some cases where the utility itself cannot be imaged, GPR can detect a trench suggesting the presence of a utility. GPR data interpretation can be complex and time consuming.

12. Multi-channel GPR

Multi-channel GPR systems use a mobile array of multiple GPR antennas mounted on a cart-based GPR unit, which is typically towed behind a vehicle during survey operations. One system, for instance, consists of 17 GPR antennas positioned in two overlapping rows of 9 transmitters and 8 receivers. This
system is collecting 16 channels of densely spaced GPR data. GPR imaging with multi-channel systems has greatly improved the areal coverage of the ground. Along with improved imaging software, datasets recorded with multi-channel systems can be processed at similar speeds to coarsely spaced single channel data that would normally require additional time for interpolation processes to fill in the gaps between lines. Data processed from several different multi-channel GPR systems are shown.

Figure 2. Left: Lightweight and Compact GPR Unit. Right: Multi-channel GPR. Used with permission.

Figure 3. Output from advanced multi-channel GPR. Used with permission.

13. Noise Emission

Noise emission is acoustic-based technology. A sound is generated in the pipe which radiates from the pipe through the soil to the ground surface where pickup transducers detect the signal. The basic premise is that the sound is the loudest directly over the pipe because the travel distance of elastic wave is the shortest at this point. However, the type of surface material, density of the in-situ soil and interferences from external sources can distort the sound distribution. There are three methods for using acoustic emission techniques: active sonics, passive sonics and resonant sonics.
Active sonics involves inducing a sound onto or into a pipe, which can be accomplished by striking the pipe at an exposed point or by introducing a noise source into the pipe. Passive sonics relies on the ability of the pipe’s product to escape. For instance, water escaping a pipe or at a leak will vibrate the pipe. The resulting vibration is carried along the pipe for some distance before attenuation allowing detection. Low ambient noise, shallow pipes, smooth stiff ground surface and high fluid pressure represent optimal conditions for this technique. Resonant sonic technique relies on the pipe’s product being a non-compressible fluid such as water. An oscillator is used to generate a pressure wave in the fluid and vibrations in the pipe that can be detected. Tuning the oscillator’s frequency to one or more of the resonant frequencies of the pipe usually increases the tracing distance. The technique is limited to relatively small wave intensities to avoid joint damage which is decreasing tracing distance.

Figure 4. Resonant Sonic Receiver. Used with permission.

14. Infrared Thermography

Infrared Thermography (IR) uses infrared cameras to “see” and “measure” thermal energy emitted from objects. The method can be used for the rapid locating of utilities whose temperature is significantly different temperature from the geological formation around them. The cameras detect IR energy (heat) of buried utilities, convert it into an electronic signal and process to produce a thermal image on a video monitor and perform temperature calculations. If the pipeline contains a flow with fluid temperature above or below the ambient ground temperature, a temperature differential is provided. If the pipeline is empty, the method is still applicable, but the time of day when the testing is scheduled becomes important.

IR imaging can be done by a drive over or fly over techniques, and involves the capturing and analysis of individual IR images using a specialized IR imaging system. The IR system gives the pipelines X, Y and Z coordinates.

15. Elastic Wave (Seismic Methods)

Spectral Analysis of Surface Waves (SASW) method uses a dynamic source to generate surface waves of different wavelengths (or frequencies) which are monitored by two or more receivers at known offsets. Typical dynamic sources are various sized sledge hammers to image the shear wave velocity structure to depths of up to 50 ft, weight drops and electromechanical shakers for depths of up to 100 ft, and bulldozers for depths as great as 300 ft. The SASW method can be performed on any material provided there is an accessible surface for receiver attachments. The method requires an accessible area on the
surface with a length equal to or greater than the measurement depth required. The method can applied on both bare ground as well as paved surfaces.

Vertical Seismic Profile (VSP) is a technique of seismic measurements used for correlation with surface seismic data. In the most common type of VSP, a seismic source is at the surface and the detectors (hydrophones, geophones or accelerometers) in the borehole. VSP can image objects within the vicinity of the borehole that could not otherwise be defined by surface techniques.

16. Electromagnetic Terrain Conductivity (EMTC)

Electromagnetic terrain conductivity method measures the average electrical conductivity of a cone-spaced volume of earth beneath the transmitting and receiving antennas. When a utility is within a cone, the average resistivity is changed to the extent based on the type of utility and its contents, and the local ground conditions. Most rocks and soils have high electric resistivity. Resistivity of pipe itself can vary from very low (metallic pipe) to very high (large empty clay pipe). Water inside the pipe has low resistivity. The bigger the contrast between the utility resistivity and earth resistivity the more effective this method is in detecting the utility. The method can be effective in locating water and sewer pipes in dry sands or gravel bedding, especially in metallic or empty pipes. The method can detect buried tanks, well shafts and vault covers.

There are two basic antenna configurations for electromagnetic terrain conductivity (EMTC). One is long and linear and the other is square. The long linear antenna measures average conductivity in a cone-shaped space from the ground surface to a depth of about 20 feet. Isolated metallic utilities, underground storage tanks, wells, and vault covers are usually detectable by means of this method. Under some conditions, large non-metallic water pipes in dry soils or large nonmetallic empty and dry pipes in wet soils may be imaged. The square antenna is more efficient than the linear one and alignment of the antenna with the utility is not a factor in detection. Multiple antennas can be combined for a broader swath of coverage, decreasing the time spent collecting data, and increasing the density of the data returned. The square antenna is usually coupled to some sort of survey equipment.

Figure 5. Terrain Conductivity Devices. Left: Long Linear Antenna. Right: Multiple Square Antenna with Integrated Survey. Used with permission.
TECHNOLOGIES

1. High Frequency Conductive P/C Locators

<table>
<thead>
<tr>
<th>Parameter</th>
<th>530 (Metrotech)</th>
<th>TMS 001 (Schonstedt)</th>
<th>8869 Path Finder (Rycom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>No</td>
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<td>Works in sandy soil?</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Min frequency (KHz)</td>
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<tr>
<td>Max frequency (KHz)</td>
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<td>Low/Med</td>
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</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>12</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Application</td>
<td>For locating buried street lighting, broken trace wires, tape and cast iron.</td>
<td>For locating underground pipes and cables.</td>
<td></td>
</tr>
</tbody>
</table>
2. **Medium Frequency Conductive P/C locators**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>510GSA (Metrotech)</th>
<th>10DX (Metrotech)</th>
<th>W-6 (Fisher)</th>
<th>aviTrack II (Ridgid)</th>
<th>869 RF (Rycom)</th>
<th>8856 (Rycom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>No</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
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<td>83</td>
<td>82</td>
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<td>N/A</td>
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<td>83</td>
<td>82</td>
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<td>Low/Med</td>
<td>Low/Med</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<td>Relative cost</td>
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<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
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<td>Max depth (ft)</td>
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<td>13</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Application</td>
<td>For locating pipes and cables.</td>
<td>For locating pipes and cables.</td>
<td>For locating pipes and cables.</td>
<td>For locating and tracing pipes and cables, energized power lines. pinpointing ferrous targets or for locating objects with large ferromagnetic objects (iron, steel).</td>
<td>For locating manhole covers, catch basins, cast iron pipe soil tanks, septic tank handles and steel drums.</td>
<td></td>
</tr>
</tbody>
</table>
3. **Low Frequency Conductive P/C locators**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>8831 (Rycom)</th>
<th>Dyntel 2273 (3M)</th>
<th>Digicat 200 (Leica)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>0.8</td>
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<td>0.8</td>
<td>200</td>
<td>33</td>
</tr>
<tr>
<td>Effort, training for data interpretation</td>
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<td>Low/Med</td>
<td>Low/Med</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>100</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Application</td>
<td>For locating pipes, cables, lines, faults.</td>
<td>For locating pipes, cables, faults, energized power cables.</td>
<td>For locating metal pipes and non-energized main cables, copper telecom cables, metallic gas pipes.</td>
</tr>
</tbody>
</table>
### Inductive P/C Locator, Med/High Frequency

<table>
<thead>
<tr>
<th>Parameter</th>
<th>XTpc (Schonstedt)</th>
<th>TW-7700 (Fisher)</th>
<th>800 Model (Pipehorn)</th>
<th>100 Model (Pipehorn)</th>
<th>110 Model (Pipehorn)</th>
<th>500 Model (Pipehorn)</th>
<th>480 (Metrotech)</th>
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<tbody>
<tr>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
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<td>9</td>
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</tr>
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<td>Max frequency (KHz)</td>
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<td>480</td>
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<td>Low/Med</td>
<td>Low/Med</td>
<td>Low/Med</td>
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</tr>
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</tr>
<tr>
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<td>Low</td>
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<tr>
<td>Max depth (ft)</td>
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<td>12</td>
<td>30</td>
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<td>15</td>
</tr>
<tr>
<td>Application</td>
<td>Used for locating buried cables and pipes.</td>
<td>For locating pipes, cables, depth measurements.</td>
<td>For locating buried metallic objects, pipes and cables.</td>
<td>For locating pipes and cables.</td>
<td>For locating pipes and cables.</td>
<td>Used for locating pipes and cables.</td>
<td>For locating pipes and cables.</td>
</tr>
</tbody>
</table>
## 5. Radio Mode P/C Locators

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RD4000 (Radio detection)</th>
<th>TW-8800 (Fisher)</th>
<th>8880-DF/RF (Rycom)</th>
<th>8879-RF/CP (Rycom)</th>
<th>i5000 (Metrotech)</th>
<th>9860 DF-XT (Metrotech)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Low/Med</td>
<td>Low/Med</td>
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<tr>
<td>Relative cost</td>
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<td>Low</td>
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<td>Low</td>
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<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Application</td>
<td>For locating buried services like electric, gas, sewer and water.</td>
<td>For detecting and pinpointing liquid leaks in pipes.</td>
<td>For locating leaks in cast iron or PVC pipes.</td>
<td></td>
<td></td>
<td></td>
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</table>
### 5. Radio Mode P/C Locators (Continue)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>850 (Metrotech)</th>
<th>Dynatel 2250M (3M)</th>
<th>Seek Tech SR 20 (Ridgid)</th>
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</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Can find non-ferrous objects?</td>
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<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
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<td>Possible</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
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<td>0.5</td>
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<tr>
<td>Max frequency (KHz)</td>
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<td>Low/Med</td>
<td>Low/Med</td>
<td>Low/Med</td>
</tr>
<tr>
<td>interpretation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Application</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
### 6. Sonde Mode P/C Locators

<table>
<thead>
<tr>
<th>Parameter</th>
<th>XLT-17 (Fisher)</th>
<th>8872-SD (Rycom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Max frequency (KHz)</td>
<td>0.8</td>
<td>51</td>
</tr>
<tr>
<td>Effort, training for data interpretation</td>
<td>Low/Med</td>
<td>Low/Med</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Application</td>
<td>For tracing pipes using a sonde.</td>
<td>For tracing pipes using a sonde.</td>
</tr>
</tbody>
</table>
## 7. Inductive Array

<table>
<thead>
<tr>
<th>Parameter</th>
<th>AIRS (MPS3D)</th>
<th>EM 31 (Geonics)</th>
<th>EM 61 (Geonics)</th>
<th>MetaVision II (UIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Min frequency (KHz)</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
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<tr>
<td>Max frequency (KHz)</td>
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<td>512</td>
<td>512</td>
<td>512</td>
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<td>Effort, training for data interpretation</td>
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<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Relative cost</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Application</td>
<td>For locating cables and metallic pipes.</td>
<td>For locating cables and metallic pipes.</td>
<td>For locating cables and metallic pipes.</td>
<td>For locating cables and metallic pipes.</td>
</tr>
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</table>
### Magnetic Methods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GA-92XT (Schonstedt)</th>
<th>GA-72Cd (Schonstedt)</th>
<th>GA-52Cx (Schonstedt)</th>
<th>MAC-51Bx (Schonstedt)</th>
<th>FX-3 (Fisher)</th>
<th>FP-ID 2100 (Fisher)</th>
<th>Magnastick MS 101/102 (Rycom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
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<tr>
<td>Works in organic soil?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Min freq.(KHz)</td>
<td>0.01</td>
<td>N/A</td>
<td>0.04</td>
<td>0.05</td>
<td>N/A</td>
<td>N/A</td>
<td>0.05</td>
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<tr>
<td>Max freq.(KHz)</td>
<td>0.01</td>
<td>N/A</td>
<td>0.04</td>
<td>0.06</td>
<td>N/A</td>
<td>N/A</td>
<td>0.06</td>
</tr>
<tr>
<td>Effort, training for data interpretation</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
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<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Application</td>
<td>For detecting markers, manholes and septic tanks made from ferrous material.</td>
<td>For locating buried metallic objects, magnetically detectable nonmetallic ducts, cables.</td>
<td>Used for detecting underground ferrous utilities.</td>
<td>For locating cables, pipes, energized power lines, line tracing, pinpointing ferrous targets</td>
<td>For locating ferromagnetic objects (iron, steel).</td>
<td>For locating manhole covers, catch basins, cast iron pipes, etc.</td>
<td>For locating ferrous objects.</td>
</tr>
<tr>
<td>Parameter</td>
<td>PRL-1 (White's)</td>
<td>ULA-3 (White's)</td>
<td>PRL-1 (White's)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
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<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td></td>
<td></td>
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<tr>
<td>Works in organic soil?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Min frequency (KHz)</td>
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<td>Max frequency (KHz)</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Effort, training for data</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
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<td>interpretation</td>
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<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>Used for locating stakes, property rings and sprinkler heads.</td>
<td>Used for locating stakes, property rings and sprinkler heads...</td>
<td>Used for locating stakes, property rings and sprinkler heads.</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
## 10. Electronic Markers and Detectors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ScotchMark Markers (3M)</th>
<th>8890-MP (Rycom)</th>
<th>60-Dx (Metrotech)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>N/A</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
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<td>No</td>
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<tr>
<td>Works in silty soil?</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
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<tr>
<td>Works in clayey soil?</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>N/A</td>
<td>Possible</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
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<tr>
<td>Min frequency (KHz)</td>
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<td>77</td>
<td>0.06</td>
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<tr>
<td>Max frequency (KHz)</td>
<td>4</td>
<td>170</td>
<td>6</td>
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<tr>
<td>Effort or Training required for data interpretation</td>
<td>Low</td>
<td>Low</td>
<td>Low/Med</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Med</td>
<td>Low</td>
<td>Med</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>12</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Application</td>
<td>For marking six standard utility types (sewer, gas, telephone, water and CATV)</td>
<td>For locating all six standard marker frequencies.</td>
<td>For locating all six standard marker frequencies.</td>
</tr>
</tbody>
</table>
11. **Ground Penetrating Radar (GPR)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Zond 12e (GPR)</th>
<th>Utility Scan 400 (GSSI)</th>
<th>Utility Scan 270 (GSSI)</th>
<th>Radar MALA Easy Locator (Gazomat)</th>
<th>2150 GR (Ditch Witch)</th>
<th>Opera Duo (IDS) ok</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Works in clayey soil?</td>
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<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>30,000</td>
<td>40,000</td>
<td>270,000</td>
<td>30,000</td>
<td>250,000</td>
<td>250,000</td>
</tr>
<tr>
<td>Max freq. (KHz)</td>
<td>300,000</td>
<td>40,000</td>
<td>270,000</td>
<td>500,000</td>
<td>700,000</td>
<td>700,000</td>
</tr>
<tr>
<td>Effort, training for data interpretation</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
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<tr>
<td>Relative cost</td>
<td>High</td>
<td>High</td>
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<td>High</td>
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<tr>
<td>Max depth (ft)</td>
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<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Application</td>
<td>For locating buried pipes, utilities (conductive, non-conduct.), sink holes, etc.</td>
<td>For locating pipes, storage tanks. Locates non-traceable utilities in real time.</td>
<td>For locating pipes, storage tanks.</td>
<td>For locating cables and pipes (metallic, non-metallic) underground storage tanks.</td>
<td>For locating cables and pipes (metallic, non-metallic)</td>
<td>For locating cables and pipes (metallic, non-metallic)</td>
</tr>
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</table>
12. **Multi-channel GPR Technologies**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RFIL (Time-Step Frequency GPR)</th>
<th>RIS MF Hi-Mod (IDS)</th>
<th>Stream EM (IDS)</th>
<th>MIRA (Mala)</th>
<th>TerraVision II (UIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Can find non-ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
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<td>200,000</td>
<td>25,000</td>
<td>400,000</td>
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<td>500,000</td>
<td>600,000</td>
<td>600,000</td>
<td>500,000</td>
<td>400,000</td>
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<td>Effort, training for data interpretation</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Med/High</td>
<td>High</td>
</tr>
<tr>
<td>Relative cost</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Application</td>
<td>Detecting pipes underground.</td>
<td>Utility detection, mapping and soil classification</td>
<td>3D utility mapping.</td>
<td>3D utility mapping</td>
<td>3D utility mapping.</td>
</tr>
</tbody>
</table>
### 13. Noise Emission Systems and Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>XLT-17 (Fisher)</th>
<th>XLT-30 (Fisher)</th>
<th>LD-8000 (Rycom)</th>
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</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Works in clayey soil?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>0.06</td>
<td>0.06</td>
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<tr>
<td>Max frequency (KHz)</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Effort, training for data</td>
<td>Low/Med</td>
<td>Low/Med</td>
<td>Low</td>
</tr>
<tr>
<td>interpretation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative cost</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Application</td>
<td>Used for detecting and pinpointing liquid leaks in pipes.</td>
<td>Used for detecting and pinpointing liquid leaks in pipes.</td>
<td>Used for locating leaks in cast iron or PVC pipes.</td>
</tr>
</tbody>
</table>
## 14. Infrared Thermography

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EnSITE I through EnSITE IX (EnTech Engineering)</th>
<th>FLIR SC8000 Series Infrared Cameras (FLIR Instruments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Max frequency (KHz)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Effort, training for data interpretation</td>
<td>Med/High</td>
<td>Med/High</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>38 ft</td>
<td>NA</td>
</tr>
<tr>
<td>Application</td>
<td>For rapid locating of pipes whose contents are at a significantly different temperature from the geological formation around them.</td>
<td>For rapid locating of pipes whose contents are at a significantly different temperature from the geological formation around them. Standard temperature range --4°F to 932°F.</td>
</tr>
</tbody>
</table>
## 15. Elastic Wave

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Engineering Seismographs</th>
<th>Spectral Analysis of Surface Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Max frequency (KHz)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Effort, training for data</td>
<td>Med/High</td>
<td>Low/Med</td>
</tr>
<tr>
<td>interpretation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative cost</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Application</td>
<td>Used for locating buried pipes, vaults and tanks. Usually relatively large diameter objects.</td>
<td>Used for condition assessments of concrete liners in tunnels and other buried structures (i.e., brick sewers).</td>
</tr>
</tbody>
</table>
16. **Terrain Conductivity**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EM31-MK2 (Geonics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can find ferrous objects?</td>
<td>Yes</td>
</tr>
<tr>
<td>Can find non-ferrous objects?</td>
<td>No</td>
</tr>
<tr>
<td>Works in silty soil?</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in clayey soil?</td>
<td>Yes</td>
</tr>
<tr>
<td>Works in organic soil?</td>
<td>Possible</td>
</tr>
<tr>
<td>Works in sandy soil?</td>
<td>Yes</td>
</tr>
<tr>
<td>Min frequency (KHz)</td>
<td>9.8</td>
</tr>
<tr>
<td>Max frequency (KHz)</td>
<td>9.8</td>
</tr>
<tr>
<td>Effort, training for data</td>
<td>Medium</td>
</tr>
<tr>
<td>interpretation</td>
<td></td>
</tr>
<tr>
<td>Relative cost</td>
<td>Medium</td>
</tr>
<tr>
<td>Max depth (ft)</td>
<td>15</td>
</tr>
<tr>
<td>Applicability</td>
<td>Used to map geological variations, groundwater contaminants or any subsurface feature associated with changes in the ground conductivity such as buried storage tanks.</td>
</tr>
</tbody>
</table>