INVESTIGATE THE AVAILABILITY OF TECHNOLOGY TO IDENTIFY BURIED NON-METALLIC PIPELINES

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The purpose of this report is to document the findings of project number 0-4376. For the purpose of this report, the information available from the vendors and scientific literature was reviewed. It was found that technologies are available which can be used to locate and identify non-metallic pipelines. However, technology constraints must be taken into consideration during selection process. CART Imaging System-Written Technologies is recommended as the primary technology, and Smart Cart from Sensors and Software, Canada, or, SIR 2002 with Sub Echo 40 from GeoQuest is recommended as secondary technology. In order to avert damage to underground Utilities during construction and minimize the associated risks to personnel and equipment, it is imperative that a research project should be undertaken to select the state-of-the-art technologies. Using these technologies, utility maps should be prepared for use during planning and execution of new construction projects.</td></tr>
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The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

IMPLEMENTATION STATEMENT

This project identified several technologies which can be used to locate and identify buried non-metallic pipelines. Characteristics of each technology have been tabulated and compared based on the information supplied by the manufacturers. Research findings of this project can be used to evaluate the suitability of these technologies for field-trials and adoption by Texas Department of Transportation.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate

(Revised September 1993)

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EXECUTIVE SUMMARY

This research project was sponsored by Texas Department of Transportation (TxDOT). The project was geared towards identifying state-of-the-art technologies which can be used to precisely locate and identify underground non-metallic pipelines.

The information available from the vendors and scientific literature was reviewed. It was found that technologies are available which can be used to locate and identify non-metallic pipelines. However, the following technology constraints must be taken into consideration during the selection process: (1) any one technology cannot locate all types of utilities, (2) soil type is a major factor affecting location and identification of utilities, (3) interference from nearby objects is noticeable in some cases, e.g., power lines and transformers, (4) effective depth for utility location and identification is a limiting factor, (5) resolution of images for smaller diameter utilities at greater depths is a problem, and (6) initial cost is far greater than what the market is willing to pay for the services.

The following criteria was used to select a technology during the evaluation phase of this project:

- Identification of both metallic and non-metallic pipes and different pipe sizes.
- Accurate location for stacked-up utilities.
- Extent of interference from nearby metallic objects.
- Level of training required to operate the equipment.
- Extent of data processing required to get a readable plot of utility locations.
- Effect of different soil layers on data acquisition and processing.
- Reproducibility of the results.

In order to minimize the risk of damage to underground utilities, precise location and identification of utilities is important within the practical constraints of the technology, operator, and operating conditions. In addition to the above criteria, the following factors were also considered: effectiveness in all types of terrain conditions; rugged construction and multi-mode operation, i.e., walk behind, wheeled carts, or truck mounted; combination of technologies to improve effectiveness; compatibility with CAD and GIS; and reasonable cost.

Cost-benefit analysis for providing a technology or combination of technologies, versus cost of possible damage resulting from bursting of underground high-dollar value assets showed that costs associated with the technology provision, modifications, and crew training can be recovered in less than an hour from revenues generated from operation of these utilities.

After review of manufacturer's literature and careful consideration of all the facts, the following technologies were selected for additional evaluation : (1) Pipe Hawk GPR System, ERA, UK, (2) SPR Scan System, ERA, UK, (3) Path Finder Utility, Geophysical, NH, (4) Subsurface Interface Radar system and Antenna, TN, (5) GPR Cart System, GeoRadar Inc., CA, (6) RAMA/GPR MALA Geosciences, (7) CART Imaging System, Witten Technologies, Inc., (8) Interragator II ACS System, VEERMER, and (9) Smart Cart-Sensors & Software, Canada.

The selection was narrowed down to three technologies based on the information available from the literature, vendors, and published electronic resources. It is recommended that the following technologies should be considered for further evaluation during the implementation phase: (1) CART Imaging System-Witten Technologies - primary technology, and (2) Smart Cart – S & S Canada, or, SIR 2000 with Sub Echo 40 from GeoQuest - secondary technology.

In order to avert damage to underground utilities during construction and minimize the associated risks to personnel and equipment, it is imperative that a research project be undertaken to select the state-of-the-art technologies for detection of underground utilities. Using these technologies, GIS compatible utility maps should be prepared to supplement the existing data for underground utilities in TxDOT rights-of-way, because precise location and identification of these underground utilities is required during planning and execution of new construction projects.

INTRODUCTION

Utilities are being deregulated across the country. Even in Texas, utilities are competing for new customers. With the development of new technologies, the demand for rights-of-way access has increased. The limited space below and around these structures has become more important than the structures. The rights-of-way have now evolved into the most sought after resources. However, these resources are limited. Efficient utilization of this space is required for developing better opportunities for our communities to become desirable places to live and work. Local, state, and federal governments have been trying to develop efficient systems for utilization and management of these resources in the post-deregulation scenario.

The utility industry is about to be transformed from a regulated market to a highly competitive deregulated market. It is going to significantly change the way utilities operate and serve their customers. With the deregulation of the utility industries and the increased public demand for these services, the number of utilities seeking to gain access to the rights-of-way has substantially increased.

COMPLEXITY OF THE PROBLEM

Utilities can be located above ground or underground in the designated space along the highways or other specified corridors. Overhead utility lines are becoming outdated except in rural areas. The urban underground has become a maze of utility lines, ranging from fiber optic cables to storm water lines. It has been reported that these underground utilities are generally poorly documented, irregularly laid out, and neglected. These utilities account for more than 3.5 million miles in the U.S. and the estimated existing investment is in trillions of dollars [1]. The deregulation of utility services further complicates this problem because numerous service providers are seeking to place their networks underground.

The underground utility lines are prone to damage during construction and renovation operations. The records of these utilities are often poorly maintained. In some cases, existing services are not even shown on the utility plans. This seriously undermines the ability of locating services to correctly identify and locate these utilities, which sometimes results in accidental damage during construction.

These conduits have differing material properties, different shapes, and their depths are highly variable. In urban areas, some utility lines (usually local utilities) may be stacked vertically in a common trench. Multiple lines may be housed in a single conduit or duct bank.

COST OF THIRD PARTY UTILITY DAMAGE

An interruption in the provision of utilities negatively impacts commerce and affects the daily life of the public. In some cases, it also exposes workers to physical danger, and may result in damage to nearby structures. These incidents result in additional costs that are borne by the affected parties: contractors, utility providers, insurance companies, and the affected public or business owners. Some incidents are presented to underscore the magnitude of this problem [2]:

- In 1993, there were more than 104,000 hits or third party damage to gas pipelines with a total cost exceeding $86 million. The Public Service Company of Colorado had reported that more than 3,000 underground lines were cut in 1998 - up by more than 1,000 over the previous year [3].
- It has been reported that for underground fiber optic cables, revenue loss can be as high as $ 1 million per hour, and repair cost averages $ 50,000 per hour [1]. A 36 fiber, fiber optic cable can carry up to 870,912 circuits, and can generate over $175,000 per minute in revenue [4]. As a result of damage to a fiber optic cable, lottery ticket sales came to a grinding halt in Boerne, TX, when an auger damaged a fiber optic cable on March 26, 1998. The disrupted services included internet access, emergency services (911), credit card transactions, and automatic teller machines. As a result of this breakdown, customers quickly switched over to cellular service, thereby overloading the system and eventually shutting it down.
- In Liberty Hill, TX, a worker using an auger to install power poles busted a gas pipeline and was killed in the subsequent explosion on August 10, 1999. The truck-mounted auger was destroyed and 20 people were evacuated from a nearby residential area. Smoke and flames shot up to 50 feet high from the crater for more than two hours. In a similar incident in 1992, the company had paid a $90 million settlement to 21 survivors and victims of a gas explosion near Brenham, TX.
- Telephone service was disrupted for some 75,000 homes and businesses in Ft. Myers, FL, on May, 09, 2000, as a result of damage to a fiber optic cable in a highway right-of-way. Both long distance and 911 services were disrupted for nearly eight hours. In a similar incident on June 01, 2000, a telephone-fiber optic cable was damaged in two different spots and caused disruption of service to about 70,000 homes and businesses for two hours in Hampton Roads VA.
- In Hebron, KY, workers installing a utility pole ruptured an 8-inch gas line with their truck-mounted auger on October 17, 2000. The truck's engine ignited the gas and flames of fire shot skyward. The truck was destroyed and vinyl siding on a nearby building was melted. Two cars parked at the building were also damaged. Total cost of damages was estimated at *$110 million*.
- In Sandy Springs, GA, thousands of homes and businesses were without telephone service when a contractor for the state DOT cut two 1,500-pair cables while moving

utility poles on November 30, 2000. The service outage lasted as long as four days for some people.

The incidents reported above serve as a reminder to the contractors and utility planners about the gravity of this problem. It also underscores the importance of precisely locating these utilities during all phases of the project development. Not all damage to utilities is reported or immediately detected. This makes assigning the responsibility for damage costs difficult. Later on, these incidents may also cause service problems that are difficult to trace and may result in unexpected severe safety consequences.

TYPES OF UTILITIES

The type of utilities which may be found within the highway rights-of-way are shown in Table 1. Information about location of utilities, chances of finding such utilities, position of pipe or conduit, diameter of conduits, and potential consequences of damage is included in the table. The last column in the table gives an indication of relative severity of the accident in three categories: low, moderate, and high. The common materials which have been used for underground utilities are shown in Table 2. With the development of new placement technologies, e.g., horizontal directional drilling, pipe jacking, and microtunneling, utilities may be placed at greater depths [3].

STATE-OF-THE-ART TECHNOLOGIES

The precise location and identification of underground utilities helps in avoiding third-party damage. It requires significantly improved utility location technologies and their integration into the planning and execution phases of project development work. A review of the information about these technologies had shown that these technologies have some limitations: (1) any one technology can not locate all types of utilities, (2) soil type is a major factor affecting location and identification of utilities, (3) interference from nearby objects is noticeable, e.g., power lines and transformers, (4) effective depth for utility location and identification is a limiting factor, (5) resolution of images for smaller utilities at greater depths is a problem, and (6) initial cost is far greater than what market is willing to pay for the services.

The methods that have been used in the past can be grouped into two categories: destructive and non-destructive methods. Among non-destructive methods, geophysical methods have figured out very prominently. Only those methods will be discussed in this report which have either been used for detecting underground utilities, or have a potential of being used for this purpose. Specifications of each system based on the information provided by the manufacturer are presented in Appendix A.

Table 1 Type of Underground Utilities [3]

Utility	Location	Position in R.O.W?	Utility Characteristics	Diameter of Service	Potential Consequences of Damage	
					Safety	Economic
Cable Television - Distribution	Urban	Common	Edge, 0 - 1.5 m deep, may be stacked	10 - 50 mm	Low	Mod.
	Suburban	Common			Low	Low
	Rural	Unlikely			Low	Low
Cable Television - Service	Urban	Common	Edge, 0 - 1.5 m deep, may be stacked	10 - 50 mm	Low	Low
	Suburban	Common				
	Rural	Unlikely				
Transportation Data and Control, e.g. traffic signals	Urban	Common	Edge, 0 - 1.5 m deep, may be stacked	10 - 25 mm	Mod.	Mod.
	Suburban	Common			Low	Low
	Rural	Varies[1]			Low	Low
Electrical - Transmission	Urban	Common	Edge, 0 - 3 m deep	25 - 100 mm	High	High
	Suburban	Varies				
	Rural	Rare				
Electrical - Distribution	Urban	Common	Edge, 0 - 2 m deep, may be stacked or in conduit or duct bank	25 - 75 mm	High	High
	Suburban	Common				
	Rural	Rare				
Electrical - Transp. R.O.W. Power, e.g. road lighting	Urban	Common	Edge, 0 - 2 m deep, may be stacked or in conduit or duct bank	10 - 50 mm	Low	Low
	Suburban	Common				
	Rural	Varies[1]				
Electrical - Service	Urban	Common	Crossing, 0 - 1.5 m deep	10 - 50 mm	High	Varies
	Suburban	Common			High	High
	Rural	Rare			High	
Gas - Transmission	Urban	Varies[2]	0 - 4 m deep[3]	0.2 - 1.5 m	Very high	n/a
	Suburban	Varies[2]				
	Rural	Rare[2]				

Table 1 Type of Underground Utilities (Continued)

Gas - Distribution	Urban	Normal	Edge, 0 - 2 m deep	50 - 400 mm	High	High
	Suburban	Normal				
	Rural	Unlikely[4]				
Gas - Service	Urban	Normal	Crossing, 0 - 1.5 m	15 - 400 mm	High	Varies
	Suburban	Normal				
	Rural	Unlikely[4]				
Telephone - transmission	Urban	Common	Edge, 0 - 2 m deep	10 - 100 mm	Low	Very high
	Suburban	Common				
	Rural	Varies[6]				
Telephone - distribution	Urban	Common	Edge, 0 - 2 m deep, may be stacked or in conduit or duct bank	10 - 50 mm	Low	High
	Suburban	Common				
	Rural	Varies[5]				
Telephone - service	Urban	Common	Crossing, 0 - 2 m deep	10 - 50 mm	Low	Varies
	Suburban	Common				
	Rural	Unlikely				

(@ — Refer to glossary for definition of some of these terms)

Notes:

1. Interstates may have continuous underground data transmission lines in rural areas, most roads will either not have a need for this service or it will be provided in overhead lines.
2. Routing will often be outside public rights-of-way.
3. Depth may be large at major crossings, e.g. rivers and other natural/environmentally sensitive areas.
4. Distribution and service may occur around major industrial plants.
5. Usually aboveground except in areas of natural beauty or environmental preservation.

Table 2 Common Materials for Non-Metallic Underground Utilities [3]

Materials	Sub-classes	Locating Parameters
Clay pipe	-	Non-magnetic, non-conducting
Concrete	Pipe	Cylindrical shape
	Plain	Non-magnetic, non-conducting
	Reinforced	Contains low volume percentage of steel but reinforcement does not form a continuous electrical path
	Shotcrete	Spray-applied concrete, may contain fiber reinforcing
	Structure	May be rectangular, i.e. planar reflecting surfaces
Fiber optic cable	-	Small diameter, non-magnetic, non-conducting unless enclosed in conducting sheath
Fiberglass reinforced plastic pipe	-	Non-magnetic, non-conducting
Polyethylene pipe	-	Diameter may be small, non-magnetic, non-conducting
PVC pipe	-	Diameter may be small, non-magnetic, non-conducting

GEOPHYSICAL METHODS

In geophysical methods, a signal /wave is introduced into the ground. The wave /signal is reflected back from the object (buried utility in this case) and picked up by the receiver. The strength of signal and time at which it is received, is used to locate and identify the buried objects [5, 6, 13].

Ground Penetrating Radar

Background

The ground penetrating radar (GPR) system was originally developed by the military and have been used commercially for more than thirty years. Recently, environmental, construction, and utility industries have realized the benefits of conducting GPR surveys to gain information about subsurface conditions. GPR is a subsurface imaging method and considered completely non-intrusive, non-destructive, and safe.

Basic Principle of Operation

A transducer generates high frequency broad band electromagnetic waves. A specially directed antenna emits the pulse into the ground. As these waves travel through the ground, these are reflected, deflected, and absorbed to varying degrees. The return signals are picked up by the antenna and processed by the receiver. Measurements are continuously recorded at a significantly higher resolution, which provides a profile of the subsurface conditions. The schematic of GPR principles is shown in Figure 1.

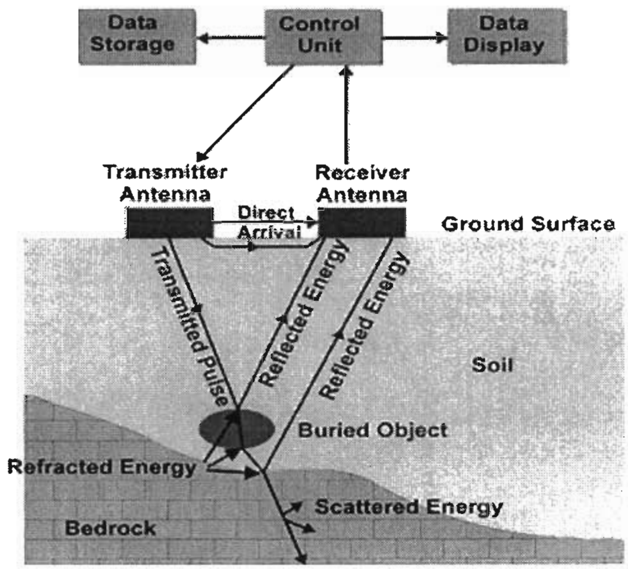

Figure 1 Schematic of GPR Operating Principles

<u>Depth of Signal Penetration</u>
The conductivity of geological materials is highly dependent upon the water content and concentration of dissolved electrolytes. Clays and silts typically exhibit higher conductivity due to presence of comparatively large number of ions. Conversely, in saturated condition, fewer ions are structurally attached in sands and gravels, and therefore have lower conductivities. Penetration of signals in clays and in materials having conductive pore fluids may be limited to less than 1 meter.

The frequency of the wave is a contributing factor in determining the depth of penetration of GPR signal. In general, lower the frequency of the pulse, deeper would be the signal penetration. However, at lower frequencies the images are not very sharp. On the other hand, at higher frequency, the depth of signal penetration is reduced but the image resolution will be better. This is attributed to the intrinsic properties of the Earth, which typically allow lower-frequency waves to travel farther within the subsurface. The effect of GPR signal decay with amplitude is presented in Figure 2.

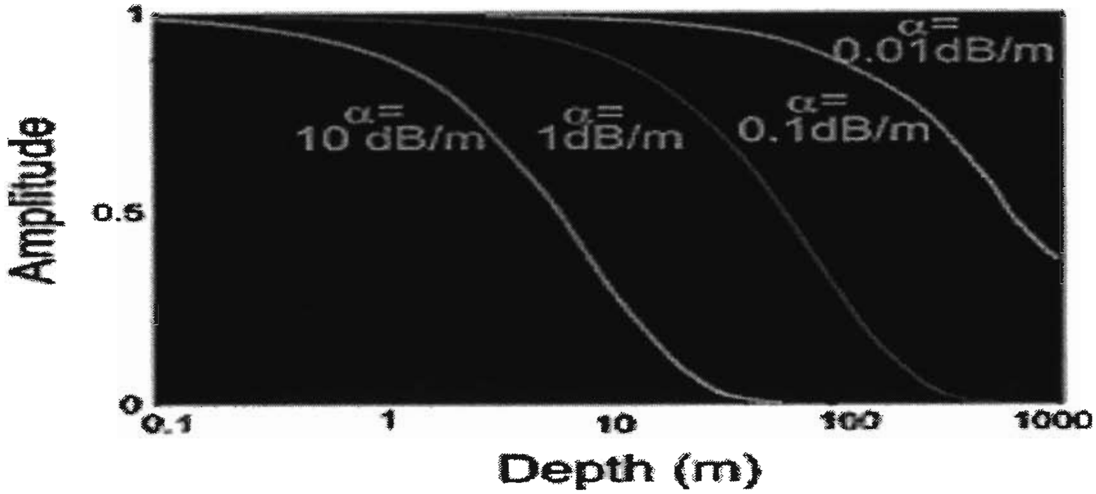

Figure 2 Exponential Decay of GPR Signals in Soil and Rock

<u>Attenuation</u>
Attenuation of GPR signals mainly results from the conversion of electromagnetic energy to thermal energy due to high conductivities of the soil, rock, and fluids. Scattering of the electromagnetic energy at sharp boundaries may become a dominant factor in attenuation. Attenuation increases with frequency as shown in Figure 3. In environments, which are favorable to GPR sounding, there is usually a plateau in the attenuation versus frequency curve, which defines the GPR window. This family of graphs depicts general trends of GPR signal attenuation.

<u>Resolution</u>
GPR provides the maximum lateral and vertical resolution of any surface geophysical method. Frequency of antennas can be selected to optimize the results. Lower frequency provides greater penetration with less resolution. Higher frequencies provide less penetration with higher resolution. Vertical resolution ranges from a few centimeters to more than 0.3 of a meter.

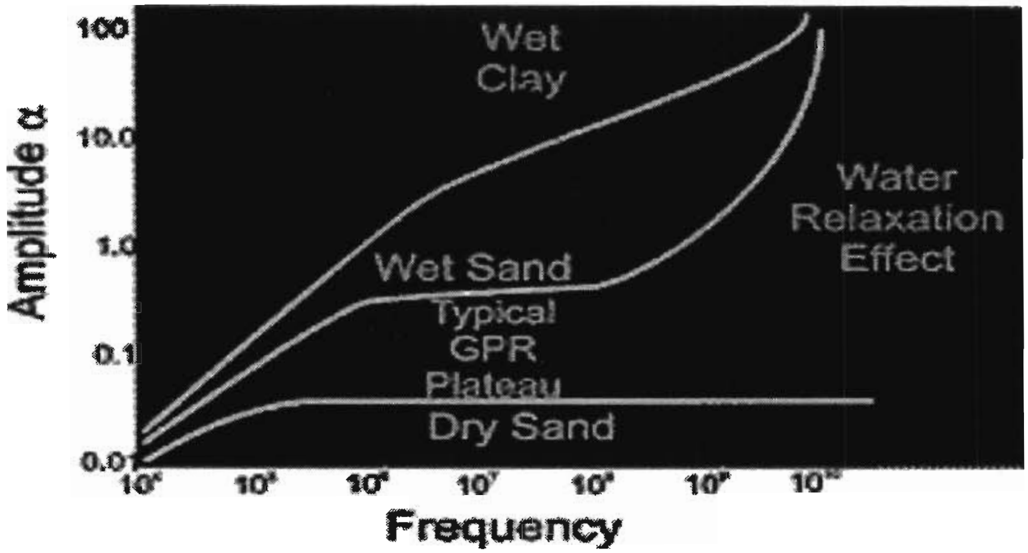

Figure 3 Attenuation Varies with Excitation Frequency and Material

Effect of Transmitter Power

The exploration depth of GPR can be increased by increasing the transmitter power. However, power has to be increased exponentially in order to increase the depth of exploration. The relative power necessary to penetrate the signals to a given depth is shown in Figure 4. It can be inferred from the Figure 4 that increases in signal penetration depth require large power sources in order to compensate for reduction in signal strength due to geological conditions.

Data Collection

Accessibility is a major consideration in GPR data acquisition. GPR antenna has to be moved over the area to be investigated to develop a GPR profile. Therefore, any type of physical barrier would adversely affect the data collection effort. A GPR profile is generated when the antenna is moved along the surface.

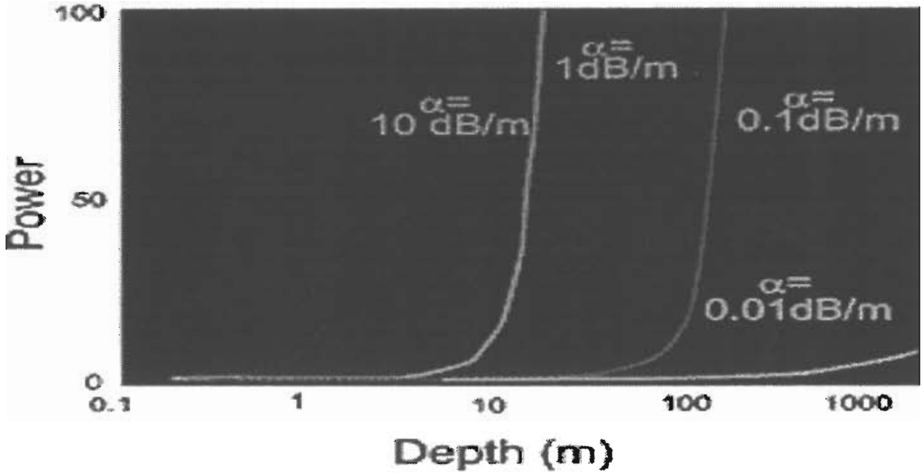

Figure 4 Effect of Signal Attenuation on its Penetration Depth

Two modes of data collection are normally used in conducting GPR surveys. In the first mode, data are acquired as the antenna(s) are towed or pulled across the survey line, and in the other mode, the GPR data are collected at specific points along the survey line both with fixed transmitter/receiver separation. The choice of operational mode depends upon the characteristics of the target, the field conditions, and the purpose of the survey.

Depth Determination

The underlying soils near the ground surface are generally not homogenous, which makes the actual target depth determination difficult, if not impossible. For most applications, an estimated depth range can be determined with fair accuracy, which is wholly dependent upon the subsurface material.

Table 3 Dielectric Constants of Different Materials

Material	Dielectric Constant	Material	Dielectric Constant
Air	1	Clay (saturated)	8-12
Pure Water	81	Sand (dry)	4-6
Fresh Water (ice)	4	Sand (saturated)	30
Granite (dry)	5		

Data Analysis

GPR data interpretation requires good training of operators, using correct procedures for data acquisition, and field experience. Currently available GPR post-processing software programs are aimed to assist in the computerization of data interpretation, and only accelerate the interpretation process.

Electromagnetic Methods

In electromagnetic (EM) method, a transmitter emits a wave and a receiver is used to detect any changes in the wave. If the wave comes in contact with a metallic object, a current is consequently generated in that object by the emitting wave. This current will then slightly alter some of the characteristic properties of the emitting wave. The receiver will detect and process the distortion, giving the operator a relative signal strength indication. Based on this signal strength indication, delineation and the dimensions of the subsurface objects can be determined. Conductive subsurface layers will delay the detection of subsurface targets.

Magnetics

Magnetic locators consist of two fluxgate magnetometer sensors which are securely mounted inside a rigid sensor tube. These sensors measure the average magnetic field component along the longitudinal axis of the sensor tube.

The magnetometer sensors are aligned for opposing polarity so that the magnetic field measured by one sensor is the negative of the magnetic field measured by the other. The locator then sums the output of the two sensors. By summing the two output signals, any field common to both sensors cancels out, e.g., Earth's Magnetic Field, and leaves only the differential magnetic field. The differential magnetic field, i.e., the magnetic field detected by one sensor and not the other, is the magnetic field of interest and generally represents the magnetic field of the target object.

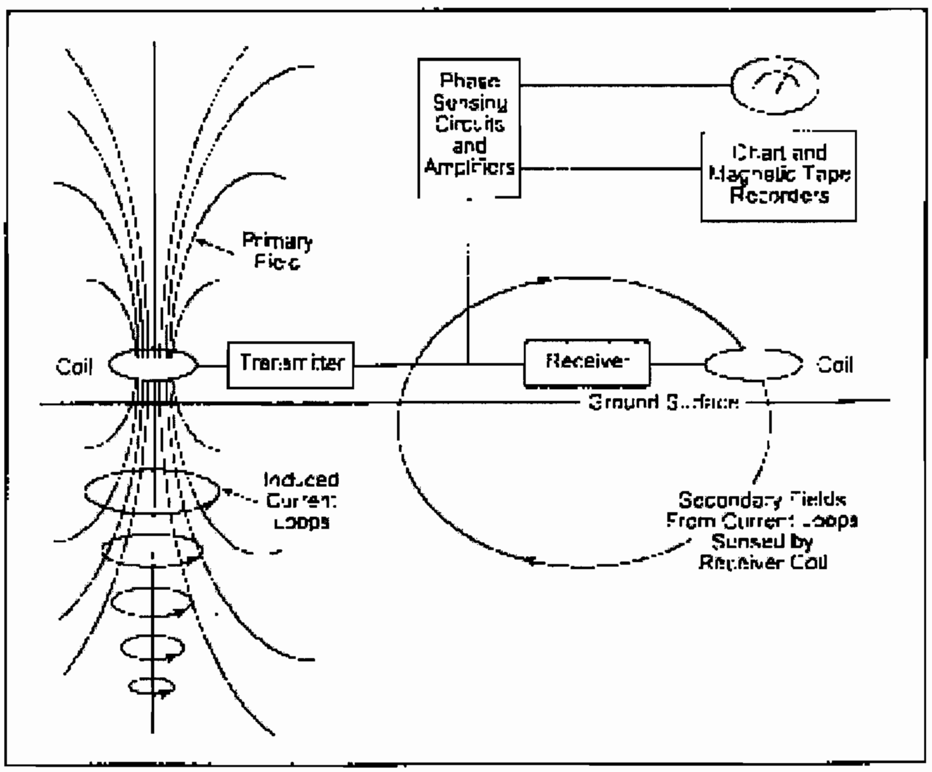

Figure 5 Schematic of Electromagnetic Operating Principles

Radio Frequency

The basic radio frequency (RF) instrument consists of separate transmitting and receiving units. When the transmitter is in proximity of a subsurface conductive object, the wave signal will be conducted along the length of the object. When the receiver is an appropriate distance away from the transmitter, it is positioned to detect and process any similar signals emanating from the ground. The transmitted signal is conducted along the length of the utility, enabling the receiver to detect and locate the exact position of the center of the pipe.

Keeping transmitter stationary, an operator can walk with the receiver along the utility line, collecting data up to several hundred feet away from the transmitter. This is called tracing or marking out the utility. The ability to trace out a utility is based on the soil parameters, the conductivity of material comprising the utility, and the ability to place a signal onto the utility. This method can only locate metallic and electrically continuous objects. Any discontinuity will affect the ability of this technology to locate the underground utilities.

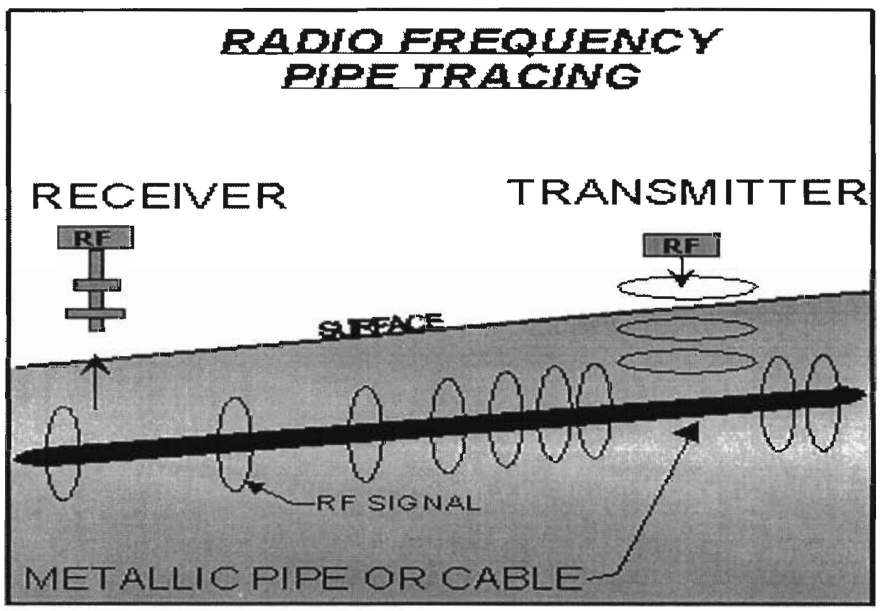

Figure 6 Location of Utilities Using Radio Frequency

Electrical Resistivity

Electrical resistivity methods are also referred as galvanic electrical methods. Shallow and deep geological conditions can be determined by measuring the electrical resistance to a direct current applied at the surface.

In this method, an electrical current is applied to the ground through a pair of electrodes. A second pair of electrodes is then used to measure the resulting voltage. The distance between two electrode pairs controls the depth of investigation, i.e., greater the distance, the deeper would be the penetration. The resistivity values of different subsurface materials have been well documented in the literature. Using this method, vertical and lateral variation of underlying materials can be determined. Similar to EM methods, the success of investigation depends upon subsurface resistivity contrasts. The schematic of electrical resistivity principles is presented in Figure 7.

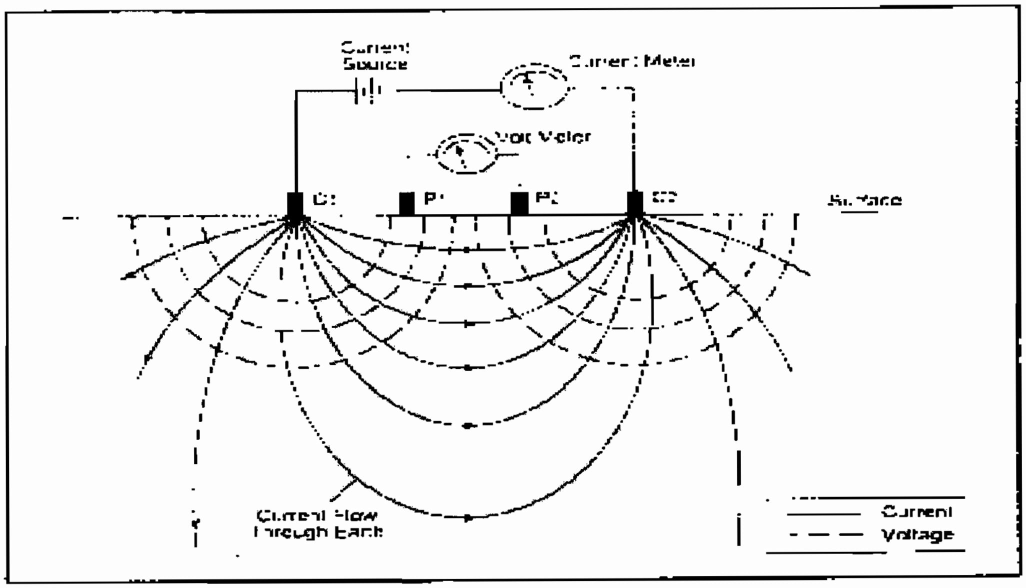

Figure 7 Schematic of Electric Resistivity Operating Principles

Seismic Methods

These methods provide information about subsurface conditions by measuring the speed of seismic waves reflected back from different boundary layers. There are mainly two types of seismic method applications: refraction, and reflection. Seismic refraction measures the travel times of multiple sound waves as they travel along the interface of two layers having different acoustic velocities. These waves are recorded by geophone sensors. The travel time of these waves is dependent upon characteristics of the subsurface geological layers, e.g., degree of weathering and fracturing of subsurface materials. The schematic of a seismic refraction operating principles is presented in Figure 8.

The equipment used includes a seismograph (which records and processes data), geophones (which measure ground acceleration), and an energy source (such as a plate and hammer, seismic gun, or weight-drop). The data obtained are velocity measurements of the acoustic energy traveling through the subsurface. As the seismic waves strike a boundary between rock units with different acoustical properties, portions of the energy will be critically-refracted along the boundary or reflected back to the surface. By measuring the time, distance, and amplitude of the returned energy, interpretations can be made of the strata's geometry.

The four major elements of a seismic investigation are: (1) the length of the survey line; (2) the survey line location; (3) the geophone spacing; and, (4) the energy source. The length and location of the survey line is dictated by the aerial extent of the study area. The geophone spacing is dependant on the desired depth of investigation and the seismic velocities of the rock units

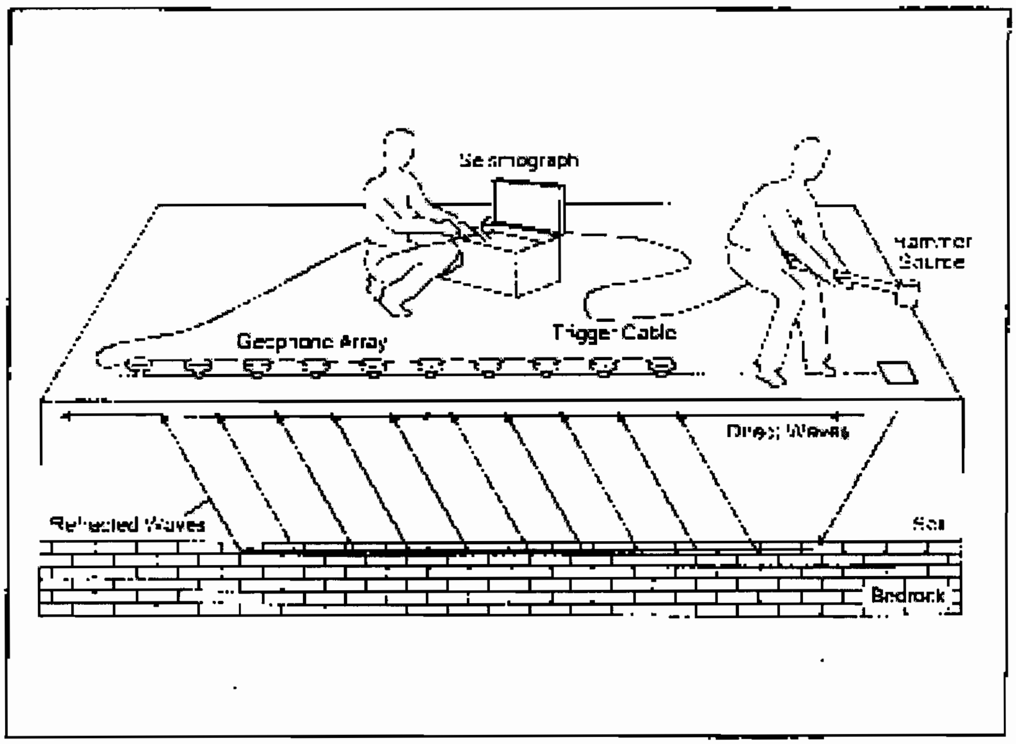

Figure 8 Schematic of Seismic Refraction Operating Principles

VENDOR INFORMATION

American Water Works Association (AWWA) Research Foundation had recently completed a comprehensive study to identify new technologies for precisely locating buried infrastructure. This study had been very valuable in identifying the appropriate technologies for buried non-metallic pipelines. Information about different manufacturers and equipment is presented in Tables 4 to 6.

Table 4 Matrix of Manufacturers and Equipment [6, 20]

	EM[1]	ER[2]	GPR[3]	SM[4]	S & A
Geometrics	X			X	
Geoincs	X				
GeoRadar			X		
Phoenix	X				
Scintrex		X			
SSI			X		
Zonge	X	X			
Sensor & Software	X	X	X	X	X
Witten Tech.			X		
MALA Geosciences			X		
Radio-detection					X

1. EM Electormagnetic Methods
2. ER Electrical Resistivity
3. GPR Ground Penetrating Radar
4. SM Seismic Methods
5. S & A Sonics and Acoustics

Table 5 Information on Geophysical Equipment Manufacturers [6, 20]

Geophysical Survey Systems 13 Klein Drive North Salem, NH 03073-0097 Tel: (603) 893-1109 Fax: (603) 889-3984 www.geophysical.com	*Geometrics* *395 Java Drive* *Sunnyvale, CA 94089* *Tel: (408) 734-4616* *Fax: (408) 745-6131* www.geometrics.com
Geonics Limited 8-1745 Meyerside Drive Mississauga, Ontario Canada L5T 1C6 Tel: (905) 670-9580 Fax: (905) 670-9204	Georadar, Inc. 19623 Vis Escuela drive Saratoga, CA 95070 Tel: (408) 867-3792 Fax: (408) 867-4900 www.georadar.com
Phoenix Geophysical. Ltd. 3871 Victoria Park Avenue, Unit No. 3 Scarborough, Ontario Canada M1W 3K5 Tel: (416) 491-7340 Fax: (416) 491-7378 www.phoenix-geophysics.com	*Scintrex, Ltd.* *222 Snidecroft Rd.* *Concord, Ontario* *Canada L4K 1B5* *Tel: (905) 669-2280* *Fax: (905) 669-6403*
Sensors & Software Inc., 1091 Brevik Place Mississauga, ON L4W 3R7 Canada Tel: (905) 624-8909 Fax: (905) 624-9365 www.sensoft.on.ca	Vermeer Manufacturing Company Pella, IOWA 50219 Te: (888) VERMEER www.vermeer.com
MALÅ GeoScience Skolgatan 11 S-930 70 Malå, Sweden Tel: +46 953 34550 Fax:+46 953 34567 www.malags.se	Radiodetection Corp., Bldg. # 1 35 Whitney Road Mahwah, NJ 07430 Tel: (201) 848-8070 Fax: (201) 848-9572 www.radiodetection.com

Table 6 Inventory of Technologies for Locating Buried Utilities [20]

Technology	Manufacturer & Instrument Model	Features	Advantages	Limitations	Comments
GPR	GSSI SIR 2000	• Easy to operate	• Light and compact • Interchange-able Antennas	• No infra-structure specific feature	• Needs 12V battery
GPR	GSSI Pathfinder System	• GPS interface • Laser interface • Voice command	• Light and compact • Centimeter-accuracy	• Requires training • Navigation system sensitive to site condi-tions	• Up to 2.5 m Depth
GPR	Vermeer/GSSI Interragator	• Easy to operate	• Rugged construction		
GPR	GeoRadar, Inc. Model 1000B	• Stepped frequency radar unit	• More accurate images	• Bulky • Experienced operator	
GPR	Pulse EKKO and noggin sensors & software	• Easy to use	• Compact and light conven-tional GPR unit. • Antennas can be inter-changed.	• Not weather resistant. • Requires 12 V battery.	
GPR	ERA Tech. Ltd. SPRScan	• Easy to use	• Compact and light conven-tional GPR unit. • Antennas can be inter-changed.	• Low position accuracy. • No infra-structure specific features.	
GPR	Mirage Systems Inc.	• Aerial antenna setup with 3-D subsurface resolution	• Mounted on a helicopter, large area can be covered	• Interference from other communi-cation infra-structure.	
GPR	EMRAD, Limited. PipeHawk	• CAD map can be viwed at site for marking the utilities.	• Easy to use • Can be operated in low temperature.	• Performance is affectd by terrain conditions.	

GPR	MALA Geosciences	• Quick and easy to operate	• Light and Compact Interchange-able antennas	• Low position accuracy	• Requires 12Volts Battery
EM	Radiodetection Acoustic Pipe Tracer (APT)	• Consists of EM trans-mitter, driver, and receiver	• Rugged design. • Can locate non metallic pipes.	• Interference from nearby utilities	• Trans-mitter powered from 10-14 V auto battery
EM	Radiodetection PDL-2 Locator	• Receiver locates signals applied to pipes	• Rugged design. • Metallic pipes.	• EM signal may jump to another conductor	
EM	Geonics	• Features ground conductivit y meter	• May locate plastic pipes	• Time consuming	• Weather resistant
EM	GSSI GEM-300	• Multi-Frequency EM unit	• May locate plastic pipes	• Instrument noise	• Weather Resistant
MAG	Shonstedt MAC-51Bx	• Magnetome ter Dual Frequency	• EM and MAG mode	• Requires special arrangement to detect non-metallic pipes	• Trans-mitter is not water proof
S &A	Radiodetection RD 500 and TransOnde	• Creates a pressure wave and detects acoustic signals	• Locates up to 500 ft from source	• Requires access to pipe	• Detects up to 2 m, requires a 9 Volt battery
S & A	Vision Technology VT-2000 and TransOnde	• Creates a pressure wave and detects acoustic signals	• Locates up to 500 ft from source	• Requires access to pipe	• Loose soils affect the perform-ance

SELECTION CRITERIA

It would be difficult to find one technology which would meet all the needs of planners. To start with the complex process of technology selection, following questions should be addressed and evaluated with reference to each technology [3]:

- Can this technology distinguish between metallic and non-metallic pipes?
- How accurate is the technology in determining the location and depth of non-metallic stacked up utilities?
- Can this technology distinguish between different pipe sizes?
- What is the effect of near by metallic utilities?
- How complex is the data obtained from on-board processor?
- How much extensive post-processing is needed to get an image?
- How precisely closely spaced utilities are located and identified?
- How reproducible are the results?
- What is the effect of different surface materials?
- What is the effect of different soil layers on data acquisition and data processing?

However, in order to minimize the risk of damage to underground utilities, precise location and identification of utilities is important within the practical constraints of technology, user, and operating conditions. The main constraints and application criteria for new technologies are listed below [3]:

- **Location-Dependency.** The potential technology should be easy to operate both in urban right-of-way settings as well as in an open-ground, non-uniform soil condition. The new technology should be equally effective under varying operating conditions: (1) different target materials, i.e., asphalt or reinforced concrete road pavements, (2) tolerate interference from nearby metallic objects, (3) effective in crowded utility settings, and (4) least interfere with traffic flows on major routes.
- **Usage Characteristics.** Technology should be of rugged construction to withstand the rigors of field use; readily portable in different modes, e.g., truck mounted, wheeled carts, or walk behind mode; dual power source, i.e., generators or batteries as appropriate; multi-sensor technology to compensate for varying operational conditions.
- **Operator Skills.** The operator should be able to operate the instrument with minimum skills and level of training required to achieve working proficiency should be modest.
- **Identification Accuracy.** Instrument(s) should be ideally able to identify utilities with a depth to diameter ratio of 30:1 or better, i.e. a 25 mm pipe or cable at 0.75 m depth or a 1 m diameter pipe at 30 m depth.
- **Positional Accuracy**. Technology should be able to resolve depth and horizontal position of utilities to within a depth to accuracy ratio of 20:1 or better, i.e. an error in depth or horizontal position of 50 mm at 1 m depth or 1 m at 20 m depth.

- **Combination of Technologies.** Compatibility with other technologies is highly desirable to able to improve detection of all kinds of pipe or cable in all soil conditions.
- **Interface with CAD/GIS.** The data acquisition mechanism of the potential technology should be compatible with CAD and GIS. This will be extremely helpful in updating the utility plans and would be a good decision making tool for the planners.
- **Cost.** The cost of acquiring, modifying, training of crews, and implementation of the proposed technology should not be prohibitive.

CHARACTERISTICS OF TECHNOLOGIES

Preliminary selection of different equipment was made based on the literature supplied by different vendors and case studies posted on their websites. Brief discussion on characteristics of selected technologies is presented.

Pipe Hawk

It is a GPR based system from United Kingdom (Figure 9). The manufacturer claims that data can be processed in real-time. Characteristics of Pipe Hawk System are summarized in Table 7 [8].

Figure 9 Pipe Hawk System – ERA (UK)

Table 7 Product Specification of Pipe Hawk GPR System [8]

	Handle Extended	**Handle Retracted**
Height	102 cm	71 cm
Length	180 cm	136 cm
Width	58 cm	58 cm
Weight	Operational Weight – 44 kg (97 lb)	
Operator Interface	7 interactive software keys. Menu driven software.	
Data Storage	Data is stored on the onboard hard disc drive. Capacity 30,000 square meters of surveyed area (300, 000 sq. ft.)	
Data Output	Data is processed on the unit while on site and is displayed on the screen.	
Detection	Down to a depth of 2.5m (8ft) depending on soil conditions. Minimum target diameter 18mm (0.75").*Plastics, fiber optics, metals, asbestos, cement, concrete, clay, wood and underground cavities.*	

SPR Scan System

It is a GPR system manufactured by ERA Technology, UK (8). Based on the manufacturer's literature, instrument can detect both metallic and non-metallic pipes, ducts and cables, voids, and structural anomalies. Specifications of different antennas which can be used with SPR Scan System are presented in Table 8 [9].

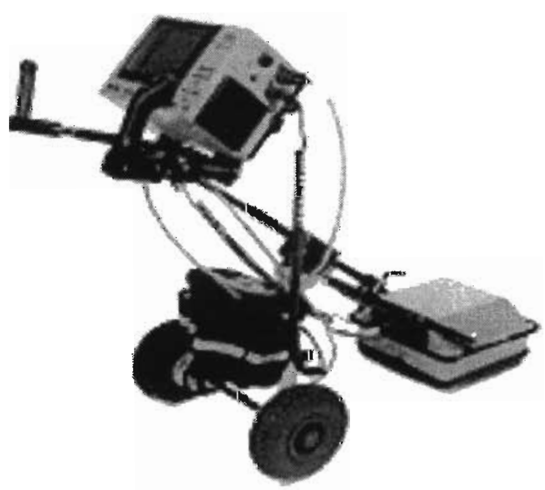

Figure 10 SPR Scan GPR System from ERA Technology, UK

Table 8 Specifications of Antennas for SPR Scan System [9]

Antenna Typical (mm)	**Maximum Penetration Depth (m)**	**Weight (kg)**	**Sizes (mm)**
250 MHz	3 to 4	6	560x560x270
500 MHz	1.5 to 2	4	400x400x250
1 GHz	0.5 to 0.75	2	200x200x95
2 GHz	< 50 cm	1	110x110x130

Path Finder Utility Mapping System

It is a GPR or laser based system from Geophysical, NH (Figures 11 & 12). It is also a voice command system. Manufacturer claims that using this system is as easy as pushing a lawn mower. Multiple polarized antennas are carried in the housing. System is characterized by automatic data processing, interactive modes for quality assurance and quality control, and three-dimensional output into a CAD system. GPR based system can provide real time differential positioning for large open sites with 0.02 meter nominal accuracy [10]. In one setting, data can be collected for a line of sight from 20 meter to
2 kilometer (Figure 13).

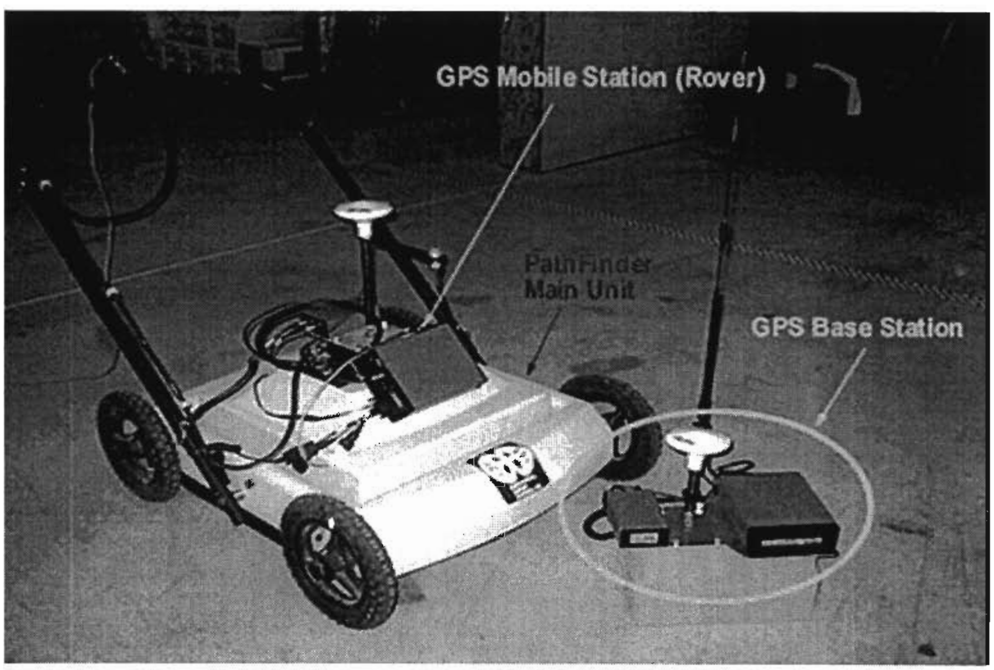

Figure 11 GPR Based Path Finder Utility Mapping System [10]

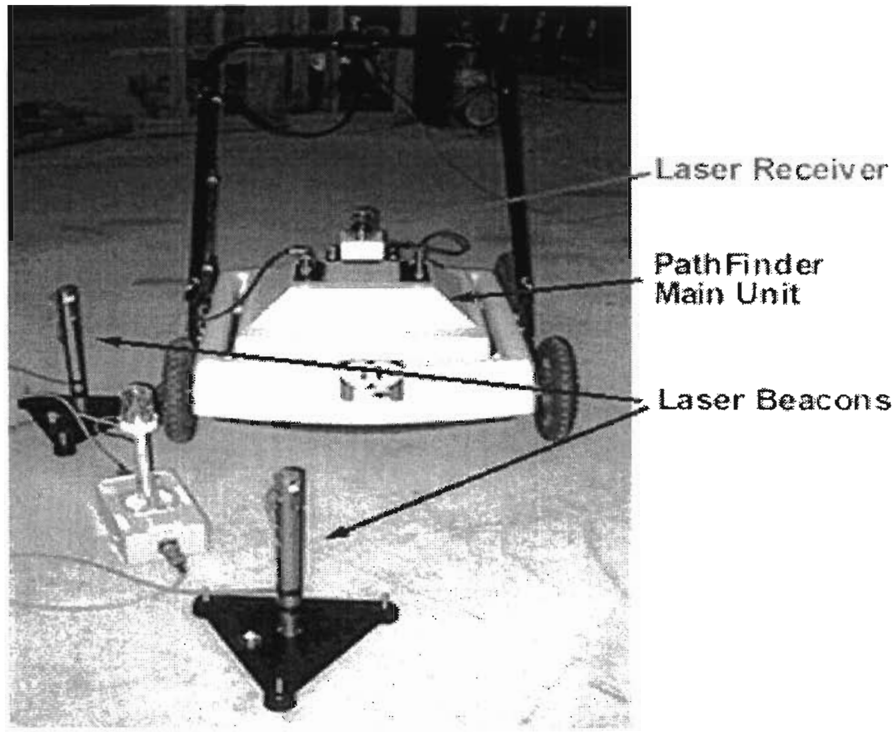

Figure 12 Path Finder Using Laser Grid Positioning System [10]

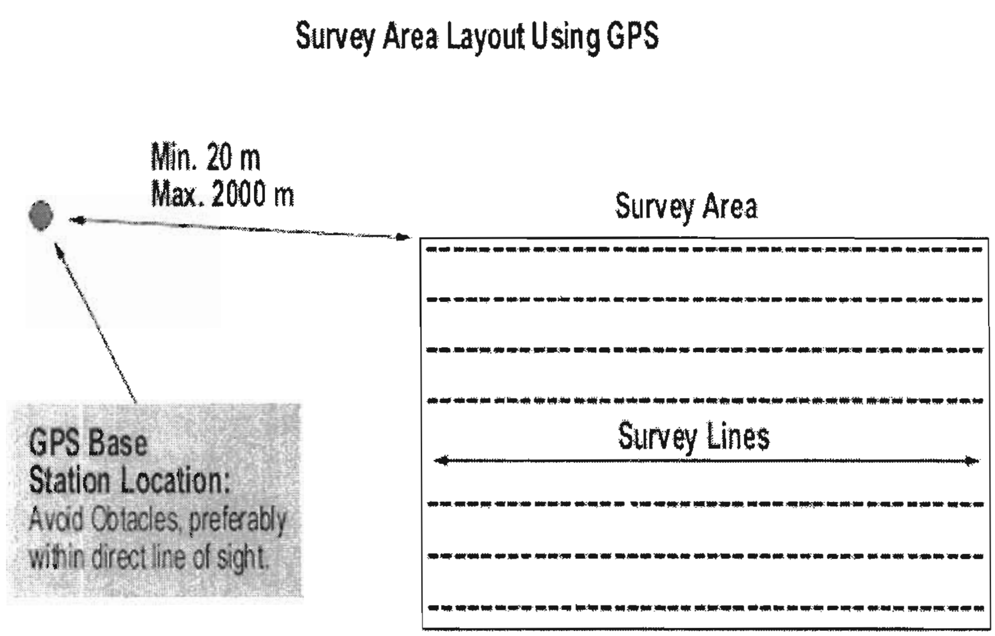

Figure 13 Survey Area Layout for Path Finder GPR Based System [10]

SUBSURFACE INTERFACE RADAR SYSTEM

It is a GPR based from GeoQuest, TN. System consists of a digital subsurface interface (Figure 14) and an antenna (Figure 15). Antennas are characterized by low frequency (35 MHz) and very high penetration, portability and lightweight. The electronics of antenna are embedded in armed fiberglass housing thus making it rugged and waterproof. The antenna has four universal fastening points thus making it suitable for carrying manually or winch mounting, and it does not have to be in contact with the ground surface. Even air borne surveys are possible with this system [11].

Figure 14 Subsurface Interface Radar System (SIR System 2000)

Figure 15 Sub Echo 40 GPR Antenna for Use with SIR System

GPR Cart System-GeoRadar Inc., CA
It is GPR system from GeoRadar Inc., CA. It is characterized by being portable, easy to operate, and on-board interface computer for processing of the information. It is claimed by the manufacturer that unit is capable of detecting and identifying the non-metallic pipelines [12].

Figure 16 GPR Cart System-Geo Radar Inc., CA.

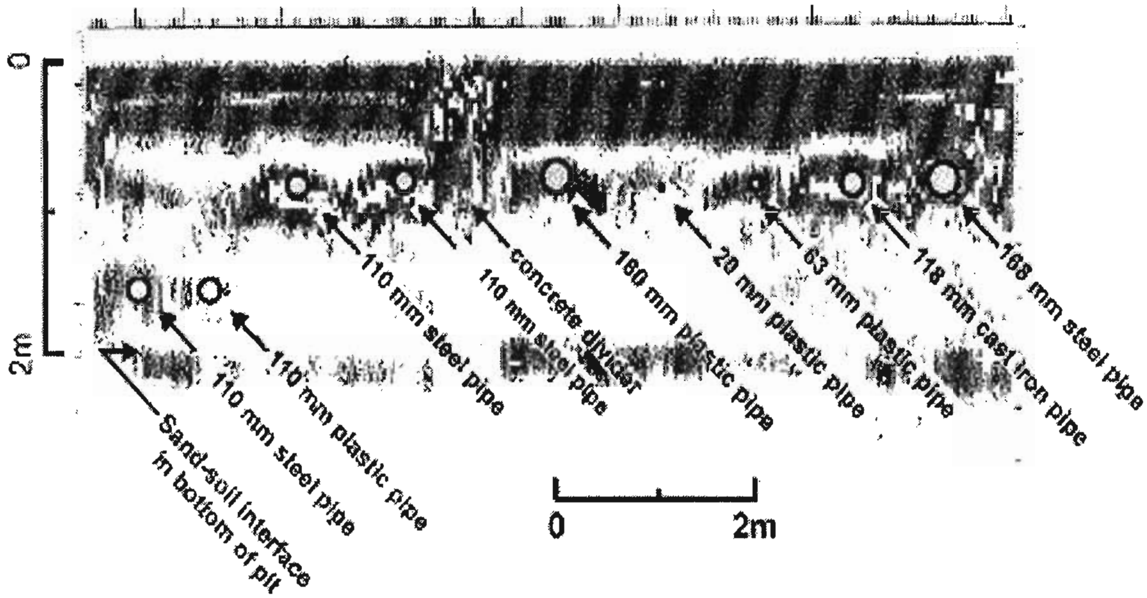

Figure 17 Processed and Labeled Images Using GeoRadar Technology

Nogging Smart Cart System
It is a GPR based cart system from Sensors and Software, Canada [13]. The system is characterized by being compact, lightweight, collapsible, integrated odometer, built-in software, and digital video logger. It can detect non-metallic objects up to 15-meter depth. *System is available on short term lease.*

Figure 18 Nogging Smart Cart from Sensors and Software Inc.

RAMAC/GPR – MALA GEOSCIENCES

It is a GPR based system with on board processing system. Available in two t is widely used types: push cart, and towed behind a vehicle. System is recognized for its modularity, flexibility, cost efficiency and its superior data quality. A single control unit supports all currently available antennas [14]. The RAMAC/GPR system uses 16 bit technology to create the cleanest, highest resolution data available. A single RAMAC/GPR control unit is capable of running all currently available antennas, including borehole, unshielded and shielded antennas. There are currently 11 different antennas available, ranging from 25 to 1000 MHz. The RAMAC/GPR surveying speed can therefore be very high without having to reduce the quality of the data. The high surveying speed will reduce costly working days in the field to a minimum. It is claimed by the manufacturer that system can detect metallic or non-metallic utility (gas pipes, water sewage pipes, telephone cables, etc.), determine utility depth and positioning.

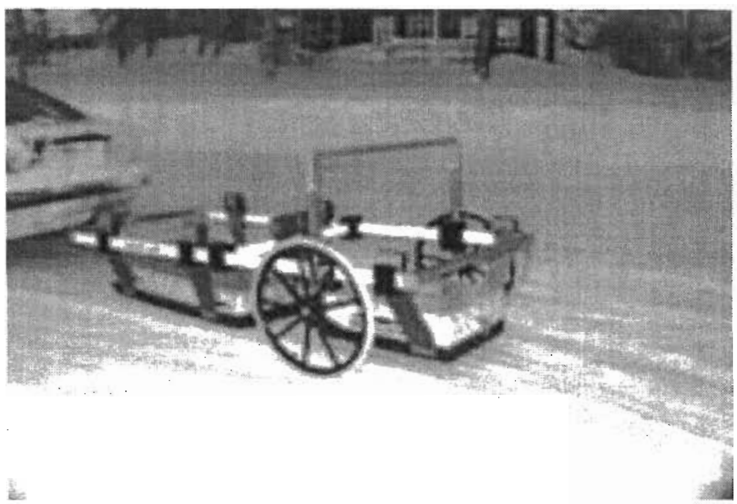

Figure 19 RAMAC/GPR System from MALA Geosciences

CART Imaging System-Witten Technologies Inc.

Computer Assisted Radar Tomography, (CART) Imaging System has been developed by Witten Technologies and extensively tested in major cities of the US and Europe. The CART system uses a highly-efficient GPR system from Malå Geoscience, which can be towed by a vehicle or attached in front of a modified commercial lawnmower (Figure 20). Speeds up to about 1 km/h (30 cm/s) are possible with this system [15].

The standard CART system uses a fixed array of 9 transmitters and 8 receivers (Figure 21). Each radar element in the array is a standard ultra-wideband GPR that broadcasts an impulse with a frequency spectrum from about 50 to 400 MHz. The array is controlled by special electronics that fires the transmitter elements and controls the receivers in sequence to create 16 standard bi-static GPR channels covering a 2 m swath on the ground (Figure 21 right). In this standard "bi-static" mode of operation, each transmitter fires twice in sequence, with each firing being recorded by an adjacent receiver. A multi-static mode, in which each transmitter fires once in sequence and is recorded by all the receivers, is also possible.

The CART systems rely on precise geometry control provided by a self-tracking laser theodolite. As the CART array moves along the ground, a laser theodolite locks on and follows a prism mounted next to the array. The CART system records the geometry data independently from the radar data and merges the two data streams using information provided by an internal trigger wheel that controls firing of the radar antennas. As part of standard CART surveys, the laser theodolite is also used to map surface features-such as curbs, manholes, valve covers, fire hydrants, and light posts-to provide a reference map for the final 3D radar images.

The CART's 3D images clearly show the approximate size, shape and depth of buried pipes and other underground structures, such as trench walls or concrete footings. CART images also contain information about the material composition of buried structures (metal vs. plastic) and soil conditions.

Figure 20 CART Imaging System –Vehicle Towed - Lawnmower Mouted

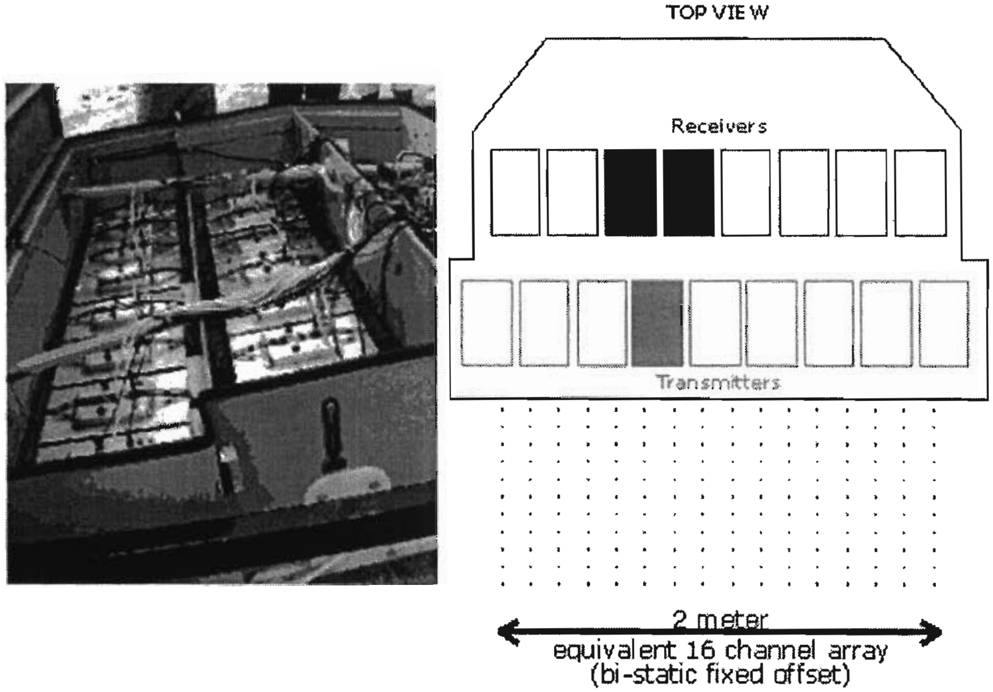

Figure 21 Inside View of CART Trailer Housing and Antenna Array

INTERRAGATOR II ACS System – Vermeer

The Vermeer INTERRAGATOR II is a GPS based system. It is claimed that system has the capability to map depth and location information of utilities as small as 0.8 inch (2.0 cm) down to 18 inch (46 cm) depth. Larger utilities can be scanned up to a depth of 20 feet (6.1 m) depth, depending on the soil conditions [16].

The system automatically adjusts the electronic parameters to ensure proper data collection. It is easy to operate and data displayed in real time.

Figure 22 INTERRAGATOR II ACS System from Vermeer

Precision Pipe Locator (PPL) from Radiodetection
Most of the techniques described so far have been based on the detection of signal currents flowing in a conducting, metallic line. Where plastic or concrete pipes, ducts and drains are concerned, there is clearly no way of detecting and tracing them electro magnetically by current flow, unless a tracer wire is inserted or laid along to the line. The instrument developed by Radiodetection consists of three components: sensor bar, transmitter, and locator [17].

Sensor Bar It has a rugged plastic housing shaped like a wooden 2 x 4 with feet. The forty-five inch long bar contains 4 magnetometer pairs, and computing capability to allow precise pipeline depth and locate measurement.

Transmitter A complex signal consisting of a 4Hz, 8 Hz., And 98 Hz. frequencies is transmitted. The higher frequency signal is used for preliminary pipe locating while low frequency signal is for precision locating. *Direct connection to the pipeline at a steel riser, test leads or other metallic connection is required.* An induced signal cannot be used as induced signals are responsible for much of the error associated with traditional pipe locators.

Locator The locator functions as a conventional locator and also serves as the interpretation and display device for the Sensor Bar. The locator is radio linked with the Sensor Bar, lightweight, and rugged.

COST– BENEFIT ANALYSIS

Utilities are placed within the rights-of-way corridors located along the highways. Utilities are normally located in their allocated place unless some technical problems preclude the possibility of accomplishing it [21].

Depending on the location of the highway, i.e., rural, suburban, or urban, a utility trench may contain one conduit or combination of utilities and pipes. The possible cost of repair or replacement of utilities resulting from bursting of these pipelines is controlled by electric, fiber optic, or gas lines, being high-dollar value items. Therefore, in cost-benefit analysis, only damage to fiber optic, electric, and gas line(s) will be. Cost of damage to other utilities may be considered as additional. In cost-benefit analysis, cost of developing a mechanism to identify buried non-metallic utilities is compared with the cost of possible damage, repair, and loss of revenue. Law suits and compensation to the victims may also result due to such accidents.

Cost of Technology

Based on the information provided by the manufacturers of different instruments, the estimated cost of equipment, modifications, and training of crew can generally be divided into following parts:

<u>Cost of Technologies</u>

1. GPPR Technology

A.	Cost	$150,000
B.	Modifications	50,000
C.	Training of Crews	50,000
D.	Miscellaneous (5%)*	12,500
	Total =	$262,500

2. EM or S & A Technology

A.	Cost	$100,000
B.	Modifications	50,000
C.	Training of Crews	50,000
D.	Miscellaneous (5%)	10,000
	Total =	$210,000

Grand Total = $472,500

(* accounts for unexpected expenses)

Cost of Possible Damage, Repair, and Loss of Revenue

Some accidents resulting from bursting of utility lines were cited in the initial part of this report along with associated cost of possible damage and loss of revenue reported. In order to analyze the complexity of this situation and simplify the analysis, only expected damage to a fiber optic cable, a high pressure gas line, and a high voltage electric conduit will be considered, individually and in combination. The possible cost associated with damage to utilities used in this analysis is based on the published information.

Pay-Back Time

Pay-back time may be defined as time required to recover the cost of technology purchased to detect underground utilities from revenues generated from the prospective utility as if it was fully operational. This analysis does not take in to account the cost of legal ramifications, which may arise in some cases. Following cases are analyzed:

Case I – Fiber Optic Conduit Damaged – Only GPR Technology Used

Case II – Electric Conduit Damaged – Only GPR Technology Used

Case III – Gas Conduit Damager – Only GPR Technology Used

Case IV – Total Loss (Fiber Optic + Electric + Gas) – Only GPR technology Used

Case V – Fiber Optic Conduit Damaged – Only EM / S &A Technology Used

Case VI – Electric Conduit Damaged – Only EM / S &A Technology Used

Case VII – Gas Conduit Damager – Only EM / S &A Technology Used

Case VIII–Total Loss (Fiber Optic + Electric + Gas)–Only EM / S &A Technology Used

Case IX – Fiber Optic Conduit Damaged – Combination of Technologies Used

Case X – Electric Conduit Damaged – Combination of Technologies Used

Case XI – Gas Conduit Damager – Combination of Technologies Used

Case XII – Total Loss (Fiber Optic + Electric + Gas) – Combination of Technologies Used

LOSS OF REVENUE

Fiber Optic Conduit

Loss of Revenue ($ I Million/Hour)	=	$12,600,000	(Estimated for 12 Hours Down Time)
Repair Cost ($ 50,000 /Hour)	=	600,000	(Estimated for 12 Hours Down Time)
Miscellaneous (5%)	=	630,000	
Total	=	$13,230,000	

Electric Conduit

Loss of Revenue,

Damage to Property, and Repair = $ 10,000,000 (Estimated Amount)

Miscellaneous (5%) 500,000

Total = $ 10,500,000

Gas Conduit

Loss of Revenue,

Damage to Property, and Repair = $ 10,000,000 (estimated amount)

Miscellaneous (5%) = 500,000

Total = $ 10,500,000

Using GPR Technology

Case I – Fiber Optic Conduit Only

= Cost of GPR Tech/Loss of Revenue x Down Time (Hrs)

= ($ 262500/$ 13230000) x12 Hrs x 60 Min/Hr = **15 min**

= ($ 210000/$ 10500000) x12 Hrs x 60 Min/Hr

Case II – Electric Conduit Only

= ($ 210000/$ 10500000) x 12 Hrs x 60 Min/Hr

= **18 min**

Case III - Gas Conduit Only

= ($ 210000/$ 10500000) x12 Hrs x 60 Min/Hr

= **<u>18 min</u>**

Case IV - Total Loss (Fiber Optic + Electric + Gas)

= Cost of GPR Tech/ Total Loss of Revenue x Down Time (Hrs)

= ($ 262500/$ 34230000) x12 Hrs x 60 Min/Hr

= **<u>6 min</u>**

<u>EM or S & A Technology</u>

Case V - Fiber Optic Conduit Only

= Cost of EM or S&A Tech/Loss of Revenue x Down Time (Hrs)

= ($ 210000/$ 13230000) x12 Hrs x 60 Min/Hr

=**<u>12 min</u>**

Case VI - Electric Conduit Only

= ($ 210000/$ 10500000) x12 Hrs x 60 Min/Hr

= **<u>15 min</u>**

Case VII - Gas Conduit Only

= ($ 210000/$ 10500000) x12 Hrs x 60 Min/Hr

= **<u>15 min</u>**

Case VIII - Total Loss (Fiber Optic + Electric + Gas)

= Cost of EM or S&A Tech/ Total Loss of Revenue x Down Time (Hrs)

= ($ 210000/$ 34230000) x12 Hrs x 60 Min/Hr

= **<u>5 min</u>**

<u>Combination of Technologies (GPR + EM or S&A)</u>

Case IX - Fiber Optic Conduit Only

= Total Cost of Tech/Loss of Revenue x Down Time (Hrs)

= ($ 472500/$ 13230000) x12 Hrs x 60 Min/Hr

= **<u>26 min</u>**

Case X - Electric Conduit Only

= ($ 472500/$ 10500000) x12 Hrs x 60 Min/Hr

= **<u>33 min</u>**

Case XI - Gas Conduit Only

= ($ 472500/$ 10500000) x12 Hrs x 60 Min/Hr

= **<u>33 min</u>**

Case XII - Total Loss (Fiber Optic + Electric + Gas)

= Total Cost of Tech/ Total Loss of Revenue x Down Time (Hrs)

= ($ 472500/$ 34230000) x12 Hrs x 60 Min/Hr

= **<u>10 min</u>**

Summary of Cost-Benefit Analysis

Twelve different cases were examined in evaluating the possible advantage of introducing the state-of-the art technologies to locate and identify the underground utilities in TxDOT rights-of-way. It is evident from the above analysis that the benefit of avoiding possible damage far outweighs the estimated costs associated with purchase of equipment and training of crews. Even in the worst case scenario when total damage to the utility lines is incurred (Fiber Optic + Electric + Gas), even using combination of technologies (GPR + EM /SA), the pay-back time is less than an hour. Therefore, it is prudent to conclude that introduction of state-of-the art technologies for the identification of buried non-metallic pipelines is in the best interest of TxDOT.

EFFECT OF NEW FCC REGULATIONS

The U.S. Federal Communications Commission (FCC) released its Report & Order on use of ultra wide band (UWB) devices which sets rules for GPR devices in the USA in April, 2002 [18]. FCC put in place new rules for use of ground penetrating radar (GPR) effective July 15, 2002. GPR Industry is of the view that these FCC regulations will impact the GPR service providers as follows [19]:

- It will ban anyone from using any UWB device (radar antennas, etc.) above 960 MHz and below 3.1 GHz.
- Geophysicists, geoscientists, engineers, and others related professionals have been excluded from list of service providers.
- Operation is restricted to law enforcement, fire and rescue organizations, scientific research institutions, commercial mining companies, and construction companies.

The FCC has made major concessions to GPS users but they still must register their existing GPR equipment and coordinate its use with the FCC. Coordination implies that users must advise the FCC where (geographically) you are planning to use the GPR, what equipment you will use and where you can be contacted. For this purpose a simple form was created by FCC legal council. The Commission's Office of Engineering and Technology (OET) has extended the deadline for filing of GPR equipment to November 15, 2002.

In accordance with new FCC regulations, all GPR equipment must be operated below 960 MHz or in the frequency band 3.1–10.6 GHz. The three technologies which have been recommended for implementation phase meet this requirement:

1. CART–WITTEN : Freq. 50-400 MHz.
2. Sub Echo 40 + SIR 2000: Freq. < 35 MHz.
3. Smart Cart (S & S) : Freq. 110 – 1200 MHz.

COMPARISON OF RECOMMENDED TECHNOLOGIES

One primary and two secondary technologies are recommended for additional testing during implementation phase of this project. The characteristics of each technology are summarized.

- **CART Imaging System – Witten Technologies**
  1. Fixed array of 9 transmitters and 8 receivers.
  2. 50 to 400 MHz bandwidth and Wavelength in soil at 200 MHz is ~15 in.
  3. Resolution is ~2-3 inches and position tracking with laser theodolite.
  4. Covers up to 30 000 sq ft per day.
  5. 3-D images show approximate size, shape, and depth of utilities.
- **SubEcho 40 + SIR 2000 –GeoQuest**
  1. Very high penetration
  2. Low frequency (35 MHz)
  3. Portable and lightweight
  4. Can be mounted on winch
  5. Electronics embedded in armed fiber-glass, making the antenna waterproof
- **Smart Cart – Sensor & Software**
  1. The built-in CartView software records data in a chart-like scrollable image.
  2. The integrated odometer gives the accurate distance measurement scale.
  3. Can detect non-metallic objects up to 15 m depth.
  4. There are virtually no user adjustments necessary. Just start pushing the Noggin Smart Cart around and record the data.
  5. Available on RENT.

RECOMMENDATIONS

- **Primary Technology.** GPR Technology is well developed and well suited for detection of underground utilities. Primary Technology should be capable of processing high resolution images at high speed, mobility across uneven surfaces, and speed of operation. CART Imaging System from Witten Technologies, Inc. is recommended as primary technology.
- **Secondary Technology.** Secondary technology is needed for cross checking of results from primary technology, and for use on paved or even surfaces. Smart Cart from Sensors & Software, Canada, or Sub Echo-40 Antenna + SIR 2000 System from GeoQuest, TN, is recommended.
- **Procurement of Technology.** The option for short-term lease may be considered for the duration of the testing, i.e., controlled testing and field-scale testing. This option will help TxDOT in preserving valuable resources and cutting down the cost of the project during implementation phase.
- **Backfill Specifications.** GPR signals are affected by the characteristics of the underground materials. It has been reported that GPR is more effective in sand and gravel layers. It is recommended that for new projects, backfill specifications may be modified to coarse-grained soils to enhance the effectiveness of locating technologies.

- **Use of Metallic Tracers.** Although state-of-the-art technologies can locate non-metallic pipelines. The effectiveness of these technologies is enhanced if signals are reflected back from a metallic object. For this reason, it is recommended that metallic tracers may be used with new non-metallic pipelines.

STANDARD OPERATING PROCEDURES

1.0 Purpose

To lay down procedures for conducting tests on new technologies for locating and identifying underground non-metallic pipelines.

2.0 Composition of Oversight Team

During evaluation phase, a project implementation team should be constituted. Following composition is recommended:

- Research Team (PI and Co-PI).
- Representative from Research and Implementation Technology Office.
- PD, PC, and PA.
- Manufacturer's Representative(s).

3.0 Data Collection

- Data should be collected in hard copy and electronic format, and documented using the procedures specified.
- A background set of data should be collected for comparison.
- To maintain the consistency in data sets, testing should be stopped during adverse environmental conditions.
- For quality assurance / quality control purposes, duplicate set of data should be collected for each test and site.
- During trial phase, manufacturer's representative should be present to review the data collection process.
- Data should be reviewed after each test for accuracy.

4.0 Evaluation Criteria

The effectiveness of any technology in detecting the underground utilities can be determined by comparing the results with actual information during controlled and field testing. The important criteria are: identification about material, horizontal accuracy, vertical accuracy, and quality of processed data. The subsurface conditions during testing must be representative of on-site conditions. American Water Works Association (AWWA) had suggested two forms for this purpose: general information and utility designation forms. These forms are presented in Figures 23 and 24.

4.1 Controlled Testing

In this phase, the selected technologies will be evaluated under controlled conditions. The effectiveness in locating underground utilities should be checked against following factors: soil conditions; moisture content, pH, electric conductivity, grain size, dielectric properties, compaction; interference / noise: electronic noise, cultural interference; equipment: calibration, antenna frequency, and antenna polarization. It is proposed that during controlled testing phase, a simulated utility trench should be prepared, utilities placed at selected points, data collected and analyzed. The layout of controlled test site is shown in Figure 25. A minimum length of 150-ft test is recommended for the test ditch. It should be divided into three sections of 50-ft each. It is considered that a run of 50-ft would provide sufficient data for image processing and analysis. The form for recording results is shown in Figure 26.

The dimensions of controlled utility trench are considered adequate to change the location and depth of different simulated utilities to determine the effectiveness of the candidate technology.

4.2 Horizontal and Depth Accuracy

During data acquisition phase, positional information in terms of horizontal distance (X) and depth (Z) should be collected. This information will be compared with controlled information, i.e., X and Z. The error in positional accuracy will be determined in terms of $\Delta \mathbf{X}$ and $\Delta \mathbf{Z}$. The plot of frequency and error will yield a curve similar to a normal distribution curve. Shape of the curve will indicate variability of data. The performance of candidate technology can be interpreted in terms of standard deviation of the data.

4.3 Effect of Soil Composition

The performance of GPR and E & M equipment is affected by the dielectric constant of the material. Best GPR signals are obtained from coarse grained backfill materials, i.e., gravel and sand. Therefore in the second phase of controlled testing, the candidate technologies should be tested with clay, sand, and gravel backfill materials. The first section of utility trench should be backfilled with fine grained soils, with dominant clay content; second with coarse grained materials, i.e., sand and gravel, and last section with select backfill as per TxDOT specifications.

5.0 Field-Scale Testing

After the completion of controlled testing, the candidate technologies should be tested in the field, at least one trial in each TxDOT district. These test sites should be representative of the typical character of the district, i.e., rural, suburban, or urban setting. The limitations of technoiogy are more pronounced in urban setting where utilities are stacked up in a limited space. In addition, performance of GPR technology has been reported to be sensitive in clay rich subsurface layers. Therefore, sites where capabilities of the equipment can be stretched to maximum limits should be selected for confirmatory testing.

6.0 Instructions for Use

Refer to the manufacturer's manual(s) for detailed instructions for use of the equipment.

SITE INFORMATION	
Utility Company	
Test Site Location:	Date:
Method / Instrument Model:	
Instrument Serial Number:	Condition of Equipment:
Evaluators:	Operators:
Test Objective:	
Map Reference:	
Reference Point / Elevation:	
INSTRUMENT SETTING/CALIBRATIONS	
GPR Settings	
Mode:	
Antenna Frequency :	Grided Survey / Search and Locate
Nav. System / Positioning	Coordinate System:
Survey Grid Size:	
File Name:	Units: Ft or m
Filters:	
Soil Type:	Max Depth:
Sampling Rate: X scans / ft or m =	Y scans / ft or m
AMBIENT FIELD CONDITIONS	
Weather Conditions:	
Surface (concrete, asphalt, soil etc.)	
Cultural Influences (power lines, transformers etc.)	
Spectral Analysis: Complete Y / N	File Name:
Subsurface (Groundwater Level):	

Figure 23 Field Test – General Information Form

Utility Company:	
Test Site Location:	
Technology being Tested:	**Operator:**
Site Feature used as Reference:	
Date:	**File Name:**

		Instrument Setting					
Location	**Distance from Datum**	**Frequency**	**Signal Strength**	**Current**	**Distance from Transmitter Location**	**Depth**	**Suspected Target**

Site Sketch	**Compass Direction:**

Figure 24 Field Test – Utility Designation Form

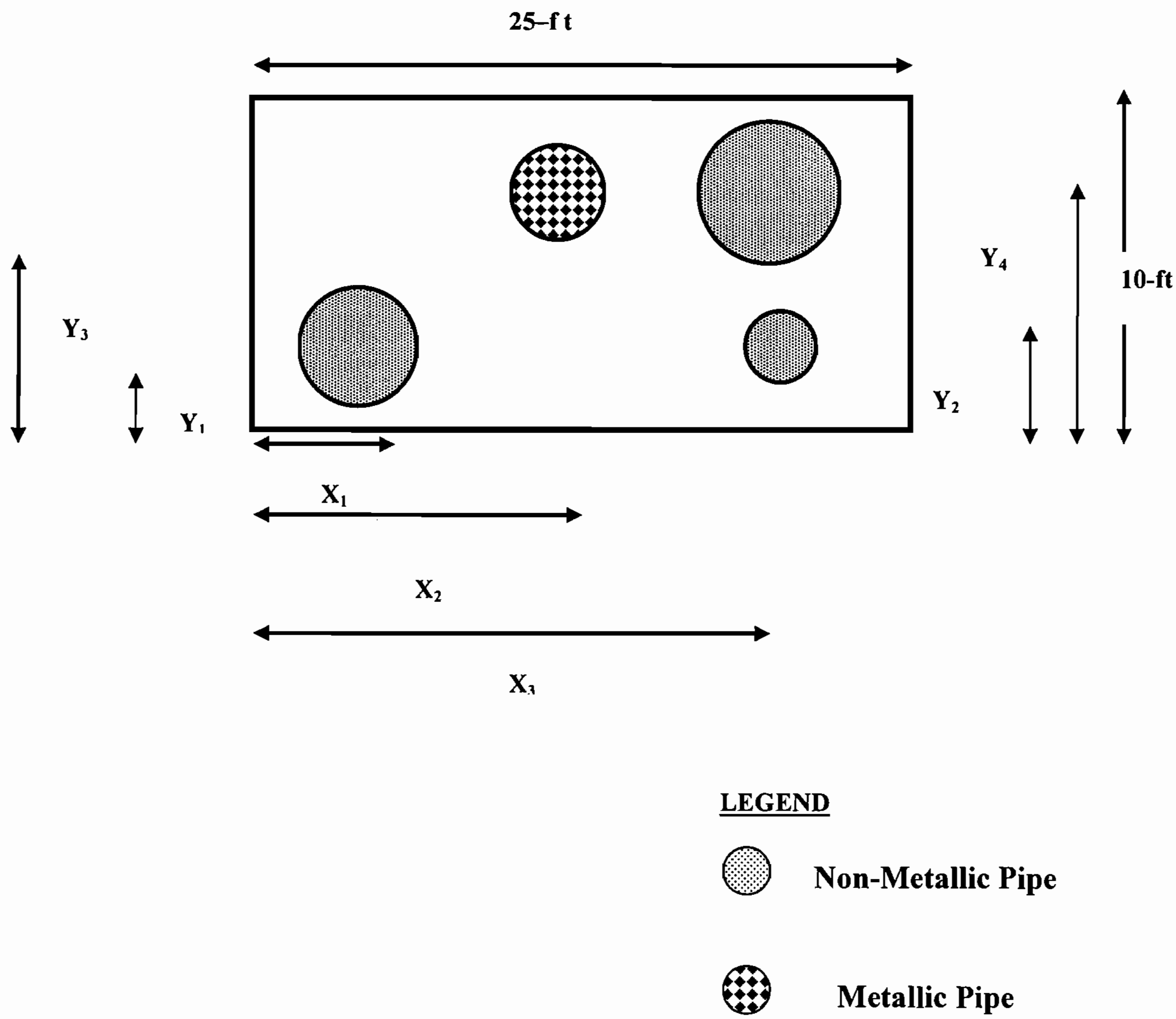

Figure 25 Layout of Controlled Utility Trench

Technology/ Instrument	GPR-1*		EM-1@		S&A-1#	
	ΔX	ΔZ	ΔX	ΔZ	ΔX	ΔZ
Site Identification						

- **GPR-1 Ground Penetrating Radar Technology -1**
- **EM-1 Electromagnetics Technology-1**
- **Seismic & Acoustics Technology -1**
- **ΔX - Error in Horizontal Direction**
- **ΔZ - Error in Depth Determination**

Figure 26 Results of Technology Tests

GLOSSARY

Backfill. Materials used to fill the trench after placement of utilities.

Flowable Fill. Lower density, low strength material used for backfilling of utility trench. These materials are more rigid than surrounding material.

Pay-Back Time. Time required to recover the cost of technology purchased to detect underground utilities from revenue generated from the prospective utility as if was fully in service.

Position of Utility. Utilities are placed in rights-of-way. Possible scenarios are:

- **Common.** Utility is commonly laid underground but may be
    - located aboveground.
- **Normal**. Utilities are normally located underground.
- **Rare**. Such utility is unlikely to be located underground.
- **Unlikely**. This type of service is unlikely.

Right-of-Way. Specially designated corridors along highways which are used for placing of utilities and other appurtenances.

Rural. Scattered housing, farms and businesses.

Soils. It is a general term used for unconsolidated materials at or near the surface of earth, used in construction. Types of soils are gravel, sand, silt, and clay.

Suburban. Built up areas of low to moderate density, small towns.

Urban. Continuously built up areas of moderate to high density, e.g. downtown areas, in-city housing, suburban commercial districts.

Utilities. All lines and or their accessories within the highway rights-of-way except those for highway-oriented needs. These utilities may involve underground, surface or overhead facilities either singularly or in combination. Accessories may be defined as any attachments, appurtenances or integral parts of the utility (i.e., fire hydrants, valves, gas regulators, etc). the placing of accessories within the highway right-of-way will be determined by such factors as type, size, safety, availability of space, etc.

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2. Accidents File. www.underspace.com.

3. Sterling, R. (2000). Utility Locating Technologies: A Summary of Responses to Statement of Need. Distributed by the Federal Laboratory Consortium for Technology Transfer, Washington, DC, Feb 2000. ISSN 1075-9492C.

4. Milliken, B. (1998). How accurate are locates? Session Handout, Session C5, Damage Prevention Convention, Atlanta, GA, Dec 2-4, 1998.

5. Theory of GPR Operation. EPA Region 5: Field services Section. http://www.epa.gov/reg5sfun/sfd/sfd_fss/htm/gpr_info.htm.

6. EPA (1997). Expedited Site Assessment Tools for Underground Tank Sites – A Guide for Regulators. Solid Waste and emergency Response 5403G, EPA 510-B-97-001. Chapter III, Geophysical Methods. http://www.epa.gov.

7. Non-Intrusive Subsurface Geophysical Investigations. http://www.geo-graf.com

8. Pipe Hawk – Your Underground Intelligence. http://www.pipehawk.com.

9. SPRScan - Ground Penetrating Radar. http://www.era.co.uk/product/spr.htm.

10. Utility Mapping System-PathFinder. http://www.geophysical.com.

11. Geo Quest, TN, and Geophysical Survey Systems Inc. http://www.gssi.com.

12. GeoRadar Inc. 12996 Somerset Drive, Grass Valley, CA 95945 U.S.A. http://www.georadar.com.

13. Sensors & Software, Mississauga, ON L4W 3R7, Canada. http://www.sensfoft.on.ca.

14. http://www.malags.se MALÅ GeoScience USA Inc. 2040 Savage Rd., PO Box 80430, Charleston, South Carolina 29416, USA.

15. Witten Technologies Inc., 295 Huntington AvenueSuite 203, Boston, MA 02115.. http://www.wittentech.com.

16. Vermeer Manufacturing Company, Pella, IA. http://www.vermeer.com.

17. Radiodetection, Western Drive, Bristol, BS14 OAZ, U.K.. http://www.radiodetection.com.

18. Federal Communications Commission, FCC 02-48, ET docket 98-153, First Report and Order, released: April 22, 2002. http://www.uwb.org/files/new/FCC_RandO.pdf

19. Stop the Ultra-Conservative UWB regulations. http://www.g-p-r.com/SB02r157.pdf.

20. New Techniques for Precisely Locating Buried Infrastructure, AWWA Research Foundation, Denver, CO. http://www.awwa.org.

21. Utility Accommodation Policy, State Department of Highways and Public Transportation, Austin, TX, 1989.

APPENDIX A

BROCHURES AND SPECIFICATIONS OF TECHNOLOGIES

- **Pipe Hawk, UK.**
  1. Product Brochure. http://www.pipehawk.com/images/pdfs/brochure.pdf
  2. Product Specs. http://www.pipehawk.com/product%20spec%201.htm
  3. Pipe Hawk GPR. http://www.pipehawk.com/images/pdfs/ces%20spread.pdf

- **SPR Scan, UK. - ERA**
  1. Product Brochure and Specs. http://www.era.co.uk/product/spr.htm

- **Utility Mapping System Geophysical.**
  1. Product Brochure. http://www.geophysical.com/UMS
  2. Product Specs. . http://www.geophysical.com/UMS

- **Sub Echo 40 and SIR 2000 – GSSI and Geophysical.**
  1. Product Brochure. http://www.geophysical.com/
  2. Product Specs. . http://www.geophysical.com/

- **GPR CART – Geo Radar Inc.**
  1. Product Brochure. http://www.georadar.com
  2. Product Specs. . http://www.georadar.com

- **Smart Cart – Sensor & Software, Canada.**
  1. Product Brochure. http://www.sensoft.ca/products/
  2. Product Specs. . http://www.sensoft.ca/

- **RAMAC/GPR-MALA Geosciences.**
  1. Product Brochure. http://www.malags.se/hardware/x3m.php
  2. Information on Products. http://www.malags.se/hardware/x3m_art.pdf

- **CART Imaging System –Witten Technologies.**
  1. Product Brochure. http://www.wittentech.com/products_CART.html
  2. Product Specs. http://www.wittentech.com/products_CART_specs.html

- **ACS Systems: INTERRAGATOR II - Vermeer**
  1. Product Brochure and Specs.
     Http://www.vermeer.com/equipment/electronics/INTERRAGATORII/