EVALUATION OF THE POSITIONAL ACCURACY OF SUBSURFACE UTILITIES

by

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ABSTRACT

Since WWII, the urban underworlds have become a web of utility lines, including telecommunication lines, buried electricity lines, gas mains, watermains, cable TV, fiber optic cables, street lighting, and storm and sanitary sewers.

From preliminary design stages to breaking ground on new construction projects; owners, designers, engineers, and contractors rely on existing underground utility records as an initial source of information. There is a constant need for underground utility information and most of the city's existing utility records are not only irretrievable, but are also out-of-date.

According to research done in the past, records and visible feature surveys by site are a significant percentage off the mark and, in some cases, considerably worse.

This study focuses on the evaluation of the positional accuracy of subsurface utilities within seven projects, within the City of Toronto, using an offset approach. It also aims to reveal the magnitude of the problem surrounding the obtainment, analyzation, and interpretation of information with respect to underground infrastructure facilities. None of the projects show any relationship or correlation with positional accuracy and the factors that are thought to affect the accuracy of underground utility information (e.g. type of soil, type of utility, date of installation, right-of-way, etc.). The analysis indicates a clear indication of no systematic patterns between the right-of-way parameters and utility type parameters.

Based on the results of this study it can be stated that the process of obtaining subsurface utility information is still a time-consuming, inefficient, costly, and difficult process.

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Viji Santhakumar

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LIST OF ABBREVIATIONS

CGARP	Canadian Regional partners of the Common Ground Alliance
CSA	Canadian Standards Association
DfT	Department of Transport
DIRT	Damage Information Reporting Tool
DMOG	Digital Map Owner's Group
EM	ElectroMagnetic
EMS	Electronic Marker Systems
EPSRC	Engineering and Physical Sciences Research Council
FHWA	Federal Highway Administration
FOC	Fiber Optic Cable
G	Gerrard Street
GIS	Geographic Information Systems
GPiR	Ground Penetrating imaging Radar
GPR	Ground Penetrating Radar
HAUC	Highway Authorities and Utilities Committee
ISTT	International Society for Trenchless Technology
KS	Kenneth and Spring Garden Avenue
LAC	Locate Alliance Consortium
MTU	Mapping the Underworld
NCHRP	National Cooperative Highway Research Program
NJUG	National Joint Utilities Group
NRS	National Referencing Standards
NUAG	National Joint Utilities Group
NUCA	National Utility Contractors Association
NULCA	National Utility Locating Contractors Association
ON1CALL	Ontario One Call
ORCGA	Ontario Regional Common Ground Alliance
ORFEUS	Optimized Radar for Finding Every Utility in the Street
PEC	Portland Energy Centre
QL	Quality Level
QW	Queensway
RF	Radio Frequency
ROW	Right-of-Way
RPWCO	Regional Public Works Commissioners of Ontario
RY	Royal York
SHRP SON	Strategic Highway Research Program Statement of Need
SUE	Subsurface Utility Engineering
THES	Toronto Hydro Electric Systems
TMA	Traffic Management Act
TPUCC	Toronto Public Utility Co-ordinating Committee
UKWIR	UK Water Industry Research
US	Union Station
YS	Yonge Street

1 INTRODUCTION

1.1 Congested Web of Underground Utilities

The urban population of industrialized cities, around the world, is expected to double in the next thirty years; from two billion in 2000 to nearly four billion in 2030 (United Nations, 2005). This means that the urban cores themselves will expand. And besides the aging of the cities' infrastructure, the alarming population increase and rapid industrial expansion, places an immense amount of pressure on the existing utilities of each city. For instance, a major metropolitan area such as Toronto is made up of roughly 500 kilometres of watermain pipe more than a century old (http://dcnonl.com/article/id32865). And according to the Ontario Sewer and Watermain Construction Association (OSWCA), Toronto alone has more than 1500 burst watermains a year costing ratepayers more than $160 million a year. Much of this money could be better used in maintaining and upgrading the system.

Proper maintenance and repair of these existing utilities is more prevalent in rapidly expanding urban environments. In North America alone, a majority of the underground infrastructure networks were built after World War II and they were designed for lifetimes of up to 50 years (Jeong et al. 2004). Since then, the urban underworlds have become a web of utility lines, including phone, electricity, gas, cable TV, fiber optics, traffic signals, street lighting circuits, drainage and sanitary sewers and water mains (Jeong and Abraham, 2004). These underground networks are continuingly being repaired and updated through renewal and new construction projects, which also increases the contractor's risk of damaging existing subsurface utility lines. There have been several instances, within Canada and the US, involving damage to underground facilities resulting in disastrous results.

1.2 Current State of Canadian Infrastructure

The City of Hamilton evaluated some of its public works infrastructure assets in 2005 and released the 2006 State of the Infrastructure (SOTI) stating that Hamilton's replacement for infrastructure will amount to $9.39 billion in the next 15 years.

Nearly 70 % to 80 % of water and wastewater assets are buried below the ground surface; which is in the "out of sight, out of mind" philosophy. Furthermore studies show that there is a lack of investment in the maintenance of infrastructure that is not readily visible. As a result, the issue is only addressed when a problem arises in the form of a leak, burst or breakage. And the magnitude of the cost for repair increases because the underlying problem is not fixed to that leak, burst, or breakage. It becomes the point when a 'band-aid' solution just will not suffice (Infrastructure Canada, 2004).

Nowadays, many systems are required to meet a longer list of standards, including seismic, safety and security standards; as well as legislative and regulatory demands for complex treatment systems. Several municipalities do not have the necessary means to upgrade or maintain these systems.

The Ontario Sewer and Watermain Contractors Association (OSWCA) states that Ontario's water mains endure 25 breaks per 100 km per year. This amounts to $40 million in repairs and a loss of 40% of purified water. According to the OSWCA an estimated 25% of the water system must be replaced along with 50% in restoration activity must take place within the next 60 years. Furthermore, the National Round Table on the Environment and the Economy (NRTEE) estimates $38 to $39 billion would be needed for maintaining existing capital stocks and services. And new and upgraded water and waste-water infrastructure would require $39 to $88.4 billion over a 15 year period or $80 to $90 billion over a 10 year period (Infrastructure Canada, 2004).

According to Infrastructure Canada, in 1995 and 1996 a survey was completed by 167 Canadian municipalities which revealed, in terms of analysis of the results, 59% noted that the water distribution infrastructure was in need of repair. And in terms of wastewater systems, 68% agreed their sanitary and combined sewers needed repair and 53% noted that their storm sewers needed upgrades. These older facilities will not suffice today's environmental and health standards or advanced treatment technology without substantial investments. And only 20% of municipality budgets is spent towards infrastructure repairs, where 80% funds new construction.

However, what municipalities are failing to understand is that once deterioration is triggered, inevitably the costs for repairing infrastructure will compound exponentially. However, the problem lies in the inventory. Several municipalities in Canada do not possess an accurate, up-to-date inventory of their underground infrastructure and those that do, do not have detailed descriptions and histories of the condition of such infrastructure facilities (Infrastructure Canada, 2004). http://www.infc.gc.ca/research-recherche/results-resultats/rs-rr/rs-rr-2004-01_01-eng.html#fn9.

1.3 Utility Damage Statistics

The American Institute of Constructors (AIC) reported that a punctured utility line is the third most important crisis for contractors (Reid, 1999). For instance, in September of 2008 a major water main break, located in London, Ontario; forced Wonderland Road closures between Riverside Drive and Kingsway Avenue. An American-run magazine known as Underground Focus contains thousands of reported accidents involving underground utility accidents over the past decade. For example, a 12-inch water main was accidentally punctured by a contractor while installing a utility service. (Underground Focus Magazine, 2008). http://www.londontopic.ca/article.php?artid=10741

Another incident involved the evacuation of 50 apartment building residents as a result of construction crews hitting a gas line. High levels of natural gas vapors were released into the atmosphere and Calgary firefighters were ordered to evacuate an entire block surrounding the ruptured area as well as entering apartments and closing all windows to prevent the high winds from spreading the deadly vapors (CBC, 2008) http://www.cbc.ca/canada/calgary/story/2008/07/10/gas-evac.html).

Also, at a Wisconsin resort cabin in June 2006, a propane leak caused by construction crews triggered a huge explosion, leveling the cottage which was, at the time, being occupied by an attorney, Mr. Hidgon, his wife, his three children and their grandparents. Sadly, Hidgon and his wife were killed, leaving their children and the grandparents with serious injuries as well (Crain's Detroit Business, 2009). (http://www.crainsdetroit.com/article/20090301/FREE/303019992).

Furthermore, another incident, which occurred in November 2004 in Walnut Creek, California, involved a punctured high-pressure petroleum pipe. Five deaths and several injuries to employees were a result of the explosion and a fire. Again, after a six-month investigation it was determined that the excavator's backhoe struck and punctured the fuel pipeline, which resulted in the explosion (State of California, 2005).

Another severe incident took place in Etobicoke, Ontario on April 23, 2003 when an explosion, triggered by a sudden rupture to a gas main, resulted in the death of seven innocent people. These underground utility accidents are only a few of the many hundreds of thousands of incidents that occur every year around the globe.

To be more specific, Western Power Distribution (UK) claims that each year there are more than 2,000 incidents of damage to their power cables alone. They also state that over the last 10 years in the UK, 86 contractor staff have been killed and more than 3,000 injured by striking live power cables (Roberts et al. 2002).

The Common Ground Alliance (CGA) created an internet application called DIRT whose main function is to allow its stakeholder members to report utility ruptures or accidents.

1.3.1 Damage Information Reporting Tool (DIRT)

Damage Information Reporting Tool is now a secure web application for the reporting and collection of underground damage information. DIRT allows users to submit damage and near-miss reports; administer role-based company and user information; revise personal profiles; alter/recover user passwords; and offer feedback and submit questions. By collecting underground damage information, CGA can analyze this data to gather a consensus as to why these events occur and what the industry can do to prevent such incidents thereby making certain of the safety and protection of people and the infrastructure. CGA can also develop trend analyses and educate all stakeholders in order to reduce damages through implementation of best practices and procedures. An important fact to remember is that CGA will not use this data for enforcement or liability purposes because individual party information is guaranteed confidential.

The fourth Annual Report, which analyzes data extracted from 2007 events and submitted to DIRT, was released in December of 2008. Since its inception in 2004, the number of events submitted to DIRT keeps increasing. According to the latest records, a reduced number of approximately 256,000 damages occurred in the United States in 2007 compared to previous years. Furthermore, the Ontario annual report, compiled by the Ontario Regional Common Ground Alliance's (ORCGA) DIRT, states that approximately 6000 incidents were reported by stakeholders in Ontario for 2007 (DIRT, 2008). (http://www.orcga.com/lib/db2file.asp?fileid=298). DIRT defines events as "the occurrence of downtime, damages, and near misses." In particular, the 2007 Report analyzes a limited number of individual data elements, from 2004 through 2007, that address an aspect of damage prevention.

Facility events submitted by year

For instance, the facility events submitted to DIRT from 2004 to 2007 has continually increased as shown in Figure 1.1. (DIRT, 2008)

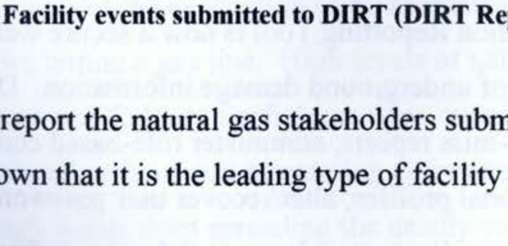


Figure 1.1 Facility events submitted to DIRT (DIRT Report, 2008).

According to the report the natural gas stakeholders submitted 365 of the facility event reports and it is shown that it is the leading type of facility operation being affected as seen in Figure 1.2.

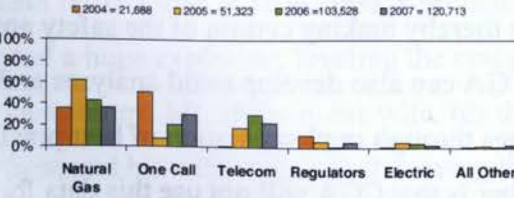


Figure 1.2 Event frequency by known excavation equipment group (DIRT Report, 2008).

When dealing with the frequency of damage events, approximately 90% of telecommunications and natural gas facilities continue to be affected by utility hits. Figure 1.3 displays these frequencies (DIRT, 2008).

(89%) 108,025 Known Facility Operation Affected Events	
-Natural Gas	(48%) 51,905 events
-Telecommunication	(38%) 41,771 events
-Electric	(8%) 8,470 events
-Cable TV	(4%) 4,066 events
-Others	(2%) 1,813 events
	108,025 events

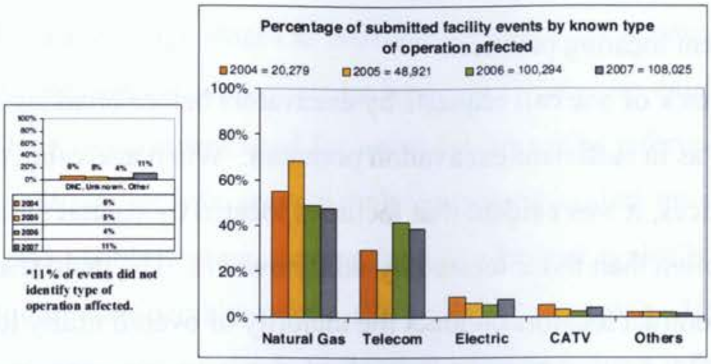


Figure 1.3 Facility events by known type of work performed group (DIRT Report, 2008).

Another 55% of all submissions involved events citing utility work by sewer, water, energy and telecommunications. The number of events associated with these operations is seen to be consistent since 2004, ranging from 50-57%. See Figure 1.4 for an illustration regarding the number of events related to works.

(57%) 69,862 Known Work Performed Type Events	
Sewer / Water	(31%) 21,454 events
Energy / Telecommunications	(24%) 16,861 events
Landscaping	(13%) 9,117 events
Street / Roadway	(12%) 8,445 events
Construction / Development	(11%) 8,097 events
Fencing	(7%) 4,652 events
Agriculture	(2%) 1,236 events
	69,862 events

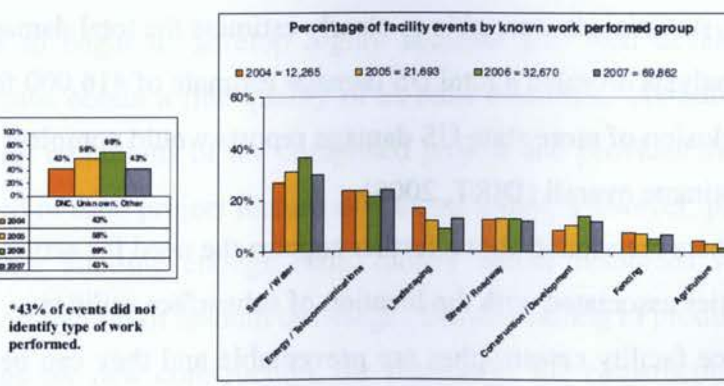


Figure 1.4 Frequency of events by known work performed type events (DIRT Report, 2008).

1.3.2 Findings

According to the report's findings, the major root causes of underground utility damage incidents are:

- No occurrence of notification.
- Insufficient excavation practices.
- Insufficient locating practices.

Apparently, the lack of one call requests by excavators before breaking ground was obvious, as well as in sufficient excavation practices. When analyzing the insufficiency in locating practices, it was evident that facilities located by contract locators are damaged more often than those located by utility owners. The main reason for this is due to the fact that contract locators conduct the majority of overall utility locates. Some contributing factors for insufficient locating practices by contract locators include inadequate mapping information, multiple facility types on a single job site, or limited completion time for the locate request.

Another significant number of facility events involved Service/Drop and Distribution facilities that have to do with the lack of one call center notification and excavation with hand tools. Notification NOT Made totaled 40% of which 63% listed hand tools as the type of excavation equipment used. The reason for this large number can be due to the fact that some states still do not require one call center notifications for excavation with hand tools within their regulations.

Furthermore, based on the number of damages reported by the state of Colorado and Connecticut, statisticians were able to clearly estimate the total damages in the US for 2007. The analysis revealed a total US damage estimate of 416,000 for 2008. Although the inclusion of more state US damage reports would complete the dataset, improving the estimate overall (DIRT, 2008).

The numbers mentioned above further support the need for action in the removal of any uncertainties associated with the location of subsurface utilities.

Subsurface facility catastrophes are preventable and they can be greatly reduced by taking proactive steps towards utility designation, location, surveying, and utility data management. Subsurface utility breaks are often a result of poor records, improper notification, and excavation errors made by the design team as well as the construction crew. However, with the proper designation and location of subsurface utilities in and around the vicinity of the project area, construction projects not only incur cost benefits, they also eliminate the major risks and results of utility punctures.

1.4 Reliance on Existing Records

From preliminary design stages to breaking ground on new construction projects; owners, designers, engineers, and contractors traditionally rely on existing underground utility records. There is a constant need for underground utility information and most of the cities existing utility records are not only irretrievable, but are also out-of-date. Existing records and visible feature surveys by site visit are typically 15-30% off the mark and sometimes considerably worse (Stevens and Anspach, 1995). Therefore, reliance on these existing records leads to damage of underground infrastructure during renewal, maintenance or new projects.

The underground facility infrastructure can be thought of as the weakest in terms of its management. Every urban city, at one time or another, have been and are continuously being faced with uncertain underground utility encounters. Most new construction projects or maintenance projects acquire underground utility information from the utility companies themselves. These come in the form of as-built drawings or maps; which are incorrect and sometimes non-existent.

1.4.1 As-Built Drawings

In order to begin to develop highly accurate and well developed engineering drawings, one must obtain a fine quality of as-built drawings. As-built drawings depict the actual as-built conditions of the completed project and provides the end-user with a permanent record of each project feature as it exists today. However, project owners still refuse to consider allotting enough time, money and/or resources when it comes to developing a thorough set of as-built drawings. Besides failing to produce a quality set of as-built drawings for new construction, the patrons of the construction industry fail to update existing as-built drawings (http://ezinearticles.com/?The-Importance-of-(Well-Built)-As-Built-Drawings&id=1380828).

As mentioned earlier, most of the underground infrastructure networks built after WWII have reached the end of their design life and require further development, maintenance and renewal work. This is a crucial point because the first step involved in infrastructure renewal is a clear set of existing records. Several water main and/or sewer main facilities have hard-copy records dating back to the 1920s. As the years went by, these utilities most likely incurred several alterations but were the original as-built drawings updated or did any entity take the time to develop a quality set of as-built drawings? It can be safely assumed that certain records were updated but not all and not to the highest standards possible.

As the technology age rapidly advanced, so did the records of underground utilities. Several municipalities took the effort to digitize these hard-copy drawings and/or maps. And a method known as composite mapping allowed for the display of a combination of information from different thematic maps. For instance, by digitizing a base map, a storm sewer drawing, along with a gas main drawing, both the facilities can now be analyzed in relation to each other and in relation to geographical coordinates. However, the accuracy of these digitized composite maps and/or drawings are only as good as its originals. A way to measure the error in accuracy is to analyze a concept known as the propagation of error; which will be discussed in later chapters.

An individuals confidence in these records and composite maps can be expected to be minimal and will probably only be utilized in conceptual design. Therefore, developing and maintaining reliable underground utility information is an important task in the development, maintenance, and upgrading of subsurface utility infrastructures around the world.

1.4.2 Spatial Information Exchange for Underground Infrastructure

Through recent observations, spatial information that deals with subsurface infrastructure can be categorized into four processes: hand mark-ups, hard-copy exchange, softcopy markups, and softcopy exchange.

Traditionally, project designers will send a base-map or base-drawing of features (i.e. street lanes, curbs, property lines, etc.) to different utility companies. These companies will then mark-up the base-map/drawing by hand, indicating the location of their buried and exposed plant.

Another option utility companies use is to send the designer a hard-copy drawing indicating the location of their buried plant within the vicinity of the proposed project.

However, with the advancement of high-speed broadband internet connections, the project designers find it efficient, in several ways, to sends an electronic base-map/drawing to different utility companies who will electronically indicate their buried facility locations. Or the utility company can choose to send the designer a soft copy drawing of their facilities within the proposed project area. Although these forms of information exchange are practiced on a daily basis, all of them are limited in terms of their accuracy and precision.

For instance, as utilities age, some plants have been abandoned. Therefore, to cut down on the clutter and storage space of records, companies simply dispose of these records. Some companies may also, unintentionally, overlook service lines within the markups; simply due to the fact that they are short. Also, as the base-map features are altered through time (i.e. wider lanes, displaced curb-lines, displaced property lines, etc.), a source of error in location arises due to the incorrect referencing to these displaced features. And finally, full-scale information exchange across different entities will always be inhibited by security, privacy, and competitive/business issues.

1.5 Objective and Organization

The objective of this study is to evaluate the positional accuracy of subsurface utilities. Also, this thesis aims to reveal the magnitude of the problem that exists when dealing with obtaining, analyzing, and interpreting information about subsurface infrastructure networks, as well as identifying the issues regarding the accuracy of the information that pertain to underground utilities. At the beginning of this Master thesis, no comparison analysis of record and surveyed results had been released, so the main task involves analyzing a certain number of projects between the City of Toronto records and TSH/TBE surveyed results.

The thesis also includes the goal to establish or verify a correlation between the location of the utilities with the date of installation, the right-of-way (ROW), the utility type, and the proximity, etc. in terms of the accuracy of its location.

The goal of this Master thesis was to:

- Gather an understanding of the current state of infrastructure networks across developed countries; in particular, focusing on Canadian infrastructure.
- Emphasize the magnitude of the problem of aging infrastructure.
- Assess the different types of technologies used and their theoretical versus practical capabilities when locating different types of underground facilities.
- Assess the quality of information that relates to the location of underground utilities through an empirical analysis that uses the offset approach within the City of Toronto.
- Provide recommendations on how to improve the current state of lack of information and poor collaboration.

Based on in-depth analysis of data projects which refer, in particular, to underground utilities, one can determine the magnitude of the problem and solutions to the problem. In this study, the projects refer to construction projects which utilize subsurface utility engineering investigations. All project data for this study are provided by the City of Toronto and TSH/TBE, as well as Enbridge Gas Distributions Inc.

This study is presented in six chapters. The first chapter presents the introduction along with the background and the objective of this study. The second chapter includes comprehensive information about the One-Call systems; SUE and its ASCE standard quality levels; international underground infrastructure efforts; and best practices dealing with the management of subsurface facilities. The third chapter identifies and analyzes the intrusive (i.e. vacuum excavation) and non-intrusive methods (i.e. geophysical techniques) used to obtain location and attribute information about underground utilities. The fourth chapter is an assessment of the contributing factors to the accuracy of utility location. The fifth chapter shows and verifies the discrepancies in utility asset records through the analysis of seven projects; and the last chapter summarizes the results of this Master thesis and suggests some recommendations for future studies.

2 BACKGROUND AND LITERATURE REVIEW

2.1 Evolution and Progress

Over the past few decades, the construction industry has found that existing records and surface appurtenance surveys are inadequate forms of information. Along with the rising numbers in deaths and accidents involving hazardous underground utilities; government officials across several American states found it necessary to enact comprehensive damage prevention legislation. This prevention legislation required the establishment of statewide notification centers to receive notices of the intent to excavate from any person engaged in excavation activity. It is known as the One-Call Notification System (One-Call) and it has been implemented in several American states since 1974. Not too long after that, the province of Ontario launched the Ontario One-Call Notification System in 1995.

Another, more interesting technology, known as Subsurface Utility Engineering, has been gaining popularity since the early 1990's. As in its title, it is a fast growing engineering process aimed at providing pre-design designating and locating services to its customers through specialized professional providers; while simultaneously reducing and/or preventing utility conflicts and disasters. This reduction of risks is achieved through mapping existing underground utility facilities, using advanced surface geophysical technologies, state-of-the-art surveying and data management systems (Jeong et al. 2004).

2.1.1 One-Call Notification Systems (ONE-CALL)

The Ontario One-Call System is a notification center, which acts as a link between excavators and facility operators. The basic operation of the Ontario One-Call System requires that the excavator provide "one-call" with the exact site and date of the proposed dig, within at least a one-week notice before digging so that their locating crews have sufficient time to locate and mark the excavation sites' underground facilities.

The One-Call center then searches its extensive spatial databases and identifies conflicts with nearby member utilities once the location request has been made. It then sends out a notification to those utility owners. This notification, also known as a 'ticket', will prompt the utility owner to assess the problem and determine whether there is a need to send out their crew to mark the proposed dig site. If the utility company finds that there is a need for a locate, they will dispatch a qualified field crew to the excavation site.

The locators must make colour coded markings on the surface of the precise location of their buried network. The One-Call system is a pre-construction designating service provided, at no cost, to excavators. In layman terms, it is an information clearinghouse for excavators. Each state and/or province has its own One-Call system, this chapter, in particular, will discuss the Ontario One-Call System (Osman and El-Diraby, 2005). Essentially, it is a system that was created to aid in the protection of people from accidentally hitting underground utility lines while working on digging projects.

Furthermore, the One-Call systems operate under a scheme that enforces member utility owners to provide a locating service for their plant prior to construction. Whereas, nowadays, several engineers, architects, and contractors require support of pre-design locates. The lack of support in pre-design locates, by One-Call, results in designs that are based on erroneous facility information, which, in turn, leads to increase in costs due to project delay, redesign, and contractor claims (Osman and El-Diraby, 2005). This is where the engineering process of SUE is considered of optimal significance.

2.1.2 Subsurface Utility Engineering (SUE)

SUE is a fast growing industry, which utilizes a combination of techniques gathered from civil engineering, surveying, geophysics and nondestructive excavation. It acts as a significant tool to reduce the compromising of utility lines as a result of construction, as well as improving worker and public safety during excavation. The obvious benefit of SUE is that their services are provided at the pre-design stage, whereas One-Call is only a pre-construction designating service. However, One-Call can always be used in collaboration with SUE. In fact, by using One-Call and SUE as a combined process, the project's risk factor is being reduced even further as supposed to implementing one over the other.

The first signs of SUE appeared in the late 1970s by a fellow named Henry Stutzman (http://www.sodeep.com/suehistory). The concept of this engineering process was further developed and systematically put into specialized practice in 1983, when state utility engineers in the Virginia Department of Transportation (VDOT) spent $10,000 for a trial project. This project reported to the Federal Highway Administration (FHWA) a saving of up to $1 million to the taxpayer (FHWA, 2002). Since this trial project, several DOTs in North America have been promoting SUE. Furthermore, SUE services were officially recognized as professional as supposed to contractor services in 1989 by a court of jurisdiction. In order to operate as a SUE provider, in Ontario, the business must be certified by the Professional Engineers of Ontario (Jeong et al. 2004). In order to capitalize on construction cost-benefits and to diminish subsurface utility-related catastrophes, the SUE process surpasses the One-Call system.

To be more specific, the American Society of Civil Engineers defines Subsurface Utility Engineering as a professional engineering practice that deals with risks related to underground utility mapping at appropriate quality levels, utility coordination, utility relocation design and coordination, utility condition assessment, distribution of utility data to involved parties, utility relocation cost estimates, implementation of utility accommodation policies and utility design. By utilizing SUE, the excavators can maintain well-timed schedules, as well as restricting fluctuations in cost estimates. In addition, the construction crew carries the advantage of preventing damage to utilities and maintains a decent relationship with the public by lessening the possibility of human fatalities or injuries, as well as preventing utility service disruptions (Borsack, 2005).

The process of SUE is comprised of five key components including, Designation, Location, Surveying, Data Management, and Engineering Service. Designation is considered as the discipline of finding a utility using subsurface geophysical methods to obtain details concerning the existence and horizontal position or alignment of the underground utility at hand. Most of the time, a designation process indicates more than one utility line. And depending on the type of geophysical method utilized and the project's requirements, the site may or may not call for a location procedure to determine the exact utilities on site (Lew, 1997).

Location is the process of exposing the utility or utilities by non-destructive digging means at critical points along the project path. Once the surface is exposed, the precise horizontal and vertical coordinates of the buried utilities can be properly determined and documented.

At last, the information that is obtained via designation and/or location is used to update existing utility drawings or construction plans by performing traditional surveys of the site of interest. Nowadays, due to the advanced technologies used in surveying, survey data is easily transferred to Computer Aided Design and Drafting (CADD) and Geographic Information System (GIS) networks.

From this point on, the data management team updates existing utility records, produces new utility records—where none existed before—and creates construction-site utility plans.

Finally, the professional services of the SUE provider take place. Conflict-scenarios/situations are discussed along with utility coordination and design between a qualified professional SUE engineer and the client regarding the proposed site (Jeong et al. 2004).

Quality Levels of SUE

SUE is unique in the sense that it is defined by quality levels. To be more specific, there exists four Quality Levels, ranging from *Quality Level "D"* to *Quality Level "A"*, pertaining to underground utility information. In order for a designer or project manager to completely comprehend the SUE process, he/she must understand the quality levels. As the quality level ranges from QL-D to QL-A, the initial cost, of obtaining higher quality information, naturally increases. However, the risk factor of damaging subsurface utilities generally decreases. Figure 2.1 displays a general idea of the cost-risk relationship.

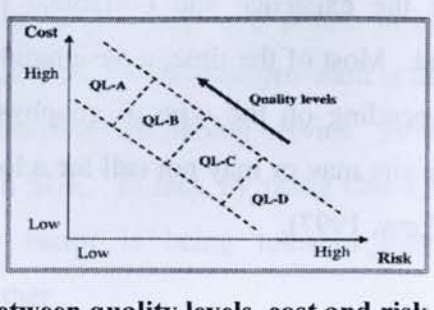


Figure 2.1 Relationship between quality levels, cost and risk factors (Jeong et al. 2004).

The cost and risk factors vary in terms of certain conditions, which will be discussed in detail in upcoming sections of this thesis paper.

Quality Level D (QL-D) is the most basic level of underground utility locating information. The information of this type is derived via existing utility records, utility as-built records, and oral testimony. Although QL-D information provides an overall sense of underground utilities location, it is limited in terms of accuracy and comprehensiveness. This level information is to provide the user with a general idea of what facilities to be encountered, relative positions, and areas of possible conflict. This quality level is often used for project planning and route selection and estimates of utility relocation costs (Lew, 1997).

Quality Level C (QL-C) involves revising and adjusting QL-D as-built information through surveying visible surface appurtenances, such as manholes, vent pipes, valve boxes, posts, etc. and correlating these findings with existing records. Quality level "C" assesses the current state of the surface appurtenances and determines inconsistencies between historical maps and actual locations. Most often than not, inconsistencies are a result of roadwork that has paved over, buried or destroyed utility markings. QL-C utility data is normally used during the planning stage and sometimes during the preliminary design stages of a project. It also serves as a precursor for the designation stage of the SUE process (GeoSpec, 2005).

Quality Level B (QL-B) involves the designation process of using surface geophysical techniques to detect the existence and approximate the horizontal position of subsurface utilities within the project limits. QL-B data, also referred to as two-dimensional information, is surveyed to tolerances defined by the project and summarized onto utility maps and construction plans. During the preliminary design stage, quality level B data is sufficient for decisions to be made on where to place drainage systems. There are several geophysical technologies to be used based on applicability and tolerances required for each project. The next few chapters will discuss different geophysical techniques and their applicability's.

Quality Level A (QL-A) is the highest level of accuracy of obtaining subsurface utility locations. It is simply an extension of QL-B information involving actual "locating". To be more specific, precise horizontal and vertical location of utilities is obtained by actual exposure—usually a critical point along the project path—and measurement of subsurface utilities. The techniques used to excavate are non-destructive, in nature, and can be used on all kinds of soil and concrete. Exact location measurements can be performed, resulting in precise three-dimensional information. In addition, while the utility is exposed, the field operator can verify the material type, the soil conditions, and other noteworthy underground information in order to assess the buried facilities. Figure 2.2 is a display of the different quality levels.

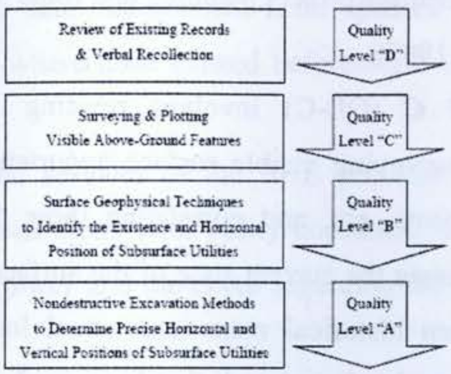


Figure 2.2 Quality levels of SUE (Jeong et al. 2004).

Most often than not, the final design stage is where most underground conflicts can be avoided by integrating this highly accurate location information. It is suggested that all four quality levels' information be used in a systematic approach to obtain optimized results while maintaining a minimal budget (Borsack, 2005). Depending on the assessment of the project at hand (i.e. location, budget, timeframe), the project manager must carefully determine which quality level data is needed to sufficiently and safely complete the task. For instance, obtaining quality level C or D data alone would be considered a risk in a congested urban area, which increases the chances of paying for the associated costs in change orders, utility damages, and other unexpected conflicts (Lew, 2000).

For the purposes of this study, the City of Toronto and a subsurface utility engineering firm known as, at the time, the TSH/TBE Group provided existing drawings and newly surveyed drawings. Depending on the client's request, five out of the possible seven projects required ASCE standard QL-D, QL-C, QL-B, QL-A data. Each quality level is represented visually through linetypes within the drawings. Please refer to the legend in Appendix E Figure E.8 (a) and (b) for a detailed drawing of the linetypes that pertain to quality levels.

The following section will discuss the initiatives being taken by several entities within Europe, USA, and Canada.

2.2 Global Initiatives

This chapter describes a collection of the subsurface infrastructure initiatives around the world. It entails a discussion on efforts including the National Joint Utilities Group (NUAG) in United Kingdom, the Common Ground Alliance (CGA) in America, the Ontario One Call (ON1CALL), and several more to be discussed in this chapter.

2.2.1 European Initiatives

The next six initiatives discussed in this section are significant research efforts funded by different entities. However, they all focus their attention on one main goal: location and protection of underground infrastructure. In essence, each initiative compliments one another in the capturing, recording, storing and exchange of subsurface asset information. A workshop held in 2001 between research establishments promoting water related research (i.e. UK Water Industry Research (UKWIR) and the American Water Works Research Foundation (AWWARF)); triggered an international workshop to reflect on deeper issues of concern including:

- Buried pipeline and appurtenance location technologies.
- Revision of state-of-the-art technologies and their limitations.
- Development of cost and performance specification for buried pipe and appurtenance locating tools.
- Identification of future technological development and research requirements.

Several skilled professionals ranging from utilities, contractors, manufacturers, research institutes, and organizations, identified highly potential research opportunities. Although the international workshop had British, American and Dutch attendees; the greatest research initiatives undertaken so far, with respect to underground infrastructure, have been by the British.

It is estimated that nearly four million excavates take place into the UK road network each year for four main reasons – safety, security of supply, to connect new customers or to enhance existing customers' supplies, or to divert apparatus to facilitate major urban regeneration or transport infrastructure projects. Hence the reason for utilities and highway authorities to enhance the recording, storing, displaying, and sharing of underground utility and appropriate above ground asset information.

The *Traffic Management Act (TMA)* was given royal assent on July 22, 2004. This act involves designation of traffic officers and their duties; regulatory management of road networks; regulating street works and other activities in the street; as well as civil enforcement of traffic contraventions. With respect to utilities, the TMA designed a framework within which utility companies are given permission to excavate roads but only under the condition that greater co-ordination and cooperation between local authorities and utility companies takes place. In addition, this act also seeks to promote all those with underground assets to exchange information to facilitate better cooperation of street works while avoiding and/or greatly reducing negative impacts. (TMA, 2004).

In the effort of reaching the relevant Traffic Management Act targets, a group of relevant stakeholders, including utilities and local authorities, was established and is now known as the *National Underground Assets Group (NUAG)*. Further academic support from the *Engineering and Physical Sciences Research Council (EPSRC)* allowed for the funding of a £1 million program known as *Mapping the Underworld (MTU)*.

Another UK-based project is known as *Visualizing integrated information on buried assets to reduce street works (VISTA)*. This project uses global navigation satellite technology to link to existing asset records in order to generate 3D images of subsurface facilities.

Other useful British organizations exist, such as the Highway Authorities and Utilities Committee (HAUC) and the National Joint Utilities Group. The HAUC, representing utilities an highway authorities, played a very crucial role in drafting the New Roads and Street Works Act 1991. And NJUG is the utility arm of the HAUC and it includes street works issues in England, Northern Ireland, Scotland, and Wales. It has members from the Energy Networks Association (i.e. electricity and gas companies), Water UK (i.e. water companies), National Grid, Buried Telecom, Virgin Media, and THUS plc (NJUG, 2007). HAUC issued a Code of Practice and NJUG published Guidelines and Recommendations. The only setback of these two efforts is their extent of regulatory power. Their guidelines and recommendations are just that--advisory, not statutory. Hence there tends to be different notions within street works communities regarding certain approaches to the capture, log, storage, and exchange of asset information. Whereas, the NUAG supports the Department of Transport (DfT), therefore, acting as a main point of focus for the underground asset community.

NUAG – National Underground Assets Group

The *National Underground Assets Group (NUAG)* was officially recognized in 2005 and its objective is to have consistent, appropriate subsurface and associated above ground asset information exchange between stakeholders on demand.

NUAG aims to achieve the most effective and efficient means of recording, storing, sharing, and displaying underground asset and appropriate above ground asset information by carrying out agreed data definitions, standards, protocols, processes, and implementation timetable. This organization also wants to ensure consistency with regard to underground and associated above ground utility information, while simultaneously keeping the wider stakeholder community informed. NUAG has produced reports discussing the current and future proposed practices of capturing, recording, storing, and sharing of subsurface utility information; condensed, summarized versions of these reports can be found in Appendix A.1.

NJUG – National Joint Utilities Group

NJUG is the UK industry association that represents utilities on street works issues. It is considered to be the utility arm of the Highway Authorities and Utilities Committee (HAUC). NJUG's aims overlap those of NUAG's some of which include ensuring general public safety, making certain damage to underground facilities is avoided, minimizing disruption through proper coordination with local authorities, promoting best practices, and developing legislation. Please see Appendix A.1 for a detailed list of NJUG objectives.

MTU – Mapping the Underworld

The UK Engineering and Physical Sciences Research Council (EPSRC) Engineering Programme and Engineering Program Network in Trenchless Technology (NETWORK) organized a workshop that triggered several MTU workshops that concentrate on solutions to complex problems involving subsurface utilities (www.epsrc.ac.uk). MTU received funding for a certain number of research projects conducted by a group of universities in the UK, as well as worldwide industry partners. A detailed description of the research endeavors can be found in Appendix A.1.

Buried Asset Location, Identification and Condition Assessment using Multi-Sensor Approach

The purpose of this research effort was to look into the need for multi-sensor devices to detect buried pipes and cables. Two approaches were analyzed including penetrating the surface to detect buried pipes and cables and/or using robotic sledges being fed into pipelines or sewers for detection.

MTU Workshops

In the efforts of improving utility location equipment and mapping techniques, MTU actively organized a series of workshops to seek out the involvement of stakeholders in this industry. It was also responsible for producing an online questionnaire in order to assess the degree of accuracy required by the utility mapping community regarding geophysical location methods. Appendix A.1 includes summaries of the five workshops that took place in England.

VISTA

'Visualizing integrated information on buried assets to reduce street works'; or in its simpler form 'VISTA', takes on a broader approach while mirroring the concepts studied by the MTU initiative. VISTA focuses more on integration, sharing, reusing, and conveying existing legacy asset data knowledge with accurate georeferenced data. Appendix A.1 includes a detailed summary of VISTA's research efforts.

ORFEUS (Optimized Radar for Finding Every Utility in the Street)

There are certain requirements for advanced technologies regarding location, maintenance and rehabilitation of buried infrastructure which ORFEUS will try to address. This effort also emphasizes the need for locating subsurface utilities. A detailed explanation of ORFEUS research objectives and practices can be found in Appendix A.1.

2.2.2 US Based Initiatives

SHRP SON – Strategic Highway Research Program Statement of Need

Noteworthy US-based initiatives include the Strategic Highway Research Program and the Strategic Highway Research Program Statement of Need for locating and characterizing technologies for buried utilities. A detailed description of both SHRP SON and SHRP II projects can be found in Appendix A.2.

CGA – Common Ground Alliance

The Common Ground Alliance (CGA) is a non-profit organization that believes in promoting shared responsibility in damage prevention by ensuring public safety, protection of the environment, and the integrity of services. The CGA aims to prevent damage to subsurface facilities by implementing shared responsibility for the protection of underground assets; encouraging continued research to enhance damage prevention practices; and serving as a damage data clearinghouse. Details on the organization's creation through a study are discussed in Appendix A.2.

Furthermore, CGA's stakeholders were keen on the development of data collection on a national level. As a result, in November 2003 the CGA successfully launched the DIRT effort.

DIRT – Damage Information Reporting Tool

As mentioned earlier the Damage Information Reporting Tool is a secure web application for the reporting and collection of underground damage information. This CGA-developed web application requires stakeholder members to submit damage and near-miss reports; administer role-based company and user information; revise personal profiles; alter/recover user passwords; and offer feedback and submit questions. This tool has been very helpful in allowing CGA to analyze the data and gather a consensus as to why these events occur and what the industry can do to prevent such incidents thereby making certain of the safety and protection of people and the infrastructure.

The fourth Annual Report, which analyzes data extracted from 2007 events and submitted to DIRT, revealing an approximate 256,000 damages. And according to the Ontario annual report, compiled by the Ontario Regional Common Ground Alliance's (ORCGA) DIRT, approximately 6000 damages were reported by stakeholders in Ontario for 2007 (http://www.orcga.com/lib/db2file.asp?fileid=298).

The inclusion of more state US damage reports would complete the dataset, improving the estimate overall.

NULCA – National Utility Locating Contractors Association

NULCA, formed in 1995, is a combined organization of contract locators, utility owners, One-Call centers, excavators, SUE, and industry suppliers that vouch for safety and damage prevention of North America's underground infrastructure. See Appendix A.2 for a detailed summary.

NUCA – National Utility Contractors Association

NUCA describes itself as 'Leading the underground utility construction industry since 1964.' This association was developed to improve the operational proficiency and economic concerns of its member companies by providing services that focus on shared industry issues. Appendix A.2 contains a more detailed explanation and url site for further details.

2.2.3 Canadian-Based Initiatives

CGARP – Canadian Regional Partners of the CGA

The Canadian Regional partners of the Common Ground Alliance are nonprofit organizations within each province made up of several industry stakeholders devoted to the shared responsibility of damage prevention and in the promotion of Best Practices. It is derived from the American based CGA. Appendix A.3 contains a more detailed summary of the organization and its details.

RPWCO – Regional Public Works Commissioners of Ontario

Member of the Regional Public Works Commissioners of Ontario (RPWCO) are responsible for planning, designing, building, operating, and maintenance of public infrastructure, including transportation, water, wastewater, solid waste, park and public buildings, which provide daily services to the citizens of the Province of Ontario.

This organization is made up of a number of municipalities including the City of Toronto, Regional Municipality of Peel, The City of Hamilton, City of Kingston, City of London, Regional Municipality of Niagara, The Corporation of Norfolk County, City of Ottawa, City of Greater Sudbury, Regional Municipality of York, City of Thunder Bay, Regional Municipality of Waterloo, City of Windsor, Durham Region, Haldimand County, Regional Municipality of Halton, and the District Municipality of Muskoka. Although this may seem like a fairly small group, they essentially supply the full range of Public Works infrastructure and services to over 80% of the population of Ontario (http://rpwco.ca/index.shtml).

Of more importance, in June 2005 the RPWCO launched the Utility Policy and Data Standards Task Force, which consists of active members from Hamilton, Ottawa, and Toronto. Furthermore, the RPWCO approved the expansion of the mandate to include utility policy development on June 22, 2007.

The mission of this task force is to develop data standards for utility construction in the road allowance so that the efficiency and safety of road and facility construction may be improved.

The task force plans to achieve their mission by requiring reliable and accurate as-built utility drawings and other records, which display the location of underground plant, as a requirement of road cut permit approval. Also, they plan to establish electronic plan and sketch submission formats to make the process of assembling utility records into one or more databases easier. And the task force must set up data standards for planned construction activity in the road allowance to aid in the development of construction planning, coordination and permitting systems. As well as, establishing standardized electronic data formats to allow for efficient data exchange and support compilation of composite utility mapping.

The task force is responsible for developing, reviewing, and recommending best practice principles, policies and standards relating to the management of utilities operating within the above-mentioned municipalities. .

The Utility Data Standards Task Force in close collaboration with the Canadian Standards Association (CSA) is developing a standard for the mapping of buried utilities. This standard will entail the content, spatial accuracy, and overall quality of as-built drawings with the aim of increasing safety of personnel and operators, improved estimates, fewer cost overruns, enhanced planning and co-ordination, and fewer service disruptions. Currently, the CSA is also forming a committee under the authority of the CSA Strategic Steering Committee on Structures (Design). This committee is responsible for conducting a feasibility study on the development of national standards for the mapping of underground facilities. This paper will take a deeper look into the development of national standards in following chapters.

ON1CALL – Ontario One Call

As mentioned earlier, the One-Call system is a pre-construction designating service provided, at no cost, to excavators. In layman terms, it is an information clearinghouse for excavators. Each state and/or province has its own One-Call system, this chapter, in particular, will discuss the Ontario One-Call System (Osman and El-Diraby, 2005). Please refer to Appendix A.3 for further details.

LAC – Locate Alliance Consortium

The LAC is a collective group of utilities and municipalities committed to providing the best locate service through a consortium approach. It is a group of Ontario facility owners working collaboratively in an effort to provide a cost efficient locate process with standardized terms and conditions, with consistency in terms of quality and outcomes. The relationship between facility owner and locate service is further simplified through the LAC and it facilitates the ideals of one call or one locate.

This is accomplished by creating an association of companies whose for the purpose of purchasing locate services. Usually, facility owners hire a contractor or utilize their individual employees to provide locates, which results in increased site visits by different locators representing each utility company at the same location. Considering the number of repeated locates, this process is redundant as well as costly.

The current members of the LAC include Union Gas, Bell Canada, Enbridge Gas Distribution, Milton Hydro, Toronto Hydro, Toronto Street Lighting, Atria Networks, and the City of Brampton.

Currently, LAC has divided the province into 10 geographic service regions with its respective committees, as seen in Figure 2.3.

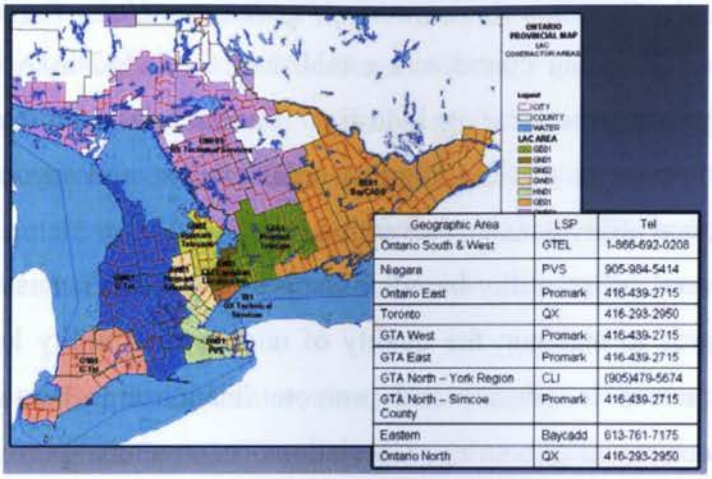


Figure 2.3 Ten geographic service locations across Ontario (LAC, 2008).

By combining a group of utilities (i.e. a consortium), facility owners/operators will be able to hire a single Locate Service Provider (LSP) per geographic location. Thus, improving the quality, timeliness and effectiveness of the locate. Also, the excavator is spared increased administration and effort. And since one call results in all locates, only one site visit is required to complete the task.

In particular, a significant development is the Common Procedures Manual, which is a product of the ORCGA best practices and aspects of the Utility locate procedures. It is a thorough procedures manual that defines exactly what is necessary when performing a locate.

The many advantages of participating in the LAC include:

- Fewer damages and costs due to one call or one locate strategy.
- Financial efficiencies including less administration work, savings per service provider, easy outsourcing, efficiency of managing the volume of work.
- Improvement in quality and performance management due to best practices approach.
- Facility owners have reduced damages and costs; locators have common standards, specifications, and efficiencies; regulators have a common industry approach; and the excavator is able to improve their overall service with consistent locates.

CAPULC – Canadian Association of Pipeline and Utility Locating Contractors

A group of locating contractors established CAPULC in April 2002 with the intention of improving the locating industry. The association is made up of clients, suppliers of equipment or training, digging organizations, and anyone with the shared goal of underground utility damage prevention.

Like several other utility-based initiatives, CAPULC's mission is to develop proactive standards to maintain the quality of underground utility locating in Canada. CAPULC also serves to educate and promote relationships between members and government agencies, neighbouring associations, contractors, professional engineers, manufacturers, suppliers, utility companies, one-call centers, the public, and the underground utility locating industry.

While developing these relationships, CAPULC will promote ethical practices, ensure and encourage safety in the conduct of their work, and support the continued education of members in the pursuit of underground utility locating.

The association also developed the Canadian Locator Technician Standards, which states the minimum technical qualifications required by any person who would like to become a Locator Technician. Further discussion will take place later on.

2.2.4 International-Based Initiatives

The International Society for Trenchless Technology (ISTT) was founded in 1986 with the intention of advancing the science and practice of Trenchless Technology; as well as, promoting the education, training, study and research in this science and practice. A complete list of the Trenchless Technology societies that exist across the globe can be found in Appendix A.4.

2.3 Global Standards and Best Practices

2.3.1 Europe – Standards and Best Practices

TMA – Traffic Management Act

The *Traffic Management Act (TMA)* was officially recognized on July 22, 2004 by the British Department for Transport (DfT). It was introduced to deal with congestion and disruption on the road network. This act involves designation of traffic officers and their duties to maintain regulatory management of road networks and to regulate street works and other activities in the street; as well as civil enforcement of traffic contraventions.

In terms of subsurface facilities, the TMA designed a framework within which utility companies are given permission to excavate roads under the clause of greater co-ordination and cooperation between local authorities and utility companies. In addition, this act also seeks to promote all those with underground assets to exchange digital (GIS) asset location information to facilitate better cooperation of street works while avoiding and/or greatly reducing negative impacts. (TMA, 2004).

Dft and HAUC – Working Together: A Good Practice GUIDE TO Managing Works in the Street

This guide discusses the steps to be taken in order to carry out utility works in the streets with the least disruption to users, frontages and local communities. Several sub-procedures must be considered the planning, coordination, monitoring, feedback, and improvement stages of street works to ensure quality, timely construction. Detailed descriptions of the stages can be found in Appendix B.1

NUAG – Capturing, recording, storing and sharing underground asset information

The NUAG effort was set up in 2005 to bring about improved coordination between various organizations including highways agencies, utility companies, civil engineers, surveyors, and regulators. It is continuously working in close collaboration with the Department for Transport to develop standard processes to assist in the coordination of activities that fulfill the targets of the Traffic Management Act (TMA).

NRS – The National Referencing Standards Project

The National Referencing Standards Project is being sponsored by NUAG. The targets of this project align with the DfT target dates for a revised Records Code of Practice. Phase 1 of the project phases develops methodologies, standards and best practices that tackle standardization issues and will run up to 2008, in terms of research. Whereas Phase 2 builds on the outcomes of Phase 1 and develops the deliverance of technology-based solutions.

The NUAG currently supports the *National Referencing Standards Project (NRS)*; which focuses on the revised Records Code of Practice of the Department for Transport. This project, in particular, has two phases of which the first one develops methodologies, standards and best practices that tackle standardization issues to 2008. Whereas Phase two builds on the outcomes of Phase 1 and develops the deliverance of technology-based solutions. Both phases are discussed in detail in Appendix B.1.

2.3.2 USA – Standards and Best Practices

ASCE Standard CI/ASCE 38-02

The American Society of Civil Engineers (ASCE) developed the ASCE C-I 38-02: *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data* in 2002. This standard is recognized as a National Consensus Standard (NCS) and an American National Standard Institute (ANSI) standard, which allows the justice system to hold this standard in great regard. The standards' steering group consisted of governmental agencies, engineers, contractors, academics and project owners who held internal as well as public meetings.

This Standard is recognized as a reliable means to classify the quality of utility location information that is drawn up in engineering design drawings. It addresses several issues dealing with subsurface utilities, including the processes of obtaining utility information; conveying that information to users; identifying responsibilities for collection and depiction tasks; determining the utility quality level to assign to the data; and assessing the relative costs and benefits of using the SUE quality levels. Several state DOTs are already in compliance with this standard due to the fact that they have used SUE services for several highway projects; and SUE concepts are very much a part of the body of the ASCE Standard 38-02.

The standard has thus far been applied as a reference and as part of construction specifications within engineering contracts. The standard has been successful in assisting engineers, project and utility owners, and contractors to develop sound strategies that tackle the risks associated with subsurface and associated above-ground assets. Overall, the ASCE Standard 38-02 improves the reliability of information on existing underground facilities in a defined manner.

According to the standard, the project owner is regarded highly responsible for dealing with utility risks. The owner will also state desired quality level of facility data to the engineer. The engineer will be responsible for advising the owner of utility risks and providing recommendations for the level of data quality required for a given project area. The engineer must consider the type of project, expected utilities to be encountered, available right-of-way, project timelines, and costs. And the engineer will also be held responsible for errors or omissions in the utility data for the certified utility quality level.

CGA Best Practices 6.0

The CGA's Best Practices guide is based on the work of the Common Ground Task Force and it contains a restatement of the best practices identified in the Common Ground Study conducted by the Department of Transportation in 1999. The latest best practices publication, Version 6.0, was released in February 2009 and it includes new and revised practices.

Of particular interest, Version 6.0 uses icons (see Figure 2.4) to help the reader identify which practices pertains to their specific industry stakeholder group.

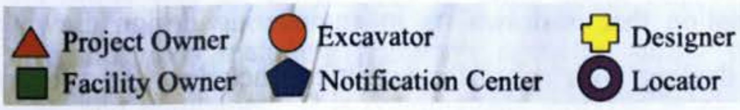


Figure 2.4 Icons identifiers for best practice-stakeholder correspondence (CGA, 2009).

This guide includes the following nine categories:

1. Planning and Design Practices
2. One-Call Center Practices
3. Locating and Marking Practices
4. Excavation Practices
5. Mapping Practices
6. Compliance Practices
7. Public Education Practices
8. Reporting and Evaluation Practices
9. Homeland Security and the Best Practices

Each category contains subsections of which the significant ones will be explained in Appendix B.2.

Domestic Scan Program: Best Practices in ROW Acquisition and Utility Relocation

The Domestic Scan Pilot Program was initiated in 2006 by the National Cooperative Highway Research Program (NCHRP) and sponsored by the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA). Two scanning programs were funded: Best Practices in Right-of-Way Acquisition and Utility Relocation; and Best Practices in Transportation Asset Management.

The Right-of-way acquisition or relocation process is the last stage before construction commences and it is believed that this stage causes the delay of construction. Since the federal and state authorities have developed protective rights for property owners, tenants, and public and private sector utilities, transportation agencies must ensure to follow these protections. However, by improving ROW and utility relocation processes the overall approach to expedite project development can take place.

Initially, the scan involved reviewing and documenting literature that dealt with best practices and innovative efforts in three host state departments:

- The Florida Department of Transportation (FDOT) – District 5 Office
- The Texas Department of Transportation (TxDOT) – Texas Turnpike Project Office
- The Minnesota Department of Transportation (Mn/DOT) – Minneapolis Office

An in-depth discussion of the federal regulatory framework can be found in Appendix B.2.

2.3.3 Canada – Standards and Best Practices

National Standards for As-Built Drawings Feasibility Study

The Regional Public Works Commissioners of Ontario is an organization made up of a number of members from different municipalities that are involved in planning, designing, building, operating, and maintenance of public infrastructure, including transportation, water, wastewater, solid waste, park and public buildings; which provide daily services to the citizens of the Province of Ontario. In June 2005, the organization established the Utility Policy and Data Standards Task Force consisting of members from Hamilton, Ottawa, and Toronto.

The Utility Data Standards Task Force in close collaboration with the Canadian Standards Association (CSA) began a feasibility study with the intention of developing national standards for the mapping underground facilities. The standards are aimed to ensure public safety and to prevent damage to public and private property. As well as, the standard, if used as part of the regulatory regime, should improve planning and co-ordination throughout the utility lifecycle, minimize construction costs, and minimize service cuts.

To be more specific the standard shall include all buried utilities ranging from supply, distribution to service laterals. The standard should also consider existing and emerging supportive data collection technologies which may present opportunities of improvement in terms of quality and reduction of costs associated with data collection.

And the standard shall include methodologies and business process that guarantee quality as-built record content without compromise to public safety (RPWCO, 2006).

More importantly, the standard should aim to prescribe the minimum content requirements of spatial details (i.e. accuracy and measuring techniques, location, size) non-spatial information (utility type, utility material, date of construction). And finally the standard should consider utilizing a quality classification system such as the SUE standard.

ORCGA Best Practices V5.0

The most recent version, Version 5.0, was published in February 2009 and it includes the following eight categories:

1. Planning and Design Best Practices
2. One-Call Centre Best Practices
3. Locating and Marking Best Practices
4. Excavation Best Practices
5. Mapping Best Practices
6. Compliance Best Practices
7. Public Education Best Practices
8. Reporting and Evaluation Best Practices

The significant sub-categories of each leading best practice are further discussed in Appendix B.3.

CAPULC's Canadian Locator Technical Standards

The Canadian Association of Pipeline and Utility Locating Contractors (CAPULC) was launched in April 2002 with the intention of improving the locating industry. The association consists of clients, suppliers of equipment or training, the digging organizations, and anyone with the shared goal of underground utility damage prevention.

The association created the Canadian Locator Technician Standards, which states the minimum technical qualifications required by any person who would like to become a Locator Technician. It outlines the requirements of the Locator Technician in terms of demonstrating the right knowledge and understanding of the practices and procedures by passing a formal closed book examination, as well as actual field scenarios to locate using equipment efficiently and effectively (CAPULC, 2006).

In particular, the viable Locator Technician candidates must display knowledge and understanding in the ten units of competency:

1. Theory of Electromagnetic Locating
2. Use of the Transmitter
3. Use of the Receiver
4. Marking Procedures
5. Knowledge of Facilities
6. Visual Observation Skills
7. Safe Work Practices and Regulations
8. Locate Request Procedure, Documentation, and Mapping
9. Federal, Provincial and Local Regulations
10. Customer Interaction

These minimum standards will be revised and improved as the locating industry continues in its efforts of damage prevention. However, this standards document only describes the knowledge and skills that have to be displayed by any entry level Locator Technician. And through the application of the practices outlined in the manual, increased knowledge and experience will take place, leading to greater competency than before (CAPULC, 2006).

Lastly, Appendix C contains detailed information regarding certain practices for managing underground utility asset information.

2.4 ASSET MANAGEMENT

Underground utility asset management is a growing concern among the infrastructure community. Several companies have developed software programs to accommodate the requirements of storing, analyzing, and sharing underground utility information. Appendix C contains four software programs including VUEWorks Works and Asset Management solutions; Autodesk's Geospatial Software; One Call Mapping, developed by Kuhagen, Inc.; and lastly the Ontario One Base Map created by Wayne Crann & Associates.

3 UNDERGROUND UTILITY DETECTION TECHNOLOGIES

Within the construction industry, it is critical to determine the on-site location, nature, and depth of underground utility facilities. This section presents a thorough review of different geophysical techniques used for designation, as well as the non-destructive extraction methods employed throughout the location component of an underground investigation.

3.1 Geophysical Techniques – Non-Intrusive

The typical subsurface imaging application involves directing energy into the earth's surface, non-invasively, and recording the energy reflected off underground objects. The recorded data is processed according to the distributions of the physical properties related to buried bodies. Interpretation of the processed data yields the horizontal position of the underground utility. Moreover, the subsurface information obtained via geophysical methods is categorized as quality level B (QL-B) data. With the advancement of certain geophysical technologies, more accurate and complete QL-B maps have been developed, which also minimized the need for vacuum excavation, hence reducing the overall project cost.

In general, the geophysical technology's basic function inputs a form of energy into the earth and the reflected energy is observed, analyzed, and interpreted to identify the exact location of the utility (Jeong and Abraham, 2004). However, different ground conditions and utility properties inhibit the locator from using a single geophysical technology for all projects. Further detail regarding non-destructive excavation will be discussed following the sub-sections of imaging technologies. This chapter, in particular, will focus on imaging methods based on electromagnetic methods, magnetic, seismic, acoustic emission methods.

3.1.1 Electromagnetic Methods

This category of techniques includes pipe and cable locators, terrain conductivity, resistivity survey, metal detectors, and electronic marker systems (EMS), and more importantly ground penetrating radar (GPR).

3.1.1.1 Pipe and cable locators

In the 1920's Dr. Gerhard Fisher sought out to build a handheld pipe locating device that used radio signals after coming across distorted signals experienced by pilots who were trying to determine their position by homing in on radio signals being broadcasted from major cities (Chernekoff and Toussaint, 1994).

Pipe and cable locators can be in either a passive or active model which involves either locating a background signal or locating a signal introduced into the utility line with the use of a transmitter.

Introducing a signal indirectly involves transmission coils, which are used to release different electromagnetic frequencies into the ground. The coil creates this electromagnetic energy, which creates magnetic fields around electrically conductive materials found beneath the earth's surface, which is then recorded by the receiver coil—located on the surface. For best performance the transmitter is recommended to lie in the same general orientation of the utility line. This is sought out by trial and error. This magnetic field energy is processed and interpreted to produce an indication of the horizontal location of the buried utility. The electromagnetic spectrum consists of a wide range of frequencies, and locators use a small, yet crucial, portion of this spectrum to locate underground utilities.

To be more specific, frequencies ranging from 50 kHz to 480 kHz can be useful to identify a utility (ASCE, 2002). However, higher frequencies (i.e. radio frequencies), cause electromagnetic current leakages. As the frequency increases, the wave increases, and the waves' travel distance decreases. Also, higher frequencies are sensitive to finding nearby structures instead of finding the utility being sought, often leading to inaccurate horizontal positions.

On the other hand, an electromagnetic signal can be introduced directly by using an induction clamp; which induces a signal into the conductor. Evidently, the more reliable tracing signals are those which are created using the direct method. This method has fewer chances of distorted signals, whereas, the indirect method may end up completing a locate on a neighbouring utility than what was begun with (Twohig, 1998).

The effective locating depth is 3.04 meters with ideal soil conditions, but this depth easily reduces if soils are of dry sand, alkaline or high iron content (Jeong and Abraham, 2004). This method works well for copper, aluminium, and steel pipes—metallic utilities, utilities that are buried with tracing materials above the utility itself, and utilities that will accept a metallic conductor or transmitter. However, a major drawback of this method is that it cannot trace non-metallic (i.e. non-conductive) utilities including cast iron. But this obstacle can be easily overcome by fishing a steel tape through non-conductive underground facilities. For instance, if the pipeline is accessible, an insulated trace wire can be fished into the conduit, allowing the signal in the wire to be traced by connecting the transmitter to the wire. Another alternative is to use an "in-pipe transmitter" sonde. The sondes act as a radio transmitter that creates an electromagnetic field of its own. So, for both choices the receiver is waved over the approximate location of the underground pipeline. And the horizontal location of the pipeline is marked by the highest signal strength.

Furthermore, the depth of the utility can be approximated but due to various error-prone factors; including proximity to other utilities and soil conditions, this measurement is prone to error. At most, a locate crew size of two people is required to locate subsurface utilities when using the pipe and cable locator method.

For the data gathered by TSH/TBE, the Metrotech 810 Pipe and Cable Locator™ was used. This system is equipped with an 810 transmitter, receiver, conductive attachments, and ground rod. The manufacturer claims that the fully automated 810 Pipe and Cable Locator™ is an excellent inductive locating and directing. It has simultaneous peak/null therefore saving the locator time in the field. It has an excellent left/right guidance system accompanied with an audible tone. Once the 810 pinpoints the utility being sought, it indicates the strength of the transmitted signal in digital form. The frequency output by the transmitter is 83.0075 kHz+.002% crystal controlled for interference resistance. And the 810 Receiver has a trace accuracy of +1 inch from 0-3 ft (91 cm) and +3% over 3 ft (91 cm) in depth. And the depth readout accuracy is ± 5% + 2" under normal circumstances. According to the manufacturer, besides depth being dependent on soil conditions and the environment at the time of the measurement, the maximum depth estimation indication for the 810 is 13 feet. One of the most common factors that affect how far you can locate these high frequency inductive systems is the effects of bleedover. Bleedover can be detected by the judgment of the locator. If there is inconsistencies in depth while tracing a utility, or large variations in signal strength over a short distance or distorted fields, or termination at a different utility; then bleedover has occurred. All of the data acquired using the 810 Pipe and Cable Locator™ is classified as Quality Level B data.

3.1.1.2 Terrain Conductivity

Terrain conductivity surveys locate buried facilities by noting the difference of conductivity between utilities and the surrounding soils. The transmitter coil emits an electromagnetic field that produces circular-shaped electric currents (also known as eddy currents) into the earth directly below the coil. These systems create and measure eddy currents due to differences in the average conductivity from the ground surface to the effective locating depth, which is around 15 feet or 5 m (ASCE, 2002). Eddy currents are defined as the electrical currents that are induced into the ground, or other conductors, by an electromagnetic field. These eddy currents reflect the current back to the ground, generating a secondary magnetic field, with different properties when it comes into contact with an object which has different conductivity characteristics from the surrounding soil. Figure 3.1 gives a better explanation of how the electromagnetic fields work using the terrain conductivity method. As seen in this figure, the induction unit initially creates a field Bp that generates the Je eddy currents into the ground; which, in turn, produce a secondary field Bs. Finally, the ratio of Bs/Bp is indirectly computed by the receiver and related to the ground conductivity (GeoPotential, 2008).

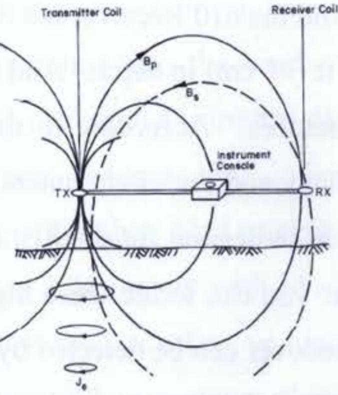


Figure 3.1 Terrain conductivity electromagnetic field concept (GeoPotential, 2008).

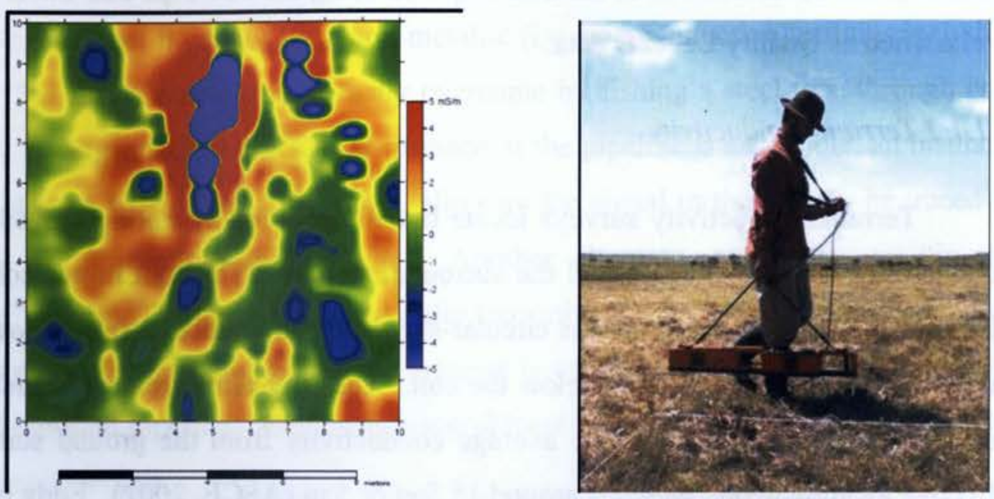


Figure 3.2 Image and survey of terrain conductivity (http://www.geovision.com).

The conductivity is influenced by the particle size of the soil, so if the particle size is smaller the conductivity increases because the current path is more direct in finer-grained soils, also termed silty soils. And if the soil grain size decreases further to that of true clays, conductivity increases (i.e. ionic conduction) due to a large number of exchangeable ions that are present on the surface of the clay particles.

A prime example is the lower conductivity levels of a buried metallic object compared to the levels in the soil which encompasses the metallic object. So, the reflected current has a distinct value and the reflected currents are recorded and analyzed, by the receiver, to designate underground utilities. This technique is put to good use in non-congested utility areas. Also, several isolated metallic utilities, subsurface storage tanks, wells, and vault covers can be efficiently sensed by this method. Moreover, under specific conditions, large non-metallic empty and dry pipes in wet soils may be detected (ASCE, 2002). However, this method does not work well along power lines, metal fences, vehicles, or buildings. This is due to the fact that these metallic components produce magnetic fields which interfere with terrain conductivity readings (Jeong and Abraham, 2004). In particular, the three factors affecting terrain conductivity surveys includes, the porosity (i.e. the measure of void spaces in a material) of the subsurface material; the degree of saturation (i.e. the ratio of water in soil); and the concentration of dissolved electrolytes in the pore fluids (http://www.geovision.com/seismic.html].

An American GPR-based surveying company called GeoModel, Inc.; which has conducted several electromagnetic conductivity (EM) surveys worldwide, uses shallow EM conductivity meters to locate metal and to measure ground conductivity up to 6 meters (20 feet) deep. Professionals within the company have been able to use this conductivity method to locate and delineate horizontal and vertical extents of buried utilities, sinkholes, landfill leachate, saltwater plumes, metal reinforced foundations and other underground features and conditions (http://www.geomodel.com/em/). Figure 3.3 displays buried metallic pipes located by electromagnetic conductivity surveys.

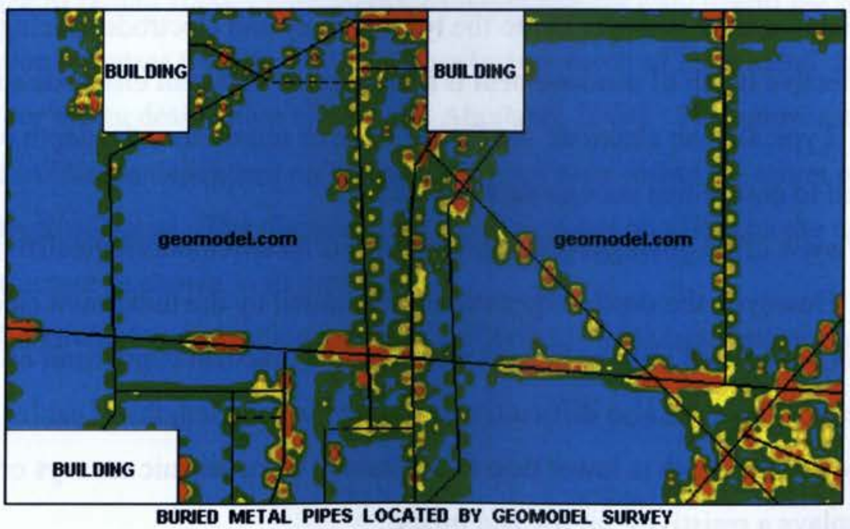


Figure 3.3 Buried metallic piping located by electromagnetic conductivity survey (http://www.geomodel.com/em/)

3.1.1.3 Resistivity Survey

As in its name, this type of survey measures the apparent resistivity of soils and rocks as a function of depth or position. And analyzing soils is complicated due to the contributing factors that affect resistivity including soil porosity, permeability, ionic content of the pore fluids, and clay mineralization. In particular, most soils are electrical insulators (i.e. highly resistive), however as the moisture or water content increases, the soil becomes less resistive.

A resistivity survey requires the locator to direct a DC current into the earth's surface using two or more current electrodes, and measuring the voltage difference between two potential electrodes. Both the current and potential electrodes are arranged in a linear array. The most popular arrays include dipole-dipole array, pole-pole array, Schlumberger array, and the Wenner array. The electrode pairs are directed along a surveyed line and the measurements will result in a horizontal profile of apparent resistivity. And the apparent resistivity is the average resistivity of all soils and rocks that have an affect on the flow of current. By knowing a few elements, such as the electrode separation, the geometry of the electrode position, the applied current, and the measured voltage, the locator can obtain the subsurface resistivity. The resistivity is calculated by division of the measured potential difference by the input current and multiplying it by a geometric factor that is specific to the type of array and electrode spacing being used. The effective depth of measurement is a function of different electrode spacings.

Typically, an electrode spacing of three or more times the depth of interest is required to ensure that enough data is obtained (http://www.cflhd.gov/agm/geoApplications/SurfaceMethod/933ResistivityMethod.htm).

However, the depth of penetration is limited by the maximum electrical power that can be directed into the ground resulting in a practical depth limit of about one kilometer. There are also difficulties in laying out long lengths of cable. And the accuracy of the depth is lower than that obtained from seismic surveys or drilling. Figure 3.4 displays a resistivity survey and image.

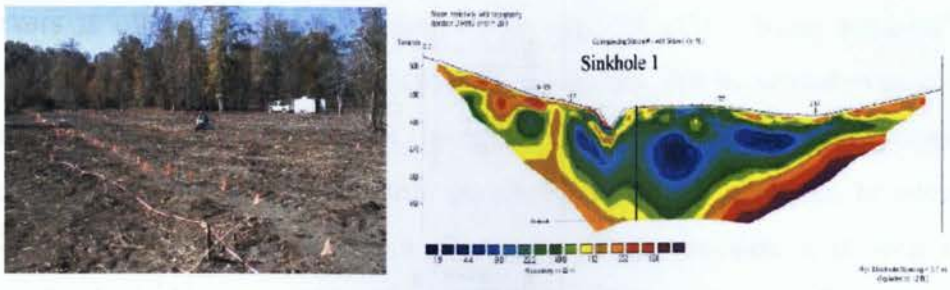


Figure 3.4 Resistivity field survey and resulting imagery.
http://www.geovision.com/resistivity.html

3.1.1.4 Metal Detectors

The earth's surface is transmitted by an alternating current (AC) magnetic field when using a metal detector. The next step involves analyzing the subsequent magnetic field to detect and monitor any significant changes. As with previous methods, different magnetic fields are reflected from metallic objects as opposed to the current reflected from the surrounding soil. The coil, which is a component within the receiver, detects the differences in the magnetic field. The output component, of the metal detector, will give off noises informing the user of a buried object. However, metal detectors have the obvious drawback of fading signals with increased depth and are only useful for shallow subsurface location purposes (ASCE, 2002). The effective depth of most metal detectors is only two feet for utility designation (Jeong and Abraham, 2004). The optimization of detecting buried utilities is dependent on increased surface area within the target mass and decreased depth of burial. The diameter of the coil also has an affect on the detection of buried infrastructure as shown in Figure 3.5. (http://www.cflhd.gov/agm/geoApplications/SurfaceMethods/946MetalDetector.htm).

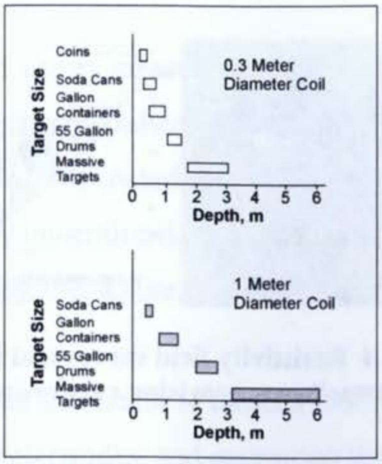


Figure 3.5 Different coil diameter used for detection (Benson et al, 1983).

Also, metal detectors react to non-conductive minerals including natural iron-bearing minerals, aluminum, copper, brass, conductive foil, salt water, acids, as a result of their high conductivity. Other factors which influence the result of metal detectors include properties of the target, properties of the soil, and target size. Therefore, the use of metal detectors alone in a locate for underground facilities is limited. Figure 3.6 illustrates and example of a metal detector and its resulting electromagnetic image.

Figure 3.6 Field survey and imagery using a metal detector (www.geomodel.com).

3.1.1.5 Electronic Marker Systems (EMS)

This method combines the use of electronic markers and electronic marker locators to detect underground utilities. These locators transmit radio frequency (RF) signals to the marker that was buried along with the utility at the time of construction. During construction, certain buried objects such as splices, valves, and non-metallic utilities are equipped with electronic markers. The marker is made up of a passive resonant circuit. This marker reflects the RF signals back to the locator and the location of the object is displayed in a visual reading along with an audible tone. The frequency of the markers is often changed according to the type of utility being acquired. In contrast with terrain conductivity, the electronic markers can still be sensed even if other metal objects, fences, or power lines exist above the surface of the utility being sought.

Ground penetrating radar falls within the electromagnetic techniques, however, an entire sub-section has been dedicated for discussion simply because it is seen as an impressive technological process within the subsurface utility engineering field.

The following table (Table 3.1) illustrates the benefits and drawbacks regarding the aforementioned electromagnetic utility searching methods.

Table 3.1 Geophysical Techniques: Electromagnetic Methods

Electromagnetic Methods	Benefits	Drawbacks
Pipe and cable locators	▪ Detects metallic objects. ▪ Effective depth is less than 4.6m (conductive mode). ▪ Good for utilities that have tracing materials installed. ▪ Inexpensive.	▪ Unable to trace non-metallic utilities. ▪ High chance of false utility identification due to EM coupling effect. ▪ Inductive mode – surface utility appurtenance is required.
Terrain conductivity	▪ Works well for locating isolated metallic utilities, storage tanks, wells, and vault covers. ▪ Best in non-utility congested areas. ▪ Effective depth of less than 4.6m. ▪ Best in areas of high ambient conductivity. ▪ Useful for tank and drum detection.	▪ Power lines and above-ground metal objects, such as fences, cars, or buildings produce magnetic fields that interfere with conductivity readings. ▪ Presence of high resistivity soils leads to greater noise. ▪ Moderately inexpensive.
Resistivity Survey	▪ Locates narrow fault/joint structures. ▪ Improves material strength classifications. ▪ Relatively rapid and inexpensive.	▪ Slow manner of taking readings. ▪ Ambiguous interpretations. ▪ Depth of penetration limited.
Metal detectors	▪ Detects metallic objects. ▪ Searches utilities in a good	▪ Only used for shallow manhole lids, valve box

	manner. ▪ Inexpensive.	covers due to decaying signal response as depth increases. ▪ Inaccurate readings due to magnetic non-conductive minerals and salts. ▪ Effective depth < 0.6m.
Electronic marker systems (EMS)	▪ Electronic markers can still be detected without interference from the magnetic field produced by power lines and above-ground metal objects, such as fences, cars, or buildings. ▪ Markers designed to react to a certain level of frequency. ▪ Inexpensive.	▪ Electronic markers must be installed at the time of construction.

3.1.2 Magnetic Method

This category of techniques includes the discussion of magnetometers to detect subsurface utilities. This technology, unlike pipe and cable locators, has no problem locating utilities under high iron content soils.

Magnetometers

Magnetometers, also called ferrous metal locators, are instruments used to measure and display the intensity of buried ferromagnetic materials (i.e. man made objects containing iron or steel) within the earth's magnetic field. Intensity deviations caused by ferrous objects can be detected by these instruments, due to the fact that most objects that contain iron cause a disturbance in the earth's magnetic field. Moreover, magnetometers are very sensitive and capable of identifying small anomalies. In addition, magnetometers are used to locate underground storage tanks and buried manhole covers, which contain large ferrous metal in terms of composition. There exist two basic categories: (1) field measurements and (2) gradiometric measurements. Both categories use the same instrument but with different features for each category. The field measurements will be obtained through the use of the proton precession magnetometer and gradiometric measurements through the flux-gate magnetometer.

The *proton precession magnetometer* uses a transducer to convert the earth's field strength into an alternating voltage, whose frequency is proportional to the field strength (Schlinger, 1990). These magnetometers are useful for utility searches over large areas, which do not consist of power lines, railroads, or other magnetic interferences. In particular, its major applications include locating buried ferrous containers (i.e. contaminant waste tanks), tracing buried pipelines in utility-type surveys, locating abandoned wells, geologic mapping, and mineral exploration surveys. This method is limited in terms of the order of magnitude that has two orders of magnitude sensitivity than potassium, low sampling rates, high power consumption and additional weight. This technique is based on the spin of protons in a magnetic field in accordance with the Larmor equation 3.1:

$$w = gB \tag{3.1}$$

where,

w angular frequency of precession

g gyromagnetic constant – much higher for electrons than protons

B magnetic induction

This type of magnetometer measures the total magnetic field, which is then analyzed to reveal any ferrous magnetic objects underground. The magnetic induction field caused by ferrous materials is measured from the total magnetic field (Jeong and Abraham, 2004). A storage tank containing a fluid made up of a several protons (i.e. kerosene) is fed a large direct current in the coil wound around the tank. The current thus creates an equivalent induced field in the direction perpendicular to the earth's magnetic field. Once the current is ceased, the protons will process (i.e. movement in a gyrating fashion along the rotational axis of the object) with a frequency that is proportional to the magnetic induction (GEM Systems, 2009).

Flux-gate magnetometers use two magnetic sensors built in such a way that they measure the difference over a fixed distance of the magnetic field (i.e. the gradient), instead of the total magnetic field. Any differences in the intensity of the magnetic field will be indicated by both a visual reading and an audible tone for the user. Typically, signal patterns for a target oriented vertically, such as iron pipe markers, display peaks. And targets oriented horizontally, such as cast iron pipes, the signal displays peaks at their joints. A peak signal around the edge of the object usually means that the target is at a closer distance to the equipment. The figure below (Figure 4.3) displays the results of a magnetometer measurement involving subsurface features within a corn field.

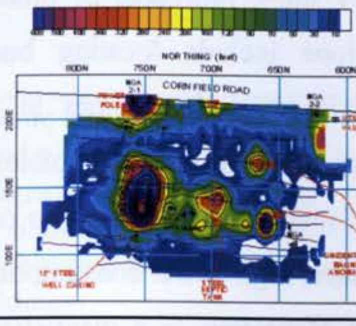


Figure 3.7 Shallow man made, underground feature detection survey image using a magnetometer (Northwest Geophysical Associates, Inc., 2004).

This type of instrument is particularly useful for detecting magnetized non-metallic fiber optic cables and cast iron pipes. The following table (Table 3.2) illustrates the benefits and drawbacks of the above mentioned magnetic utility searching methods.

Table 3.2 Geophysical Techniques: Magnetic Methods

Magnetic Methods	Benefits	Drawbacks
Proton precession magnetometer	▪ Identifies ferrous materials. ▪ Useful for utility search over large areas in absence of power lines, railroads, or other magnetic interferences. ▪ Inexpensive.	▪ Equipment has to be held vertically to reduce interference form solar magnetic storms. ▪ Non-ferrous objects not locatable.
Flux-gate magnetometer	▪ Detects non-metallic objects (FOC) and cast iron pipes. ▪ Detects valve boxes, steel drums, iron markers and manhole lids. ▪ Inexpensive, reliable, and have low energy consumption.	▪ Most flux-gate magnetometers provide analog instead of digital output.

3.1.3 Seismic Methods

This category of techniques employs seismic technology to detect underground utilities. In particular, there are two types of surveys that can be performed: (1) seismic refraction and (2) seismic reflection. Seismic methods measure the emittance of mechanical vibrations (i.e. sound waves) through the earth's surface and correlate those to subsurface properties based on models for the emittance, reflection, and/or refraction of the sound waves. The mechanical vibrations can be created in several ways, such as hitting a steel plate with a hammer to explosives, electromechanical sparkers, and truck mounted vibrators. These sound waves are then recorded through a series of geophones that are placed at the surface or set up in boreholes. Figure 3.8 displays a seismic survey setup.

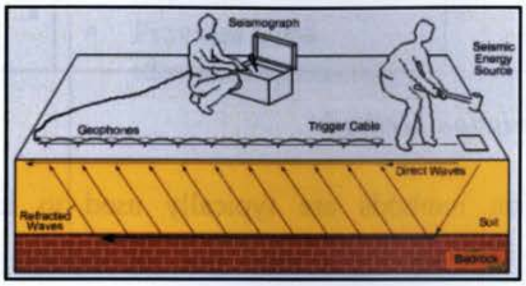


Figure 3.8 Seismic refraction survey (Northwest Geophysical Associates, Inc. 2004).

Seismic refraction is the simplest technique that uses surface sources and geophones to record the initial arrivals of seismic waves refracted at a subsurface boundary. The nature of and depth to subsurface utilities can be computed by measuring the travel times of the waves. Seismic refraction can be used in the engineering industry for design and cost estimates of road cuts, pipelines, etc. Likewise, *seismic reflection* surveys use surface sources and arrays of geophones, which record the seismic waves from subsurface boundaries. However, this type of survey uses the travel time and the amplitude of all the reflected sound waves returning to each geophone. Reflection surveys are useful in producing detailed images of subsurface geologic structures. This method is designated as a very expensive means of locating underground utilities. Furthermore, according to certain literature, it is reported that seismic surveys have a maximum exploration depth of nearly 500 m, but current results only display results no deeper than approximately 150 m

(http://www.cflhd.gov/agm/geoApplications/SurfaceMethods/945SeismoelectricalMethod.htm). A list of the benefits and drawbacks for seismic methods can be found below in Table 3.3.

Table 3.3 Geophysical Techniques: Seismic Methods

Method	Benefits	Drawbacks
Seismic method	▪ Subsurface can be directly imaged from the acquired observations. ▪ Reflection seismic more readily interpreted in terms of complex geology.	▪ Amount of data in a survey is overwhelming to handle. ▪ Data is expensive to acquire. ▪ Reflection seismic processing is computer intensive. ▪ Equipment is more expensive.

3.1.4 Acoustic Emission Method

Acoustic location methods are typically used to identify waterlines. By connecting an opening on a service or main line, an acoustic transducer applies sound waves of 132 to 210 Hz into the pipeline. These waves travel along the pipeline and ease through the walls of the pipe into the surrounding soil. The sound waves that eventually make its way to the surface are detected using specialized sensors such as geophones or accelerometers as shown in Figure 3.9.

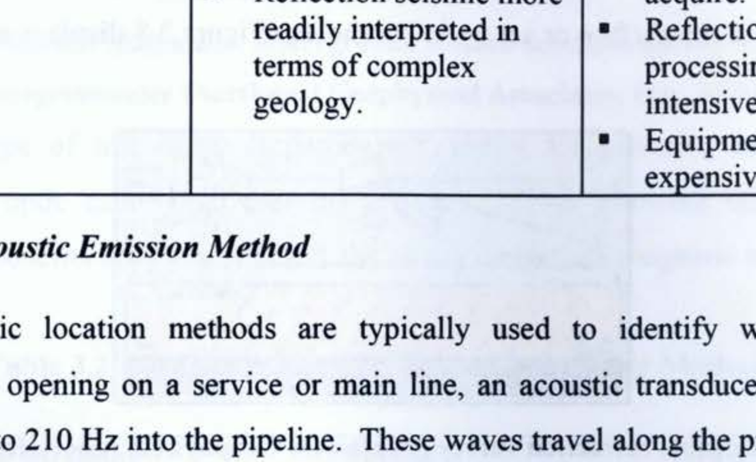


Figure 3.9 Principle of acoustic emission method (Jeong and Abraham, 2004).

The buried facility is roughly determined by measuring the peak vibration amplitude at the surface. The detectable range all depends on the rigid factor of the material. As the rigidity increases, the detection capabilities in depth and horizontal distance from source also increase. The horizontal detection can range up to 300 m for plastic gas pipelines and more than 150 m for water pipelines. In addition, for gas pipelines, the effective detection depth (i.e. vertical depth) is around 2.5 m and 2.0 m for water pipelines. However, a major limitation of this method requires a priori information of surface appurtenance of the targets (Jeong and Abraham, 2004). The following table (Table 3.4) displays some benefits and drawbacks of the acoustic emission method.

Table 3.4 Geophysical Techniques: Acoustic Emission Method

Method	Benefits	Drawbacks
Acoustic emission method	▪ Determines the location of plastic water pipelines and gas pipelines. ▪ Provides good identification results.	▪ Only used as a tracing method instead of a 'blind' location method due to the need of a priori knowledge of surface appurtenances. ▪ Highly susceptibility to noise interference (i.e. airplane, vehicle, train noise) ▪ Can be inaccurate.

3.1.5 Thermal Survey (Infrared Method)

Variations in the temperature field are used to identify underground utilities that usually disturb the existing ground temperature field due to the function of utilities. Steam pipelines or utilities that have different thermal characteristics than the surrounding ground emit different temperature fields (Sterling, 2000). This method is ideal for conducting surveys due to its avoidance of digging up entire pipelines to search for leaks. This technique detects and measures the heat flux emitted from utilities including steam systems, high-voltage power lines, and sanitary sewers. Underground pipelines can have flows that are gravity fed or pressurized. According to thermography consultants, steam branch lines are one to three inches in diameter and are made up of metal that is insulated the same way along the entire length. Therefore, the steam within the pipeline remains the same temperature throughout. But the depth of burial is the largest variable in obtaining images of steam lines (Weigle, 2005). Moreover, sufficient changes in the thermal field for shallow buried utilities can be detected easily due to the changes in solar radiation input to the ground or in the case of air temperature variations (Hoover et al, 1996). However, the locator must understand the makeup of the local ground including the soil properties which is vital in locating thermal data. The local weather also affects a thermographic survey including changes in sky patterns and wind movement. The following image (Figure 3.10) shows a thermal LV system and it's resulting image.

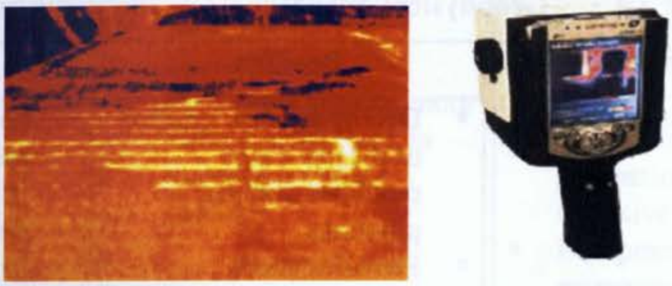


Figure 3.10 Image and LV System of Thermal Survey (www.thermal-imaging-survey.co.uk/.../dampsu4.jpg, http://www.thermal.co.uk)

The following table (Table 3.5) displays the benefits and drawbacks of the acoustic emission method.

Table 3.5 Geophysical Techniques: Thermal Survey (Infrared Method)

Method	Benefits	Drawbacks
Thermal Survey (Infrared)	▪ Quantitative results obtained remotely, rapidly, and from long and short distances. ▪ Simplicity yet great precision and accuracy.	▪ Environmental conditions. ▪ Constant change in surface makeup. ▪ Burial depth of pipelines. ▪ Temperature of fluid.

3.1.6 Gravity Survey

Locators can opt to use gravity surveys for detection of underground utilities or objects that exhibit density differences from surrounding materials. A microgravity method should be used for utility designation due to the fact that variations in gravitational fields are very small (Anspach 1994). Gravity is the attraction of the earth's mass for bodies near its surface. And the gravitation between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them. In general, the strength of the gravitational force is a result of the mass and distance separating them. And the presence of underground utilities or objects can be detected by noticing gravity anomalies that are captured due to differences in density. An empty utility that is buried at a certain point can be subject to a lower gravitational force measurement at the surface than at surrounding areas that are occupied with soils. Figure 3.11 displays a gravity anomaly and an in-field survey.

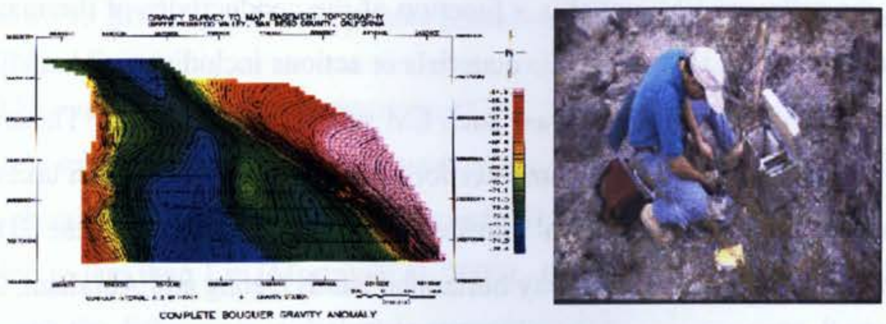


Figure 3.11 Gravity Anomaly and Survey (http://www.geovision.com).

Table 3.6 Geophysical Techniques: Gravity Survey

Method	Benefits	Drawbacks
Gravity Survey	▪ Easily automated. ▪ Provide improved calibration.	▪ Expensive and slow.

3.1.7 Ground Penetrating Radar – GPR

This non-invasive geophysical technique allows fast and low cost investigation of the subsurface for the detection of features such as utilities. The methods discussed above usually result in two dimensional utility information. On the contrary, since buried objects are three-dimensional, in reality, it would be beneficial to obtain subsurface utility information in 3D. And this is exactly what GPR provides the construction industry. With the aid of certain applications, ground penetrating radar (GPR) can effectively detect and map out the location of buried utilities with the highest resolution (Olheoft, 1996). Also, GPR is very useful not only in detecting underground utilities but also in examining vast regions of interest, given limited timelines.

This method is an electromagnetic method that senses subsurface materials with differing dielectric constants. The GPR system consists of an antenna, which includes the transmitter and receiver, and a recorder that processes the received signal and finally produces a graphic representation of the data (GeoSpec, 2005). The transmitter emits EM signals into the ground via the antenna that moves across the grounds surface along preset transect lines. These transect lines are designed based on the dimensions of the proposed construction site. The EM waves are reflected back to the receiver from boundaries at which there are contrasting differences in electrical properties. The intensity of the reflected EM signal is a function of the conductivity of the material and the frequency of the signal. Man-made materials or actions including soil backfill, buried tanks, pipelines, and utilities often cause such EM subsurface reflection. These reflected waves/data are then passed on to a computer for processing. Analysis then takes place to produce the two-dimensional vertical profile of the imaged area. These 2D vertical profiles appear as black, white, and gray horizontal bands (Jeong and Abraham, 2004).

High frequency waves (commonly ranging from 10 MHz to 1,000 MHz/1 GHz) are used by GPR to obtain shallow (i.e. 1 m for 900 MHz) subsurface feature information down to a few centimeters in diameter. Although lower frequency antennae generate longer wave-lengths that can penetrate up to 50 meters to detect large subsurface features, the ability to identify smaller features lessens as frequency decreases. Along with subsurface utilities, GPR has the ability to detect subsurface structures, rock formations, and the water table. Within the 2D vertical profiles, the subsurface utilities give off strong reflections which generally generate distinct black and gray cone shaped bands, as shown in Figures 3.12 and Figure 3.13—its corresponding 3D image.

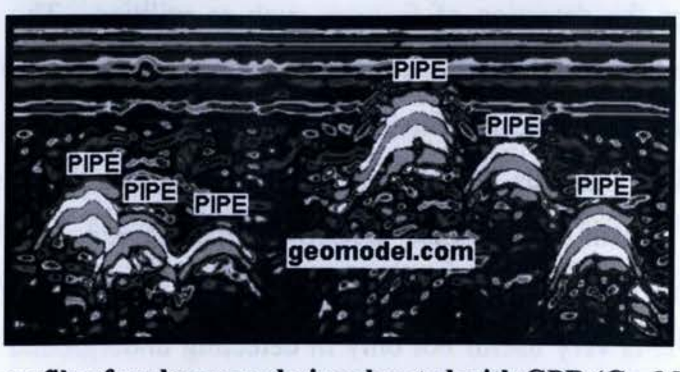


Figure 3.12 2D profile of underground pipes located with GPR (GeoModel Inc., 2005).

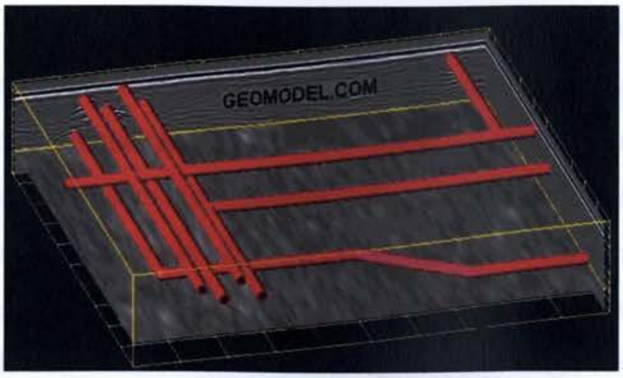


Figure 3.13 3D image of underground pipes from GPR data (GeoModel Inc., 2005)

The overall depth of investigation of GPR depends on the electrical conductivity of the site's subsurface soil. Large amounts of clay, saturated sands, and tidal areas where high salt contents exist (i.e. highly conductive soils) can prevent radar wave penetration to less than 1 m (Murray et al. 2005). GPR is most beneficial in the sense that, through the differences in dielectric properties of the soil and pipe, it can detect and plot both metallic and non-metallic utilities. However, GPR is limited in terms of soil conditions. Even in ideal conditions, GPR cannot image utilities at depth greater than 2m (ASCE, 2002).

According to the Natural Resources Conservation Service (NRCS), the soil attribute index values and relative soil suitability indices are gathered from observations taken from GPR antennas with center frequencies between 100 and 200 MHz. Under saturated conditions the depths of penetration along with the relative suitability of contrasting materials is less. And contrasting physical and chemical properties affect the attenuation signals. GPR applications are suitable in settings where the mineral soil materials contain less than 10 percent clay or deep organic soils with pH values less than 4.5. The signal attenuation and depth of penetration varies depending on the soil solution's ionic concentration and the amount and type of clay minerals within the soil mix. However, with a 200 MHz antenna, in GPR capable soils the penetration reaches an average of 16.5 feet. But like all geophysical methods, the soil alone cannot be held accountable for the depth of penetration, other variations including textural layering, mineralogy, soil water content, and the ionic concentration of the soil water result in an infiltration depth anywhere between 3.3 to greater than 50 feet (NRCS, 2009).

Soils that contain 18 to 35 percent of clay or 35 to 60 percent clay minerals have moderate potential when considering the use of GPR. At the moderate levels the effective depth of penetration, while using a 200 MHz antenna is about 7 feet including a range of 1.6 to 16 feet. In particular, GPR is unsuitable in areas consisting of saline and sodic soils, but these soils are restricted to arid and semiarid regions and coastal regions across America (Doolittle, 2009).

Witten Technologies Inc., along with Mala Geoscience, ConEdison, Schlumberger, the Electric Power Research Institute (EPRI), and GTI, developed a Ground Penetrating imaging Radar (GP*i*R) known as the Computer-Assisted Radar Tomography - CART Imaging System. This is one of the newer technologies of the GPR series. It has been implemented in several underground utility searches across major cities in the US and Europe. This system is a combination of an efficient radar surveying and precise positioning control and advanced signal processing that yields high-resolution 3D radar images of the subsurface area on a large-scale. It consists of 17 antennas (i.e. 9 transmitters and 8 receivers) the ultra-wideband GPR array (200 MHz center frequency) that spans 2 m in swath coverage along with a 5 inch channel or cross-line spacing. The penetration depth ranges between 2 to 3 meters in sandy-clay soils (6 to 7 meters in sandy soils) (Birken et. al., 2002). And the depth accuracy is five percent (i.e. +/- three inches over five feet). Moreover, underground objects can be resolved within about three to four inches but the resolution will submit to degradation as the depth increases at a rate of about one inch per foot (Witten Technologies, 2004). Table 3.7 provides an overview of the general advantages and disadvantages of using GPR as a utility detecting technique.

Table 3.7 Geophysical Techniques: Ground Penetrating Radar

Ground penetrating radar	▪ Detects both metallic and non-metallic utilities (i.e. metallic, plastic, and concrete). ▪ Frequency ranges : 10 MHz–1GHz ▪ Works well for searching or tracing utilities. ▪ Geophysicist or well-trained personnel are required to operate GPR technology. ▪ Highly interpretative.	▪ Low effective penetration depth of 1.8m. ▪ Large amounts of near-surface clay and highly saturated soil prevent radar wave penetration. ▪ Data quality is relatively moderate. ▪ Moderately expensive.

3.2 INTRUSIVE TECHNIQUES

Non-destructive vacuum extraction, also known as potholing, is used to physically expose a subsurface utility to verify its existence and to determine its exact location. Currently, it is the only method that is capable of outputting the highest accuracy in terms of location. Throughout a construction project, environmental soil sampling must take place; which requires soil technicians to hand auger the first five feet to verify that no utilities are present. Although hand auguring is deemed safe, it can occasionally cause damage to delicate underground facilities, including petroleum product lines. This technique can be used in all kinds of soils, and under concrete as well. This quality level A data retrieval method involves installing test holes, which identify the three-dimensional location of a subsurface asset.

The process of installing test holes is as follows. The surface material is removed over approximately a 0.3 m to 0.5 m diameter hole area at a pre-determined QL-B horizontal location, which was produced during the designation stage. The removal of the surface proceeds using either a dry vacuum method or a wet vacuum method. Figure 3.14 illustrates a simple concept image of the vacuum excavation process.

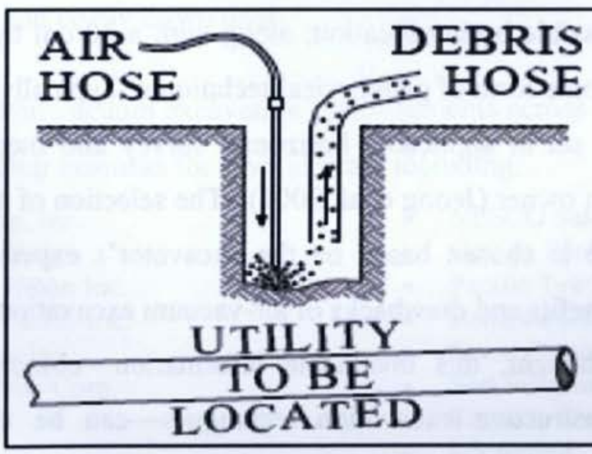


Figure 3.14 Vacuum excavation intrusive locate (Noone, 1997).

Vacuum Excavation Systems

Air vacuum excavation systems have been in used since the late 1950s. Initially, air-vacuum systems were costlier than water jet based systems. However, with continuing technological advances, the air excavation system is currently the predominant leader of vacuum excavation systems. The air-jets will simultaneously loosen the soil and the vacuum will extract the resulting rubble (Sterling, 2000). The air method is relatively slow compared to that of a high-pressure water system; however, it retrieves the soil in a dry condition which allows the material to be used later as backfill for the pothole. The air excavation method also provides less erosion to the surrounding area. However, a water-based system is lower in cost and it is regarded effective when locating utilities submerged in wet soils, heavy clays and caliches. But due to its high-pressure nature, inappropriate usage of the water system can have potential damaging effects on underground utilities.

Typically, for each and every vacuum excavation (i.e. test hole) the following information is recorded and analyzed: utility size, material, type, condition, location (x, y, z), orientation, roadway section materials, soil type, pavement thickness and water table (GeoSpec Inc., 2005). Furthermore, in order to reduce the risk to utilities during the initial drilling process, an effective vacuum excavation depth of around 2.4 m can also be implemented at a possible boring location; along with a 30 cm by 30 cm hole that has been designated by some form of geophysical technique. Typically, the accuracy is set at 15 mm vertical and set at applicable horizontal survey and mapping accuracy levels defined by the project owner (Jeong et al. 2004). The selection of an appropriate vacuum excavation technique is chosen based on the excavator's experience and knowledge. Table 3.8 lists the benefits and drawbacks of air-vacuum excavation.

As a final thought, this invaluable information—obtained through advanced imaging and non-destructive excavation techniques—can be used to provide very accurate subsurface "pictures" for designers. Hence, substantially reducing the overall costs of a project, including minimizing or eliminating construction delays, design change orders, claims, property damages, service breakdowns, and finally injury and loss of lives.

Table 3.8 Intrusive Techniques: Air-Vacuum and Water-Vacuum Excavation

Method	Benefits	Drawbacks
Non-destructive air or water-vacuum excavation	▪ Provides precise horizontal and vertical location of utilities. ▪ Provides other features, such as utility type, material, size, condition, orientation, pavement depth, soil type, and water table. ▪ Vertical accuracy of 15 mm. ▪ Eliminates damage to underground utility caused by backhoes. ▪ Ensures the integrity of utility line during vacuum excavation without using hammers, blades, or heavy machinery that might come into contact with the utility.	▪ Initial cost of implementing technology is quite high. ▪ Certain projects may not require vacuum excavation; imaging technology may be significant enough for utility detection.

This process, indeed, ensures the prevention of utility line damage during the excavation process as no hammers, blades, or heavy machinery come into contact with the utility line, eliminating the risk of damage to utilities and workers. And with the rising municipal and government demand for extraction of utility location and clearance by all contractors, vacuum excavation can be used to confidently clear work sites while increasing job safety and costly down time.

There are several vacuum excavation establishments across North America that have been in the locating business for several years including:

- Amerivac Group, Inc.
- Badger Daylighting
- BOC Edwards Hibon Inc.
- Christianson Systems Inc.
- COE Equipment Inc.
- DeMarco MaxVac Corp.
- Ditch Witch
- E. H. Wachs Co.
- Excavac Corp.
- GapVax
- Guzzler Mfg. Inc.
- Hi Vac Corp.
- Keith Huber Inc.
- McLaughlin Mfg. Co.
- Miller Pipeline Corp.
- NESCO Sales and Rentals
- Omega Tools
- Pacific Tek Inc.
- Remediation Vacuum Systems
- Sewer Equipment Co. of America
- Soil Surgeon
- Tornado Technologies Inc.
- US Jetting
- Utiliscope Corp.
- Vac-Tron Equipment, a Division of American Mfg.
- Vacmasters/Div. of Barone In,
- Vacutrux Ltd.
- Vector Technologies Ltd.
- Vermeer Mfg. Co.

The various methods described earlier are certainly advanced technologies and are also considered to be state-of-the-art equipment. However, all of these methods have drawbacks in one or more areas. For example, some methods cannot locate all types of utilities. A few cannot be used in all types of soils. Certain techniques have very low effective penetration depths and they may have interferences from nearby objects, such as overhead utility lines, vehicles, and buildings. Also, only a few technologies can resolve smaller utilities at the required depths. Not to mention, a number of methods use hazardous materials that increase the cost and risk of utility information extraction. Furthermore, the cost of normal practice usually exceeds what the market is willing to pay.

After careful consideration of the aforementioned drawbacks, it is critical that certain criterion, which affect the accuracy of locates, be discussed; thereby assisting in the process of which technique to use under which conditions.

A broad analysis of the characteristics of each geophysical technology and available data from as-built drawings and site visits led to the identification of seventeen significant criteria that can be declared to have an affect on utility locates. These affecting factors are as follows and will be discussed in the next chapter:

(1) location of the project (i.e. rural or urban area)
(2) type of project (e.g. bridge or new road construction)
(3) limited, narrow, or congested right-of-way (ROW)
(4) type of utility
(5) material of utility
(6) joint type of metallic utility
(7) special materials for detection
(8) access points to utility
(9) ground surface condition
(10) soil type
(11) depth of utility
(12) internal condition of utility
(13) proximity to built up areas (i.e. residential, commercial, etc.)
(14) critical schedules of high profile projects
(15) initial cost of imaging method
(16) qualified SUE consultants
(17) Date of installation

4 FACTORS AFFECTING THE ACCURACY OF UTILITY LOCATES

Every geophysical technique has its own abilities in terms of successfully and accurately locating underground utilities. However, each technique has limitations, as well, which makes it difficult to rely on one method alone. As soil and site conditions change, so do the capabilities of each technology to those changes.

4.1 Location of the Project (i.e. rural or urban area)

Nowadays, a number of design and construction projects are taking place in both rural and urban environments. Cities, process plants, airports, and highways, are among the many places in which urban planning and development takes place. These hot spots require special care during construction due to the fact that underground utilities already exist. For instance, a highly dense urban street in need of a highway construction project may require the use of quality level A information. And since this is an urban street, it most likely has a complicated underground network of metallic, non-metallic pipelines, cable and telephone lines, water and sewage pipelines, fiber optic cables, etc. Therefore, the more widely used methods, including pipe and cable locators, GPR, and metal detectors, may be used as a combination to designate the underground utilities. Once the designation is complete to QL-B standards, test holes along the project's path can be exposed by a non-destructive air-vacuum in order to map the exact location of the subsurface utilities. Whereas, a sub-urban or rural area, where the surroundings include scattered housing, farms and even businesses, may choose to gather subsurface information using terrain conductivity meters and magnetometers to find underground storage tanks, large non-metallic water pipes and large non-metallic empty and dry pipes.

4.2 Type of Project (e.g. bridge or new road construction)

Certain technologies are useful for detection in specific projects. The type of project can also aid in the selection process of particular methods. For example, bridge construction, with a strong presence of new underground utility construction, in a utility-congested area requires QL-A information. Again, GPR and pipe and cable locators are useful in tracing and detecting metallic and non-metallic utilities in a sufficient manner. This QL-B information obtained from highly ranked imaging technologies can be used to locate the exact spot of buried utilities.

4.3 Limited, Narrow, or Congested Right-of-Way (ROW)

Right-of-way has several meanings, however, the definition useful for this paper is as follows: according to the City of Sacramento's Development Services Department, right-of-way is subsurface land or property acquired for or intended to be occupied by either a street crosswalk, railroad electric transmission line, oil or gas pipeline, water main sanitary, or storm sewer main, shade trees and/or other special private and public utility facilities. Due to the plethora of underground utility facilities within cities, construction projects require precise utility locations in order to deal with limited, narrow or highly congested right-of-ways. Most of the time, by precisely locating subsurface utilities at the site of interest, project costs—monetary or time wise—can be minimized.

4.4 Type of Utility

Several geophysical methods are used to identify specific types of utilities. One technique may be preferred over another due to its ability to locate a certain type of utility. The utility types that are identified by most SUE companies include:

- BE – Buried Electric
- BT - Buried Telephone
- CATV – Cable Television
- FM – Force Main
- FOC – Fiber Optic Cable
- G - Gas
- RW – Reclaimed Water
- S – Sanitary
- STM – Storm
- UNK – unknown
- W – Water

For example, the use of pipe and cable locators is only applicable for detecting metallic pipelines and cables. Whereas, the acoustic emission method is used for imaging plastic water and gas pipelines. This criterion required the designation of what type of utility exists at the construction site. Utility types may be water, sewer, gas, oil and chemical, steam, electric, or telecommunication.

4.5 Material of Utility

This criterion identifies the material characteristics of the utility which can be further divided into three sub-categories as follows: (1) ferrous metal, (2) non-ferrous metal, and (3) non-metallic material. Based on their imaging capabilities, the geophysical methods, mentioned earlier, can be classified into the category of material they best identify. Ferrous metals include steel and iron. Non-ferrous metals can be comprised of copper and metallic conduit. And non-metallic material can range from fiberglass reinforced plastic, concrete, asbestos-cement, brick, cement, plastics, fiber optic cables and more (Jeong et al. 2004). According to TSH/TBE's locate data form; the following materials of utilities may exist within Toronto streets:

- AC – Asbestos Cement (Transite)
- CI – Cast Iron
- CP – Clay Pipe
- CD – Concrete Duct
- CP – Concrete Pipe
- CMP – Corrugated Metal Pipe
- CPP – Concrete Pressure Pipe
- DBC – Direct Buried Cable
- DIP – Ductile Iron Pipe
- FG – Fiberglass
- PE – Polyethylene Pipe
- PVC – Polyvinyl Chloride
- ST – Steel
- UNK - Unknown

4.6 Joint Type of Metallic Utility

This criterion is used to assess the continuity of the electrical current within the metallic utility. Joints can also be categorized into three sub-sections of continuous, semi-continuous, or discontinuous electrical continuity. To be more specific, semi-continuous joints can by penetrated by only high frequencies of electromagnetic waves. And discontinuous joints cannot be penetrated by electromagnetic waves at all. Furthermore, the shield effect—reflection of waves against the inner wall of pipes—sometimes prevents reflected electromagnetic waves from being detected by geophysical instruments.

4.7 Special Materials for Detection

At the time of construction, special materials such as electronic markers are placed either on or above the utility. This is due to the fact that non-metallic utilities are often considered difficult to locate. These materials can be electronic markers, tracing wire, metallic marking tape, which all require the use of marker locating technology for detection.

4.8 Access Points to Utility

This criterion requires identifying surface appurtenances, such as valves, manholes, vent pipes, utility poles, and so on, which are connected to underground utilities. These above-ground utility features are an initial necessity for certain designation methods, such as pipe and cable locators and acoustic emission method. The various entries for this criterion are as follows: actual presence of the utility (PRE), the known location of the utility—as a result of surface appurtenance—(KL), estimated location of utility (EL), and none of the above (NA).

4.9 Ground Surface Condition

This criterion is used to identify the condition of the ground surface above the utility. The ground surface may be a natural surface (i.e. grassland), asphalt, cement, concrete pavement, or interlock. Often, reinforced concrete pavement poses a problem for emitted electromagnetic waves, while using electromagnetic methods, such as terrain conductivity, metal detectors, electronic marker systems, and ground penetrating radar.

4.10 Soil Type

Under certain conditions specific imaging technologies are limited in terms of their capabilities. For instance, large amounts of clay, saturated sands, and tidal areas where high salt contents exist (i.e. highly conductive soils), limits the use of the terrain conductivity method and GPR. This criterion is developed using soil characteristics as follows: highly conductive soil, clay soil, silt soil, sandy soil, granular and compacted soil.

4.11 Depth of Utility

This criterion is developed and used according to the effective penetration depth of each geophysical utility designating technology. The depths range from less than... 0.6 m, 1.8 m, 2.4 m, 3.0 m, 4.6 m, 15.2 m, and greater than 15.2 m (Jeong et al. 2004).

4.12 Internal Condition of Utility

The internal state of a utility refers to the filled level in empty utilities with fluid, gas, or other materials. Certain geophysical techniques are more efficient depending on the internal nature of the buried utilities. For instance, the acoustic emission method can be selected in the case of locating a pipeline that is filled with fluids or gases due to this methods use of fluid or gas pressure to propagate sound waves. Also, the density anomalies of the gravity survey are affected by the internal atmosphere of utilities because the gravity survey detects varying densities due to the presence of underground pipelines that are distinct from surrounding materials. For example, an empty water pipeline will be detected easily compared to that of a full one as a result of the density differences between air and water (Jung, 2007).

4.13 Proximity to Built-Up Areas (i.e. residential, commercial, etc.)

Utilities in close proximity to built-up areas can often pose problems during the designation and/or location stage of a construction project. For instance, an underground gas main located in close proximity to a commercial area requires quality level A information extraction in the case of a new construction plan in that area. The closer the proximity of underground utilities to their surroundings (i.e. residential or commercial built-up areas), the greater the need for QL-A and QL-B information gathered by appropriate detection methods.

4.14 Critical Schedules of High Profile Projects, Initial Cost, Qualified SUE Consultants.

This criterion is used to identify the urgency of subsurface utility data. For instance, several government funded projects require precise utility information in order to complete high-profile projects within stringent deadlines to avoid unnecessary use of taxpayer dollars, traffic delays and congestion.

This criterion also includes the use of the initial cost of applying a certain imaging technology over another.

Years of experience and knowledge in the field of geophysical techniques makes selecting a qualified sue consultant a major step in the locating process of a construction project. They possess the right skills and knowledge to select the most appropriate geophysical method to apply, to survey underground utilities and to interpret the results of each survey. Insufficient expertise in the locating field only results in additional surveys and delays for the project.

4.15 Date of installation

The date of installation may be an affecting factor in terms of the accuracy of utility locates. By studying the errors in locations between as-built drawings and field-surveys, one can determine a correlation between the date of installation and the error in the location as determined by comparing the two. The next chapter will discuss the methodology and analysis of the correlation between utility installation dates and location errors between field survey data and as-built drawing data.

5 EMPIRICAL ANALYSIS

This chapter introduces and explains the way in which the data was acquired, compiled, interpreted, and analyzed. It is useful for the reader to gain some knowledge about the geophysical equipment used to extract subsurface utility information for the given projects. This chapter also entails the phases of data compilation before any sort of analysis can be initiated. Moreover, this chapter covers a brief explanation of the project sites which provides further direction into the characteristics surrounding data collection within these areas.

Prior to moving on to the methodological steps taken throughout the study, a short discussion regarding the soil composition of some popular Canadian cities is given, allowing the reader to gain a better understanding of the study area and how the soil type affects the detection process of subsurface utilities.

5.1 Soil Composition of Canadian Cities

It is useful to mention the soil nature of some popular Canadian cities to gather an understanding of the geophysical characteristics within these regions.

HAMILTON

Hamilton is a port city in Ontario incorporated by George Hamilton on June 9th, 1846. It is the centre of a densely populated and industrialized region at the west end of Lake Ontario, also known as the Golden Horseshoe. Located in southern Ontario on the west end of the Niagara Peninsula.

Burlington Bay is a natural harbour with a large sandbar that was deposited during a period of higher lake levels during the last ice age and extends southeast through the central lower city to the escarpment.

MONTREAL

The City of Montreal was founded in 1642 and established in 1832. It is known as the largest city in Quebec and the second-largest in Canada. The region of Montreal is covered by a layer of unconsolidated materials consisting of clay, sand and gravel.

QUEBEC CITY

The city of Quebec was founded in July 3, 1608 by Samuel de Champlain. Second most populous city in the province after Montreal. Located in the Saint Lawrence River valley. Low-lying region and flat, and the river valley have rich, arable soil.

Quebec is at the junction of 3 major geological domains: the Grenville Province, the St. Lawrence Platform and the Appalachian Oregon. These domains are partially overlain by unconsolidated sediment (clay, sand and gravel).

Cities like Montreal and Quebec City contain utilities of a much older vintage due to the fact that immigrants coming up the St. Lawrence River situated closer to the river which is located in the vicinity of the Saint Lawrence River Valley.

However, Toronto soon became one of the popular cities to situate in and this study analyzes projects which took place within the City of Toronto.

TORONTO

The most populous city in Canada was incorporated on March 6th, 1834 and officially created in 1867 as the capital of Ontario. The Toronto Harbour was naturally created by sediment build-up from lake currents that created the Toronto Islands.

Creeks and rivers running from north toward the lake created large tracts of densely forested ravines. But Toronto is not hilly, elevation differences range from 75 meters above sea level at Lake Ontario shore to 270 m above sea level near York University grounds. During the last ice age, the lower part of Toronto was beneath Glacial Lake Iroquois. Escarpments mark the lake's former boundary known as the Iroquios Shoreline. The escarpments are prominent from Victoria Park Avenue to Highland Creek forming the Scarborough Bluffs.

The ice sheet deposited compact layers of sediments called tills. Sediment from melting glaciers was deposited in lakes and in ridges creating eskers, drumlins and moraines. Glacial meltwaters formed a lake basin into which gravel and sand were deposited; the lake drained leaving the moraine above the surrounding landscape. Oak Ridges Moraine, rises 300 m above Lake Ontario and contains deposits of sand and gravel 200 m thick.

Currently, the land area fronting the Toronto Harbour is artificial landfill implemented in the late 19th century. Since the 1850s the Toronto shoreline was extended 1 kilometer into the harbour by dumping millions of tones of fill.

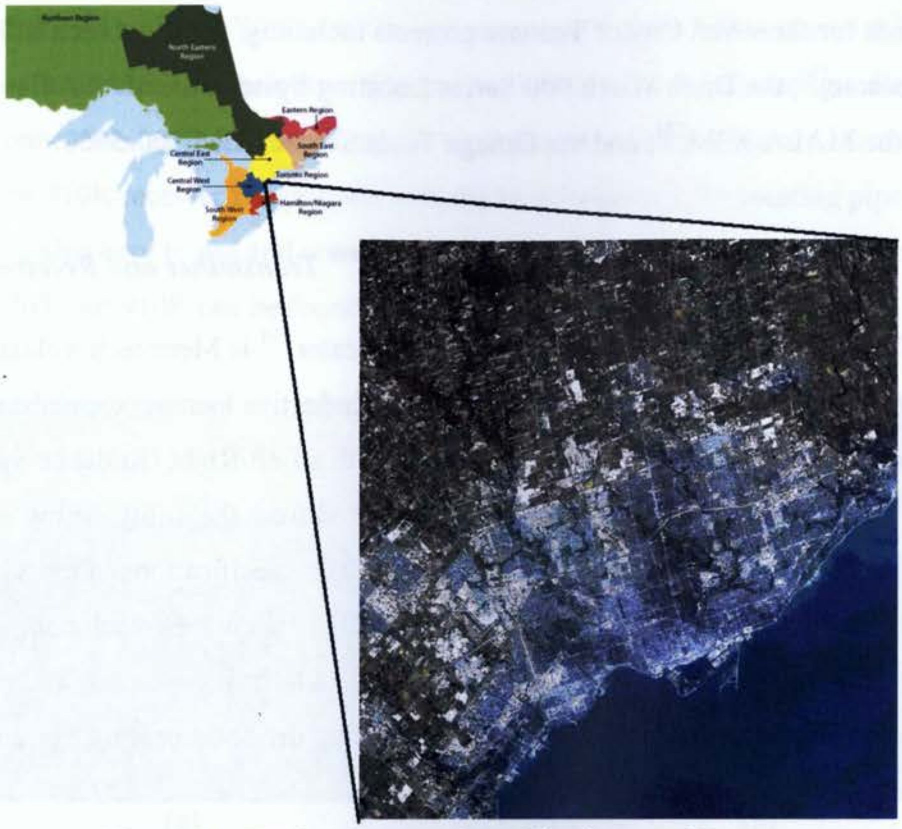


Figure 5.1 Regional map and satellite image of Toronto
(http://en.wikivisual.com/index.php/Toronto).

5.2 Equipment Used to Extract Underground Utility Data

There are a few mentionable apparatus used to extract the underground utility information for the seven City of Toronto projects including, the Metrotech 810 Pipe and Cable Locator™; the Ditch Witch 900 Series Locating System; the MALA Easy Locator System; the MALA X3M™; and the Omega Tools Servac SBM-100-5080.

5.2.1 Metrotech 810 Pipe and Cable Locator™ Transmitter and Receiver

The fully automated 810 Pipe and Cable Locator™ is Metrotech's classic pipe and cable locator (see Figure 5.2). It has excellent inductive locating capabilities through the use of a direct clamp. It also directs the user with a Left/Right Guidance System and an audible tone. The strength of the signal transmitted from the utility during a designating procedure is indicated on the receiver. The specifications of the 810 transmitter and receiver can be found in Appendix D. 1 (www.metrotech.com). As stated by the manufacturer, the depth of a utility is dependent on soil conditions and the environment, but the maximum depth estimation using the 810 Locating System is 30.48 cm (13 feet).

Figure 5.2 810 Pipe and Cable LocatorTM (www.metrotech.com).

According to the TSH/TBE team, who used this system to designate pipes and cables for the City of Toronto projects, this device is a fairly efficient method of initially detecting watermains and gas mains within centimeter to decimeter accuracy. However, this is dependent on equipment capability, along with locator expertise in terms of theoretical, practical knowledge and field experience.

5.2.2 Ditch Witch 970T Transmitter and 910R Receiver

This pipe and cable locator system was also used for the projects analyzed for this Master's thesis. The Ditch Witch 970T transmitter (see Figure 5.3) is one of the more productive transmitter's in their line of products. It transmits signals using a direct pipeline connection, an induction clamp, or via induced broadcast signals. Similarly, the Ditch Witch 910R receiver is equipped with the best frequency for locating pipes and cables. It is also easy to use and comes with four frequencies. The specifications for both the 970T and 910R can be found in Appendix D.2 (www.ditchwitch.com).

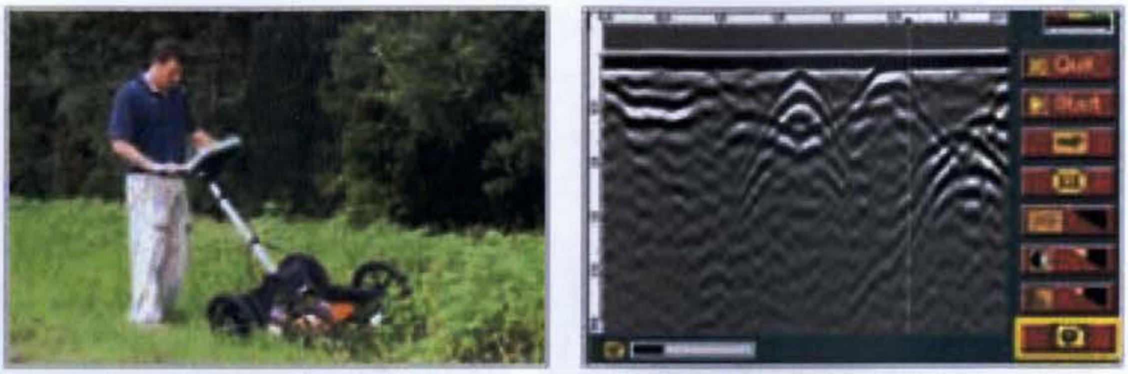
(a)

(b)

Figure 5.3 (a) Ditch Witch 970T and (b) 910R (www.ditchwitch.com).

5.2.3 MALA Easy Locator System

This system is an entry level Ground Penetrating Radar (GPR) that can be used to quickly identify or designate existing buried utility networks of metallic and non-metallic nature. Figure 5.4 displays a field operator using the Easy Locator System and its resulting digital imagery. Due to the increased use of non-metallic materials for construction during burials of utilities, companies like MALA look to address the difficulties associated with non-metallic utilities.



(a) (b)

Figure 5.4 (a) Easy Locator used by utility locator; (b) Digital image of signals. (www.malags.com).

This GPR is a technology that does not need a physical connection to the utility and it does not rely on radiating electromagnetic (EM) fields. It is recommended for use in utility detection, utility mapping, and Underground Storage Tank (UST) detection, void detection, locate service or illegal connection, lost cover, valve, cable box or vault detection.

This device provides real-time locates and it has a back up cursor for quick and easy interpretation of data and accurate utility marking.

According to the manufacturer, the antennas highest resolution at shallow penetration is 500 MHz. At deeper penetration the high resolution is 350 MHz. Refer to Appendix D. 3 for further specifications regarding this system (www.malags.com).

5.2.4 MALA X3MTM

This is an integrated radar control unit that goes well together with the 100, 250, 500, and 800 MHz shielded antennas. The X3M and the XV Monitor or notebook PC are linked through an Ethernet connection, which allows the user to obtain high speed point to point communication for reliable and high quality data transfer.

This system also has a built-in auto stacking feature that allows for high quality data collection at maximum survey speeds and its low power consumption ensures more than six hours measuring time with its standard battery.

The application of this device classifies it as a pushing or pulling system. The pushing system exists when the MALA X3M is connected to a 250, 500, or 800 MHz antenna that is mounted into the MALA Rough Terrain Cart (RTC). Figure 5.5 displays an X3M mounted on a RTC. It is classified as a pulling system when a measuring wheel is fitted to the mounting block on the back of the shielded antenna; and the antenna with the fitted MALA X3M is dragged across the survey areas with a handle or strap. For a list of the technical specifications of this product see Appendix D.4.

Figure 5.5 MALA X3M mounted on a Rough Terrain Cart (www.malags.com).

Although the abovementioned technologies are worthy choices to designated underground utilities; they are still limited in terms of their penetration of depth. Depending on the project and the desired and/or required level of accuracy, digging test holes to gather the exact depth of a utility may be the preferred choice. TSH/TBE uses the Omega Tools Servac for their test-hole investigations.

5.2.5 ΩOMEGA TOOLS SERVAC – SBM-100-5080

TSH/TBE uses the SBM-100-5080 SerVac system. This SerVac^{TM} Industrial Vacuum Excavation system is designed to function as a complete soil removal system; which will provide an efficient, reliable, and cost-effective solution to test hole excavation. The system is comprised of several interdependent sub-systems that is tailored to the user's specific needs. A few of the common sub-systems include the main frame, filtration system, control panel, diesel engine, high pressure receiver, vacuum source system, hopper assembly automatic dump valve, dump valve hydraulic arm, compressed air system, pressurized water system fuel tank, tools, and accessories.

The filtration system uses pulse-jet technology and contributes to the overall success of the SerVac excavation system. The vacuum source system combines a positive displacement blower and a diesel engine for power. This autonomous and balanced power unit is provided with a full range of system controls and gauges.

The systems hopper consists of a collection chamber that can easily remove dirt, mud, water, and other debris from an test-hole excavation site. And routine maintenance of the hopper will prevent vacuumed solids from blocking the air passage, which, if blocked, effects overall system capability.

The compressed air system, powered by the diesel engine, generates the compressed air required to run pneumatic tools including the Wet Air Lance, Sand Blaster, and the Filtration System.

The three essential factors that affect the performance of the vacuum excavation system are pressure, flow and hose velocity (Omega Tools, Inc., 2005). For a more detailed look into the vacuum's technical specifications, please refer to Appendix D.5.

5.3 RESEARCH METHODOLOGY

Before moving on to the analysis, it is essential to understand the way in which the data was collected for this particular project. In order to asses the quality of information that relates to the accurate and precise location of underground utilities, the offset approach was seen as a suitable evaluation technique.

To analyze locational accuracy of subsurface utilities within a Canadian context, the City of Toronto was chosen due to its proximity and data accessibility to the student. The City of Toronto and a subsurface utility company formerly known as the TSH/TBE Group provided several data sets from current surveys relating to locational or positional accuracy of underground utilities within the Greater Toronto Area (GTA). Moreover, a total of seven extensive projects were used for research purposes within this Master's thesis.

5.3.1 City of Toronto – DMOG – Digital Map Owner's Group

The City of Toronto's Survey and Mapping department developed the DMOG Maintenance Program. This program allows the City to manage the underground facility features on behalf of the Digital Map Owners Group (DMOG); which is a sub-group of the Toronto Public Utility Co-ordinating Committee (TPUCC). The joint undertaking consists of the City of Toronto and Bell Canada, Toronto Hydro Electric Systems Limited, Enbridge Gas Distribution Inc., Rogers Cable Communications Inc., the Toronto Transit Commission, Telus Communications Inc., MST Allstream Inc. and Hydro One Networks Inc.

The main goal of the DMOG is to protect underground infrastructure within their rights of way; as a result it also provides underground mapping. There are currently nine members that share the cost of maintenance of these composite underground utility maps.

According to the City of Toronto, DMOG maps are the most comprehensive environment to access digital spatial records of as-built subsurface facilities. The utilities themselves are characterized as double line features and they include significant mapping details such as ROW, street curbs, building outlines, and municipal numbers (i.e. lot numbers).

The DMOG map colour-codes its utilities. However, from the analysis of the seven project DMOG maps provided by the City of Toronto, it is notable that the representative colours for certain utilities differ from map to map. The most frequently employed utility colour codes include:

Water mains – Blue or Aqua or White
T.H.E.S. Conduit – Red
Storm sewer – Bright Green or Red
Fiber Optic Cable or Buried Telecom Orange
Sanitary sewer – Green
Buried electric – Red
Gas – Yellow
Combined sewer – Dark pink or Grey

5.3.2 TSH/TBE Subsurface Utility Engineers – Surveys

TSH/TBE Subsurface Utility Engineers, founded in 2002, was a joint venture between TSH Associates (now AECOM) and TBE Group (now CARDNO TBE). They work together to provide the Canadian marketplace with SUE services including utility records research, utility designating, utility locating, manhole and vault investigations using CCTV cameras, data management, utility coordination, and utility design to public and private clients across the nation (www.tshtbe.ca).

The City of Toronto hired TSH/TBE consultants to conduct SUE investigations on several municipal projects; seven of which were provided for this master's thesis. Lawrence Arcand, manager of the SUE Services Department at TSH/TBE, was responsible for compiling the projects into a useable format for this particular thesis project.

TSH/TBE was given DMOG maps and as-built drawings from the City of Toronto and several utility companies, which was analyzed by the technicians, engineers and taken to the field for verification. The data provided by the City is ASCE Standard quality level D; which simply represents information derived via existing utility records, utility as-built records, and oral testimonials. The DMOG provides an overall sense of underground utility location, however, it is limited in terms of accuracy and comprehensiveness.

TSH/TBE conducted surveys on a limited level with respect to the requests from the project owners throughout the in-field surbsurface utility locates.

It is evident that ASCE quality level B information is gathered for water mains and storm sewers using geophysical techniques. TSH/TBE uses single and multi-frequency electromagnetic cable locating instruments for their investigations. Gas lines and fiber optic cables (FOC) are located using test holes and air vacuum excavation after they have been designated using some form of geophysical method. Also, surface appurtenances were used to verify quality level D data and to establish a direct connection to the utility where possible.

The designated data and the investigated surface feature, including manhole lids, water valves, etc., are surveyed by a sub-consultant (e.g. Marshall Macklin Monaghan). The survey essentially attaches appropriate x, y, z coordinates, within a recognizable coordinate system, to the facility locations found to be critical by TSH/TBE.

Once the data is gathered in the field by both the field investigators and surveyors, it is transported to the office to create composite utility drawings. The CAD technician will verify the data, process it, and translate it into a comprehensive utility map with the utilities, its corresponding coordinates, and the ASCE quality levels for each buried facility. AutoCAD software was used to place TSH/TBE gathered information into distinct layers according to utility type, thereby creating a detailed composite utility map. It now represents an accurate depiction of the location of utilities as per the appropriate quality level. The ASCE standard quality levels are represented in the form of different linetypes within TSH/TBE's digitally prepared drawings. See Figure E.8 in Appendix E for further information regarding linetypes and quality levels.

For the purposes of this Master's thesis, the DMOG drawing was implemented within the SUE Survey drawing within a distinct layer through the alteration of certain parameters in order for a useful analysis to take place. Certain differences between both forms of mapping included scale, origin offset, and rotational variation. The City's DMOG maps were used as base maps, which show certain fundamental information used as a base upon which the additional surveyed utilities' data are compiled creating enhanced composite maps for the end user (i.e. the Master's student).

For instance, the surveyed drawings are in a local coordinate system whereas the City's DMOG composite maps are in Toronto's operational coordinate system called the Modified Transverse Mercator (MTM) projection, North American Datum 1927 (NAD 27), with a truncated northing value or y value (-4,000,000).

The province of Ontario uses the MTM in which a region is divided into zones of 3° longitudinal zones. Across Canada, the first zone begins east of Newfoundland, and the province of Ontario is covered by 10 zones out of a possible 32 zones across Canada. Zone 10 encompasses the city of Toronto (see Figure 5.6). In order to lessen the distortion throughout the zone a 0.9999 scale factor is used along the zone's central meridian. Also, something of interest involves the true origin of the grid coordinates is shifted to avoid negative coordinates by introducing false northing 0.0m and false easting of 304,800m (El-Rabbany, 2002).

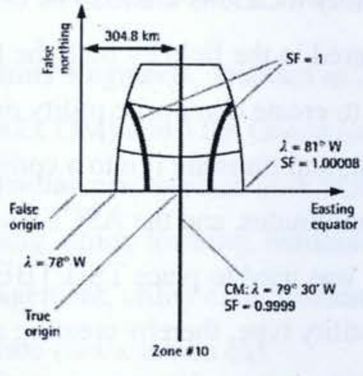


Figure 5.6 MTM Projection (El-Rabbany, 2002).

A geodetic coordinate system is a coordinate system where the position is defined by geodetic latitude, geodetic longitude, and ellipsoidal height http://www-lite.larc.nasa.gov/level1doc/geodetic_coords.html).

The latitude refers to the angle between the equatorial plane an the perpendicular line intersecting the normal line at the point on the Earth's surface. Whereas, the longitude represents the angle in the same plane between the line *a* which connects the Earth's center to the prime meridian and the line *b* that connects the center with the meridian on which the point lies. The Meridian refers to a straight path on the surface of the datum that is the shortest distance between the poles. Figure 5.7 depicts geodetic latitude and longitude clearly.

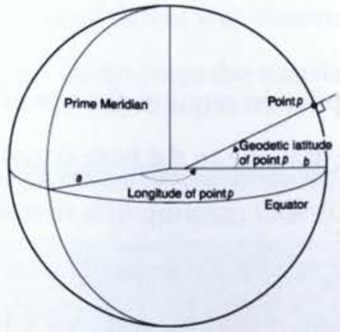


Figure 5.7 Geodetic latitude and longitude.
(http://publib.boulder.ibm.com/infocenter/db2luw/v8/index.jsp?topic=/com.ibm.db2.udb.doc/opt/csbgeo06.htm).

And the North American Datum 1927 (NAD27) is a horizontal control datum for the United States which was derived from the location and azimuth on the Clarke spheroid of 1866 with the origin located at the Meades Ranch survey station (http://www.ngs.noaa.gov/faq.shtml#WhatNAD).

The survey control networks branched out from the Meades Ranch datum point across North America using Laplace azimuths and the Bowie method finally creating the NAD27 reference frame. Later on the NAD83 system was established using precise Doppler networks in North America and around the world along with the GRS80 reference ellipsoid to create a better fitting reference frame (http://www.geod.rncan.gc.ca/edu/geod/reference/reference04_e.php). Figure 5.8 represents the reference frames NAD27 and NAD83.

Figure 5.8 Reference Frame for NAD27 and NAD83.
http://www.geod.rncan.gc.ca/edu/geod/reference/reference04_e.php

The newly surveyed drawings had to be georeferenced to a common base using functions such as scale, rotate, and move within Autodesk's AutoCAD software.

5.3.3 Data Processing

Step 1 of the data compilation requires the use of the *xref* command in AutoCAD to attach an external reference drawing to the base drawing. In Figure 5.9 you can see the result of attaching the City's DMOG drawing of a stretch of Gerrard Street to the survey drawing. When a drawing is referenced into another drawing, the referenced drawing acts as a single object. Therefore if the user selects a line or point within the reference drawing, the entire reference will be selected or highlighted. Alteration of the reference drawing can only be done by accessing the original file. The SUE survey drawing was used as the base because the elements of this drawing were required to select individual elements at their critical and/or benchmark points.

As you can see in the figure below, the DMOG (i.e. the reference drawing) is smaller in scale and rotated; thus it can be stated that both the DMOG and the current survey lie within different coordinate frames.

Figure 5.9 Sample Data Set .

In order to begin the evaluation through the offset approach, both drawings must be coincident. Therefore, the first step requires that the DMOG be translated to fit the same origin. A common point must be found within both drawings before translating the reference drawing to the live survey drawing. In this case, a single point, on the DMOG, on the bottom left-hand corner of the North-East gas chamber that lies within the intersection of Yonge Street and Gerrard Street was chosen and moved to the same point within the survey drawing. Figure 5.10 displays the translated image of the DMOG to the SUE survey.

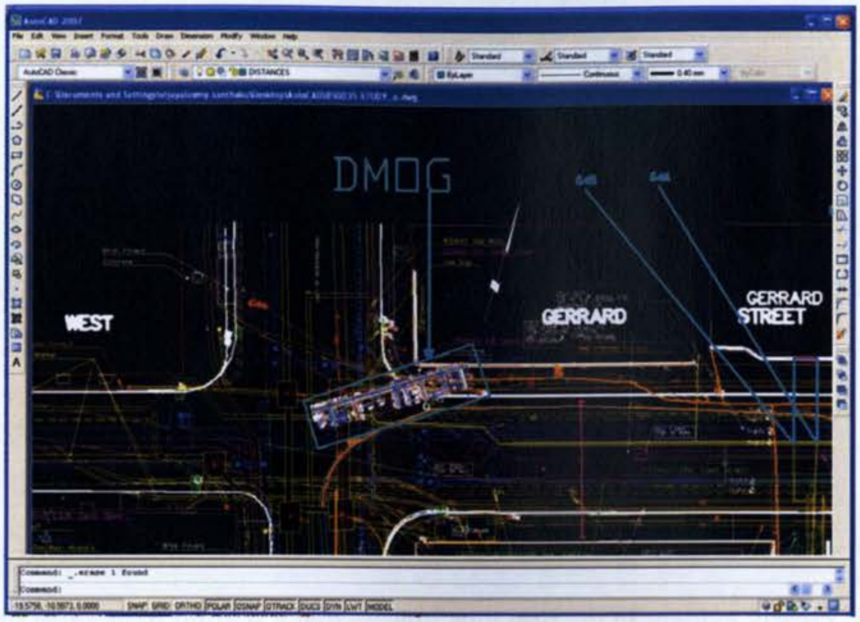


Figure 5.10 Translate x, y coordinates.

The next step involves rotating the reference image to align with the survey drawing. For this particular example, the rotational angle is 343.30° and Figure 5.11 and 5.12 illustrates the rotational angle and the rotated image.

Figure 5.11 Rotational Angle.

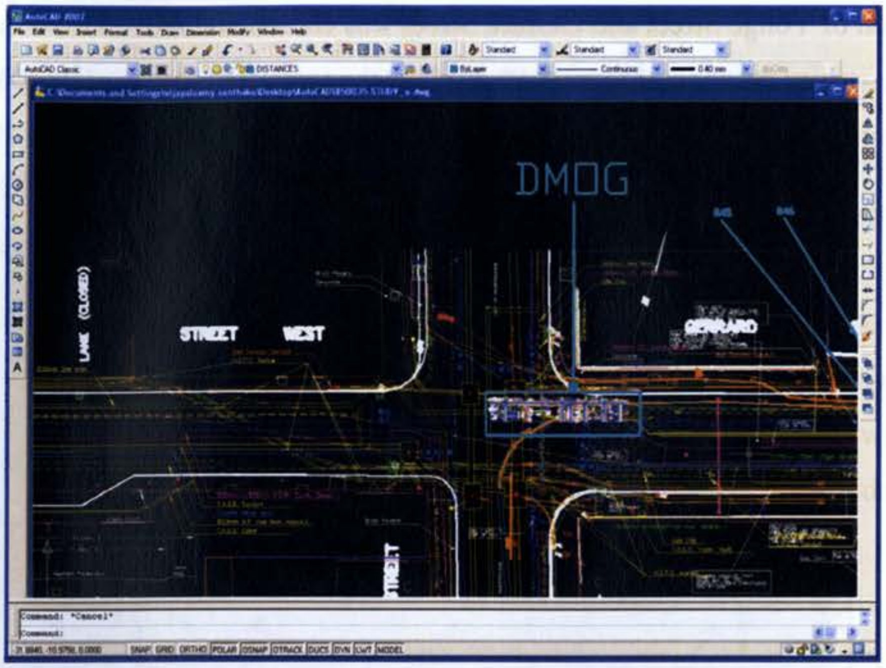


Figure 5.12 Rotated Image.

It is clearly evident in the previous images that a scaling issue must be accounted for. In this particular case, the scale factor is uniform with a value of 39.378, which successfully aligns both drawings and finally sets it up for the evaluation process. Figure 5.13 displays the aligned DMOG and SUE survey drawings.

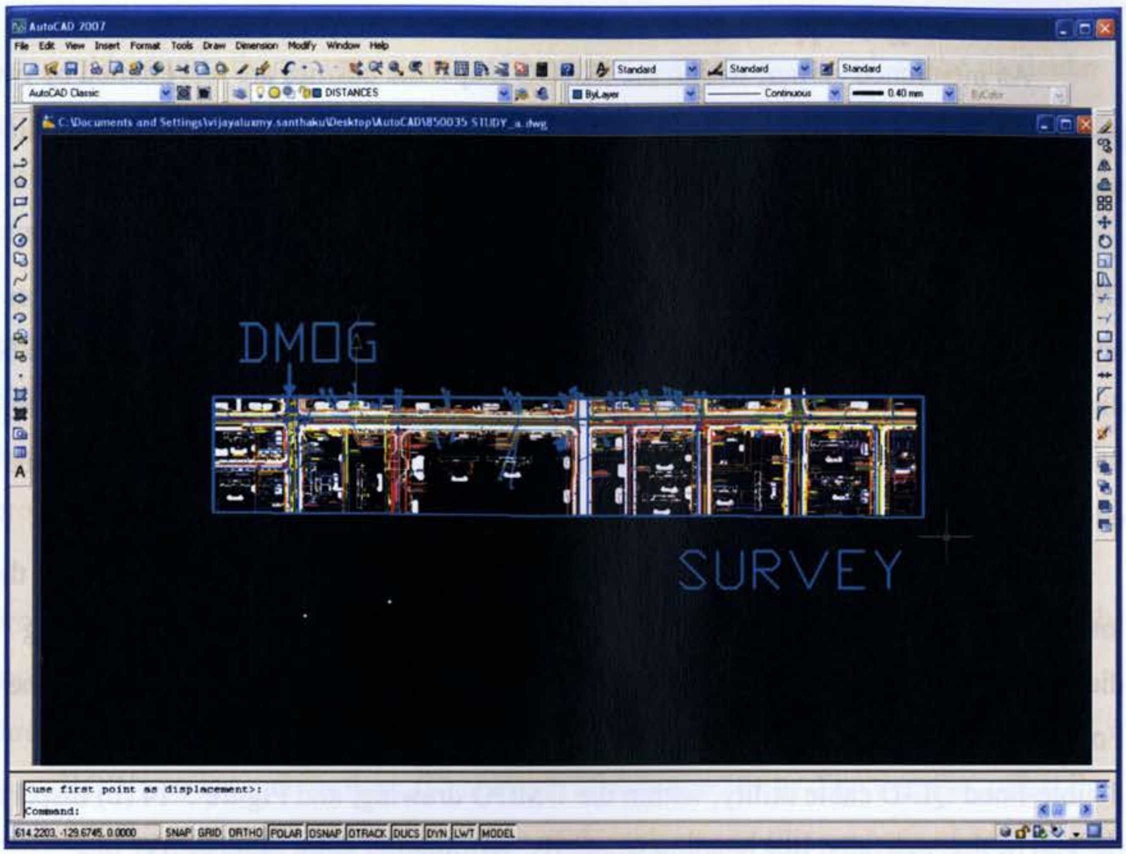


Figure 5.13 DMOG and SUE Survey drawings in a single coordinate frame.

Once the newly surveyed map was aligned with the City's base DMOG map the offset technique could be applied in order to evaluate the locational accuracy of subsurface utilities obtained via existing records/maps and current field surveys.

Another important factor to consider before evaluation is the comprehension of the City's and company's digital, as well as, hard-copy drawings. In other words, the images had to be decoded before any sort of evaluation could take place. Each end point on the line segments within the survey drawings represent survey endpoints where accurate x and y coordinates were measured. And within the DMOG drawings, every utility is represented using double line segments rather than a single line segment compared to those in the TSH/TBE survey drawings.

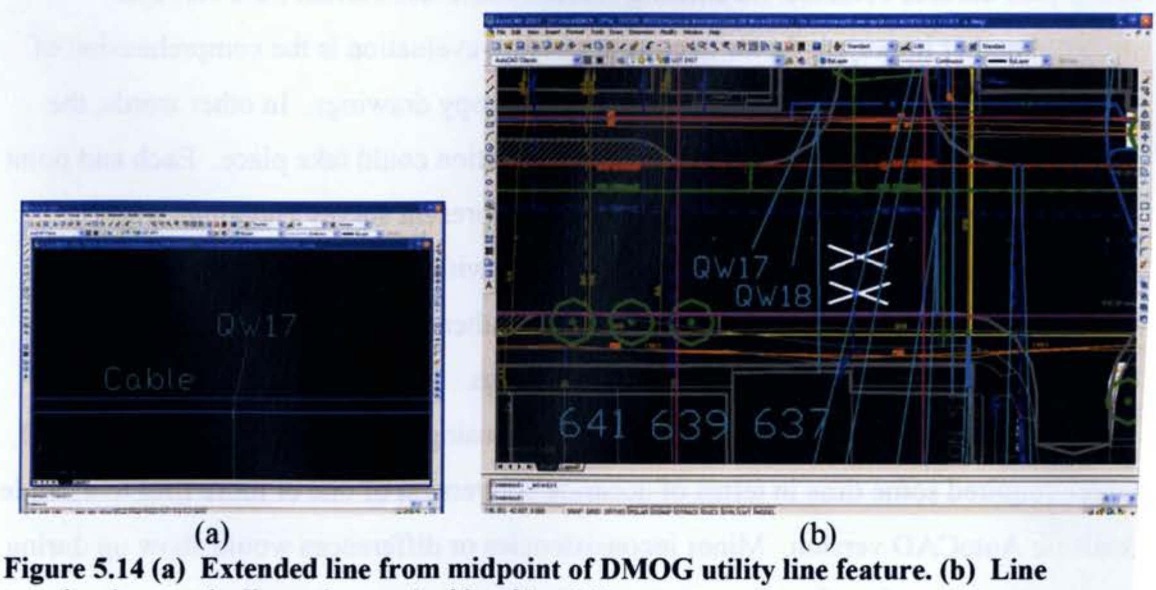
Furthermore, certain projects were created using different versions of AutoCAD, which required some time in terms of accurate conversion of one or more files to a single readable AutoCAD version. Minor inconsistencies or differences would show up during a conversion procedure from one version to the next.

5.3.4 The Offset Approach

As mentioned earlier, within the DMOG maps, the utilities are represented by two parallel lines, whereas the newly surveyed underground utilities are made up a single line segment within the drawings produced by the TSH/TBE Group.

The first step involves measuring the linear perpendicular distances from the DMOG utility features to the curb or to lot lines, where applicable. The offset distances taken using lot lines could only be applied to two out of the possible seven projects, to be discussed in the following section, provided by the City of Toronto and TSH/TBE. The line extends from the center of the double lined feature, vertically at a right angle, to the edge of the closest lot, where applicable.

Next follows another distance measurement from the survey utility features to the lot lines along the same line as the DMOG measurement. In the case where a drawing did not contain lot lines, curb lines were used as the termination points of the offset lines. For instance, Figure 5.14 (a) displays the extension of a line from the center of the double-lined QL-D cable utility, within the DMOG drawing, and Figure 5.14 (b) displays the end of that extended line heading southerly, terminating at lot number 637 in a perpendicular manner. The point identifiers labeled QW17 and QW18 correspond to the DMOG distance measurement and the TSH/TBE survey measurement; which lie in the spreadsheets where the offset distances have been tabulated. Further discussion will take place regarding the offset distances following this chapter.



(a) (b)

Figure 5.14 (a) Extended line from midpoint of DMOG utility line feature. (b) Line terminating vertically at the north side of lot 637.

Moreover, the appropriate point identifiers, which corresponds to the particular project, were implemented alongside the perpendicular distances being measured. For instance, in Figure 5.16 the identifiers QW17 and QW18 correspond to DMOG point number 17 and survey point number 18 within the **Q**ueens**W**ay project.

Of particular interest, the distance measurement taken from the survey drawings extend from the survey endpoint where accurate x and y-coordinates are known. The difference between the existing DMOG measurements and the newly acquired survey measurements was tabulated into spreadsheets creating sets of extensive tables for each project.

After the data collection from all seven projects was gathered, the analyzation proceeded using descriptors including the mean, the mean of the absolute values, and the root mean square. These descriptors were used to evaluate the offset data sets through three approaches: (i) analysis of data of utilities that lie within and outside the right-of-way (ROW) across each project; (ii) analysis of data specific to direction (i.e. offset line extended North, South, East, West) within each project; and (iii) analysis of data specific to each utility within each project.

The data was partitioned into utilities that lie within the right of way and those which do not. When referring to how the measurements were made with respect to direction, the utility was examined to see whether it lies North or South of a major roadway (i.e. in the case where the major roadway, e.g. the Queensway, runs East-West, the utilities within this project were labeled as either lying North or South of the Queensway). The same concept applies when a major roadway runs North-South, e.g. Yonge Street runs northerly, so the utilities within the Yonge Street project can be identified as either being situated to the East or West of Yonge Street.

The same perpendicular distance measurements were made for several points within the remaining five out of seven project sites extending from the utilities of interest to the curb lines, in the case where lot lines were not readily available.

There is a wide range of utilities that lie beneath the surface within the City's streets; however, according to the City of Toronto's DMOG maps, a smaller number of utilities are identified common to all seven project sites including,

a. Watermains
b. T.H.E.S. Cable
c. Storm Sewer
d. Fiber Optic Cable
e. Buried Telecom
f. Sanitary Sewer
g. Buried Electric
h. Gas Main
i. Combined sewer

Detailed explanations of the seven project sites; which are discussed in the next section, will provide a better understanding of the complexity of the issues surrounding the locational accuracy of subsurface facilities.

Other utilities were highlighted that are specific to certain projects. For instance, the Yonge Street project extending from Lawrence Avenue to Eglinton Avenue, included labeled features such as Bell Canada Conduit, Telus CoBuilt (GT), Abandoned Sewer, Abandoned Gas Main, T.H.E.S. Conduit, etc.

According to the subsurface utility investigation performed by the THS/TBE Group a number of utilities can exist within the area of interest including,

BE	Buried Electric
G	Gas
BT	Buried Telephone
FOC	Fiber Optic Cable
W	Water
SAN	Sanitary
STM	Storm
CATV	Cable Television
FM	Force Main
RW	Reclaimed Water
SL	Street Light
TS	Traffic Signal
EXP	Exploratory
UNK	Unknown

Several of these utilities are encased in conduits or cobuilts as well as being buried directly into the ground. The seven projects used for this Master's thesis are as follows and will be discussed in the next section:

1. The Queensway
2. Gerrard Street East Watermain Replacement Project
3. Reconstruction of Royal York Road

4. Kenneth Avenue and Spring Garden Avenue – Overflow Link of Storm and Sanitary Sewer
5. Union Station North West PATH
6. Yonge Street – Two New Watermains
7. Portland Energy Centre – NPS 20 HXP Gas Pipeline Project

5.4 RESEARCH SITES

The City of Toronto, in collaboration with the formerly known TSH/TBE Group, provided a set of seven projects for this Master's thesis. Each project was unique in its purpose, however, each and every project required an investigation of the subsurface to detect and locate utilities. Satellite imagery of all seven project areas can be found in Appendix E, which were obtained using Google Earth.

5.4.1 The Queensway – Subsurface Utility Investigation from MOYNES AVENUE to BERL AVENUE and from WINSLOW STREET to MILTON STREET

The SUE investigation took place on the Queensway from Moynes Avenue to Berl Avenue and from Winslow Street to Milton Street. An area of 6.5 square kilometers. This research area lies in the Etobicoke region of residential detached bungalow and 2-storey houses, as well as apartment complexes on the south side of the Queensway. A few small businesses also exist along this stretch of road including Staple-Man Ltd., Momos Bistro, Latina Restaurant, Izba Restaurant Ltd, Three Brothers Restaurant. Several utilities serve this relatively busy neighbourhood of residential and commercial property. Figure E.1 in Appendix E displays a satellite image of the study area. From the field analysis, and from discussions with property owners, this stretch of land is pretty old in terms of its vintage. Several of the houses are nearly forty to fifty years of age.

The utilities located by the TSH/TBE Group within this project include:

a. Buried Telecom
b. Gaslines
c. Fiber Optic Cable
d. Watermains – 300 mm, 150 mm
e. Storm Sewer – 750 mm, 675 mm, 375 mm
f. Sanitary Sewer – 200 mm, 375 mm,

5.4.2 Gerrard Street East - Subsurface Utility Investigation for Watermain Replacement Project

This SUE investigation took place in October 2005 along a corridor on Gerrard Avenue from Yonge Street to Jarvis Street. TSH/TBE was hired to identify the location of existing utilities to facilitate the design of the new watermain. The proposed watermain is to run within the West Bound lane between Yonge and Church and within the east or west bound lanes between Church Street and Jarvis Street. The utilities located by the TSH/TBE, at the time of the investigation included:

a. Gaslines
b. Watermains – 300 mm, 150 mm
c. Storm Sewers – 750 mm, 675 mm, 375 mm
d. Sanitary Sewers – 200 mm, 375 mm
e. Buried Telecom
f. Fiber Optic Cable

The area of investigation is located in a high volume urban roadway with a dense population of congested underground utilities. Figure E.2 in Appendix E displays a high resolution image of the investigation area. Major facilities on the south side of Gerrard Street East include Ryerson University and small businesses along with high-rise apartment buildings on the north side of Gerrard Street East. Ryerson University moved into century old buildings of the Toronto Normal School and in the 1950's, a multi-million dollar modernization program resulted in incorporating new facilities for classrooms (www.ryerson.ca/archives/ryehistory.html).

Many of the structures, including the subsurface infrastructure of this area are aged in terms of its vintage. For instance, at the corner of Gerrard Street East and Church Street lies the Monetary Times Building; which was built by the Monetary Times Printing Company in 1931 and was later purchased by 1966 and finally restored in 1993 by Merber Corporation, Basterfield & Associates, and Read Jones Christofferson (http://www.lett.ca/Site/Education_-_Monetary_Times.html). During the months of September to May, these streets are highly condensed with road traffic as well as pedestrian post-secondary as well as general public traffic.

Furthermore, a 900 mm water main east of Yonge Street did not output a unique signal possibly due to interference from the shallower, abandoned gas main within close proximity. The locating crew also found it difficult to verify the origin of storm sewers which they believed could have been capped outside the chamber.

5.4.3 Reconstruction of Royal York Road – from Delroy Drive to Leland Avenue

This SUE investigation took place between April and July 2006 and it was conducted for UMA and the City of Toronto for a corridor along Royal York road between Delroy Drive and Leland Avenue; which is about a 1.5 km stretch of road. Figure E.3 (a) and (b) displays a satellite image of the area of interest. TSH/TBE was hired to identify the location of existing subsurface facilities in order to provide assistance to the design component of the road reconstruction. The various utilities that exist within this study area include:

a. Gaslines
b. Watermains – 300 mm, 150 mm,
c. Storm Sewer – 750 mm, 675 mm, 375 mm
d. Sanitary Sewer – 200 mm, 375 mm,
e. Buried Telecom –
f. Fiber Optic Cable

The area of investigation is a continuation of previous restructuring work on Royal York Road, which involves new installation of sewers and road reconfiguration. This one kilometer stretch of road falls in a sub-urban residential/industrial area. The east side of Royal York Road is dense with trees, while the west side is dense with residential housing and new industrial buildings. A major facility on the east side known as the Bishop Allen Academy.

According to the locating crew's observations, a significant number of manholes and catch basins were bolted shut or filled with debris which prohibited access. And other locations of existing manholes could not be verified visually in the field. Also, watermains on the east side of Royal York Road were not validated because it had been abandoned or it was plastic with no tracer wire. What's more, the gas mains in the vicinity of Leland Avenue were not verified because they were abandoned or made of plastic with no tracer wire.

5.4.4 Kenneth Avenue and Spring Garden Avenue – SUE Investigation

This SUE investigation took place in September 2007 in the intersection of Kenneth Avenue and Spring Garden Avenue. A satellite image of this intersection can be found in Appendix E, Figure E.4. TSH/TBE was hired to identify the location of existing underground utilities in order to facilitate the design of a proposed overflow link between the existing storm and sanitary sewer network in the area. This area is highly residential including large 2-storey detached homes as well as two condominiums.

According to the locating crew's observations, additional conflicting plant (unspecified) was identified, which was in close proximity of the proposed construction area. This also led to the increase in the number of test holes being excavated. Additionally, two gas mains were identified, one made of PVC excluding tracer wire which triggered the need for a test hole to determine its exact location.

5.4.5 Union Station NW PATH - Subsurface Utility Investigation

This SUE investigation took place over the summer of 2007 for the City of Toronto along York Street from Front Street to Wellington Street. Figure E.5 in Appendix E shows a satellite image of the investigation site. The area of investigation is located in a high volume urban roadway with a dense population of congested underground utilities. TSH/TBE was hired to identify the location of existing subsurface facilities to facilitate the design of a route for the new PATH tunnel.

Apart from the existing PATH tunnel on Wellington Street, the City of Toronto plans to install a new PATH network connection from Union Station to the existing PATH. This area of interest is highly commercial as well as business oriented. PATH is downtown Toronto's underground walkway that currently links 27 kilometers of shopping, services and entertainment. The system is highly advanced, providing pedestrian linkages to the largest underground shopping complex (i.e. 27 km shopping arcades). It also connects more than 50 buildings or office towers, including twenty parking garages, five subway stations, two major department stores, six hotels, a railway terminal; as well as connections to some major tourist spots the Hockey Hall of Fame, Roy Thomson Hall, Air Canada Centre, Rogers Centre, and the CN Tower, City Hall and Metro Hall.

Currently, the PATH tunnel has more than 125 grade level access points and 60 decision points for pedestrians to decide whether to turn left, right, or to go straight ahead. The connecting links alone range from 20 meters long by 6 meters wide. And the letters of PATH represent different directions; for instance P is red and means south, A is orange and represents west, blue is T which directs pedestrians north, while the yellow H directs them east (http://www.toronto.ca/path/).

The underground tunnel is approximately 3 m by 5 m in size and it will have a significant affect on the existing subsurface utility network within the area.

This routes traffic is congested during daytime working hours and on-going construction for new infrastructure, as well as maintenance, makes room for the need to install new utilities into the ground to accommodate the infrastructure need of the area.

The utilities found by the TSH/TBE Group include:

a. Gaslines – 600 mm, 500 mm, 300 mm, 150 mm, 100 mm
b. Watermains – 1200 mm, 600 mm, 300 mm, 150 mm
c. Storm Sewers – 1800 mm, 1500 mm, 750 mm, 675 mm, 375 mm
d. Sanitary Sewers – 375 mm
e. Combined Sewers – 600 mm, 375 mm, 300 mm
f. Buried Telecom
g. Fiber Optic Cable

5.4.6 Yonge Street – Eglinton Avenue to Lawrence Avenue – Subsurface Utility Investigation

This SUE investigation took place in October 2007 with a second part completed in January 2008 along a corridor on Yonge Street from Lawrence Avenue to Eglinton Avenue; which is approximately 2.1 km. Figure E.6(a), (b) and (c) in Appendix E illustrates an aerial view of the area under investigation. The City of Toronto hired TSH/TBE to identify the location of existing utilities to facilitate the design of two new, 300 mm watermains that will on either side of Yonge Street. TSH/TBE was also required to provide the current state of specific storm and sanitary chambers because several of these manholes require rehabilitation, therefore resulting in extensive road reconstruction.

This area of investigation is located in a high volume urban roadway with a very dense population of congested underground utilities. It is one of the busiest roadways in the City of Toronto and the province overall. There are several facilities that have to be served by the underground network of facilities including shops, departmental stores, grocery stores, funeral parlors, a cemetery, parks, clothing stores, specialty businesses, doctor's offices, and major hotels and newly built high rise condominiums at the intersections of Yonge Street and Lawrence Avenue and Yonge Street and Eglinton Avenue.

Particular to this investigation was the fact that the storm and sanitary sewers were investigated by taking pipe invert measurements in 150 manhole chambers. Besides capturing photographs from the collar of the chamber down to the bottom for each wall, another shot was taken facing directly down the manhole chamber; the size and material were also noted. The observed data and surface appurtenance data (i.e. manhole covers, water valves, etc.) were surveyed by Marshall Macklin Monaghan (TSH/TBE, 2008).

5.4.7 Portland Energy Centre – Subsurface Utility Investigation for NPS 20 XHP Gas Pipeline Project [Enbridge Gas Distribution Inc.]

This SUE investigation took place from February to April 2007 for Enbridge Gas Distribution Inc. Within Toronto, Enbridge proposed the installation of the NPS 20 extra high pressure (XHP) gas pipeline to serve the Portlands Energy Centre (PEC). This pipeline stretches along a few municipal streets including Eastern Avenue, Booth Avenue, Lake Shore Boulevard East, Logan Avenue, Commissioner's Street, and Bouchette Street. Figure E.7(a), (b), and (c) presents satellite imagery of the streets along which the pipeline stretches.

It will stretch from Enbridge's Station B Regulator Station, situated at 405 Eastern Avenue, heading west of the intersection of Eastern Avenue and Booth Avenue ending off at the PEC at 470 Unwin Avenue; which is west of Leslie Street directly across from the Hearn Generating Station. This area is a mix of residential, commercial and industrial. It cuts across a major arterial road, LakeShore Blvd East, and heads down toward the port. This investigation area serves several industrial complexes south of Lake Shore Blvd. East.

According to the report prepared by the TSH/TBE Group, some areas were not investigated due to constraints. The stretch between Basin and Unwim was avoided due to deep directional drilling and only certain sides of the road because of alignment restraints issues. Also, the area adjacent to the existing Hearn Generating Station was avoided because permission to investigate was not acquired for that site. However, inverts at key storm and sanitary manholes and catch basins were acquired along with additional inverts and testholes based on final design (TSH/TBE, 2007).

Also, further consultation took place to select the optimal test hole locations and areas where 3D imaging would be useful to gather further detailed underground information. And 3D imaging of the underground network was completed in three main areas including, Eastern and Booth; Lakeshore between Booth and Logan; and Commissioners and Bouchette.

Enbridge was a key stakeholder in the consultation and selection of the test holes required for this TSH/TBE were able to coordinate with Enbridge's paving contractor – Pave X – to pave over the test hole locations with hot-mix asphalt. And all utility location markings were surveyed by Schaeffer Dzaldov and tied into the coordinates of the base drawing; which was later used to create the composite utility drawing (TSH/TBE, 2007).

5.4.8 Digital Data Collection Procedure

The TSH/TBE Group took a series of steps to collect the data that was used in each of the above-mentioned projects. The first step is to collect all available utility records. The Toronto Public Utilities Coordinating Committee maintains maps, called DMOG's, which are made up of underground utilities within the City of Toronto. The primary data source for collection of utility information is this DMOG. Additionally, records from Bell and Enbridge and other utility companies, that own buried plant within the study area, were sought out and acquired by TSH/TBE. These records all represent QL-D information.

The next step involved using multi-frequency electromagnetic cable locating instruments to collect ASCE Standard quality level B information. Direct connection methods were applied wherever possible and for the existing watermains, inductive techniques were employed. The company chooses to use the Metrotech 810 Pipe and Cable Locator™ and the Ditch Witch 970T Transmitter and 910R Receiver to designate certain utilities within the area. The projects also involved the use of the MALA Easy Locator GPR device. Several utilities were located, however, buried electric, gas, water services and telecommunications are surveyed first. Unless specified by the client, the above-mentioned utilities take first preference.

Following the designation procedure, ASCE Standard 38-02 quality level A data is acquired depending on the client's request for depth information regarding certain utilities within critical areas. The number and location of test holes were identified and implemented at critical locations after consultations with TSH/TBE, the City of Toronto, and any other parties involved in the project. For instance, a few test holes were identified, by UMA, and implemented at critical locations to obtain quality level A information within the Royal York Road reconstruction project. A total of 24 test holes were collaboratively decided on and marked in the field for investigation (TSH/TBE, 2006) .

The acquisition of these test holes is performed through the use of an air based vacuum excavation unit known as the ΩOmega Tools SERVAC Model SBM-100-5080. The test holes that were excavated using this system provided precise x, y, z information at the key areas where knowledge of the depth, size and nature of the existing utilities is crucial (TSH/TBE, 2005).

Also, sub-consultants are hired to survey the utility location markings indicated by TSH/TBE field locators. To name a few, Marshall Macklin Monaghan (MMM) and Schaeffer Dzaldov were hired to perform field surveys of the utility markings, which was then tied into the coordinates of the base drawing used to create the composite utility drawing

The final step involves using drafting software, such as AutoCAD or Microstation, to import the designated and located utility information into distinct levels on the City of Toronto's DMOG drawing. Thus resulting in a composite map or drawing consisting of utility information ranging from ASCE Standard 38-02 quality level D to quality level A. This will contribute to the confidence factor of the design engineer and the bidders of the project.

5.5 DATA ANALYSIS

As mentioned earlier, the evaluation technique used for this project was the offset method. When referring to the offset distances, the terms 'paired data sets' or 'coupled data distances' or 'paired distances' all represent the distances taken for each utility measurement from (a) the DMOG utility segment and (b) the field located segment. And the descriptors involved in analyzing the data included (a) arithmetic mean error, (b) arithmetic mean error of the absolute values, and the (c) root mean square.

The average of the offset measurements $y_1, y_2, \ldots, y_n$ for a set of n offset measurements yields the arithmetic mean error, y_{avg}, and is calculated using this equation (5.1):

$$y_{avg} = \left(\sum_{i=1}^{n} y_i\right)/n \qquad (5.1)$$

The average of the absolute values of the offset measurements $y_1, y_2, \ldots, y_n$ for a set of n offset measurements yields the arithmetic mean error of the absolute values, y_{abs}, and is calculated using this Equation (5.2):

$$y_{abs} = \left(\sum_{i=1}^{n} |y_i|\right)/n \qquad (5.2)$$

With respect to the mean, it displays the offset that is signed which does not provide the locator with a real idea of where the utilities might lie. For instance, if the mean value is -0.01m then the expected value of the utility under investigation is going to be 0.01m to the South (assuming the North is defined as being positive) when a locate is being performed. However, in the case where the sample size is small, this is not a solid statistic since an equal number of observations can be positive and an equal number of observations can be negative, practically cancelling out each other. However, the mean of the absolute value will yield an unsigned mean offset value that is either a positive or negative indication of dispersion (Ghilani and Wolf, 2006).

Lastly, the root mean square is a measure of the magnitude of a set of numbers and represents a measure of dispersion for a small set of numbers. It is literally the square root of the mean of the squares of the values in a data set of n values $\{y_1, y_2, \ldots, y_n\}$ (See Equation 5.3)

$$y_{\text{rms}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2} = \sqrt{\frac{y_1^2 + y_2^2 + \cdots + y_n^2}{n}} \tag{5.3}$$

These descriptors were used to evaluate the offset data sets through three approaches: (i) analysis of data of utilities that lie within and outside the right-of-way (ROW) across each project; (ii) analysis of data specific to direction (i.e. offset line extended North, South, East, West) within each project; and (iii) analysis of data specific to each utility within each project.

The first approach involves examining the descriptor values within each project in order to distinguish whether a systematic pattern exists with regards to utilities lying within or beyond the right of way. The utilities include Buried Electric, Gas, Water, and Sewer. Storm sewer and sanitary sewer lines were designated and/or located in only two projects out of the possible seven; the first being Kenneth Avenue and Spring Garden Avenue and the second being the Yonge Street investigation.

The second approach involves assessing the descriptive parameters after it has been appropriately partitioned into North, South, East, and West lying utilities in order to see whether a systematic pattern exists. Utilities were partitioned according to the where they exist relative to the major roadway within each project. For instance, within the Queensway project the utility data was partitioned into those which lie North or South of the Queensway, which runs East-West. In the analysis specific to each project, some observed data sets have been partitioned into North, South, East, and West. In other words, some examined utilities are on connecting roads which are generally perpendicular to the primary road of interest. For instance, within the Queensway project, those distances that have been partitioned East or West exist within or along the intersecting roadways including Moynes Avenue, Winslow Street, Berl Avenue, and Milton Street.

The last approach looks at the analysis of the descriptor parameter values of each utility within each project. For instance, comparing and evaluating the values between buried electric, gas, water, and sewer within the Queensway project.

Another important point to mention is the outlier value; which refers to any value that does not appear to possess the characteristic distribution of the rest of the data. For instance, in the data set {2, 7, 4, 5, 31, 3, 3, 9, 13, 11, 15) the value of 31 can be labeled as an outlier. Statistically speaking, any measurement that falls outside of two standard deviations (i.e. 95.45% of all collected measurements) is considered to be an outlier. One standard deviation represents the variance in measurements that includes 68% of all measurements. This is under the assumption that the collected measurements are distributed normally.

Within the analyses of this project, it is recommended that the outliers be excluded due to the fact that they are unrepresentative measurements that can significantly skew the results. Therefore, the results were tabulated twice, the first phase involved including the outliers within the entire sample set and the second phase involved tabulating the data sets after the exclusion of the outliers. The outliers were determined by simply eliminating any measurement whose absolute offset value was more than two standard deviations (2σ) of the total rms value of the entire data set. The root mean square is considered to be a measure of dispersion. And as the sample size increases, this parameter is to be seen as an approximation of the standard deviation. In the case of this project, the sample sizes were relatively small, hence the choice of the root mean square.

If the entire data set tabulation displayed a value of 1.85 as the rms, then the outliers can be identified by eliminating those absolute offset values that are higher than two times or 2σ the total rms value or, in this case, anything higher in value than 3.70. The analysis of each project will display the significant affects of the above-mentioned outliers.

5.5.1 The Queensway – Subsurface Utility Investigation from Moynes Avenue to Berl Avenue and from Winslow Street to Milton Street

The SUE investigation took place on Queensway from Moynes Avenue to Berl Avenue and from Winslow Street to Milton Street, an area of 240m by 50m. See Figure 5.15 for a detailed look at the above-ground surface image and subsurface utilities web. The data set involves a collection of 21 paired distances, each point representing the offset distances from the utility, in question, to the corresponding lot line, perpendicularly.

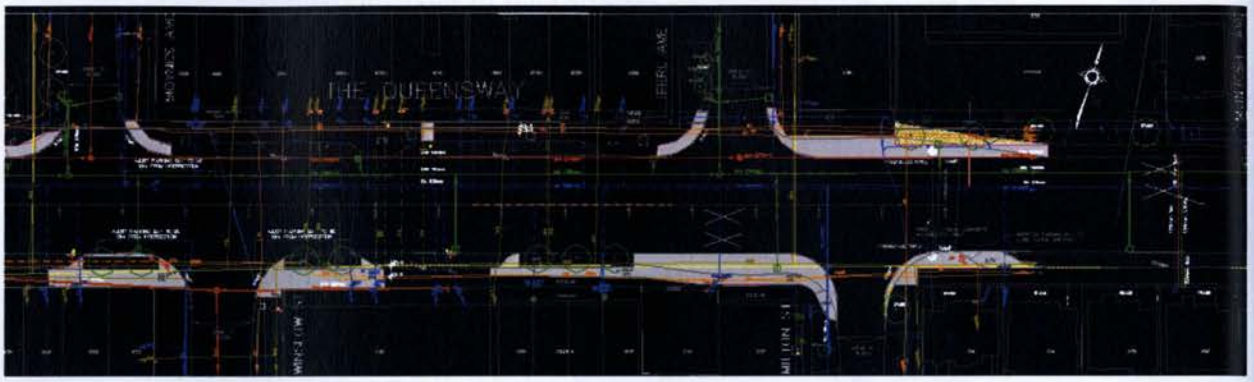


Figure 5.15 Digital image of subsurface utilities within the Queensway project (TSH/TBE, 2008).

The measurements taken from the DMOG record are all in QL-D due to the fact that they were compiled using as-built records and existing utility drawings. Whereas, the measurements taken from the formerly known TSH/TBE company are quality level B and D for this particular project.

According to the data measurements of the entire sample set, the offset measurements can range from a minimum value of 0.02m to a maximum value of 7.35m. Table F.1 in Appendix F displays extensive data sets collected for the Queensway project. However, when the maximum value is compared to the entire data set and the rms, it clearly satisfies the condition to be classified as an outlier.

The first approach resulted in sixteen paired data sets (i.e. one from the DMOG drawing and the other observed in field) that have been partitioned to lie within the right of way, whereas, the remaining five lie beyond the right of way extents. The average of these planimetric offsets with outliers in tact is 0.32m within the right of way and 1.24m beyond the right of way. The average of the offsets with the outliers removed, within the right of way is -0.11m and -0.29m as shown in Table 5.1. The outlier removal condition value (i.e. the standard deviation value of the total rms multiplied by two) is also shown below each table.

Taking a look at these values, it can be stated that no systematic nature exists, since both values are closer to zero so it can be equally distributed. The numbers are not significant enough to say that when performing a locate the utilities that lie within the ROW are easier to find compared to those that lie beyond the ROW. However, based on the rms statistics gathered from the observed data, 68% of the time, the utility that lies within the ROW is locatable within ±0.77m from the starting point. And 68% of the time, the utility that lies beyond the ROW is locatable within ±0.90m from the starting position.

Table 5.1 ROW Partitioned Differences: Queensway Project

Sample size = 21	**WITHIN ROW**			**OUTSIDE ROW**		
	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
	0.30	0.30	0.09	7.35	7.35	54.04
	1.76	1.76	3.10	0.28	0.28	0.08
	0.32	0.32	0.10	0.47	-0.47	0.22
	0.47	0.47	0.22	0.47	-0.47	0.22
	0.40	-0.40	0.16	0.47	-0.47	0.22
	0.37	-0.37	0.13	**1.81**	**1.24**	**3.31**
	0.02	-0.02	0.00	**0.42**	**-0.29**	**0.90**
	6.75	6.75	45.62			
	1.78	-1.78	3.16			
	0.28	0.28	0.08			
	0.34	-0.34	0.11	**2σ=**	**6.62**	
	0.45	-0.45	0.20			
	0.69	-0.69	0.47			
	0.46	0.46	0.21			
	0.86	-0.86	0.73			
	0.31	-0.31	0.10			
OUTLIERS	**0.97**	**0.32**	**1.85**			
OUTLIERS REMOVED	**0.59**	**-0.11**	**0.77**			

2σ = 3.70

According to the values obtained from the direction partitioned statistics (see Table 5.2), 68% of the time, for those utilities that lie North of the Queensway, it is detectable ±0.37m from the starting position. Likewise, the values for the South and East side can be seen in the Table 5.2. The west partition does not exist because the data set does not include any measurements taken to the west of any streets within this particular project.

Table 5.2 Direction Partitioned Differences: Queensway Project

NORTH			SOUTH			EAST		
$\|y_i\|$	y_i	$(y_i)^2$	$\|y_i\|$	y_i	$(y_i)^2$	$\|y_i\|$	y_i	$(y_i)^2$
0.47	0.47	0.22	0.30	0.30	0.09	0.28	0.28	0.08
0.40	-0.40	0.16	1.76	1.76	3.10	0.45	-0.45	0.20
0.37	-0.37	0.13	0.32	0.32	0.10	0.86	-0.86	0.73
0.02	-0.02	0.00	1.78	-1.78	3.16	0.31	-0.31	0.10
0.28	-0.28	0.08	0.69	-0.69	0.47	**0.47**	**-0.34**	**0.53**
0.47	-0.47	0.22	0.46	0.46	0.21			
0.33	**-0.18**	**0.37**	0.47	-0.47	0.22			
			0.47	-0.47	0.22			
		OUTLIERS	**0.78**	**-0.07**	**0.97**			
2σ=	**0.74**		**2σ=**	**1.94**		**2σ=**	**1.06**	

Again, the data was partitioned into direction dependent values for analysis, however, statistically, the results do not display any systematic pattern and they all possess the equal chance of being locatable North, South, or East.

According to the third approach, within the Queensway project the averages between buried electric, gas, and water are -0.13m, -0.52m, and 1.88m with outliers in place. Once the outliers have been removed, the buried electric value becomes 0.89m. Again, no significant pattern is recognized to help the locator determine whether or not buried electric facilities are more accurate, in terms of its location, compared to those of gas and water (see Table 5.3). However, according to the statistical results, 68% of the time when locating a buried electric utility within the Queensway corridor, it is likely to lie ±2.31m from the starting position and likewise ±0.46m for gas utilities and ±0.55m for water utilities.

TABLE 5.3 Utility Partitioned Differences: Queensway Project									
	BURIED ELECTRIC			GAS			WATER		
	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
	0.304	0.30	0.09	0.45	-0.45	0.20	0.86	-0.86	0.73
	1.76	1.76	3.10	0.69	-0.69	0.47	0.31	-0.31	0.10
	0.319	0.32	0.10	0.46	0.46	0.21	0.47	-0.47	0.22
	0.467	0.47	0.22	0.28	-0.28	0.08	0.47	-0.47	0.22
	0.4	-0.40	0.16	0.28	0.28	0.08	0.47	-0.47	0.22
	0.367	-0.37	0.13	**0.43**	**-0.13**	**0.46**	**0.52**	**-0.52**	**0.55**
	7.351	7.35	54.04						
	0.023	-0.02	0.00					**2σ=**	**1.10**
	6.754	6.75	45.62	**2σ=**	**0.92**				
	7.351	7.35	54.04						
	2.47	2.47	6.10						
	1.778	-1.78	3.16						
	0.276	0.28	0.08						
OUTLIERS	**2.28**	**1.88**	**3.58**						
OUTLIERS REMOVED	**1.36**	**0.89**	**2.31**						
	2σ=	**7.16**							

5.5.2 GERRARD STREET - Subsurface Utility Investigation for Watermain Replacement Project

As mentioned earlier, this SUE investigation dealt with a corridor along Gerrard Street, stretching from Yonge Street to Jarvis Street, an area of 520m by 35m. Mapping of existing utilities was required in order to design a new watermain in the area. An image of the underground facilities within the study area can be seen in Figure 5.16.

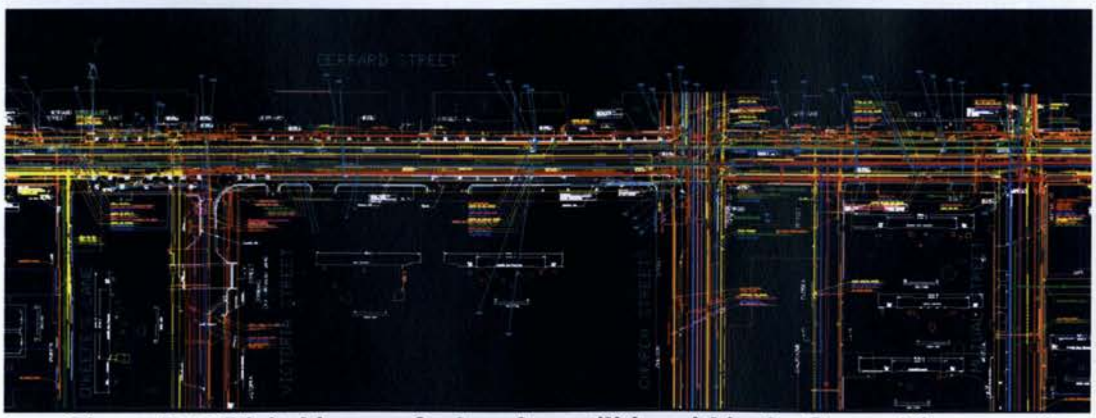


Figure 5.16 Digital image of subsurface utilities within the Gerrard Street project (TSH/TBE, 2005).

The scope of this investigation involved quality level D information from the City supplied DMOG drawing and QL-B and QL-A collection by the SUE services team (i.e. the TSH/TBE group). QL-B data refers to utilities detected using geophysical methods and QL-A data refers to utilities located using vacuum excavation techniques.

This data set collection consists of 19 paired distances, where each pair represents the offset distances from the utility, in question, to the corresponding curb in a perpendicular manner.

With respect to the measurements of the entire sample set, the offset measurements can range from a minimum value of 0.00m to a maximum value of 4.33m. A detailed table of the entire data collected for this project can be found in Table F.2 in Appendix F. In this case, the maximum value is highly likely to be an outlier.

The first approach resulted in four data pairs that lie within the ROW, whereas, fifteen remain beyond the ROW. The average of these planimetric offsets with outliers in tact is 0.85m within the right of way and 0.04m beyond the right of way. The average of the offsets with the outliers removed, within the right of way is -0.31m and 0.10m as shown in Table 5.4. The outlier removal condition value (i.e. the two standard deviation value of the total rms) is also displayed beneath each table.

Table 5.4 ROW Partitioned Differences: Gerrard Street Project

	WITHIN ROW			OUTSIDE ROW		
SAMPLE SIZE=	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
19	0.33	-0.33	0.11	1.84	1.84	3.40
	0.11	-0.11	0.01	1.49	1.49	2.23
	0.49	-0.49	0.24	0.36	0.36	0.13
	4.33	4.33	18.71	1.54	-1.54	2.36
OUTLIERS	**1.31**	**0.85**	**2.18**	2.54	-2.54	6.46
OUTLIERS REMOVED	**0.31**	**-0.31**	**0.35**	0.23	0.23	0.05
				0.78	0.78	0.61
				0.40	-0.40	0.16
				0.07	0.07	0.00
				0.34	0.34	0.11
				0.38	-0.38	0.15
2σ= 4.36				0.28	0.28	0.08
				0.17	0.17	0.03
				0.33	0.33	0.11
				0.48	-0.48	0.23
				0.75	**0.04**	**1.04**
		2σ=	**2.08**	**0.53**	**0.10**	**0.83**

Again, from the evidential statistics of this project, the average offset measurements do not display any useful information to distinguish whether locating utilities are better or worse when trying to seek them within or beyond the ROW. And in the case of the sample size of four within the ROW table is not significant enough to draw any solid conclusions.

The root mean square values illustrates that 68% of the time, the utility that lies within the ROW is locatable within $\pm$0.35m from the starting point. And 68% of the time, the utility that lies beyond the ROW is locatable within $\pm$0.83m from the starting position. These statistics are slightly better than those of the Queensway, nevertheless nothing significant enough to draw any solid conclusions with respect to utilities that lie within or beyond the ROW.

Table 5.5 displays the data partitioned into North, South, East and West direction values. After the analysis of the statistical values of their mean and rms took place, it can be safely said that no systematic pattern was evident.

Table 5.5 Direction Partitioned Differences: Gerrard Street Project

NORTH			**SOUTH**			**EAST**			**WEST**
$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	y_i
4.33	4.33	18.71	0.33	-0.33	0.11	1.49	1.49	2.23	1.84
1.54	-1.54	2.36	0.11	-0.11	0.01	0.36	0.36	0.13	
0.40	-0.40	0.16	0.49	-0.49	0.24	2.54	-2.54	6.46	
0.34	0.34	0.11	0.23	0.23	0.05	**1.47**	**-0.23**	**1.71**	
0.33	0.33	0.11	0.78	0.78	0.61				
1.39	**0.61**	**2.07**	0.07	0.07	0.00				
0.65	**-0.32**	**0.83**	0.38	-0.38	0.15	**2σ=**	**3.42**		
			0.28	0.28	0.08				
2σ=	**4.14**		0.17	0.17	0.03				
			0.48	-0.48	0.23				
			0.33	**-0.03**	**0.39**				
			2σ=	**0.78**					

According to the last approach, within the Gerrard Street project the averages between buried electric, gas, and water are 0.70m, -0.37m, and 0.04m including outliers and 1.10m and 0.45m for gas and water excluding outliers. When the locator is in the field, no apparent pattern can be used, from this study's results, to state that locating a gas utility is easier than a water facility. However, according to the statistical results, 68% of the time when locating a buried electric utility within the Gerrard Street project area, it is likely to lie ±1.10m from the starting position and likewise ±0.45m for gas utilities and ±0.34m for water utilities.

Table 5.6 Utility Partitioned Differences: Gerrard Street Project

	BURIED ELECTRIC			**GAS**			**WATER**		
	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
	0.33	-0.33	0.11	2.54	-2.54	6.46	0.34	0.34	0.11
	0.11	-0.11	0.01	0.23	0.23	0.05	0.38	-0.38	0.15
	0.49	-0.49	0.24	0.78	0.78	0.61	0.28	0.28	0.08
	4.33	4.33	18.71	0.40	-0.40	0.16	0.17	0.17	0.03
	1.84	1.84	3.40	0.07	0.07	0.00	0.33	0.33	0.11
	1.49	1.49	2.23	**0.80**	**-0.37**	**1.21**	0.48	-0.48	0.23
	0.36	0.36	0.13	**0.37**	**0.17**	**0.45**	**0.33**	**0.04**	**0.34**
	1.54	-1.54	2.36						
OUTLIERS	**1.31**	**0.70**	**1.84**	**2σ=**	**2.42**				
OUTLIERS REMOVED	**0.88**	**0.18**	**1.10**				**2σ=**	**0.68**	
	2σ=	**3.68**							

Furthermore, according to the TSH/TBE Group, the DMOG map had shown two Hydro One structures along the south side of the road beneath the sidewalk and in a section on the north side of the road. However, the locating crew was not successful in verifying the two structures because distinct signals could not be distinguished. Also, distinct signals could not be distinguished between two Toronto Hydro structures that run along Gerrard Street due to the fact that both were in close proximity of one another.

5.5.3 Reconstruction of Royal York Road from Delroy Drive to Leland Avenue

SUE services were acquired to locate utilities on the premises of Royal York Road between Delroy Drive and Leland Avenue, an area 1150m by 45m. Figure 5.17 displays the underground drafted utility image. Previous reconstruction work had been completed in the same area with specific assets directed to installation of new sewers.

[illegible] accordingly to [illegible] through [illegible] for the gas utility [illegible]

Furthermore, upon discussing the ESN/TRS surveys that the TRS had shown two Hydro One surveys along the south side of the road beneath the sidewalk and in a [illegible] south side of the road. However, the location [illegible] would not be [illegible]. Also, [illegible] between two Toronto Hydro [illegible] along [illegible] Street due to the fact that both were in close proximity of one another.

5.5.3 Reconstruction of Royal York Road from Delroy Drive to Leland Avenue

SUE services were acquired to locate utilities on the boundaries of Royal York Road between Delroy Drive and Leland Avenue, an area 115m by 40m. Figure 5.17 displays the underground drafted utility image. Previous reconstruction work had been completed in the same area with specific scope devoted to installation of new sewers.

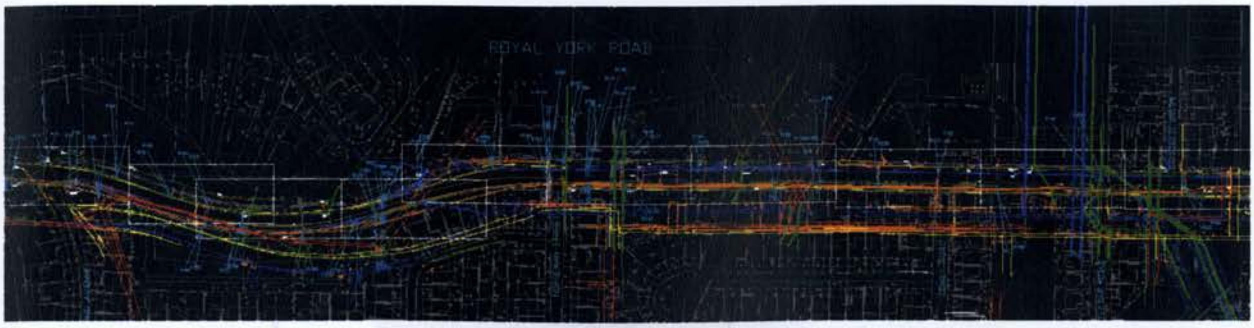


Figure 5.17 Imagery of underground utilities along Royal York Road (TSH/TBE, 2006).

Like the Gerrard Street project, this project also included a collection of QL-D, QL-B, and QL-A data. A total of paired distances of observed data was collected.

Analyzing the entire sample set, the offset distances contain a minimum value of 0.01m to a maximum value of 6.54m. A detailed table of the entire data collected for this project can be found in Table F.3 within Appendix F.

The first approach resulted in five data pairs that lie within the ROW, whereas, 28 lie beyond the ROW. The average of these planimetric offsets with and without outliers within the ROW is 0.47m and -0.05m for outliers remaining for those values beyond the ROW. Once the outliers are removed for the values that lie outside the ROW, a value of 0.19m results (see Table 5.7). Again, with the statistical mean being so close to zero, there is no systematic nature to the data which can distinguish whether or not a locate within or beyond the ROW is better or worse than one another.

However, according to the statistical data gathered from the observed data, 68% of the time the utility that lies within the ROW can be located anywhere between $\pm$0.84m and for those outside the ROW $\pm$1.30m. The measure of dispersion within this reconstruction project is higher than that of the Queensway and the Gerrard Street project. However, the sample data set for the values within the ROW is significantly low (i.e. five) to draw any solid conclusions from this particular data set. Table 5.8 contains direction partitioned planimetric offsets. The South partition does not contain any planimetric offset values due to the fact that no measurements were on the south side of any streets within this particular project.

TABLE 5.7 ROW Partitioned Differences: Royal York Road Project

WITHIN ROW			OUTSIDE ROW			
$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	
0.24	-0.24	0.06	0.46	0.46	0.21	**SAMPLE SIZE=**
0.88	0.88	0.77	0.68	-0.68	0.47	33
0.97	0.97	0.94	1.19	1.19	1.41	
1.23	1.23	1.50	0.20	0.20	0.04	
0.47	-0.47	0.22	0.47	0.47	0.22	
0.76	**0.47**	**0.84**	1.06	1.06	1.12	
			1.14	1.14	1.31	
			0.18	0.18	0.03	
			0.19	-0.19	0.04	
			0.44	-0.44	0.20	
			0.98	-0.98	0.97	
			3.09	3.09	9.56	
			0.01	-0.01	0.00	
			0.04	-0.04	0.00	
			1.67	-1.67	2.80	
			0.08	0.08	0.01	
			1.09	-1.09	1.19	
			6.54	-6.54	42.72	
			0.17	0.17	0.03	
			0.44	-0.44	0.20	
			0.76	-0.76	0.58	
			0.50	-0.50	0.25	
			0.77	-0.77	0.59	
			1.35	1.35	1.84	
			2.79	-2.79	7.80	
			2.86	2.86	8.21	
			2.41	2.41	5.83	
			0.73	0.73	0.53	
			1.15	**-0.05**	**1.77**	**OUTLIERS**
			0.95	**0.19**	**1.30**	**OUTLIERS REMOVED**

2σ= 1.68 **2σ= 3.54**

TABLE 5.8 Direction Partitioned Differences: Royal York Road Project

NORTH $\lvert y_i \rvert$	NORTH y_i	NORTH $(y_i)^2$	SOUTH	EAST $\lvert y_i \rvert$	EAST y_i	EAST $(y_i)^2$	WEST $\lvert y_i \rvert$	WEST y_i	WEST $(y_i)^2$
6.54	-6.54	42.72		0.46	0.46	0.21	0.68	-0.68	0.47
0.17	0.17	0.03		0.24	-0.24	0.06	0.88	0.88	0.77
3.35	**-3.18**	**4.62**		0.47	0.47	0.22	1.19	1.19	1.41
				1.14	1.14	1.31	0.20	0.20	0.04
				0.18	0.18	0.03	1.06	1.06	1.12
				3.09	3.09	9.56	0.19	-0.19	0.04
				0.01	-0.01	0.00	0.44	-0.44	0.20
				0.08	0.08	0.01	0.98	-0.98	0.97
				0.97	0.97	0.94	0.04	-0.04	0.00
				1.23	1.23	1.50	1.67	-1.67	2.80
				0.79	**0.74**	**1.18**	1.09	-1.09	1.19
				0.53	**0.48**	**0.69**	0.44	-0.44	0.20
							0.76	-0.76	0.58
							0.50	-0.50	0.25
							0.77	-0.77	0.59
				2σ=	**2.36**		1.35	1.35	1.84
							0.47	-0.47	0.22
							2.79	-2.79	7.80
							2.86	2.86	8.21
							2.41	2.41	5.83
							0.73	0.73	0.53
							0.20	0.20	0.04
					OUTLIERS		**0.99**	**0.00**	**1.26**
					OUTLIERS REMOVED		**0.80**	**0.00**	**0.98**
							2σ=	**2.52**	

With respect to the last approach, the averages for the Royal York Road project are 0.30m, 0.28m, and -0.40m for buried electric, gas, and water with outliers in tact. Whereas, the mean values with the outliers removed are 0.05m and 0.08m for gas and water. Again, there exists no systematic pattern within these values (see Table 5.9). One type of utility locate does not seem better than another in terms of locational accuracy.

Based on the statistical results, 68% of the time when locating a buried electric utility within the Royal York Road study area, it is likely to lie ±0.70m from the starting position and ±0.80m for gas utilities and ±1.45m for water utilities.

TABLE 5.9 Utility Partitioned Differences: Royal York Road Project									
BURIED ELECTRIC			GAS			WATER			
$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	
0.46	0.46	0.21	0.47	0.47	0.22	1.09	-1.09	1.19	
0.24	-0.24	0.06	1.06	1.06	1.12	0.17	0.17	0.03	
0.68	-0.68	0.47	1.14	1.14	1.31	0.44	-0.44	0.20	
1.19	1.19	1.41	0.18	0.18	0.03	0.76	-0.76	0.58	
0.20	0.20	0.04	0.19	-0.19	0.04	0.50	-0.50	0.25	
0.88	0.88	0.77	0.44	-0.44	0.20	0.77	-0.77	0.59	
0.61	**0.30**	**0.70**	0.98	-0.98	0.97	1.35	1.35	1.84	
			3.09	3.09	9.56	0.47	-0.47	0.22	
			0.01	-0.01	0.00	2.79	-2.79	7.80	
2σ=	**1.40**		0.04	-0.04	0.00	2.41	2.41	5.83	
			1.67	-1.67	2.80	0.73	0.73	0.53	
			0.08	0.08	0.01	6.54	-6.54	42.72	
			0.97	0.97	0.94	2.86	2.86	8.21	
			0.79	**0.28**	**1.15**	0.20	0.20	0.04	
			0.60	**0.05**	**0.80**	**1.51**	**-0.40**	**2.24**	**OUTLIERS**
						1.12	**0.07**	**1.45**	**OUTLIERS REMOVED**
			2σ=	**2.30**		**2σ=**	**4.48**		

Finally, distinct signals could not be distinguished between two Toronto Hydro structures that run along Gerrard Street due to the fact that both were in close proximity of one another.

5.5.4 Kenneth Avenue and Spring Garden Avenue – SUE Investigation

This investigation took place at the intersection of Kenneth Avenue and Spring Garden Avenue, an area of 50m by 60m. An overflow link was being proposed in this particular intersection between the existing storm and sanitary sewer network. The SUE investigation required that the existing utilities be located in order to accommodate for the new link. Since this project only mostly involved the storm and sanitary sewer system, the TSH/TBE Group only designated for storm and sanitary sewers. The intersection itself lies within a new residential area as well (see Figure 5.18).

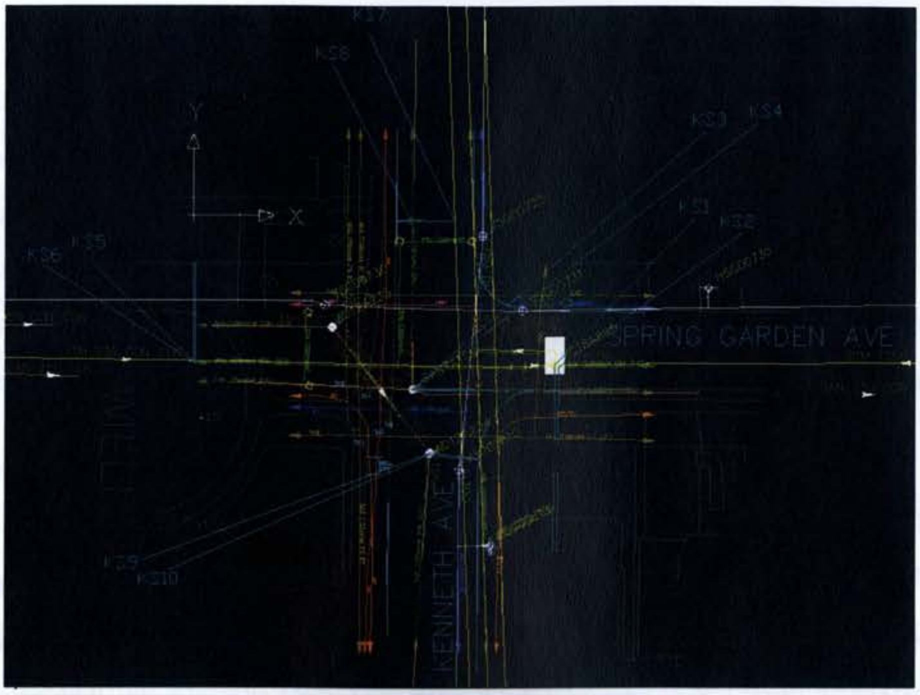


Figure 5.18 Imagery of underground utilities within Kenneth Avenue and Spring Garden Avenue (TSH/TBE, 2007).

There were a total of 5 paired distances collected. Each point represents the offset distances from the utility, in question, to the closest curb in a perpendicular fashion. This data set is relatively small compared to the previous projects and all collected distances lie within the row. The reason for the collection of such a small data set was due to the size of the project, it is relatively small compared to the other six projects provided by the City of Toronto and TSH/TBE. Table 5.10 displays the statistical values of the offset measurements.

	TABLE 5.10 ROW Partitioned Differences: Kenneth and Spring Garden Ave. Project		
		WITHIN ORIGINAL	
SAMPLE SIZE=	$\lvert y_i \rvert$	y_i	$(y_i)^2$
5	0.22	-0.22	0.05
	0.09	0.09	0.01
	4.80	-4.80	23.03
	0.19	-0.19	0.04
OUTLIERS-------	**1.32**	**-1.28**	**2.40**
OUTLIERS REMOVED-------	**0.17**	**-0.11**	**0.18**

2σ= 4.80

According to the statistical results, 68% of the time the utility being located within this intersection may lie $\pm$0.18m from the starting position. And the average is -0.11m which is close to the zero value making it evident that a clear logical pattern does not exist within this project either. Since this project only investigated the storm and sanitary network, only one utility was investigated. And since the sample data set is so small, a solid conclusion cannot be drawn form the resulting statistical values.

5.5.5 Union Station NW PATH - Subsurface Utility Investigation

This new PATH tunnel extension is approximately 3m by 5m, and the investigation area runs along York Street from Front Street to Wellington Street, which is significantly large for an area of land within the City's core streets. The area is roughly 360m by 280m and Figure 5.19 exhibits the subsurface nature of the study area. A total of 37 coupled distances were collected from the composite maps.

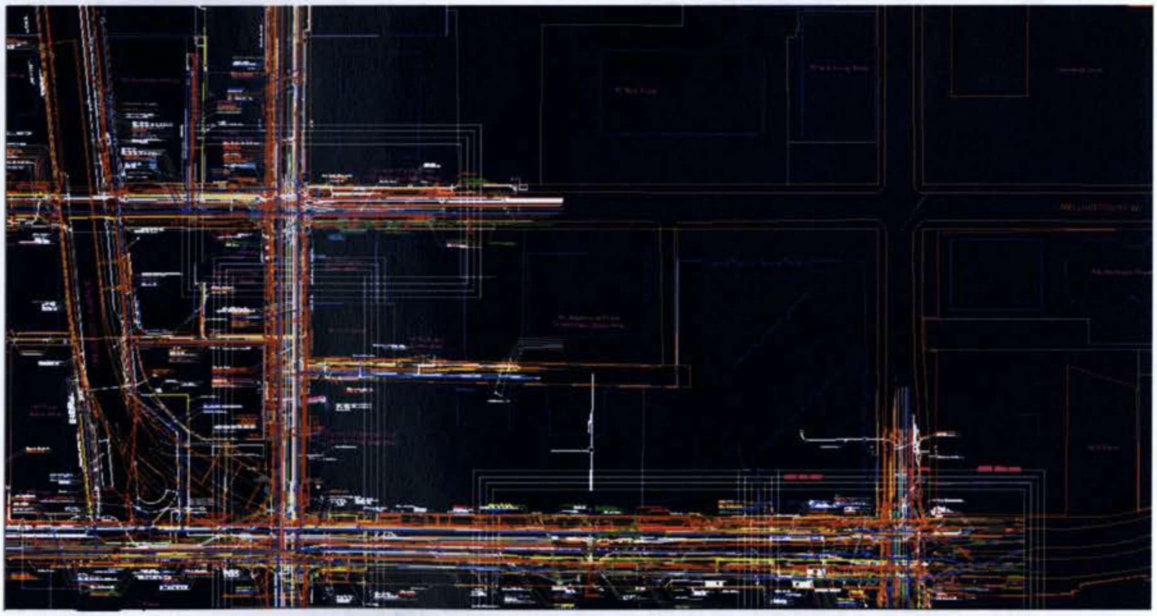


Figure 5.19 Imagery of subsurface utilities within the Union Station NW PATH project (TSH/TBE, 2007).

The observed data set shows a minimum value of 0.06m and a maximum value of 13.16m as the offset distances. The measurements performed by the TSH/TBE Group are of QL-A, QL-B, and QL-D for this particular project. An in-depth table is available in Appendix F, Table F.5 containing the entire data collection and statistical results.

Within this project, most of the observed data (i.e. 34 out of a possible 37 measurements lie within the ROW whereas only four lie outside the ROW. The average values with outliers intact is–0.73m within the ROW and -0.28m outside the ROW. Once the outliers were removed, the results were much more logical, -0.01 for those within ROW and -0.23m for those that lie beyond the ROW. The statistical values for the average data that lie beyond are not that significant due to the size of the sample. However, the values for those that lie within the ROW simply states there is no real pattern as to how good or poor a locate will be when locating utilities within the ROW in this project area. Table 5.11 displays the observed data and its statistical values. 68% of the time the locators locating a utility within the right of way in this project area is either $\pm$0.45m from the starting location. And when locating outside the ROW, it is $\pm$1.10m on either side of the initial point. The measure of dispersion is quite high for both inside and outside ROW limits.

TABLE 5.11 ROW Partitioned Differences: Union Station NW PATH Project						
	WITHIN			**OUTSIDE**		
SAMPLE SIZE=	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
38	0.19	0.19	0.04	0.76	-0.76	0.57
	0.23	-0.23	0.05	0.72	0.72	0.53
	0.22	-0.22	0.05	0.71	0.71	0.50
	0.45	-0.45	0.20	1.81	-1.81	3.27
	0.22	-0.22	0.05	**1.00**	**-0.28**	**1.10**
	0.78	-0.78	0.60			
	0.41	0.41	0.17	**2σ=**	**2.20**	
	0.36	0.36	0.13			
	0.22	-0.22	0.05			
	0.57	-0.57	0.33			
	0.63	0.63	0.40			
	0.48	0.48	0.23			
	0.35	-0.35	0.12			
	0.56	0.56	0.31			
	0.63	-0.63	0.39			
	0.27	-0.27	0.07			
	0.14	-0.14	0.02			
	0.58	0.58	0.33			
	11.39	-11.39	129.82			
	0.33	0.33	0.11			
	0.33	0.33	0.11			
	0.62	0.62	0.39			
	0.20	0.20	0.04			
	0.40	0.40	0.16			
	13.16	-13.16	173.19			
	0.06	0.06	0.00			
	0.22	-0.22	0.05			
	0.60	-0.60	0.37			
	0.49	0.49	0.24			
	0.28	-0.28	0.08			
	0.44	-0.44	0.19			
	0.39	-0.39	0.15			
	0.70	-0.70	0.49			
	0.75	0.75	0.57			
OUTLIERS	**1.11**	**-0.73**	**3.02**			
OUTLIERS REMOVED	**0.41**	**-0.01**	**0.45**			
	2σ=	**6.04**				

Likewise the statistical parameters of mean, mean of absolute values and root mean square were tabulated after the data had been partitioned into North, South, East and West-specific data (see Table 5.12).

TABLE 5.12 Direction Partitioned : Union Station NW PATH Project

NORTH			SOUTH			EAST			WEST		
$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.63	0.63	0.40	0.72	0.72	0.53	0.76	-0.76	0.57	0.23	-0.23	0.05
0.48	0.48	0.23	0.71	0.71	0.50	0.78	-0.78	0.60	0.22	-0.22	0.05
0.35	-0.35	0.12	0.22	-0.22	0.05	0.41	0.41	0.17	0.45	-0.45	0.20
0.33	0.33	0.11	0.56	0.56	0.31	0.36	0.36	0.13	0.63	-0.63	0.39
0.33	0.33	0.11	0.14	-0.14	0.02	0.22	-0.22	0.05	1.81	-1.81	3.27
0.42	**0.28**	**0.44**	0.58	0.58	0.33	0.57	-0.57	0.33	0.22	-0.22	0.05
			0.62	0.62	0.39	0.27	-0.27	0.07	0.60	-0.60	0.37
2σ=	**0.88**		0.20	0.20	0.04	11.39	-11.39	129.82	0.49	0.49	0.24
			0.40	0.40	0.16	13.16	-13.16	173.19	0.28	-0.28	0.08
			0.06	0.06	0.00	0.39	-0.39	0.15	0.44	-0.44	0.19
			0.75	0.75	0.57	0.70	-0.70	0.49			
			0.45	**0.39**	**0.51**	**2.64**	**-2.50**	**5.27**	**0.54**	**-0.44**	**0.70**
						0.50	**-0.32**	**0.53**	**0.39**	**-0.28**	**0.42**
			2σ=	**1.02**							
						2σ=	**10.54**		**2σ=**	**1.40**	

As displayed in Table 5.12, the statistical values for the mean and rms are still quite large in terms of its dispersion pattern.

According to the last approach, the mean offsets for the Union Station NW PATH project are 0.02m, -1.91m, and –0.17m for buried electric, gas, and water with outliers in tact (see Table 5.13). Whereas, the mean values with the outliers removed for the gas utilities is -0.03m. Again, there exists no systematic pattern within these values and a locator cannot be told that when conducting a locate in the field, he/she will be able to find the gas facilities easily compared to the others.

However, based on the statistical results, 68% of the time when locating a buried electric utility within the Union Station corridor, it may exist ±0.50m from the starting position and ±0.67m for gas utilities and ±0.52m for water utilities.

TABLE 5.13 Utility Partitioned Differences: Union Station NW PATH Project								
BURIED ELECTRIC			**GAS**			**WATER**		
$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.76	-0.76	0.57	0.63	-0.63	0.39	0.22	-0.22	0.05
0.72	0.72	0.53	0.27	-0.27	0.07	0.60	-0.60	0.37
0.71	0.71	0.50	1.81	-1.81	3.27	0.49	0.49	0.24
0.19	0.19	0.04	0.14	-0.14	0.02	0.28	-0.28	0.08
0.23	-0.23	0.05	0.58	0.58	0.33	0.44	-0.44	0.19
0.22	-0.22	0.05	11.39	-11.39	129.82	0.39	-0.39	0.15
0.45	-0.45	0.20	0.33	0.33	0.11	0.70	-0.70	0.49
0.22	-0.22	0.05	0.33	0.33	0.11	0.75	0.75	0.57
0.78	-0.78	0.60	0.62	0.62	0.39	**0.48**	**-0.17**	**0.52**
0.41	0.41	0.17	0.20	0.20	0.04			
0.36	0.36	0.13	0.40	0.40	0.16			
0.22	-0.22	0.05	13.16	-13.16	173.19	**2σ=**	**1.04**	
0.57	-0.57	0.33	0.06	0.06	0.00			
0.63	0.63	0.40	**2.30**	**-1.91**	**4.87**	**OUTLIERS**		
0.48	0.48	0.23	**0.49**	**-0.03**	**0.67**	**OUTLIERS REMOVED**		
0.35	-0.35	0.12						
0.56	0.56	0.31	**2σ=**	**9.74**				
0.46	**0.02**	**0.50**						
2σ=	**1.00**							

5.5.6 Yonge Street – Eglinton Avenue to Lawrence Avenue – Subsurface Utility Investigation

As mentioned earlier, a SUE investigation was performed for the Yonge Street stretch from Lawrence Avenue to Eglinton Avenue in order to facilitate the design of two new 300mm watermains. Figure 5.20(a), (b), and (c) displays clear images of the underground facilities of congested intersections within this project.

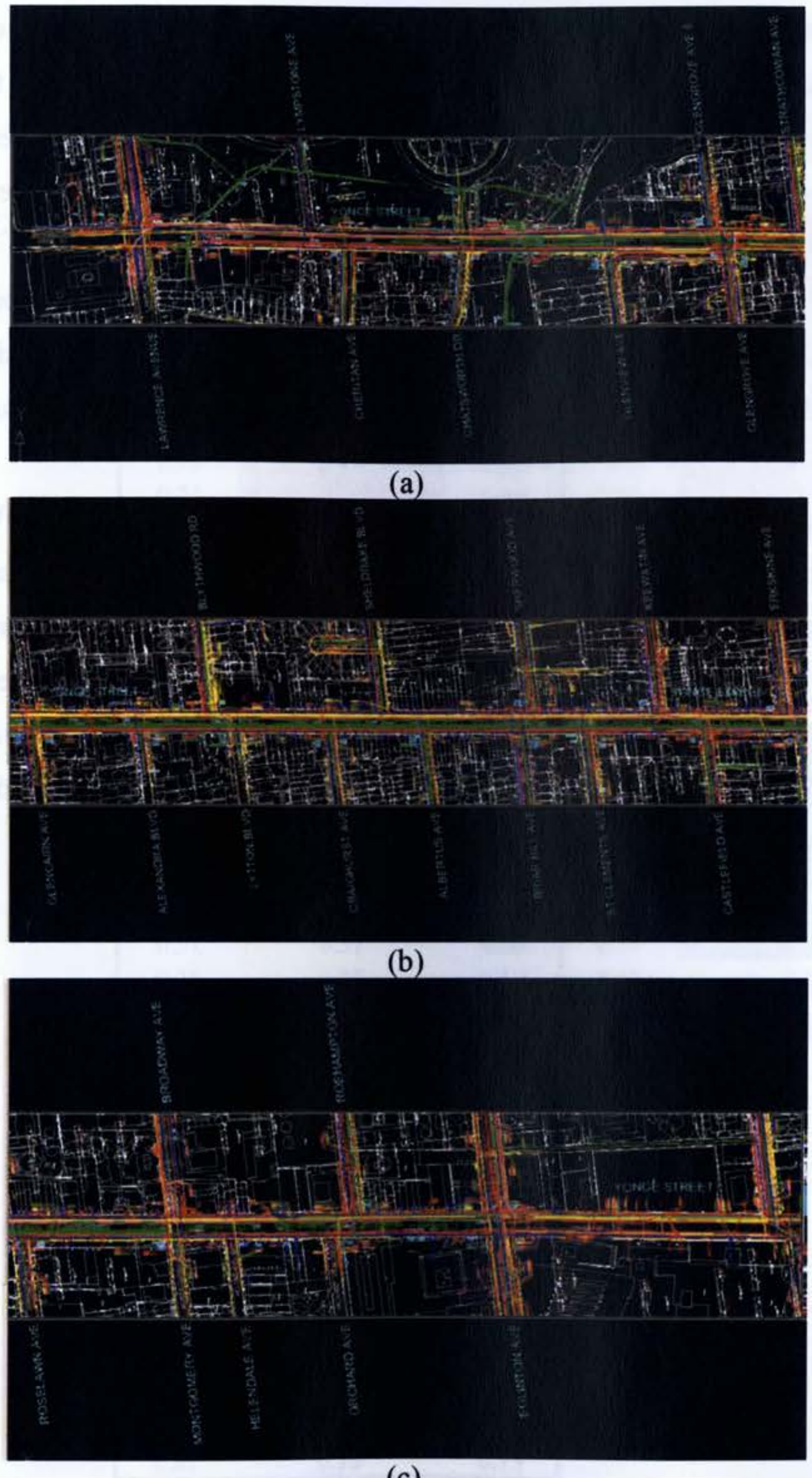


Figure 5.20 Underground utilities along Yonge Street from (a) Lawrence Avenue to Strathcowan Avenue (b) Glencairn Avenue Erkskine Avenue and (c) Roselawn Avenue to Eglinton Avenue (TSH/TBE, 2009).

A total of 58 coupled distances were collected each representing offset distar extending from the utility segment (i.e. one from the DMOG utility and one from th current survey drawing) to the curb in a perpendicular manner. The measurements f the DMOG drawing are classified as QL-D and those taken by TSH/TBE are of QL- QL-C, and QL-B.

With regards to the observed data, the offset data for this particular project c range anywhere from a minimum residual value of 0.11m to a maximum residual of 1.97m. In Appendix F, Table F.6 shows the entire data collected for the Yonge Stre project.

The initial approach resulted in 36 sets of data that lie within the ROW after partitioning them and 22 that lie beyond the ROW. The average of these planimetri offsets with outliers included display a value of 0.23m within the right of way and 0 beyond the right of way. The average of the offsets with the outliers removed, withi right of way is 0.25m and 0.05m as shown in Table 5.14. The outlier removal condi value (i.e. the two standard deviation value of the total rms) is also displayed below table.

TABLE 5.14 ROW Partitioned Differences: Yonge Street Project

SAMPLE SIZE= 58

WITHIN

	$\lvert y_i \rvert$	y_i	$(y_i)^2$
	0.62	0.62	0.39
	0.28	0.28	0.08
	0.68	0.68	0.46
	0.34	0.34	0.11
	0.21	-0.21	0.05
	0.16	0.16	0.03
	0.35	0.35	0.13
	0.16	0.16	0.03
	0.21	0.21	0.04
	0.90	0.90	0.81
	0.35	0.35	0.12
	0.20	0.20	0.04
	0.33	-0.33	0.11
	0.46	0.46	0.21
	0.48	-0.48	0.23
	0.75	0.75	0.56
	0.89	-0.89	0.79
	0.64	0.64	0.41
	0.60	0.60	0.36
	0.39	0.39	0.15
	0.51	-0.51	0.26
	0.51	0.51	0.26
	0.35	0.35	0.12
	0.67	0.67	0.45
	0.71	-0.71	0.51
	1.35	1.35	1.83
	1.97	-1.97	3.88
	1.75	1.75	3.06
	0.22	0.22	0.05
	0.11	0.11	0.01
	0.55	-0.55	0.30
	0.90	-0.90	0.81
	1.07	1.07	1.14
	1.00	1.00	1.01
	1.06	1.06	1.13
	0.46	-0.46	0.21
OUTLIERS	**0.62**	**0.23**	**0.75**
OUTLIERS REMOVED	**0.54**	**0.25**	**0.62**

2σ= **1.50**

OUTSIDE

$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.53	-0.53	0.28
0.20	0.20	0.04
0.64	-0.64	0.41
0.21	-0.21	0.04
0.22	0.22	0.05
0.31	0.31	0.10
0.33	0.33	0.11
0.28	-0.28	0.08
0.51	-0.51	0.26
1.42	1.42	2.02
0.27	0.27	0.08
0.26	-0.26	0.07
0.60	0.60	0.36
0.16	0.16	0.03
0.37	0.37	0.14
0.20	0.20	0.04
0.19	0.19	0.04
0.37	0.37	0.14
0.24	0.24	0.06
0.42	0.42	0.18
0.19	-0.19	0.04
0.30	-0.30	0.09
0.37	**0.11**	**0.46**
0.32	**0.05**	**0.35**

2σ= **0.92**

After analyzing the mean values, it can be stated that there is no evident sign of a systematic pattern, since both values are close to zero the locator's chances of finding the utility within the ROW in this particular project area is equally the same to finding it outside the ROW. Nonetheless, the measure of dispersion gathered from the statistical values suggests that 68% of the time, the utility that lies within the ROW is locatable within ±0.62m from the starting point. And 68% of the time, the utility that lies beyond the ROW is locatable within ±0.35m from the starting position.

According to the values obtained from the direction partitioned statistics (see Table 5.11), 68% of the time, for those utilities that lie East Yonge Street, it is detectable ±0.45m from the starting position. Likewise, the values for the West, North and South sides can be seen in the Table 5.15. The observed data that has been partitioned to the North lie on streets that are relatively perpendicular to Yonge Street.

TABLE 5.15 Direction Partitioned Differences: Yonge Street Project

NORTH $\lvert y_i \rvert$	y_i	$(y_i)^2$
0.20	0.20	0.04
0.64	0.64	0.41
0.37	0.37	0.14
0.71	-0.71	0.51
1.35	1.35	1.83
1.07	1.07	1.14
1.00	1.00	1.01
0.46	-0.46	0.21
0.73	**0.43**	**0.81**

2σ= 1.62

SOUTH $\lvert y_i \rvert$	y_i	$(y_i)^2$
0.53	-0.53	0.28
0.21	-0.21	0.05
0.16	0.16	0.03
1.42	1.42	2.02
0.46	0.46	0.21
0.75	0.75	0.56
0.27	0.27	0.08
0.51	-0.51	0.26
1.75	1.75	3.06
0.37	0.37	0.14
1.06	1.06	1.13
0.68	**0.45**	**0.84**
0.58	**0.32**	**0.69**

2σ= 1.68

EAST $\lvert y_i \rvert$	y_i	$(y_i)^2$
0.62	0.62	0.39
0.28	0.28	0.08
0.22	0.22	0.05
0.16	0.16	0.03
0.21	0.21	0.04
0.90	0.90	0.81
0.35	0.35	0.12
0.26	-0.26	0.07
0.60	0.60	0.36
0.60	0.60	0.36
0.39	0.39	0.15
0.16	0.16	0.03
0.51	0.51	0.26
1.97	-1.97	3.88
0.11	0.11	0.01
0.55	-0.55	0.30
0.19	0.19	0.04
0.90	-0.90	0.81
0.24	0.24	0.06
0.42	0.42	0.18
0.19	-0.19	0.04
0.30	-0.30	0.09
0.46	**0.08**	**0.61**
0.39	**0.18**	**0.45**

2σ= 1.22

WEST $\lvert y_i \rvert$	y_i	$(y_i)^2$
0.68	0.68	0.46
0.34	0.34	0.11
0.64	-0.64	0.41
0.21	-0.21	0.04
0.35	0.35	0.13
0.31	0.31	0.10
0.33	0.33	0.11
0.28	-0.28	0.08
0.51	-0.51	0.26
0.20	0.20	0.04
0.33	-0.33	0.11
0.48	-0.48	0.23
0.89	-0.89	0.79
0.35	0.35	0.12
0.67	0.67	0.45
0.20	0.20	0.04
0.22	0.22	0.05
0.41	**0.02**	**0.45**

2σ= 0.90

Once again, from the analysis of Table 5.16, no real conclusion can be gathered as to whether a utility that lies East of Yonge Street will be easily located compared to one that lies South of Yonge Street, statistically, the results only suggest that at one standard deviation or 68% of the time, the utility being located to the East of Yonge Street will lie anywhere between ±0.45m from the locators starting point, and ±0.45m in the West direction; ±0.81m in the North direction and finally ±0.69m in the South direction.

According to the last approach, the mean offsets for the Yonge Street project are 0.14m, 0.32m, and 0.19m for buried electric, gas, and water with outliers in tact (see Table 5.16). There was only one measurement taken for the sewer utility so its value is not considered to be significant for analysis. Whereas, the mean values with the outliers removed for the buried electric and water facilities are 0.09m and 0.31m. Again, no clear pattern exists, so, the field locator will not be able to determine whether a buried electric cable or a water pipeline will be easier to find based on these statistics.

TABLE 5.16 Utility Partitioned Differences: Yonge Street Project

	BURIED ELECTRIC			GAS			WATER		
	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
	0.62	0.62	0.39	0.64	0.64	0.41	0.71	-0.71	0.51
	0.28	0.28	0.08	0.27	0.27	0.08	1.35	1.35	1.83
	0.68	0.68	0.46	0.26	-0.26	0.07	1.97	-1.97	3.88
	0.53	-0.53	0.28	0.60	0.60	0.36	0.20	0.20	0.04
	0.34	0.34	0.11	0.60	0.60	0.36	1.75	1.75	3.06
	0.21	-0.21	0.05	0.39	0.39	0.15	0.22	0.22	0.05
	0.16	0.16	0.03	0.51	-0.51	0.26	0.11	0.11	0.01
	0.20	0.20	0.04	0.16	0.16	0.03	0.55	-0.55	0.30
	0.64	-0.64	0.41	0.51	0.51	0.26	0.19	0.19	0.04
	0.21	-0.21	0.04	0.37	0.37	0.14	0.37	0.37	0.14
	0.22	0.22	0.05	0.35	0.35	0.12	0.90	-0.90	0.81
	0.35	0.35	0.13	0.67	0.67	0.45	0.24	0.24	0.06
	0.31	0.31	0.10	**0.44**	**0.32**	**0.47**	1.07	1.07	1.14
	0.16	0.16	0.03				1.00	1.00	1.01
	0.33	0.33	0.11				1.06	1.06	1.13
	0.28	-0.28	0.08	**2σ=**	**0.94**		0.42	0.42	0.18
	0.21	0.21	0.04				0.19	-0.19	0.04
	0.90	0.90	0.81				0.30	-0.30	0.09
	0.35	0.35	0.12				**0.70**	**0.19**	**0.89**
	0.51	-0.51	0.26				**0.63**	**0.31**	**0.78**
	0.20	0.20	0.04						
	1.42	1.42	2.02				**2σ=**	**1.78**	
	0.33	-0.33	0.11						
	0.46	0.46	0.21						
	0.48	-0.48	0.23						
	0.75	0.75	0.56						
	0.89	-0.89	0.79						
OUTLIERS	**0.45**	**0.14**	**0.53**						
OUTLIERS REMOVED	**0.41**	**0.09**	**0.46**						
OUTLIERS REMOVED	**2σ=**	**1.06**							

SEWER

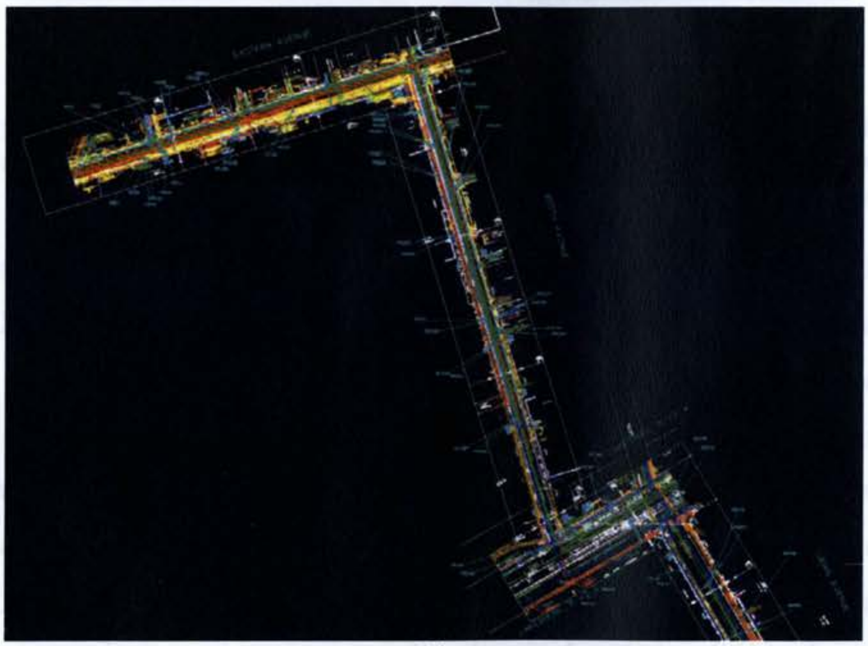
$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.46	-0.46	0.21

However, based on the statistical results, 68% of the time when locating a buried electric utility within the Yonge Street investigation area, the locator may be able to find it within ±0.46m from their starting position and ±0.47m for gas utilities and ±0.78m for water utilities.

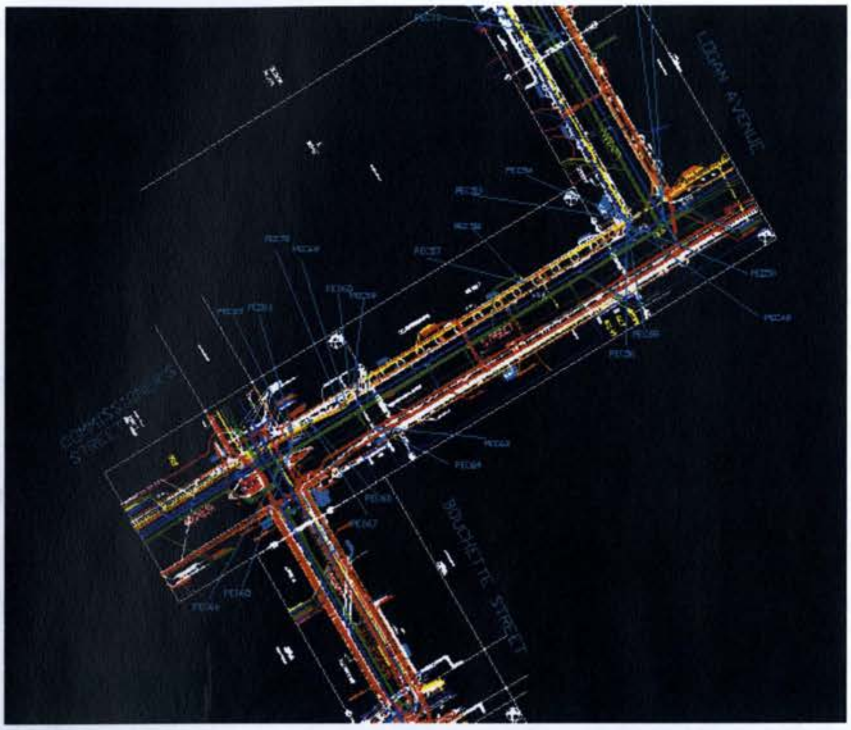
Moreover, the statistics derived from the observed data suggest that on Yonge Street, the utilities shown in the existing plans are relatively close to the utility location of the survey drawings; which merely suggests that maybe importance of accurate, up-to-date drawings within major city streets is greater compared to those located in streets within rural or remote areas.

5.5.7 Portland Energy Centre – Subsurface Utility Investigation for NPS 20 XHP Gas Pipeline Project [Enbridge Gas Distribution Inc.]

For this particular project, the City of Toronto hired the TSH/TBE Group to conduct a SUE investigation to accommodate the newly proposed installation of the NPS 20 extra high pressure (XHP) gas pipeline to serve the Portlands Energy Centre (PEC). Enbridge is the company proposing the new installation. A detailed image of the above-ground state and below ground nature of the PEC project area can be seen in Figure 5.21 (a) and (b).



(a)



(b)

Figure 5.21 Underground utilities for the Portland Energy Centre project along (a) Eastern Avenue down Booth Avenue onto Lake Shore Blvd East straight down Logan and (b) onto Commissioner's Street ending off at Bouchette Avenue (TSH/TBE, 2007).

A total of 38 coupled distances were collected each made up of distances that extend from the desired utility segment (i.e. one measurement from the DMOG utility and one measurement from the most current survey drawing) to the curb in a perpendicular manner. A total of seven extra measurements were made, these distances are horizontal or vertical distances between the DMOG utility segment and the survey utility segment. The measurements from the DMOG drawing are classified as QL-D and those taken by TSH/TBE are of QL-D, QL-C, QL-B, and QL-A.

According to the observed data, the offset data for this particular project has a minimum residual value of 0.06m and a maximum residual value of 9.09m. Table F.7 in Appendix F contains a detailed look into the entire data set collected for the PEC project.

The first approach displayed a value of 28 paired distances that exist within the ROW, whereas, 17 lie beyond the ROW. The mean value of the residuals that include the outliers is 0.41m within the ROW and -0.71m beyond the ROW. The average of the planimetric offsets without the outliers are 0.01m within the ROW and 0.39m beyond the

ROW. Although the statistics seem better when the outliers have been eliminated, it still does not allow for the assumption that the chances of finding utilities are easier or faster within the ROW rather then beyond the ROW. However, what can be stated is that 68% of the time the measure of dispersion gathered from the statistical values display the utility that lies within the ROW is locatable within $\pm$0.58m from the starting point (see Table 5.17). And 68% of the time, the utility that lies beyond the ROW is locatable within $\pm$1.17m from the starting position.

TABLE 5.17 ROW Partitioned Differences: PEC Project

	WITHIN			OUTSIDE		
	$\|y_i\|$	y_i	$(y_i)^2$	$\|y_i\|$	y_i	$(y_i)^2$
SAMPLE SIZE=	0.22	-0.22	0.05	0.06	0.06	0.00
45	0.32	-0.32	0.10	4.05	4.05	16.41
	2.91	2.91	8.47	0.28	-0.28	0.08
	0.26	-0.26	0.07	0.67	-0.67	0.45
	1.24	-1.24	1.53	0.51	0.51	0.26
	5.48	5.48	30.01	0.87	0.87	0.75
	0.49	-0.49	0.24	0.31	0.31	0.09
	0.40	-0.40	0.16	1.40	1.40	1.96
	0.25	-0.25	0.06	0.21	0.21	0.04
	2.90	2.90	8.43	9.09	-9.09	82.65
	0.57	-0.57	0.33	8.93	-8.93	79.70
	0.61	0.61	0.37	0.26	0.26	0.07
	0.26	0.26	0.07	0.57	-0.57	0.33
	0.07	0.07	0.00	0.22	-0.22	0.05
	1.90	1.90	3.63	0.13	-0.13	0.02
	0.17	0.17	0.03	0.14	-0.14	0.02
	0.42	0.42	0.17	0.21	0.21	0.04
	0.28	0.28	0.08	**1.64**	**-0.71**	**3.28**
	0.25	0.25	0.06	**0.66**	**0.39**	**1.17**
	0.33	-0.33	0.11			
	0.76	-0.76	0.58			
	0.26	-0.26	0.07	**2σ=**	**6.56**	
	0.21	-0.21	0.04			
	0.20	0.20	0.04			
	0.40	0.40	0.16			
	0.34	0.34	0.11			
	0.40	0.40	0.16			
	0.20	0.20	0.04			
OUTLIERS	**0.79**	**0.41**	**1.40**			
OUTLIERS REMOVED	**0.43**	**0.01**	**0.58**			

2σ= 2.80

The statistical values for the data that has been partitioned direction-wise is displayed in Table 5.18. The one standard deviation value or, in other words, 68% of the time when locating a utility on the North, South, East or West side of a street within this project area, it can lie anywhere from ±0.87m (N), ±0.91m (S), ±0.38m (E), or ±0.57m (W) on either side of the starting position. Again, statistically speaking, there appears to be no significant pattern that can be used to assist the locator during a locate within this study area.

TABLE 5.18 Direction Partitioned Differences: PEC Project

	NORTH			SOUTH			EAST			WEST		
	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$	$\lvert y_i \rvert$	y_i	$(y_i)^2$
	0.06	0.06	0.00	0.22	-0.22	0.05	0.28	-0.28	0.08	5.48	5.48	30.01
	4.05	4.05	16.41	0.32	-0.32	0.10	0.67	-0.67	0.45	0.21	0.21	0.04
	0.87	0.87	0.75	0.26	-0.26	0.07	0.51	0.51	0.26	0.28	0.28	0.08
	1.24	-1.24	1.53	0.49	-0.49	0.24	0.26	0.26	0.07	0.33	-0.33	0.11
	0.31	0.31	0.09	0.40	-0.40	0.16	0.22	-0.22	0.05	0.76	-0.76	0.58
	1.40	1.40	1.96	0.25	-0.25	0.06	0.25	0.25	0.06	0.26	-0.26	0.07
	0.26	0.26	0.07	2.90	2.90	8.43	0.13	-0.13	0.02	0.20	0.20	0.04
	0.07	0.07	0.00	0.57	-0.57	0.33	0.40	0.40	0.16	0.34	0.34	0.11
	1.90	1.90	3.63	9.09	-9.09	82.65	**0.34**	**0.02**	**0.38**	0.20	0.20	0.04
	0.17	0.17	0.03	8.93	-8.93	79.70				**0.89**	**0.60**	**1.86**
	0.42	0.42	0.17	0.57	-0.57	0.33	2σ=	0.76		**0.32**	**0.05**	**0.57**
	0.21	-0.21	0.04	0.14	-0.14	0.02						
OUTLIERS	**0.91**	**0.67**	**1.43**	0.21	-0.21	0.04				2σ=	3.72	
OUTLIERS REMOVED	**0.63**	**0.36**	**0.87**	0.40	0.40	0.16						
				1.77	**-1.30**	**3.51**						
	2σ=	2.86		**0.56**	**-0.01**	**0.91**						
				2σ=	7.02							

According to the last approach, the mean offsets for the study area involving the Portland Energy Centre are as follows 0.91m for buried electric, -0.63m for gas, -0.09m for water, and 0.33m for sewer facilities (outliers inclusive) (see Table 5.19). Whereas, the mean values with the outliers removed for the buried electric and gas facilities are -0.49m and 0.35m. Once again, there is no evident systematic nature to the residuals. Therefore, if a locator approaches the field with the existing drawings for this study area, he/she will not have an idea of how far one utility may be from another.

However, based on the statistical results, 68% of the time when locating a buried electric utility within the Portland Energy Centre project area, the locator has a probable chance of locating it within ±1.60m from their starting position and ±0.97m for gas utilities and ±0.32m for water utilities and 0.34m for sewer facilities.

TABLE 5.19 Utility Partitioned Differences: PEC Project

BE

$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.22	-0.22	0.05
0.32	-0.32	0.10
0.06	0.06	0.00
0.28	-0.28	0.08
0.67	-0.67	0.45
0.51	0.51	0.26
0.87	0.87	0.75
0.26	-0.26	0.07
1.24	-1.24	1.53
5.48	5.48	30.01
2.91	2.91	8.47
4.05	4.05	16.41
1.41	**0.91**	**2.20**
1.04	**0.49**	**1.60**

2σ= 4.40

GAS

$\lvert y_i \rvert$	y_i	$(y_i)^2$	
0.49	-0.49	0.24	
0.40	-0.40	0.16	
0.31	0.31	0.09	
0.25	-0.25	0.06	
0.57	-0.57	0.33	
0.21	0.21	0.04	
9.09	-9.09	82.65	
8.93	-8.93	79.70	
0.26	0.26	0.07	
0.57	-0.57	0.33	
0.22	-0.22	0.05	
0.26	0.26	0.07	
0.07	0.07	0.00	
0.17	0.17	0.03	
0.42	0.42	0.17	
1.40	1.40	1.96	
2.90	2.90	8.43	
0.61	0.61	0.37	
1.90	1.90	3.63	
1.53	**-0.63**	**3.06**	**OUTLIERS**
0.65	**0.35**	**0.97**	**OUTLIERS REMOVED**

2σ= 6.12

WATER

$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.28	0.28	0.08
0.25	0.25	0.06
0.33	-0.33	0.11
0.76	-0.76	0.58
0.26	-0.26	0.07
0.13	-0.13	0.02
0.14	-0.14	0.02
0.21	-0.21	0.04
0.20	0.20	0.04
0.21	0.21	0.04
0.28	**-0.09**	**0.32**

2σ= 0.64

SEWER

$\lvert y_i \rvert$	y_i	$(y_i)^2$
0.40	0.40	0.16
0.34	0.34	0.11
0.40	0.40	0.16
0.20	0.20	0.04
0.33	**0.33**	**0.34**

2σ= 0.68

The third and final approach of the comparison of utilities within each project did not reveal any systematic patterns. However, it is noticeable through the statistical values that locating utilities along major roadways (i.e. Yonge Street, York Street, and Gerrard Street) is deemed to be more reliable in terms of the locational accuracy of its existing records.

6 SUMMARY, CONCLUSION, RECOMMENDATIONS

6.1 Summary

From the design stage to construction of new projects; project owners, designers, engineers, and contractors rely on existing underground utility records as a starting point. These crucial underground asset records are not only irretrievable, but are also out-of-date.

In order to begin to develop highly accurate and well developed engineering drawings, one must obtain a fine quality of as-built drawings. However, the patrons of the construction industry, and any other stakeholders involved in utility record creation or maintenance, fail to update as-built records.

The objective of this study is to evaluate the positional accuracy of subsurface utilities using existing records and current field surveys. This project also seriously considers the problem that exists when dealing with gathering, analyzing, and interpreting subsurface utility information.

The thesis also aims to establish or verify a correlation between the location of the utilities with the date of installation, the right-of-way (ROW), the utility type, or the proximity, etc. in terms of the accuracy of its location. The offset approach was conducted for seven projects provided by the City of Toronto and, the formerly known, TSH/TBE Group.

In order to gain a better understanding of the factors involved in accurate, up-to-date underground utility information, this study covers the global efforts surrounding the improvement of underground infrastructure information; and comprehensive information on the geophysical techniques and the factors affecting the accuracy of utility locates.

In this study, the offset approach has been selected to identify whether any systematic approach can be used to assist locators in detecting and locating subsurface utilities using existing records within the City of Toronto. The offset approach was developed using Microsoft Excel software to populate tables; which was then used to analyze the mean of the residuals, the mean of the absolute value of the residuals, and the root mean square with respect to the right-of-way and the different types of utilities.

From the analysis, the seven projects showed arithmetic averages, with respect to right-of-way, that range anywhere from -1.28m to 1.24m with the inclusion of outliers. After the outliers have been removed, the average means range from -0.31m to -0.01m. The mean of the absolute offsets range from 0.37m to 1.81m with outliers and ranges from 0.17m to 0.73m. This means that the values are not significant enough or do not display any sort of systematic pattern in order to state that when locating utilities within or outside the right-of-way, the locator will be closer to or further away from his/her starting position by a certain number of meters.

The root mean square (rms) parameter was determined for utility offsets throughout all seven projects. Some of the projects displayed higher dispersion patterns compared to others. According to the statistics gathered from the observed data within the Queensway project, 68% of the time (1σ), the utility that lies within the ROW (outliers removed) is locatable within ± 0.77m from the starting point. And 68% of the time, the utility that lies beyond the ROW is locatable within ± 0.90m from the starting position.

In line with the previous project results, the statistics tabulated from the observed data within the Portland Energy Centre project statements regarding the rms can be made including the fact that 68% of the time the measure of dispersion gathered from the statistical values show that the utility that lies within the ROW is locatable within ± 0.58m from the starting point (see Table 5.12). And 68% of the time, the utility that lies beyond the ROW is locatable within ± 0.55m from the starting position.

The results of the mean, mean of the absolute values, and the rms for the North, South, East and West partitioned observations revealed no systematic relationships.

This study shows no apparent correlation between the location of subsurface utilities and the right-of-way or the type of utilities. However, the statistical results of the observed data do reveal the dispersion values of subsurface utilities from their initial locate position within certain streets in the City of Toronto.

6.2 Conclusions

Based on the results of this study it is clear that no apparent correlation exists between the location of a buried facility and the right-of-way; which is evident through the lack of systematic patterns within the results. Hence the reason why a statement cannot be made as to whether a utility may lie within 0.5m or 5m from its record-specified location. But, what can be said, is that a definite large variability in utility location exists. The analysis of the results conclude that access to numerous data sets would be more useful to assess and or recognize any correlation between the locational accuracy of underground assets and the date of installation, the ground surface, the right-of-way (ROW), the utility type, and the proximity, etc.

However, this study did reveal the magnitude of the problem that exists when attempting to obtain any sort of information regarding aging subsurface infrastructure as it is being altered, modified or expanded. It is a complexly tangled and confusing analog world that is still in two-dimensional form. In other words, from the point of obtaining existing records to the position of generating new field locate surveys; there is an absence of the third dimension. Most, if not all, of the information obtained from existing records are in planimetric form; therefore, the excavator or project owner will not have an idea of how far to dig. This simply proves that what is available, in terms of existing utility records, is not actually a true representation of what exists beneath surface with respect to underground utilities. There are in fact several discrepancies within these records, however, quantifying this problem will require more resources (i.e. time, monetary support, and assistance from patrons of the industry).

Based on the results, the process of obtaining information regarding underground utilities is time-consuming, inefficient, costly, and difficult. Also, the facts regarding the current, buried utility damage occurrences reveal that subsurface utilities are treated with the "out of sight, out of mind" mentality. The underground network of facilities is only dealt with on an incident-based schedules; and it seems to be done this way in Toronto due to its cost-prohibitive nature in order to maintain or rebuild infrastructure that is nearing the end of its life expectancy.

6.3 Recommendations

This research project contributes to an expanding area of underground infrastructure research. It helped in proving that there is a shortage of underground utility data and information related to this data; which results in incomplete, out-of-date records. The problem does not lie simply within existing records, it reaches beyond to cover issues regarding the collection of practices, standards, and initiatives surround the underground utility world.

Several variables have to be accounted for including time, various companies implement utilities into the ground for service, roadway changes that alter existing subsurface plans, and bench marks to which utilities are referenced to. However, greater collaboration between these variables can result in higher quality existing subsurface utility records. Early coordination with project owners, utility companies, municipalities and other operators within this field would allow better research analysis of the existing nature of underground facilities. Further research should be pursued in the field of geophysical techniques, the accuracy of their detection and how it can be used to generate an in-depth collection of what exists below the surface; not only for new projects but simply as an inventory of the current state of underground infrastructure.

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APPENDIX A

GLOBAL INITIATIVES

A significant portion of the content within Appendix A, B, and C were extracted from papers and projects compiled beforehand by three Ryerson University students including Justin Nadeau, David Tulloch, and Nick Muth. Extensive research, on their part, allowed for a more direct approach to the literature review for this Master's thesis.

A.1 EUROPEAN INITIATIVES

NUAG – NATIONAL UNDERGROUND ASSETS GROUP

The *National Underground Assets Group (NUAG)* was officially recognized in 2005 and its relevant stakeholders range from local authorities to major utilities including:

- Department for Transport
- National Joint Utilities Group
- Highways Authorities and Utilities Committee
- Institution of Civil Engineers/ Institution of Civil Engineering Surveyors
- UK Water Industry Research (UKWIR)
- Pipeline Industry Guild (PIG)
- Ordnance Survey
- Association for Geographic Information (AGI)
- County Surveyors Society (CSS)
- National Street Works Highways Group (NSWHG)

NUAG's vision is to have consistent, appropriate subsurface and associated above ground asset information exchange between stakeholders on demand. To be more specific, in order for NUAG to support the Department for Transport, it must meet and/or exceed the targets of the Traffic Management Act.

The concern over quality buried asset information arose about a decade ago with the obvious state of differences in referencing standards, media storage, accessibility, and accuracy. This is exactly the reason why the TMA was passed; in order to facilitate the appropriate exchange of quality asset information that would, in turn, smooth the progress of improved street works coordination and cooperation.

In essence the NUAG has a few objectives including:

- To achieve the most effective and efficient means of recording, storing, sharing, and displaying underground asset and appropriate above ground asset information by carrying out agreed data definitions, standards, protocols, processes, and implementation timetable.
- To make certain that the NUAG's vision of consistency of underground and associated above ground asset information is met.
- To represent and to keep the wider stakeholder community informed.

The NUAG currently supports the ***National Referencing Standards Project (NRS)***; which focuses on the revised Records Code of Practice of the Department for Transport. This project, in particular, has two phases of which the first one develops methodologies, standards and best practices that tackle standardization issues to 2008. Whereas Phase two builds on the outcomes of Phase 1 and develops the deliverance of technology-based solutions.

PHASE 1

The NUAG is currently directed by the Steering Group and the Working Group. The Steering Group is responsible for the strategic management and direction of work. And the Working Groups are created by the Steering Group in order to carry out the work set up by the Steering Group itself. Members of both the Steering Group and the Working Group arise from stakeholder organizations and can be found in Appendix ?.

The NUAG has since published two reports in efforts of displaying the current practice and future recommendations for quality and consistency in dealing with underground and appropriate above ground asset information. The first report entitled, '*Capturing, recording, storing and sharing underground asset information; A review of current practice and future requirement*', was released in September of 2006. And another report was published in July of 2007 called, '*A National Report for capturing, recording, storing and sharing underground asset information*'.

NUAG REPORT SEPT. 2006

This report illustrates the work of the Phase 1 Working Group, which assisted in the development and completion of a successful User Survey representing samples of utilities and highway authorities. This Survey was generated to obtain a sample of and to assess the condition of certain issues including:

- the range of practices currently being used to gather, record, and store utility asset data and the sharing methods of asset information;
- changes in future improvements and the use of new technologies as they become more available and widespread;
- expectations of practitioners and reactions to the concept of a mandatory revised Code of Practice

The outcomes of this survey are presented in both qualitative and quantitative forms of data. The Quantitative aspect deals with responses to a questionnaire that covers details of current practice, aspects of future practice, and the use of an industry-wide standard Code of Practice.

Based on an analysis of the User Survey, the conclusions of the survey were as they predicted. The Survey further proved the existence of significant variations in practices, approaches, attitudes, emphases within and between utilities and highway authorities with regards to recording, storing, and sharing of subsurface utility information. These variations lead to obvious variability in accuracy, incompleteness of records, a wide variety of base maps; unnecessary timescales and conflicting tactics to third party and legacy data.

The lack of a statutory-based Code of Practice is also an evidential factor of contributing to the current state of conditions.

However, the support for a change to standardize approaches and implement a mandatory Code of Practice seems strong across utilities and highway sectors. Also, the likelihood of costs and resource issues to deploy a new Code arose. Nonetheless, in order for utilities and highway authorities to benefit from new technology and technology-based aspirations of the TMA, consistency and compatibility must be established in recording, storing and sharing asset record information.

As a result of the NUAG Sept. 2006 report a few recommendations were set out in order to reach the targets of the TMA including:

1. The development and deployment of a revised Records Code of Practice on a mandatory basis
2. Implementation of a mandatory national standard high-level framework, with effective ownership and management for capturing, recording, storing and sharing buried plant information; which will allow the successful use of a revised Records Code of Practice
3. Individual utilities and highway organizations must possess clearly-defined processes compatible with the national standard framework, along with appropriate ownership and management for the implementation and utilization of a revised Records Code and Code's standards.
4. The revised Records Code of Practice must include a set of minimum standards to be achieved:
    a. every subsurface asset must be recorded in unison with its appropriate above ground asset or appurtenance
    b. utility data must be captured during the planning, urgent and emergency types of work (planned and immediate)
    c. data must be captured and recorded for assets in any location
    d. data must be recorded for all new, replacement, amended or abandoned assets
    e. All previously-unrecorded existing assets, belonging to the organization carrying out the work, should be recorded if found during work.

f. Any unidentified third party asset found in the course of work must be captured, and recorded as an Unidentified Buried Object (UBO), by the organization finding it.

g. Any historical discrepancies between recorded and actual data found during work should be reported to the asset's owner, including third parties.

h. Attributes that must be captured are: location (x and y); top of asset (z); diameter (including any changes); material (including any changes), and pipe or cable run

i. Asset data must be captured and recorded at a minimum standard of accuracy of +/- 100 mm in x, y and z dimensions

j. Location data must be recorded using relative and absolute referencing

k. All geospatial data must be recorded using an agreed framework and agreed scales (DNF)

l. Asset data must be available for external inspection within one month of capture

m. Record information must be made available in electronic from through a web-based service

n. Each organization is responsible for managing their responses to requests for record information

5. Standard data definitions and data standards must be incorporated in the Records Code of Practice

6. In order to measure performance against the Code's standards, an annual review process must take place which will also lead to the deployment of appropriate minimum

7. For the successful deployment of the Code, any resource and cost associated with the new Code should be managed effectively.

8. The national high level standard framework and the revised Records Code must be fully implemented within a compulsory timetable.

NUAG REPORT JULY 2007

This document, similar to the 2006 report, presents a new method to capture, record, store, and share subsurface utility information. As the recommendation of the 2006 report, this method forms the foundation of a national high-level framework to deliver a set of minimum performance standards. The development of this method has been achieved by experts from utility companies, highway authorities, contractors, surveyors, and IT specialists. (NUAG, 2007).

This document also expresses what needs to be done and not how to do it. And it is not meant to replace current organization practices but its implementation may entail organizations to refine their processes, systems, procedures, and approaches.

Of particular interest, the report emphasizes key principles including

- the notion of capturing data and/or improving data quality every time a hole is opened;
- considering the health and safety of everyone working on or in the area of subsurface and associated above ground assets, and the general public, as being of utmost importance;
- the asset's Owner is solely responsible for capturing and recording asset data and the asset's Owner shall be notified immediately of any discrepancies found with third party assets found during work; as well as capturing and recording third party asset data as an Unidentified Buried Object (UBO).

Finally, this report also addresses the fact that by implementing the standards, organizations may require increased investments in new data capture, electronic storage, web-based service and communications technologies, and more advanced modern digital data or map backgrounds that those in current use.

The Sept. 2006 and July 2007 reports complete Phase 1 of the NRS, and Phase 2 of NUAG's work started in Jan. 2008 in the efforts of describing established processes, protocols, etc. for Sharing Asset Data and Displaying Asset Information. Details of the project scope, approach, resource management, timeline, deliverables can be found in the

NUAG *National Referencing Standards Project Phase 2: Terms of Reference* document (http://www.nuag.co.uk/outputs/nuag-phase2-terms-of-reference.pdf).

The NUAG also published a third report entitled, '*Defining the Technological Capability necessary for Sharing and Displaying Asset Information: User Requirements*' for comprehensive capture of data using GPS methods of which can be held electronically in GIS systems for web-based enquiry and information sharing.

The requirements developed in this report will be useful for:

- the definition of the 'technological capability' setting out in detail business process definitions with associated protocols and guidelines;
- implementation of an approach that incorporates recommendations for future ownership and management, and
- description of the nature of, and requisites for, a schema to facilitate future system development.

NJUG – NATIONAL JOINT UTILITIES Groups

NJUG is the UK industry association that represents utilities on street works issues. It is also considered to be the utility arm of the Highway Authorities and Utilities Committee (HAUC) signifying street works in England, Northern Ireland, Scotland and Wales. Its key stakeholders include the Energy Networks Association (electricity and gas), Water UK (water companies), National Grid, BT, Virgin Media and THUS plc. NJUG aim's and objectives are similar to those of NUAG:

- encourage all utilities and contractors to take responsibility in caring for utilities whilst carrying out street works
- ensure the safety of the general public and street workers as number one
- ensure practicable steps are taken to ensure damage to subsurface utilities is avoided whilst carrying out works
- ensure all utilities work in unison and in partnership with local authorities to minimize disruption
- promotion of best practice among stakeholders

- advancement of the industry's image in legislation (i.e. government and parliament)
- development of legislation and regulations affecting the industry
- promote a discussion forum on issues
- support NJUG policy and act cooperatively on critical issues

MTU – MAPPING THE UNDERWORLD

Issues of inaccurate location of buried pipes and cables, causing increased traffic congestion in UK's major urban areas, were stressed at the first workshops hosted by the UK Engineering and Physical Sciences Research Council (EPSRC) Engineering Programme Network in Trenchless Technology (NETWORK) (Chapman et al., 2002; Rogers et al., 2004). This is how the Mapping the Underworld (MTU) sandpit arose. Basically, a sandpit is winning research funding to find suitable solutions to complex problems of national importance. To be more specific, an interactive workshop made up of 20-30 academic researchers drawn from a variety of academic disciplines and independent potential users of research outcomes drive lateral thinking and deep-seated approaches to address particular research challenges (www.epsrc.ac.uk).
The major UK initiative, MTU, seeks to address the crucial social, environmental and economic consequences taking place as a result of the incapacity to accurately and entirely locate the underground utility service infrastructure without turning to excavations.

MTU RESEARCH PROJECTS

In particular, these issues were addressed by a group of universities in the UK, as well as worldwide industry partners. Phase one of the initiative involved a total of five workshops taking place between April 2006 and spring 2008 on different aspects of buried utility service infrastructure. These workshops were a result of research projects being pursued by academics in seven universities including the University of Birmingham, Bath, Sheffield, Southampton, Oxford, Nottingham, and Leeds.

This section, in particular, will outline the four research projects funded by the EPSRC and the details of involved parties, principal researchers, timelines, amount of funding and the topics of research (gow.epsrc.ac.uk).

BURIED ASSET LOCATION, IDENTIFICATION AND CONDITION ASSESSMENT USING MULTI-SENSOR APPROACH

This topic was researched by the Department of Civil Engineering at the University of Birmingham, in conjunction with the Universities of Bath, Sheffield, and Southampton. The principal investigator is Professor C.D.F. Rogers and the duration of the research was estimated to run from April 1, 2005 to March 31, 2009 with a funding amount of £500 188. The purpose of this research effort was to address the necessity for a multi-sensor device to detect buried pipes and cables. It also aims to review a variety of technologies that the industry can combine into a single tool to determine the location of pipes and cables. This project involved two approaches: the first being from the surface looking downwards; which is currently the most commonly used approach with the obvious drawbacks of penetrating through complex layers of different road surface materials. And the second approach of locating subsurface pipes and cables from the inside outwards by means of a robotic sledge that is fed into a pipeline or sewer.

ENHANCED METHODS FOR THE DETECTION OF BURIED ASSETS

This area of research was taken on the Department of Engineering Science at the University of Oxford led by Dr. H. Burd and ran from April 18, 2005 to October 17, 2008 with an approximate budget of £189 663. In general, Oxford's researchers looked into the improvement of using electromagnetic techniques to visualize underground pipes when surveyed from the ground surface. These academic experts will develop a series of 'resonant labels', which are essentially metallic structures that will be encapsulated within a new pipe prior to installation. This, in turn, will allow electromagnetic signals to be reflected at predetermined frequencies. The results of this research will promote cost-effective solutions of labeling new pipelines for unproblematic future locates.

GPS-BASED POSITIONING SYSTEM

This project was taken on by the University of Nottingham's Institute of Engineering Surveying and Space Geodesy with the principal investigator as Dr. G.W. Roberts. The duration ran from August 1 2005 to November 30, 2008 with a value of £116 734. This research endeavor involved the development of a surface mounted mapping system, employing geoscience techniques to detect subsurface assets. The goal of this work involves the integration of GPS and INS to optimize positional accuracy and precision to approximately one centimeter.

KNOWLEDGE AND DATA INTEGRATION

The integration research area is being performed by the School of Computing at the University of Leeds under the supervision of Professor A. Cohn. It has a timeline that runs from July 1, 2005 to June 30, 2009 with a value of £158 437. It involves the investigation into the creation of a highly advanced, unified database of every location data from various utility companies; which, in turn, will lead to the production of an effective network for data sharing. However, several challenges are expected in these efforts, due to the simple fact that the current state of underground asset data is incomplete, inaccurate, and different in terms of its format (i.e. hard-copy data).

INFORMATION NETWORK

The last of the research projects funded by the ESPRC is being taken on by the Department of Civil Engineering at the University of Birmingham by Professor C.D.F. Rogers. It has been in progress since May 27, 2005 and has an expected completion date of May 26, 2009 with an allotted fund amount of £63 759. This information network is a coordination of the above-mentioned projects, gathered in the hopes of meeting the broad objective of the MTU. This network will ideally initiate interaction of each project while facilitating a broad participation from the UK and overseas.

MTU WORKSHOPS

In the efforts of improving utility location equipment and mapping techniques, MTU actively organized a series of workshops to seek out the involvement of stakeholders in this industry. It was also responsible for producing an online questionnaire.

WORKSHOP ON SENSORS FOR BURIED ASSET LOCATION

The first workshop covered both industry and current research perspectives involving new pipe detection sensors and methods. It took place at the University of Birmingham on April 26th, 2006. This workshop was a great kick-off to allow representatives of organizations involved in buried asset location to present their observations on current best practice and the future of utility-sensor detection. This workshop also involved discussion into Ground Penetrating Radar (GPR) being used to illuminate buried objects efficiently. As well as, further discussions on the distortion of magnetic fields due to the conductivity of soils, water pipes and ground return currents. The workshop also had insight into how acoustic waves can be used to detect subsurface utilities and how it can be used in wet soil conditions unlike GPR. In the end, it was a successful workshop that allowed stakeholders to discuss potential utility location methods, as well as bringing attention to challenges currently being faced by delegates and the need for improved accuracy of underground utilities using modern technology (pamphlet 1).

WORKSHOP ON MAPPING TECHNOLOGIES

The second workshop was held at the University of Nottingham on September 14th, 2006 and it covered mapping technologies. It covered issues dealing with the most cost-effective and accurate surveying techniques involved in positioning buried facilities; the affects of the Digital National Framework (DNF) on utility companies; the augmentation of GPS with Inertial Navigation Systems (INS), pseudolites, locatalites, and survey total stations. It also covered alternative approaches (i.e. HSGPS, Network RTK GPS, and laser distance measurement) to overcome difficulties of positioning in problematic areas; difficulties in positioning in certain areas. Researchers also covered satellite positioning beyond the year 2010. Several academic speakers and industry patrons focused on GPS positioning accuracy and existing and effective future technologies. Further details involving a device—that can be inserted into a pipeline, equipped with an INS that has the ability to track and record positions of joints and valves—was presented; along with discussion on the ASCE 3802 standard. By the end of the workshop, many stakeholders agreed that services should be surveyed to at least map accuracy accompanied by attribute data records. There was also a strong agreement in regulating utilities to record their buried assets and QA ought to be implemented through policing (www.mappingtheunderworld.ac.uk/workshops/buried%20assets%20workshop.pdf).

WORKSHOP ON BURIED ASSETS: DATA INTEGRATION AND VISUALIZATION

The third in a series of five workshops was held at the University of Leeds on April 17th, 2007 and it discussed the ongoing research efforts around integration of existing legacy data with new accurately, dynamically acquired geo-referenced asset information; which, in turn, allows for the successful development of novel technologies for displaying the resulting knowledge to excavators and network planners. In particular, the workshop covered NUAG's plans to develop a standard framework for recording, storing, sharing and displaying subsurface asset information. Leeds academics also researched the challenges of automatically converting a paper map to a full GIS representation—a process known as knowledge-based raster to vector conversion. Also, Yorkshire Water discussed the integration of asset data without the loss of quality. Furthermore, discussions on MTU and VISTA (a complementary Department of Trade and Industry (DTI) project) projects directed towards a framework for data integration took place. What's more, presentations of data were discussed including the use of Augmented Reality (AR) with 3D modeling being used to solve sector specific obstacles; the uncertainties of modeling and representing data; and finally the use of NERVE to allow for real-time visualization of a shared geo-spatial model.

WORKSHOP ON UNDEGROUND ASSETS CONDITION ASSESSMENT

The next workshop held at the University of Sheffield on October 31, 2007 and it involved ideas surrounding the ability to characterize and assess subsurface infrastructure data in terms of its condition and failure potential. The research in this workshop looks at how extending the signal examination techniques might be used to determine the condition of services. Research presentations also included a feasibility study that provides a platform for specifications, developments, and construction of a National Test Facility that makes room for accurate, reliable, comprehensive concept studies at minimal costs.

WORKSHOP ON NOVEL TECHNOLOGIES FOR FUTURE UTILITY PROVISION – THE NEXT 5 TO 10 YEARS

The last of a series of five workshops being held at the University of Oxford, took place on April 16th, 2008. Whereas the previous workshops focused on issues related to locating, mapping and assessment of buried assets, this workshop dealt with issues that will ultimately alter the shape of the utility supply industry in the next 5 to 10 years. In particular, this workshop focused on three principal themes including sustainability; new forms of utility provision and technical developments.

VISTA

'Visualizing integrated information on buried assets to reduce street works'; or in its simpler form 'VISTA', is the broader development of the concepts explored by the MTU initiative. Where MTU focused on 'GPS Based Positioning' and 'Knowledge and Data Integration', VISTA anticipates to research methods to integrate, share, reuse, and convey knowledge of existing legacy asset data along with accurately geo-referenced data.

VISTA aims to combine existing paper and digital records with data from satellite and ground-based positioning systems. The coordination of this data system will eventually assist in the creation of a three-dimensional map of underground pipelines and cables. This project is funded by the Technology Programme of the Department of Trade and Industry—now known as the Department for Business, Enterprise and Regulatory Reform (BERR). A total funding amount of £900 000 is being provided by BERR with £630 000 allotted for research pursued by University of Leeds and £270 000 for study by the University of Nottingham. And the remaining portion is contributed in kind by 23 partners including academia, consultants, contractors, manufacturers, transport authorities, and utilities; a detailed list can be found in Appendix something.

University of Leeds and Nottingham have been given the challenge of conjuring up ways to integrate existing digital and paper-based records, as well as linking these records with accurately geo-referenced data acquired via satellite and ground-based positioning systems. The ultimate goal would be to combine the above-mentioned information so that it is understandable for contractors, utility companies, planners, and highway authorities.

As a result, this project will aid in the reduction of the number of excavates; assure that the excavation is taking place in the right location; and avoid any damage if digging crews stumble upon unexpected pipes and cables. According to VISTA, by reducing roadworks by 0.1% per annum, the UK economy can save millions of pounds a year (www.vistadtiproject.org).

UNIVERSITY OF LEEDS

Thus far, the University of Leeds has released four research papers and are as follows:

- A Framework for Utility Data Integration in the UK
- Integrating the UK's Utility Data
- The Uncertain Reality of Underground Assets
- Knowledge-Based Recognition of Utility Map Sub-Diagrams

Each research topic produced several ideas and recommendations for reaching the target of quality asset information sharing.

A Framework for Utility Data Integration in the UK

This research effort investigates various factors which prevent utility knowledge from being fully exploited. It also suggests the fact that data integration techniques can be employed to enhance the quality of utility records. For improvement of utility records, the paper suggests creating a suitable framework that would integrate information from multiple utility asset stores. In particular, utility integration support will take place via two levels: the schema and data level. The schema level integration makes certain that a single, integrated geospatial data set is available upon inquiry. Whereas, the data level integration improves asset data quality through the reduction of inconsistencies, duplications and other conflicts. What's more, this framework is intended to preserve autonomy and distribution of underground asset data.

Initially, the project looks into the problems associated with the fact that utility data is created and maintained independently by individual companies. This data, which is held by the utility owner, creates heterogenieities when all infrastructure data is combined. To be more specific, there are three heterogeneites that exist: syntactic, schematic, and semantic.

Finally, the general framework of knowledge and data integration is created. The schema will be constructed using a bottom-up approach; which is contrary to the shared, standard models that exist. So now, the framework inputs shema level knowledge, government legislation, codes of practice and users' knowledge and produces maps between global and local schemas. The Data Integration Manager supports utility integration at the data level. Now, in addition to the Data Integration Manager, the Query Manager supports run-time integration activities. A point to note would be that all queries are specific to the global schema. So, the QM is the first to receive a query that has been submitted to the utility integration system. The QM breaks down the query into local queries specified in terms of local schema based on the maps generated by the Schema Integration Manager. The decomposed local queries are sent to the utility Database Management Systems (DBMS); which is made up of individual utility company data. The results from the local DBMSs are fired off to the DIM, to reduce any duplications or conflicts. When the DIM clears these results, they go on to the user interface via the QM.

Although the framework is seen to be an effective step towards knowledge and data integration, several stakeholders are concerned about the security of their asset information. In general, the global schema was successful in storing information across utility domains. However, researchers are proposing further investigation into advanced Data Integration Frameworks.

The Uncertain Reality of Underground Assets

This paper aims to identify the optimal methods of showing assets records that reflect actual accuracy of the data being presented. The objectives of this research topic involve identifying the different user groups and their needs; as well as evaluating methodologies to represent uncertainty of underground infrastructure information. The papers initial step is to evaluate the uncertainty and the history of the definition of uncertainty. It also outlines the categories of uncertainty as defined by the *Spatial Data Transfer Standards (SDTS)* (STD, 2007). The formalization and conceptualization of uncertainty has been greatly improved by GIS, but the integration of uncertainty in raw data and visual display still needs improvement. This could be a result of SDTS being designed for data transfer and not direct use and visualization.

After analyzing the *Visualization Questionnaire* (see appendix something) researchers found that it would not be practical to aim for a *one-map-for-all* concept.

The initial prototype system connects to a data source through a web service, then relevant details, such as the attributes of the global schema that are of interest to the user, are extracted. The mapping stage receives this information where there are two different sets of rules. The rule of assets that transforms data attributes from the global schema to geometry and the other rules to map uncertainty data. The result is a two-dimensional map displayed on the web. The user can now interact with the display and the web server pulls out the data and responds with a new map. In particular, two schemes are used to visualize uncertainty, blurring and traffic lights visualization.

By analyzing the evaluation of uncertainty, it is useful to assess whether including uncertainty information in representations is in any way useful; which raises different concerns:

- the incorporation of visualization information for depiction of uncertainty into decision making.
- different users being able to incorporate uncertainty information in the same way .
- does the inclusion improve decision making.
- Is there a difference between expressing uncertainty information (i.e. implicitly or explicitly)

Researchers have made further propositions for investigation of uncertainty visualization and are as follows:

- Assessing the usefulness of 3D displays for occlusion of depth or depth uncertainty
- Addressing congestion of maps
- Including qualitative uncertainty

Knowledge-Based Recognition of Utility Map Sub-Diagrams

This research paper addresses the aspect of an integrated map of all utility services in a locale that would assist in improved management of road infrastructure and utilities. To achieve this goal, raster scans of paper maps must be integrated into a well-defined GIS. This is done by capturing the semantic relationships between the existing objects within a drawing. Currently, there are several commercial vectorisation algorithms available for such use, however, they are insufficient in terms of producing rich object representations. This paper presents a structural object recognition system that isolates sectional sub-diagrams in underground utility maps. This system is created upon vectorisation system based on a Constrained Delaunay Triangulation (CDT) of pen strokes.

By counting the neighbouring triangles created by the CDT, the graphical primitives (i.e. termination points, paths and junctions) can all be obtained. This approach easily deducts medial axes of the straight lines which allow the use of the contour and triangulation data to resolve the perception of junctions and higher-level objects in a range of ways. In order to define the diagram, the methodology calls for the use of a dictionary that entails graphical primitives and spatial grammar. In particular, the Active Chart Parsing (ACT) algorithm is then used to parse the dictionary elements to determine whether they are a part of a predefined grammar (Hickinbotham, 2007).

The paper concluded on the note that the examined sub-diagrams had approximately constant orientations and that the data sets were all fixed scale. To be more specific, 10 images consisting of 15 tiles were scanned and manually examined, to find that out of 1,128 trench diagrams, 748 features conformed to the grammar. And 594 trench diagrams were detected not including 18 false positives. The precision factor was

97.1% and the recall was 79.4% and the failure to detect trenches were due to circles not being completely scanned or not being drawn to form a continuous loop; lead lines crossed the base of the trench diagram; and drafted circles were overlapping. The recommendations that arose from this research are as follows:

- To enrich the grammar and connectivity rules.
- To evaluate alternative approaches to the CDT based vectorisation strategy.
- To apply the approach to recognize the drawing conventions that associate the sub-diagrams to underground cabling
- To seek new vectorisation techniques for richer classification of curves, arcs, crossings, etc.

ORFEUS (Optimised Radar for Finding Every Utility in the Street)

This project addresses the requirement for advanced technologies for the location, maintenance and rehabilitation of buried infrastructures. To be more specific ORFEUS fulfils the need for locating buried assets, including the utilization of trenchless methods for deploying pipelines and cables in a congested urban environment. It is partly supported by the European Commission's 6th Framework Program-Priority (Global Change and Ecosystems), managed by Directorate General for Research under the contract No 036856 (GOCE).

The main objective of this project is to further develop two radars including surface operating radars and subsurface radars. The second radar involves installing a bore-head GPR into the drilling head of Horizontal Directional Drilling (HDD) equipment in order to avoid collision and any damages to existing subsurface infrastructure.

After a technical analysis of current impulse GPRs, researchers found that the penetration depth is limited in approximately 1m when the soil is highly conductive (i.e. clay with a 50 dB/m two-way attenuation) with a detection rate of 80% and a confidence level of around 90%. This makes it difficult to detect non-metallic objects beyond 0.5 m in depth. ORFEUS was proposed to overcome these limitations by two radar systems.

The ORFEUS surface GPR operates from the road surface and is used in the planning phase of the drilling. And the ORFEUS bore-head GPR is implemented during the pipe-laying phase and will be able to locate in good time obstacles that may otherwise compromise the excavation work.

So far, research has taken place on surface GPR and it intends to develop a system that has the capability of increasing the penetration depth by 50% with respect to pulsed state-of-the-art equipment. They must also identify the critical aspects limiting the overall performance by completing a revision of the current architectural solutions. The project is set to run until November 2009 (Pasquale, G. and Scott, H, 2008).

A.2 US BASED INITIATIVES

STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP)

The SHRP was authorized by the U.S. Congress in 1987 as a five-year research initiative that would develop and evaluate techniques and technologies to deal with the deteriorating conditions of the nation's highways; as well as improving highways performance, durability, safety and efficiency. SHRP is directed by a top-level management of state highway agencies, industry and academia and is operated as a unit of the National Research Council. And the research effort is funded by 1 percent of the federal-aid highway funds. In particular, the research areas of concentration are as follows:

- Asphalt.
- Concrete and structures.
- Highway operations (maintenance and work-zone safety).
- Pavement performance (long-term pavement performance study).

At the end of this research phase, the Federal Highway Administration (FHWA) decided to coordinate a national program that would move the 100-plus products developed and evaluated under the SHRP to those state and local agencies responsible for building and maintaining the nation's highway network. The American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB) also assigned their resources behind the SHRP implementation by creating the AASHTO Task Force on SHRP Implementation as a catalyst and the TRB-SHRP Committee to monitor progress. To be more specific, the program was successful in two particular areas; the practice of improved winter highway maintenance and innovative asphalt pavement design by the production of Superpave®.

SHRP SON: Strategic Highway Research Program Statement of Need for locating and characterizing technologies for buried utilities.

This SON is a research study at Louisiana Tech University and its purpose is to survey and document existing utility location and characterization technologies and practices. It will aim to identify and prioritize promising technologies for further development, which, in turn, are expected to improve the ability of transportation agencies to accurately and successfully locate and characterize buried utility lines. Due to the growing success of the SHRP research from 1988 to 1993, Congress decided to establish the second ***Strategic Highway Research Program (SHRP 2)*** in 2006 (USDOT, SHRP WEBSITE). And it is being funded over the next four years at an estimated $205 million under the authorization of the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)*, Section 5210 (Public Law 109-59) through federal fiscal year 2009. Furthermore, it is being managed by the *Transportation Research Board (TRB)* on behalf of the *National Research Council* alongside the *U.S. Department of Transportation* and the *American Association of State Highway and Transportation Officials*. Also, in order to oversee all aspects of the SHRP 2 research activities an *Oversight Committee* was set up along with *Technical Advisory Committees* in order to gather experience, expertise and counsel from academic, government and other interested parties.

SHRP 2

This effort focuses on applied research in four areas:

- Safety - Prevention or reduction of the severity of highway collisions by trying to comprehend driver behavior.
- Renewal – addressing the aging infrastructure through rapid design and construction methods that cause minimal disruption to produce time-withstanding facilities.
- Reliability – reduction of congestion through incident reduction, management, response, and mitigation.
- Capacity – integration of mobility, economic, environmental and social needs in the planning and design stages of new transportation capacity.

In order to improve the safety and reliability of the US highway system, useful developments in research and technology involving advanced materials, new data collection technologies, communication devices, and human factors science must take place. For this purpose, buried assets are found within the *Renewal Research Area*. In particular, eight approaches have been proposed to reaching the objective of Renewal within the SHRP 2 initiative including:

1. to perform rapid In Situ construction
2. to minimize field fabrication efforts
3. to perform rapid construction inspection and monitoring
4. to facilitate innovative and equitable contracting environment
5. to plan improvements to mitigate disruption
6. to improve customer relationships
7. to design and construct low-maintenance facilities
8. to preserve facility life

Within the renewal research area, there are 14 active projects in progress. In particular, two of them focus on buried assets:

1. Encouraging Innovation in Locating and Characterizing Underground Utilities
2. Strategies for Integrating Utility and Transportation Agency Priorities in Highway Renewal Projects

ENCOURAGING INNOVATION IN LOCATING AND CHARACTERIZING UNDERGROUND UTILITIES

This project was being pursued by Louisiana Tech University under the supervision of Ray Sterling with an approximate funding value of $ 299 983 USD. The objective is to seek new and improved equipment to locate and identify underground utilities in the preliminary design phase of a particular project. This area is considered to be a hot topic arising continued interest from project and utility owners. Firstly, this project will document existing technologies for locating and characterizing various buried assets. And secondly, it will aim to identify emerging or potential technologies and initiate a research plan that will encourage the development of the technology into a useful tool for utility stakeholders.

Phase I of this project is to survey the state-of-the-art methods and technologies and determine the areas with the most potential for innovation and improvement. Whereas, Phase II will develop specific research and development projects for funding within the SHRP 2 program, based on the assessment of Phase I. Phase I was completed on June 15, 2007 where Louisiana Tech University published a '*Statement of Need (SON): Locating and Characterizing Technologies for Buried Utilities*'. This report outlines the problems of locating underground facilities, costs and problems associated with inaccurate location and drawbacks of current locating agencies. The report also includes current state-of-the-art technologies along with its potential future work in the industry.

STRATEGIES FOR INTEGRATING UTILITY AND TRANSPORTATION AGENCY PRIORITIES IN HIGHWAY RENEWAL PROJECTS

This project was taken on by ICF International under the supervision of Marie Venner with a funding amount of $250 000 USD. This research area focuses on ways to improve the coordination of utility and highways agencies and to reduce the negative impacts to the parties involved including the general public. ICF International is looking to propose procedures to facilitate fine utility management during the entire duration of a project. Also, this project investigates and develops new strategies to enhance cooperation between utilities and highway agencies in order to mitigate delay. Finally, this project aims to plan the evaluation of strategies to mitigate utility-related delays to highway renewal projects. The final report will include causes of highway renewal delay relating to buried assets; revision of current policies, practices, procedures, and methods that have mitigated delays; and plans for evaluating innovative strategies to mitigate delays with regard to buried assets.

COMMON GROUND ALLIANCE

The Common Ground Alliance (CGA) is recognized as a leading organization in its efforts to practice safe and reliable operation, maintenance, construction, and protection of underground facilitate in North America through mutual responsibility among all stakeholders. The various stakeholder groups include Excavators, Locators, Road Builders, Electric, Telecommunications, Oil, Gas, Railroad, Water, One Call, Public Works, Equipment Manufacturing, State Regulators, Insurance, Emergency Services and Engineering/Design. The alliance represents more than 1300 individuals from 15 stakeholder groups, over 165 member organizations, and 40 sponsors. This effort was made official in 2000 representing damage prevention efforts embodied by the Common Ground Study. This study was sponsored by the U.S. Department of Transportation and was completed in 1999 with deliverables of collaborative work of 160 industry professionals who identified best practices concerning damage prevention.

The CGA plans to prevent damage to underground infrastructure by implementing shared responsibility for the protection of underground facilities; supporting research in damage prevention; running public awareness and education programs; identifying and disseminating the stakeholder best practices; acting as a clearinghouse for damage data collection, analysis, and dissemination.

The main purpose of the CGA study was to classify and validate existing best practices that prevent damage to underground facilities. This collection of stakeholder best practices were intended to be published among the organization and would be dependent upon the safe and reliable operation, maintenance, construction, and protection of underground facilities. The Study was divided into nine areas, which focused on work practices within the natural groupings of damage prevention activities. Nothing contained in the study supercedes existing State laws, instead, the Secretary of Transportation encourages each State and operator of one-call notification programs to implement the practices shown in the Study.

After the completion of the Study in 2000, the Best Practices Committee was formed and developed a Best Practices document made up of eight areas of interest including: Planning & Design Best Practices; One Call Center Best Practices; Location & Marking Best Practices; Excavation Best Practices; Mapping Best Practices; Compliance Best Practices; Public Education Best Practices; Reporting & Evaluation Best Practices. The most recent version is Best Practices Version 6.0 released in February 2009 and it contains best practices from the Study to any new practices passed by the Committee.

DIRT – DAMAGE INFORMATION REPORTING TOOL

As mentioned earlier the Damage Information Reporting Tool is a secure web application for the reporting and collection of underground damage information. This CGA-developed web application requires stakeholder members to submit damage and near-miss reports; administer role-based company and user information; revise personal profiles; alter/recover user passwords; and offer feedback and submit questions. This tool has been very helpful in allowing CGA to analyze the data and gather a consensus as to why these events occur and what the industry can do to prevent such incidents thereby making certain of the safety and protection of people and the infrastructure.

The fourth Annual Report, which analyzes data extracted from 2007 events and submitted to DIRT, revealing an approximate 256,000 damages. And according to the Ontario annual report, compiled by the Ontario Regional Common Ground Alliance's (ORCGA) DIRT, approximately 6000 damages were reported by stakeholders in Ontario for 2007 (http://www.orcga.com/lib/db2file.asp?fileid=298).

The inclusion of more state US damage reports would complete the dataset, improving the estimate overall.

NULCA – National Utility Locating Contractors Association

NULCA aim is to define, establish, and maintain the highest standards and practices possible in the subsurface utility contract locating industry. Its main concern is the safety of the general public, locaters, and excavators. This organization intends to achieve its goals by developing strong relationships with facility owners, excavating contractors, suppliers, and regulatory agencies; as well as leading the pack in the efforts to eliminate underground facility damage. What's more, several of the NULCA members participate on CGA committees, which has been beneficial towards the aim or damage prevention. Their participation has led to better locating practices, advanced locating technology, and protection of locating companies from practices that inhibit the CGA's ability to be successful.

Like many other damage prevention associations and/or organizations, NULCA also recognized the need for a common set of standards and practices for contract utility locators to follow. In 2002, NULCA publicly presented *NULCA Locator Training Standards and Practices*. This standard covers the competencies for basic level locators involved in buried facility locating. NULCA has also released a Recommended Marking Guidelines For Underground Utilities in September of 2001.

NULCA is an Honorary Host of the Locate Rodeo and it is responsible for sponsoring an increasing number of regional feeder events that promote underground infrastructure education and training. This, in turn, allows locators to keep abreast of the most recent resources and industry regulations (NULCA PDF - http://www.nulca.org/associations/7786/files/NULCANews_Fall2006.pdf).

NUCA – National Utility Contractors Association

NUCA serves as one clear, authoritative voice for the underground utility construction industry, whether it be for the promotion or defense of stakeholder interests and/or concerns. The nationwide committees include the Trenchless Technology Committee, Contract Documents and Specifications Committee, Damage Prevention Committee, Safety and Risk Management Committee, Government Relations Committee, among others.

More importantly, NUCA's envisioned future recognizes national assets as being vital, and those responsible for building and maintaining them have the public's full confidence and respect in mind (http://www.nuca.com/files/public/NUCA_Strategic_Framework.pdf).

A.3 CANADIAN-BASED INITIATIVES

Canadian Regional Partners of the CGA

The Canadian Regional partners of the Common Ground Alliance are nonprofit organizations that contain several industry stakeholders devoted to the shared responsibility of damage prevention and in the promotion of Best Practices. Currently, five provinces including Alberta, British Columbia, Ontario, Saskatchewan, and Quebec are regional partners of the CGA. Each and every active group has developed a best practices document that entails the type of actions that would provide optimum levels of due diligence in damage prevention of underground infrastructure. The provinces across Canada have been trying to form the "Canadian" CGA since 2006 with the goal of harmonizing the Federal Best Practices and to act as an "umbrella" organization for working with Federal organizations (http://www.orcga.com/, 2007).

Of particular interest is the Ontario Regional Common Ground Alliance. It was recognized as a significant chapter of the CGA in April 2003. Several industry stakeholders quickly fell under the banner of the ORCGA including the *Third Party Damage Prevention Task force* – created by the *Technical Standards and Safety Authority (TSSA)* to oversee plant damage specifically related to the pipeline industry and gas distribution utilities in Ontario. It is a continually growing association composed of 230 organizations as active members and sponsors, representing a wide array of stakeholders from:

Oil & Gas Distribution
Transmission Pipeline
Road Builders
Safety Organization
Homebuilder
Engineering/Land-Surveying
Equipment & Suppliers
One-Call
Insurance
Regulator
Locator
Railway
Lansdscape/Fencing
Telecommunications
Excavator
Municipal and Public Works
Electrical Distribution
Electrical Transmission

This amalgamation of stakeholders, under one banner, provided a single voice in promoting damage prevention.

The ORCGA also developed its own version of Best Practices, which was an extension of the established CGA Best Practices document. Like all proposed standards, there is an initial reluctance on the part of stakeholders to adopt these practices; but, progress will follow over time through enhanced public awareness and education.

The main objective of the ORCGA is to be recognized as the safest jurisdiction with the most reliable infrastructure in North America and to ensure optimum public safety and utility infrastructure through a combined effort to efficient damage prevention. Like the CGA, the ORCGA is managed by the board of directors who oversee several subcommittees that watch over the operations, projects, research, deliverables, etc. of the association. More importantly, the Best Practices Committee is considered to be one of the more significant groups due to its focus on damage prevention of underground infrastructure.

Thus far, the Best Practices Committee has released three Best Practices since its' inception, in the hopes of further developing new and improved practices. A more detailed look into the ORCGAs Best Practices will follow later on in this paper.

ONTARIO ONE CALL

The Ontario One Call notification center serves as an information clearinghouse for excavators. Each state and/or province has its own One-Call system, this chapter, in particular, will discuss the Ontario One-Call System (Osman and El-Diraby, 2005). Essentially, it is a system that was created to aid in the protection of people from accidentally hitting underground utility lines while working on digging projects.

It was first developed and implemented in several American states starting in 1974. In 2005 the Federal Communications Commission (FCC) designated a national three-digit telephone number **811** under the Act of Congress in 2002. In 2006, the FCC spent two years for the official implementation of the 811 abbreviated dialing to take place. Finally on May 1, 2007, the Common Ground Alliance (CGA) joined with U.S. Secretary of Transportation Mary Peters, the FCC, and representatives from national launch partners the Associated General Contractors of America, John Deere, The

Travelers companies, Inc., and Cox Communications, ceremonially connected 811 as the official national "Call Before You Dig" number. Fifteen industry stakeholder groups encouraged the development of its creation and continues to promote the use of 811 nationwide. Canadian provinces have yet to pass a national "Call Before You Dig" number, however, provincial One-Call systems have been implemented.

The Ontario One-Call System is a notification center, which acts as a link between excavators and facility operators. In most cases, One-Call is funded by member facility operators including communications, electric power, gas distribution, gas transmission and gathering, pipelines, water and wastewater, etc. Since 1995, the Ontario One-Call System requires that the excavator provide One-Call with the exact site and date of the proposed dig, within at least a one-week notice before digging so that their locating crews have sufficient time to locate and mark the excavation sites' underground facilities. For instance, a homeowner or contractor can submit an Ontario One Call **e-Ticket** Form online in order to notify the center of a proposed excavation. This form (Figure 1) includes several key fields that must be filled out so as to initiate the process. Such fields include, the homeowner or contractor's contact information, the dig location (i.e. nearest intersection), the work information (i.e. hand dig or machine dig), and the specific date(s) of excavation.

Once the location request has been made, One-Call searches its extensive spatial databases and identifies possible conflicts dealing with nearby member utilities and sends out a notification to those utility owners. This notification, more commonly referred to as a '**ticket**', prompts the utility owner to assess the problem and determine whether there is a need to send out their crew to mark the proposed dig site. If the utility company finds that there is a need for a locate, they will dispatch a qualified field crew to the excavation site. These trained professionals are required to make colour coded markings on the surface of the precise location of their buried network. Often the cost of One-Call services will fluctuate depending on the cost of repairs due to damaged utilities.

Additionally, in Ontario, commodity utilities have been deregulated. This means that historical monopolies granted to a few large utility service providers providing electricity, telephone, and natural gas are eliminated. Therefore, competitors are not limited to where and how they place their new utility lines underground. So, the accuracy of the exact location of their facilities has decreased immensely; along with further congesting the buried utility network. Therefore, the need for One-Call centers is very significant to aiding in the effort of damage prevention. It is considered to the initial step to safer practices regarding underground and associated above-ground infrastructure.

A.4 INTERNATIONAL-BASED INITIATIVES

The International Society for Trenchless Technology was founded in 1986 with the intention of advancing the science and practice of Trenchless Technology; as well as, promoting the education, training, study and research in this science and practice.

Trenchless Technology refers to the rehabilitation and installation of new underground infrastructure such as electrical conduits, gas, sewer, storm, and water. It involves performing subsurface construction without the traditional open-cut methods. Trenchless Technology has several benefits including reduced impacts to the environment; increased safety due to stationary work sites; far less construction impacts as opposed to open-cut method; minimization in traffic and noise impacts; reduction in import backfill, pipe bedding; longer pavement life surrounding area of construction; relatively lower costs in trenchless construction.

More importantly, the ISTT encourages the development of affiliation of societies sharing its goals globally. Currently, there are 24 Affiliated Societies across six continents, each having the equal opportunity to select a nominee for Director on the ISTT Board. Here is a list of the known societies for Trenchless Technology:

- Australasian Society for Trenchless Technology (ASTT)
- Austrian Association for Trenchless Technology (OGL)
- Brazil Association for Trenchless Technology (ABRATT)
- Bulgarian Association for Trenchless Technology (BATT)
- China Beijing Society for Trenchless Technology
- China Hong Kong Society for Trenchless Technology (CHHSTT)
- China Shanghai Society for Trenchless Technology
- China Taipei Society for Trenchless Technology (CTSTT)

- Czech Society for Trenchless Technology (CzSTT)
- Finnish Society for Trenchless Technology (FiSTT)
- French Society for Trenchless Technology (FSTT)
- German Society for Trenchless Technology (GSTT)
- Iberian Society for Trenchless Technology (IbSTT)
- Indian Society for Trenchless Technology (INDSTT)
- Italian Association of Trenchless Technology (IATT)
- Japan Society for Trenchless Technology (JSTT)
- Lithuanian Association of Trenchless Technology
- Netherlands Society for Trenchless Technology (NSTT)
- North American Society for Trenchless Technology (NASTT)
- Polish Foundation for Trenchless Technology (PFTT)
- Russian Society for Trenchless Technology (RSTT)
- Scandinavian Society for Trenchless Technology (SSTT)
- Southern African Society for Trenchless Technology (SASTT)
- Ukraine Association for Modern Trenchless Technology
- United Kingdom Society for Trenchless Technology

Due to this gathering of international associations under one umbrella society, several "Trenchless Technologies" conferences and "No Dig" shows are held each year across the globe.

APPENDIX B

GLOBAL STANDARDS AND BEST PRACTICES

B.1 EUROPE

Dft and HAUC – WORKING TOGETHER: A GOOD PRACTICE GUIDE TO MANAGING WORKS IN THE STREET

This practice guide aims to show how utility infrastructure maintenance, improvements and replacements can be carried out with least disruption to highway users, frontages and local communities. The guide itself is recommended for use by highway authorities, utility companies, contractors, and their suppliers. Through better coordination and management of works in the street, all stakeholders will reap the benefits of safety, reduced congestion and disruption, environmental and public service improvements.

FORWARD PLANNING AND COORDINATION

A fine practice before the commencement of construction work is to plan to minimize disruption through certain elements such as cooperation, flexibility, coordination, and good communication.

Large scale projects, as well as smaller timescale projects, require time for coordination and planning. And by preparing early and planning forward, dividends may be experienced in the form of reduced disruption and inconveniences to highway users during construction. All stakeholders shall be involved in reviewing and improving work practices, as well as, introducing new types of contract or non-contractual mechanisms to appropriate incentives to minimize disruption (HUAC MANUAL)

This guide also suggests following the key principles of effective coordination as follows:

- Sharing and consulting information at the earliest stage among all interested parties.
- Regular participation of relevant personnel at coordination meetings.

- Sharing business development plans and replacement programmes for ageing assets between utilities and authorities.

All parties should also conduct open and regular meetings between the promoter planning proposed work and the person coordinating the work in the authority, thereby ensuring the coordinator of what is proposed, helping him/her assess the impacts, assisting in the design process, and encouraging further coordination.

Moreover, this guide suggests presenting information on a map base that will facilitate the sharing of information about planned works.

<u>ON SITE</u>

The safety of both workers and the public must be considered of utmost importance during street works. It is good to develop a culture that has the mentality of reducing the impact of works during a limited timeframe (i.e. emergency works). An significant way to minimize works is to complete the task quickly and efficiently, without losing the quality of work performed. This can only be performed by collecting correct information on existing apparatus and assessing the possible conflicts that may be encountered while on site. Also, by coordinating multi-task teams to continue the job right through to the finish without unnecessary delays will ultimately minimize the time on site.

Before any street works can take place, the public must be informed through public meetings, personal visits, written notification, local media, websites, and telephone messages.

More importantly the Safety at Street Works and Road Works Code of Practice must be followed by providing all required signing, lighting, and guarding before work commences; building the appropriate ramps and aids for pedestrians and disabled people; maintaining a clean work area through regular on-site inspections. Also, promoters of street works shall avoid any damage to the surrounding environment (i.e. trees, shrubs, archeologically sensitive sites, conservation areas). Finally, it is the responsibility of those performing highway works to maintain the structural integrity of the highway and the apparatus beneath it. They must ensure long-term performance of the above ground and underground infrastructure by ensuring that appropriate training, equipment, and materials are being provided to produce high-end performance.

MONITORING, FEEDBACK AND IMPROVEMENT

All stakeholders working in the streets for excavation, reinstatement and repairs shall operate a quality assurance system that provides customers and the public with confidence that work is being performed to produce a high-quality product. Also, it is recommended that any conflicts be resolved in an efficient manner and that the appropriate discretion is utilized when handling these problems. And the authorities, promoters, and contractors should facilitate continuous improvements through learning from their own experience and that of others.

All in all, the Good Practice Guide is to demonstrate how utility infrastructure can be maintained, improved, and replaced in conjunction with the road network needs. And it is highly commended to all those working in the highway, including highway authorities, utility companies, contractors, suppliers, and all those involved in coordinating and managing street works.

NUAG REPORT SEPT. 2006

This report illustrates the work of the Phase 1 Working Group, which assisted in the development and completion of a successful User Survey representing samples of utilities and highway authorities. Over 500 organizations in England and Wales currently gather, store and share utility asset information. However, from a group of 500, 27 facility companies from electricity, gas, telecommunications, water, pipeline, and network rail sectors in different regions were surveyed. Also, 12 highway authorities were surveyed including those from urban and rural geographic areas. This Survey was generated to obtain a sample of and to assess the condition of certain issues including:

- the range of practices currently being used to gather, record, and store utility asset data and the sharing methods of asset information;
- changes in future improvements and the use of new technologies as they become more available and widespread;

- expectations of practitioners and reactions to the concept of a mandatory revised Code of Practice

The outcomes of this survey are presented in both qualitative and quantitative forms of data. The Quantitative aspect deals with responses to a questionnaire that covers details of current practice, aspects of future practice, and the use of an industry-wide standard Code of Practice.

Based on an analysis of the User Survey, the conclusions of the survey were as they predicted. The Survey further proved the existence of significant variations in practices, approaches, attitudes, emphases within and between utilities and highway authorities with regards to recording, storing, and sharing of subsurface utility information. These variations lead to obvious variability in accuracy, incompleteness of records, a wide variety of base maps; unnecessary timescales and conflicting tactics to third party and legacy data.

The lack of a statutory-based Code of Practice is also an evidential factor of contributing to the current state of conditions.

However, the support for a change to standardize approaches and implement a mandatory Code of Practice seems strong across utilities and highway sectors. Also, the likelihood of costs and resource issues to deploy a new Code arose. Nonetheless, in order for utilities and highway authorities to benefit from new technology and technology-based aspirations of the TMA, consistency and compatibility must be established in recording, storing and sharing asset record information.

As a result of the NUAG Sept. 2006 report a few recommendations were set out in order to reach the targets of the TMA including:

9. The development and deployment of a revised Records Code of Practice on a mandatory basis
10. Implementation of a mandatory national standard high-level framework, with effective ownership and management for capturing, recording, storing and sharing buried plant information; which will allow the successful use of a revised Records Code of Practice

11. Individual utilities and highway organizations must possess clearly-defined processes compatible with the national standard framework, along with appropriate ownership and management for the implementation and utilization of a revised Records Code and Code's standards.
12. The revised Records Code of Practice must include a set of minimum standards to be achieved:
    a. every subsurface asset must be recorded in unison with its appropriate above ground asset or appurtenance
    b. utility data must be captured during the planning, urgent and emergency types of work (planned and immediate)
    c. data must be captured and recorded for assets in any location
    d. data must be recorded for all new, replacement, amended or abandoned assets
    e. All previously-unrecorded existing assets, belonging to the organization carrying out the work, should be recorded if found during work.
    f. Any unidentified third party asset found in the course of work must be captured, and recorded as an Unidentified Buried Object (UBO), by the organization finding it.
    g. Any historical discrepancies between recorded and actual data found during work should be reported to the asset's owner, including third parties.
    h. Attributes that must be captured are: location (x and y); top of asset (z); diameter (including any changes); material (including any changes), and pipe or cable run
    i. Asset data must be captured and recorded at a minimum standard of accuracy of +/- 100 mm in x, y and z dimensions
    j. Location data must be recorded using relative and absolute referencing
    k. All geospatial data must be recorded using an agreed framework and agreed scales (DNF)
    l. Asset data must be available for external inspection within one month of capture

m. Record information must be made available in electronic from through a web-based service

n. Each organization is responsible for managing their responses to requests for record information

13. Standard data definitions and data standards must be incorporated in the Records Code of Practice
14. In order to measure performance against the Code's standards, an annual review process must take place which will also lead to the deployment of appropriate minimum
15. For the successful deployment of the Code, any resource and cost associated with the new Code should be managed effectively.
16. The national high level standard framework and the revised Records Code must be fully implemented within a compulsory timetable.

NUAG REPORT JULY 2007

This document, similar to the 2006 report, presents a new method to capture, record, store, and share subsurface utility information. As the recommendation of the 2006 report, this method forms the foundation of a national high-level framework to deliver a set of minimum performance standards. The development of this method has been achieved by experts from utility companies, highway authorities, contractors, surveyors, and IT specialists. (NUAG, 2007).

This document also expresses what needs to be done and not how to do it. And it is not meant to replace current organization practices but its implementation may entail organizations to refine their processes, systems, procedures, and approaches.
Of particular interest, the report emphasizes key principles including

- the notion of capturing data and/or improving data quality every time a hole is opened;
- considering the health and safety of everyone working on or in the area of subsurface and associated above ground assets, and the general public, as being of utmost importance;

- the asset's Owner is solely responsible for capturing and recording asset data and the asset's Owner shall be notified immediately of any discrepancies found with third party assets found during work; as well as capturing and recording third party asset data as an Unidentified Buried Object (UBO).

Finally, this report also addresses the fact that by implementing the standards, organizations may require increased investments in new data capture, electronic storage, web-based service and communications technologies, and more advanced modern digital data or map backgrounds that those in current use.

The Sept. 2006 and July 2007 reports complete Phase 1 of the NRS, and Phase 2 of NUAG's work started in Jan. 2008 in the efforts of describing established processes, protocols, etc. for Sharing Asset Data and Displaying Asset Information.

NRS - PHASE 1

The NUAG is currently directed by the Steering Group and the Working Group. The Steering Group is responsible for the strategic management and direction of work. And the Working Groups are created by the Steering Group in order to carry out the work set up by the Steering Group itself. Members of both the Steering Group and the Working Group arise from stakeholder organizations and can be found in Appendix ?.

The NUAG has since published two reports in efforts of displaying the current practice and future recommendations for quality and consistency in dealing with underground and appropriate above ground asset information. The first report entitled, '*Capturing, recording, storing and sharing underground asset information; A review of current practice and future requirement*', was released in September of 2006 (see Appendix A for a detailed summary). And another report was published in July of 2007 called, '*A National Report for capturing, recording, storing and sharing underground asset information*' (see Appendix A for an extended explanation).

NRS - PHASE 2

NUAG *National Referencing Standards Project Phase 2: Terms of Reference* (http://www.nuag.co.uk/outputs/nuag-phase2-terms-of-reference.pdf).

In terms of capturing, recording and storing subsurface utility and associated above-ground asset information, Phase 1 delivered a good set of standards and high level processes. Phase 2 develops the sharing aspect of asset information. This phase is intended to deliver a document consisting of business processes, protocols and guidelines for sharing asset data and displaying asset information.

The processes involve providing a subset of asset data for a specified geographic region during an enquiry from a third party, as well as delivering the data as information to be utilized for visualization and analysis. According to the referencing standards project, each enquiry shall be dealt with through a web portal, thereby creating access paths which send the request to the appropriate facility owner's/operator's system. The web portal will execute the request and send the required information to the user's system. Also, there are issues concerning entitlement rights, and those organizations that own asset information must hold a register of permitted users and their associated entitlements. A minimum standard set by NUAG is to supply asset information as an image file in read-only format.

The NUAG also published a third report entitled, '*Defining the Technological Capability necessary for Sharing and Displaying Asset Information: User Requirements*' for comprehensive capture of data using GPS methods of which can be held electronically in GIS systems for web-based enquiry and information sharing.

The requirements developed in this report will be useful for:

- the definition of the 'technological capability' setting out in detail business process definitions with associated protocols and guidelines;
- implementation of an approach that incorporates recommendations for future ownership and management, and
- description of the nature of, and requisites for, a schema to facilitate future system development.

B.2 USA – STANDARDS AND BEST PRACTICES

CGA BEST PRACTICES V6.0

This best practices guide includes the following nine categories:

- Planning and Design Practices
- One-Call Center Practices
- Locating and Marking Practices
- Excavation Practices
- Mapping Practices
- Compliance Practices
- Public Education Practices
- Reporting and Evaluation Practices
- Homeland Security and the Best Practices

Each category contains subsections of which the significant ones are as follows

PLANNING AND DESIGN PRACTICES

This best practice section deals with the different aspects to consider during the preliminary planning and design phases of a construction project. In particular, this guide suggests that the designer shall use all reasonable means to gather and identify all underground utility information in the proposed excavation area. The project owner and the facility owners/operators should also develop proper coordination throughout the duration of a project.

Furthermore, during the planning and/or design stages, the designer must ensure the compliance of all federal, state and local guidelines, codes, statutes and other facility standards during the installation of new or replacement underground facilities. And the project owner shall use qualified contractors to perform the necessary excavation activities.

More importantly, it is the duty of the project owner, designer, and excavator to prepare as-built drawings by recording underground utility information to assist with future locates.

The guide suggests a minimum of 12 inch radial separation be maintained between supply facilities when installing direct buried facilities in a common trench.

It is also highly recommended to use SUE during the design phase, seeing as how it delivers significant cost and damage avoidance and ample opportunity to correct inconsistencies in existing underground utility records.

ONE CALL CENTER PRACTICES

The best practices for One Call Centre involves the organizations responsibilities towards its members; the governance, agreements, and administration of the centres; as well as the smooth flow of locate requests while following all documented operating procedures, human resource policies and training manuals.

LOCATING AND MARKING PRACTICES

While locating and marking underground facilities the document suggests that locators use all available records and that they provide the necessary information upon coming across errors or omissions in records.

It is suggested that a single, properly trained locator be used for multiple facility locates in a specified project area. Locators should also follow a uniform color code and marking symbols. And all qualified locators have the responsibility of performing safe locates while providing information about all facilities, including abandoned assets, when possible. The locator should also maintain appropriate documentation of any work performed on a locate and to follow the Quality Assurance program to monitor locating and marking facilities.

EXCAVATION PRACTICES

Most of the practices in this section are directed towards excavators. The excavator must make sure to make a request through the one-call system for the location of underground facilities. It is the responsibility of the excavator to pre-mark the excavation site using a white outline before the locator arrives on said site. The excavator must also coordinate work appropriately during the temporary or permanent interruption of any facility within the excavation area. Also, the excavator must, at all times, use extra caution around underground facilities, while adhering to all federal and state safety regulations.

It is the duty of the excavator to preserve the staking and marking of the underground facilities, along with observing a tolerance zone comprised of the width of the facility plus 18" on either side of the facility on a horizontal plane. The excavator shall notify the facility owner/operator of any mis-marked facility and must protect all exposed facilities from damage. Finally, the excavator must protect all facilities from damage when backfilling an excavation; ensuring that no trash, debris, coiled wire, or other utility damaging objects get into the excavation site.

MAPPING PRACTICES

This section of the guide simply states the practices needed to map underground facilities in five distinct areas: One-Call Center, Locator, Excavator, Facility Owner/Operator, and Project Owner. The one-call center must ensure that the land base is accurate, up-to-date and that it uses latitude and longitude.

The locator must be trained in proper map reading and symbology recognition, ass well as being able to provide precise facility location to the utility owner operator.

The excavators mapping practices consist of providing accurate location information and basic asset attributes to the one-call center.

The facility owner should provide the one-call center with their facility locations and it should adhere to mapping standards that are consistent and current.

Finally, the project owner is responsible for providing accurate mapping information and shall determine basic coordinates.

COMPLIANCE PRACTICES

This section promotes compliance through public education and mandatory education as a penalty. It also states incentives and penalties should be put into place to promote compliance with damage prevention laws or regulations. Also, an authority shall be chosen to enforce the law and conduct a structured review process to impartially adjudicate alleged violations.

PUBLIC EDUCATION PRACTICES

This portion of the best practices guide simply entails details on how to use marketing plans to increase the awareness of effective damage prevention. By using target mailings, paid advertising, free media, giveaways, and by developing strategic relationships awareness surrounding damage prevention should improve greatly.

REPORTING AND EVALUATION PRACTICES

These practices ensure that all stakeholders report the required information for analysis. It is best to have the data collected in a common database which is then summarized by key components. As a result of the data analysis, root causes may be identified and the results are quantified against a standardized risk factor. Also, the results are compared to assess the trends and performance levels.

HOMELAND SECURITY AND THE BEST PRACTICES

The CGA understands that many of the practices involves sharing critical asset information. All parties are responsible for ensuring that this information is only distributed to individuals who truly require it to satisfy the concerns over Homeland Security. All appropriate authorities must make sure that critical infrastructure information does not reach individuals or groups that may try to damage, alter, or destroy the infrastructure. [CGA BEST PRACTICES 5.0 2008]

DOMESTIC SCAN PROGRAM: BEST PRACTICES IN ROW ACQUISITION AND UTILITY RELOCATION

FEDERAL REGULATORY FRAMEWORK

RIGHT – OF – WAY ACQUISITION

People affected by federally funded projects have the Uniform Relocation Assistance and Real Property Acquisition Policies Act (1970) for protection and assistance. However, this Uniform Act had a rigid set of regulatory requirements which started to be revised in 1999. A clarification made on April 19,2002; which also became effective on February 3, 2005, allowed state and local agencies to use innovative incentive payments to help in the quick and efficient relocation of individuals, families and businesses.

UTILITIES

Ultimately, States decide whether they want to include utilities on highway right-of-way; which must be documented in an FHWA-approved utility accommodation policy. Highway authorities decide the conditions under which public funds may be allocated to relocate utility infrastructure to accommodate highway construction. In particular, several of the FHWA regulations, policies, and practices concerned with utility relocation issues have evolved. For instance, public rights-of-way are being leased for fiber optics services by private telecommunication companies.

FHWA – EUROPEAN RIGHT-OF-WAY AND UTILITIES BEST PRACTICES SCAN

In 2002 published a report on a right-of-way and utilities scan conducted in 2000. It included visits to Oslo, As, Moss Norway; Bonn, Germany; The Hague, Netherlands; and London, England. This scan provided new insights into right-of-way acquisition and utility relocation practices. One thing all the regions visited revealed that when dealing with transportation decisions, community welfare was high on the priority list close to bottom line costs. The scan also revealed an early involvement of property owners in the design process, along with extensive interviews with property owners throughout a project. And another useful technique used to speed-up the process of right-of-way negotiations involved prompt settlements. Of particular interest, many of these European countries continue to place their underground facilities underground for safety and aesthetic reasons.

After the completion of the European scan, several states ran pilot projects using the procedures found in the scan. The pilot projects covered processes from waivers of appraisals, modified appraisal reviews, acquisition and relocation incentive payments, conflict of interest, land consolidation, to preliminary engineering cost reimbursement for utilities.

For the purpose of this paper discussion will only take place on the pilot state of Virginia; which conducted the preliminary engineering cost reimbursement for utilities project. Virginia state was successful in its reimbursements to utility companies for 100 percent of their preliminary engineering cost to quicken the development of utility plans and cost estimates. A relocation move incentive was also initiated and it was successful in that the relocation of over 400 tenants took place in eight months, offsetting a cost of $1.2 million by construction-related savings of $6 million.

B.3 CANADA – STANDARDS AND BEST PRACTICES

NATIONAL STANDARDS FOR AS-BUILT DRAWINGS FEASIBILITY STUDY

The Regional Public Works Commissioners of Ontario is an organization made up of a number of members from different municipalities that are involved in planning, designing, building, operating, and maintenance of public infrastructure, including transportation, water, wastewater, solid waste, park and public buildings; which provide daily services to the citizens of the Province of Ontario. In June 2005, the organization established the Utility Policy and Data Standards Task Force consisting of members from Hamilton, Ottawa, and Toronto.

The Utility Data Standards Task Force in close collaboration with the Canadian Standards Association (CSA) began a feasibility study with the intention of developing national standards for the mapping underground facilities. The standards are aimed to ensure public safety and to prevent damage to public and private property. As well as, the standard, if used as part of the regulatory regime, should improve planning and co-ordination throughout the utility lifecycle, minimize construction costs, and minimize service cuts (pdf on terms of reference).

To be more specific the standard shall include all buried utilities ranging from supply, distribution to service laterals. The standard should also consider existing and emerging supportive data collection technologies which may present opportunities of improvement in terms of quality and reduction of costs associated with data collection. And the standard shall include methodologies and business process that guarantee quality as-built record content without compromise to public safety.

More importantly, the standard should aim to prescribe the minimum content requirements of spatial details (i.e. accuracy and measuring techniques, location, size) non-spatial information (utility type, utility material, date of construction). And finally the standard should consider utilizing a quality classification system such as the SUE standard.

ORCGA BEST PRACTICES V 5.0

Version 3.0, published in March 2007, includes the following eight categories:

9. Planning and Design Best Practices
10. One-Call Centre Best Practices
11. Locating and Marking Best Practices
12. Excavation Best Practices
13. Mapping Best Practices
14. Compliance Best Practices
15. Public Education Best Practices
16. Reporting and Evaluation Best Practices

Each category contains subsections of which the significant ones are explained as follows.

PLANNING AND DESIGN BEST PRACTICES

This section focuses on the factors to consider when determining the placement of underground utilities. It also deals with having new utility plant, planners and designers protecting the survey infrastructure and how development plans should include the designation of existing and proposed underground and associated above ground infrastructure. Of particular interest, this best practice proposes the project owner opting to use Subsurface Utility Engineering (SUE) techniques to gather and depict utility information for design purposes and how project owners and facility operators should coordinate with each other concerning current and proposed projects, as well as establishing Utility Coordinating Committees (UCCs) to deal with project issues. Since new utilities are being placed underground everyday, underground facilities should also consider making facilities locatable by using tone-able pipes, cables, tracer wire, locator balls, and permanent above or below ground markers. This section also outlines the designer's responsibility to comply with all applicable codes, regulations and facility owner/operator standards when planning and designing the installation of new or replacement facilities.

Finally, an important subsection is the one of specifying as-built or as-constructed drawings as a contract or project deliverable. Essentially it will serve as location information for future locates and construction. According to the ORCGA, the as-built drawings must include the following: deviations in construction from design, the level of accuracy in the horizontal and vertical locations, the form of survey used, the survey date, the method of construction, and the location of valves, access chambers, manholes, service boxes and stub connections for services, final invert elevations, pipe size, and grade changes.

ONE CALL CENTRE BEST PRACTICES

These practices focus on the Centre's rights and responsibilities towards its members; the requirements, limits, records, administration, governance of One Call; as well as the maintenance needs and locating responsibilities the organization holds (i.e. necessary information for a locate request, procedure of locate, the receipt of locates, etc.).

LOCATING AND MARKING BEST PRACTICES

This section of the document contains eighteen subsections, the first being the practice of locators utilizing on-site facility records at all times and the locator must provide updating information for errors in records. Alike the CGA best practices, a uniform colour code and set of marking symbols must be adopted across Ontario and project owners should opt to use a properly trained and officially documented, qualified locator for multiple facilities.

Furthermore, the recommended method when locating electro-magnetically is to use active/conducting locating over passive/inductive locating and in the order of a direct connection (i.e. a tracer wire), an induction clamp, or an induction or broadcast mode on a transmitter.

Another significant subsection outlines the maintenance of documentation work completed on a location. This will ensure that an accurate record of work performed by the locator exists, which, in turn, eliminates confusion regarding what work was requested by the excavator.

EXCAVATION BEST PRACTICES

This section highlights practices of construction activity with respect to underground facilities from the pre-construction phase to its completion.

It states that excavators must call the one-call center at least four working days prior to breaking ground and they must also request the private facility owner to locate their facilities in the case of privately owned buried facilities existing in the work area.

Also, the excavator is responsible for coordinating work with the affected facility owner and the project owner in the case of an interruption of a facility owner's service. Conference calls and pre-planned meetings must take place to resolve the issue immediately.

Moreover, before the excavator breaks ground, verification must be made in terms of the limits of the locate markings and proposed excavation limits correspond. If, for any reason, the locate is incomplete or inaccurate, it is the responsibility of the excavator to call the locator directly to correct the locate within a maximum of four hours, after which the excavator can direct the locate to the one-call centre as an overdue request.

Furthermore, if an excavator encounters an inaccurately marked or unidentified facility, excavation must come to a complete stop until notification to the facility operator/owner or to the one-call system has been made; after which work may continue.

In terms of As-Built documentation best practices, it is recommended that the contractor installing the new facility notifies the facility owner/operator of any deviations to the planned installation. In fact, ideally the utility owners/operators should develop a standard of notification if the deviation is beyond a specified tolerance. For example, a tolerance of alterations of 150mm or more in depth and lateral changes of 300mm or greater must be brought to the attention of the utility owner immediately in order to maintain a quality set of As-Built records.

Another useful best practice is to have the requirement that only competent workers as defined by the OH&S regulations for construction projects. These qualified individuals shall operate vacuum excavation equipment, specifically following the manufacturer's recommended practices, procedures, and complying with the facility owner guidelines. As well as, these vacuum excavators shall obtain training as outlined by the "*EUSA Safe Practice Guide for Excavating With Hydrovacs in the Vicinity of Underground Electrical Plant*" and further training specific to any utility in the dig area.

MAPPING BEST PRACTICES

This section deals with recording, storing, and displaying underground utility information in the forms of maps. It states that the One-Call Center must make certain that the land base used in their for electronic mapping system should be accurate and constantly updated with new information from facility owners/operators on a regular basis.

It is also recommended that the locator notify the owner/operator and the One-Call Center after an encounter with any discrepancies between mapping and facilities location. Furthermore, the excavator must provide the one-call centre with accurate excavation location information. And the facility owner/operator should collect and notify the one-call center and the locator on a regular basis regarding their existing and newly constructed utilities. As far as the project owner's responsibilities, they should provide basic coordinates which define the area of construction. Finally, the mapping best practices suggests that the land base be made available to the public.

COMPLIANCE BEST PRACTICES

Basically, this portion develops the practices that should be implemented in order for all stakeholders to comply accordingly. The first being organizing public education programs to promote compliance and implementing mandatory educational sessions as a form of penalties for delinquents who violate damage prevention laws and regulations.

The best form of compliance would be to provide incentives that encourage stakeholders to comply with laws and regulations. However, this document states that authorities should be specified through provincial statutes and given the necessary resources to enforce the law. And a structured review process must take place which includes a document containing who receives reports of violations; who responsible for investigation; the possibilities in terms of the outcomes of the investigation; and who conducts informal and formal hearings.

PUBLIC EDUCATION BEST PRACTICES

This section of the document entails developments in increasing awareness around damage prevention regarding underground facilities. For effective education, the organization must initially identify the target audience. Proceed to establish their training needs and create a communications package tailored to those specific needs. Also, the organization should develop a marketing plan intended to consider the training needs of participants, resources, communications media and timeframes. More importantly, for effective promotion of damage prevention, a brilliant message that "sticks" must be created and put forward. During the promotion process it is crucial to establish strategic relationships that assist in promoting damage prevention. And an annual review is essential in determining the successes and failures, and the improvements to the public awareness campaigns.

REPORTING AND EVALUATION BEST PRACTICES

The final portion of this document discusses best practices for reporting facility information including the opportunity for all stakeholders to report information in a standardized format. Also, the person reporting must provide detailed information in a simple, one page form of data collection provided by the one–call center. The data should be collected in a common database which is then summarized by key components. As a result of the data analysis, root causes are identified and the results are quantified against a standardized risk factor. Also, the results are compared to assess the trends and performance levels.

CAPULC's CANADIAN LOCATOR TECHNICIAL STANDARDS

The Canadian Association of Pipeline and Utility Locating Contractors (CAPULC) was launched in April 2002 with the intention of improving the locating industry. The association consists of clients, suppliers of equipment or training, the digging organizations, and anyone with the shared goal of underground utility damage prevention.

The association created the Canadian Locator Technician Standards, which states the minimum technical qualifications required by any person who would like to become a Locator Technician. It outlines the requirements of the Locator Technician in terms of demonstrating the right knowledge and understanding of the practices and procedures by passing a formal closed book examination, as well as actual field scenarios to locate using equipment efficiently and effectively (STANDARDS MANUAL).

In particular, the viable Locator Technician candidates must display knowledge and understanding in the ten units of competency:

- Theory of Electromagnetic Locating
- Use of the Transmitter
- Use of the Receiver
- Marking Procedures
- Knowledge of Facilities
- Visual Observation Skills
- Safe Work Practices and Regulations

- Locate Request Procedure, Documentation, and Mapping
- Federal, Provincial and Local Regulations
- Customer Interaction

These minimum standards will be revised and improved as the locating industry continues in its efforts of damage prevention. However, this standards document only describes the knowledge and skills that have to be displayed by any entry level Locator Technician. And through the application of the practices outlined in the manual, increased knowledge and experience will take place, leading to greater competency than before.

APPENDIX C

ASSET MANAGEMENT

C.1 VUEWORKS

VUEWorks Inc. is a company that develops, markets, and supports Work and Asset Management solutions that help local municipalities, utility companies, and other organizations. VUEWorks helps these organizations by managing their work, tracking conditions, minimizing failure risks, optimizing expenditures, and estimating project costs for any group of assets.

The VUEWorks software program has the ability of loading any GIS-based asset data such as pipelines, roadways, buildings, parcels, and so on. It is capable of linking multiple electronic documents to any asset or map feature for quick recalls. The user may also graphically move, add, and delete asset data inside a browser window. And a list of the assets may be created using a proximity tool. This program has the function of displaying as-built drawings, building plans, permits, forms, reports, tie cards, and videos associated with the project asset data.

VUEWorks displays a map of a region's infrastructure assets that allows the users to access extensive information regarding the assets via a map that is created from the internal software database or from existing in-house databases. The users have the ability to login from their Windows desktop; which then opens up an Internet browser window. It has two windows, one window is the Menu View and it contains folders that can be chosen to activate specific databases and functions. Whereas, the second window, also referred to as the Data View, is used for data reading and data entry.

In general, a map can be generated by calling up specific information about the preferred infrastructure assets such as a sewer system. These features can be linked to inspection reports, photographs, or other documents in external database files. The application itself can handle a wide range of asset collections hence allowing users to activate and de-activate different layers in a map accordingly. Furthermore, the basic software program can add-on more modules that, for example, allow the user to maintain inventory, link to other databases, manage service calls, track financial matters including depreciation expense, and to plan capital projects.

C.2 AUTODESK GEOSPATIAL SOFTWARE

Autodesk carries several specialized geospatial software products designed particularly for each utility sector. For example, Autodesk infrastructure modeling software allows electric and gas utilities to extend the value of asset information for underground projects and for facility renewal for intelligent grid sustainability.

As for the telecommunications industry, Autodesk's model-based design and 3D mapping tools allow for the integration of design and asset management that result in up-to-date, accurate geographic information that improves efficiency, response time, and customer service.

Autodesk's infrastructure modeling software also allows the water and wastewater facilities to plan effectively, lead efficient operations, and respond without delay due to increased precision in design and integration of design and GIS data [REF. AUTODESK WEBSITE].

C.3 ONE CALL MAPPING

A company by the name of Kuhagen, Inc. developed a One Call ticket management program known as the Vista One Call Mapping. The mapping program is designed to efficiently deal with 50 to 200,000 incoming tickets, map said tickets, as well as simultaneously displaying a utility's overlay.

More importantly, Kuhagen Inc. is working with the One Call System to notify utility companies of impending encroachments. The ultimate goal would be to develop and standard integrated system between utility companies and the One Call System in order to create a consistent nature during the processing stage of data and tracking of facilities across the United States (Kuhagen, 2009).

C.4 ONTARIO ONE CALL BASE MAP

The Ontario One Call Mapping Department hired Wayne Crann & Associates to assist in the creation and maintenance of an extensive up-to-date digital base map of Ontario. It is in MapInfo GIS format consisting of DMTI's CanMap, Land Information Ontario data, Bell Canada's street centre line information, and municipal data for the streets layer. The street data, in particular, is updated monthly along with smaller corrections done weekly depending on its necessity.

APPENDIX D

EQUIPMENT SPECIFICATIONS

D.1 810 Pipe and Cable Locator™ Specifications

810 Transmitter Technical Specifications

Nominal Output Power	250 mW
Frequency	83.0775 kHz + 0.002% Crystal Controlled for interference resistance
Battery Type	Six NEDA 13F Alkaline D Cells
Battery Life	170 hours
Dimensions	8"L x 3.25"W x 7.75"H (20.3 x 8.3 x 19.7 cm)
Weight	3.9 lbs (1.8 kg)

810 Receiver Technical Specifications

Trace Accuracy	+1 inch from 0 – 3 ft (91 cm) +3% over 3 ft (91 cm) in depth
Depth Readout Accuracy	± (5% + 2") under normal conditions
Depth Readout Range	To 13 ft (400 cm)
Sensitivity Control	Automatic, no adjustments
Battery Type	Four NEDA 1604A Alkaline (9V)
Battery Test	Indicated on Meter
Battery Life	140 hours
Temperature Range	0 - 110°F (-18 - 43°C)
Dimensions	(Extended length) 32.5"L x 7.5"W x 12.5"H (82.6 x 19.1 x 31.8 cm)
Weight	4.4 lbs (2.0 kg)

D.2 Ditch Witch 970T and 910R Specifications

970T Transmitter Technical Specifications

DIMENSIONS	U.S.	METRIC
Height	11 in	280 mm
Length	14 in	355 mm
Width	4.2 in	107 mm
Operating weight	7.25 lb	3.3 kg

OPERATIONS	U.S.	METRIC
Operating Temperature Range	-4° F to 122° F	-20° C to 50° C
Maximum power output	5 W	

Operating modes: 512 Hz, 1 kHz, 8 kHz, 29 kHz, 80 kHz, 200 kHz (optional), and dual (8 kHz and 29 kHz)

Timer: Unit runs continuously or shuts off after running for selected hour interval (8-hour maxium)

BATTERIES	U.S.	METRIC
Type	8 D-cell alkaline	

Battery life: Approximately 80 hours (continuous use at power level 2)

910R Receiver Technical Specifications

OPERATIONS	U.S.	METRIC
Lines	15 ft	4.6 m

DIMENSIONS	U.S.	METRIC
Height	27.8 in	70.5 cm
Length	12.8 in	3.5 cm
Width	5.9 in	14.5 cm
Operating weight	4.5 lb	2 kg

OPERATIONS	U.S.	METRIC
Operating temperature range	-4° F to 122° F	-20° C to 50° C
Antenna configurations: Single peak, twin peak, null, left/right (line only)		
Audio output	Speaker	
Depth estimate tolerances*		
Active line ± 3%	0.2 ft - 5 ft	0.06 m - 1.5 m
Active line ± 10%	10 ft and deeper	3 m and deeper
Passive line ± 10%	0.5 ft - 10 ft	1.5 m - 3 m
Beacon ± 5%	0.5 ft - 10 ft	1.5 m - 3 m
LCD backlight: LED (green)		
External Ports	RS-232 serial	

BATTERIES	U.S.	METRIC
Type	6 C-cell alkaline	

Battery life: Approximately 50 hours (continuous use at 70° F/21° C)

Battery saver: Unit shuts off after 5 minutes of inactivty

OPERATIONAL FREQUENCIES

Passive: 50 Hz, 60Hz, 100 Hz, 120 Hz, 50 P, 60 P

Active: 512 Hz, 1 kHz, 8 kHz, 29 kHz, 80 kHz, 200 kHz

Active other: 400 Hz, 560 Hz, 815 Hz

Beacon (non-roll): 512 Hz, 29 kHz, 33 kHz

Other: 31 kHz CATV passive, 33 kHz EML, radio passive (no depth capability)

Other: 31 kHz CATV passive, 33 kHz EML, radio passive (no depth capability)

D.3 MALA Easy Locator System Technical Specifications

Power supply: Li-Ion 11,1V battery

Operating time: Approx. 5h

Operating temp: -20° to +50°C or 0° to 120 °F

Environmental: IP65

Display: 10.4" Color TFT Ultra-Hi-Brite or trans-reflective

Dim. with wheels: 67x47x19cm / 26"x19"x7"

(excluding handle)

Weight: 18 kg / 40 lb (Shallow), 19 kg / 42 lb (Mid)

Antennas: Shallow: 500 MHz. Shallow penetration, highest resolution.

Mid: 350 MHz. Deeper penetration, high resolution.

D.4 MALA X3M Technical Specifications

Power supply: Li-ion battery pack 12V

Operating time: >6h with standard battery pack

Operating temp: -20° to +50°C/ 0° to 120 °F

Environmental: IP65

Dimensions: 310 x 180 x 30 mm/ 12.2 x 7 x 1.2 in

Weight: 1.7 kg/ 3.7 lb

Antennas: The MALÅ X3M fully supports the range of MALÅ

Shielded Antennas (100, 250, 500 & 800 MHz).

D.5 ΩOMEGA Tools SERVAC – SBM-100-5080 Technical Specifications

Filtration System:

Filter Cartridge Part #	23-361E-260
Number of filter cartridges	2
Design pressure	15 IN HG
Design flow	890 CFM @ 2800 RPM
Number of pulse valves	2
Electrical requirement	12 VDC @ 2 Amp
Receiver pressure (max)	120 PSIG
Receiver coalescor element	12-430E-20A
Blower relief valve set	12 IN HG
Pulse system	Compressed air
Pulse Pressure	110 PSIG
Pulse cycle	Continuous

Power Module:

Engine	4-cylinder diesel, 80 HP @ 2500 RPM
Air Compressor	185 CFM @ 100 PSIG, Direct drive
Vacuum producer	890 CFM @ 2800 RPM Rotary lobe blower
Blower drive system	Electric clutch/ Belt drive

Soil Collection System:

Automatic dump valve	ADV 3800 Series Auto-Dump Valve
Soil tank (optional)	Hydraulic lifting mechanism

Appendix E

SATELLITE IMAGERY

Figure E.1 Satellite imagery of the Queensway from Moynes Avenue to Berl Avenue (Google Earth, 2009).

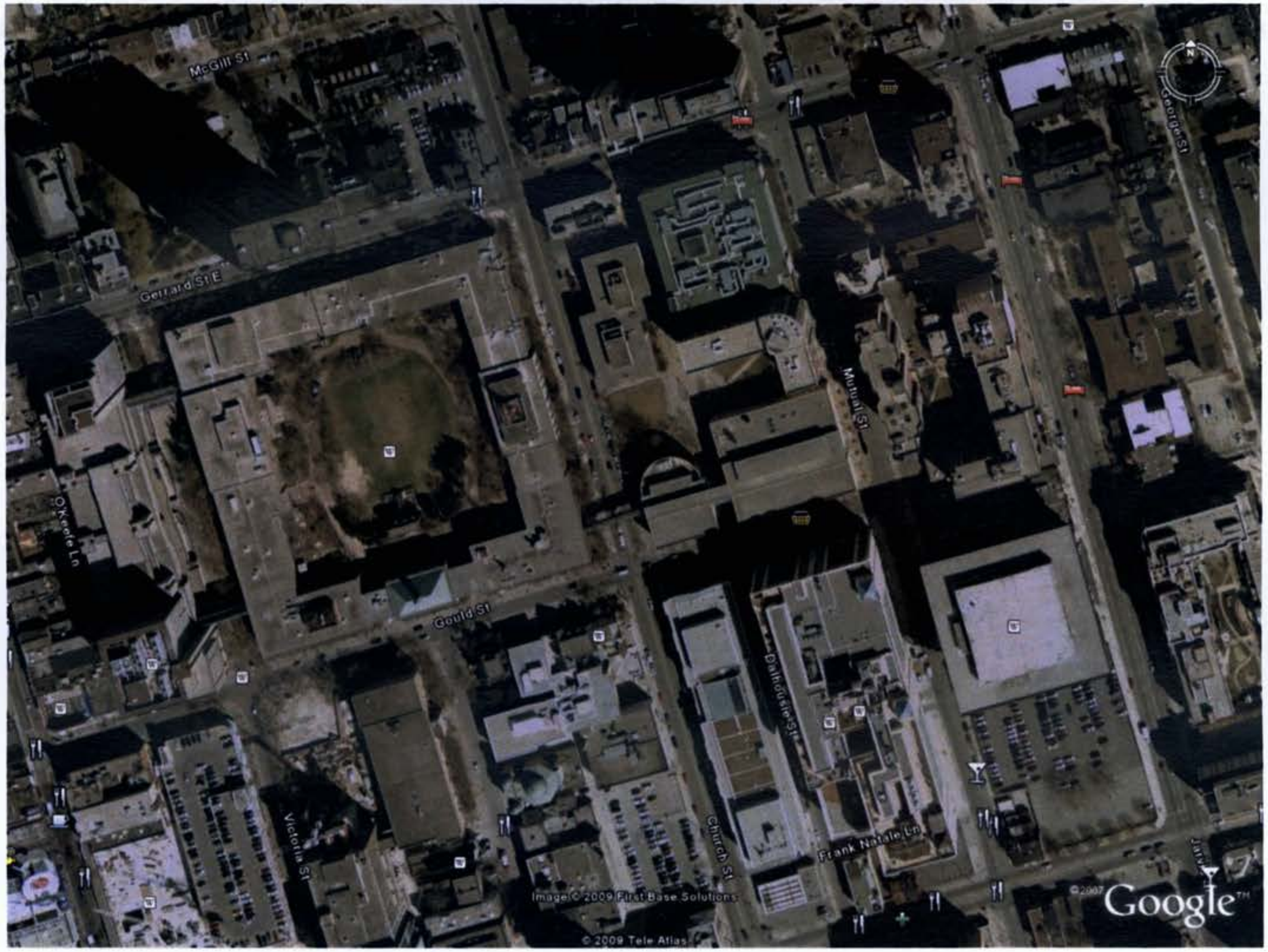

Figure E.2 **Satellite imagery of Gerrard Street from Yonge Street to Jarvis Street (Google Earth, 2009).**

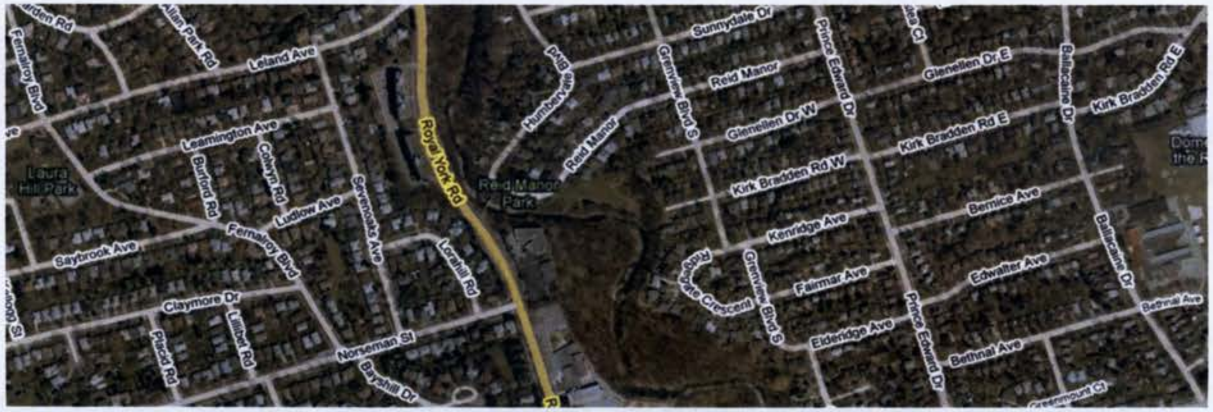

Figure E.3 (a) **Satellite imagery of Royal York Road from Leland Avenue to Norseman Street (Google Earth, 2009).**

Figure E.3 (b) **Satellite Imagery of Royal York Road from Norseman Street to Delroy Drive (Google Earth, 2009).**

Figure E.4 Satellite Imagery of Kenneth Avenue and Spring Garden Avenue (Google Earth, 2009).

Figure E.5 Satellite imagery of Union Station NW PATH. (Google Earth, 2009).

Figure E.6 (a) Satellite Imagery of Yonge Street from Lawrence Avenue to Strathgowan Avenue (Google Earth, 2009).

Figure E.6 (b) **Satellite Imagery of Yonge Street from Glencairn Avenue to Sherwood Avenue (Google Earth, 2009).**

Figure E.6 (c) **Satellite Imagery of Yonge Street from Sherwood Avenue to Eglinton Avenue E (Google Earth, 2009).**

Figure E.7 (a) **Satellite Imagery of Portland Energy Centre from Eastern Avenue along Booth Avenue (Google Earth, 2009).**

Figure E.7(b) Satellite Imagery of Portland Energy Centre from Booth Avenue along Lake Shore Blvd East (Google Earth, 2009).

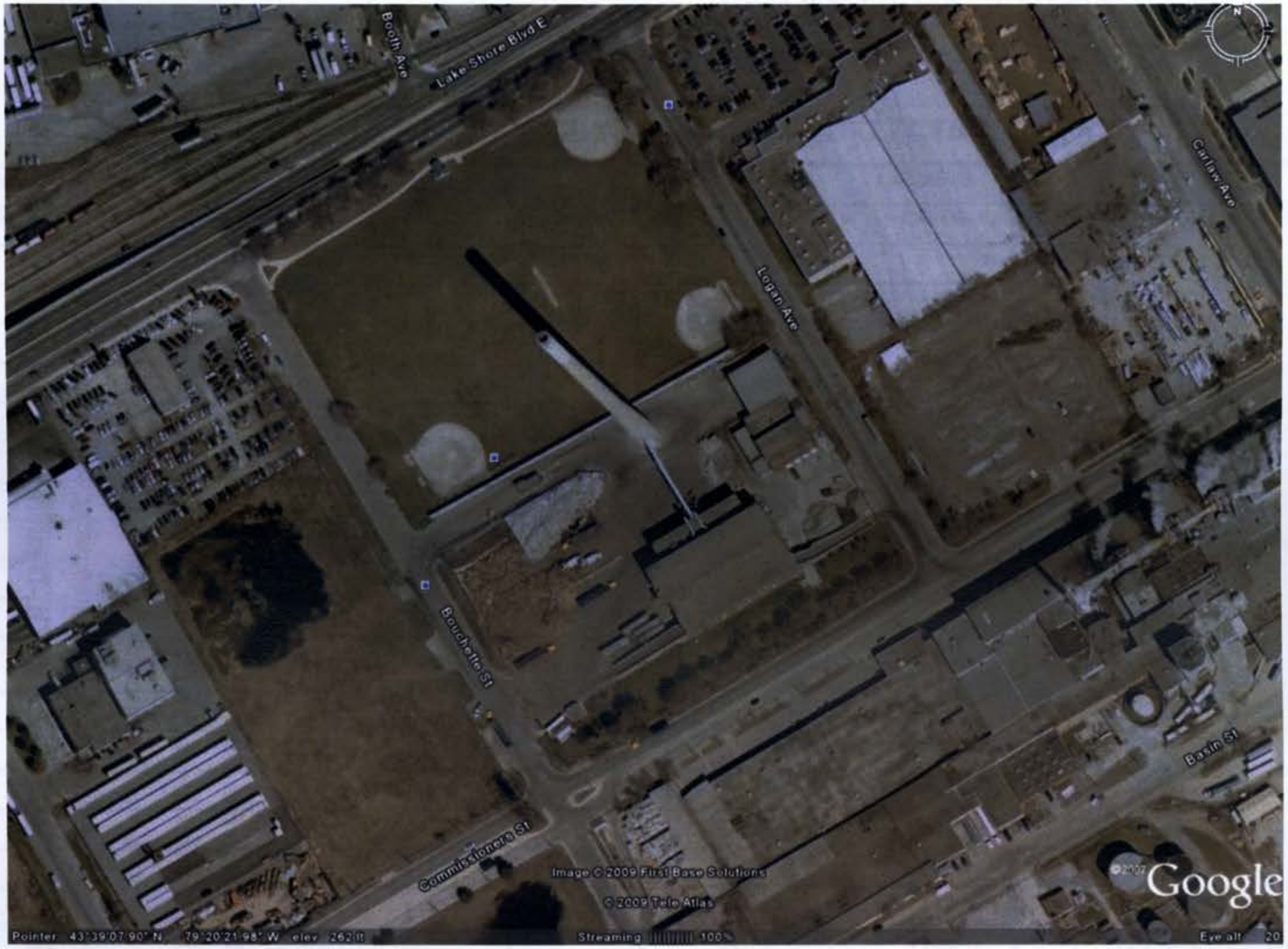

Figure E.7 (c) **Satellite Imagery of Portland Energy Centre Lake Shore Blvd East along Logan Avenue onto Commissioner's Street and Bouchette Street (Google Earth, 2009).**

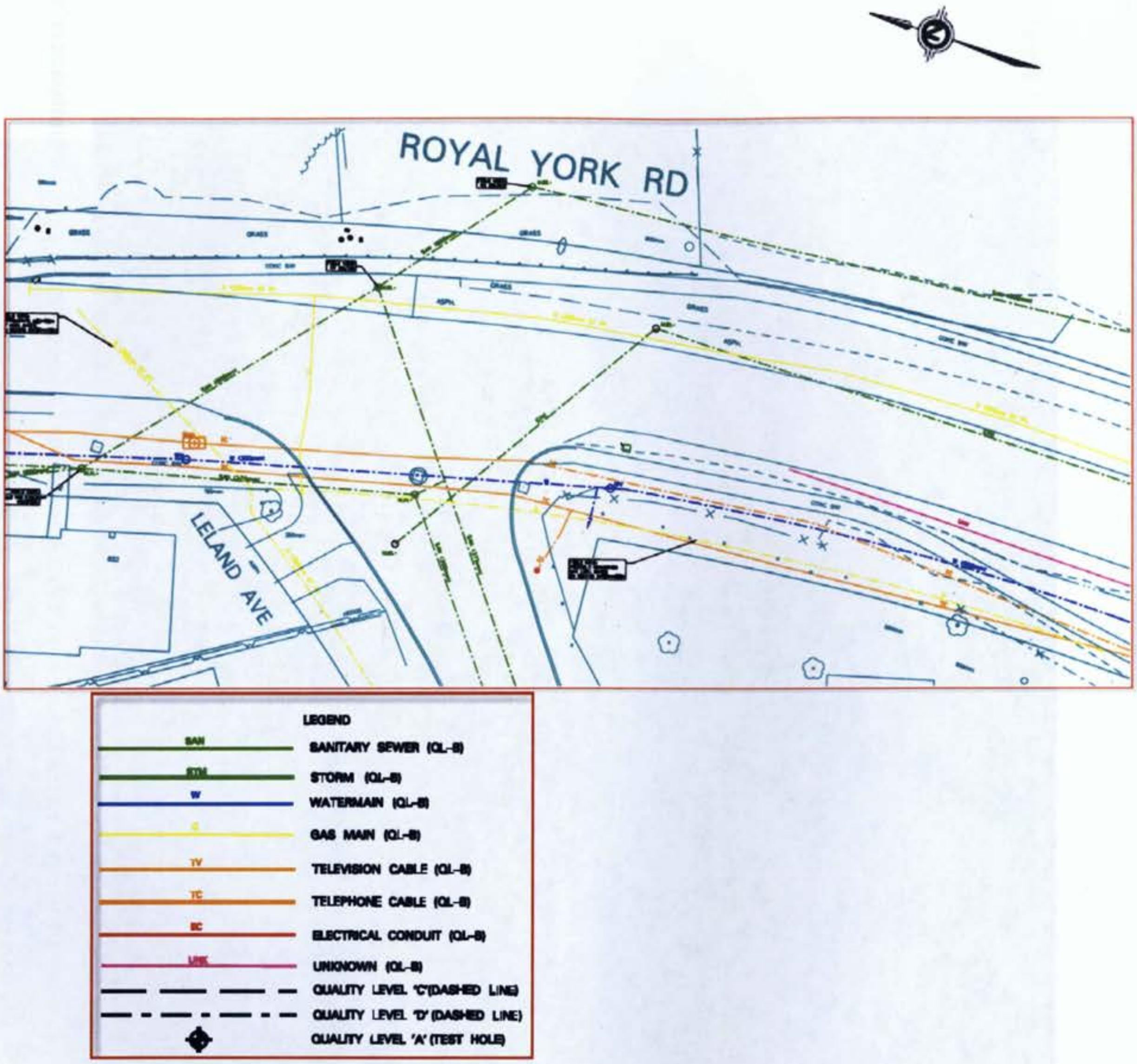

Figure E.8 Subsurface Utility Engineering Drawing of Royal York Road (TSH/TBE, 2006). The utility information in this drawing was gathered in compliance with ASCE Standard 38-02. Quality Level D – utility information from existing records or verbal statements. Quality Level C – surveyed information using visible above ground appurtenances and correlating this information to the QL-D information. Quality Level B – information obtained through geophysical techniques used to detect the existence and approximate horizontal (x, y) position of the utilities. Quality Level A – accurate horizontal position and depth of underground utilities through exposure of and measurement of utilities.

APPENDIX F
DATA COLLECTION TABLES
TABLE F.1 THE QUEENSWAY DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS					CURB
(Queensway, QW)			LOT LINE	DIRECTION	ROW (IN OR OUT)	PERP. DIST	DIFFERENCES	CURB
QW1	CABLE	D	663	S	OUT	-25.75	0.30	
QW2	BT	B	663	S		-26.05		
QW5	cable	D	657	S	OUT	-26.73	1.76	
QW6	BT	B	657	S		-28.49		
	HOR.DIFF.							
QW7	CABLE	D	653	S	OUT	-26.14	0.32	
QW8	BT	B	653	S		-26.46		
	HOR.DIFF.							
QW7a	CABLE	D	668	N	OUT	2.99	0.47	
QW8a	BT	B	668	W		2.53		
QW9	CABLE	D	668	N	OUT	3.22	-0.40	
QW10	BT	B	668	N		3.62		
QW11	CABLE	D	664	N	OUT	3.40	-0.37	
QW12	BT	B	664	N		3.77		

purple	HOR.DIFF.						7.35	
QW13	CABLE	D	664	N	OUT	7.43	-0.02	
QW14	BT	B	664	N		7.45		
purple	HOR.DIFF.						6.75	
QW15	CABLE	D	664	N	WITHIN	22.73	7.35	
QW16	BT	B	664	N		7.45		
purple	HOR.DIFF.						2.47	
QW17	CABLE	D	637	S	OUT	-27.21	-1.78	
QW18	BT	B	637	S		-25.43		
QW19	CABLE	D	642	E	OUT	3.08	0.28	
QW20	BT	B	642	E		2.81		
QW23	CABLE	D	642	N	OUT	18.88	0.00	
QW24	BT	B	642	N		18.88		
purple	HOR.DIFF.						3.99	
QW3	GAS	D			OUT		0.34	-0.93
QW4	Gas Main	B						-1.27
QW21	G.S.	D	642	E	OUT	0.68	-0.45	

QW22	GAS	B	642	E		1.13		
QW35	G.S.	D	657	S	OUT	-2.26	-0.69	
QW36	GAS	B	657	S		-1.57		
QW37	G.S.	D	635	S	OUT	-5.17	0.46	
QW38	GAS	B	635	S		-5.64		
	HOR. DIFF						0.28	
QW39	G.S.	D	664	N	WITHIN	25.12	-0.28	
QW40	GAS	B	664	N		25.39		
	HOR. DIFF						0.07	
QW25	Water Main	D	668	E	OUT	4.98	-0.86	
QW26	WM	B	668	E		5.84		
QW27	Water Main	D	642	E	OUT	3.82	-0.31	
QW28	WM	B	642	E		4.13		
QW29	Water Main	D		N	WITHIN		-0.47	4.52
QW30	WM	D		N				4.99
QW31	Water Main	D		S	WITIHN		-0.47	-10.58
QW32	WM	D		S				-10.11

QW33	Water Main	D		s	WITHIN		-0.47	-10.78
QW34	WM	D		s				-10.31

TABLE F.2 GERRARD STREET DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS			
(Gerrard, G)			DIRECTION	ROW(IN OR OUT)	DIFFERENCES	CURB
G1	THES conduit	D	S	OUT	-0.33	-1.93
G2	BE	B	S			-1.60
G3	THES conduit	D	S	OUT	-0.11	-2.43
G4	BE	B	S			-2.32
G5	THES conduit	D	S	OUT	-0.49	-1.96
G6	BE	B	S			-1.47
G7	BCC	D	N	OUT	4.33	6.28
G8	FOC	B	N			1.95
G9	BCC	D	W	IN	1.84	3.49
G10	FOC	B	W			1.65
G21	BCC	D	E	IN	1.49	6.03
G22	FOC	B	E			4.54
G23	THES conduit	D	E	IN	0.36	1.44
G24	BE	B	E			1.08

G25	BCC	D	N	IN	-1.54	0.61
G26	FOC	B	N			2.15
G11	GAS MAIN	D	E	IN	-2.54	3.03
G12	G	B	E			5.57
G13	GAS MAIN	D	S	IN	0.23	-5.47
G14	G	B	S			-5.70
G17	600 mm H.P. Gas Main Aband'd	D	S	IN	0.78	-0.65
G18	G-ABN	B	S			-1.43
G27	300 mm Gas Main	D	N	IN	-0.40	5.84
G28	G	B	N			6.24
G35	300 mm Gas Main	D	S	IN	0.07	-7.98
G36	G	B	S			-8.05
G15	900 mm Water Main	D	N	IN	0.34	4.17
G16	WM	A	N			3.83
G19	200mm Water Main	D	S	IN	-0.38	-3.37
G20	WM (200mm)	B	S			-2.99
G29	200mm Water Main	D	S	IN	0.28	-7.76

G30	WM (200mm)	B	S			-8.03
G31	200mm Water Main	D	S	IN	0.17	-3.65
G32	WM (200mm)	A	S			-3.82
G33	900mm Water Main	D	N	IN	0.33	3.73
G34	WM (900mm)	A	N			3.40
G43	200mm Water Main	D	S	IN	-0.48	-3.66
G44	WM (200mm)	B	S			-3.17

TABLE F.3 ROYAL YORK ROAD DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS					
(Royal York, RY)			LOT LINE	DIRECTION	ROW (IN OR OUT)	PERP. DIST	DIFFERENCES	CURB
RY33	TC & TVC	D	763	E	OUT	49.69	0.46	
RY34	TC (TELEPHONE CABLE)	B		E		49.23		
RY35	TVC	D	763	E	IN	68.54	-0.24	
RY36	TC (TELEPHONE CABLE)	A		E		68.78		
RY43	TD & TVC	D	1	W	OUT	-8.25	-0.68	
RY44	TC (TELEPHONE CABLE)	B		W		-7.57		
RY45	TD	D		W	IN		0.88	-3.35
RY46	TC (TELEPHONE CABLE)	B		W				-4.23
RY49	TD & TVC	D	756	W	OUT	-14.09	1.19	
RY50	TC (TELEPHONE CABLE)	B		W		-15.28		
RY59	TD & TVC	D	730	W	OUT	-15.91	0.20	
RY60	TC (TELEPHONE CABLE)	A		W		-16.11		
RY1	G	D	108	E	OUT	75.01	0.47	
RY2	G 200mm ST IP	B		E		74.54		

RY7	G	D	1	W	OUT	-26.82	1.06	
RY8	G 200mm ST IP	B		W		-27.88		
RY9	G	D	111	E	OUT	81.31	1.14	
RY10	G 200mm ST IP	B		E		80.16		
RY11	G	D	106	E	OUT	63.06	0.18	
RY12	G 200mm ST IP	B		E		62.89		
RY13	G	D	810	W	OUT	-27.60	-0.19	
RY14	G 200mm ST IP	B		W		-27.41		
RY17	G	D	107	W	OUT	-42.64	-0.44	
RY18	G 200mm ST IP	B		W		-42.19		
RY27	G	D	7	W	OUT	-61.26	-0.98	
RY28	G 200mm ST IP	B		W		-60.28		
RY31	G	D	767	E	OUT	37.25	3.09	
RY32	G 200mm ST IP	B		E		34.16		
RY37	G	D	102	E	OUT	43.80	-0.01	
RY38	G 200mm ST IP	A		E		43.81		

RY53	G	D	740	W	OUT	-9.63	-0.04	
RY54	G 100mm PE IP	B		W		-9.59		
RY57	G	D	736	W	OUT	-12.50	-1.67	
RY58	G 100mm PE IP	D		W		-10.83		
RY63	G	D		E	OUT		0.08	17.11
RY64	G 100mm PE IP	B		E				17.04
RY65	G	D		E	IN		0.97	11.45
RY66	G 100mm PE IP	A		E				10.48
RY3	WM 200mm	D	107	W	OUT	-22.76	-1.09	
RY4	W 200mm	D		W		-21.66		
RY5	WM 200mm	D		N	OUT		-6.54	3.76
RY6	W 200mm	D		N				10.29
RY15	WM 200mm	D	3	N	OUT	81.23	0.17	
RY16	W 200mm	D		N		81.06		
RY19	WM 200mm	D	800	W	OUT	-13.15	-0.44	

RY20	W 200mm	D		W		-12.70		
RY21	WM 200mm	D	29	W	OUT	81.02	-0.76	
RY22	W 200mm	B		W		81.78		
RY23	WM 200mm	D	7	W	OUT	48.90	-0.50	
RY24	W 200mm	B		W		49.40		
RY25	WM 200mm	D	7	W	OUT	61.78	-0.77	
RY26	W 200mm	B		W		62.54		
RY29	WM 200mm	D	17	W	OUT	32.07	1.35	
RY30	W 200mm	B		W		30.72		
RY39	WM 200mm	D	1	W	IN	19.71	-0.47	
RY40	W 200mm	B		W		20.17		
RY41	WM 200mm	D	1	W	OUT	21.81	-2.79	
RY42	W 200mm	B		W		24.61		

RY47	WM 200mm	D		W	OUT		2.86	-0.65
RY48	W 200mm	B		W				-3.51
RY51	WM 200mm	D	750	W	OUT	-27.68	2.41	
RY52	W 200mm	B		W		-30.10		
RY55	WM 200mm	D	736	W	OUT	-27.00	0.73	
RY56	W 200mm	D		W		-27.73		
RY61	WM 200mm	D		W	OUT		0.20	-0.21
RY62	W 200mm	B		W				-0.41

TABLE F.4 KENNETH AVENUE AND SPRING GARDEN AVENUE DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS					
(Kenneth and Springs, KS)			LOT LINE	DIRECTION	ROW(IN OR OUT)	PERP. DIST	DIFFERENCES	CURB
KS1	STM 1050 CON CLIV	D		S	IN	-20.44	-0.22	
KS2	STM (1050mm CON. CLIV)	D		S		-20.22		
KS3	SAN 750 CON	D		E	IN		0.09	13.74
KS4	SAN (750mm CON.)	D		E				13.65
KS5	STM 525 CON CLIV	D		N	OUT		-0.23	10.67
KS6	STM (525 mm CON CLIV)	D		N				10.91
KS7	SAN 750 CON	D		W	IN		-4.80	-6.42
KS8	SAN (750mm CON.)	C		W				-1.62
KS9	SAN 1050 CON	D		E	IN		-0.19	5.39
KS10	SAN (1050mm CON.)	D		E				5.58

TABLE F.5 UNION STATION NW PATH DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS			
(Union Station, US)			DIRECTION	ROW (IN OR OUT)	DIFFERENCES	CURB
US1	H.E.P.C 115 Kv Conduit	D	E	OUT	-0.76	2.48
US2	T.H.E.S.	B	E			3.23
US3	H.E.P.C 115 Kv Conduit	D	S	OUT	0.72	-2.08
US4	T.H.E.S.	B	S			-2.81
US5	Bell Canada Conduit	D	S	OUT	0.71	-2.42
US6	T.H.E.S.	B	S			-3.13
US7	T.H.E.S. Conduit	D	N	IN	0.19	1.56
US8	T.H.E.S.	B	N			1.37
US9	Bell Canada Conduit	D	W	IN	-0.23	-0.18
US10	UNK FOC	B	E	OUT		0.05
US11	Bell Canada Conduit	D	W	IN	-0.22	-0.34
US12	BT/ROGERS	B	W			-0.12

US13	Bell Canada Conduit	D	W	IN	-0.45	-1.10
US14	BT/ROGERS	B	W			-0.65
US15	T.H.E.S. Conduit	D	S	IN	-0.22	-4.57
US16	UNK FOC	B	S			-4.35
US27	T.H.E.S. Conduit	D	E	IN	-0.78	14.48
US28	T.H.E.S.	B	E			15.25
US29	Bell Canada Conduit	D	E	IN	0.41	2.90
US30	BT/ROGERS	B	E			2.48
US31	Bell Canada Conduit	D	E	IN	0.36	2.99
US32	BT/ROGERS	B	E			2.63
US33	Bell Canada Conduit	D	E	IN	-0.22	2.53
US34	BT/ROGERS	B	E			2.75
US35	Bell Canada Conduit	D	E	IN	-0.57	4.09
US36	BT/ROGERS	B	E			4.67
US41	T.H.E.S. Conduit	D	N	IN	0.63	12.40
US42	T.H.E.S.	B	N			11.77

US61	T.H.E.S Conduit	D	N	IN	0.48	11.07
US62	BE (HYDRO ONE)	B	N			10.59
US63	T.H.E.S Conduit	D	N	IN	-0.35	10.11
US64	BE (HYDRO ONE)	B	N			10.46
US75	T.H.E.S. (4WX4H+4D)	D	S	IN	0.56	3.87
US76	T.H.E.S. (4WX4H+4D)	B	S			3.31
US45	500mm L.P. Gas Main Aband'd	D	W	IN	-0.63	-10.33
US46	GAS (500mm ABDN)	D	W			-9.71
US47	500mm L.P. Gas Main Aband'd	D	E	IN	-0.27	3.33
US48	GAS (500mm ABDN)	D	E			3.60
US49	500mm L.P. Gas Main Aband'd	D	W	OUT	-1.81	-2.12
US50	GAS (500mm ABDN)	D	W			-0.31
US51	500mm L.P. Gas Main Aband'd	D	S	IN	-0.14	-0.54
US52	GAS (500mm ABDN)	D	S			-0.40

US53	600mm Gas Main	D	S	IN	0.58	-2.05
US54	GAS (600mm ABDN)	B	S			-2.63
US55	500mm Gas Main Aband'd	D	E	IN	-11.39	4.36
US56	GAS (500mm ABDN)	B	E			15.76
US57	500mm Gas Main Aband'd	D	N	IN	0.33	3.20
US58	GAS (500mm ABDN)	B	N			2.86
US59	500mm Gas Main Aband'd	D	N	IN	0.33	3.04
US60	GAS (500mm ABDN)	B	N			2.71
US65	300mm Gas Main	D	S	IN	0.62	-7.57
US66	GAS (300mm)	B	S			-8.19
US67	300mm Gas Main	D	S	IN	0.20	-7.63
US68	GAS (300mm)	B	S			-7.83
US69	300mm Gas Main	D	S	IN	0.40	-6.92
US70	GAS (300mm)	B	S			-7.32
US71	300mm Gas Main	D	E	IN	-13.16	175.10
US72	GAS (300mm)	B	E			188.26
US73	600mm Gas Main Aband'd	D	S	IN	0.06	-1.44
US74	GAS (600mm ABDN)	B	S			-1.50

US17	150mm Water Main	D	W	IN	-0.22	-2.03
US18	WM (150mm)	D	W			-1.82
US19	150mm Water Main	D	W	IN	-0.60	-1.96
US20	WM (150mm)	D	W			-1.35
US21	150mm Water Main	D	W	IN	0.49	1.83
US22	WM (150mm)	D	W			1.34
US23	150mm Water Main	D	W	IN	-0.28	-4.54
US24	WM (150mm)	D	W			-4.26
US25	150mm Water Main	D	W	IN	-0.44	-9.91
US26	WM (150mm)	D	W			-9.47
US37	300mm Water Main	D	E.	IN	-0.39	1.47
US38	WM (300mm)	D	E			1.86
US39	300mm Water Main	D	E	IN	-0.70	1.85
US40	WM (300mm)	D	E			2.56
US43	300mm Water Main	D	S	IN	0.75	-12.94
US44	WM (300mm)	D	S			-13.69

TABLE F.6 YONGE STREET DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS			
(Yonge Street, YS)			DIRECTION	ROW (IN OR OUT)	DIFFERENCES	CURB
YS3	BE	D	E	IN	0.62	1.93
YS4	T.H.E.S. Conduit	B	E			1.31
YS5	BE	D	E	IN	0.28	6.94
YS6	T.H.E.S. Conduit	B	E			6.66
YS9	BE	D	W	IN	0.68	-13.25
YS10	T.H.E.S. Conduit	B	W			-13.93
YS11	BE	D	S	OUT	-0.53	-1.48
YS12	T.H.E.S. Conduit	B	S			-0.95
YS15	BE	D	W	IN	0.34	-1.00
YS16	T.H.E.S. Conduit	B	W			-1.34
YS29	Bell Canada Conduit	D	S	IN	-0.21	-4.55
YS30	BT	B	S			-4.34
YS31	Bell Canada Conduit	D	S	IN	0.16	-4.39
YS32	BT	B	S			-4.55

YS33	BE	D	N	OUT	0.20	0.86
YS34	T.H.E.S. Conduit	D	N			0.66
YS35	Bell Canada Conduit	D	W	OUT	-0.64	-21.41
YS36	BT	B	W			-20.77
YS37	Bell Canada Conduit	D	W	OUT	-0.21	-3.76
YS38	BT	B	W			-3.55
YS43	Bell Canada Conduit	D	E	OUT	0.22	4.66
YS44	BT	B	E			4.44
YS47	T.H.E.S. Conduit	D	W	IN	0.35	1.56
YS48	BE	B	W			1.20
YS53	T.H.E.S. Conduit	D	W	OUT	0.31	-1.59
YS54	BE	B	W			-1.91
YS57	Telus CoBuilt (GT)	D	E	IN	0.16	6.53
YS58	BT_TV_FOC	B	E			6.37
YS63	T.H.E.S. Conduit	D	W	OUT	0.33	2.74
YS64	BE	B	W			2.41
YS65	T.H.E.S. Conduit	D	W	OUT	-0.28	1.53
YS66	BE	B	W			1.81

YS67	Telus CoBuilt (GT)	D	E	IN	0.21	4.70
YS68	BT_TV_FOC	B	E			4.48
YS69	Bell Canada Conduit	D	E	IN	0.90	2.92
YS70	BT	B	E			2.01
YS73	Telus CoBuilt (GT)	D	E	IN	0.35	4.65
YS74	BT_TV_FOC	B	E			4.30
YS81	T.H.E.S. Conduit	D	W	OUT	-0.51	-3.37
YS82	BE	B	W			-2.87
YS87	H.E.P.C. 115 kV Conduit	D	W	IN	0.20	-8.28
YS88	BE	B	W			-8.48
YS93	T.H.E.S. Conduit	D	S	OUT	1.42	-2.89
YS94	BE	B	S			-4.31
YS95	T.H.E.S. Conduit	D	W	IN	-0.33	-1.04
YS96	BE	B	W			-0.71
YS99	Bell Canada Conduit	D	S	IN	0.46	-2.27
YS100	BT_TV_FOC	D	S			-2.73
YS101	T.H.E.S. Conduit	D	W	IN	-0.48	-2.85
YS102	BE	B	W			-2.37

YS103	Bell Canada Conduit	D	S		0.75	-2.30
YS104	BT_TV_FOC	D	S			-3.05
YS113	T.H.E.S. Conduit	D	W	IN	-0.89	-3.42
YS114	BE	B	W			-2.53
YS1	100mm Gas Main	D	N	IN	0.64	1.31
YS2	GAS (100m)	B	N			0.67
YS7	100mm Gas Main	D	S	OUT	0.27	-1.70
YS8	GAS (100m)	B	S			-1.97
YS13	150mm Gas Main	D	E	OUT	-0.26	1.47
YS14	GAS (150m)	B	E			1.73
YS51	300mm Gas Main	D	E	IN	0.60	3.79
YS52	GAS (300m)	B	E			3.19
YS59	300mm Gas Main	D	E	OUT	0.60	21.10
YS60	GAS (300m)	B	E			20.50
YS61	300mm Gas Main	D	E	IN	0.39	0.91
YS62	GAS (300m)	B	E			0.52

YS75	100mm Gas Main Aband'd	D	S	IN	-0.51	-0.55
YS76	GAS	B	S			-0.04
YS77	300mm Gas Main	D	E	OUT	0.16	1.84
YS78	GAS (300mm)	B	E			1.68
YS83	300mm Gas Main	D	E	IN	0.51	0.90
YS84	GAS (300mm)	B	E			0.39
YS85	100mm Gas Main Aband'd	D	N	OUT	0.37	0.62
YS86	GAS	B	N			0.25
YS107	400mm Gas Main Aband'd	D	W	IN	0.35	0.86
YS108	GAS (400mm ABAND.)	B	W			0.52
YS111	400mm Gas Main Aband'd	D	W	IN	0.67	1.25
YS112	GAS (400mm ABAND.)	B	W			0.58
YS17	150mm Water Main	D	N	IN	-0.71	4.82
YS18	WM (150mm)	B	N			5.53
YS19	150mm Water Main	D	N	IN	1.35	10.56
YS20	WM (150mm)	B	N			9.21
YS21	400mm Water Main	D	E	IN	-1.97	0.95
YS22	WM (400mm)	B	E			2.92

YS23	400mm Water Main	D	W	OUT	0.20	-0.98
YS24	WM (400mm)	B	W			-1.18
YS27	400mm Water Main	D	S	IN	1.75	-5.80
YS28	WM (400mm)	D	S			-7.55
YS39	300mm Water Main	D	W	IN	0.22	-15.14
YS40	WM (300mm)	B	W			-15.36
YS41	200mm Water Main	D	E	IN	0.11	3.20
YS42	WM (200mm)	B	E			3.09
YS45	200mm Water Main	D	E	IN	-0.55	2.42
YS46	WM (200mm)	B	E			2.96
YS49	300mm Water Main	D	E	OUT	0.19	1.62
YS50	WM (300mm)	B	E			1.42
YS55	150mm Water Main	D	S	OUT	0.37	-1.24
YS56	WM (150mm)	B	S			-1.62
YS71	250mm Water Main	D	E	IN	-0.90	1.31
YS72	WM (250mm)	B	E			2.21

YS79	300mm Water Main	D	E	OUT	0.24	1.69
YS80	WM (300mm)	B	E			1.45
YS89	150mm Water Main	D	N	IN	1.07	2.96
YS90	WM (150mm)	B	N			1.89
YS91	150mm Water Main	D	N	IN	1.00	2.48
YS92	WM (150mm)	B	N			1.48
YS97	300mm Water Main	D	S	IN	1.06	-6.47
YS98	WM (300mm)	B	S			-7.53
YS105	300mm Water Main	D	E	OUT	0.42	2.27
YS106	WM (300mm)	B	E			1.85
YS109	300mm Water Main	D	E	OUT	-0.19	2.10
YS110	WM (300mm)	B	E			2.29
YS115	300mm Water Main	D	E	OUT	-0.30	1.71
YS116	WM (300mm)	B	E			2.01
YS25	525mm V.P. Comb. Sewer	D	N	IN	-0.46	7.69
YS26	SAN (525mm VP)	C	N			8.15

TABLE F.7 PORTLAND ENERGY CENTRE DATA COLLECTION

POINT NUMBER	TYPE OF UTILITY	QUALITY LEVEL	OFFSETS			
(Portland Energy Center, PEC)			DIRECTION	ROW(IN OR OUT)	DIFFERENCES	CURB
PEC5	Bell Canada Conduit	D	S	IN	-0.22	-3.85
PEC6	BT	B	S			-3.63
PEC7	T.H.E.S. Conduit	D	S	IN	-0.32	-1.45
PEC8	HYDRO	B	S			-1.13
					2.91	
PEC9	T.H.E.S. Conduit	D	N	OUT	0.06	0.54
PEC10	HYDRO	B	N			0.48
	HOR.DIFF.				4.05	
PEC19	T.H.E.S. Conduit	D	E	OUT	-0.28	1.36
PEC20	HYDRO	B	E			1.63
PEC27	T.H.E.S. Conduit	D	E	OUT	-0.67	1.54
PEC28	HYDRO	B	E			2.21
PEC29	T.H.E.S. Conduit	D	E	OUT	0.51	1.58
PEC30	HYDRO	B	E			1.07
PEC45	Bell Canada Cable	D	N	OUT	0.87	32.30
PEC46	BT	B	N			31.43

PEC63	T.H.E.S. Conduit	D	S	IN	-0.26	-1.77
PEC64	HYDRO	B	S			-1.50
PEC67	Bell Canada Conduit	D	N	IN	-1.24	1.26
PEC68	BT	B	N			2.49
PEC75	Bell Canada Cable	D	W	IN	5.48	-1.03
PEC76	BT	B	W			-6.51
PEC1	600 mm Gas Main	D	S	IN	-0.49	-2.68
PEC2	GAS (600mm ST HP LAM SCAN)	D	S			-2.18
PEC3	600 mm Gas Main	D	S	IN	-0.40	-2.67
PEC4	GAS (600mm ST HP LAM SCAN)	B	S			-2.26
PEC11	300 mm Gas Main	D	N	OUT	0.31	1.21
PEC12	GAS (300mm ST IP)	B	N			0.90
	HOR.DIFF.				1.40	
PEC15	600 mm Gas Main	D	S	IN	-0.25	-2.48
PEC16	GAS (600mm ST HP LAM SCAN)	B	S			-2.23
	HOR.DIFF.				2.90	
PEC17	600 mm Gas Main	D	S	IN	-0.57	-2.97
PEC18	GAS (600mm ST HP LAM SCAN)	B	S			-2.40

	HOR.DIFF.				0.61	
PEC37	300 mm Gas Main Aband'd	D	W	OUT	0.21	1.63
PEC38	GAS (300mm ABAND)	B	W			1.42
PEC41	300 mm Gas Main	D	S	OUT	-9.09	-9.69
PEC42	GAS (300mm)	B	S			-0.60
PEC43	300 mm Gas Main	D	S	OUT	-8.93	-11.24
PEC44	GAS (300mm)	B	S			-2.31
PEC51	300mm H.P. Gas Main	D	E	OUT	0.26	1.82
PEC52	GAS (300mm)	B	E			1.56
PEC53	300 mm Gas Main	D	S	OUT	-0.57	-2.21
PEC54	GAS (300mm)	B	S			-1.64
PEC55	150mm Gas Main	D	E	OUT	-0.22	2.60
PEC56	GAS (150mm ST IP)	A	E			2.82
PEC57	Gas Trans Line	D	N	IN	0.26	1.09
PEC58	GAS (150mm ST IP)	B	N			0.83
PEC59	150mm Gas Main	D	N	IN	0.07	0.98
PEC60	GAS (150mm ST IP)	B	N			0.92
	HOR.DIFF.				1.90	

PEC61	150mm Gas Main	D	N	IN	0.17	1.49
PEC62	GAS (150mm)	B	N			1.32
PEC69	150mm Gas Main	D	N	IN	0.42	1.58
PEC70	GAS (150mm)	B	N			1.16
PEC21	300mm Water Main	D	W	IN	0.28	-2.40
PEC22	WM (300mm)	B	W			-2.68
PEC25	150mm Water Main	D	E	IN	0.25	1.31
PEC26	WM (150mm)	A	E			1.06
PEC31	300mm Water Main	D	W	IN	-0.33	2.38
PEC32	WM (300mm)	B	W			2.70
PEC33	300mm Water Main	D	W	IN	-0.76	2.34
PEC34	WM (300mm)	B	W			3.10
PEC35	300mm Water Main	D	W	IN	-0.26	2.25
PEC36	WM (300mm)	B	W			2.51
PEC47	300 mm Water Main	D	E	OUT	-0.13	3.44
PEC48	WM (300mm)	B	E			3.56
PEC49	300 mm Water Main	D	S	OUT	-0.14	-1.35
PEC50	WM (300mm)	B	S			-1.21

	HOR.DIFF.				0.21	
PEC65	600 mm Water Main	D	N	IN	-0.21	6.95
PEC66	WM (600mm)	B	N			7.17
PEC73	300 mm Water Main	D	W	IN	0.20	-11.85
PEC74	WM (300mm)	D	W			-12.05
PEC13	600mm x 900mm E.S.Br. Stm. Sewer	D	S	IN	0.40	-6.76
PEC14	STM (600mm x 900mm E.S.BR)	D	S			-7.16
PEC23	450mm V.P. Stm. Sewer	D	W	IN	0.34	-4.56
PEC24	STM (300mm V.P.)	C	W			-4.90
PEC39	300mm V.P. San. Sewer	D	E	IN	0.40	3.80
PEC40	SAN (300mm V.P.)	D	E			3.40
PEC71	325mm V.P. Stm. Sewer	D	W	IN	0.20	-8.85
PEC72	STM (375mm V.P.)	D	W			-9.04