North American Society for Trenchless Technology (NASTT)
No-Dig Show 2010

Chicago, Illinois
May 2-7, 2010

Paper C-1-01

MAPPING THE UNDERGROUND INFRASTRUCTURE:
LEVERAGING GPS TECHNOLOGY TO LOCATE AND IDENTIFY PROBLEMS

Joe Purtell[1]

[1] Director of Software Development, Cues, Inc., Orlando, FL

ABSTRACT: Precisely identifying sewer and storm water pipelines is a critical job for Utilities¸ system operators and contractors. Locating techniques that incorporate radio frequency sondes have been successfully used to trace the horizontal and vertical positions of existing pipeline and lateral service connections.

New construction projects benefit from GPS technology to more accurately document the location of new assets so that "As Built" mechanical designs more closely match "As Constructed" actual map surveys.

Locating buried pipelines is traditionally done by painting the surface grade with color markings to represent the location and path of a pipeline based on historical "As Built" drawings. Unfortunately, many older-constructed utilities have positional errors within their design drawings that have led to accidents and damage from new construction. Obtaining old, sub-surface utility maps can be difficult and time consuming for locators and engineers. And making updates to the drawings because of their archaic format prevents enhancements for future construction activities.

Adopting GPS mapping and locating technology provides the ability to store and retrieve accurate location information nearly instantaneously. Furthermore, any observed inconsistencies or changes to the location information can be updated to continuously improve the quality and accuracy of the buried infrastructure location data, including any verification notes that work may have been completed as planned.

Combining GPS-referenced pipeline utility locates with other technologies results in huge advantages. The combination of GPS, GIS and digital video inspections of both main line and lateral service connections is helping Utilities¸ system operators and construction contractors collaborate to reduce costs, improve safety and create a better infrastructure mapping and locating system.

The paper will illustrate a successful pilot project that incorporated the combined technologies of electromagnetic sonde¸ GPS¸ CCTV Video and GIS in Lexington¸ Kentucky. The project's goals were to identify where homeowner lateral service connections existed in a historic section of the city that was also being installed with natural gas lines using trenchless horizontal directional drilling. In addition to tracing the homeowner lines to prevent possibly dangerous natural gas cross bores, the project inspected wastewater lines after the natural gas lines were installed as a quality control measure. The results were successful and demonstrated that the combination of these new technologies can offer significant advantages. Discussion of the advantages will include the permanent record keeping¸ GIS integration with local and remote viewing of maps¸ depth measurement recording and the advantage of being able to provide verification that a particular line and address was inspected. Project information including pictures of the process¸ flow charts¸ aerial maps and the project results will be presented.

INTRODUCTION

Buried throughout the U.S. are millions of miles of hazardous-liquid pipelines, natural gas pipelines, water pipelines, fiber optic lines, electrical lines and many other forms of conduit and sub-surface structures. As the nation's infrastructure continues expand with new construction while simultaneously being rehabilitated to replace old and corroded lines, the potential for accidental construction damage is fairly significant. The public generally recognizes that pipelines represent a potential hazard to people and property, but the extent of the danger is not well understood by the public, nor their local officials. Nevertheless, the public rightly expects that pipeline safety regulators will take every reasonable action to prevent accidents and minimize their consequences. When tragedy strikes, the financial penalties from Regulators and the settlement costs to the injured parties can be crippling to the operator. [See Jury Verdict Headline]

NEW ENGLAND JURY VERDICT REVIEW & ANALYSIS

$17,200,000 RECOVERY – UTILITY COMPANY NEGLIGENCE – ALLEGED IMPROPER MAINTENANCE OF GAS EQUIPMENT – GAS EXPLOSION IN RESIDENTIAL HOME – WRONGFUL DEATH OF TWO CHILDREN AGES FIVE AND FOUR.

Figure 1: Court Settlement costs from July 24, 2002 home explosion, parents survive.

Utilities and system operators have evolved from a "corrosion control" and "post-accident support" operational perspective to a more risk-based, proactive strategy focused on reducing the probability of accidents and mitigating the consequences of pipeline failure. Today, utilities are much more focused on assessing risk and trying to avoid it.

Statistically, the number one cause of infrastructure damage is attributed to human error operating excavation equipment.

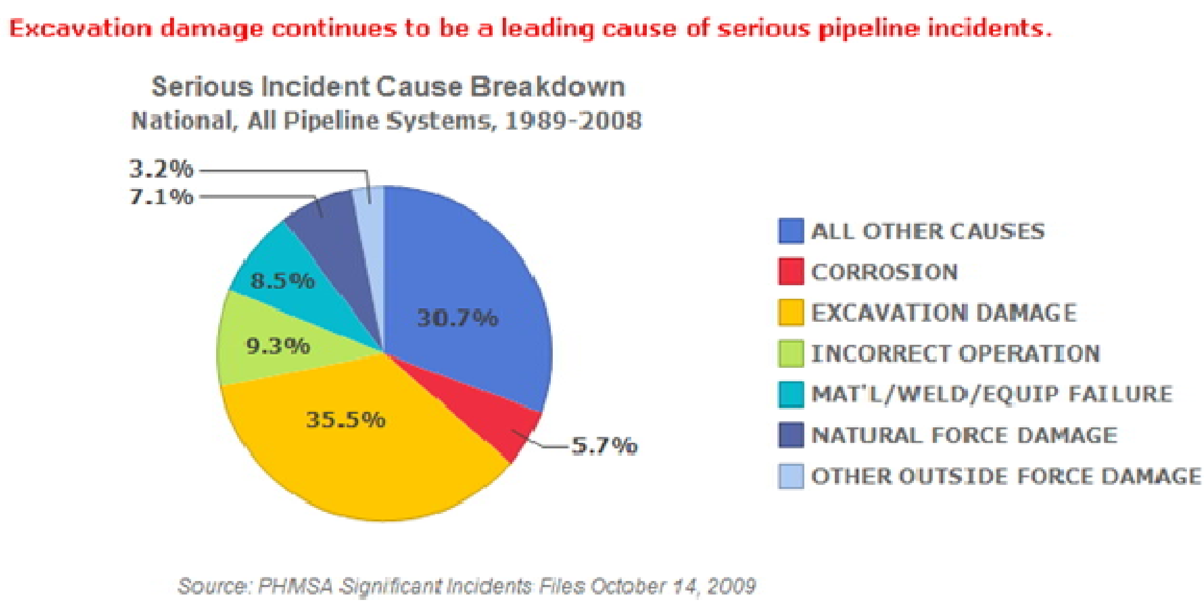

Figure 2: Excavation Damage is the leading cause of accidents

Excavation damage is most often caused by contact with the pipe while digging around it. Much of the damage is caused by operators of backhoes, bulldozers, drilling equipment and even shovels who have failed to locate the pipe before digging.

Determining the location of all the buried infrastructure in a specific construction location is a daunting task. Most State laws require that all utility lines and conduit be documented with location data and retained on file with the local municipal government Engineering Departments so that construction planners can take the appropriate steps to mitigate the risk of disturbing another utility's lines. But there are exceptions and some infrastructure is not mapped. For example, locating sewer lines has been one of the last frontiers to fall under regulation and is now required in over 40 states, to varying degrees, and with inconsistent language between the states.

Major Causes of the problem, Risk factors

Unfortunately, much of our infrastructure was built before Global Positioning System (GPS) technology existed so the quality of the location data was not deemed to be as important given the costs associated with performing "old fashioned" surveys. Inspectors in the previous century were far more concerned with the quality of the construction work instead, which could be easily seen because pipeline installers dug large trenches which would expose all infrastructures in the path of the pipeline.

Figure #3: Sewer Construction Circa 1889

Last century's inspectors and utility owners often used "As Designed" engineering plans as the record for buried infrastructure mapping. And often in the field, changes to the "As Designed" plans would be made for a variety of reasons. In theory, the updated plans would then become "As Built" designs. But ultimately the legacy drawings we have today are inaccurate from a locational perspective. Thus, a fairly large percentage of our underground mapping data is wrong or in some cases non-existent. Contractors and utility construction crews today should not be blamed for accidents that occur as a result of inaccurate or missing data.

In addition to poor quality mapping data, the industry is challenged by the use of new "Trenchless" technology methods of construction that involve the widespread use of directional drills, moles and plows. 19th Century hand digging done by immigrant laborers has been replaced by equipment that provides far more economical means to install and replace buried pipelines. The problems arise when these sub-surface tools encounter buried infrastructure and are unable to discriminate between the earth and the pipeline material, and proceed ahead causing damage by "an outside force" to the infrastructure in its path. This incidence is called a "Cross Bore".

Figure #4: Horizontal Directional Drilling equipment

Utility cross bores are defined as "an intersection of an existing underground utility or underground structure by a second utility resulting in direct contact between the trans-sections of the utilities that compromises the integrity of either utility or underground structure."

Therefore the challenge to the industry today is to identify safe methods of installing and replacing pipelines using new trenchless equipment despite having potentially poor and inaccurate legacy data about the location of other buried utility infrastructure in the area. To meet this challenge, forward-thinking utilities are applying Risk Management tactics to take precautions whereby the risks can be minimized or avoided entirely. They have devised a comprehensive, systematic method of assessing risk by centralizing pipeline data on the condition of the system, the engineering design, the service history, and the physical environment in which the pipeline is being operated, including the co-location of other buried utilities in the area. By understanding these details, Utility operators can create probability-of-failure models and then analyze the consequences-of-failure using a Risk-based methodology.

Focus on High Impact Risk

Accidental cross bores can happen with any buried infrastructure. In 2006, Verizon placed 268 million feet of fiber optic lines in the 16 states where it had upgraded its networks. A common fiber industry statistic indicates that for every 10,000 feet of installation, approximately 11 incidents are recorded where the new service disturbs an existing buried pipeline asset. (Steve Helber, Associated Press, July7, 2006).

Due to the sheer size of the statistical opportunity of the risk and the potentially lethal consequence specifically associated with natural gas cross bores, this paper only concentrates on this area of high impact risk mitigation. Risk Management focuses on reducing the probability of accidents and mitigating the consequences of pipeline failure. Damage Prevention utilizes Best Practices to prevent or reduce damage to pipelines to improve safety. Although the two methodologies go hand-in-hand, this paper only illustrates how new technology was used to reduce risk for two utilities which collaborated together to focus this specific area of high impact, natural gas cross bore risk.

Natural gas is indispensible for the public and is expected to increase in use as the nation tries to reduce its dependence on foreign oil. Unfortunately a high potential for damage and injury exists when a gas line has been accidentally placed within a sewer line unintentionally during construction, using trenchless drilling equipment. This type of cross bore represents a tremendous danger to the public and can sit for many years dormant and unnoticed. The natural gas cross bores can penetrate through “main” sewer lines that run the length of the street as well as in separate private “lateral” sewer lines or “service connections” that typically connect perpendicularly from the main to dwellings, businesses, hospitals and factories. Like natural gas, conveying sewerage to the waste treatment plant is indispensible for public health. State and Federal regulators mandate that both Gas and Water utilities conduct ongoing maintenance and repair of their systems to prevent pipeline failures. In the case of wastewater management, utilities and contractors routinely perform cleanings and inspections of the pipes. When debris accumulates in the pipe, powerful jetting and cutting tools are deployed to remove the blockages. Similarly, when a sewer backup occurs, the home or business owner calls for a drain cleaner to come out and clear the blockage. Plumbers often use a rotary cutting device which, when it encounters a gas line, can accidentally cause the utility line to rupture. In both sewer “main” and sewer “lateral” cases, if natural gas leaks out and forms a cloud, the consequences are devastating and lethal. Nearly every Water department has discovered some form of a cross bore in its system. Through the widespread use of CCTV video inspection, inspectors are able to visually notice the cross bore and flag it for immediate repair by the gas company or its contractor.

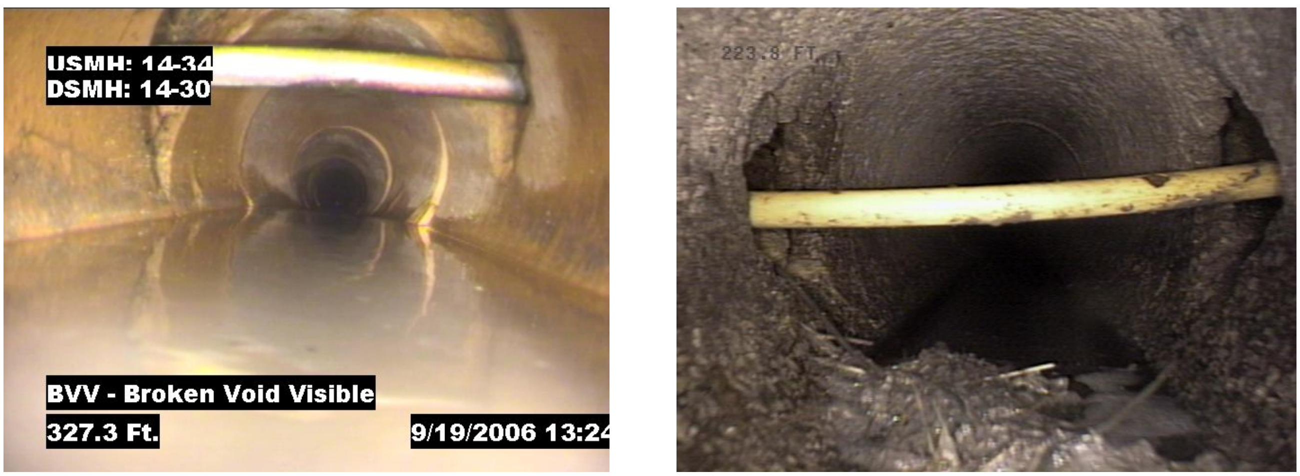

Figure 5: Two Examples of Natural Gas Cross Bores

Based upon the results of several cross bore elimination projects conducted in high risk areas by specialized contractors, natural gas cross bores are estimated to occur at a rate of 2 to 3 incidents per mile of main sewer line buried under ground. With some larger U.S. cities having over 6,000 miles of sewer lines, there could be 2,400 potential cross bores that pose significant risk to the gas distributor, the wastewater utility, and the public. Gas companies are concerned that this is an unacceptably high level of risk that must somehow be mitigated.

The Technology used to detect and mitigate cross bores

There are multiple technologies available today which can improve safety and reduce risk associated with drilling and boring. However, the industry must identify ‘cost effective’ tools to accelerate the adoption and use of these technologies to reduce the potential for cross-bores. Although serious injury and death has occurred as a result of improper installation of gas utility lines, simply burdening those responsible for performing the installation work with exorbitant technology costs is not a practical solution.

For the project completed and illustrated in this paper, the Gas utility’s focus was to deploy locating technology to an old, historic area of the city that had been provisioned with gas line service connections decades ago which had been determined to have reached their end-of-life. The gas lines needed to be replaced and in a manner that would be the least disruptive to the community. The gas utility had very little location information as to the position of the Sewer department's lateral service connections in relation to their existing legacy gas line service connections. In fact, it was quite possible that existing cross bores could be discovered during the replacement program for individual lines that may have been added or repaired using trenchless technology. Both utilities had a mutual interest in documenting the exact GPS location, and the estimated depths, for all of the private Lateral Service Connections in the vicinity. The gas company could reduce the risk of accidentally creating new cross bores as well as identify legacy cross bores that had gone undiscovered. Its contractor could better implement proper operating procedures for safe drilling because the proposed bore path could stay clear of the sanitary lines. Meanwhile the Water and Sewer department would collect detailed location and connection information about its system, as well as understand the current, "before construction", condition of its pipelines while detecting the presence of any cross bore damages that may have been done by other third parties to its buried infrastructure assets. Also, as a side benefit, the Sewer department would also get a better understanding of the overall condition of the laterals in a particular neighborhood or sub-basin to estimate likely sources of unwanted inflow and infiltration (I&I) that dramatically increases waste water treatment costs. This was a 'win-win' situation for both utilities. The Water and Sewer department agreed to collaborate and share information with the Gas Utility and its contractor to locate the GPS positions and depths of the sewer mainlines and the lateral connections that had been made to them. The utilities also understood that obtaining a permanent and accurate record of the infrastructure would be highly useful and valuable for future construction planning so the ability to retain the data in a universal format acceptable to both utilities was a key requirement.

The technologies used consisted of the following:

1) Lateral Launch robotic camera system
2) Electromagnetic Sonde hardware
3) GIS Mapping Software and GPS collection devices

Jointly they decided to use this combination of technologies to meet their goal of collecting accurate sewer lateral line traces with sub-meter accuracy (*centimeter accuracy is possible but was not deemed necessary in this project*). The CCTV inspection vehicles deployed to the area of the city were each provided a GPS receiver, an electro-magnetic sonde and receiver, a lateral launch camera and a pipeline inspection software with GIS mapping capabilities.

Figure 6: The Technologies Used: GIS Software, Wireless GPS, Digital Video, Sonde and Robotic transporter.

Prior to starting the project, the water department made the community aware that in order to provide safer pipelines in the neighborhood, permission was needed to access private property which would include accessing the sewer connections below ground leading to homes and businesses with small robotic cameras that would be propelled up the lateral from the main line and in some cases, above ground from the homeowner's "clean-out" where the building connects to the lateral. The utility obtained nearly 100% permission from the public to inspect and trace the GPS locations of the lateral service connections.

The Sewer department utilized "Lateral Launch" robotic cameras that have the ability to send a secondary camera up the lateral to the homeowner's property.

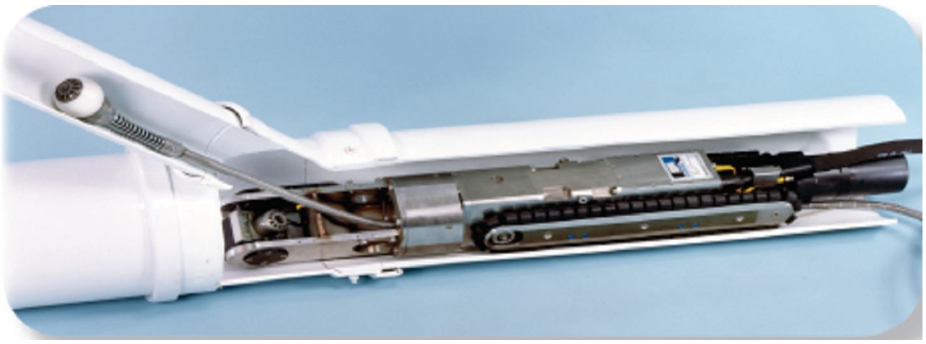

Figure 7: Example of a Lateral Launch camera robot with built-in Sonde

The secondary camera that is propelled up the lateral has a built-in sonde transmitter. A sonde is a self-contained transmitter that sends out electromagnetic signals as it is propelled through non-metallic pipes which can be detected above ground with a receiver. The receiver provides estimated depth calculations which are recorded in a database and the sonde also allows the inspector above ground to trace the path of the sewer line, often using spray paint or flags.

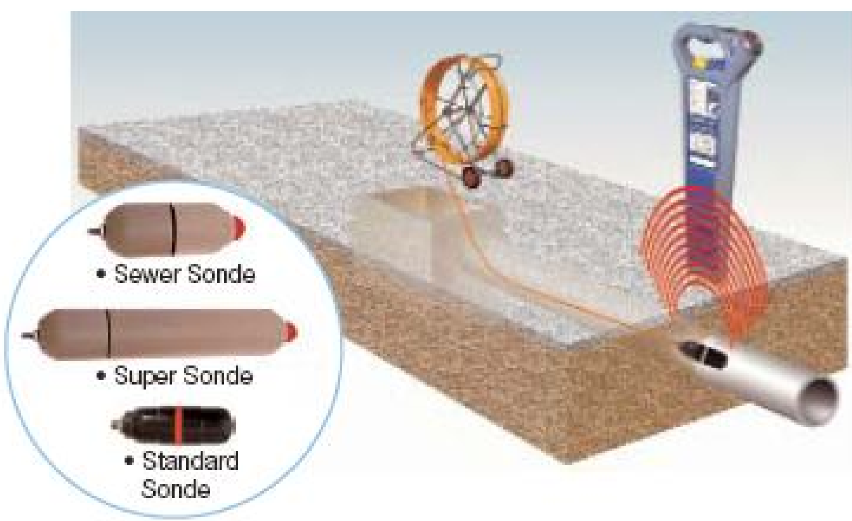

Figure 8: Sonde technology provides depth estimates for buried infrastructure.

Next, the utilities identified a common database structure which both could work with independently, and collaboratively as well. The Water and Sewer Department had created an asset database of its pipelines and had begun to populate its ESRI Geographic Information System (GIS) master database with coordinate and attribute data about its pipeline network. The Gas company also found the GIS technology from ESRI to be acceptable as well. The Windows-based CCTV inspection vehicle computers were pre-loaded with live GIS digital maps that reside in pipeline inspection software (Granite XP) that simultaneously integrates with the robotic Lateral Launch camera, the footage counter, the digital Mpeg video collection, and the GPS receiver. The pipeline inspection software also has bi-directional communication with ESRI GIS to allow GIS analysts at both utilities to update or further inspect and verify new data that is discovered in the field. The CCTV operators easily navigate within the digital maps on their vehicles to pre-populated GIS assets and they are able to start an inspection directly from the map with a simple mouse click. Field inspectors are not able to create new GIS assets in the field to eliminate bad data entry or typos.

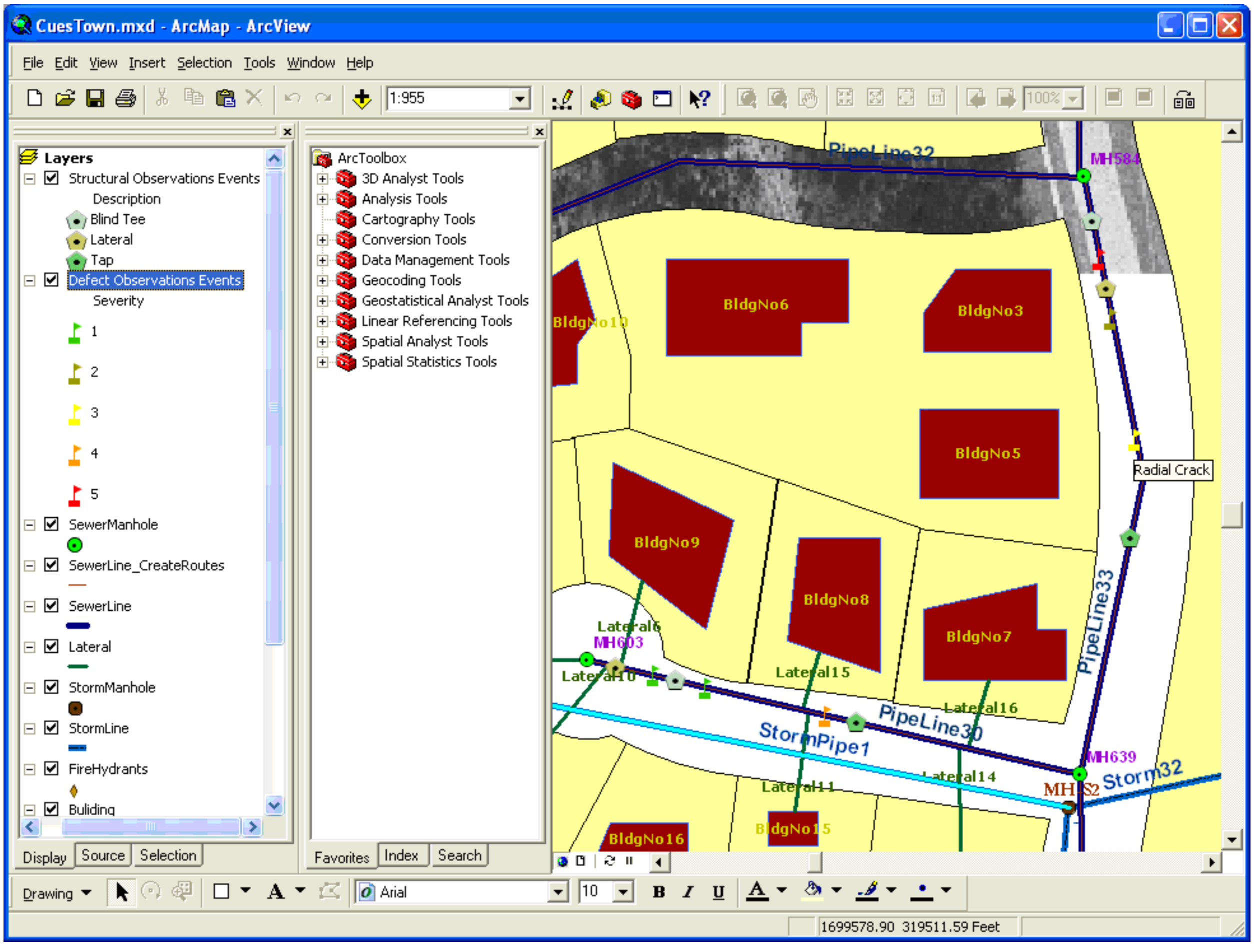

Figure 9: ESRI GIS Software with selected infrastructure layers for presentation in the map.

With a foundation established for the GIS, a tool called the *Wireless GPS Mapping Stick* was deployed to precisely locate structures such as manholes, catch basins, Lateral cleanouts, etc. and collect sub-meter accurate GPS coordinates and transmit them seamlessly from a distance of up to 1,500 feet into the pipeline inspection software.

This GPS data, collected in the field by the CCTV crew, is exactly associated to the specific asset identified by the crew member and then updated into the GIS map each day. When identified in the field, each asset—whether it's a manhole cover, a valve or a homeowner's cleanout—can be given a unique identification number and stored in the GIS database. The field-based pipeline inspection software synchronizes the GPS data back to the office where it can be further validated by the Supervisor and/or GIS department for final approval. The pipeline inspection software records GPS "accuracy" parameters (i.e., number of satellites, signal to noise Ratio, HDOP, PDOP, etc) which enable GIS analysts filter on the quality of the coordinate captures collected in the field. Once the data is loaded into the master GIS geodatabase, linear references can be created with corresponding hyperlinks to spawn video, still images and other inspection data from the pipeline inspection software or the GIS.

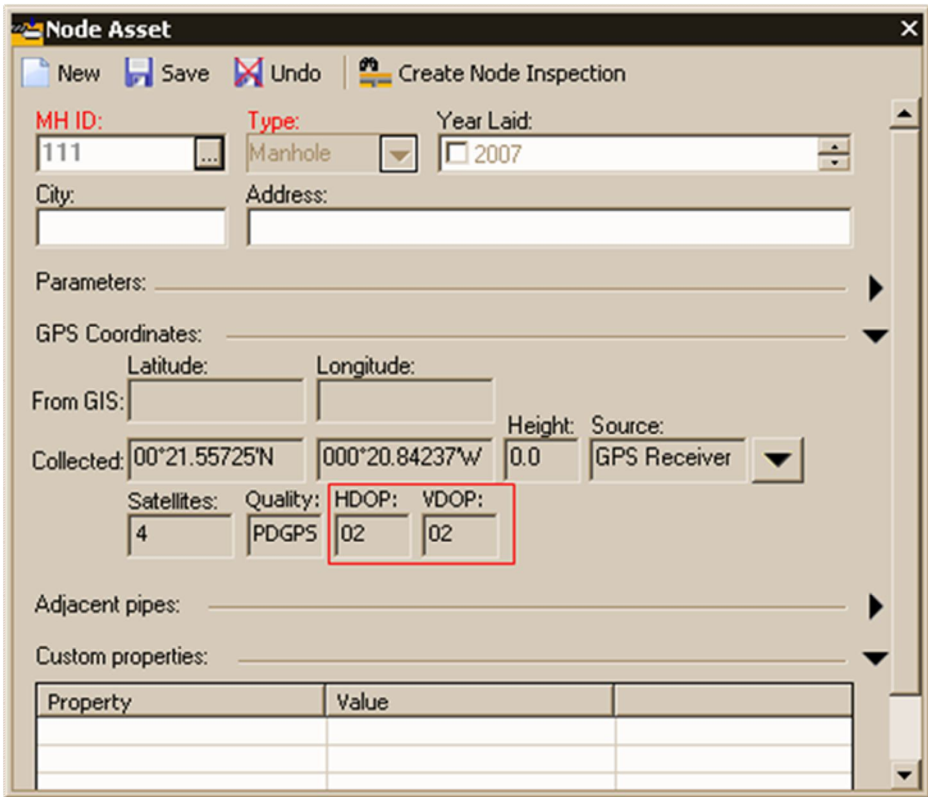

Figure 10: GPS coordinate captures retain additional "quality of capture" data for analysts

Each week, as more and more data is accepted and inserted into the relevant GIS infrastructure layer, the quality and value of the utility's maps is increased, allowing for this data to be shared among other departments and agencies as appropriate. Once captured, the data will exist for future reference, making it easier to find specific assets that may have been paved over or buried by debris.

Figure 11: CCTV Field inspector captures lateral line trace with sonde receiver and Wireless GPS Mapping Stick

Figure 12 : GPS Backpack kit for Sub-centimeter survey grade data collection (alternative)

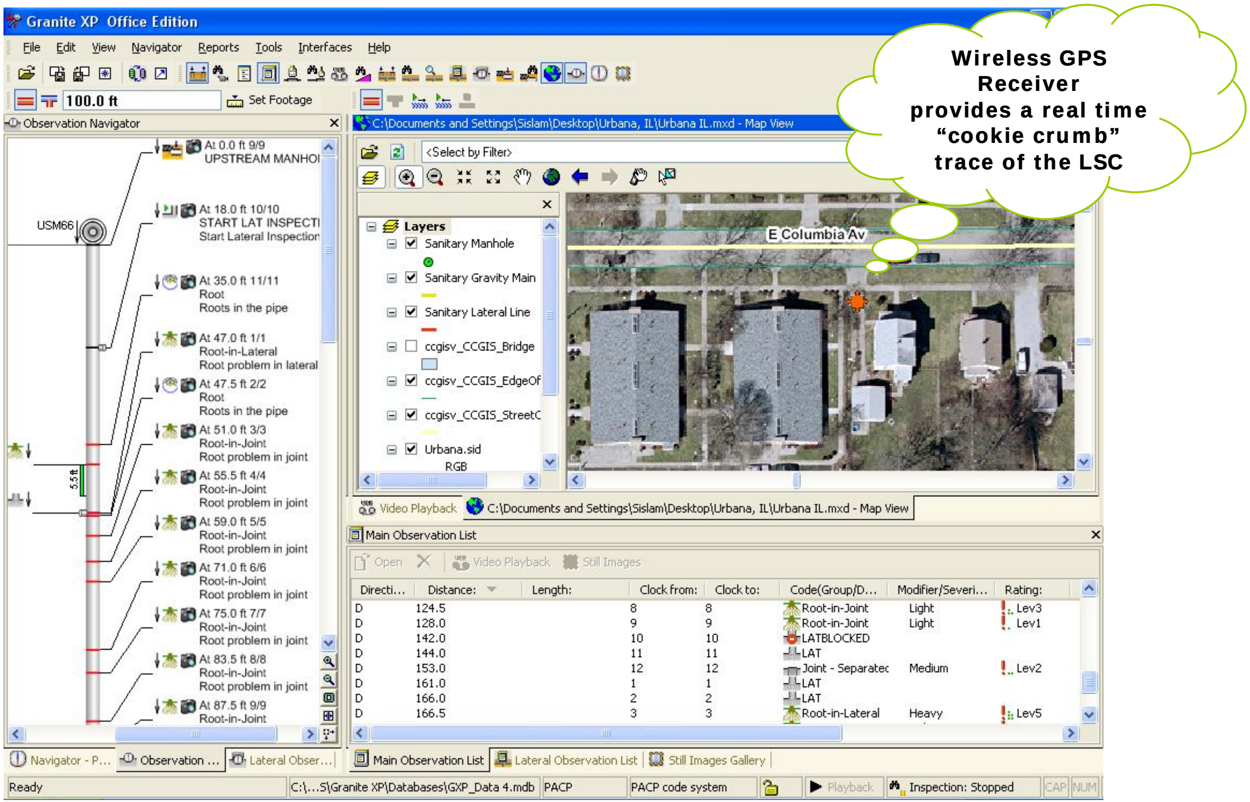

Figure 13 : Pipeline inspection software enables GPS captures associated with sonde depth readings rendered as real time "cookie crumb" tracing of the line.

Figure 14 : CCTV Field inspector captures lateral line trace that has an unusual bend in the line

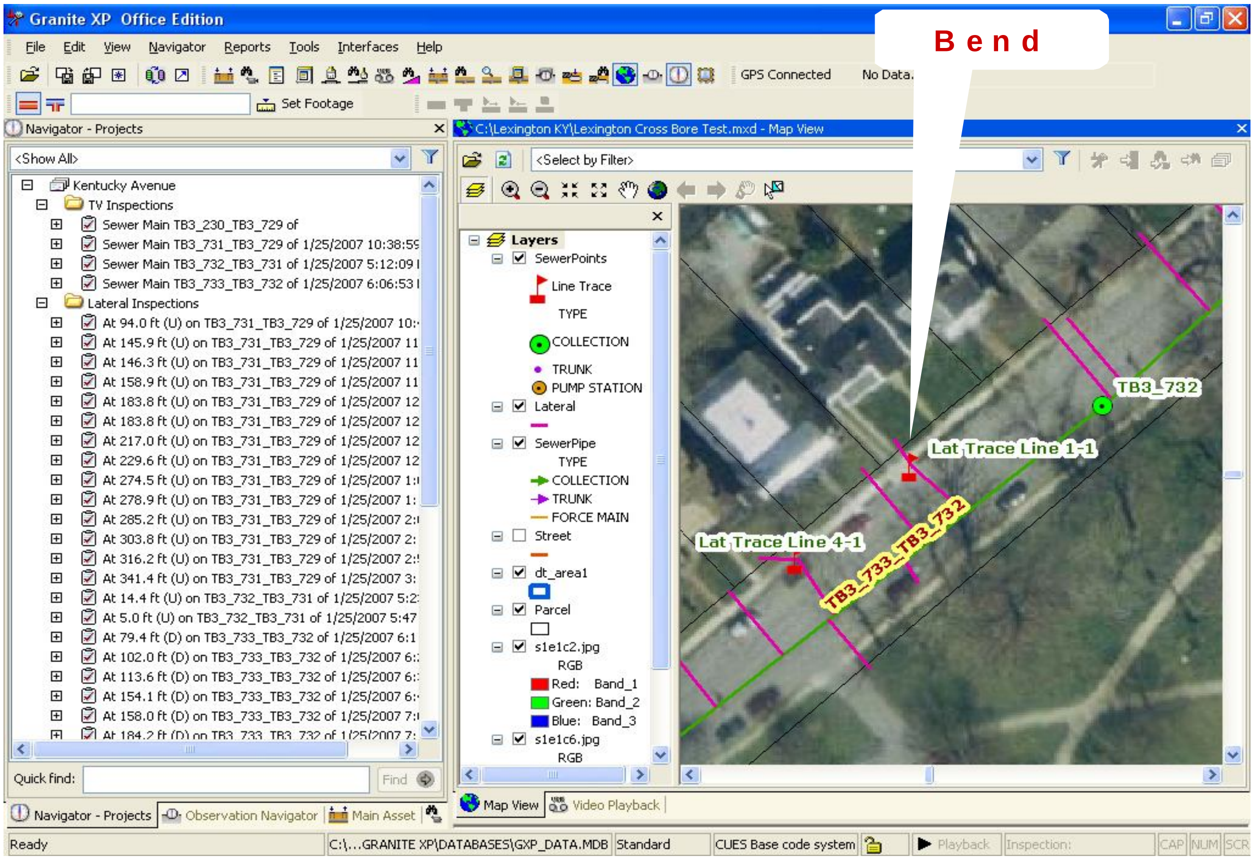

Figure 15: Pipeline inspection software shows a map with multiple sewer Lateral Trace Lines collected in the field, including the property with the unusual bend.

Summary of Benefit and Conclusion

The Water and Sewer department spray painted and flagged the lateral trace lines for the inspected properties. Once the data had been collected and each lateral inspection completed, the gas company was then able to come in and perform its line replacement program with quality data and greatly reduced risk. The Water and Sewer department gathered high-quality location and lateral condition assessment data with the comfort of knowing that no legacy gas line cross bores were identified on the lines inspected. Although the utility elected not to perform a "post construction" inspection, this process could be replicated to verify if any new damage occurred. With a proven foundation for collecting and sharing the data between the Gas company, future collaboration will allow both utilities to better collect, store, display, manipulate, analyze, prioritize, and then link the information to locations on a map for more effective decision making. Public safety and risk management are primary goals for the Gas company and the readily available inspection technologies used in this project demonstrated how one segment of high impact risk related to sanitary sewer cross bores could be greatly reduced. With hands-on training for workers who perform locates using this technology, and better coordination between pipeline operators and excavators, this solution can serve the needs of the industry to reduce risk and improve utility locating techniques, procedures and best practices.

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