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Investigating New Underground Utility Location Technologies and Novel Methods to Improve the Safety and Efficiency of Highway Construction

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CENTER FOR IMPACTFUL RESILIENT INFRASTRUCTURE SCIENCE & ENGINEERING

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16. Abstract

In the field of highway construction, where locating underground utilities is crucial for safety and efficiency, recent advancements in underground utility detection technologies, particularly ground-penetrating radar (GPR), have revolutionized the industry. GPR offers faster and more accurate data acquisition through multi-channel devices and various wave frequencies. Software developments have eliminated the need for extensive training, making GPR more accessible. Moreover, data interpretation and visualization techniques have been refined to enhance location accuracy and user-friendliness. In conjunction with GPR, acoustic methods are being explored to address limitations of traditional technologies. Although no single technology can meet all objectives simultaneously, a combination of devices can be employed based on site conditions. Factors such as pipe material, environmental conditions, and the presence of other utilities or underground objects must be considered. This study evaluated several GPR-based devices and recommends three equipment types for different construction stages. Kontur offers a detailed site overview, providing future design insights. Screening Eagle's step-frequency handcart facilitates efficient utility analysis and marking, aiding excavation planning. RodRadar serves as a crucial safety measure, alerting excavator operators of potential utilities near their digging bucket. While more vendors exist, these recommendations align with objectives outlined by local contractors and agencies. The findings of this study contribute to the selection and implementation of advanced technologies for improving the safety and efficiency of highway construction by accurately locating underground utilities.

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The views and conclusions contained in this document are those of the authors and should not be interpreted as representing official policies, either expressed or implied, of the Pennsylvania Department of Transportation, the Pennsylvania Turnpike Commission, Allegheny County, Golden Triangle Construction, Michael Baker International, the Constructors Association of Western Pennsylvania or CDR Maguire.

Table of Contents

List of Figures

List of Tables

1. Identifying Top Scenarios for Underground Utility Location

1.1 Current Procedures for Underground Utility Location

The research team visited a typical utility installation project of new water pipes in March 2022. The project was located in the Castle Shannon borough in Allegheny County. To install the water pipes, contractors must be weary of existing utilities, whether active or inactive. As shown in Figure 1, contractors removed the existing pavement structure close to the sidewalk to avoid hitting other cables, pipes, conductors, and conduits.

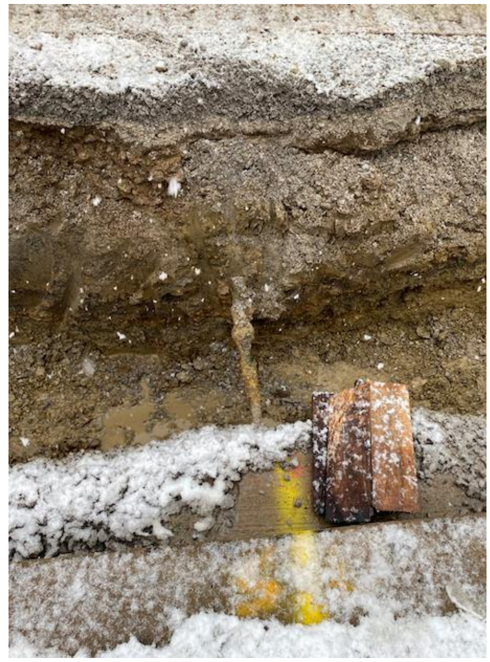
The contractor team used a portable electromagnetic detector prior to excavation to obtain an approximate location of existing utilities. This type of device is designed to locate metallic pipes, but it can also locate other pipes, including plastic, if a tracer wire is placed within the non-metallic pipe. This makes the device highly dependent on the proper installation of utilities' curb boxes and trace wires. If trace wires were not installed, misplaced, or damaged in installation, the device will be unable to give accurate location results.

For this particular project, contractors used the Radiodetection RD7100 [1], developed by the SPX Corporation in the United Kingdom. Figure 2 shows the process of using this equipment to detect and locate underground utilities. The following steps were performed:

1) Set up the transmitter (Figure 2a): Connect the black lead to the ground rod and hook the red lead on the tracer wire.
2) Tune the transmitter parameters (Figure 2b): Adjust the frequency and power of the transmitter.
3) Set up the receiver (Figure 2c): Match the receiver frequency to the transmitter and start locating the underground utilities near a proposed detection area.
4) Find possible locations (Figure 2d): Keep reading the measurements (e.g., peak response, guidance response, etc.) on the receiver display and use the receiver to find the possible location of underground utilities.

The device gives lateral and depth information. However, the contractor team mentioned that the depth location was often inaccurate.

(a)



(b)

Figure 1: (a) water pipe installation and (b) existing natural gas pipe

(a)

(b)

(c)

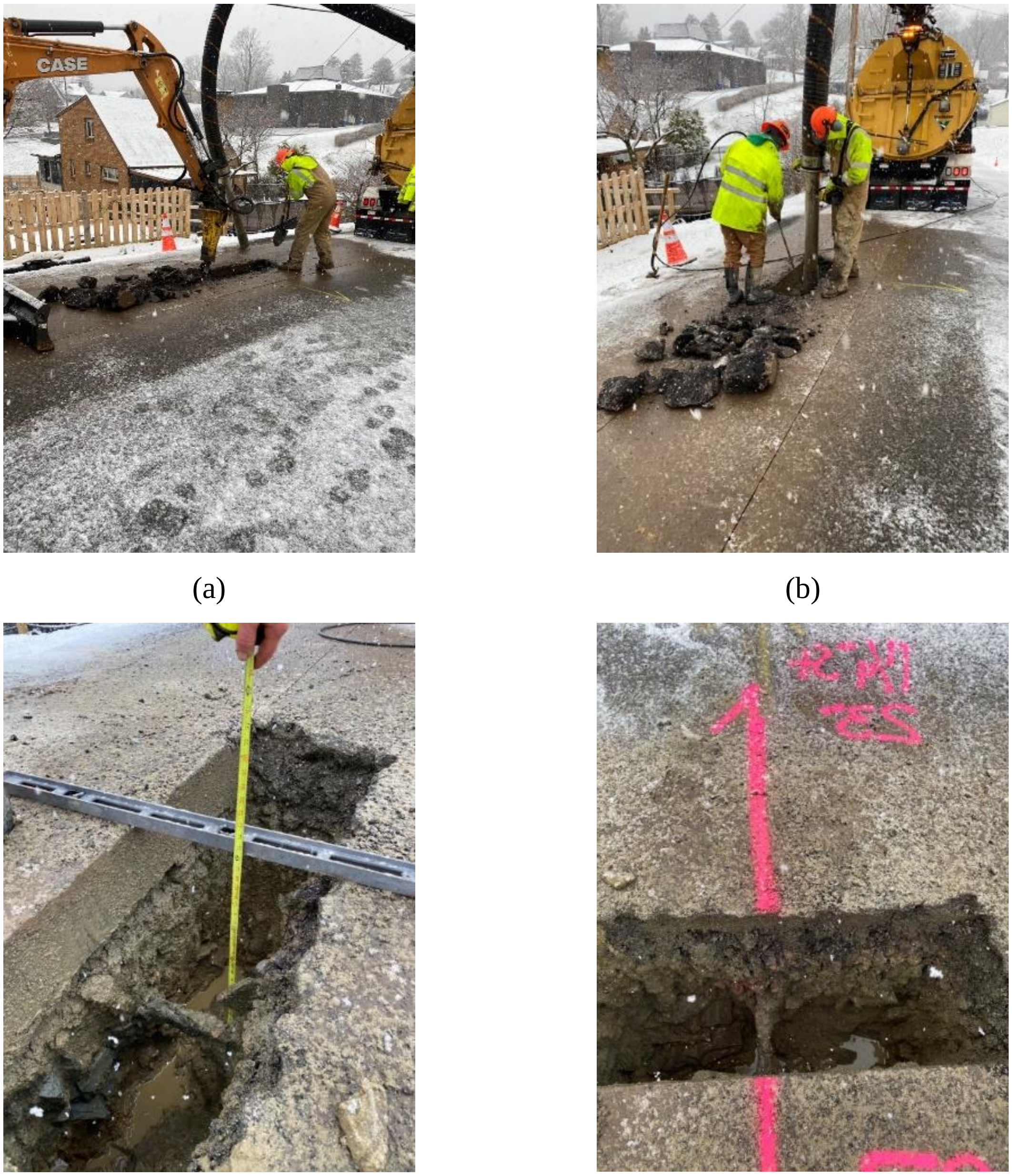
(d)

Figure 2. Radiodetection RD7100 locator equipment process: (a) set up the transmitter; (b) tune the transmitter; (c) set up the receiver; (d) locate utilities using receiver

Based on the information received by the electromagnetic locator, a proposed area was marked on the pavement surface. With that, the contractor performed the destructive excavation according to the following steps:

1) Break the pavement surface layer (asphalt concrete), as seen in Figure 3a.
2) Use a vacuum truck to carefully remove smaller debris from the surface layer and materials from the pavement underlayers (base and top of the subgrade), as seen in Figure 3b.
3) Identify and perform measurements of the existing utilities with annotations on paper records and markings on the pavement of lateral location, depth, and pipe dimensions (Figure 3c and Figure 3d).

According to contractors, the use of the vacuum truck is necessary due to the lack of confidence in the utility records and in the accuracy of the locator device. However, this necessity causes significant increases in project costs due to the expensive machinery and maintenance.



(a) (b)

(c) (d)

Figure 3. Excavation process: (a) destruction of the pavement surface layer; (b) excavation with vacuum truck; (c) measurement of utility pipe dimensions; (d) marking the utility location

1.2 Recent Incidents with Underground Utilities

The research team had access to three recent incidents involving damage to existing underground utilities. These incidents were reported within the first two months of 2022 and, according to contractors, are typical examples of the difficulties faced when working with and around underground utilities.

Consequences from accidentally hitting underground utilities are costly. The three incident reports show costs regarding work interruption and down time for operators beyond costs attributed to the damaged lines and traffic interruption. In the case of a damaged natural gas line, fire and police response were present. There were no injuries related to these incidents but incidents with injuries are not uncommon.

Incident #1: Unmarked communication cable

The first incident involved damage to a communication cable (cable TV) which was unmarked and unknown to lay in the construction site. Figure 4 shows the severed cable in what appears to be a PVC conduit. The photograph also shows that the utility is buried in a dense silty or clay composed subgrade. One of the concerns pointed out by the Technical Panel is the ability of nondestructive devices to accurately locate utilities in different subgrades. Special consideration was given for western Pennsylvania area due to coal mining activities in metropolitan areas creating a “blue slab” subgrade and how devices would operate with this unique material.

Figure 4. Damaged unmarked cable TV line

Incident #2: Communication cable outside of tolerance zone

The second incident also involved communication cables (cable TV). This time the contractor was able to locate the cable conduit based on a pavement mark left by the utility provider. However, as the contractor continued to excavate the project length, another conduit was hit and damaged outside the tolerance zone of the original mark as seen in Figure 5. This example also goes in accordance with comments from the Technical Panel on the lack of accurate records from utility providers on the location or replacements of underground utilities.

(a)

(b)

Figure 5. Cable TV utility incident: (a) intact and damage cable and (b) location of marked cable and unmarked damaged cable

Incident #3: Abandoned natural gas line

The third incident involved an abandoned natural gas line with a plastic pipe (Figure 6). The report states the utility provider curb box was removed but the gas line was not cut from the main line. Again, there were no marks in the area and the utility provider had no record of the damaged line. Besides similar issues regarding lack of records with the other incidents, this example illustrates the difficulties of locating plastic pipes using the current device if a wire tracer is unavailable or has been removed.

Figure 6. Abandoned natural gas line with a plastic pipe

1.3 Preliminary Conclusions

This investigation detailed the current challenges faced by projects that require excavation work around underground utilities. To avoid hitting existing utilities, contractors use expensive excavation equipment and nondestructive testing that is highly dependent on records, marks, and other utility indicators (curb boxes and tracer wires). Accurate records are rare and often marks and tracer wires are misplaced or not present.

Based on current practices and typical incidents regarding underground utility location, the objectives of this project is to find devices that can:

1) Provide accurate lateral and depth information of underground utilities.

2) Locate plastic pipes with and without tracer wires.
3) Scan a whole project segment in case of potential unmarked or abandoned utilities.
4) Provide fast and easy to interpret results.
5) Present accurate results in different subgrade materials, especially considering the “blue slab” subgrade in Pennsylvania.

2. Literature Review on Potential Technologies

This section will identify and review potential technologies that can address some, or all of the technical challenges mentioned above. Advantages and disadvantages of each potential technology will be considered for different circumstances including possible updates for those technologies currently in use.

2.1 Classic Devices

2.1.1 Tracer Wires

Tracer wires are a commonly used method of locating underground utilities but have many challenges and issues. Tracer wires are single conductor wires placed along the buried pipe as it is being installed. The tracer wire is coated in an insulation that protects the wire against abrasion, chemical, and moisture damage. The wire carries a radio signal to be detected later when maintenance is needed on the pipe.

Tracer wires provide a reliable method for underground utility pipes when they are present, but this is often a concern in itself. Tracer wires must be installed when the pipe is being constructed which creates a heavy reliance on the initial pipe installers. Any pipes installed before this technology was common or instances where they were simply neglected would not be detected. The wires could be damaged over time which interrupts the circuit, removing the detectability once again. If there are many pipes and tracer wires in a small area, the location accuracy will be reduced. These issues have led contractors to other methods which allow the pipes themselves to be detected and removes the dependence on the initial pipe installer.

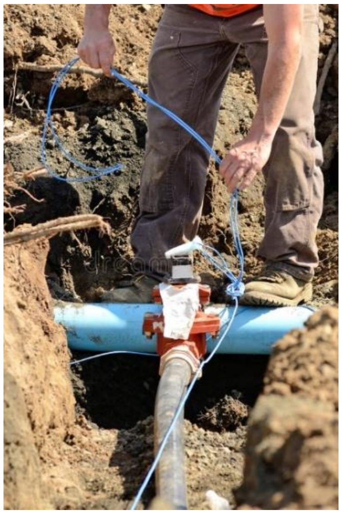


Figure 7: Tracer wire being laid along a pipe

2.1.2 Magnetic Locators

Magnetic surveys are another common method used to locate underground utilities. This method measures changes in the natural magnetic field and requires no preinstallation. Magnetic surveys are simple to conducted permitting large construction sites to be searched quickly and are very sensitive to small objects creating a thorough inspection.

There are significant disadvantages to this method. Obviously, the underground utilities must be metal to be detected; any pipes that are plastic or non-magnetic metals will not be detected. Magnetic surveys are only accurate to approximately 15 feet below the surface. Advances have been made to reduce the noise from above ground magnetic interference, however, if the area is especially congested, above-ground metal objects may still interfere with detection of underground objects.

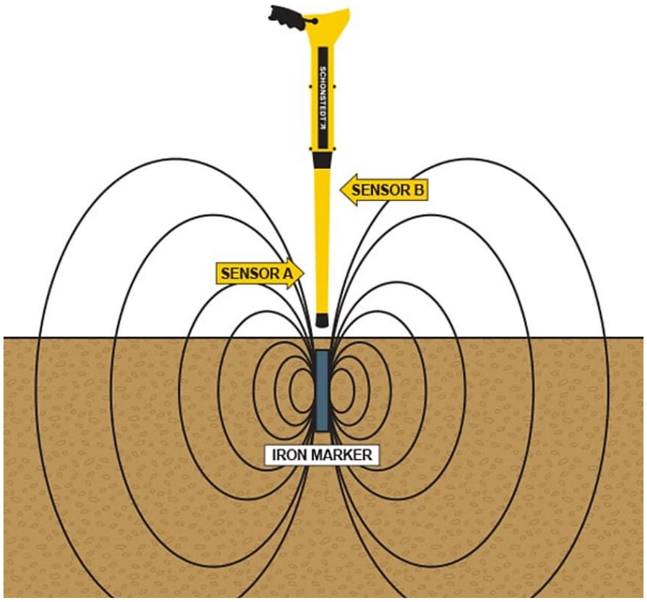


Figure 8: Using a magnetic locator [1,2]

2.1.3 Electromagnetic Induction

While magnetic methods detect disruptions in the natural magnetic field, electromagnetic induction requires an external current that will move along the pipe generating its own field that is detectable from the surface. A transmitter is used to transfer this electromagnetic current onto the pipe and a receiver reads and interprets the signal for pipe location and depth. There are several transmitter types: straight induction, direct contact, and induction clamp [3]. In straight induction methods, the transmitter is placed above a suspected pipe and the current runs through the ground into the pipe. The other two methods require direct access to the pipe to transmit the current. Changing the wave frequency can change the abilities of the device for locating deeper utilities or improving accuracy [4]. Pipes as deep as 35 feet can be located depending on the device used.

Electromagnetic induction has a significant disadvantage because to locate utilities, the pipe must be metal to conduct a signal. Non-metallic pipes cannot be found unless a tracer wire is present. The results can also be affected by soil properties, such as conductivity, saturation, or clay content, or other metallic objects, including other utilities or surface structures [5].

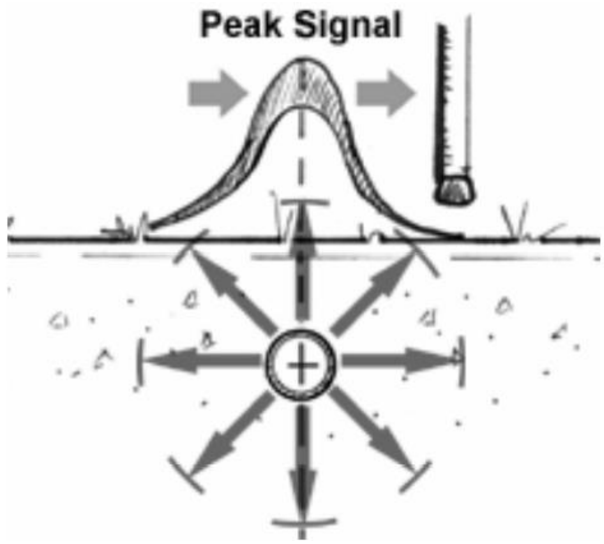


Figure 9: Diagram of an electromagnetically charged metallic pipe being located [6].

2.2 Ground Penetrating Radar

Ground penetrating radar (GPR) could also be considered a classic device as it has been used for many years to locate underground utilities. However, this technology is continuously developing, and new devices have improved this method to address previous concerns such as location accuracy and signal interpretation.

GPR uses high frequency electromagnetic waves to identify signal changes caused by underground utilities. Using lower frequency antenna allow GPR to potentially scan deeper but have a low resolution [7]. A transmitter antenna emits a wave into the ground which deflects off buried objects and is reflected where a receiver antenna will record the signal variation. This signal measures the dielectric or conductive properties allowing GPR to locate any material, metallic or non-metallic, that has a different dielectric constant than the surrounding soil.

GPR can be either ground- or air-coupled which changes the wave energy transfer. A ground-coupled device will have accurate scans as the energy transfer is more direct, but this slows the data collection process. An air-coupled device will reduce the spatial resolution and subsurface signal strength, but it can gather more data quickly as it is typically on wheels or attached to a vehicle [8]. If the scans can be limited to a shallow range, air-coupled is acceptable but will lose accuracy with depth. GPR can also have two types of wave frequency: impulse or step-frequency radar. Impulse systems emit several very short pulses of energy whereas step-frequency systems emit a series of sine waves with increasing frequency (Figure 10). Step-frequency radar has better signal-to-noise ratio, larger frequency bands, and more complete data collection over traditional impulse systems [8]. However, devices that use step-frequency tend to be more expensive than impulse devices.

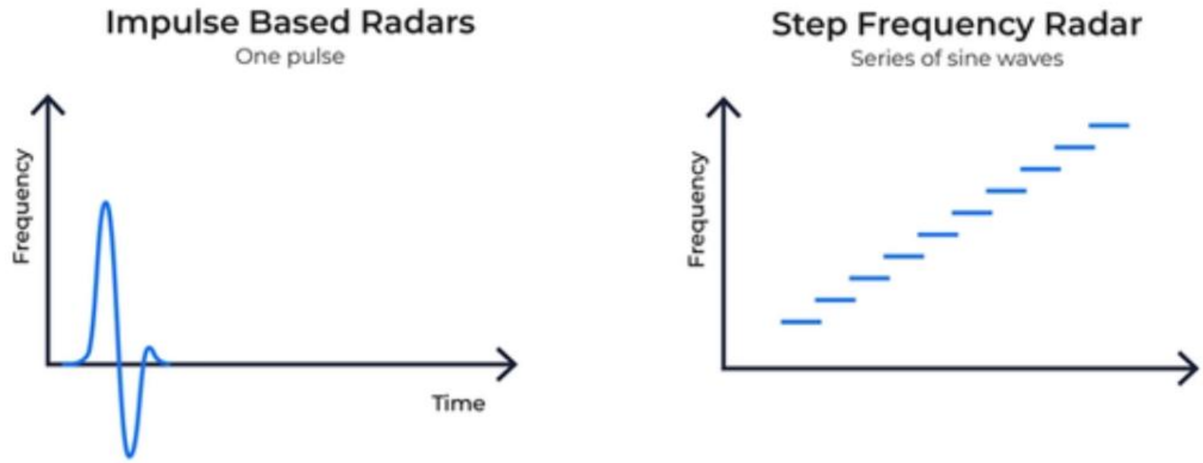


Figure 10: Comparison of impulse and step-frequency radars [9]

GPR provides data in several ways: A-scan or signal based, a single B-scan creating a 2D image, and a series of B-scans creating a 3D image [7]. A-scans have a peak when intercepting a target and when placed together in a B-scan, will form a hyperbola indicating where a utility is located. Different companies display data differently, some including the raw scan or some providing a processed version as a map or 3D area. Interpreting these signals and images depends highly on user knowledge and experience [7,8]. Raw signals require the user to have significant knowledge about GPR to determine what is being detected and if there are any discrepancies in the reading. 2D scans provide only a single cross-section which can certainly identify materials with a different dielectric constant than the surrounding soil. However, this is not necessarily a utility pipe as tree roots or rocks can cause a deflected signal similar to that of a pipe which can be mislabeled [7,8]. Creating a 3D image from a series of scans can better define a utility by easily identifying the entire utility line path.

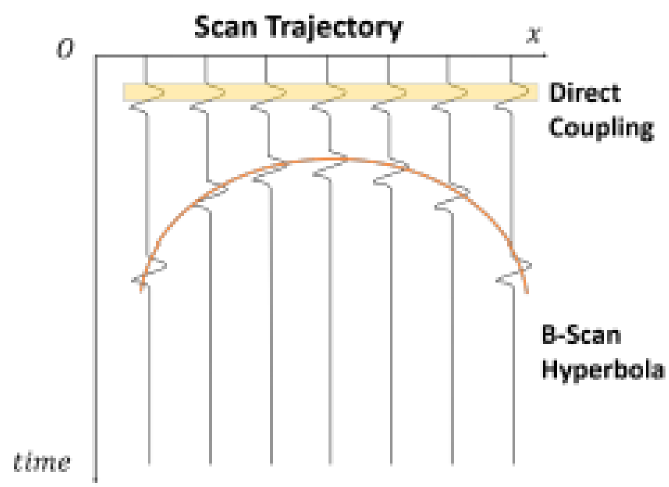


Figure 11: B-scan display showing the makeup of A-scans [10]

In the past, GPR antennas have been single-channel devices which are excellent handheld devices as they are small and portable. However, in underground utility detection, users are looking to scan a large, often heavily trafficked, area therefore using a traditional single-channel GPR device for this purpose can be tedious. In recent years, a multi-channel array has been developed which uses the same technology but aligns several antenna in different orientations to best capture the location of underground objects [11]. This allows for more data to be acquired at a higher quality by increasing resolution and decreasing the noise to signal ratio. Multi-channel arrays have not only improved upon the data quality GPR can provide, but also increases the speed of data collection. Multi-channel GPR devices are attached to a vehicle or handcart for quick data collection, including at the speed of traffic if need be.

Additional technology has been added to GPR devices to further improve underground utility mapping. Global positioning systems are often used to improve image stitching for cleaner, more precise maps. Future GPR developments include full scale digital mapping and augmented reality. Cities including Las Vegas, London, Singapore, Hong Kong, Zürich, and Rotterdam are beginning to digitally map all underground utilities using 3D GPR for when the pipe is not exposed [12,13]. The goal of these projects is a 3D map of underground utilities that would be publicly available, as shown in Figure 12, with several aiming to include an augmented reality software for site use. Singapore specifically aims to merge existing data with new data collected using GPR and other data sources and devices to map all underground utilities, objects, and infrastructure [13].

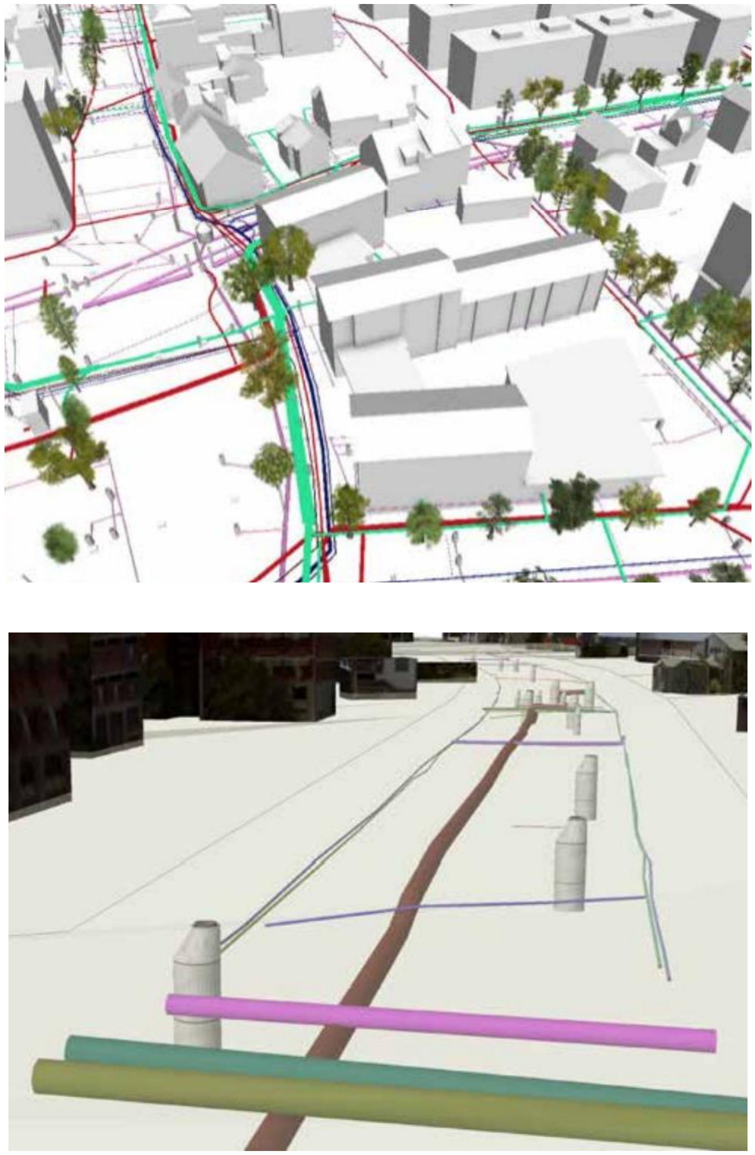
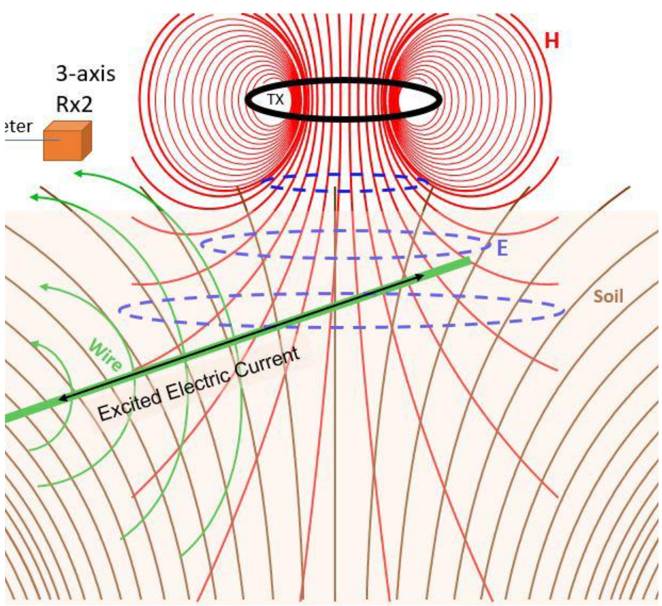


Figure 12: 3D model of underground utilities in Zürich and Toa Payoh [12,13]

Modern GPR does not have all the same disadvantages as older models. Data analysis used to take several days; however, new software allows for real-time 3D images of detected utilities. New technology also helps to remove some human error that was common in older devices that rely on 2D scans. However, extensive training is still needed for best result interpretation especially in pipe congested areas. Soil properties can have a significant effect on the results regardless of the current technological updates. Clay or saturated soil can cause large signal attenuation which can lead to the scan losing accuracy or not detecting pipes. This can also affect depth measurements as soil properties can change the return signal velocity [7]. Another limitation is the accuracy of detection depends on pipe depth and size. The deeper a pipe lays, the greater the pipe size needs to be for it to be detectable. Despite the limitations that remain, GPR is one of the most common methods of underground utility detection and has several devices with these updates available for use.

Further research into GPR is being conducted to improve both the signal device and the data interpretation for underground utility detection. Hartshron 2022 conducted research on the linear current sensing (LCS) method, an improvement on the classic GPR signaling method [14]. LCS uses a primary electric field to excite a linear current through the target metal utility. Two triaxial receivers are used along with this method to improve the data filtering between the soil and the utility. To improve the usability of the device, they are exploring attaching the device to a drone to cover larger areas. Initial tests saw an increase in penetrating depth and area coverage. Feng 2021 continues research to improve data filtering and interpretation by designing MigrationNet [10]. This is a learning-based approach to better detect and visualize utilities from raw GPR data through improved filtering and interpretation of B-scan hyperbolas. This method requires less GPR data for pipe reconstruction, produces improved images with less computation, and reduces human error. Kang 2020 developed a neural network for data interpretation to identify and classify cavities, manholes, and pipes [15]. This is a continuously evolving technology that will need to be monitored for future industrial updates.



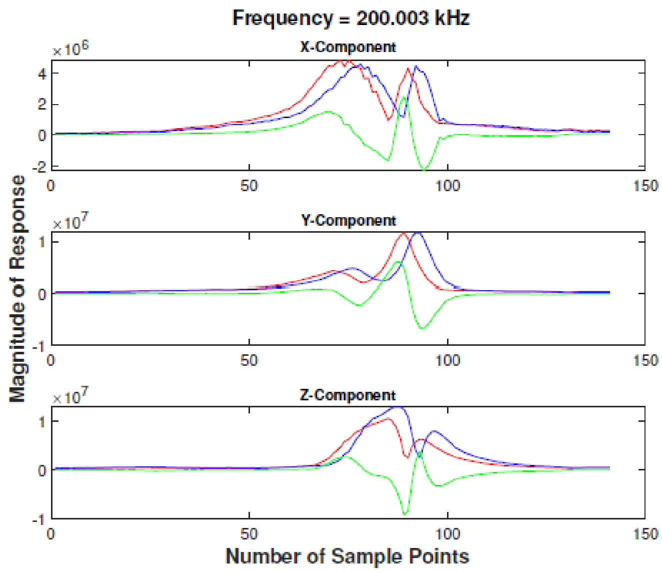


Figure 13: Linear current sensing method exciting a metallic wire (top) and signal peaks from a triaxial receiver indicating a utility (bottom) [14].

The advances in GPR technology have been explored in several cases studies which special consideration to accuracy in utility location. Table 1 summarizes the reported accuracy these studies encountered. Many of these case studies are farther described in the following section as specific devices were used in each. These studies were met with success but highly depended on the location, soil type, pipe depth, and data interpretation method.

Table 1: Accuracy claims of several case studies using different GPR devices in the field

Source	Accuracy Claims
Feng 2021 [10]	• RMSE of 10 – 11.5 cm for low noise and 41 – 45 cm for high noise depending on the neural network type
Gabrys 2020 [16]	• RMSE = ± 0.052 m using GPS PPS location system
Kang 2020 [15]	• All pipes, manholes, and intact sections were correctly identified • 11% of cavities were misclassified as pipes • 3% of cavities were misclassified as intact
Karle 2022 [17]	• 7 of 8 pipes located • Several unmapped pipes located

Karszina 2021 [18]	• Average Error of 0.01 – 0.07 m depending on soil type, depth of pipe, and data interpretation method
Koganti 2020 [19]	• Success rate of 0 – 99% depending on soil type and pipe depth
Muggleton 2014 [20]	• 9 of 11 pipes located
Sarlah 2020 [21]	• RMSE of 13 cm for location and 11.25 cm for depth

2.2.1 Available GPR Devices and Software

Several companies supply modern GPR devices that utilize different combinations of features explained in the section above. Companies also have new data processing software that has been developed alongside the devices. There are many additional companies that provide GPR devices however, those identified in this report are common and accessible in the US.

Kontur

Kontur is a provider that specializes in step-frequency devices [9]. They use a multi-channel multi-frequency radar called a Geoscope. This can then be paired with different antenna arrays, including air, ground, or deep-coupled, with different number of channels. Kontur devices can be personalized as the user can choose the antenna array, channel number, mounting method, and size of the device. For utility location, they recommend ground-coupled devices which are listed in Appendix A. Figure 14 shows an example of a Kontur GPR device in use. Kontur has a visualization software called Examiner that overlays the scanned utilities onto maps or photos for easier analysis.

Figure 14: Kontur GPR device attached to an auto vehicle [9].

Kontur equipment has been used in several case studies with success. Kang 2020 had the objective to locate cavities under roadways using GPR to monitor potential sinkholes [15]. While detecting underground utilities was not the prime objective, cavities and pipes look similar in the raw data, especially when the pipe is perpendicular to the scan direction. They were able to successfully identify cavities and utilities under the roadway and distinguish the two through background filtering. This project particularly enjoyed the vehicle mounted capabilities that allow roadways to be analyzed quickly. An advantage of Kontur equipment is the vehicle compatibility. A second case study displays this ability by attaching the equipment to an all-terrain vehicle to locate drainage pipes below farm land [19]. This project specifically aimed to test the step-frequency method this technology uses and to pair the device with EM devices for complementary information. This study did identify the same struggle with the certain soil types but were successful in locating pipes that were perpendicular to the scan direction.

Screening Eagle

Screening Eagle is another provider that focuses on step-frequency continuous waveform GPR [22]. They have a single device called GS8000 (Figure 15) to be primarily used for utility detection. They promote wireless technology, accurate geo-referencing for improved mapping, and simple user experience. The visualization software is an app called Proceq GPR Subsurface, also shown in Figure 15. This software analyzes the scans and GPS data to provide a real time 2D or 3D map which the user can use to clearly mark and label different utility lines detected.

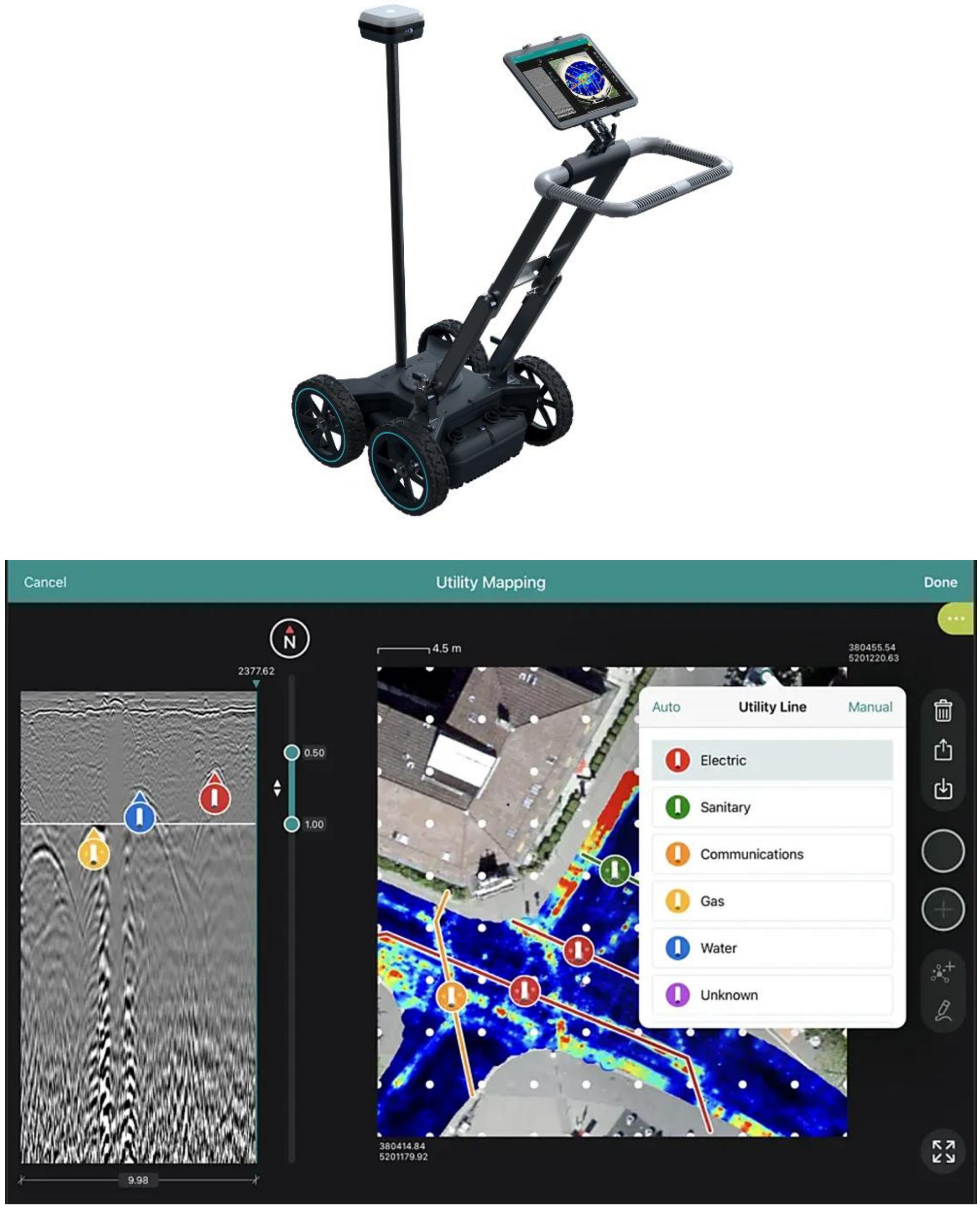


Figure 15: Screening Eagle GPR device and software [22].

GSSI

Geophysical Survey Systems Inc. (GSSI) is a major provider of GPR devices and has a device specific to utility detection called UtilityScan (Figure 16) [23]. This device provides real time map or 3D images of the utilities like many other distributors. The difference in this device is it is designed to be compatible with an additional sensor, LineTrac. This accessory uses electromagnetic induction to locate lines, combing the benefits of both GPR and EM into a single device. GSSI also has a visualization software called RADAN 7 that displays and processes the GPR and possible LineTrac data.

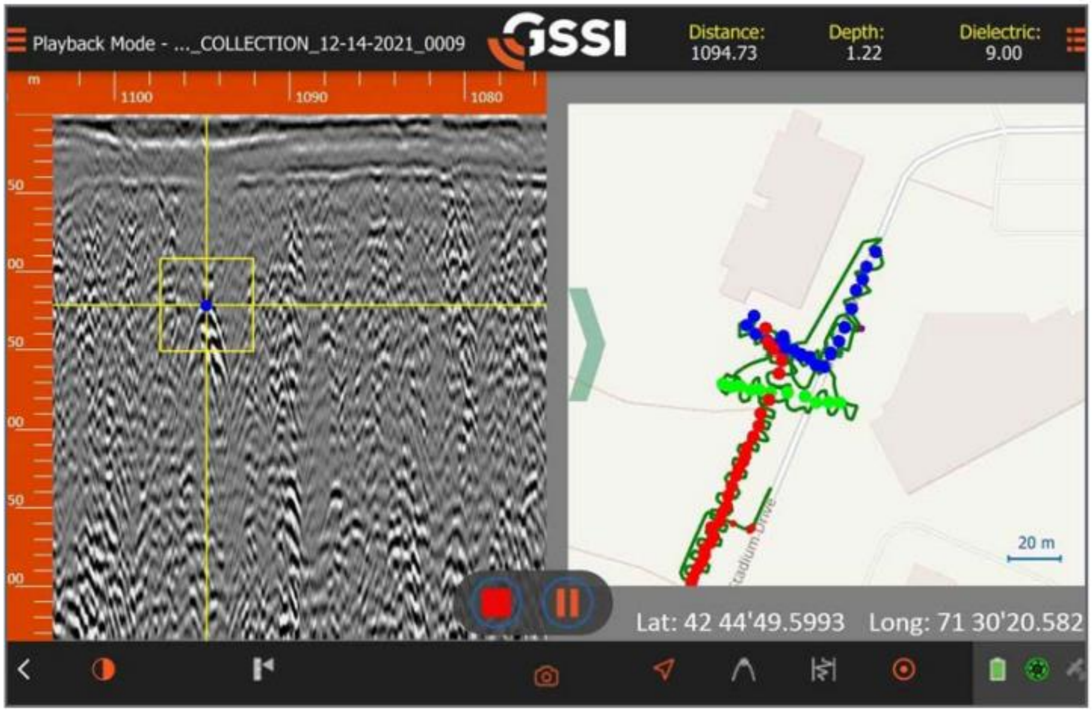


Figure 16: GSSI GPR device and software [23].

UtiltiyScan has been tested in several case studies. Iftimie 2021 particularly wanted to test UtilityScan by locating underground drain pipes under unfavorable conditions such as varying water contents along a river bank, rough terrain along a bike path, surrounded by close, tall buildings, and varying weather conditions [24]. They were able to approximate the location, depth, and profile of the pipes with success using a certain image processing method. Koosha 2022 used UtiltiyScan to locate air voids around buried culverts [25]. This case study was also met with success, and they particularly noted the advantage of using different frequencies.

IDS GeoRadar

IDS GeoRadar provides a line of GPR equipment that is multi-channel multi-frequency technology (Figure 17) [26]. The first device is the Opera Duo which is a handcart version. This device also has an accessory camera that is used to overlay the GPR data onto the surface in real time and a spray paint attachment for marking. Stream C is another GPR device which can be transformed into either a handcart or towed behind a slow-moving vehicle. This device is equipped with automatic pipe detection software for easy use. IDS GeoRadar also has a fully towed GPR device, called Stream UP, which allows utilities to be detected at driving speed. For best results, they recommend a driving speed of 37 mph, but the device can function up to 93 mph.

IDS GeoRadar has several visualization software for their devices (Figure 18). The uNext platform is compatible with the Opera Duo device and connects GPR and GPS data for accurate mapping. There is also an advanced version with additional features to improve data processing and user friendliness. OneVision and IQMaps are platforms that function with Stream C and Stream UP devices as this software is designed for more advanced data collection. IDS also has an additional visualization software called uViewer. This provides a 2D, 3D, or augmented reality map using any data collected on the utility. The device is designed to operate on site with a positioning system allowing the user to precisely relocate utilities.

Figure 17: IDS GeoRadar GPR devices Opera Duo, Stream C, and Stream UP [26]

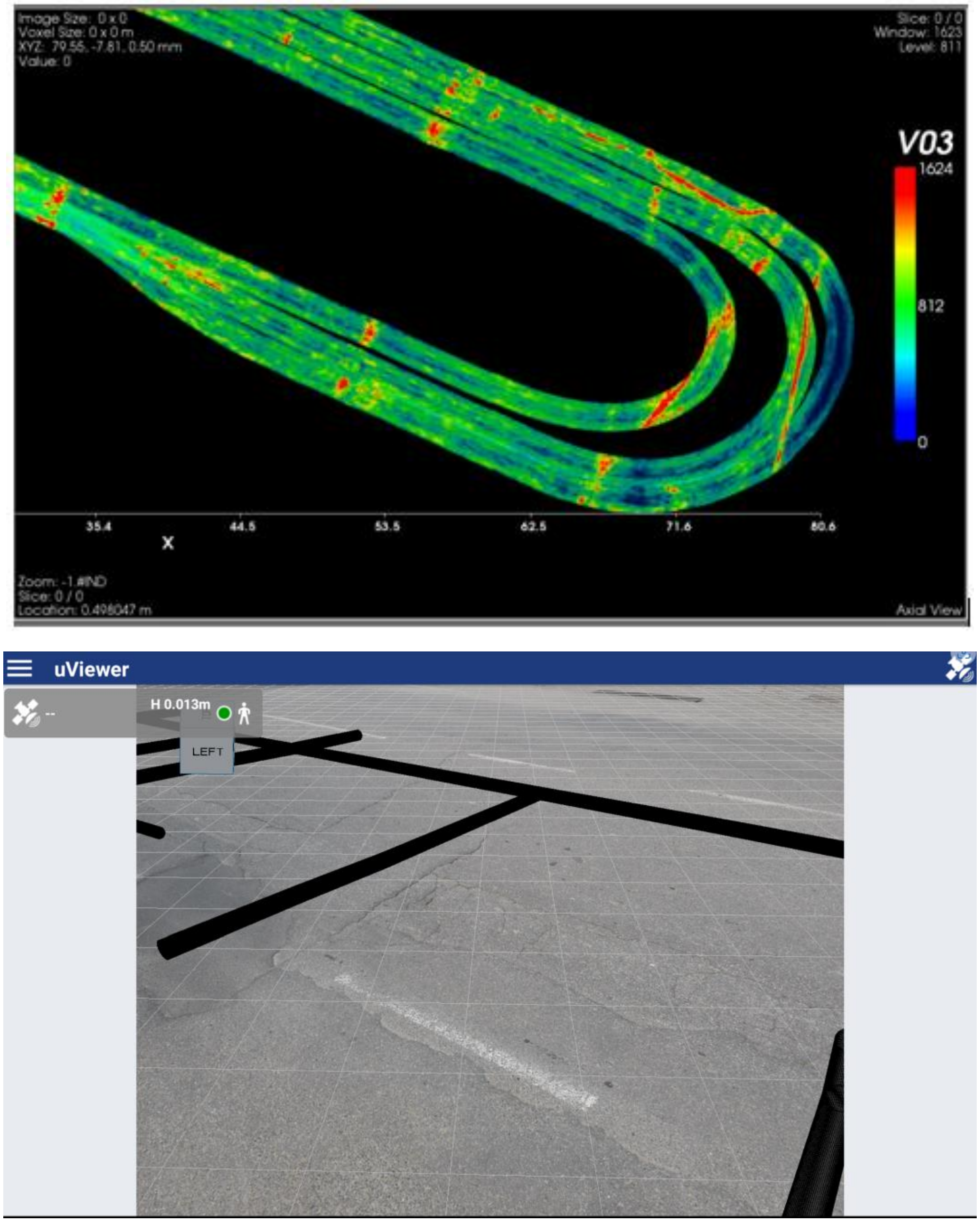


Figure 18: IDS GeoRadar visualization platforms OneVision and uViewer [26].

Several case studies have been performed using IDS GeoRadar Equipment. Cardoso 2021 used Stream C to map the utilities in Sao Paulo, Brazil [27]. They decided to use this specific device for several reasons including high productivity, minimal training, automatic pipe detection, pipe display in real-time, motor assisted hand cart, and towing capabilities. Overall, they found that GPR, and this device specifically, decreases time and amount of people needed in the field and increases the efficiency of the project. Gabrys 2020 aimed to explore multi-channel GPR devices and specifically used Stream C along with the OneVision software [16]. This study also enjoyed the motor assisted hand cart to improve device use and the improved compatibilities with global positioning devices. They found the multi-channel device not only improved coverage, but also increased accuracy. This study found that mapping accuracy has a dependence on the type of global positioning used, especially with irregular passes (Figure 19). Karle 2022 used Stream C data and explored new data filtering methods for different field conditions [17]. They were able to identify most pipes in the system including those parallel and perpendicular to the scan direction (Figure 20).

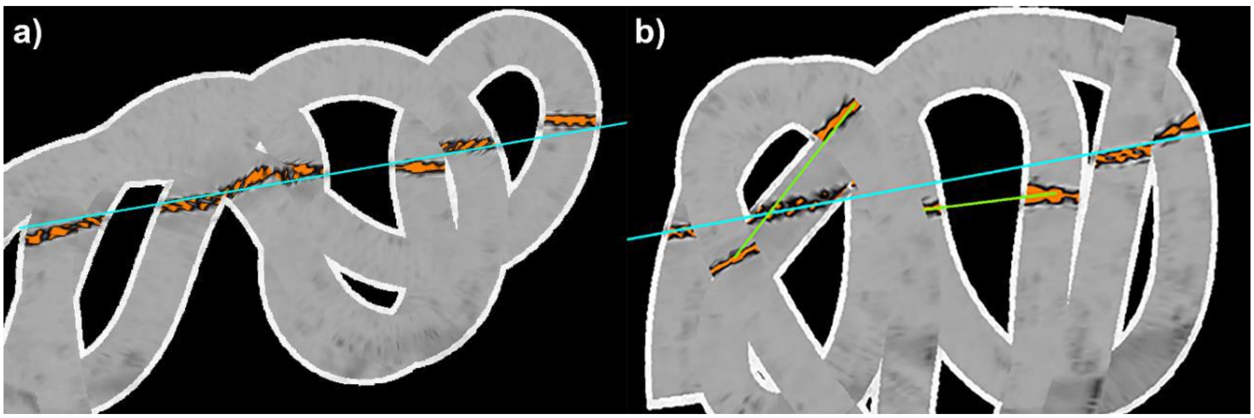


Figure 19: Resulting map of irregular passes using different locating methods: (a) GPS PPS and (b) GPS [16]

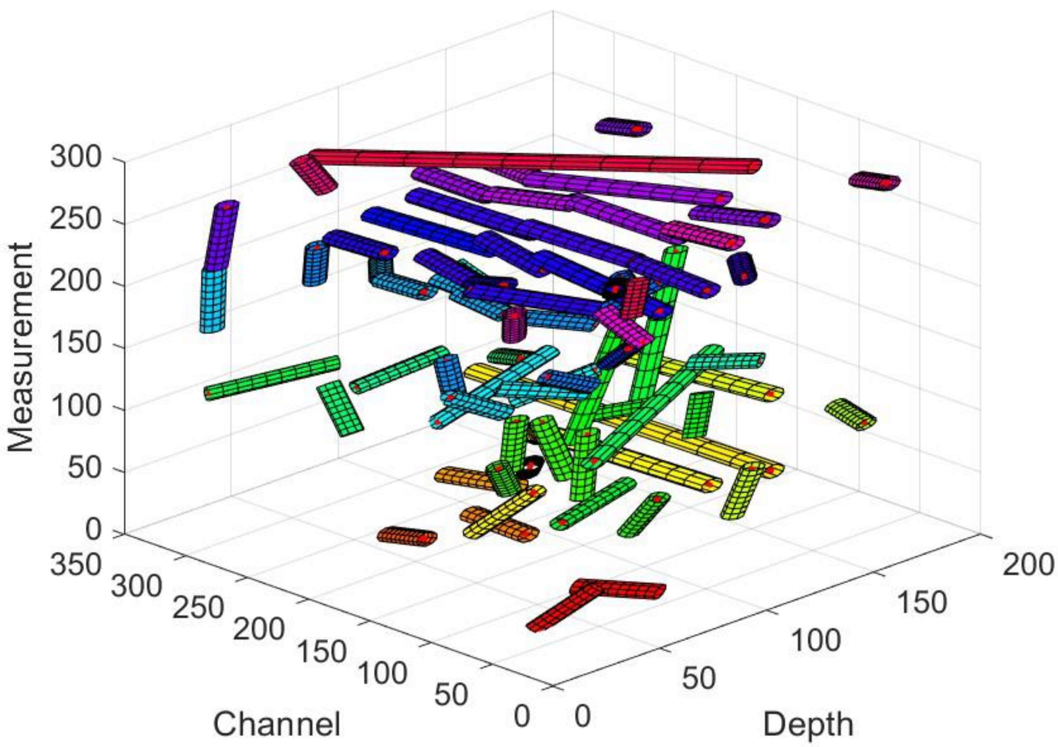


Figure 20: Visualization of detected pipes using Stream C in [17]

While the Stream C is a popular device, others were explored in case studies as well. The Opera Duo with DS2000 device was explored in Karszina 2021 [18]. This report aimed to assess positioning precision, repeatability, and reliability of the device and the softwares uNext and GRED HD. They also began to explore the effect of soil moisture on location accuracy and found some correlation. They found that the GPS attached to the device has some issues rebounding off other objects and suggested a georeferenced baseline and measuring out in a grid system. Issues with location using GPS is a common problem that is currently being improved [18,21]. The repeatability and overall reliability of finding utilities with the DS2000 and Opera Duo was excellent.

2.3 Acoustic Methods

Acoustic methods are able to differentiate between buried objects and the surrounding soil medium using mechanical waves [28]. This method begins with a wave source that may be applied on the pipe itself or on the ground above the buried portion. The wave propagates through the soil-pipe system to be received again at the surface. The data from the receiving wave can be interpreted to determine the location of the buried pipe.

A benefit of acoustic methods is pipe material is irrelevant. Acoustic methods are also less affected by saturated or clay soils. Only a combination of saturated soil with high porosity and loose compaction can impact wave radiation or result interpretation [28]. A significant disadvantage of acoustic methods is they are only applicable for shallow pipes less than 8 feet deep. There are several technologies that utilize acoustics and mechanical waves. Each has their own requirements and benefits.

Traditional acoustic transmission method and pipe excitation method both require the pipe be accessible. An acoustic wave is sent through the pipe and receivers are set up in the surrounding area to detect the waves following the pipe. This is a good way of determining the location of the pipe but not the depth. The traditional method uses a simple listening rod or a single receiver, heavily relying on the operator. This was originally used to detect leaks in the pipe but was found it could be used in pipe location. This new knowledge was used to create a different method. Pipe excitation method improves the traditional method by adding an improved wave source and a receiver grid system, to accurately locate pipes. Pipe excitation method is better with fluid filled pipes and can identify bends, change in pipe material and dimensions, or a leak [28]. This method also functions well under excessive noise and with different ground surfaces.

Both these methods require surface access to the pipe. Two other methods can be used to locate pipes that are fully buried: point vibration measurements and seismic wave methods. These methods can locate underground targets, but it is best to have a general idea of where at least part of the pipe is located to have a better starting point.

Point vibration measurements detect pipes through changes in mechanical wave frequency and magnitude. To use, the wave source is placed on the ground surface and an acoustic wave is sent through the soil system. The system will have a specific frequency that will be interrupted if there is a pipe underneath. This is called impedance mismatch and is used to accurately locate the pipe through the wave disruptions [29]. This method has been shown to be effective even in congested areas with noise filtration [28,29]. Determining pipe depth is possible but inaccurate. For best results, the operator should take care to avoid mixing surface types in a single scan and avoid scanning over cracks and expansion joints.

Seismic waves have been used in the past for many other applications in the oil and gas, structural, and pavement industries to locate or analyze targets. This method involves sending seismic waves through the soil to strike the pipe or buried object. The waves will scatter and be collected again at the surface by receivers. This will reveal the precise location of the pipe including the depth. There are different wave types and velocities that can be used to locate pipes at different depths and circumstances [28]. This method has been known to have a lower resolution which results in lower stability and accuracy. However, the current, most pressing issue is that this is still emerging technology and does not have many commercialized products yet and none developed specifically for utility locating. Despite the lack of devices, technology utilizing seismic waves exists in other industries and is beginning to be explored in utility location. While this technology may not exist at this time, it is a device to look for in the near future.

2.3.1 Available Acoustic Devices

The ULTRATRAC® Acoustic Pipe Locator (APL) was commercialized by SENSIT Technologies in 2011 and uses pipe vibration measurements [29]. This device is able to locate metallic and non-metallic pipes in any soil type at various depths depending on the pipe diameter and is unaffected by surrounding electrical fields. Any pipes under 12 inches cannot be detected. A ½ inch pipe can be located until 30 inches below the surface, a 2 inch pipe until 48 inches, and a 4 inch pipe until 96 inches [28]. The accuracy is within 18 inches.

This device, as shown in Figure 21, consists of an actuator that sends the acoustic waves and a dual matched accelerometer at the other end to receive the wave after it reflected off the pipe [29]. The newer devices include a Window-based tablet to improve user friendliness and reduce false readings [29]. SENSIT Technologies recommends scanning a minimum of three rows about 5 to 25 feet apart to create a survey grid to locate pipes accurately. The scan data can be stored for further analysis and record keeping.

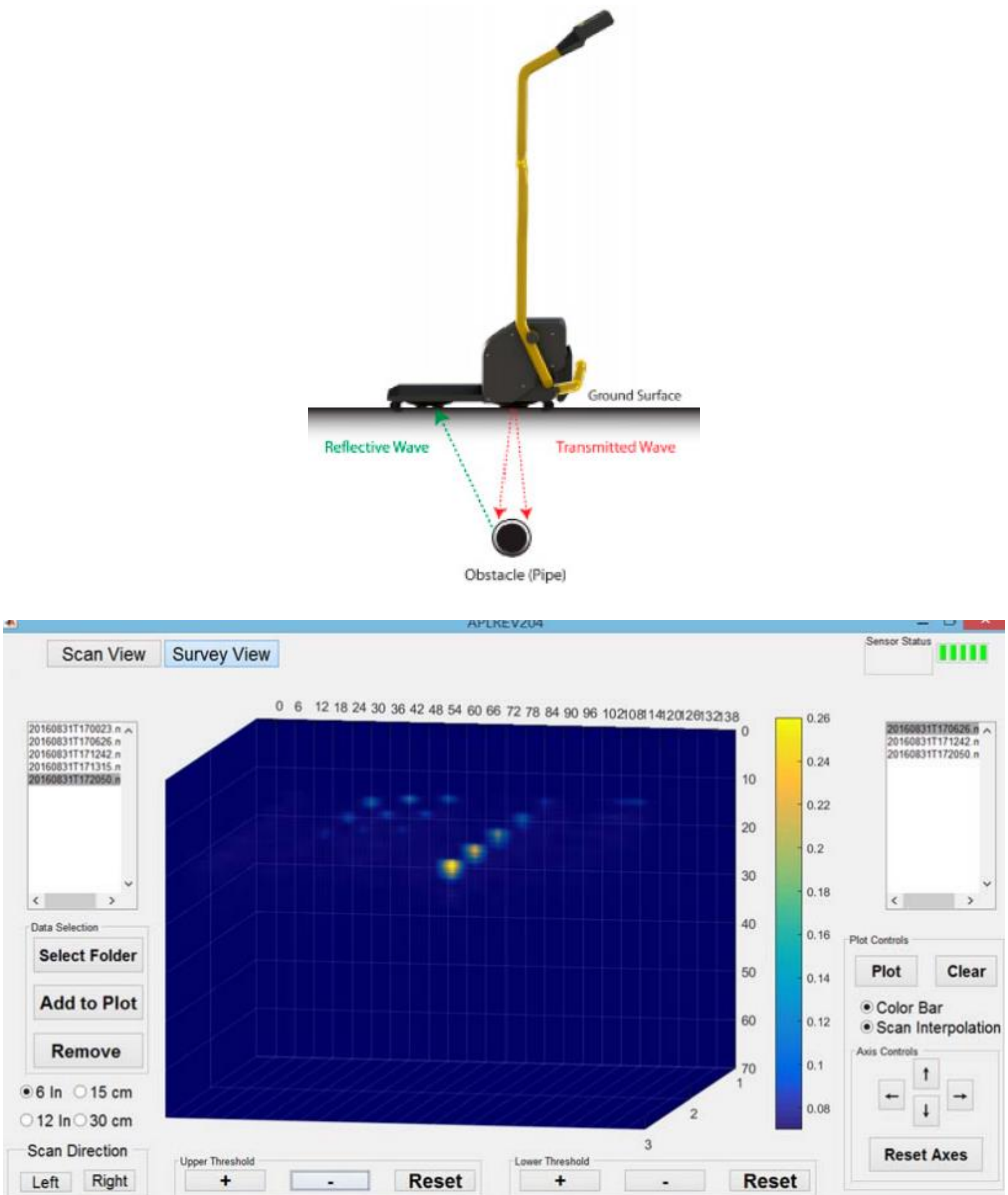


Figure 21: Point vibration measurements device, ULTRATRAC® Acoustic Pipe Locator [29,30]

Acoustic technology has been investigated in several case studies. Muggleton 2014 explored low frequency vibro-acoustics typically used in military applications [31]. They explored point accelerance measurements to find shallow pipes with success. This study also found advantages in the quick measurements and simple data that is easy to interpret. Kleppe 2016 performed a case study using the ULTRATRAC Acoustic Pipe Locator [32]. This study used this device to successfully locate a natural gas line that was repeatedly falsely located in the past using traditional methods.

Table 2 shows a comparison of each technology described in this report.

Table 2: Advantages and disadvantages of underground utility detection technologies

Device	Advantages	Disadvantages
Tracer Wire	• Accurate	• Wires are often damaged or missing
Magnetic Locators	• Simple, handheld • Sensitive to small objects	• Metal pipes only • Only detects pipes to 15 ft • Affected by noise from other metal
Electromagnetic Induction	• High or low frequencies used • Can locate deeper utilities	• Metal pipes only • Interference from soil or surroundings
Ground Penetrating Radar	• Pipe can be any material • Scans a large area quickly • 3D image results	• Can be affected by environmental noise • Complex results
Acoustic Methods	• Pipe can be any material • Less affected by difficult soil • Good in congested areas	• Only detects pipes to 8 ft • Does not detect depth

2.4 Current Methods Used by One Call Services

There are many services available to locate underground utilities that utilize all kinds of locating methods including available maps, visual inspection, vacuum excavation, and all the tools discussed in this paper. They range significantly in the level of certifications, quality, and technology used. Engineers can be hired to find utilities with the highest level of accuracy but there is a basic requirement by law that must be performed regardless of the project.

One Call services (811) are required to be called before any sort of excavation. This service will employ separate contractors to detect and mark the different utilities known to be on site depending on the utility owner. Often these will be performed using visual ques, tracer wire, and/or magnetic/electromagnetic pipe locator. There is significant variation in accuracy and quality of inspection because there is no standardized training between the contractors sent to detect these pipes. They also rarely use GPR or other mapping devices to scan an entire site, as they are more focused on finding the specific utilities they have been hired to mark. This can lead to mislabeling or lack of detection altogether depending on the competency of the technician on site.

3. Experimental Comparison of Potential Technologies

The main objective of this section was to provide an experimental review of the identified technologies that can be used in underground utility detection by designing and executing a field experiment to compare the devices.

3.1 Literature Review

To evaluate the ability of an underground utilities detection device to locate a range of buried pipes and cables, there are two common methodologies: using a utility already in service or burying a new pipe specifically for the project.

Gabrys and Ortyl (2020) explored the accuracy of geopositioning when using underground utility detection devices, specifically the GPR device Stream C from IDS GeoRadar [16]. As their study focused on geopositioning, they first performed a simple preliminary test using metal tape on a pavement surface. They then moved to an urban environment with known underground utility to test the effects of urban development on location detection. Koganti et al. (2020) tested the ability of GPR and EM to locate drainage grids below farming fields [19]. They used several plots of land with different soil properties, water dynamics, and utility specifications. The measured pipe locations were overlaid on the known utility maps. Several other studies have used in service utilities to test the abilities of detection devices and also relied solely on accurate utility mapping to compare results [13,18,21].

Several studies have chosen sites based on utility maps, however, they also used vacuum excavation to confirm the location and depth of the utility [24,27,32]. These studies occurred before general maintenance to the chosen pipe therefore accurate locations could be established later and compared to the nondestructive results.

The alternative methodology to determine the accuracy of underground utility detection is to bury a set of pipes and cables in a controlled environment. Muggleton et al. (2014) tested vibro-acoustics on shallow pipe detection using buried plastic pipes [20] They used two three meter lengths of high density polyethylene (HDPE) pipe joined at a right angle (Figure 22). They kept the pipes empty so there would be a greater difference in stiffness between the pipe and the soil. The system was buried 30 cm deep on a thin layer of sand, covered with the original soil, and left for a year to consolidate before testing.

Figure 22: Buried system used in Muggleton (2014) [20]

Karle et al. (2022) focused more on the effect of geotechnical properties on scan accuracy [17]. Difference surfaces and subsurfaces were imported and arrange in a grid as shown in Figure 23. They also included water troughs to change and test the effect of differing saturation levels. Forty types of pipes and cables of all different materials, diameters, depths, and inclines were buried to be located using GPR, specifically the Stream C from IDS GeoRadar.

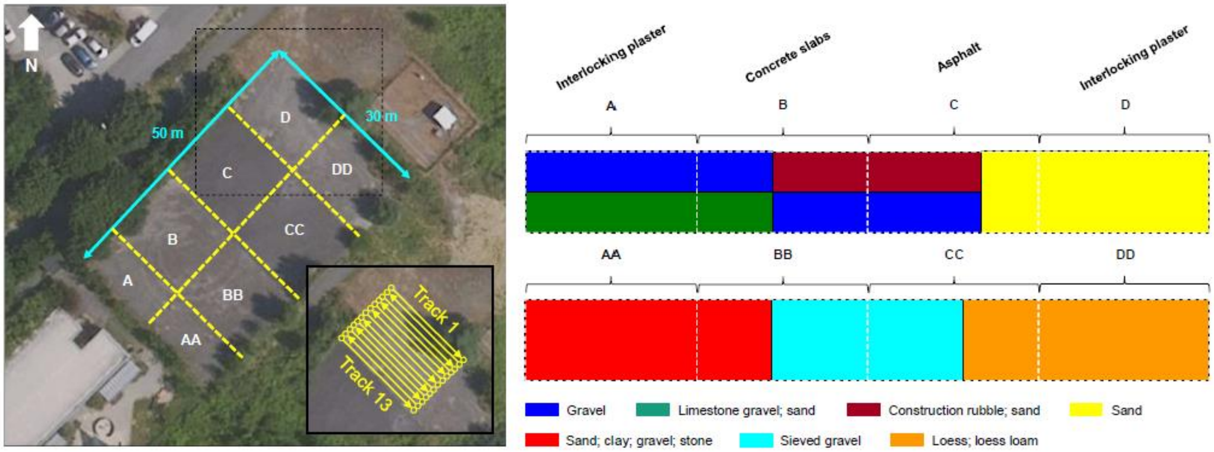


Figure 23: Karle et al. (2022) test site with different surface and subsurface materials [17]

Royal et al. (2011) explored how ground properties affect multi-sensor array GPR and vibro-acoustics. The buried targets consisted of a water filled plastic pipe they installed and an electrical cable already present on the site (Figure 24). They also tested the ability of vibro-acoustics to detect water leaks using access points on the water pipe.

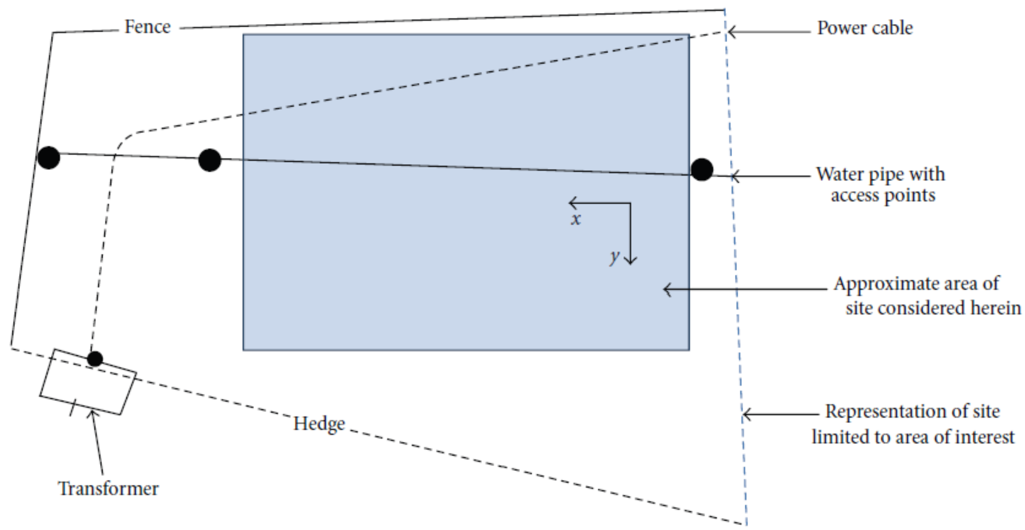


Figure 24: Royal et al. (2011) testing site [11]

Hartshorn et al. (2022) was testing an improved electromagnetic induction device which used linear current sensing and was held several feet off the ground either through a handheld device or drone [14]. They used a mixture of sites with in-service utilities and newly installed test pipes and wires.

Building and burying a test pipe and wire system requires time and planning for construction, however, once installed the exact position and type of utilities are known for improved location comparison. The soil properties of the site can also be more controlled through site location.

3.2 Methodology

3.2.1 Controlled Testing Site

The testing site consists of a 25 x 23-foot area located in a dump site used by Casper Colosimo & Son, Inc (CCSI) located in McKee’s Rocks, Pennsylvania. The soil contains a mixture of different soils and recovered road materials from the southwestern Pennsylvanian region. Several utility pipe materials and sizes were buried at different depths depending on the standard use of the pipe. The site was constructed on November 10, 2022.

Pipe Materials

There are two types of plastic piping used in underground utilities: polyethylene (HDPE) and polyvinyl chloride (PVC). HDPE pipes are often used in higher risk or sensitive utilities like industrial, geothermal, natural gas, or landfill uses, as it is a stronger, yet flexible pipe with a long life span. PVC is more common for municipal applications as it makes up 66% of water lines and 75% of sewer lines [33]. It is also common in the electrical and telecommunications industries as a cover. Corrugated plastic piping is used for drainage and is often shallower than other utility pipes. Another more traditional material in water and sewage lines is ductile iron.

Pipe Dimensions

All pipes are different lengths depending on the standard manufacturer length. Pipe diameters also differ depending on use. Table 3 and Figure 25 shows the diameters of each pipe.

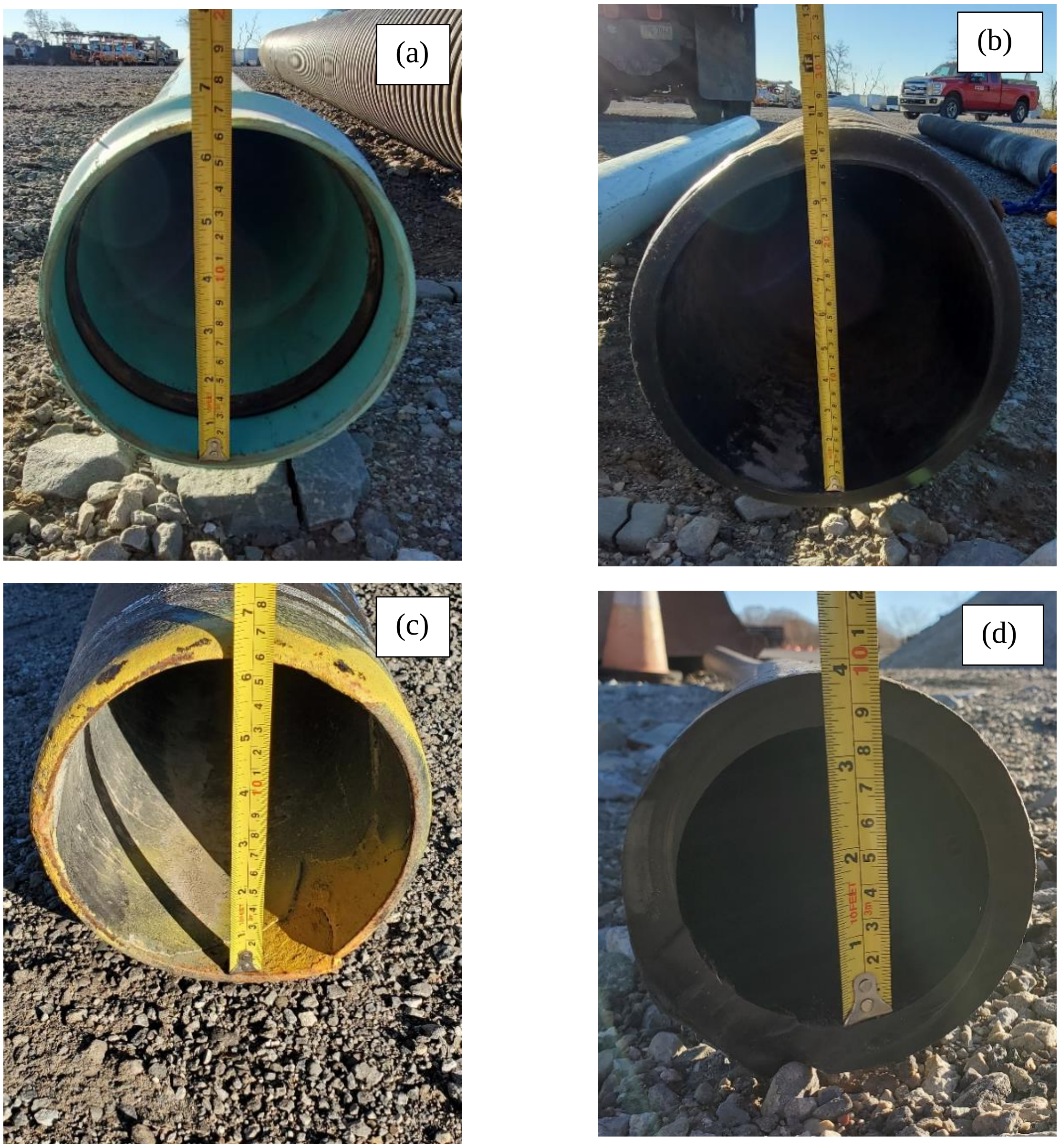


Figure 25: Pipe dimensions for (a) PVC, (b) Corrugated, (c) Ductile Iron, and (d) HDPE

<u>Pipe Depths</u>

Test pipes were buried at different depths depending on the typical use of the pipe. Exact depths are detailed in Table 3. Prior to burial, the pipe ends were capped with plastic sheeting to prevent soil from entering. Pipes were buried using a backhoe shown in Figure 26. Each pipe aligns a few feet off the fence and extends into the site depending on the pipe length. Depths were measured from the base of the pipe. After burial, pipe location was marked using labeled stakes.

The general layout of the pipe is shown in Figure 27.

Figure 26: Pipe burial

Table 3: Pipe parameters

Pipe Label	Material	Diameter (inch)	Length (feet)	Depth (feet)
Pipe 1	PVC	6.5	12	6
Pipe 2	Corrugated	10	15	3.5
Pipe 3	Ductile Iron	6.5	20	6.5
Pipe 4	Plastic Speed Duct	1	17	3
Pipe 5	HDPE	4	12	4.5

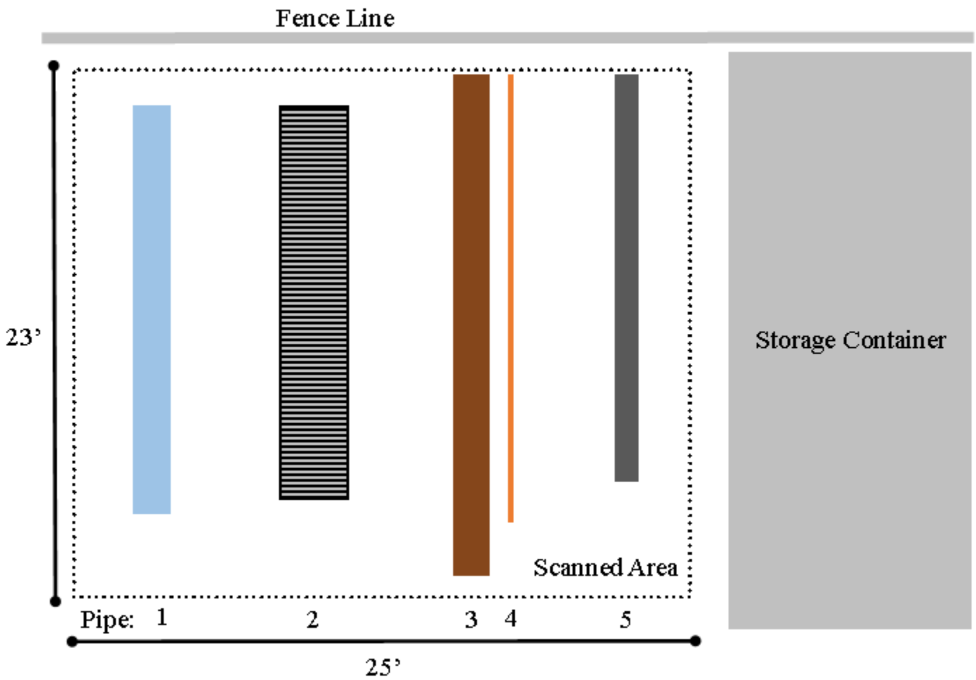


Figure 27: Pipe layout

3.2.2 Urban Site

The urban site was an active construction zone near Homestead, Pennsylvania. Utilities at this project were vacuum excavated therefore locations of utilities were known to a depth of 5 feet. The pavement surface consisted of asphalt or concrete with steel mesh depending on location. GPR technology has difficulty seeing below steel reinforcement due to the strong reflection from the metal. Waterlines to be scanned were in trenches with 2A backfill that was unpaved at the time of testing until mid-January when it was paved with asphalt.

Specific utilities in the area that could be located:

- Ductile iron pipe 4 feet deep
- Unmapped 1 inch copper electrical conduit about 6 feet deep
- Two ductile iron pipes running parallel 2 feet away from each other, one 16 inch diameter and the other 6 inch diameter, buried about 4 feet deep, and contains a right angle bend
- The continuation of the 16 inch pipe with an unmapped gas main running parallel
- Additional sewer and gas lines running under the concrete portions

The electrical conduit will be very difficult to spot for GPR devices as the general rule is 1 inch diameter can be found up to 1 foot deep, 2 inch diameter to 2 feet deep, and so on. However, it is active so there is potential.

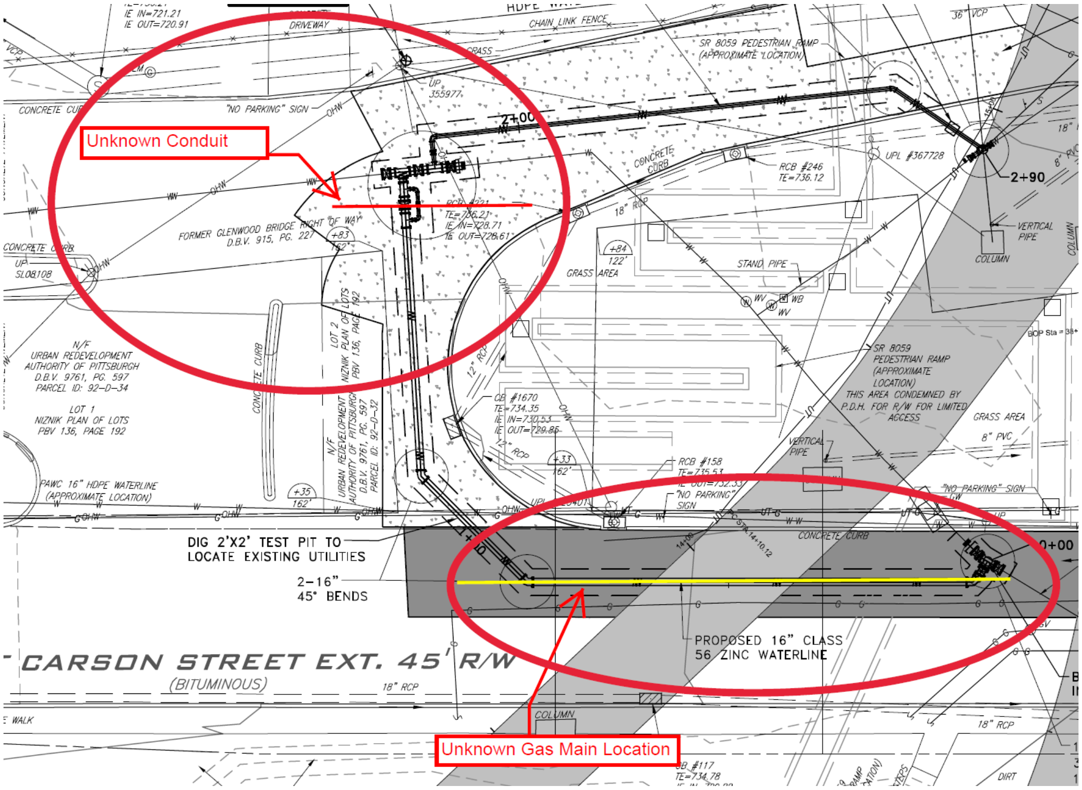


Figure 28: Urban site plan

3.2.3 Driving Site

There are some devices that can be used at driving speed and attached to a vehicle rather than a handcart. The controlled and urban testing sites are too small to test these devices therefore a third site was chosen south of Pittsburgh. This was a Golden Triangle Project where they installed sewage lines, so the exact locations of these utilities are accurately mapped. The driving site will consist of three roadways as shown in Figure 29.

Figure 29: Driving site plans

3.2.4 Collected Data

Vendors for each device were scheduled for demonstrations. They visited the appropriate testing site and instructed the team on how to use the device to assess useability. Estimated location and depth of any utilities were recorded. The results display, including ease of interpretation, speed of results, and accessibility to raw and processed data were noted.

In summary, data collected for each device will include:

- Usability of device
- Location and depth of all utilities
- Results display
- Immediate and processed data

3.3 Results

Demonstrations were held between November 2022 and February 2023. Vendors that were able to provide in-person demonstrations include Screening Eagle, GSSI, Kontur, IDS GeoRadar and ImpulseRadar. Results are discussed in the order the experiments were performed.

Across all tests, there were general limitations to GPR devices regularly met in this experiment. Scans over concrete mesh is difficult since the wire will reflect the signal first, limiting data from below. Ground-couple GPR, which is preferrable for locating utilities, relies on good ground contact for data quality. In excessively rocky terrain, data may be more difficult to interpret. Also, small cables cannot be identified at deep levels. The general rule is 1 inch cables can be found up to a depth of 1 foot, 2 inch cable at 2 feet, etc.

3.3.1 Screening Eagle

Screening Eagle demonstrated a device, the GS8000 (Figure 30), on November 17th, 2022. This is a step-frequency continuous waveform GPR system specifically designed for utility detection. Leading up to the day of testing, it was consistently well below freezing temperatures with snow. There was still a thin layer of snow on the control site at the time of testing. This is not an ideal condition for GPR technology in general and must be taken into consideration.

Figure 30: GS8000 in use at the controlled site

This device specifically focuses on usability as it fully runs on an iPad adding to the versatility and user friendliness. The visualization software is an app called Proceq GPR Subsurface. This software analyzes the scans and GPS data to provide a real time 2D or 3D map which the user can use to clearly mark and label different utility lines detected. The app is free, but an account requires a subscription. Data filtering and collection can be automated or manual depending on user experience. Calibration is done on site using hyperbola matching. All hyperbolas are manually identified and tagged on a B-scan on the screen. Under difficult conditions, it will still require experience to accurately identify pipes, but the app is designed to be simple and practical for beginners to learn.

There are different measurement configurations: line, grid, and free path. Free path was demonstrated for the team as it worked best for the sites. The app works with spatial data to stitch B-scans together to show the path taken during the scan and to align the marked tags to visualize the entire pipe length. Figure 31 shows how the app displays the data. The left side of the screen is the B-scan of the area where the user can tag the hyperbolic curves that indicate something below. The tags align with the satellite image of the scanned area. The green tag on the B-scan is reflected with a green tag on the satellite image. Figure 32 shows the B-scan again with the hyperbolas clearly identifiable and a green line approximately the depth at 4 feet. The majority of data analysis is done on site, but data can be revisited if necessary to improve filtering settings.

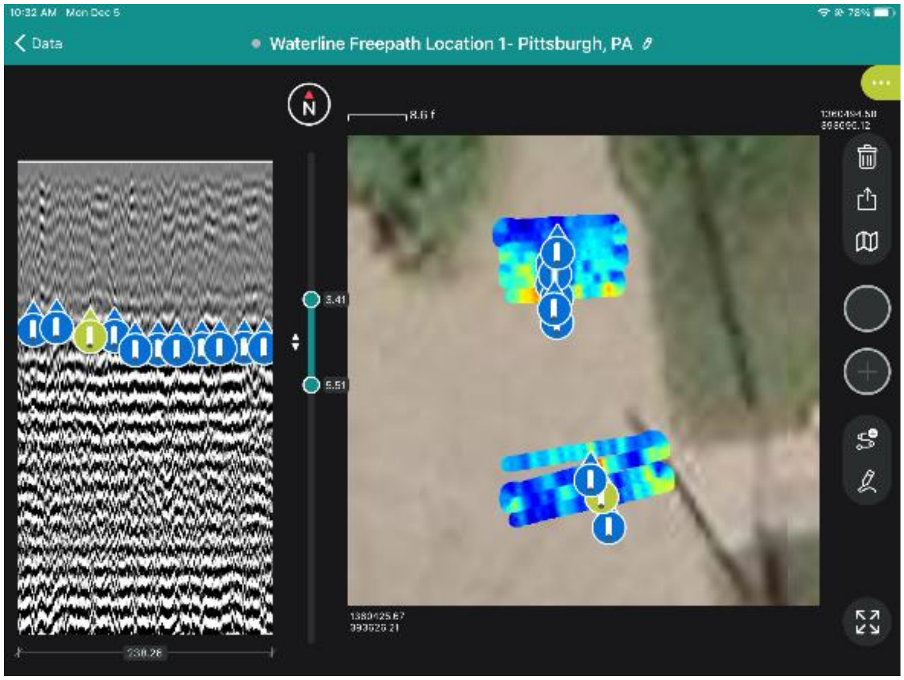


Figure 31: Proceq GPR app screenshot shows a found utility pipe

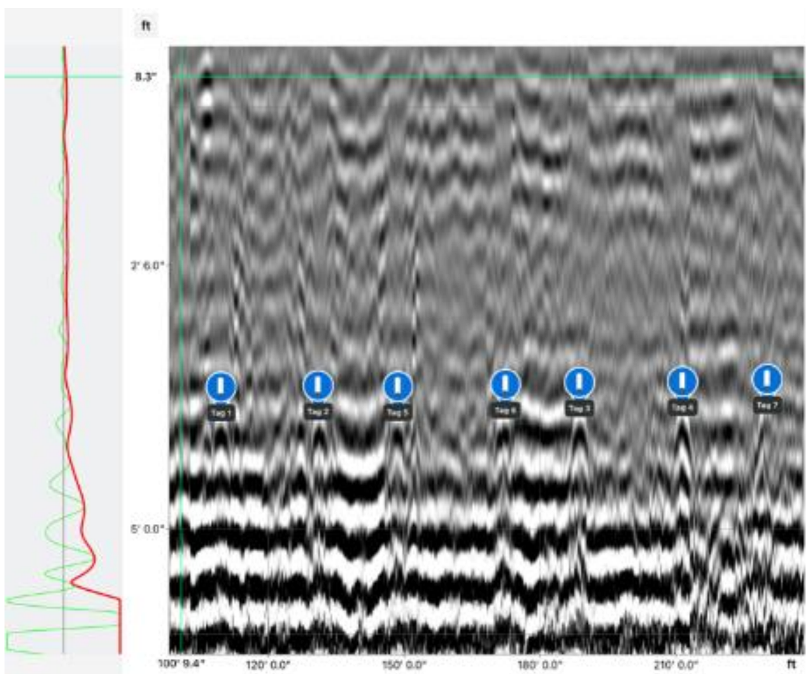


Figure 32: A-scan and B-scan with tags marking hyperbolas

All data backs up automatically to the cloud and is available immediately online through their workspace webpage (Figure 33). A report is automatically created that provides all the scan details including hardware information, filtering and data collection settings, pictures or screenshots taken, tags marked, measurement mode, and a summary of objects found (Appendix C).

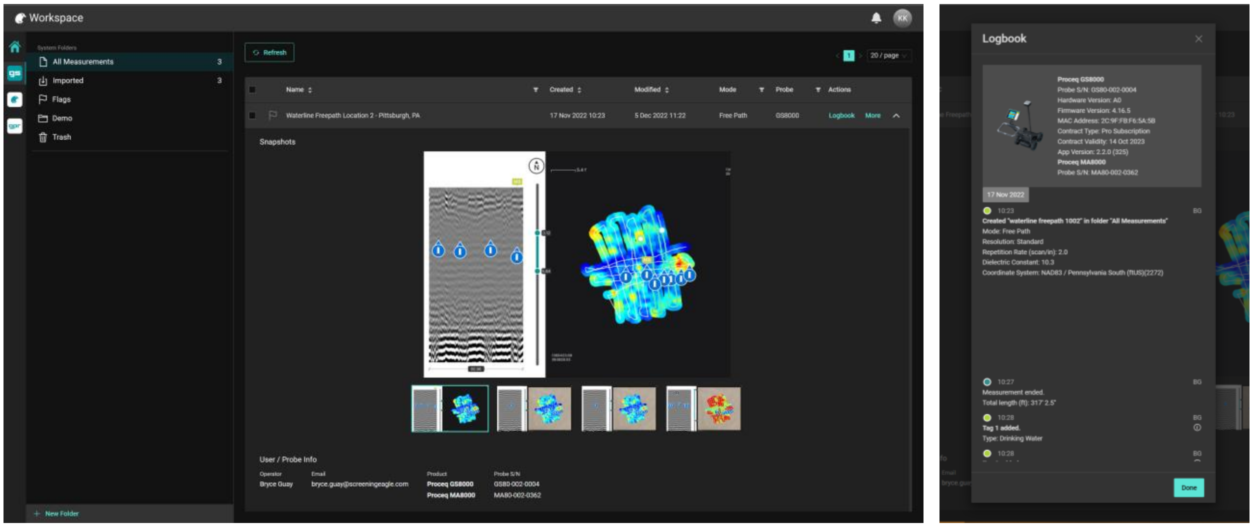


Figure 33: Screening Eagle Workspace

The hardware for the GS8000 is portable and easy to set up. It is powered using rechargeable C batteries and has an operation time of about 5 hours. The GPS can be attached to the top for spatial data, although it is not necessary to run the device. With the attachable GPS, pipe locations can be accurate to 5 cm in typical conditions. The hardware can be used with urban or all-terrain wheels. The GS8000 hardware costs approximately $11,000 and there is a monthly subscription to their cloud and processing software. When purchased, there is a 1 day training seminar to learn how to use the software and practice field measurements. This company is Swedish based but has an American headquarters nearby in Aliquippa, Pennsylvania.

The following sections discuss how GS8000 performed in this area using the controlled and urban testing sites.

<u>*Controlled Site Analysis*</u>

The controlled site was constructed only a week before and the weather conditions were wet and frozen. The device had potential data points, but nothing that was particularly clear and most identified points were closer to the surface than the pipe depths (Figure 34). The satellite image in Figure 34 limits the tagged points to those found between 2 and 6.5 feet deep, about the depths of the buried pipes. It can be observed that hints of the pipes could be identified but nothing could be confirmed only using this data. The technician hypothesized the limited and uncertain data could be from the recently disturbed soil not being fully compacted, from poor environmental conditions, or this GPR was simply unable to measure in the soil type at this site.

Figure 34: Image of data gathered at the controlled site

<u>*Urban Site Analysis*</u>

The urban site was met with more success. The scanned area was 2A backfill therefore it was not as saturated as the controlled site. In the areas that were scanned, there was a 6 inch ductile iron pipe at 4 feet, 6 inch and 16 inch ductile pipe running parallel at 4 feet deep, and a small 1 inch electrical copper conduit at 6 feet deep. The GS8000 easily identified the 6 inch pipe when it was by itself and was very accurate on the depth measurement (Figure 35 and Figure 36). The second major area scanned on this day included the two pipes running parallel. The device measured the depth of the 16 inch pipe easily, however the 6 inch pipe was not clearly distinguishable. The 1 inch electrical conduit was not identified.

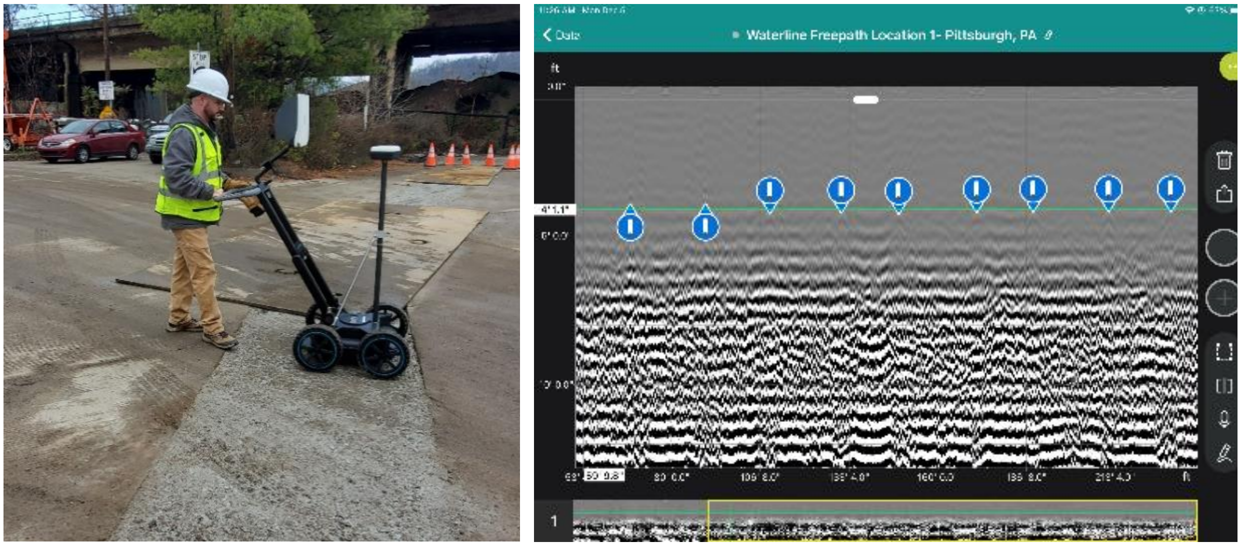


Figure 35: Screening Eagle at the urban site with the single 6 inch pipe at 4 foot depth

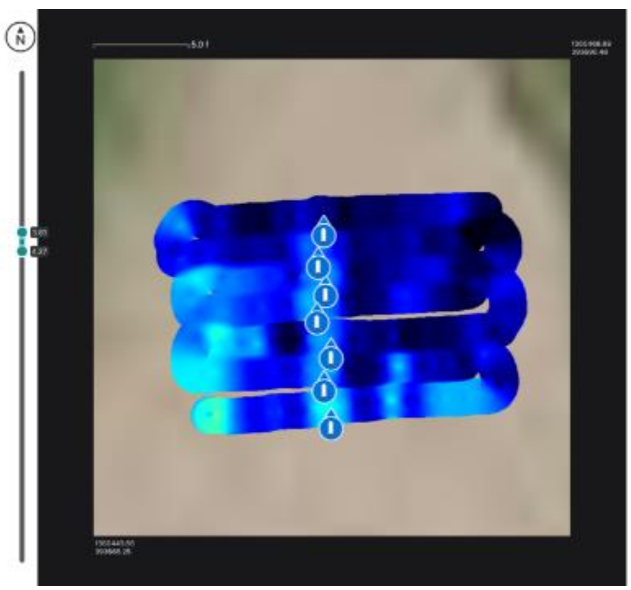


Figure 36: Data after filtering at a depth of 4 feet deep

Figure 37: On site demonstration

Below is a summarized list of key takeaways from the Screening Eagle demonstration:

- Step frequency device
- Automatic stitching for a view of an entire site.
- App and cloud provide easy and immediate data processing and sharing.
- Local headquarters for training seminars.

3.3.2 GSSI

GSSI demonstrated their utility detection devices on December 6th, 2022. Before and on the day of testing, there was heavy rain with 50°F temperatures. This is very poor conditions for GPR technology and must be taken into consideration in this analysis. GSSI brought their two common devices for utility locating: UtilityScan and SIR4000 (Figure 38). Generally, these devices can see up to 30 feet deep in ideal conditions but in poor conditions, depth is restricted to 2 feet.

UtilityScan is a fairly basic model that uses a single antenna and frequency. It uses a wirelessly connected tablet but is restricted in operating systems and tools. The battery life is about 8 hours but this is due to the tablet battery life not the device. UtilityScan costs about $16,500. SIR4000 is their second utility detection device which has more capabilities and options than the smaller UtiltiyScan. This device can be paired with different antenna and frequency options. SIR4000 uses a specific platform wired into the GPR device. This battery lasts 3-4 hours. Both devices provide

A and B scans on screen for manual interpretation and are compatible with an external GPS (Figure 39).

Neither device has path stitching capabilities that visualizes the entire pipe immediately. When a GPS is used, there is a playback option to review the B scans at tagged locations. When marking hyperbolas there are color options for marking different targets. Calibration for both devices is done through hyperbola matching. The devices have a quick set up and the original carts are better for finished surfaces but there is a separate cart for rougher terrain. Training is provided through YouTube tutorials.

GSSI also has postprocessing software available separate from the devices called RADAN. This software cleans and improves data for visualization, creates more complex and stitched utility maps, and generates AutoCAD outputs.

Figure 38: GSSI utility detection devices: UtilityScan (front) and SIR4000 (back)

Figure 39: Immediate output the user views while scanning

<u>*Controlled Site Analysis*</u>

The environment for this day of testing could not have been worse for GPR. It had been raining for days including the morning of testing. There was standing water at this site the soil was so saturated. No pipes were detected.

Figure 40: GSSI devices in use at the controlled site

Urban Site Analysis

The urban site provided better data since it was much drier. Both devices were used over each location and provided similar data in this case. They were able to identify several lengths of the 6 inch pipe over multiple right turns including when it ran parallel to the 16 inch pipe. It also found the 16 inch pipe and a potential, unmapped utility about 8 feet deep, below where the site had confirmed utility locations. It did not identify the electrical conduit.

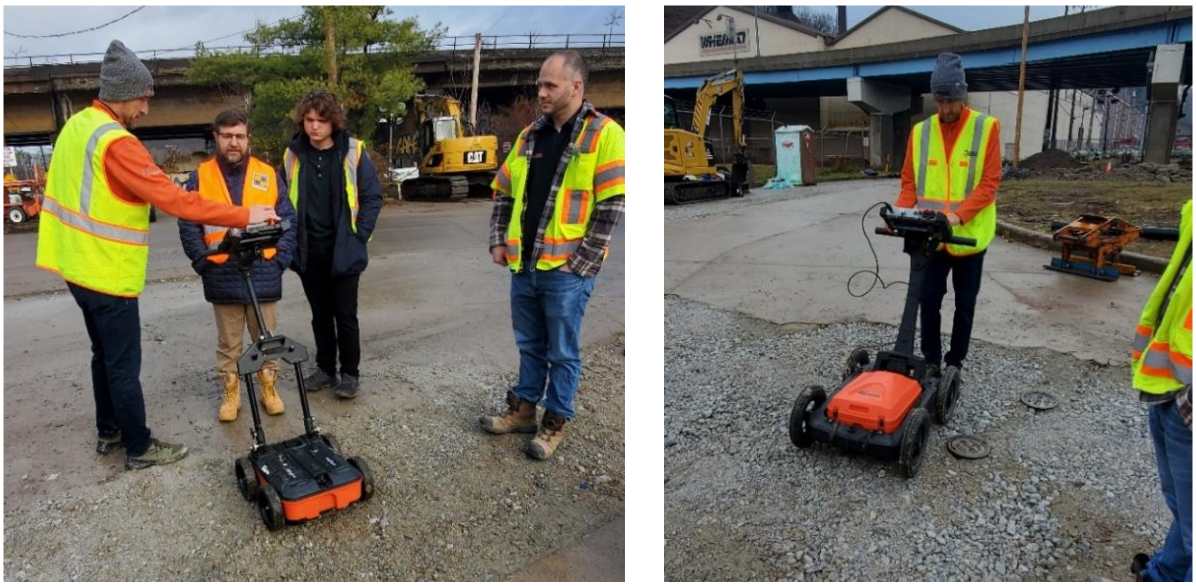


Figure 41: GSSI devices at the urban site

Figure 42: UtilityScan locating a visible pipe

Below is a list of key takeaways from the GSSI demonstration:

- Single frequency device
- Multiple levels of utility detection equipment and software
- Simple field use with the option for in depth postprocessing

3.3.3 Kontur

Kontur demonstrated their utility detection devices on December 16th, 2022. Before and on the day of testing, there was minimal rain with temperatures in the upper 30°F. Kontur brought their device that is towed behind a vehicle (Figure 43). This device is more involved than a smaller handcart and is intended for large area scans. The device is a linear array device that uses 20 channels and uses step frequencies between 40 MHz – 3 GHz. These are the major advantages of this device because it allows the pipe to be scanned in any direction and entire pavements or large areas to be scanned quickly. The cart takes under 15 minutes to assemble onsite and can be pulled behind any vehicle that has a hitch connection. This allows any terrain to be scanned including rough, unfinished areas.

Like any GPR device, saturation and soil content reduces visibility. The technician related the Pittsburgh area to Boston, which has similar weather conditions and high clay content. They were able to regularly achieve 6 feet of visibility. With poor soil conditions, data collection can be improved with a slower collection speed. There is a smaller, separate software specific for data collection that shows the suggested driving speed and very basic data (Figure 44).

This device requires a GPS in order to accurately map and visualize. A GPS can be attached to the device or is compatible with an external station. As with other GPR devices, depth accuracy depends on dielectric constant calibration which is done with hyperbola matching.

Figure 43: Kontur tow behind GPR linear array antenna

Figure 44: Software for data collection to be used in the vehicle

Examiner 3 is the postprocessing software required for utility location. The software allows for analysis at any point along the roadway at different depths. This allows for more than just the utilities to be analyzed as pavement quality control can be performed as well. Within utility detection, the benefit is the entire length of the pipe is easily identifiable from the map. An additional page can be opened for each scan that cuts a virtual trench to show the pipes' unstitched A and B scans. Examiner is comprehensive software that allows for extensive filtering and data visualization. This also results in a fairly complex program that is not ideal for simple or quick utility location. This is best for large scans, likely for design work or quality control. Results can be output as AutoCAD or Google Earth files.

The linear array antenna costs $200,000 plus an annual licensing fee for Examiner 3. There is device training and software support that continues past the initial purchase.

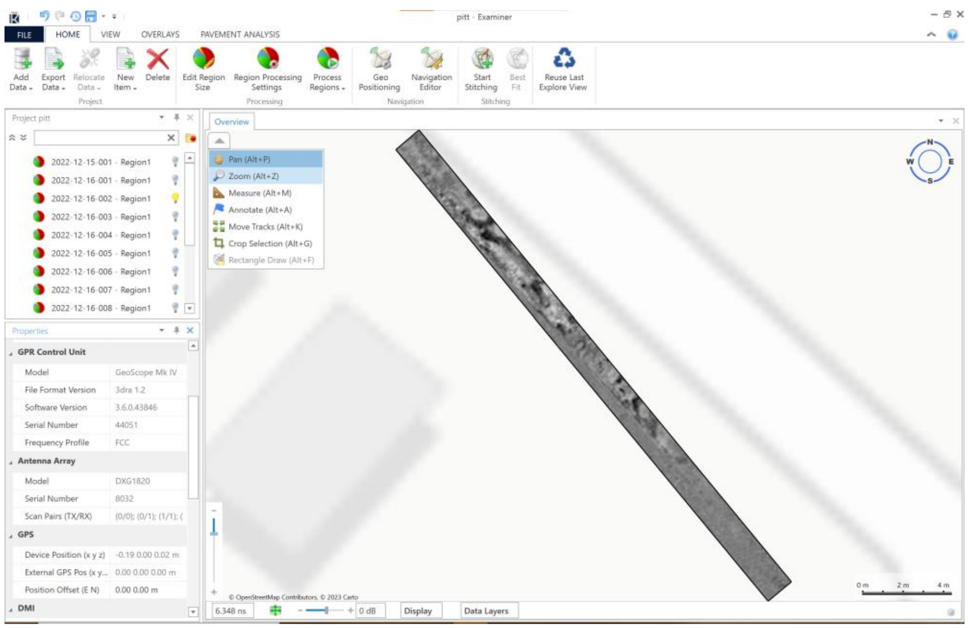


Figure 45: Examinar 3 software overhead map of scan

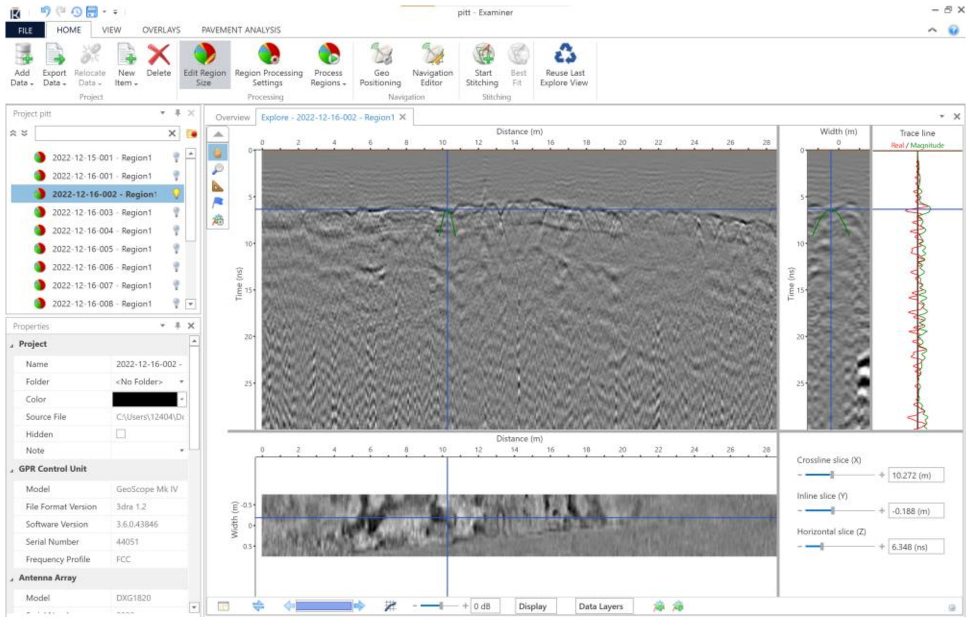


Figure 46: The above, A, and B scan shown in Examiner 3

<u>*Driving Site Analysis*</u>

Kontur primarily focuses on the tow behind device and does not have a less popular handcart option for demonstration, therefore, the only demonstration occurred on the driving site. The device had clear images of all known pipes and a few unknown features (Appendix D). Figure 47 shows the target water pipe at two different virtual trench cuts. The device was driven parallel, overtop of the pipe so the B-scan looks like a single long line. To scan all three roadways only took 20-30 minutes. This data can be merged with GPS data to form detailed maps of the site (Figure 48).

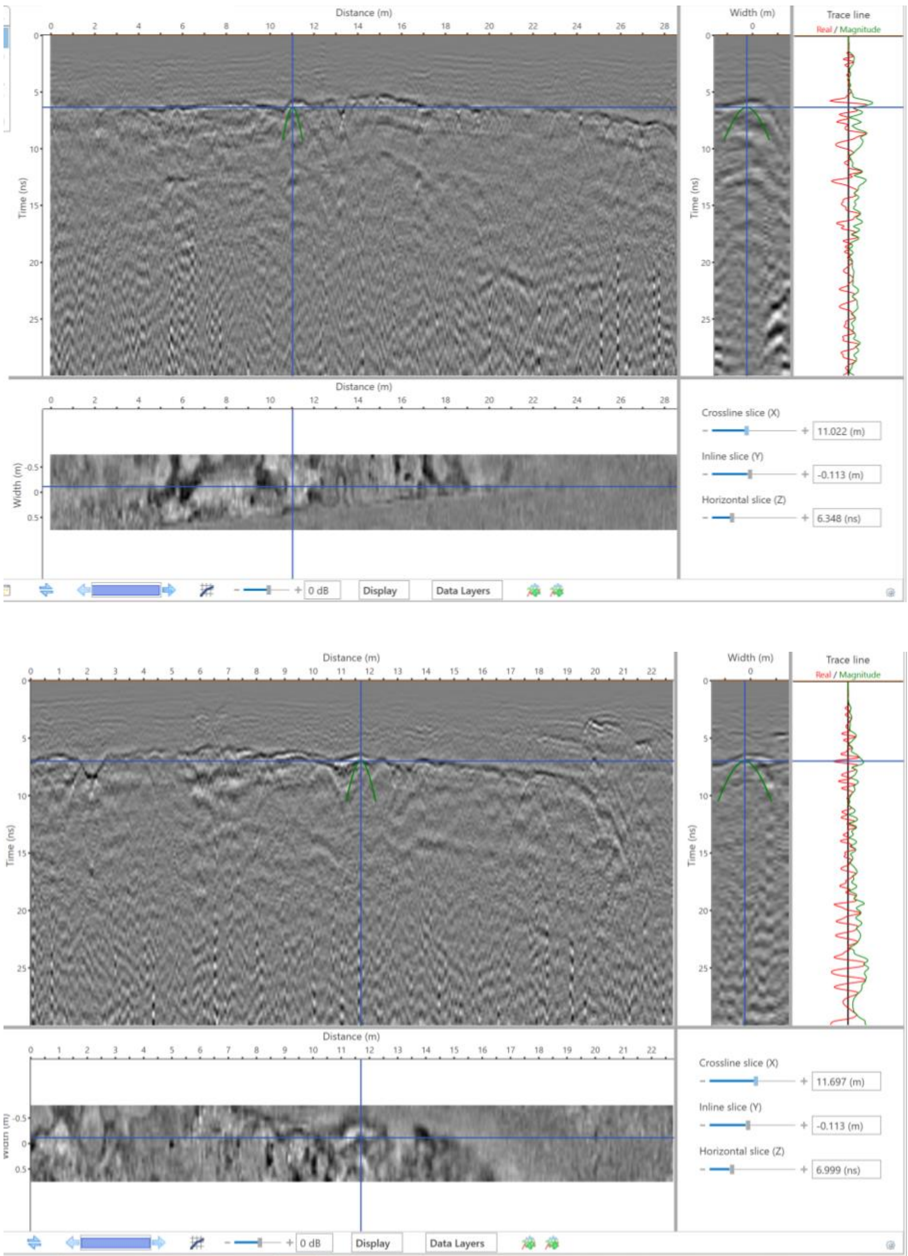


Figure 47: Virtual trench of driving site

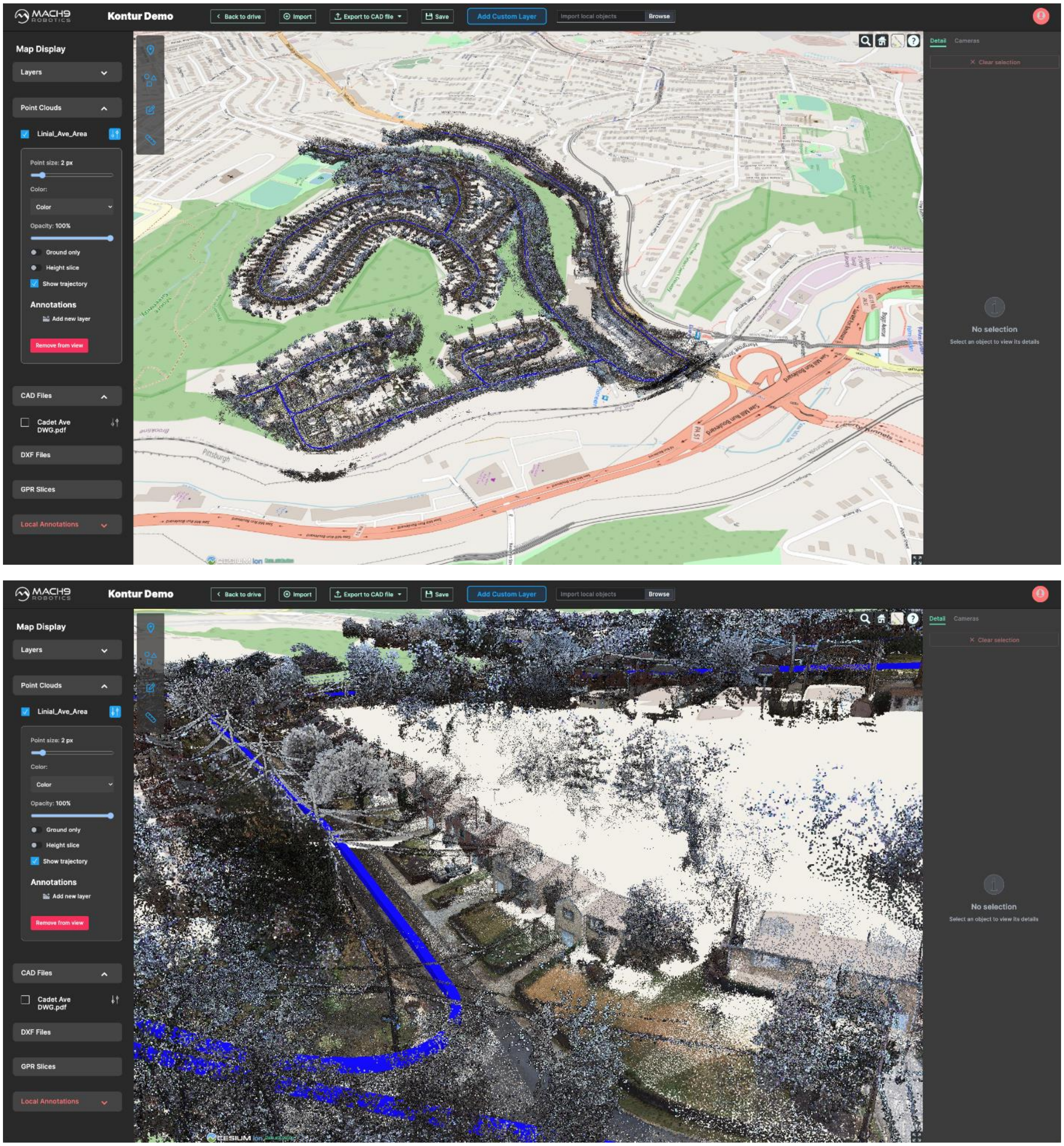


Figure 48: Kontur GPR data merged with GPS data

Below is a list of key takeaways from the Kontur demonstration:

- Step frequency and linear array antenna makes for accurate data for an entire pipe
- Can scan entire roadways quickly
- No immediate results and complex postprocessing
- Can be used for more than utility detection
- Better for design or mapping large areas

3.3.4 IDS GeoRadar

IDS GeoRadar demonstrated a device, the DS2000 (Figure 49), on January 18th, 2023. This is a dual frequency GPR system specifically designed for utility detection. Leading up to the day of testing, it was consistently around freezing temperatures with minimal rain.

IDS GeoRadar provides a line of GPR equipment that uses multi-channel multi-frequency technology. The device tested in this study was the DS2000 handcart but this company has several other larger devices, Stream C and Stream UP, that are recommended for full underground mapping and were not tested here. With these other devices comes more advanced postprocessing software with more data analysis and visualization features not considered. These devices are advanced, linear array versions of the DS2000 and are available for demonstration if desired.

DS2000 is a dual antenna handcart that runs on two frequencies: 250 and 700 MHz. This allows for accurate scans at two depth ranges. This device has the option to attach a spray can for marking or a GPS for image overlay and locating. The visualization platform for the DS2000 is called uNext which provides data immediately as B-scans (Figure 50) or can connect GPR and GPS data for accurate mapping. There is also an advanced version of this software available [26].

This device runs on Windows, saves all data, and provides a report at the end of collection. This device requires manual identification of the pipes on a B-scan. There are filtering aspects with the program to improve visualization. Both back wheels are connected to the positioning system which allows the cart to traverse rough terrain without losing accuracy. The technician did note that while the device works with GPS congruently, he recommended locating using the spray paint option and then surveying afterwards.

Figure 49: IDS GeoRadar DS2000 system

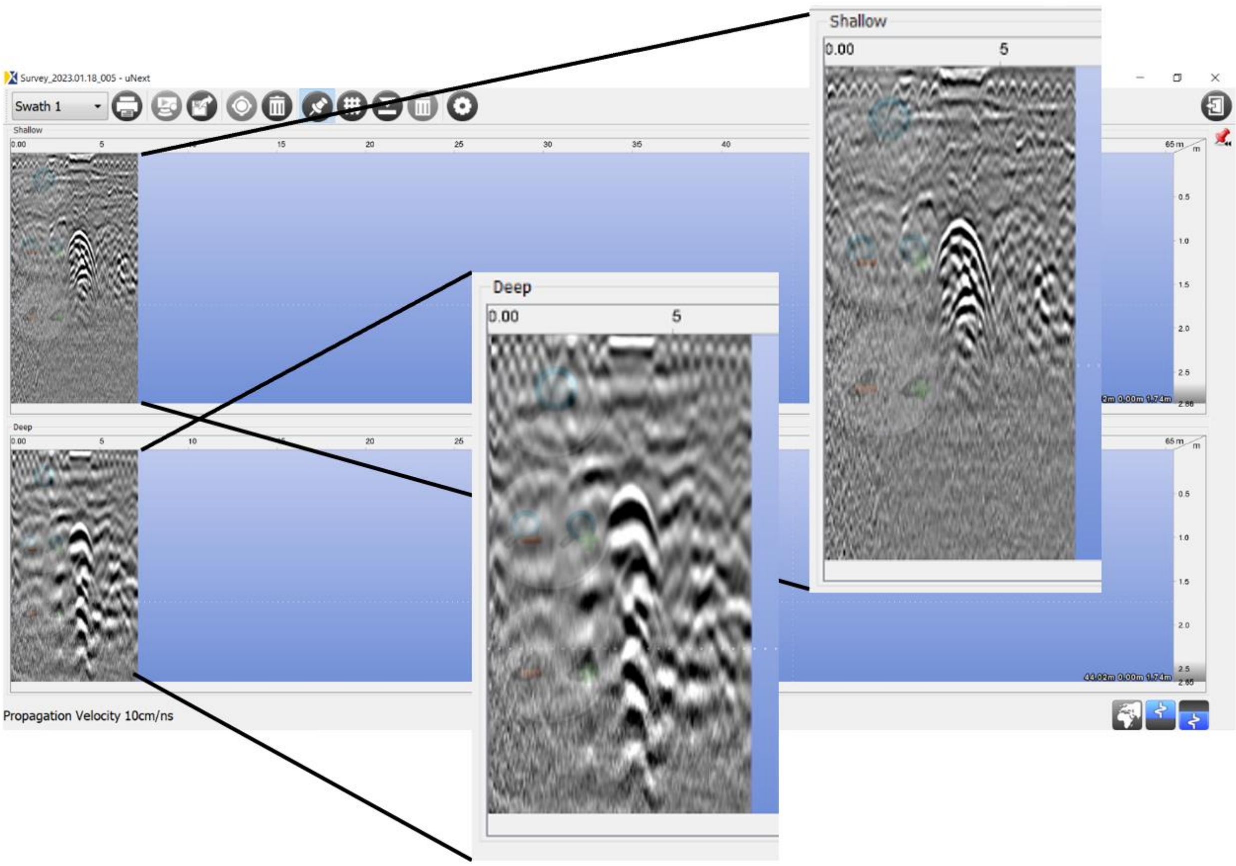


Figure 50: uNext with the dual frequency antennas

Controlled Site Analysis

The DS2000 system was able to identify many areas of excavation as well as the HDPE, corrugated plastic, and ductile iron pipes in certain locations. The image was not perfectly clear the entire length of the pipe, but they were identifiable from the B-scans. This system performed well considering these rough conditions.

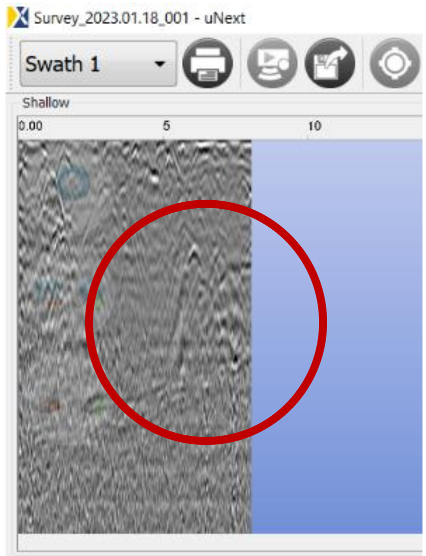


Figure 51: DS2000 on controlled site

Urban Site Analysis

In the areas that were scanned, there was a 6 inch ductile iron pipe at 4 feet and at a certain point it met up with a 16 inch ductile pipe running parallel at 4 feet deep. The DS2000 easily located these water pipes with accuracy. The technician moved farther along the pavement onto the concrete sections and located additional sewer and gas lines. These pipes were identified through the concrete mesh and the technician even located an area where they were mismarked on the pavement surface. Figure 52 shows the located pipes and the line of wire mesh within the concrete slab.

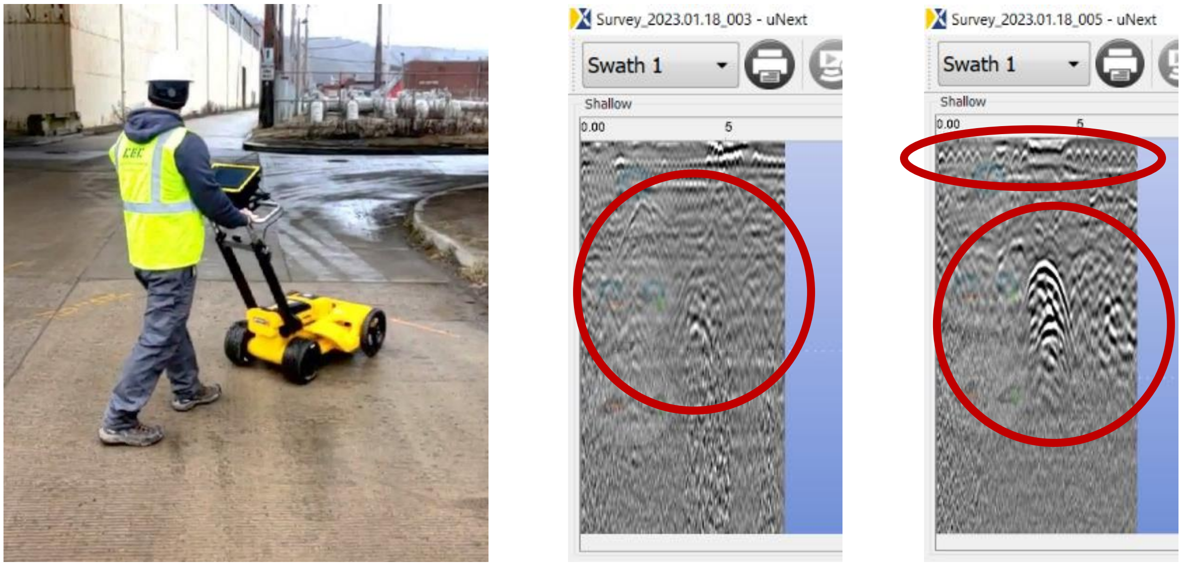


Figure 52: DS2000 at the urban site

Below is a list of key takeaways from the IDS GeoRadar demonstration:

- Dual frequency device
- Functional on rough terrain.
- Device is simple for utility detection but also available in larger, more accurate versions.

3.3.5 ImpulseRadar

ImpulseRadar is a utility detection vendor identified after the publication of Task B. They specialize in GPR equipment and have a line of devices ranging from dual antenna hand carts to linear array multi-antenna tow behind trailers. The multi-channel devices, called Raptors, are primarily advertise their fast data collection as collecting speeds can be up to 80 mph. These devices are more for full underground mapping and pavement quality control.

The device for utility detection is called PinPointR (Figure 53). This is a dual antenna hand cart that uses frequencies 400 and 800 MHz. This hand cart is light, compact, and collapsible making it easily transportable with hardly any set up time (Figure 53). The software connects wirelessly to the GPR and is available on android devices. The purchaser can either use their own tablet or one can be purchased through ImpulseRadar that is already set up and connected. The software app is called ViewPoint and allows utilities to be identified in individual scans, line scans, or multi-line stitched maps when used with GPS.

Figure 53: ImpulseRadar detection device PinPointR and ViewPoint App [34]

PinPointR can use the internal tablet GPS for 10 foot accuracy or for higher accuracy has a point for external GPS attachment. The device has a 7 hour battery life and is easier to use on rough terrain because it is so lightweight. This device has a local distributor, MJ Friedl & Associates, that has experience with this GPR device in the Pittsburgh area and in general, they have found utilities with accuracy up to a depth of 6 feet. They are, like any other GPR technology, restricted in areas with high slag or clay contents.

PinPointR is available for purchase for about $16,000, depending on the addition of a tablet, and it comes with full training for proper use. They advertise the cheapest multi-frequency GPR device which allows the technology to scan different depths with the best frequency. The device is very simplified so it is user friendly but located targets cannot be specifically labeled and reporting is limited to screenshots of the app. The technician recommended scanning and marking identified pipes on the surface and performing GPS locating afterwards for more in-depth and efficient reporting.

This device was demonstrated on January 24, 2023 when conditions were dry and overcast in with temperature in the low 30s °F.

Figure 54: PinPointR device demonstration

<u>*Urban Site Analysis*</u>

In the areas that were scanned, there was a 6 inch ductile iron pipe at 4 feet and at a certain point it met up with a 16 inch ductile pipe running parallel at 4 feet deep. The PinPointR easily located these water pipes with accuracy even when they were directly next to each other. This device was easy to use and those in attendance were able to use the device easily. Figure 55 shows the technician explaining data gathered by an attendee.

Figure 55: PinPointR device used on the urban site

Below is a list of key takeaways from the ImpulseRadar demonstration:

- Dual frequency device
- Lightweight and compact
- Had been used in this area before and has a local distributor and training services

3.3.6 RodRadar

RodRadar is a new startup specifically focusing on locating underground utilities while trenches are being dug. They are an Israel-based company aiming to modernize excavation by offering a digging bucket with imbedded GPR antenna. The Live Dig Radar (LDR) technology consists of two parts: LDR Excavate which is the imbedded GPR in the digging bucket and LDR Visualize which is the display unit in the excavator cabin that provides automated alerts when an object is near the bucket [35]. Each pass with the bucket provides a new scan so objects in the vicinity of the bucket are identified. RodRadar advertises their bucket is compatible on any platform for easy installation.

RodRadar recently debuted in the U.S.. A contracting company, Haskell, who has invested in RodRadar, received their first bucket in December 2022. They have been pleased with the product but currently, the product is still in alpha production and has not been widely released yet [36]. There is limited data available on device specifications or case studies performed.

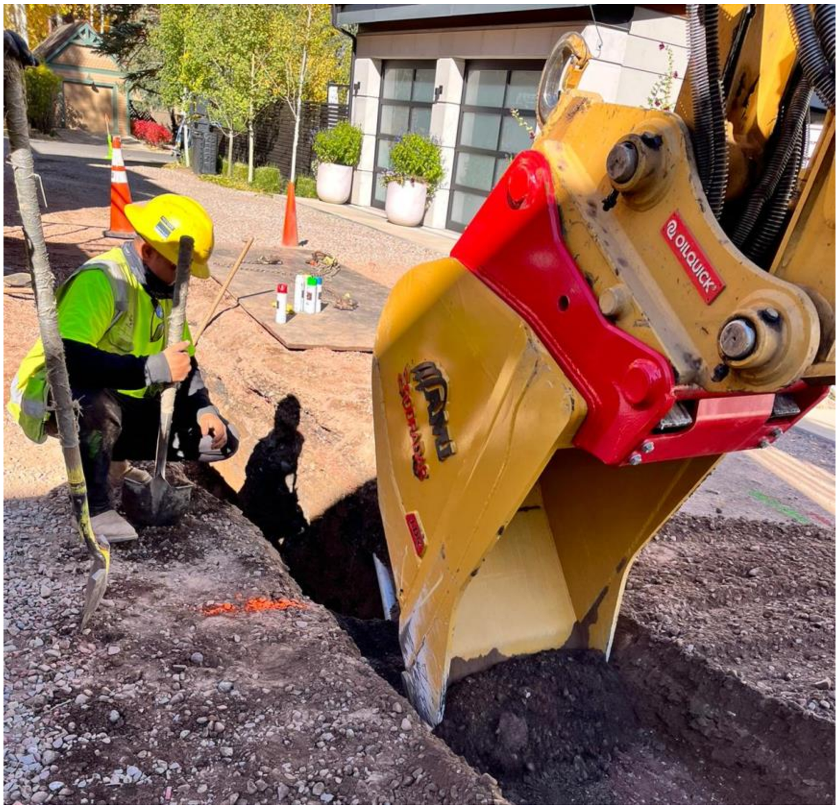


Figure 56: RodRadar digging bucket with GPR

Table 4 summarizes the key takeaways provided at the end of each section.

Table 4: Summary of key takeaways

Company	Takeaways
Screening Eagle	• Step frequency device • Automatic stitching for a view of an entire site. • App and cloud provide easy and immediate data processing and sharing. • Local headquarters for training seminars.
GSSI	• Single frequency device • Multiple levels of utility detection equipment and software • Simple field use with the option for in-depth postprocessing
Kontur	• Step frequency and linear array antenna makes for accurate data for an entire pipe • Can scan entire roadways quickly • No immediate results and complex postprocessing • Can be used for more than utility detection

	• Better for design or mapping large areas
IDS GeoRadar	• Dual frequency device • Functional on rough terrain. • Device is simple for utility detection but also available in larger, more accurate versions.
ImpulseRadar	• Dual frequency device • Lightweight and compact • Local distributor and training services

4. Recommendation of Detection Technologies

Ground-penetrating radar (GPR) is a rapidly advancing technology that has made major strides in recent years to improve underground utility detection. The advances have diversified the field and allowed GPR devices to be used in multiple stages of construction. Three different stages during a construction project were considered for device recommendations, since the objective for underground utility detection at each stage is quite different. The first to be considered is the design stage. This stage is more relevant to the site or road owners who may be more invested in mapping underground utilities for design considerations on future projects. The second stage is preconstruction, where the on-site contractor is planning necessary excavation and determining where utilities may interfere. The final stage is excavation, when the focus is on worker safety. These types of devices would alert operators of potential utilities directly below where they are currently digging.

The following sections detail recommendations for each stage, but recall that the advancements of GPR do not lessen the effectiveness of other underground utility detection methods. Electromagnetic methods or tracer wires are still preferable for cables, as GPR is limited by size and depth of the cable. Mixing non-destructive testing when available is advised to get a comprehensive map of underground utilities.

4.1 Design Stage

The design stage is primarily for site or road owners who may want to map the existing utilities to plan construction projects or simply to know what exists in their lot as a future resource. Cities including Las Vegas, London, Singapore, Hong Kong, Zürich, and Rotterdam are beginning to digitally map all underground utilities as a resource for city planning [12,13]. To realistically map large areas, the size and speed of a scan is important to consider. Of the vendors and devices tested in this project, Kontur's linear array antenna is highly recommended for this stage.

This device is a large tow-behind linear array consisting of numerous channels of antenna. The antennas use step-frequencies that vary between 40 MHz – 3 GHz. This set-up allows utilities at a large range of depths to be scanned in any direction. Data can be collected at low driving speeds therefore there is a minimum disruption to traffic if used on a roadway. A GPS is required for accurate use and can be attached directly to the device.

The limitation of this device is the immediate data after scanning is restricted. This is not the best fit for small areas or during construction but perfect for the design stage because immediate data is not necessary. More complex and full data is preferred to produce detailed underground mapping. Kontur has a postprocessing software called Examiner 3 that provides in-depth analysis of GPR data. It accurately reports entire pipe lengths while also creating virtual trenches for more detailed section analysis if desired. Further data filtering and visualization is also possible to enhance the mapping. An additional benefit of this device is pavement quality control can also be determined using the same data collected during utility locating.

The linear array antenna costs about $200,000 plus an annual licensing fee for Examiner 3. There are companies that can be employed to performs scans with this device as an alternative to ownership. If the device is purchased, there is device training and software support that continues past the initial purchase.

Kontur's linear array is recommended for site or road owners to create detailed maps of underground utilities. It is a more expensive option but the amount of information it can provide is extensive.

4.2 Preconstruction Stage

The preconstruction stage is primarily for contractors to perform a final check for utilities on their site. This can be done using many techniques described in previous tasks including tracer wire, magnetic locators, and electromagnetic induction (EM). Modern GPR is not a full replacement for these methods, and it is encouraged to continue using them in tandem. For example, EM is still better at locating cables because GPR technology in general has a rule of thumb that a 1 inch cable can be located to a depth of 1 foot, a 2 inch cable can be located until 2 feet, and so on. This is because GPR relies on size and material differences to locate objects while EM locates cable based on a current running through the utility. Despite the limits when locating cables, modern GPR is still much more thorough that traditional GPR and it is highly recommended to transition into the new devices.

Table 5 shows a brief comparison of the different GPR handcarts tested in this study comparing price, frequency type, and other benefits unique to that device. For the most part, basic GPR technology is at the same level regardless of the company. How the devices use antennas, frequency, and data visualization is what is important for data clarity and user friendliness.

Table 5: GPR handcart device summary

Company	Device Name	Price	Frequency Type	Advertised Unique Benefits
GSSI	UtilityScan	$16,500	Single Antenna	Basic device, but they have a second device, SIR4000 with a few more benefits
IDS GeoRadar	DS2000	$19,000	Dual Antenna (250 and 700 MHz)	Good on rough terrain
Impulse Radar	PinPointR	$16,000	Dual Antenna (400 and 800 MHz)	Lightweight, compact, easily transported
Screening Eagle	GS8000	$11,000 + software/cloud subscription	Step-Frequency	Easy to use software and data sharing

Any devices tested in this study will locate utilities and additional discussion on each can be found in the previous task report. However, based on observations, the Screening Eagle device, GS8000, is recommended for the preconstruction stage. Of the handcarts tested, this is the only device that is a step-frequency system. Recall step-frequency systems emit a series of sine waves with increasing frequency causing better signal-to-noise ratio, larger frequency bands, and more complete data collection over traditional impulse systems [8]. Both the IDS GeoRadar and Impulse Radar devices use dual antennas which allow for deep and shallow scans separately. This is less encompassing but still acceptable for locating utilities.

The Screening Eagle device also had the best on-site data analysis while maintaining user friendliness. The user could filter data automatically or manually, mark and label different utility lines, print clear reports of objects found, and automatically save data to a cloud that allows data to be viewed immediately by anyone in the account. The price of this handcart is $11,000 which is cheaper than the other handcarts however, there is additional costs for an account with their processing app and cloud usage.

Ultimately, any device tested in this study will locate underground utilities and the handcarts have similar abilities with mobility and transportation. Screening Eagle device is recommended for the preconstruction stage to locate utilities quickly on-site due to the advantages in frequency type and user friendliness.

4.3 Excavation Stage

The excavation stage has a greater focus on increasing operator safety by alerting operators of nearby underground objects. This is past any planning stage or attempt to map utilities but rather is a final warning so the excavator operator can avoid hitting a utility, causing damage or personal injury. Of the devices researched in this study, RodRadar is the only company focused on the advantages GPR can apply to this stage of construction.

RodRadar is a new company specifically focusing on locating underground utilities while trenches are being dug by offering a digging bucket with imbedded GPR antenna. The Live Dig Radar (LDR) technology consists of two parts: LDR Excavate (Figure 57) which is the imbedded GPR in the digging bucket and LDR Visualize (Figure 58) which is the display unit in the excavator cabin that provides automated alerts when an object is near the bucket [35]. Each pass with the bucket provides a new scan so objects in the vicinity of the bucket are identified. If the operator is alerted of an unknown object, they can immediately stop excavation with the large equipment and proceed with more caution until the object is identified.

Currently this device is still in a trial period and is only available to select users. They are working with manufacturers for a public release in 2024. If there is interest in being a part of the trial, refer to Appendix A for contact information. They anticipate the price will be $35,000 to $45,000 depending on which of the six types of buckets available is purchased. This device is unique to the industry therefore for excavation stage, RodRadar’s digging bucket is recommended for use to improve the safety of site excavation.

Figure 57: RodRadar's Live Dig Radar Excavate device

Figure 58: RodRadar's Live Dig Radar Visualize device

5. Conclusion

In recent years, even newer technologies like GPR have undergone significant advancements. GPR can provide faster and more accurate data through multi-channel devices and varying wave frequencies. Software has also made significant progress, as extensive training and advanced knowledge of GPR is no longer a necessity. Data interpretation and visualization are being improved to further increase location accuracy and user-friendliness. Additional methods are also being developed through acoustic means to fill in gaps left by traditional technology.

There are many technologies that can detect underground utilities under different circumstances, and GPR and acoustic technologies are very promising for use in this area. GPR is commonly used and readily available in Pennsylvania. Unfortunately, no current technology is a cure-all that can meet every objective desired in this study. However, a combination of devices could be used depending on the site conditions. Pipe material must be considered, as some devices only detect metallic pipes. The environmental conditions of each site must also be considered, as the surface layer and soil characteristics, like saturation, compaction, and clay content, can affect the results. Other utilities or underground objects interfere more with some devices; therefore, congestion of pipes needs to be considered as well.

Several GPR-based devices were evaluated in this study. Three types of equipment were recommended for the three construction stages. Kontur provides an extremely detailed view of an entire site with quick collection time, which provides site owners a map of utilities on their site for future design work. Screening Eagle has a step-frequency handcart that is ideal for contractors to analyze and mark utilities on their site efficiently and clearly report data for excavation planning. RodRadar provides a last line of defense for excavator operators by alerting them directly if there is a potential utility immediately below their digging bucket. There are more vendors available for many of these construction stages; however, based on those tested in this study, these are the recommendations of this research team based on objectives outlined by local contractors and agencies.

GPR is an ever-changing technology, and even since these devices were tested in the field, there have been software updates or new products from several of the companies. This is certainly a field to watch for further advancements in the next several years as companies aim to locate more underground objects and significantly reduce the risk of damage or injury from hitting an unmarked utility.

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Appendix A: Full Device List

Table A. 1: List of companies that provide underground utility detection devices

Company	Method	Device
GSSI	GPR	UtilityScan RADAN 7 Software
IDS GeoRadar	GPR	GPR Devices • Stream UP • Opera Duo • Stream C Visualization • uNext • IQMaps • OneVision • uViewer
Kontur	GPR	Geoscope Radar Antenna Arrays (Figure A. 1) • G0908: 8 channels • G1212: 12 channels • G1820: 20 channels • G2124: 24 channels • G2428: 28 channels Examiner Visualization Software
Screening Eagle	GPR	GS8000 Proceq GPR Subsurface App
Sensit Technologies	Acoustic	ULTRATRAC Acoustic Pipe Locator

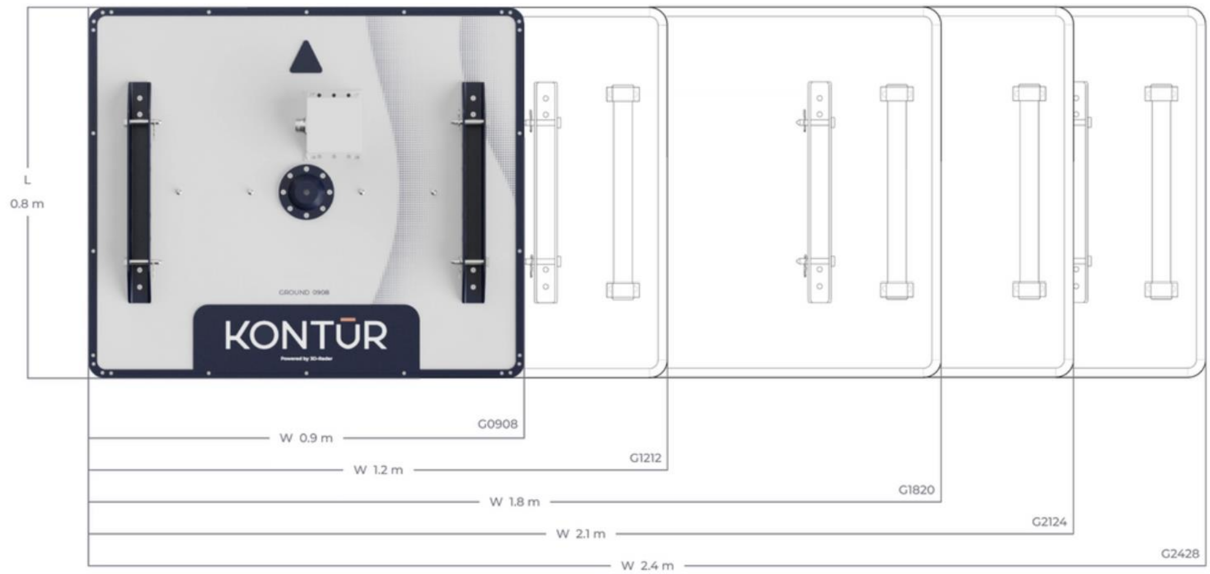


Figure A. 1: Kontur antenna array dimensions [9]

Appendix B: Driving and Urban Site Plans

This appendix has the site plans for the driving and urban site.

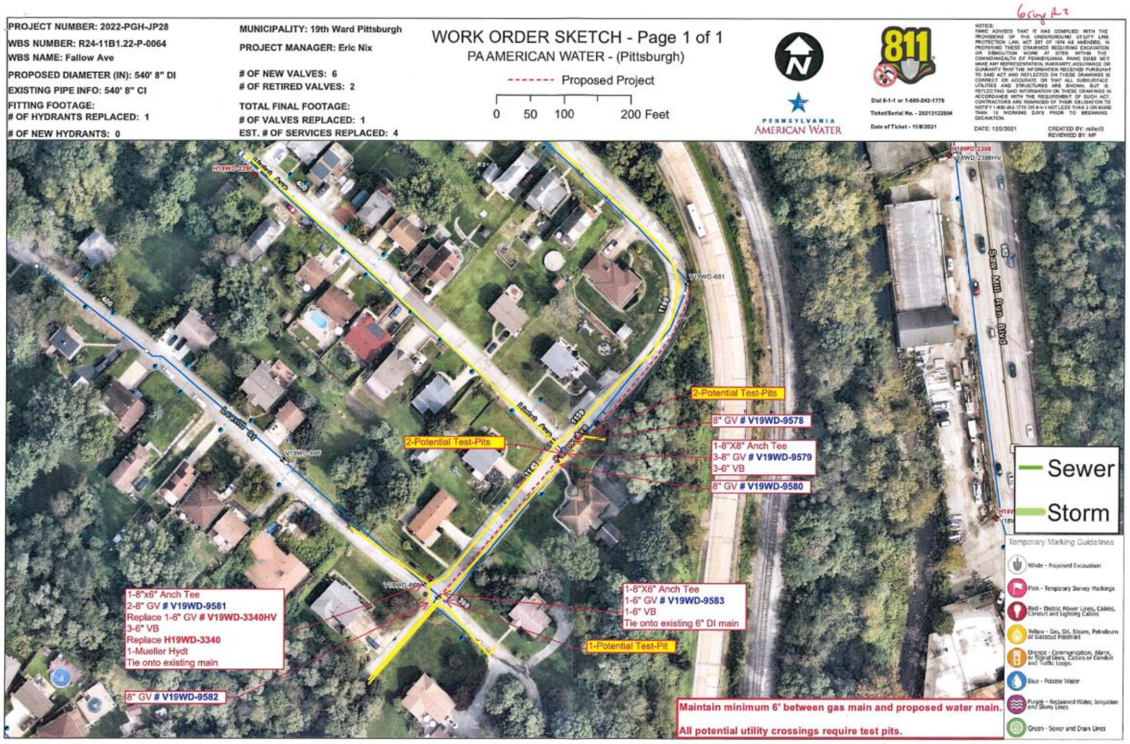


Figure A 1: Site plans for Fallow Avenue

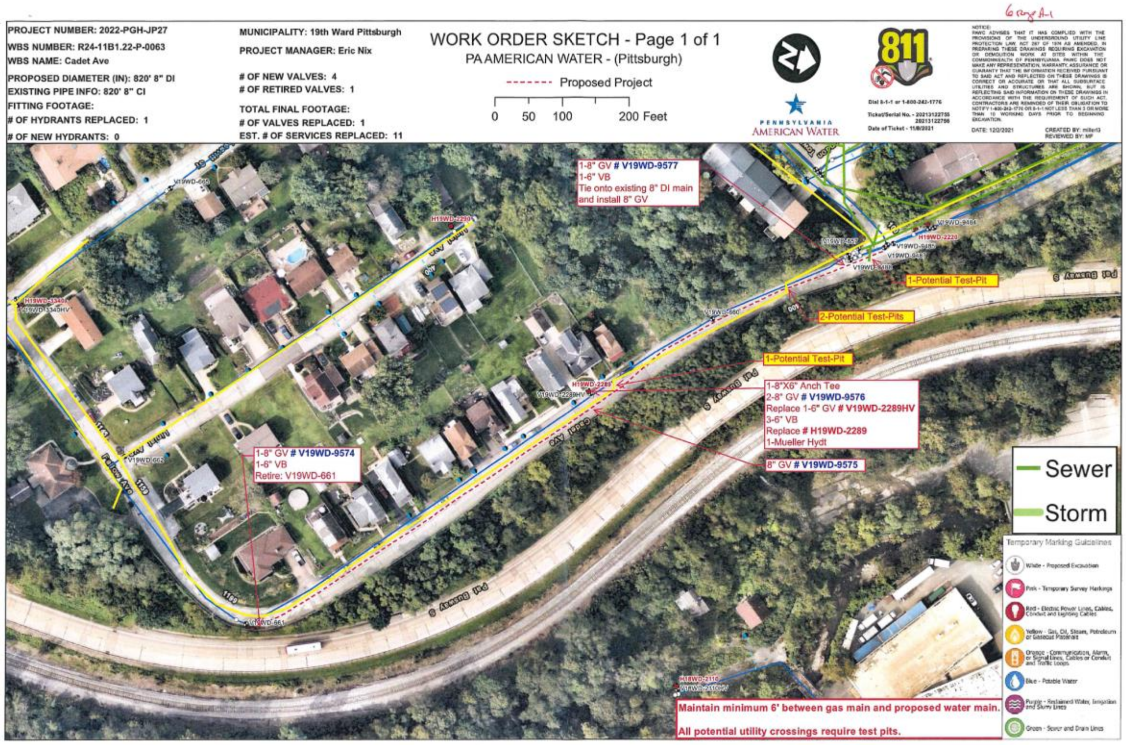


Figure A 2: Site plan for Cadet Avenue

Figure A 3: Site plans for Linial Avenue

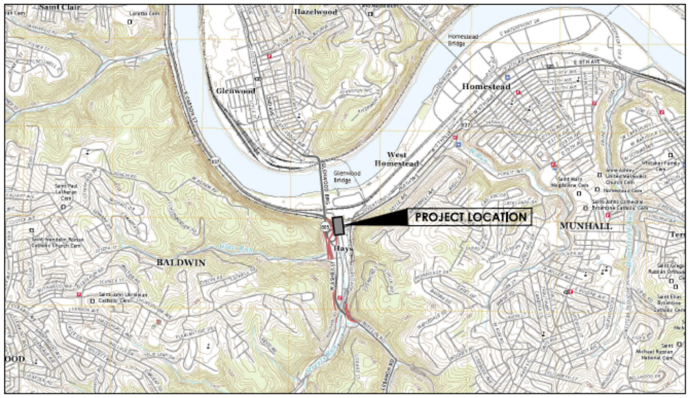
PENNSYLVANIA-AMERICAN WATER COMPANY

S.R. 0837 WATERLINE RELOCATION

HIGHWAY OCCUPANCY PERMIT

31ST WARD, CITY OF PITTSBURGH, ALLEGHENY COUNTY, PA

McMURRAY DISTRICT



LOCATION MAP

(PITTSBURGH EAST, PA, QUADRANGLE)
SCALE=1:24000

PA One Call Contacts			
Utility	Company	Address	EMAIL
	PEOPLES GAS COMPANY LLC CONTACT: MICHAEL DENNY	375 NORTH SHORE DR PITTSBURGH, PA. 15212	MICHAEL.DENNY@PEOPLES—GAS.COM
	VERIZON PENNSYLVANIA LLC CONTACT: DEBORAH BARUM	1026 HAY ST PITTSBURGH, PA. 15221	DEBORAH.D.DELIA@VERIZON.COM
	PITTSBURGH WATER & SEWER AUTHORITY THE CONTACT: RICK OBERMEIER	1200 PENN AVENUE PITTSBURGH, PA. 15222	ROBERMEIER@PGH2O.COM
	PITTSBURGH CITY DEPT OF MOBILITY & INFRA CONTACT: BRIAN RALSTON	611 SECOND AVE PITTSBURGH, PA. 15219	BRIAN.RALSTON@PITTSBURGHPA.GOV
	ALLEGHENY CITY ELECTRIC INC CONTACT: TOM ULIZZI	3080 BABCOCK BLVD PITTSBURGH, PA. 15237	TMU@ALLEGHENYCITYELECTRIC.COM
	DUQUESNE LIGHT COMPANY CONTACT: KYLIE PARISON	2645 NEW BEAVER AVE PA—TD PITTSBURGH, PA. 15233	KPARISON@DUQLIGHT.COM
	CENTURY LINK CONTACT: CENTURY LINK OPERATOR PERSONNEL	1025 ELDORADO BLVD BROOMFIELD, CO. 80021	RELOCATIONS@LUMEN.COM
	COMCAST CONTACT: CHARLES DETWILER	1530 CHARTIERS AVE PITTSBURGH, PA. 15204	CHARLES_DETWILER@CABLE.COMCAST.COM
	PENNSYLVANIA AMERICAN WATER CONTACT: LUCIAN CAPPETTA	500 NOBLESTOWN RD CARNEGIE, PA. 15106	LUCIAN.CAPPETTA@AMWATER.COM

Signing, Pvm't Markings, and Delineation Notes:

1. Install signs, pavement markings, and delineation in accordance with the most current PennDOT Publication 111 Traffic Control, TC-8600 and TC-8700 series June 2013, PennDOT Publication 46, the Federal Highway Administration Manual on Uniform Traffic Control Devices, Pub. 212, Official Traffic Control devices, or as directed by the PennDOT District 12-0 representative.

2. Details other than those indicated are on the following standard drawings:

   a. TC-8600 11 sheets June 13, 2013

   b. TC-8604 4 sheets June 13, 2013

   c. TC-8701D 9 sheets June 13, 2013

   d. TC-8701S 4 sheets June 13, 2013

   e. TC-8702B 9 sheets June 13, 2013

   f. TC-8702C 2 sheets June 13, 2013

   g. TC-8702D 2 sheets June 13, 2013

   h. TC-8702E 5 sheets June 13, 2013

   i. TC-8710 1 sheet June 13, 2013

3. Any legal or private sign that is to be removed for construction that is within the project limits but is not included in the projects sign tabulations shall be reinstalled at or nearest its original location. If sign is determined unnecessary, it shall be returned to its owner.

4. Any sign that is to remain or be reinstalled, that becomes damaged in any way during construction or during removal, storage, or reinstallation, shall be replaced in kind with a new sign at no additional cost to the Department.

5. Place all signs entirely within the Legal Right-of Way.

6. For fabrication of all standard signs, refer to Pennsylvania Department of Transportation Publication 236.

7. All Type B post mounted signs are to be installed using square channel posts and anchors of the appropriate size. Anchors shall not extend more than 1 inch above the ground line.

8. Do not remove existing signs until the new signs are installed. If existing signs conflict with construction, install temporary signs as directed by a PennDOT District 12-0 representative. Do not remove the temporary signs until the new signs are installed.

9. Apply an installation date permanently to the back side of each sign installed within the projects limits of work.

10. Contractor shall call PA One Call System, Inc at 1-800-242-1776 prior to digging for all signs.

11. Apply pavement markings at the width indicated.

12. Use waterborne paint for all longitudinal lines. On the final bituminous wearing course or concrete surface, apply two applications of paint. Apply the second application after the first is dry, within 24 hours.

13. For all transverse applications, use epoxy (on concrete) and hot thermoplastic (on asphalt).

14. Apply all pavement markings in accordance with the manufacturer's recommendations.

14. The contractor shall reapply any pavement marking that is damaged within or beyond the start/stop of work due to construction activity at no additional cost to the department.

16. Install Raised Pavement Markers in accordance with the PennDOT Publication 111 Traffic Control.

17. Install Type B and D delineators to all guide rail within plan limits at intervals specified per Pub. 111, TC-8604, or as directed by PA Dept. of Trans.

18. Refer to the Signals plan for additional signs and pavement markings associated with all traffic signals, if applicable.

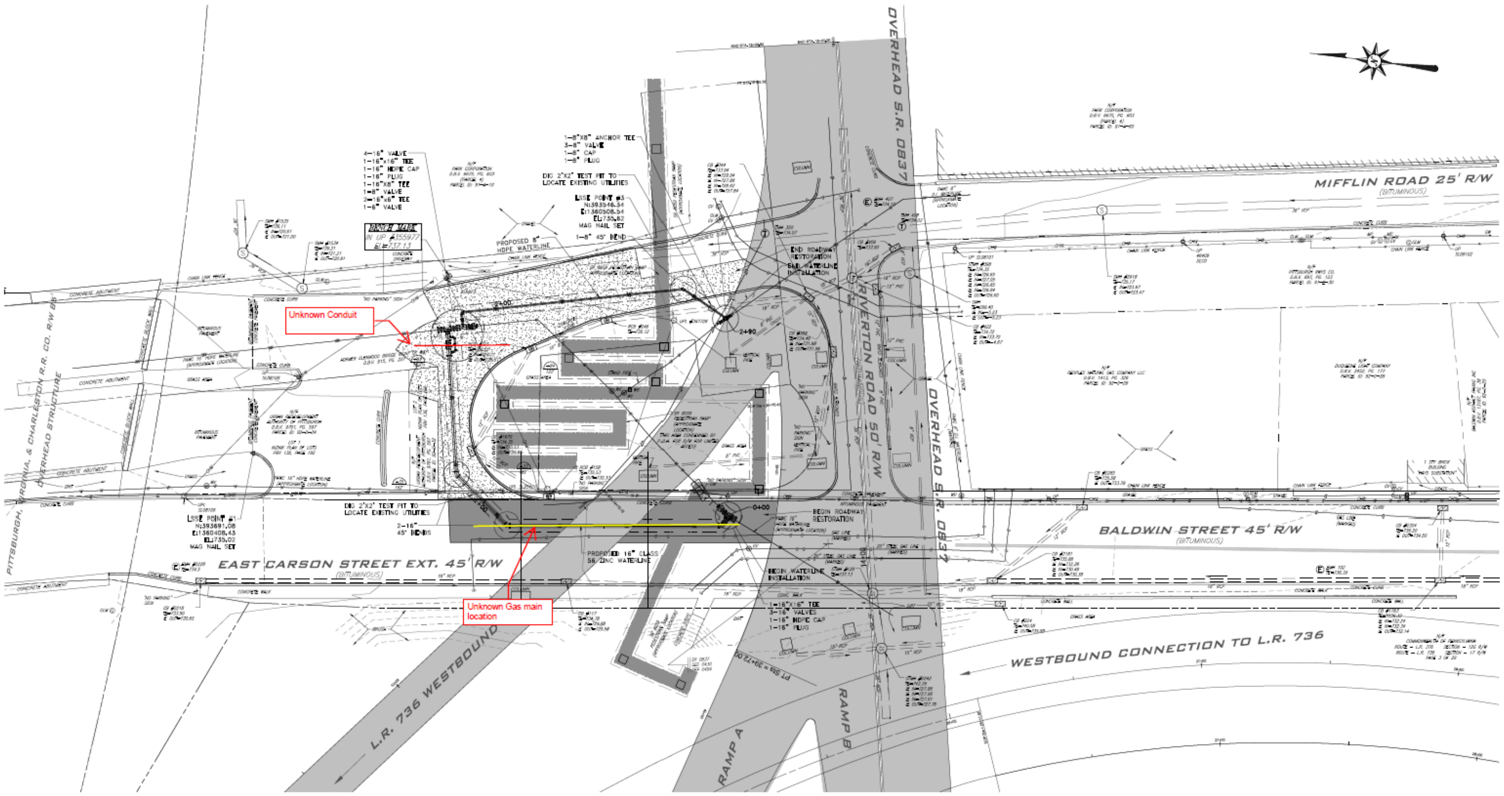
Sheet List Table	
Sheet Description	Drawing No.
TITLE SHEET	--
INDEX SHEET	1 OF 6
PLAN VIEW	2 OF 6
CROSS SECTIONS	3 OF 6
TRAFFIC CONTROL PLAN	4 OF 6
STANDARD DETAILS	5 OF 6
STANDARD DETAILS	6 OF 6

NOTICE:
PAWC ADVISES THAT IT HAS COMPLIED WITH THE PROVISIONS OF THE UNDERGROUND UTILITY LINE PROTECTION LAW, ACT 287 OF 1974 AS AMENDED, IN PREPARING THESE DRAWINGS REQUIRING EXCAVATION OR DEMOLITION WORK AT SITES WITHIN THE COMMONWEALTH OF PENNSYLVANIA. PAWC DOES NOT MAKE ANY REPRESENTATION, WARRANTY, ASSURANCE OR GUARANTY THAT THE INFORMATION RECEIVED PURSUANT TO SAID ACT AND REFLECTED ON THESE DRAWINGS IS CORRECT OR ACCURATE OR THAT ALL SUBSURFACE UTILITIES AND STRUCTURES ARE SHOWN, BUT IS REFLECTING SAID INFORMATION ON THESE DRAWINGS IN ACCORDANCE WITH THE REQUIREMENT OF SUCH ACT, CONTRACTORS ARE REMINDED OF THEIR OBLIGATION TO NOTIFY 1-800-242-1776 OR 8-1-1 NOT LESS THAN 3 OR MORE THAN 10 WORKING DAYS PRIOR TO BEGINNING EXCAVATION.

Dial 8-1-1 or 1-800-242-1776
Ticket Serial No. - 20221992187

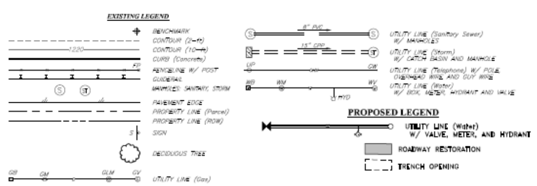
Date of Ticket - 07/18/2022

PENNSYLVANIA AMERICAN WATER



GENERAL NOTES:

1. ROADWAY RIGHT-OF-WAY STATIONING SHOWN IS BASED ON PENNDOT HIGHWAY DRAWINGS FOR ROUTE 0837, SECTION A43 R/W, SHEETS 1 THROUGH 6 OF 6, AS RECORDED IN PBV 187 PAGE 88.
2. ROADWAY RESTORATION SHOWN IS BASED ON PENNDOT HIGHWAY DRAWINGS FOR ROUTE 0837, SECTION A43, SHEETS 6 AND 21 OF 28, LAST REVISED 08/16/22 AS PROVIDED.



EXISTING CONDITION NOTES:

1. THE UNDERGROUND UTILITIES SHOWN HAVE BEEN LOCATED BY FIELD SURVEY OF MARKINGS MADE IN THE FIELD BY THE RESPECTIVE UTILITY COMPANY OR TAKEN FROM DRAWINGS OF THE EXISTING UTILITIES PROVIDED BY THE UTILITY COMPANIES. ALL EXISTING SUBSURFACE UTILITY INFORMATION PRESENTED ON THE CONTRACT DRAWINGS IS CHARACTERIZED AS UTILITY QUALITY LEVEL C OR D PER "CI/ASCE 38-02 - STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUBSURFACE UTILITY DATA" UNLESS SPECIFICALLY NOTED OTHERWISE.
2. THE ENGINEER OR SURVEYOR MAKES NO GUARANTEE THAT THE UNDERGROUND UTILITIES SHOWN COMPRISE ALL SUCH UTILITIES IN THE AREA, EITHER IN SERVICE OR ABANDONED.
3. FURTHERMORE, THE ENGINEER OR SURVEYOR DOES NOT WARRANT THAT THE UNDERGROUND UTILITIES SHOWN ARE IN THE EXACT LOCATION INDICATED. THEY ARE LOCATED USING ORDINARY STANDARDS OF CARE AND PRACTICE AND SHOWN HEREON BASED UPON AVAILABLE INFORMATION.
4. THE ENGINEER OR SURVEYOR HAS NOT PHYSICALLY LOCATED ANY OF THE UNDERGROUND UTILITIES.
5. PROPERTY LINES SHOWN HEREIN ARE PREPARED FROM DEED PLOTS AND/OR FROM TAX MAP INFORMATION. NO FIELD PROPERTY SURVEYS WERE PERFORMED. PROPERTY LINES NOT FIELD VERIFIED.

NOTICE:
PAWC ADVISES THAT IT HAS COMPLIED WITH THE PROVISIONS OF THE UNDERGROUND UTILITY LINE PROTECTION LAW, ACT 287 OF 1974 AS AMENDED, IN PREPARING THESE DRAWINGS REQUIRING EXCAVATION OR DEMOLITION WORK AT SITES WITHIN THE COMMONWEALTH OF PENNSYLVANIA. PAWC DOES NOT MAKE ANY REPRESENTATION, WARRANTY, ASSURANCE OR GUARANTY THAT THE INFORMATION RECEIVED PURSUANT TO SAID ACT AND REFLECTED ON THESE DRAWINGS IS CORRECT OR ACCURATE OR THAT ALL SUBSURFACE UTILITIES AND STRUCTURES ARE SHOWN, BUT IS REFLECTING SAID INFORMATION ON THESE DRAWINGS IN ACCORDANCE WITH THE REQUIREMENT OF SUCH ACT, CONTRACTORS ARE REMINDED OF THEIR OBLIGATION TO NOTIFY 1-800-242-1776 OR 8-1-1 NOT LESS THAN 3 OR MORE THAN 10 WORKING DAYS PRIOR TO BEGINNING EXCAVATION.

0' 20' 40' 60'

Dial 8-1-1 or 1-800-242-1776
Ticket Serial No. - 20221992187
Date of Ticket - 07/18/2022

REVISIONS
1. 01/27/22 REVISED PER PAWC MARKUPS.
2. 09/19/22 REVISED PER PAWC COMMENTS VIA EMAIL DATED 09/13/22.

S.R. 0837 WATERLINE RELOCATION
PLAN VIEW
HIGHWAY OCCUPANCY PERMIT
31ST WARD, CITY OF PITTSBURGH, ALLEGHENY COUNTY, PENNSYLVANIA

PENNSYLVANIA-AMERICAN WATER COMPANY
McMURRAY DISTRICT

Pennsylvania-American Water Company
300 Galley Road
McMurray, PA 15317

PENNSYLVANIA AMERICAN WATER

DRAWN BY
PROJECT ENG'R
APPROVED
DATE FEBRUARY 2022
PROJECT
USE DIMENSIONS ONLY
SCALE 1"=20'

USE APPROVED DRAWINGS ONLY FOR CONSTRUCTION PURPOSES

SHEET 2 OF 6

Figure A 4: Site plan for urban site

Appendix C: Screening Eagle Report

KK

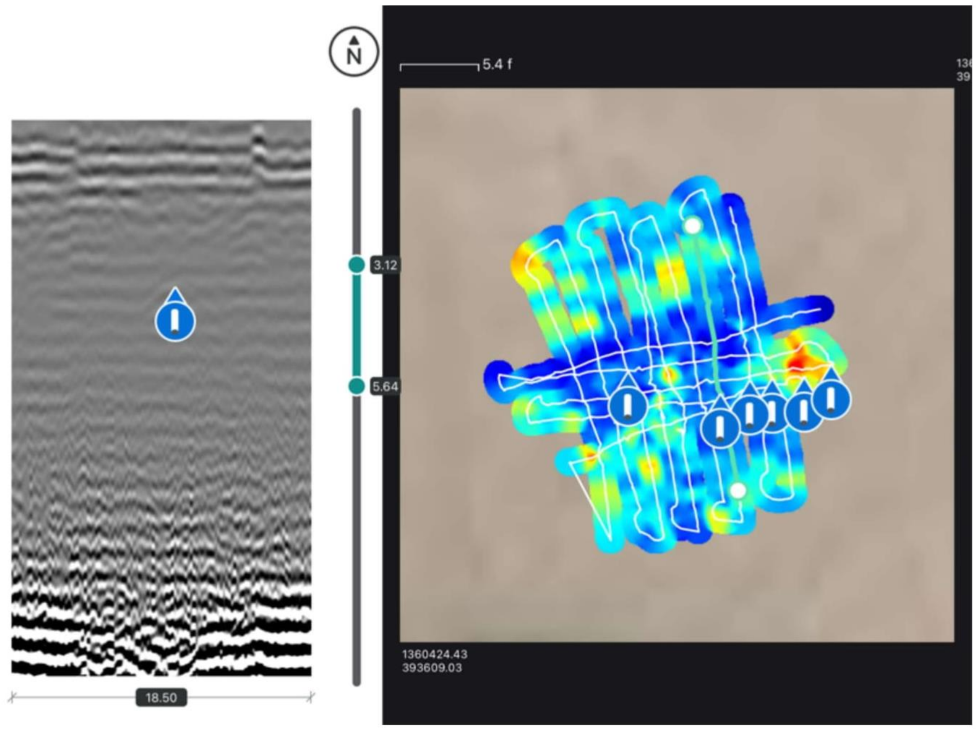
Waterline Freepath Location 2 - Pittsburgh, PA

Proceq GPR Subsurface
Export HTML Format Version:1.8.7 (1178)

User / Probe Info	
Operator	Bryce Guay
Email	bryce.guay@screeningeagle.com
Product	**Proceq GS8000** **Proceq MA8000**
Probe S/N	GS80-002-0004 MA80-002-0362
Hardware Version	A0
Firmware Version	4.16.5
App Version	2.2.0

Settings » Measurement Presets	
File Name	Waterline Freepath Location 2 - Pittsburgh, PA
Folder	All Measurements
Mode	Free Path
Units	Imperial
Resolution	Standard
Repetition Rate [scan/in]	2.0

Settings » Snapshots



File Name	Waterline Freepath Location 2 - Pittsburgh, PA_20221205_104825	
Dielectric Constant (ε_r)	10.3	10.3
Linear Gain [dB]	-11.4	-12.9
Time Gain Compensation [dB/in]	0.01	0.08
Background Removal Depth [ft]	262.47'	
Separation Slider Depth [ft]	0.00'	

Objects							
Line	Tag	Tag Type	Easting	Northing	Distance along line [ft]	Calculated Depth	Set Depth
1	1	Drinking Water	1360449.929	393627.112	12.27'	3' 6.0"	-
1	2	Drinking Water	1360448.404	393627.001	32.06'	3' 7.1"	-
1	3	Drinking Water	1360446.384	393626.076	59.94'	3' 5.9"	-
1	5	Drinking Water	1360452.123	393627.187	232.62'	3' 7.5"	-
1	13	Drinking Water	1360440.060	393627.587	156.39'	3' 4.1"	-
1	14	Drinking Water	1360453.973	393628.049	271.97'	3' 5.5"	-
1	15	Water Valve	1360442.823	393627.374	107.52'	1.3"	-
1	16	Water Valve	1360442.249	393625.310	127.72'	1.1"	-
1	33	Drinking Water	1360444.641	393628.063	84.01'	3' 11.4"	-

Utilities Line

Group	Number	Colour	Set Size [in]	Comment
No data				

Markers

Line	Marker Number	Easting	Northing	Distance along line [ft]	Comment
1	M1	1360444.628	393628.109	84.11'	
1	M2	1360444.628	393628.109	84.11'	
1	M3	1360444.612	393628.166	84.17'	

Points of Interest

Category	Easting	Northing	Ground Elevation	Set Depth	Set Size
No data					

Scan Distance [ft]

Line 1	317.21'

Logbook

Proceq GS8000

Probe S/N: GS80-002-0004

Hardware Version: A0

Firmware Version: 4.16.5

MAC Address: 2C:9F:FB:F6:5A:5B

Contract Type: Pro Subscription

Contract Validity: 14 Oct 2023

App Version: 2.2.0 (325)

Proceq MA8000

Probe S/N: MA80-002-0362

17 Nov 2022

10:23 BG

Created "waterline freepath 1002" in folder "All Measurements"

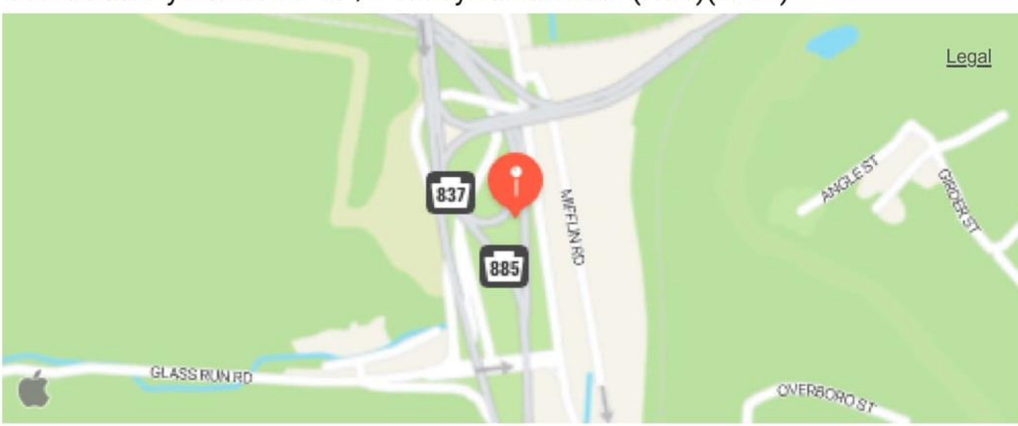
Mode: Free Path

Resolution: Standard

Repetition Rate (scan/in): 2.0

Dielectric Constant: 10.3

Coordinate System: NAD83 / Pennsylvania South (ftUS)(2272)



10:27 BG

Measurement ended.

Total length (ft): 317' 2.5"

10:28 BG

Tag 1 added.

Type: Drinking Water

Type	Drinking Water
Distance (ft)	12' 3.3"
Time Gain Compensation (dB/in)	0.1
Calculated Depth (ft)	3' 6.0"
Set Depth (ft)	-
Set Size (in)	-
Comment	
Name	

10:28 BG

Tag 2 added.

Type: Drinking Water

Type	Drinking Water
Distance (ft)	32' 5.5"
Time Gain Compensation (dB/in)	0.1
Calculated Depth (ft)	3' 6.8"
Set Depth (ft)	-
Set Size (in)	-
Comment	
Name	

Appendix D: Kontur Report

KONTŪR

Washington Hill Survey Report - December 2022

Contact: Dave Barry

(650)388-0862 | dbarry@kontur.tech

Key Points:

- Water pipe traced on Cadet ave, Linal ave, and Fallow ave
- Top of pipe variable depth from 4 to 6 ft
- 7 unknown features or pipes identified in the survey area

Report

GPR collection on the three roads in Washington Hill completed in December 2022. Multiple passes were taken targeting the water pipe buried beneath Cadet ave, Fallow ave, and Linial ave. Six unknown features were identified in addition to the target pipe.

Survey area consisted of approximately 1800 linear feet of residential streets with three passes per road on Cadet ave and Fallow Ave (one as close as was possible to the curb with existing street parking, and one along the center of the road) and two passes on the thinner Linial Ave. We targeted the water pipe trench which was visually evident at the surface. Collection took approximately 20 minutes and was completed using a 1.8m wide ground-coupled Kontur antenna. Interpreted frequencies were filtered from 200-1200 MHz. GPR Trigger spacing was 7.6cm. Videos of depth slices at the relevant depths accompany this report to visualize the pipes.

1 Water Pipe

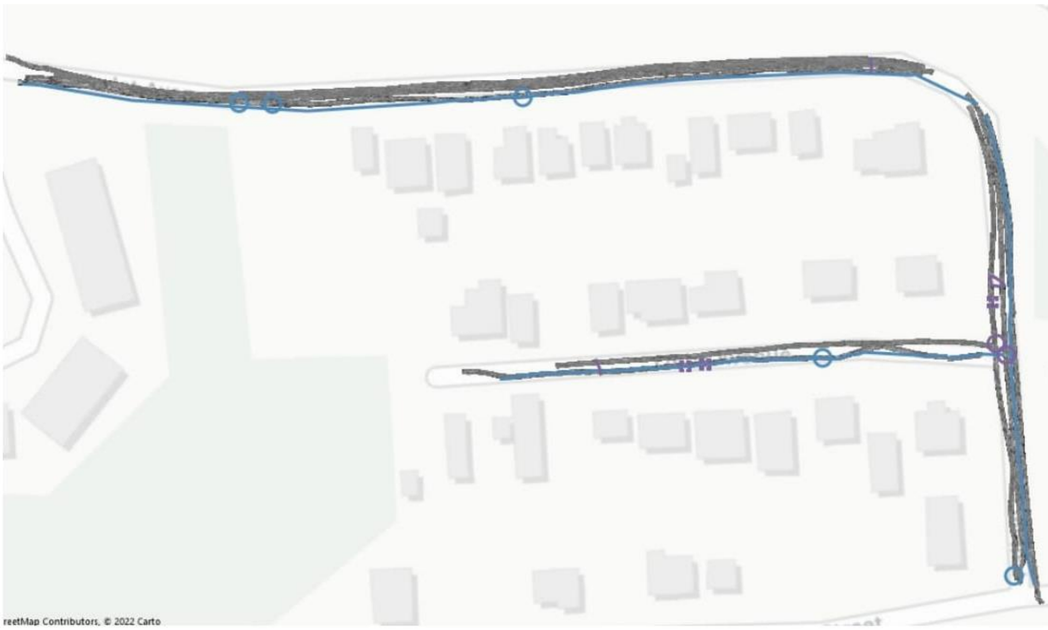


Figure 1. GPR collection on Cadet ave, Fallow ave, and Linial ave. Blue for water, purple indicates unknown features.

Depth estimate to top of pipe ranges from 4 to 6 feet. Virtual trenches of the water pipe on the three streets follow in Figures 2,3,4. These are constructed by cutting the collected GPR data along the annotated blue line Figure 1. Blank portions indicate regions inaccessible due to parked cars or other obstructions.

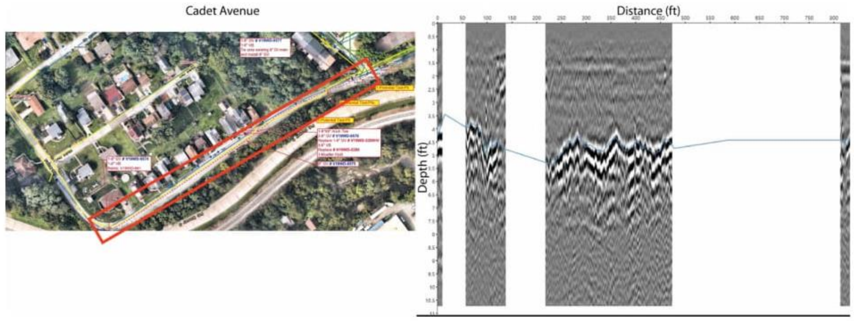


Figure 2. Virtual trench tracing the top of the water pipe beneath Cadet ave using the blue line from Figure 1. Relevant street region indicated by the red box.

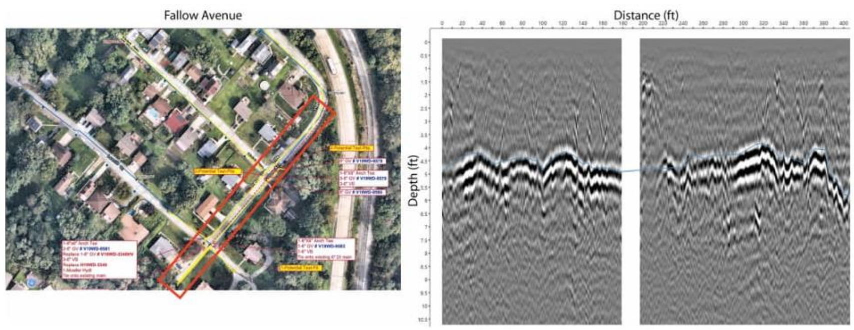


Figure 3. Virtual trench tracing the top of the water pipe beneath Fallow ave using the blue line from Figure 1. Relevant street region indicated by the red box.

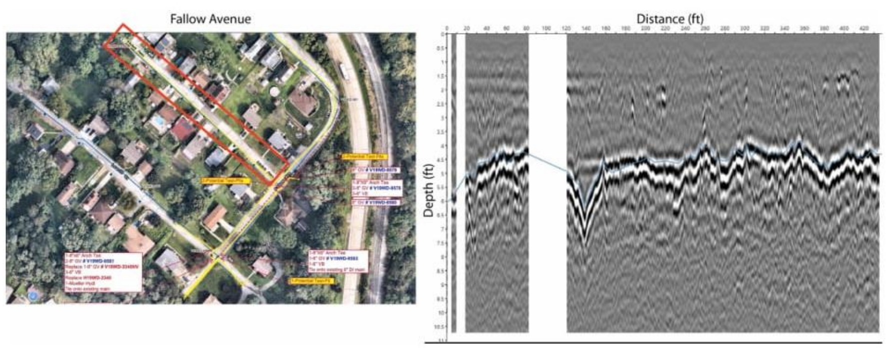


Figure 4. Virtual trench tracing the top of the water pipe beneath Linial ave using the blue line from Figure 1. Relevant street region indicated by the red box.

2 Other Example Radar Findings

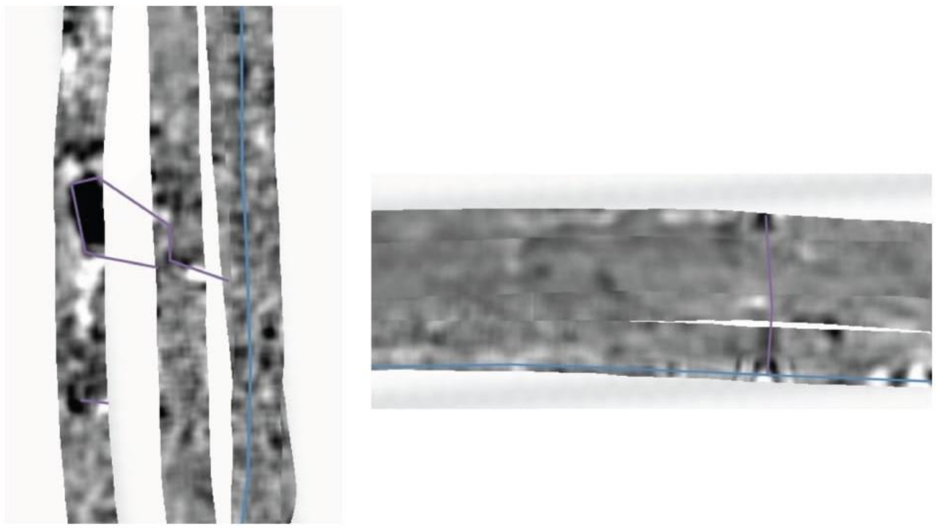


Figure 5. LEFT: Unknown feature traced in purple on Fallow Ave at approximately 6 ft depth. RIGHT: Unknown pipe crossing Cadet Ave diving from 2.5 to 4 ft depth.

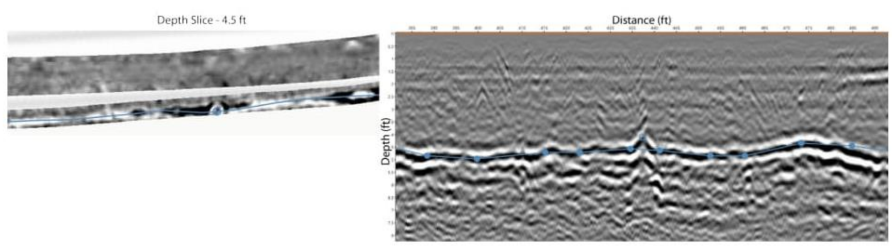


Figure 6. Water pipe junction point on Cadet Ave. LEFT: Depth slice at 4.5 ft. RIGHT: cross-section of the same region.

Rounded features like this were observed on the water pipe at several locations.

Appendix E: Contact Information

This is a list of people in sales who were contacted in this project.

Company	Name	Title	Email	Phone
Kontur	Dave Berry	Americas Sales Manager	dbarry@kontur.tech	(650) 388-0862
GSSI	Brett Caldwell	Commercial Territory Manager	calbwellb@geophysical.com	(603) 893-1109
Impulse Radar	Noah Nelson	Sales & Marketing	Noah.nelson@impulseradar.se	(714) 316 8185
IDS GeoRadar	Thaddeus Bullock	Utility Detection Specialist	Thaddeus.bullock@hexagon.com	(419) 280-3743
Screening Eagle	Darrel Stanyard	Regional Sales Manager	darrel.stanyarfd@screeningeagle.com	(724) 920-1232
RodRadar	Yuval Barnea	VP Sales and Marketing	yuvalb@rodradar.com	(972) 52-6006-335

University of Pittsburgh

Swanson School of Engineering

Department of Civil and Environmental Engineering
IRISE Consortium
742 Benedum Hall
3700 O'Hara Street
Pittsburgh, PA 15261