METHODS OF PIPE AND LEAK DETECTION

IN

UNDERGROUND WATER AND SEWER RETICULATIONS

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UNDERGROUND WATER AND SEWER RETICULATIONS

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Study Leader

Mr. J.H. Cruywagen

October 2009

Declaration by student

I, the undersigned, herby confirm that the attached treatise is my own work and that any sources are adequately acknowledged in the text and listed in the bibliography.

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Signature of acceptance and confirmation by student

Abstract

Title of treatise	:	Methods of pipe and leak detection in underground water and sewer reticulations
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Traditionally when new underground utilities where added to an area where other utilities where already installed, like a water reticulation networks, and the new utility was to pass by or cross the existing one the party doing the installation would run a big risk of damaging the existing utility. This risk would greatly be reduced if the exact position of existing utilities where known.

Another problem is detecting water leaks in services because of the natural flow of water. (Flowing through the path of least resistance.) This causes excavations to be large in comparison to what is needed for the repair of the leak.

The aim of this treatise will be to investigate different technologies available to discover leaks and/or the positions of underground water, storm water and sewer reticulation networks.

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Chapter 1 - Introduction

1.1 Background

After the design of sewer, storm-water and water reticulations as-built drawings are drawn up. These drawings serve as a reverence document to any person whom might at a later stage needs to know exactly where these services are installed. Persons using these as-built drawings include maintenance contractors, quantity surveyors, project managers, clients and any other body involved with payments of the services or involved in further working thereon.

One area of concern in South Africa is that as-built drawings are commonly done wrong. This is due to a variety of reasons with one being that they are normally only drawn up only after they are covered up. A second problem is the record keeping of the existing as-built plans, plans sometimes get lost or the original parties involved in drawing them is no longer involved in the project which makes attaining them and the plans difficult. This has the following effects:

- It is more difficult to find out the exact position of the pipes making maintenance, installation of other services and upgrades to the system more labour intensive and time consuming.
- The difficulty of checking and measuring the works are increased.
- Risk of damage to existing services is increased when installing further services or doing maintenance on existing services.

Another big problem in sewer, storm-water and water reticulations are that when a fault occurs in the reticulation it might be difficult to find the exact positions. This is mainly due to a number of facts namely:

- When a pipe leaks and water surfaces it will follow the route of least resistance and might surface quite a distance away from the actual problem.

- When blockages occur the problem is normally seen at the entry positions of the fluid or an alternative exit point, not at the blockage self.

1.2 Main problem

How can more accurate as-built drawing be drawn up even after installation and/or faults discovered in sewer, storm water and water reticulations?

1.3 Sub-problems

1. Define the current methods of drawing as-built drawings and the way to discover faults or old networks?

2. Is it feasible to use transmitter technologies to draw as-built drawings, detect leaks or detecting old networks in storm water or sewer networks?

3. Is it feasible to use smart pipe or transmitter technologies to draw as-built drawings, detect leaks or detecting old networks in storm water or sewer networks?

4. What is the current demand for such technologies?

1.4 Hypotheses

1. Currently as-built drawings are done by hand by the sub-contractor and faults are discovered in water reticulation with surfacing water and in sewer and storm water reticulations by use of cameras and blockages.

2. A round transmitter linked to a program with a pre-synced site layout left to roll down the pipes, and so draw up plans or identify blockages.

3. There will be looked at “smart” pipes with transmitter. These transmitters should have to be able to show flow drops between lengths where there should not be. This will show faults in the lines and speed up reaction time.

4. There is a great demand for these technologies but also not enough knowledge on them.

1.5 Delimitations

This research investigates the methods employed, on the main reticulations of residential full title- and sectional title- estates in Pretoria - South Africa and will look at methods employed and patents registered in the United States of America.

1.6 Definition of terms

As-built

A drawing done after the installations of reticulations to show the position of the reticulation.

Reticulation

In this case a sewer, storm water or water network servicing an estate.

Utilities

Collective name for services underground like pipes, power lines, etc

GPR

Ground penetrating radar

Rodding-eyes

Also called an inspection eye, used for rodding

Rodding

A process where a flexible steel rod is pushed down the pipe to clear the blockage

Interferometer

Measurement & analysis surfaces and transmitted wave front.

Piezoelectric transducers

Is used for conversion of electrical pulses to mechanical vibrations and the conversion of returned mechanical vibrations back into electrical energy is the basis for ultrasonic testing.

Notating

To read off. Information does not have to be remembered.

1.7 Assumptions

It is assumed in this research that the water reticulations works on a pressure system and the storm-water and sewer reticulations work on gravity driven systems. These systems are the general norm for urban areas in South Africa although other systems do exist but will not form part of this research.

1.8 Importance of the study

Currently there are a large movement away from traditional full title stands towards full title stands in security estates. Keeping this in mind on may safely assume that bulk services are no longer just installed by state but also private developers. These developers will typically apply for a service connection for the whole estate and then employ his engineers and installation firms to do the relevant works. After the development is sold or handed over to a body corporate the developer normally cuts his involvement to the bear minimum and moves on the next development. A body corporate or other relevant body will the take over and maintain and make decisions on further upgraded to the system.

With all this said one may assume that the body corporate may elect not to use the original contractors or engineers to do the maintenance or to upgrade the system. Because of this accurate ass-build drawings are essential, it will safe time and money. Where the original ass-builds are no longer available for whatever reason it becomes extremely difficult to draw new as-built drawings on an existing reticulation. (One cannot see thru ground) This makes upgrades to existing reticulations almost impossible and when maintenance work on a service needs to be done one may suffer the risk of damage to the other reticulations in the area.

For the developer as-built drawings are important for similar reasons but also the following:

- A situation at any time during or after construction may arise where the developer does not have the original engineer or contractor in his employment.
- The developer or a contractor may take over and un-completed job where accurate drawings will point out the remainder of works.
- Where payments are concerned it can be of great help to have a system of drawing accurate as-built drawings to help with the quantification of works done.

1.9 Research methodology

Literature

- Literature of hydraulics will help with flow strengths and design criteria
- Literature electronics and transmitters will help in design of drawing system

Broachers and advertisements

- Will help with finding current available technologies

Chapter 6 – How can more accurate as-built drawing be drawn up even after installation and/or faults discovered in sewer, storm water and water reticulations?

6.1 Summary

As-built drawings are mostly done by hand by the contractor on site and then redrawn by an engineer. This procedure opens up room for human error. In this research document there was no method found for an automated method of drawing these plans but the technology to enable this was found.

Some of these technologies that can be use either individually or in combination with others include the use of strong enough transmitting signals in combination with triangulation and a mapping program. A practical method for doing this was looked at but no working model or tests was done in this regard.

Currently the most reliable technology to discover buried pipelines and other utilities in the area is GPR. GPR is an accurate and safe method for detecting under ground reticulations when there are numerous other services in the area but requires an engineer to operate and interpret.

Research was also done into the possible cost savings of knowing the exact position of where the utilities were located before any further excavations was done. There was also looked at water wasted out of small leaks under five bar pressure and an average South African for excavation. There was also briefly discussed a new emerging field called Utility Engineering Works aimed at locating buried utilities.

Lastly there was looked at methods of discovering existing faults in reticulations as well as early detection methods. The technologies currently used most for discovering faults are:

- Rodding

- Cameras
- Jetting
- Opening pipes
- The contractors ingenuity
- GPR

Detection systems in water reticulations have been around for a number of years. They include systems using electrical conductors to measure voltage drops to methods measuring the flow through the pipes, but these technologies are seldom to never use in South Africa. From this research it is clear that centrally control systems are available and has a multiple of advantages connected to them but not developed to its full potential.

6.2 Conclusion

It is clear that no automated systems are being used in South Africa for civil reticulation mapping or early fault discovery but that the relevant technologies exist, but has not been developed properly.

6.3 Recommendations

An engineering research project aimed at either developing a automated utility mapping system or a centrally controlled early leak detection system.

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Chapter 2 - Defining the current methods of drawing as-built drawings and the way to discovering faults in old networks

2.1. Introduction

Normally not much care is been taken on a construction site when drawing up as-built plans. This is a matter that is left up to site representative of the various construction companies doing the installations. The site representative of the plumbing sub-contractor will draw on the original designed plan, supplied by a civil engineer, any and all amendments made to the original design. This amended plan will then be send to the civil engineer who will redraw it and then issue the new plan as an as-built drawing.

The installation is deemed to be checked while in process of installation by the relevant civil engineer who is supposed to certify the correctness of the service installed and the accuracy of the as-built drawing after completion. Furthermore in most cases the civil engineer will also monitor the progress of the works and be involved subsequently in the payments of the contractor, but this is not always the case.

These as-built drawings after completion will serve the following roles in future:

- Serve as a way to evaluate the relevant reticulation for possible upgrades or extensions
- Help contractor to fix the latent and patent defects while he is still responsible for the works
- Help with the future maintenance on the system
- Help in the co-ordination of other services in the same area
- Help in the measurement of the works done

Because of the lack in accuracy of these as-built drawings all the above roles, that was supposed to be served and simplify, are made more difficult and inaccurate.

Currently there is little to be done after the installation is done to receive an as-built drawing if one was not provided by the contractor. This is especially difficult in water reticulations because of the absence of man-holes and rodding-eyes as found in sewer reticulations and man-holes in storm water reticulations.

The fact that as-built drawings are done firstly by hand in most cases and the multitude of uses of these drawings increases the need to find a procedure of drawing more accurate as-built drawing.

2.2. Body of the chapter - Discovering faults and drawing as-built drawings

2.2.1 Discovering faults

Discovering faults in reticulations is in many cases a long and tedious exercise which includes a long waiting period in residential estates for the system to become fully operational and faults to surface. These faults can take various forms like design faults, crushed pipes, blockages, loose couplings, missing peaces and other incorrect installations which include varying to far off from the original design. For the purpose of this research faults in the original design will fall outside the scope.

Because of the large extent of the cost implications on the contractor and the inability to finish the retention on the site quickly many innovative ways have been invented to overcome these problems or faults even thou they are not used until a problem services to save costs.

One of the most widely used methods for fault detections is the use of cameras.

2.2.2 Cameras

Cameras used for inspections of reticulations fall into a large variety of kinds mostly using CCTV (closed-circuit television) technologies.

Kinds of cameras used:

Crawler drain camera

They work by propelling themselves through the system.

For Inspection of 150mm - 600 mm pipeline diameter.

Figure 1 – Crawler drain camera unit (My Pipe Lines, 2009)

Figure 2 – Crawler drain camera system (My Pipe Lines, 2009)

Push rod drain camera

These cameras are used by pushing (rodding) them into the reticulation system.

For Inspection of 15 up to 400mm pipeline diameter.

Figure 3 – Push rod drain camera system (My Pipe Lines, 2009)

2.2.3 Blockages

The most common way of discovering a blockage in practice is when the system malfunctions. This may be in the form of water not flowing, sewer's pushing back or storm-water pushing back. When this happens the system is normally already in use and this will have an adverse effect on the user's comfort. Because of this and other reasons like easier repairs and less call backs, one may look at early detection methods and quick effective means of fixing the defects as a money saving method.

Currently cameras are used for sewer and storm water reticulations in cases where a fairly good idea exists to where the fault is and if the nature of it is a blockage. These blockages will have to be of such a nature and extend that normal rodding does not work.

When one is uncertain of whether a blockage actually exists in a sewer or storm water reticulation and wants to test the lines, one may use a system involving balls being thrown down the lines. These balls are marked from one onwards up to when numbers of balls have been reached. Then each one of the balls is introduces into the line through manholes, storm-water inlets or rodding eyes and caught at a point where the lines meet. If any of the balls don't make it one can determine the line with a blockage.

In water reticulations there will be a loss of flow rate or a complete stop of flow when a blockage occurs. It is very difficult with current technologies to discover the exact position of these blockages without testing sections of the reticulation at draw off points. If these draw off points are very far from each other it becomes very expensive and time consuming to discover where exactly the blockage is.

An easy way of discovering blockages is by means of cameras like discussed above. Thou this it is not always necessary to discover the exact position of the blockage, one may elect to flush the whole system to get rid of any blockages. This may be done by using high pressure water equipment like:

Pressure hoses and jetting machines

These pressure hoses compresses water and then releases the water at a desirable flow rate. They come in various sizes and may be used for most reticulations. Examples:

Figure 4 – Hand held pressure hoses and jetting machines (My Pipe Lines, 2009)

Figure 5 – Push pressure hoses and jetting machines (My Pipe Lines, 2009)

Figure 6 – Heavy duty pressure hoses and jetting machines
((My Pipe Lines, 2009)

2.2.4 Crushed pipes

Crushed pipes do not pose a major problem in sewer, storm-water of water reticulations unless the structural stability of the structure is so decreased that it will lead to structural failure, the flow of fluids or solids are restricted or the pipe is no longer sealed and fluids can pass into or out of the pipe networks.

It is vary difficult to discover such faults and sometimes not necessary because it does not always lead to failure. When the flow of fluids is severely restricted one does not always pick up the cause immediately because rodding will seem to have cured the fault. The current methods of discovering crushed pipes are the following:

- Opening the pipe for inspection
- Using a camera

2.2.5 Loose connections, holes in pipes or missing peaces

In most cases this is the most severe of the three mentioned faults. The reason for this is that if there is a place in the reticulation that is not closed it may have the following results:

- In storm-water or sewer reticulations water and soil will be allowed into the reticulation, this has the result of soil erosion underneath the natural ground level. This may result in a sinkhole effect.
- If water is allowed to flow out of the sewer pipes and there exists a high water table level, the natural ground water will be polluted.
- Fluids escaping out of the reticulations will also have the effect of creating possible areas where the soil's ability to retain water is overexerted. This will damage plants or roads in that area.

2.2.6 Incorrectly drawn as-built drawing

When an as-built drawing has been drawn incorrectly it will have immediate and long term affects like previously discussed. One of the more used systems for detecting utilities underground is ground penetrating radar.

2.2.7 Ground penetrating radar (GPR)

GPR has been used for sensing a wide variety of specific targets. Any object which has electrical parameters different than the surrounding soil and a distinctive shape is a candidate for such efforts. In detecting underground objects is has been used for buried tanks, landfill debris water levels and contaminated liquids. There are also quite a lot of possible military uses which includes it being used in terms of environmental sensing which includes, land mine and unexploded ordnance detection. For this chapter there will be looked at its ability of utility location. The need for GPR utility locators was spawned by the use of plastic pipe for natural gas and water distribution and GPR technology is currently the most accurate and safest method but needs engineers to operate and interpret. (Peters, 1994)

Figure 7 – GPR transmitter (GeoModel inc, 2009)

The properties of such a radar are restricted to the frequency, bandwidth, etc., that are required to detect the desired target, either natural or man-made, in the presence of a possibly inhomogeneous medium. Propagation losses, antenna size, and size of the scatterer to be detected dictate the frequency band of operation.
(Peters, 1994)

Utilities (pipes, power lines, etc.) represent another possible application. The ElectroScience Laboratory (ESL) under gas company sponsorship developed radar subsequently produced by MACOM known as the Terrascan 1141. The goal was the detection of 90Y. This was never adopted by the gas industry, even though there was no other viable method of plastic pipe detection because of potential labilities. There are several major difficulties in GPR design and usage that are not inherent in more conventional radar design. Since the usual GPR has a much broader bandwidth than even the so-called Ultra Wide Band Radars 1181 that have been investigated in recent years, they are extremely vulnerable to interference. This can be reduced by averaging a number of returns obtained as a function of time without moving the antenna. However signals generated by various types of clutter are not reduced by signal averaging. Clutter can be subdivided into various

categories including multiple Intiman reflections, scattering generated by surface roughness, and undesired buried targets within the radar field of view. Intiman reflections re minimized by system design. The other forms of clutter remain as a serious problem. These problems are compounded by poor antenna design.
(Peters, 1994)

2.2.7.1 GPR mapping

Utility mapping systems have been developed and tested both in the U.S. and in several other countries. In general, the mappers have increased capability compared to the man-portable instrument, but they still require engineering interpretation of the results.
(Olhoefts, 1999)

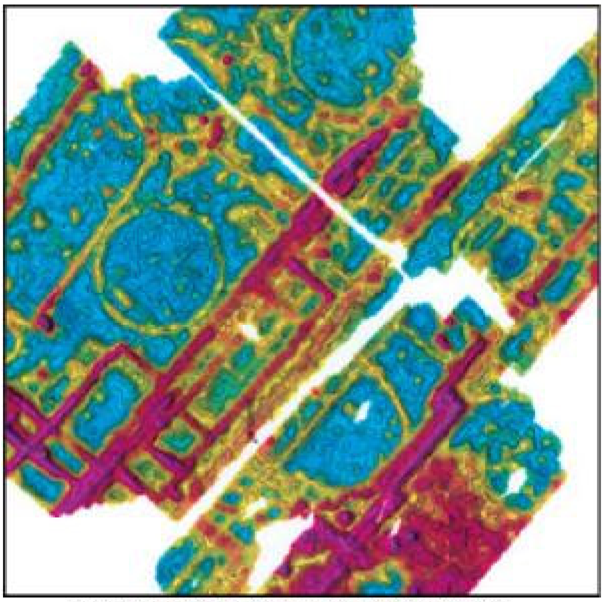

Figure 8 – Site mapped with GPR (GeoModel inc, 2009)

The data in the radar image exhibit several problems. The image is horizontally distorted by uneven towing speed (uneven spacing of the marks across the top) and vertically by an unknown velocity of wave propagation.

There is horizontal banding running across the image from less than optimal coupling of the antenna to the ground and unwanted oscillatory ringing of the antenna. There are five vertical lines coming up from the bottom of the image caused by radio frequency interference from nearby portable radios or cell phones (see). Nonetheless, about a third of the way down from the top, a reflection caused by a layer in the geology may be seen to run horizontally across the image, broken in the middle by the trench created to bury the pipe, and exhibiting the characteristic “hyperbola” scattering shape caused by the metal pipe. If the problem were utility location, then the problem is solved at this point by noting the presence of a metallic reflector at the horizontal position of the top of the hyperbola. By rotating the antenna electric field orientation while centred above the pipe location indicated by the hyperbola, the azimuthally strike orientation of the pipe may also be quickly determined from the change in polarization response.

(Olhoefts, 1999)

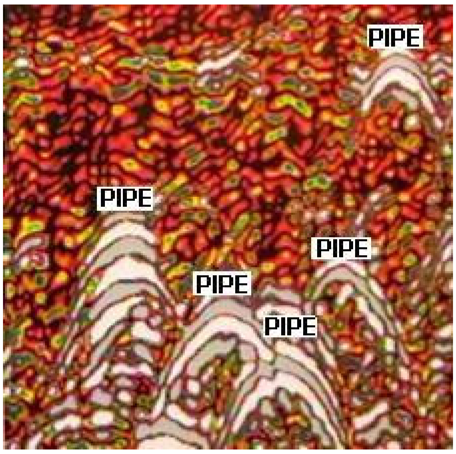

Figure 9 –Side elevation of underground piped drawn by GPR (GeoModel inc, 2009)

2.2.8 Transmitter Cable Locator System - Signal type not defined

These systems use a transmitter which is coupled to a push wire and a receiver unit. The transmitter is pushed through the pipes and the transmitter will pick it up if it is held above the transmitter. It is normally a hand held device and readily available. It is not as highly accurate like the GPR though. These devices will be dept with in more depth in chapter 3.

3 Summary

As-built drawings are mostly done by hand and then redrawn by an engineer. There are currently available technologies to discover buried reticulations.

The technologies currently used most for discovering faults and help with mapping are:

- Rodding
- Cameras
- Jetting
- Opening pipes
- The contractors ingenuity
- GPR

When looking defaults in a reticulation one must look at the most financially feasible method and depending on the situation it might be one of any of the above mentioned. GPR is the most accurate and safest method for detecting under ground reticulations when there are numerous other services in the area but requires an engineer to operate and interpret. There is currently no automated method for discovering leaks or drawing as-built drawings readily available. Other technologies like the transmitter technologies also give an alternative to these methods.

4 Testing of hypothesis

Hypothesis:

Currently as-built drawings are done by hand by the sub-contractor and faults are discovered in water reticulation with surfacing water and in sewer and storm water reticulations by use of cameras and blockages

Answer:

True but with technologies similar and including those working with transmitters and GPR technologies one may now find existing pipes easier. This is still a time consuming procedure and there are still no technologies to link this with automatic drawings.

Chapter 3 – Using positioning technologies to draw as-built drawings, detect leaks or detecting old networks in stormwater or sewer networks

3.1 Introduction

In this chapter a study is done into a few different types of positioning methods using transmission technologies currently available as well as some of the positioning technologies needed for use in utility location in the building and civil field. The aim will be to look at whether it is possible to incorporate these technologies into a system that draws as-built drawings as well as to show if there is a blockage in a reticulation and its position.

3.2 Body of the chapter

3.2.1 Suitable positioning systems

This concept will involve the transmitter moving thru the relevant network and the receiver mapping its progress. The map produces should be drawn as a new layer on an existing map of the site. This new layer should convey information on the location, length and depth of the network. In doing this accurate as-built drawings will be produced and if the size of the vessel of the transmitter is chosen correctly it will stop at blockages, crushed pipes or places where the pipes are missing and so show the exact position on a map. (Bar-Shalom, 2001)

The positioning system should have the following strengths:

- Accurate – This means it should have a low-latency, real-time operation.

- Have a strong enough signal to penetrate the earth to the relevant level.
- Be mobile
- Work outdoors
- The transmitter should not be damaged by water
- The transmitter should be small enough to fit thru the networks
- The transmitter should not get lost in the networks
- The system must be able to incorporate a mapping system as well as an tracing system

3.2.2 Triangulation

Triangulation is a system involving three receivers to form a triangle. The transmitter will move within this triangle and the distances between each of the receivers and the transmitter will then pin point the exact position of the transmitter.

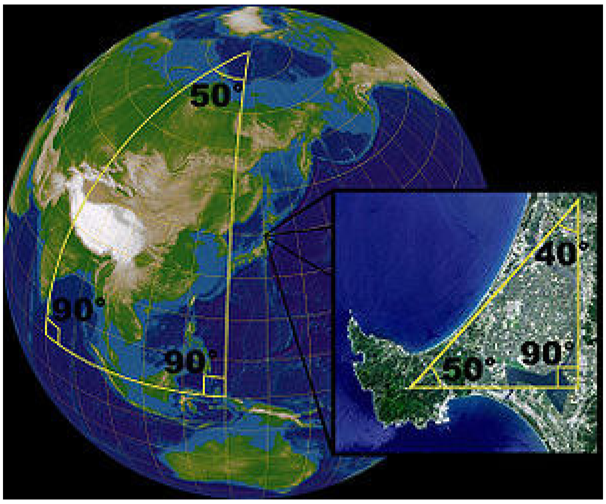

Figure 10 – Triangulation on earth (Triangulation, 2009)

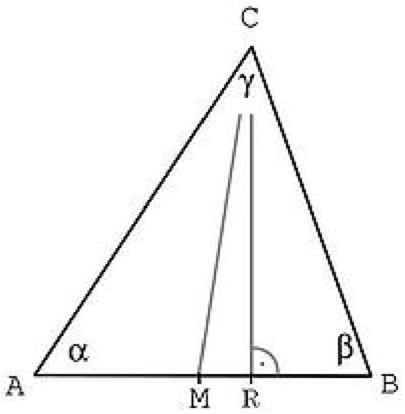

Figure 11 – Triangulation triangle (Triangulation, 2009)

3.2.3 Problems that should be overcome

Soil may case attenuations in any transmitting signal. The receiver may be drilled into the earth in an aim to minimize the amount of soil between the transmitter and the receiver. (Darilek, 1983)

Weather and the environment are both also major factors to be considered when designing a system. Constructions sites are normally dusty, this dust has a very fine gradient produced by heavy construction vehicles and machinery, and there is also always a chance rain, high winds, cold or extreme heat.

If the transmitter is to move through the utility pipes and the pipes are of cast iron it will cause considerable difficulty in transmitting and detecting the signals emitted from the head due to interference from the metal pipe. In addition other utilities such as electricity and telephone are often in the same location as the pipe being cleaned this may result that they detect false and spurious signals because of "signal jumping" resulting in wasted time and considerable needless expense.
(Tashjian, 1992)

3.2.4 What systems are currently available?

The most readily available positioning systems used are the GPS devices. The chip- sized GPS receiver can readily be found in cell-phones or specifically designed products. These GPS work outdoor and are not completely accurate but shows the capability of these and similar devices. More and more companies are beginning to bridge the gap between outdoor and indoor positioning good examples of these are the following:

- MS location WiFi Finder – This allows WiFi users to obtain information of there current location where a WiFi network is present.
- RIFD – In a few hospitals small radio frequency identification(RIFD) tracking devices are used to make sure that babies are not moved out of the restricted rooms.
- Esahau Finder: Is a tool used in supply chain management to locate assets in for instance a warehouse.
- MSR radar – Indoor wireless LAN-based location system able to locate within a 2.3m accuracy
- MIT Criket – A system working on RF transmitter and ultra-sound technologies. Providing precision of up to 1-3 cm.
- RFID – Proximity sensors for close distances.

(Bar-Shalom, 2001)

3.2.4.1 MIT Criket

This system was designed to operate using low-power and may be used for a location aware sensor computing node. It works with a hybrid of a RF transmitter and an ultra-sound system. It computes the one-way propagation time of the ultra sound emitted by a beacon. This is done because of the short time ultra-sound takes to travel thru the air which is faster than the speed of light.

(Bar-Shalom, 2001)

Figure 12 – Ultrasound identification tag (Ultrasound Identification, 2009)

Relevance: This design shows a way of connecting a transmitter to an actual position on a map and it further shows a method of real time tracking. The transmitter is also small enough to pass through utility pipes. Since it uses a mobile transmitter's position it will also indicate blockages.

3.2.4.2 EasyLoc Cable Locator System - Signal type not defined

This system uses a transmitter which is coupled to a push wire and a receiver unit. The transmitter is pushed through the pipes and the transmitter will pick it up if it is held above the transmitter. The Easyloc receiver shows the signal level received, and with a "Max" marker.

(My Pipe Lines, 2009)

Figure 13 – EasyLoc equipment (My Pipe Lines, 2009)

Figure 13 – EasyLoc in operation (My Pipe Lines, 2009)

Relevance: This system is good at locating underground utility pipes, the transmitter is easy to recover, it is easy to pick up blockages and it is accurate. As-build drawings must still be done by hand because there is no way to link the receiver to a pre-sync plan for automatic drawing.

3.2.4.3 Detection systems using signals from transmitters

In this patent an apparatus intended to be used with equipment that is inserted into an underground pipe or conduit, which equipment may include a head that is attached to a member such as a hose or cable, which has a wire attached thereto along its length, the wire is connected to a signal generator which provides a signal to be detected by a receiver above ground to provide the location of the member and its depth is described. The antenna wire is of a highly electrically conductive metal, such as copper. The construction of the wire may be coaxial employing a flexible, yet rigid, spiralled coil steel cable which surrounds the antenna wire.
(Tashjian, 1992)

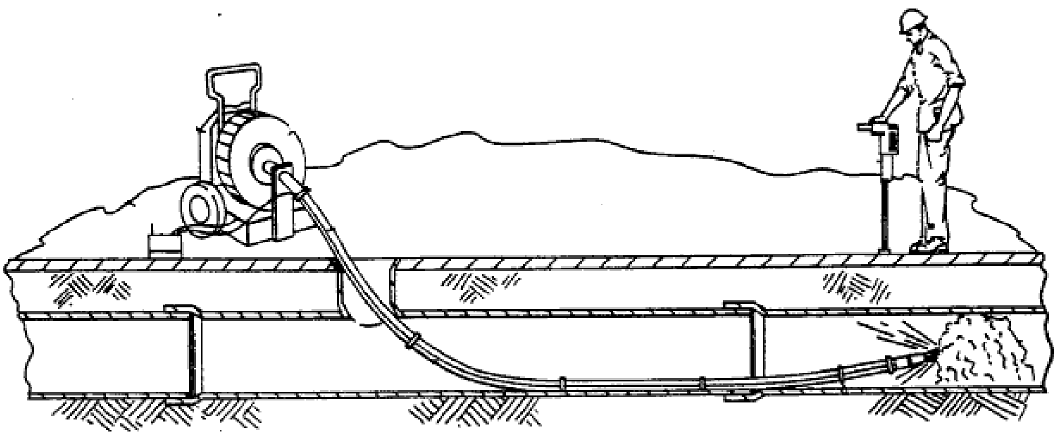

Figure 15 – A typical transmitter and receiver (Tashjian, 1992)

This underground locating apparatus includes a pipe cleaning head carried on a hose and a high pressure water hose whereby high pressure water is fed to

the head which pulls both the water hose and the antenna wire forward through the pipe.
(Tashjian, 1992)

Relevance: This is a system that combines location with maintains and/or repairing. For this reason it is not curtail to know the exact position of a blockage. This system shares most of the traits found in EasyLog system but ads maintains or repair.

3.2.4.4 Detection systems using signals from transmitters – Electrical signal

The devices use an alternating current which is impressed on the concealed conductive object, such as a pipe or cable, by direct connection or by inductive coupling. The object can be located in a horizontal underground plane or in a lateral plane by use of a suitable horizontal axis pickup coil and amplifier with an appropriate indicating device such as a meter or audio transducer. When the receiver pickup coil is brought closer to the object being investigated, the AC signal level increases and the position nearest the object produces the strongest signal.
(Wilkison, 2001)

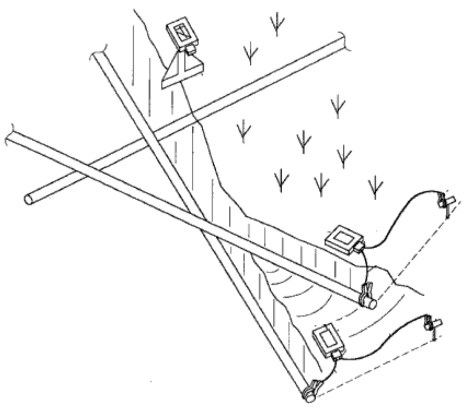

Figure 16 – Setup for an electrical receiver (Wilkison, 2001)

The location of underground objects such as pipes and conduits are located by detecting electrical signals emitted by the underground objects where the radiated signals include spread spectrum modulated RF signals. The system

can operate in a passive or active mode, and in the active mode pseudo-noise (PN) generators can be employed or frequency-hopping can be employed. The use of spread spectrum minimizes or eliminates conflicting signals radiated from a plurality of underground objects and can improve signal to noise ratio of the detected signals.
(Wilkison, 2001)

The system can be operated in either a passive mode or an active mode. In the passive mode a receiver operates in several discrete frequency bands which are detected along with harmonics of the fundamental frequency signals. In an active mode the transmitted signals are modulated by pseudo-noise (PN) signals which are selected for their correlation properties. A direct sequence (DS) method is employed in which a carrier signal is mixed with a pseudo-random pulse train from a spreading code generator in a doubly balanced mixed for RF carrier suppression.
(Wilkison, 2001)

However, these techniques cannot be applied if the "tracer wire" breaks or otherwise corrodes.
(Wilkison, 2001)

Relevance: Because this system works simultaneously on large sections of pipe it does not require real time receiving of the transmitted signal. The system will however not be implementable on non-conductive pipes if it has not been installed with the pipeline. If a mapping system is used on this system it will draw the whole as-build instantly. This system is also not able to indicate defects on the reticulations.

3.2.4.5 Detection systems using acoustic signals for detecting pipes

This invention relates to a method for locating concealed or buried pipe using the "time-of-flight" of pulsed acoustic signals injected into the pipe. The signal is generated, it propagates through the interior of the pipe and is detected by

an array of detectors which, in turn generate signals which are processed in a mathematical algorithm to determine the location of the pipe.
(Huebler, 1992)

The acoustic signal can be introduced in one of the following ways:

- By placing a loudspeaker in an end of a service line of the pipe.
- Attaching a shaker to a service line or main pipe, a riser, a stake pounded into the ground near the pipe or placing the shaker directly on the ground.
- By mounting shakers in a geometric array which is time-phased to focus sound at the pipe or is compression-wave maximized in a circular array.
- By mounting a loudspeaker on a robot inside of the pipe.
- By injecting it into the pipe by using a pressure regulator whose diaphragm is driven with a speaker or a vibrator.

(Huebler, 1992)

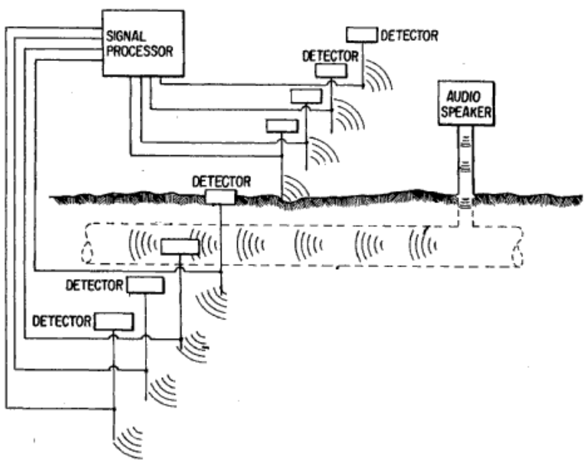

Figure 17 – Detection using acoustics showing positions of detectors
(Huebler, 1992)

Usually, several frequencies will be selected - low frequencies for better wave propagation and general pipe location and higher frequencies for more precise pipe location.
(Huebler, 1992)

Relevance: In this system there is seldom other interfering signals introduced by other utilities but it does not allow for vary accurate locations even with vary high frequencies signals. There is also no way currently available for automated mapping of the utilities. Even thou this system do not indicate methods of detecting damaged pipes acoustic signals have been know to be used for these means.

Another way for detecting the location of an underground sewer by introducing an identifiable, for example, a pulsed acoustic signal into the sewer line at an accessible location and transmitting the signal through the sewer along the underground portion of the sewer line and sensing the signal from the surface at a remote location. The system utilizes a single detector and relies merely on sensing the amplitude of the acoustic signal to determine the sewer line location. Measurement of the amplitude of the acoustic signal is suitable for determining the general location, that is, within a few feet, of the underground pipe.
(Ziska, 1990)

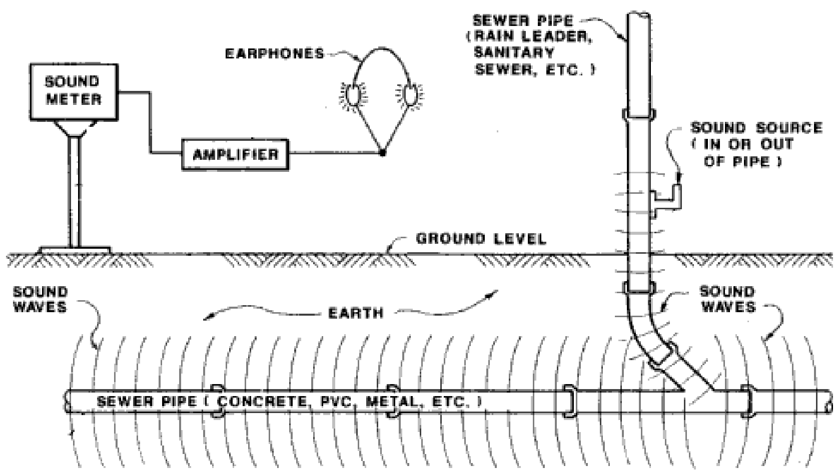

Figure 18 – Detection using acoustics showing pulses in pipe (Ziska, 1990)

Yet another way of acoustic detection is by injecting an acoustic signal into the pipeline and, using a laser interferometer system, measuring the time varying displacements of the earth's surface which are propagated at the site of the leak.
(Murphy, 1979)

Generally, these methods involve generation of an acoustic signal at a point within a pipeline, detecting the signal at another point in the pipeline and analyzing the differences in the signal between the point at which it is generated and the point at which it is detected to determine the location of the leak.
(Murphy, 1979)

The last method of acoustic detection discussed in this chapter is that of where an apparatus is used for locating a leak in a medium such as a steam, gas or liquid pipeline. The apparatus requires a pair of spaced apart piezoelectric transducers which are mechanically coupled to the surface of the pipeline and between which is located a leak. A pressurized leak in the pipeline generates acoustic emissions which propagate along the surface of the pipeline. The emissions are detected by the piezoelectric transducers. By measuring the differences in arrival times of spikes in the acoustic emission at the piezoelectric transducers, the location of the leak can be determined.
(Coulter, 1989)

3.2.4.6 Problems using and acoustic signal injected

Acoustic signals is not suitable for precise location, that is, within a few cm, of the underground pipe as required by most pipe location applications due to complex acoustic ground boundary effects which can reduce the amplitude of an acoustic signal at ground locations above the underground pipe. In addition, coupling of the detector to the ground will vary from placement to placement thereby introducing another uncertainty into the pipe location process, namely, the effect of the variances in coupling on the measured amplitude of the acoustic signal.

3.2.5 What system or what part can be used for this system?

As seen from the above the utility detection systems used in the build and civil environment does not currently include automated mapping programs. It only concentrates on the location of pipes and damages. This being said it is also clear that mapping technologies have been developed and is currently in use in both GPS and other indoor systems.

It is clear that the system should use a system that gives accurate positions to receiver to enable accurate readings. Further the receiver must be placed on a position that has relevance to real position on the site to enable the transmitted signal to be tracked and mapped automatically. For this reason principles like triangulation can be used with multiple receivers. Sensors can give physical or symbolic data. For this specific use physical location data must be given in the form of geographical co-ordinates. A problem which might surface is the signal strength.

3.2.6 Drawing programs

The type of drawing program will have work with the chosen location system. If the location system is like the radar discussed it will have to be interpreted by an expert and redraw on to the correct drawings. If the system works on an positioning system it can be directly linked to a drawing program to draw in heights and positions in there correct positions on a pre-sync plan.

3.3 Summary

There are numerous different of relevant technologies that can be use either individually or in combination with others. By using strong enough transmitting signals in combination with triangulation and a mapping program this system should work in theory. Further research should be done in the relevance of these technologies in the application of reticulation mapping systems.

How this is proposed is by using a transmitter small enough to fit into a water tight ball roughly the size of a tennis ball. This will be placed into the network through manholes and be caught at the next. The position will be worked out by use of triangulation (a system using three receivers to work out the exact position of the transmitter). As the transmitter moves thru the network it‘s progress will be drawn.

3.4 Testing of hypothesis

Hypothesis:
A round transmitter linked to a program with a pre-synced site layout will be left to roll down the network, and so draw up plans and/or identify blockages.

Answer:
Yes, this system could work but feasibilities should be done.

Chapter 4 – Is it feasible to use smart pipe or transmitter technologies to detect leaks, breakages or missing pipes in water reticulations?

4.1 Introduction

For a long time the main focus in the development of pipes used in reticulations have been done in the type of material being used. This chapter will propose an upgrade of the pipes used by adding transmitter technologies into them to create a 'smart pipe' that are able to identify small leaks and there position before they become major problems.

Firstly focus is made on either monitoring the flow of fluids or the strength of a signal in pipes and in so doing discovering faults with the logic that if the flow or signal strength decreases at a specific identifiable point in the pipeline it will indicate a fault like a rupture. Secondly there will be looked at integrating technologies into the reticulation for the identification of the position of the pipeline.

4.2 Body of the chapter

4.2.1 Detecting leaks

It is proposed that this system use a central control apparatus to enable the communication of the possession and severity of a leak or other failure in a pipe carrying a liquid. One existing method uses probes to detect and then to communicate the water leak to the central apparatus. These probes will consist of specially designed fibre glass cloth able to sense water leaks via its build-in plurality of sensors constructed from corresponding plurality of

conductive wires enabling the location and extent of a water leak to be ascertained.
(Doumit, 2003)

Because the central control apparatus is above ground it is able to communicate the relevant information to a preferred medium like for example a cell phone or a computer.
(Doumit, 2003)

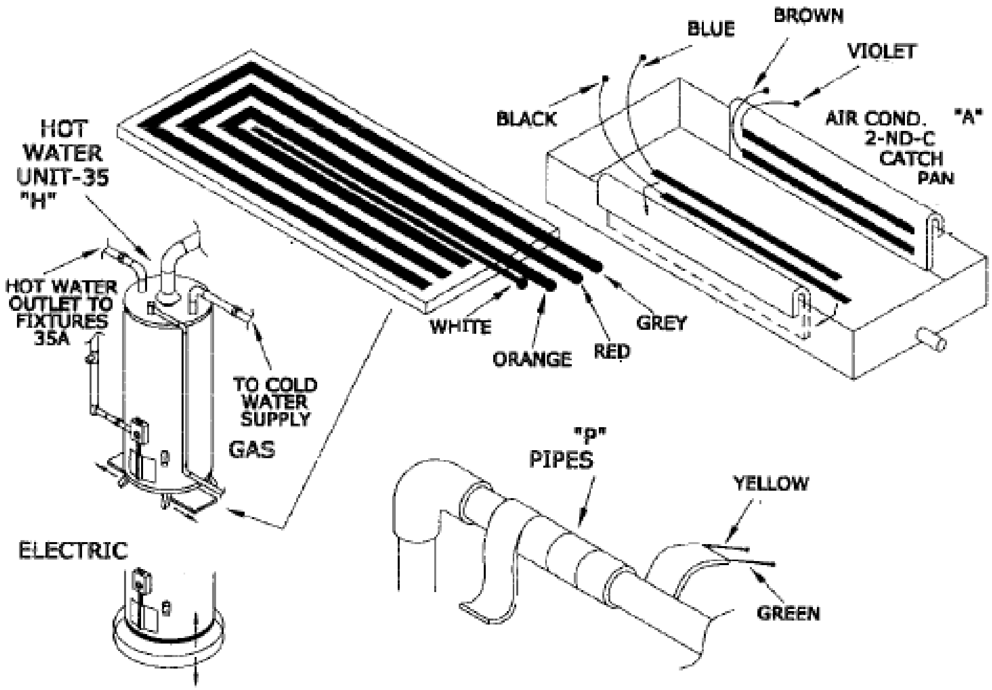

Figure 19 – An example of a centrally controlled detection device (Doumit, 2003)

4.2.2 Technologies for Measuring Flow

Having data collected automatically by the system has the following benefits; it is useful for monitoring flow parameters such as peak flow rate, volume, time to peak flow rate, and water quality indicators for individual events. If this data is correctly interpreted it can be converted into valuable information which will aid in early leak detection.
(Kanwar 1997)

Possible drawbacks

One drawback of this system is the buried component is made of metal like wires. Corrosion and breaks of the metal component may occur after installation which may result in high maintenance costs. When planning a new system, serious consideration should be given to minimizing the distance between monitoring equipment and instruments used underground and the type of material used. Troubleshooting and maintenance are much easier if monitoring equipment is located near the place of measurement.

(Kanwar 1997)

4.2.2.1 Bypass flow meter

A small percentage of the total flow passes through the meter, the dial will then indicate the complete amount of flow due to the directly proportional relationship between the two flows. The main body tube of the unit is simply a section of the same diameter as the pipeline, so that a minimal amount of pressure resistance is created across the meter.

(Conflow, 2009)

Figure 20 – Bypass flow meter (Conflow, 2009)

Relevance:

The bypass flow meter in the above picture uses an analog meter, this can easily be replaced by a digital meter which can be placed at a above ground position for measuring. If an electronic meter is connected it can also be coupled to an automatic data collection system to draw from the benefits from such a system.

4.2.2.2 Data logging system

Subsurface drains from individual sites can be intercepted at the end of specific locations and routed to individual sumps to collect drain water. Flow meters connected to individual sump pumps measured the volume of water pumped from these sumps. Electronic outputs of the flow meters were recorded with data loggers, and readings of the analog registers were recorded manually. The data loggers will record the time when each sump pump starts and stops pumping water. Data collected by data loggers are used to calculate drain discharge volumes and drain flow rates. Subsurface drain flow measured by the data logger system was not significantly different from the manual readings taken by the flow meters.

(Kanwar 1997)

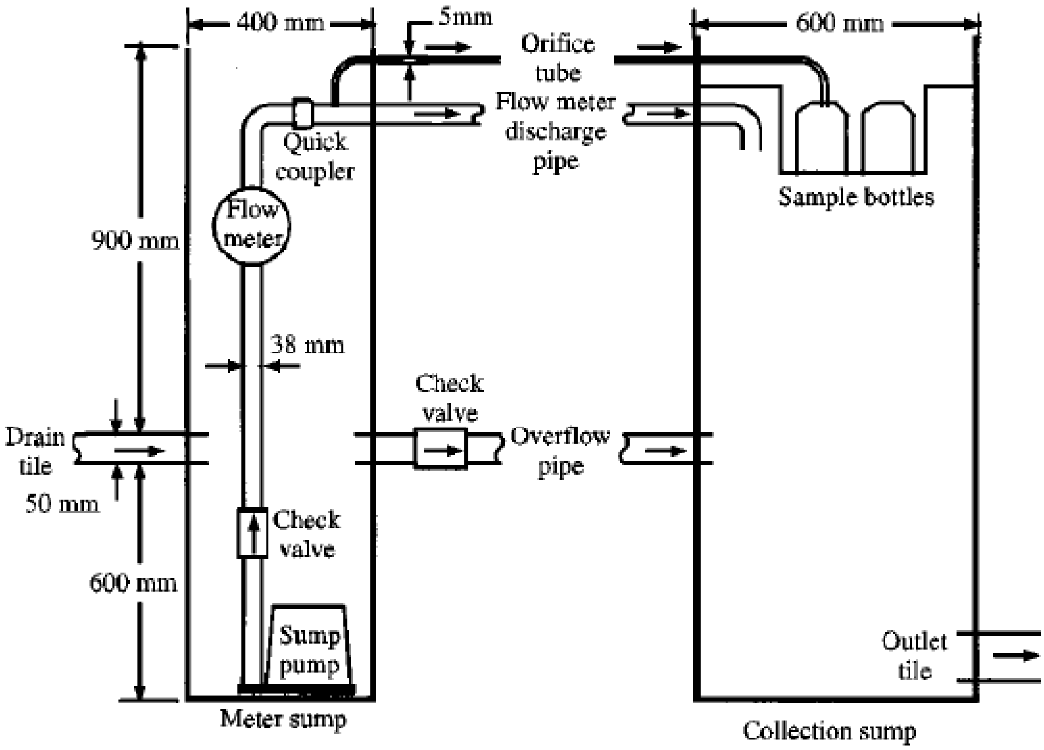

Figure 21 – A schematic of a meter and collection sump (Kanwar 1997)

Automatic samplers can be connected to the system for collecting discrete water samples in addition to the continuous samples collected through tubes.
(Kanwar 1997)

The Neptune T-10 is one example of flow meters. It uses notating disc measuring chambers which measure volume by the positive displacement principle. Analogue registers and transmitters are used in conjunction with this system and they can be mounted on the meters. The electronic transmitters output both current and pulses. The pulse output monitored volume by sending a pulse every time approximately a certain specified amount of water flows through the meter. Data loggers are used to monitor output from the transmitters.
(Kanwar 1997)

The data loggers measured drain flow rate more precisely than the manual readings of flow meters taken three times per week. Although drain flow rates calculated with data logger information were more dynamic than the rates calculated from manual readings, the discharge volumes were not significantly different. The differences between the two methods appear to be random and do not increase with time. Measurement differences also do not appear to vary directly with drain flow rate. These results confirm that the automatic data collection system properly read the flow meter.
(Kanwar 1997)

The results of this study indicate that subsurface drain flow data collected with the data logger system were within 2% of the data collected manually using the analogue readout on the flow meters. The data logger system provides an opportunity to collect essentially continuous data on subsurface drain flows. It is capable of measuring large drain flow rate increases in short time periods that could not be detected with manual flow meter readings.
(Kanwar 1997)

4.2.3 Existing technologies for locating pipe work

4.2.3.1 By using electrical wire

A design is available for introducing a continues electrical conductive wire. This conductive wire is placed underground next to the continuance item or location in future. The wire is then supplied with a high frequency current, electromagnetic waves are emitted from the wire that can later be detected and so doing detect the object to be located.

(Nakamura, 1984)

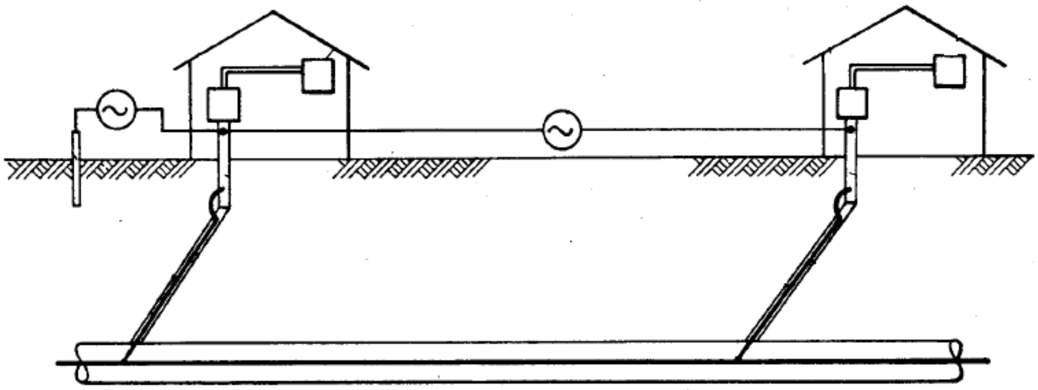

Figure 22 - Electrical wire detection system (Nakamura, 1984)

A major problem with similar types of systems is the fact that if the wire is damaged that the propagation of electrical current will be completely interrupted. This has the effect that the electromagnetic wave that is generated will also cease and this will make detection using these methods impossible from above ground. This problem is bridged by the extremely high frequency of the electromagnetic wave generated. This may enable the current to be transmitted from one end of the cut conductive wire to the next. However is will not be possible to do detections over log distances from the power supply point.

(Nakamura, 1984)

If the wire is coated with a material like a high polymeric organic material having electrical conductivity it will rust. It will also make the wire more rigged and less likely to get cut.

(Nakamura, 1984)

4.2.3.2 Detecting leaks in a water supply line

Detecting leaks in water pipes is in general an inaccurate science and normally involves physical investigation. Some of the methods that have been employed in the past include injecting radioactive materials into the fluid and then the pipe gets rinsed out leaving the radioactive material behind that escaped through the leak. This radioactive material is then picked up by the use of a radioactive detector like a Geiger counter. Where the radioactive concentration is found would be the vicinity of the leak. The accuracy of this method is not very high and it might be difficult to find the position of the highest concentration of radioactivity. Further drawbacks to this method are the fact that the pipe work has to be relatively close to the ground level and there is an accompanied health risk carried. Another method is that of introducing water into the system under high pressure and to then listen for a sound generated by the flow through the leak.

(Offner, 1978)

4.2.3.3 Filling the pipe work with electrical current

One method of detecting a leak in a water supply pipe is by filling the supply pipe and the passing an electrical current through it. This is done to establish a voltage gradient along the length of the fluid in the pipe and then analyzing the gradient to determine the location of the leak.

(Offner, 1978)

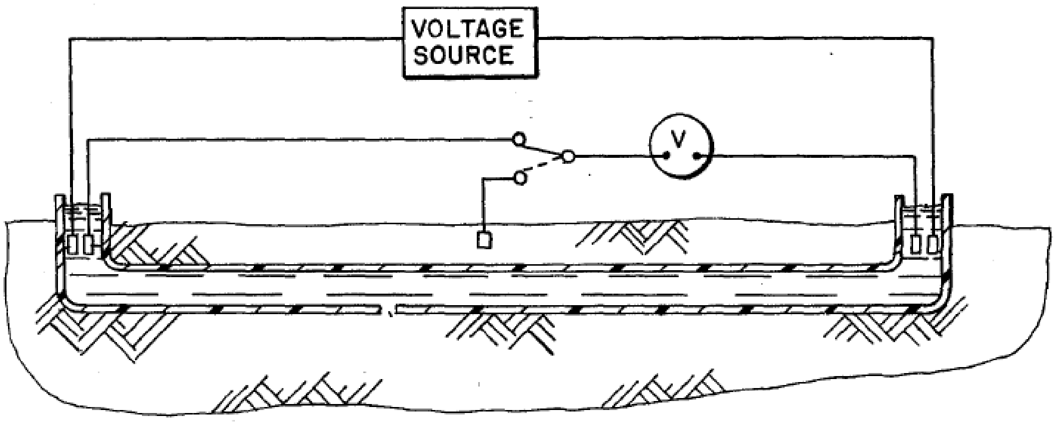

Figure 23 – A detection system using the liquid in the pipe as a conductor

(Offner, 1978)

Another method that may be employed is that of using an electrical conductor. This can be done by both connecting the one bare end of an insulated conductor to one terminal of a voltmeter and grounding the other. This is then drawn through the pipe to discover the gradient. A voltage gradient is established for the distance of the pipe and then the voltage drop between the fluid at one end and ground is measured and the distance from that end of the pipe to the leak point is determined by the relationship between these two voltages and distances.
(Offner, 1978)

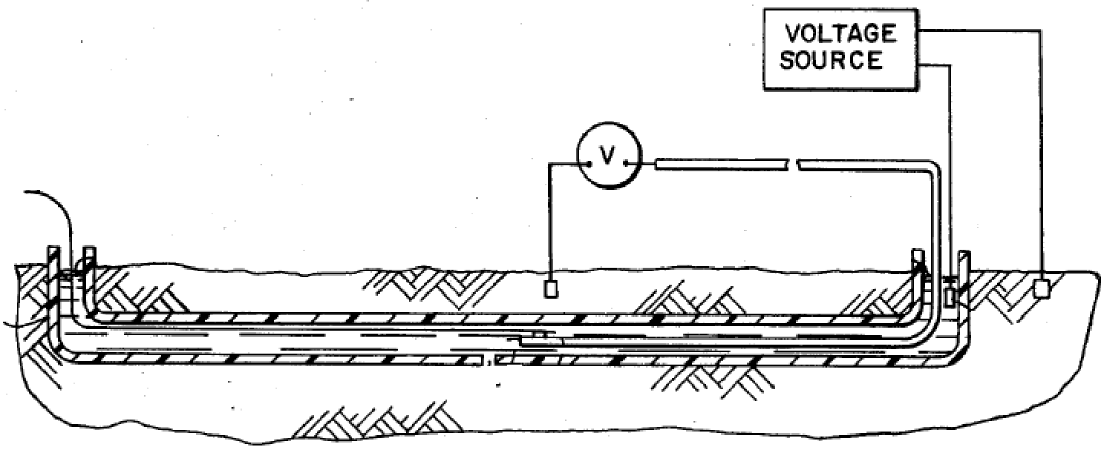

Figure 24 – A detection system utilize a metal conductor in leak detection
(Offner, 1978)

In both these two methods the voltage source of this method should be preferably ac but dc power can also be used with alterations.

4.3 Summary

Detection systems in water reticulations have been around for a number of years. They include systems using electrical conductors to measure voltage drops to methods measuring the flow through the pipes.

It is also clear that centrally control systems are available and has a multiple of advantages connected to them.

4.4 Testing of hypothesis

Hypothesis:

There will be looked at “smart” pipes with transmitter. These transmitters should have to be able to show flow drops between lengths where there should not be. This will show faults in the lines and speed up reaction time.

Answer:

There is no reason that such technologies can not be developed further and then centrally controlled to gain the full benefit.

Chapter 5 – What are the demand for these technologies?

5.1 Introduction

Water supply and distribution network systems in almost all old cities are deteriorating and leaking significantly. The systems thus suffer from high loss of water produced and high system operation cost. In practice, funds are usually allocated to each pipe section based on the expected number of leak occurrences, leak size and leak duration or the expected leak volume.

According to the American Institute of Constructors damage to utility lines is the third most important crisis for contractors after on-the-job accidents requiring hospitalization and contractual disputes with a client resulting in litigation.
(Jeong, 2004)

Reliable information showing to the location of underground utilities is critical for the success of a project and subsurface information is often inaccurate in as-built drawings, and composite drawings that incorporate all the utility records for different owners are not readily available. Existing records and visible feature surveys are typically 15–30% off mark and in some cases, considerably worse.
(Jeong, 2004)

According to Zembillas, 2004, a lack of reliable information on the location of underground services may result in a lot of problems namely costly conflicts, damages, delays, service disruptions, redesigns, claims, and even injuries and lost lives during construction activities. He further states that the location of subsurface utilities might be found on plans and records, but that

experience has often shown that the locations are not exactly as recorded or the records do not fully account for the buried systems.
(Zembillas, 2004)

5.2 Body of the chapter

5.2.1 Subsurface Utility Engineering – SUE

A new field of work has developed know as Subsurface Utility Engineering to fill the need created form the lack of accurate as-build drawings. This fact alone already helps prove that there is a need for more accurate drawn plans. This is coupled with the abundance of sub-surface utilities existing or new involved on construction projects.
(Jeong, 2004)

Subsurface Utility Engineering (SUE) is the field concerned with providing utility information. It combines civil engineering, surveying, geophysics, non-destructive excavation, and other technologies, SUE is charged with provides accurate mapping of existing underground utilities in three dimensions during the early design phase, which avoids unnecessary utility relocations and related downtime, eliminates unexpected conflicts with utilities, and enhances safety during construction. The use of SUE services has become a routine requirement on highway and bridge design projects, and is strongly advocated by the Federal Highway Administration and many State Departments of Transportation.
(Zembillas, 2004)

Subsurface utility engineering (SUE) is the specific field that is interested with buried pipelines and is a fast growing industry segment in the civil engineering arena. SUE has the aim to be seen as a significant tool to reduce the risk from informational uncertainty associated with underground facilities in a construction project. Subsurface utility engineering can minimize the risk primarily through mapping existing underground utility facilities, utilizing surface geophysical technologies, surveying and data management systems. (Jeong, 2004)

5.2.2How does Subsurface Utility Engineering work?

Subsurface utility designating determines the existence and approximate horizontal position of underground utilities using surface geophysical techniques, which include pipe and cable locators, magnetic methods, metal detectors, ground penetrating radar, acoustic emission methods, etc. In the subsurface utility locating activity, minimally intrusive methods of excavation are used such as vacuum excavation, allowing the determination of the precise horizontal and vertical position of the underground utility line to be documented.
(Jeong, 2004)

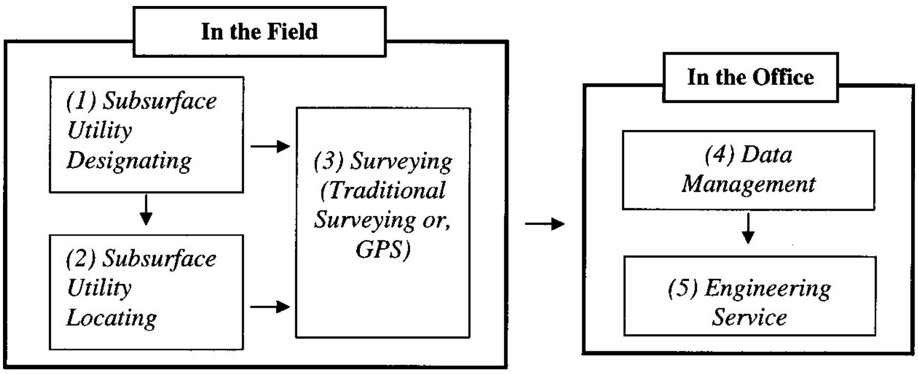

Figure 25 – The flow of data between the field and the office (Jeong, 2004)

The following figure shows the loss of accuracy relating to the stage of the construction project with the use of SUE.

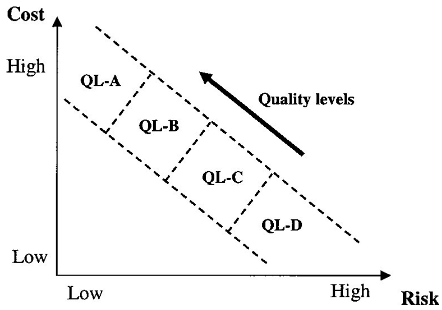

Figure 26 – A comparison between risk and cost and their affects on quality (Jeong, 2004)

5.2.3Cost benefits derived from accurate as-built drawings

The cost for obtaining underground utility data varies greatly as a factor of climate, soil, project specifications, geography, etc., however, in general, the higher the quality level desired, the higher the costs will be to obtain data. The increased accuracy and reliability of the data typically result in lower probabilities of utility-related damages.
(Jeong, 2004)

DID YOU KNOW	Leak size		Litres per		
	mm	Diameter	Min	Hour	Day
A leak does not have to be large to be significant	0.5		0.33	19.8	475.2
	1.5		1.82	109.2	2,620.8
	3.0		8.15	489.0	11,736.0
	5.0		22.30	1,338.0	32,112.0
(calculated for pressure of 5 bar)	7.0		39.30	2,358.0	56,592.0

Table 1 – Water loss for different size of holes under fife bar pressure (Find a Leak 2009)

5.2.4A survey done on highway construction projects

Please note: The following information was relevant on projects done in1997and 1998.

A look at various highway construction projects, in 2004, in the States showed the following results by looking at the savings they had in having more accurate knowledge of subsurface utilities: The cost savings generated by SUE application in 71 highway construction projects in Virginia, North Carolina, Texas, and Ohio were examined by. The total construction costs of these projects were in excess of $1 billion. The construction budget of the various sizes of projects were examined with the construction cost ranging from $0.3 million to $238 million and the cost of using SUE for each project ranged from $2,200 to $500,000. It was determined that the ratio of the cost of SUE to the total construction cost ranged from 0.02 to 10.76%, and the average ratio was 1.39% with the standard deviation of 1.86% was used. (Jeong, 2004)

The following table lists the various categories of cost used in the article *Evaluation of an Emerging Market in Subsurface Utility Engineering*.

Table 2 - Categories for quantification of subsurface utility (Jeong, 2004)

Number	Description
1	Reduced the number of utility line relocations
2	Reduced project delays due to utility relocations
3	Reduced construction delay due to utility cuts
4	Reduced contractor's claims and change orders
5	Reduced delays caused by conflict redesign
6	Reduced accidents and injuries due to line cuts
7	Reduced travel delays to the motoring public
8	Reduced loss of service to utility customers
9	Improved contractor productivity and methods
10	Increased the possibility of reduced bids
11	Reduced contingency fees from all parties
12	Reduced the cost of project design
13	Reduced the damage to existing pavements
14	Reduced damage to existing site facilities

15	Reduced the cost of needed utility relocates
16	Minimized disruption to traffic and emergency
17	Facilitated electronic map accuracy, as-built
18	Minimized chance of environmental damage
19	Induced savings in risk management and insurance
20	Introduced concept of SUE
21	Reduced right-of-ways acquisition costs

The cost in table 3 was derived from extensive interviews with State Departments of Transportation, utility companies, SUE consultants, and contractors. The cost savings in each category were measured using two different methods—estimated cost and projected cost.
(Jeong, 2004)

In table 3 a summary of the research done, in 2004, on the highway construction projects is given.

Table 3 **-** Summary of Cost-Benefit Analysis of Subsurface Utility Engineering (SUE)
(Jeong, 2004)

Items	N	Mean	SD	SE	Min	Max
Construction cost	71	$16,028,648	$31,717,159	$3,764,134	$275,333	$238,000,000
Cost of SUE	71	$86,156	$111,443	$13,226	$2,279	$545,907
SUE cost ratio	71	1.39%	1.86%	0.22%	0.02%	10.76%
SUE savings	71	$398,920	$546,688	$64,880	$6,000	$3,136,000
% of CCS	71	4.26%	6.38%	0.76%	24.11%	34.17%
ROI	71	$12.23	$29.25	$3.47	$0.59	$206.67

Note: CCS=construction cost savings; SD=standard deviation; SE=standard error; and ROI=amount of money saved by the expenditure of one dollar

5.2.5Direct costs associated with finding leaks

Because each construction project is unique it is difficult to generalize when talking about construction projects. This being said one may look at some general costs related to discovering problems in pipelines. This excise was done above on the highway construction projects.

An example of costs that may be incurred on any construction site, in 2009, may be the following: TLB hire, on the 25/08/2009 in Pretoria as per the Junk Mail, will cost you R195-00 per hour and between R220-00 and R240-00 per hour at Mr TLB. An operator for the TLB roughly costs about R20 per hour, a supervisor or foreman about R120 per hour. This totals at about R358.33 per hour and excludes all costs except a part of point four of table 2. Because water follows the route of less resistance and most leaks are discovered by penetrating water, the leak may appear to be at a much different pace than it truly is; this is especially relevant on a site that slopes. This being said fault discovery may even take a couple of day.

5.3 Summary

In construction projects there are many costs involved in not having proper leak detection techniques and proper as-built drawings, a lot of which is underling costs. This has resulted in a lot of research and new technologies in to overcome these problems on construction site

A new field has emerged in the States called Utility Engineering Works that evolved out of the need to know where subsurface utilities are and to more accurately record the installation of new services. On a civil road project in the States a saving of about 4.26% was recorded, in 2004, in the study *Evaluation of an Emerging Market in Subsurface Utility Engineering*.

5.4 Testing of hypothesis

Hypothesis:

There is a great demand for these technologies but also not enough knowledge on them.

Answer:

True there is a great demand but there is enough knowledge about it even if it does not get used in practice often.