# Investigation methods for pipe line tracing on University campus, and leakage detecting in water utility networks: a case study in Miskolc

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**Abstract**. Today, preserving, using drinking water rationally and eliminating water loss are becoming multi-sectors' primary concern all over the world. The considerable amount of water loss due to the ruptures of the aging distribution networks is challenging the water utilities and authorities. The first and most difficult issue is how to find breaks among a vast water main, whose pipes are often made of various materials and buried at different depths. This paper places emphasis on several efficient geophysical methods, compares them, and suggests some ways to combine these methods. The paper also provides a Hungarian case study, which would be solid evidence for water leakage detection in Hungary, one of the most famous country for water resource management. In addition, the authors have put forward several sensible hypotheses to partly account for possible causes of this deteriorated water infrastructure that exist throughout the world. Several geotechnical factors and possibly relevant geotechnical testing methods are also referred put forward for further studies.
**Key Words**: leakage, pipe line, geophysical methods, remote sensing, accoustic methods.

**Introduction**. A safe and reliable water supply is an important component in basic preconditions for human life. In the history of development, past and present, proper handling of water has been thought of as a key factor in all countries and societies in the world (Maidorn & Sewilam 2011).

In recent years, as a result of groundwater depletion in combination with climate change (Taylor et al 2013), preserving, rationally using drinking water and eliminating its loss are becoming multi-sectors' (private sector, public utilities) particular concern all over the world (Carmona et al 2017).

However, a leakage-loss-rates of 50% is still not uncommon in urban distribution systems. Some 250 to 500 million m³ of drinking water is wasted in many mega cities each year (UNW-DPAC 2010). In addition, the water quality can get worse due to direct contact with the bedding layers (Hem & Skjevrak 2002; Fox et al 2016), and leaks also cause low pressure and disturbance in water supply. Sometimes, uncontrolled outflow from high-pressure water pipes can cause damage to infrastructure (Puust et al 2010) and injury to people too.

The water mains are aging due to a lack of resources for replacement, posing a major problem to water utilities and authorities all over the world, even in developed countries. North America, Europe, and Australia are good examples with a huge number of 100-year old-asbestos cement water pipes, which still play a central role in the water distribution system (Hu & Hubble 2007).

To both water companies and authorities, apart from the difficulties because of a lack of resources, another practical issue is how to find breaks along a vast water main, whose pipes are often made of various materials (Fuchs & Riehle 1991) and buried at different depths (Costello et al 2007; Puust et al 2010). So far, however, there has been little innovation to be applied in this area. Meanwhile traditional acoustic survey methods are facing more and more challenges such as not enough workforce, small area of covering per day, selection of pipe material (Ben-Mansour et al 2012), time consuming with tiny number of leaks are found.

Richardson (1935) and Larson (1939) were apparently the first two authors employing acoustic measurements to identify leaks in conduits. As time passes, apart from the traditional methods, including acoustic listening devices, leak noise correlators and tethered hydrophone systems (Khulief et al 2012), the contemporary ones worth mentioning are in-line detection techniques, free-swimming systems (Kurtz 2006) and remote sensing based approach. Each system has its own advantages and limitation as well. Cost effectiveness seems to be a significant element in deciding which method should be broadly used. This paper attempts to propose a combination of traditional and novel methods which might be a good choice for utilities and authorities. This paper also gives an account of several efficient geophysical methods to trace pipelines and shed light on methods for locating leakages.

## Material and Method

***Pipe line tracing and leakage detecting**.* New construction, installment, replacement of pipeline network development has been taken place by different techniques, parties, at different times, and in different places. Consequently, the system is very heterogenic, it may have a high degree of uncertainty, and in many cases even the exact location of the pipe itself is unknown. Thus, tracing is an inevitable activity of each water utility.

***Pipe tracing methods**.* As time goes by, together with the development of materials science, many different types of pipe materials have been used, and each type has its own characteristics to meet the three crucial functions: to ensure the pressure, discharge and provide good water quality. Asbestos cement has played the main role in the whole world in water distribution from 1950s (Howe et al 1989; Hu & Hubble 2005; Ramazzini 2010). And from the 1980s the use of plastic pipe has come to the fore: first PVC, then later HDPE spread (Hu & Hubble 2005). Due to the different requisitions, other types of pipes, such as cast iron or steel, which have their own strengths, have also been used.

In Hungary nearly half of the pipeline networks are asbestos. This is also the case in Miskolc, a city in Northeastern Hungary, which was known for its heavy industry (Máttyus 2008).

Being laid at various depth in a diversity of geomorphological, topographical and geotechnical conditions, the aging pipe line system is posing major problems for water work companies in operating and maintaining them.

Considering the above-mentioned rationales, four different pieces of equipment including ground penetrating radar (GPR), magnetometer, multichannel resistivity - induce polarization (IP) and electromagnetic locator were chosen to detect pipes.

The ground penetrating radar was used because of the positive professional representation and its easy operation process, which could be important in an industrial environment. The proton precession magnetometer was also a reasonable choice to detect metallic pipes. The third method was a combination of the multichannel resistivity and induced polarization method. It took more time and effort to use it, though it provides the most information about the subsurface. The fourth was a professional electromagnetic locator, which operates only for metallic pipe detection.

One area of the University of Miskolc campus was selected for testing the pipe tracing instruments. The validation of the water network map of the University was necessary before the upcoming test of leakage detection. For the appropriate environment, we chose one measuring profile above one large diameter (400 mm) pipe to provide a geophysical noiseless measurement.

Figure 1 presents the measuring profile. Building 1 represents the library, Building 2 represents the University canteen. Point A shows one end of the profile. Its coordinate is N 48°04,805 E 20°46,040. Point B shows the other ends of the profile. Its coordinate is N 48°04,810 E 20°46,061. The yellow line represents the length of the profile (40 m). The blue line shows the water network, which is known in Cadastral Office.

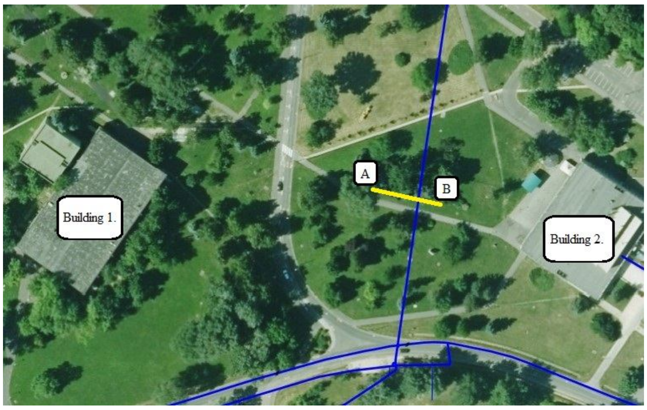


Figure 1. Location of measured profile (Tamás 2017).

*Magnetic method.* Magnetic geophysical survey method is a very popular and inexpensive approach for near-surface metal in the sense that steel and iron pipes should be applicable.

The magnetic field was measured along the 40 m profile on April 20th, 2017, parallel with the sidewalk. Three profiles were measured every five meters. The sampling distance was 1 m. Every point was measured in lower and upper position to detect the near surface acting. The equipment was made by the GEM Systems Inc., the model type was Overhauser GSM-19. This magnetometer is a proton precession magnetometer.

Because of the flat terrain of the measured area, it was not necessary to make topography correction. We had a base station to monitor the diurnal variation. After every profile, we measured the base station. But for the quick measurement, it does not change too much in value.

The interpretation of magnetic anomalies has special difficulties. The finite body invariably contains positive and negative elements because of the dipolar nature of magnetism. The intensity of magnetization is a vector so the shape of a magnetic anomaly is manipulated by the direction of magnetization in a body. For that reason, the magnetic anomalies are not closely related to the shape of the causative body (Kearey et al 2013). Therefore, it presents a maximum and a minimum peak at 32 m and 17 m respectively.

In Figure 2, there was a metal manhole cover, which is presented as noise. Related to magnetic measurement, ambiguity can be a problem. In this case, because of the proper environment, this method operates well and shows the searched pipe, which is between 15-20 m in this research area. With this method, we do not get any information about the depth, but it could be appropriate in locating the metallic pipe.

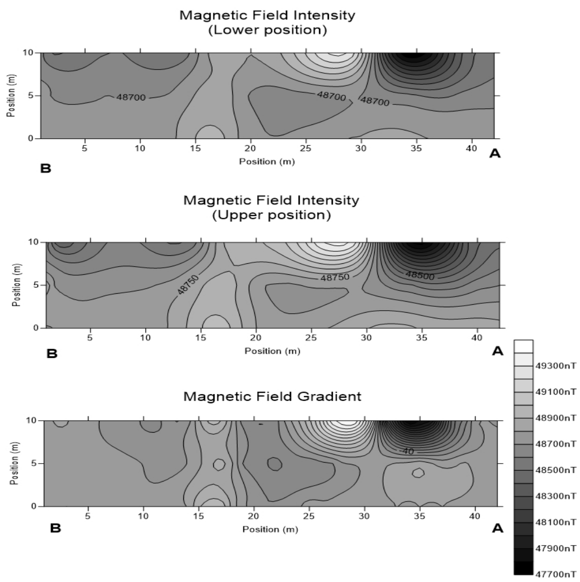


Figure 2. The magnetic anomaly map of the explored area.

*Electrical methods.* The most widely used method is the electrical method. It can be divided into two groups.

The resistivity is measurable in case of artificially-generated electric currents that are introduced into the ground, called resistivity method. Because of the inhomogeneity of the subsurface, the measured value will be apparent resistivity.

The other method is called electrical polarization, whose ground is: if the current is abruptly switched off, the voltage across the potential electrodes will not immediately drop to zero. When the direct current is used to make the polarization, it is time-domain induced polarization and with frequency variation, we can make frequency-domain IP measurement (Kearey et al 2013). The geological rationale of the polarization is also important; therefore, we discriminate filtration, membrane and electrochemical polarization (Turai & Hursán 2012).

The electrical conductivity properties of buried objects (channels, metal objects, etc.) measurably differ from covering soils. We then examined what kind of anomaly images can appear in artificial environment on the resistivity and polarizability maps.

The electrical conductivity of soil is caused by the fluid and the metallic conduction in nature. Small values of resistivity, or in other words, negative anomaly is measured when fluid saturates sedimentary rocks or clay or when fluid flows in large diameter pipes. On the contrary, positive resistivity anomaly is present in case of channels made of stone, concrete and ceramics.

Concerning IP, it is defined to be all polarization such as membrane-, redox- and metallic polarization. Compared to the environment, the anomalies are positive of IP measurements, while the resistivity maps show negative anomalies. The two measurement methods may confirm each other.

Along the same profile as the magnetic method was applied, electrical measurement was conducted on April 28th, 2017. The starting point (0.0) corresponds B in Figure 1, the electrode spacing was 0.5 m and 72 electrodes were used, so the profile distance was 35.5 m and the apparent resistivity values were measured on 16 depth levels. We used Iris Syscal Pro multichannel resistivity and induced polarization instrument. The geoelectric measurement was done in Wenner electrode arrangement. By the 2D inversion method the measured apparent resistivity distribution was transformed to vertical resistivity distribution. The used program was the Res2DInv. Figure 3 presents the 2D inversion result of the measured data. The first vertical section shows the measured apparent chargeability. The last vertical section presents the chargeability model that indicates the geological structure, and the second vertical section shows the calculated apparent chargeability based on the built model. There is 0.3 percentage fitting root mean square error between the measured and calculated values. It is a low value of the fitting error. It could have happened because the soil was wet because of the rain before the day of measurement and the value of contact resistivity was appropriate.

By making comparison between the inverse model of chargeability and resistivity, the pipe location can be determined. In Figure 4, two circles show the probable location of the pipes. The first is horizontally between 17.8-18.3 m and vertically between 2.0-2.5 m. The second is horizontally between 12.2-12.8 m and vertically between 3.5-4.0 m. The first pipe can be found where the resistivity and chargeability values are low. Subsequently, it is probably a plastic or concrete pipe which supplies water. Based on the field observation, it should be a sewage pipe. And there is another anomaly which refers to the location of the second pipe. There is lower resistivity and higher chargeability value relative to the environment. It suggests a metal pipe (steel or iron). This conclusive result shows that the method is appropriate for pipe detection even though it is a time-consuming method.

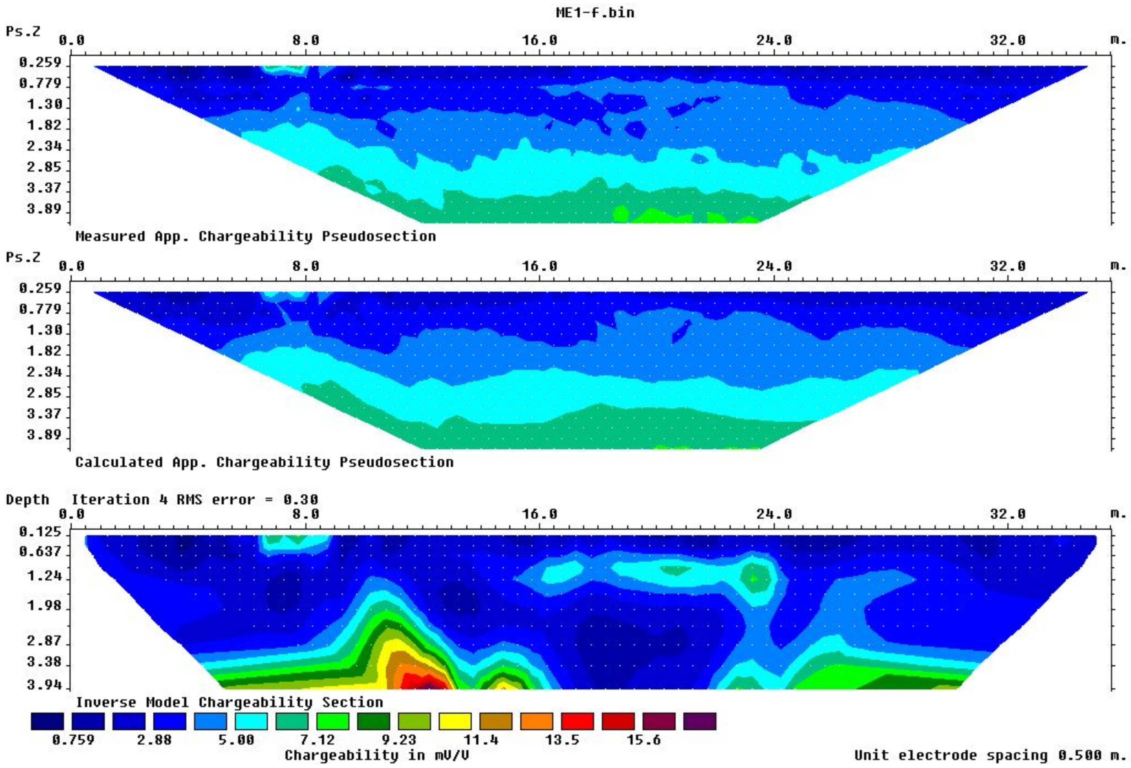


Figure 3. 2D inversion result of chargeability
(Measured by the author, interpreted by Dr. Endre Turai).

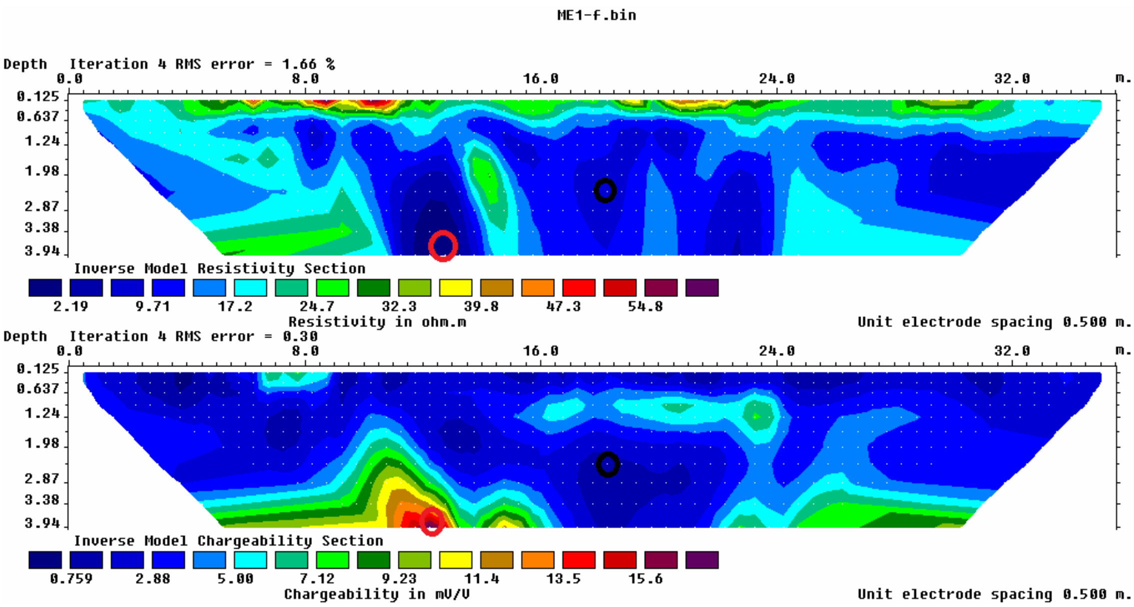


Figure 4. 2D inversion result of resistivity and chargeability
(Measured by the author, interpreted by Dr. Endre Turai).

*Electromagnetic methods.* The conduction of the electromagnetic space is related to the frequency, the specific conductivity of the media, permittivity and the magnetic permeability in homogenous isotope case. Based on the source, it can be categorized. The source can be natural or artificial, in other respects it can work in frequency interval or in time interval (Pethő & Vass 2011).

The ground penetrating radar (GPR) shares this common principle as well. Nevertheless, the used frequency is bigger than the other electromagnetic methods. The horizontal and vertical resolution of the wave length mainly depends on the offset, the distance of the transmitter and receiver. In accordance with the purpose of research, the frequency is selected. The high frequency provides good resolution but only in shallow depth. Whereas, the low frequency provides information about deeper layers with the poorer resolution (Pethő & Vass 2011).

*a) Electromagnetic locator.* In electromagnetic field, two pieces of equipment were employed. The first was the vLocPro from Vivax Metrotech (Figure 5), and the other was the SebaKMT FME990 XT measuring instrument (Figure 6).

The SebaMT locator is made for active line locating. For one measurement, two pieces of equipment were used: the transmitter and the receiver. The transmitter generates electromagnetic field, which helps the receiver to find the pipe if it is made of iron.

Figure 5. vLocPro receiver (middle), transmitter (right) and principle of operation.

Figure 6. FME990 XT in operation at field.

The deepest point from which we can obtain information is approximately 6 m, and because of the electromagnetic principle it can be used for locating only metallic pipe. Noted that, in the environment of the pipe, there can be another metallic conductor, which can also take the generated signal. The correctness of the measurement can be reduced if we do not take it into consideration. Furthermore, if we use the inductive method, it may occur that the signal comes directly from the transmitter when the receiver is too close to the transmitter. In this case, we should use less power. After setting up, the receiver was moved from side to side to trace the path, and three feature conductions would be referred at the same time.

The other instrument, which was used at the same time is the vLocPro. Like many utility line locators, it works on electromagnetic principle. In the receiver, there are four antennas, and as well as some coils in which different voltage is induced. That is why different measurement methods are available for this equipment. The vLocPro's strength is the capability of locating a large number of frequencies or frequency combinations, ranging from 512 Hz to 200 kHz. The above mentioned methods are for conductive pipe location. This instrument has an additional function to survey the plastic pipes. The probe location is used for locating the probe only, but it can be indirectly used to locate the pipe. In practice, the probe is used for locating non-metallic pipes or ducts, and the camera end is a sewer inspection camera. This type of equipment is prevalent in the practice because it is easy to use, and the measurement is quite quick. However, when locating an object, always be aware that radiated signal can be affected by other electromagnetic buried lines or metallic features (e.g. crash barriers or wire mesh fences).

*b) Ground penetrating radar.* The ground penetrating radar (GPR) (Figure 7) has many applications such as imaging shallow soil at high resolution, mapping water tables or locating buried channels. The radar velocity depends mainly on the dielectric constant and conductivity of the subsurface.

There is a connection between the depth of penetration and resolution. Greater penetration can be achieved with lower frequency, so the penetration depends on not only the frequency but also the properties of subsurface.

Due to the lack of soil parameter information, two frequencies (500 MHz and 100 MHz) were chosen to detect pipes. We crossed several different diameter pipes on the surface, but we did not get encouraging results.

The waves move slowly in wet clay and the energy is moderately absorbed. However, based on the raw data (Figure 8), one may conclude that this instrument is suitable for pipe detecting only if the antenna is fitted to the relevant soil properties.

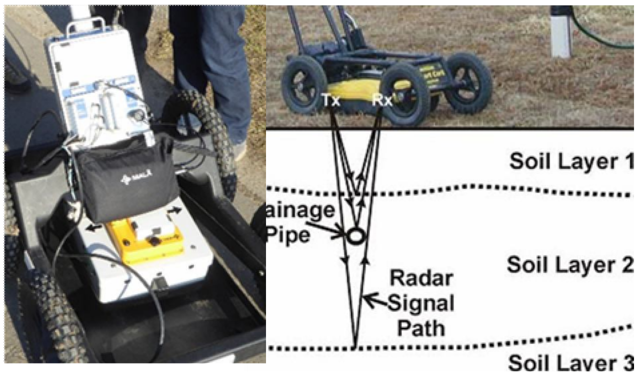


Figure 7. Ground Penetrating Radar with 100 and 500 MHz antenna and principle of operation (retrieved from: https://goo.gl/images/ixvJzd).

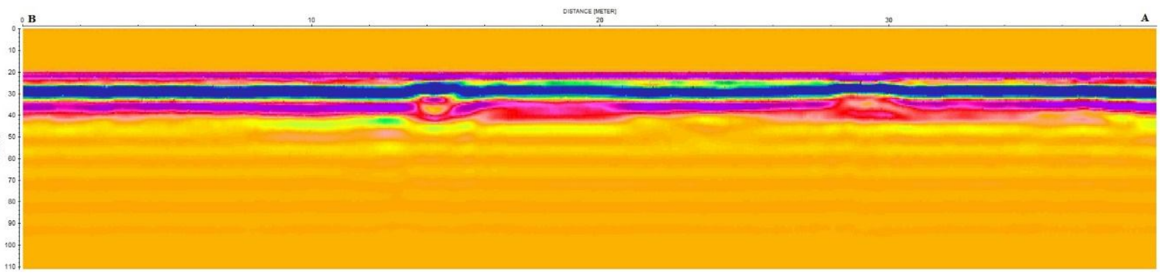


Figure 8. Raw radar gram on B-A profile.

***Leakage detection methods***. There are several methods to identify leaks: the water loss analysis, pressure management, acoustic methods, and remote sensing-based method.

Water loss analysis and pressure management are the two methods of measuring either water consumption or water pressure in the pipe line during night time in several days to show the existence of loss. Both are not thoroughly effective to identify leakage.

Acoustic methods have been used widely for many years. These methods allow a continuous operation of water distribution network , while the measurement is still being conducted. Besides, they are highly reliable and would be reasonable as well if the leaking zone are predefined within a walking distance. However, some drawbacks like being time consuming, and not being economical due to upfront investment and preparation, lead us to a convincing remote sensing-based method.

*Remote sensing-based method.* Up until now, in a passive manner, the leakage detection can start only after a consumer error report or if the seepage appears on the surface. However, it can take quite a long time, and huge amount of water can flow away in small intensity. The remote sensing-based technique can offer a solution to these problems.

Remote sensing-based method, a method of determining underground water content was patented by the United Stated, coded 9285475 (Guy & Nevo 2016) under the name "System and method of underground water detection".

**Discussion**. In cooperation with Utilis Ltd., we carried out the verification of new remote sensing-based method in two cities: Budapest and Miskolc. In this paper, we introduce a case study of Miskolc city only (Figure 9). A scan of satellite image dated April 25th, 2017 was used to analyze and resulted in 235 leaks over 450 km of pipeline in conjunction with their degrees of probability.

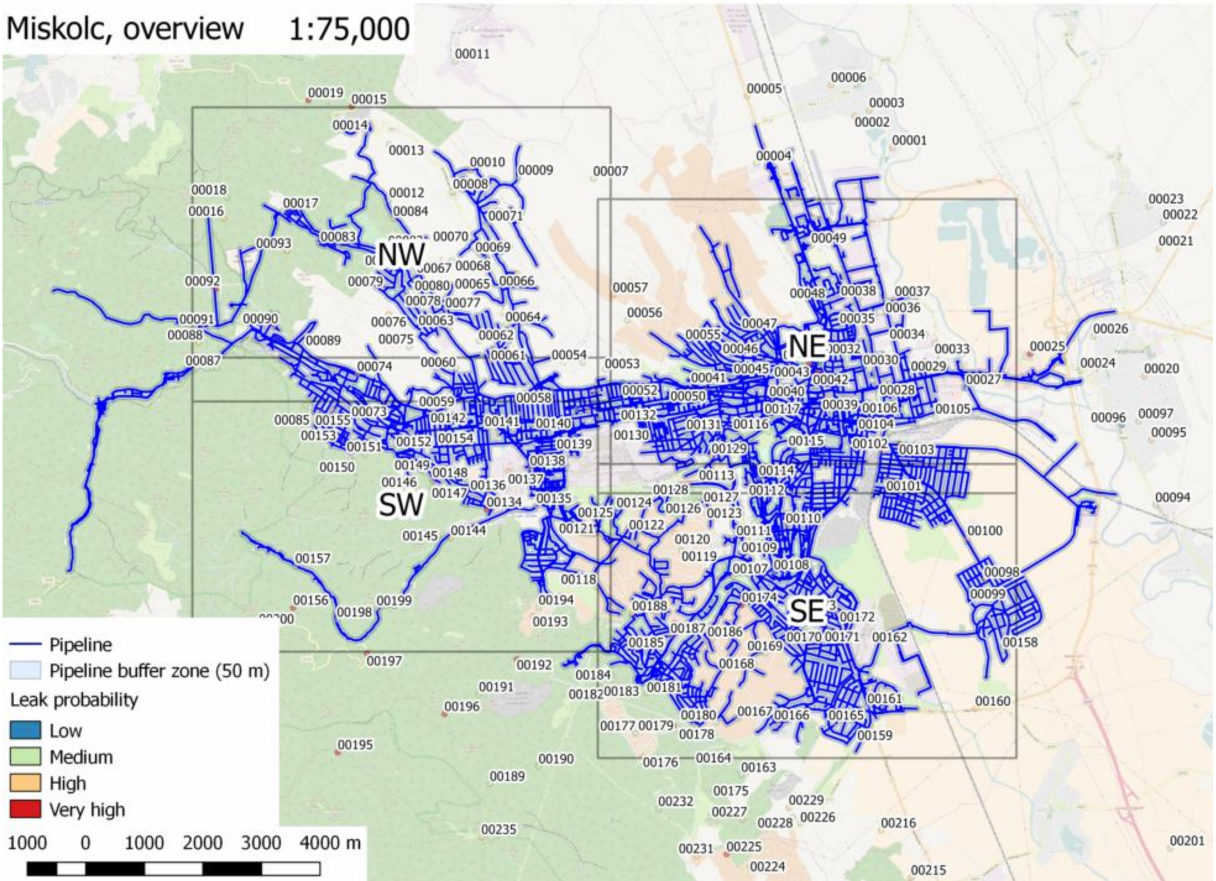


Figure 9. Suspected leak map of water pipeline network in South-western Miskolc, Hungary.

The essence of remote sensing is the information collection about surface, objects etc. without direct physical connection. The information comes mainly from the behavior of electromagnetic waves. Based on the source of waves, we distinguish passive and active forms. The passive form means the source is natural such as sunlight, Earth's magnetic field or artificial source but not for remote sensing aim. The active method means that the source or the field is artificial, and can be made by radar or sonar. Related to the leakage detection, the radar technique is important.

Short electromagnetic wave is emitted by an antenna and the reflected wave provides the information. The travel time of the wave gives information about the distance, and from the amplitude we get information about the reflection property of the reflecting object. Radars use microwaves. It is suitable to investigate the Earth because the microwave is not absorbed into the atmosphere, and the dispersion is negligible, so it is insensitive for the weather. Advanced Land Observing Satellite (ALOS) satellite has a channel, the PALSAR L. Its pixel size is 10 m and its band is 23.3 cm. Therefore, it could be a good radar to observe the seepage in the soil. To gather information about soil moisture, we need to use the L band, which means 15-30 cm wavelength and 1-2 GHz frequency.

The received image is affected by amplitude, which depends on target property structures and the dielectric properties. This is a useful connection because the water's dielectric constant on one order of magnitude is bigger than other objects in the environment. Hence it could provide information about leakage.

According to Utilis Ltd., treated drinking water has unique reflection signal and thus potable water can be distinguished from rainwater, groundwater or any subsurface water bodies. Figure 10 briefly presents the filtration and analysis procedure so as to result in the final products including suspected leak map, leak sheets, web application link and data form file (Figure 11).

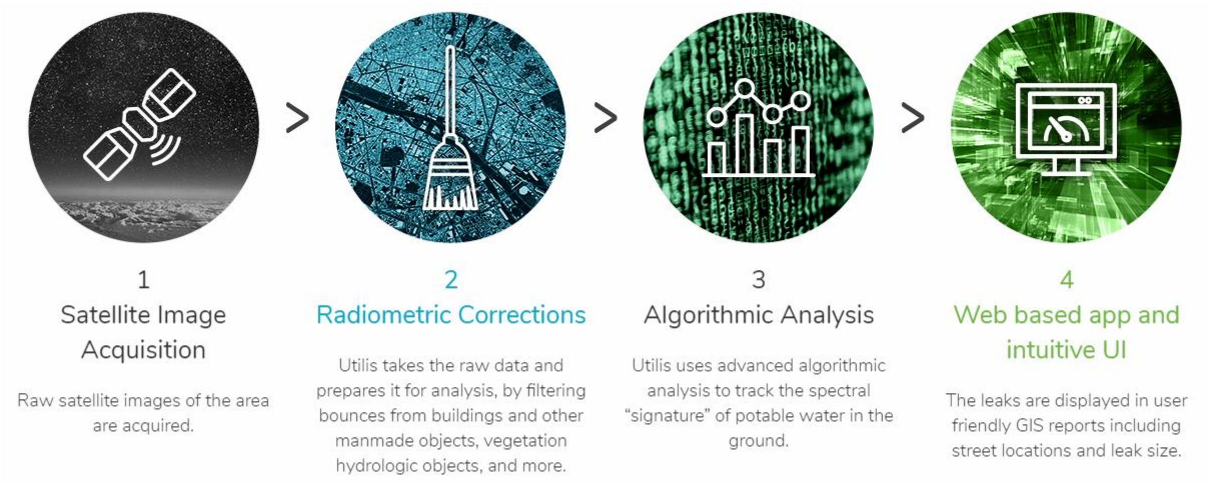


Figure 10. Flow chart of leak detection technique by Utilis Corp (Guy 2017).


Figure 11. Final products of remote sensing technique by Utilis Corp (Guy 2017).

GIS files are polygon layers of the suspected leaks locations. This map file is delivered in both KML and SHP formats for direct use via Google Earth, or extra analysis which may be conducted by GIS experts.

Leak sheets are a series of maps for the field survey, showing the location of potential leaks. This is a PDF file with a map for each leak with all of its criteria: address, image date, pipe material, etc. with the purpose of field data collecting and monitoring.

Web application link is a link for an interactive map of the leaks that is based on Google maps. This is for office use and can be used on the field with the mobile phone GPS locator for better navigation and accuracy.

The data form is a sophisticated Excel form with all of the analysis data in an Excel table. It holds all the data from the GIS layers.

This method does not substitute the acoustic method, but it helps improve the efficiency of the acoustic method and prevents the long-term leakage. To determine the exact location of the leakage with a considerable degree of certainty, the method itself needs to decrease the noise, which is caused by vegetation, high building and metal object etc. (Guy 2017).

*Acoustic method.* The acoustic leak-detection technique has been used for many years, drawing on external measurements of noise and vibration emitted from the turbulent jet of water escaping the leak site to locate leaks with ease (Gupta et al 2014).

The sound waves propagate along the pipe wall, fittings and via the water. The sound velocity depends on the ratio between the diameter, the wall thickness, and the pipe material. The metallic pipes propagate the noise well. On the contrary, due to its elastic characteristic, plastic pipes reduce noise. The attenuation is also in connection with the frequency. The higher frequencies are always attenuated more quickly than lower frequencies as the distance goes greater. One of the basic methods is the leak noise correlation. It works by comparing the noise detected at two different points in the pipeline. If the leak is in a different distance from the sensors, then from this different arrival time, the accurate location of the leakage can be calculated. Figure 12 presents the method. Where Td: time delay, V: velocity of sound, L: the distance from the nearer logger to the leak site, D: distance between the loggers (Hamilton & Charalambous 2013).

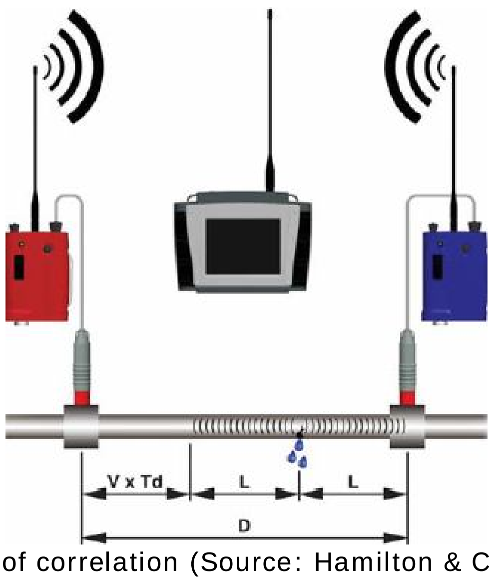


Figure 12. Principle of correlation (Source: Hamilton & Charalambous 2013).

In combination with previously mentioned methods, the most commonly used pieces of equipment are the ground microphone and the correlator. During our field work, from the 14th to the 16th of June, we used the Hydrolux HL 50 hand-held leak locator (Figure 13) which has an integrated sensor and wireless headphones.

The Correlux P-1 digital correlator (Figure 13) was used for leak location on water pipelines for clarification. It is a reliable device, which is ideal on plastic pipes too. When we know the approximate location of the leakage, then we specify it with Correlx P-1.

The escaping water from a leak under pressure creates a noise which travels along the pipe in both directions, and the measurement operates well only in sections without branches. Because the noise is recorded by two sensors (piezo-microphones and hydrophones) attached to the pipes, valves or hydrants, it is amplified and transmitted to the correlator. The Correlux P-1 correlator compares both signals and calculates the exact distance of the leak by using the signal delay, the sound velocity and the sensor distance (Seba KMT 2000). For the calculation, we have to enter the pipe properties (i.e. material and diameter) and the distance of the two correlators. This equipment has many advantages, one of which is that it identifies the leak fast and easily by using the overview measurement with unknown pipe parameter.

For an efficient measurement, a good knowledge of the pipe system is necessary because if there is one branch in the measured line, the equipment will show false data. Furthermore, if there are more leaks on the measured section, the outcome will be wrong, leading to different results of each repeated measurements. In addition, the precipitated content on the inner wall of the pipe can lead to incorrect results. Under ideal circumstances, when we have all the necessary information about the network, we can enter even more pipe materials for one section if the pipe was partly reconstructed earlier; thus, we can have centimeter accuracy result.

Figure 13. Leak locator (left and right) and Digital correlator for leak location on pipe (middle).

Gorján (2016) mentions that real losses are in connection with two main parameters. The first includes the soil and environment conditions. The main effects are the soil types and their movement, the corrosions on the pipe and the heavy road traffic. Failures rarely occur because of street earthwork or frost. Seventy percent (70%) of all failures are linked to these conditions. The second parameter is in connection with pipes, construction and the operation. According to Gorján (2016), the factors affecting real loss are:

- the soil type;
- the number of service connection;
- network pressure;
- the pipe diameter;
- pipe material;
- pipe connection;
- the efficiency of the corrosion protection;
- fittings;
- the earth works nearby the pipe environment;
- the bedding type and the pipe-laying depth.

Some other factors include the widespread types of pipes in terms of diameter, material and age. From the relevant literature (Habibian 1994; Boxall et al 2007; Hu & Hubble 2007), we know that there is a connection between pipe materials and errors. The major risk frequently comes from asbestos cement pipes, which were laid around 1960-1970. Furthermore, extreme weather like capricious change in precipitation and temperature probably makes a considerable contribution to a high burst rate.

Nowadays, there are many methods of leakage detection, but all of them need an accurate knowledge of the water network. Thus, we examined many geophysical methods related to pipe detection. We applied multichannel resistivity and induced polarization methods. Based on measurements, it could be concluded that each method is serviceable for pipe detection in an appropriate environment. Because of the different operating principles of the equipment, we know that not all instruments are suitable for each pipe type. In respect of leakage detection, the acoustic and correlation methods in leak detecting are time consuming and expensive if they are carried out for the whole city. Besides, challenges posed by pipe material is another issue. Since the introduction of Utilis' Remote sensing-based method, the leakage detection has not had to rely on a customer failure report only, but has been operated much more easily, much faster, more economically and with higher efficiency. The combination with acoustic methods could accelerate the leakage detection and obviously reduce the water loss.

**Conclusions**. Regardless of global growing demand for drinking water, a great deal of this resource is still lost throughout the world. This situation may become even more serious due to a variety of reasons such as: the depleted pipe line system, extreme weather in the context of climate change, the complicated changes of bedding layer condition.

Lacking resources in maintaining or changing these water distribution system is common even in developed countries. In that milieu, thoroughly overcoming water loss in discharges of potable water is the first priority.

With a 70% success rate in Miskolc, the combination of Utilis methodology and on field acoustic measurement has proved to be an ideal method for effective leak detection. Nevertheless, for a sustainable development in a long-term plan, the authors would suggest a greater detail study on considerable variation of bedding layer condition that emphasizes on geotechnical aspect to thoroughly and closely examine the principal causes of this deteriorate situation.

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