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Reduction of Non-Revenue Water through Continuous Acoustic Monitoring

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ILLINOIS SUSTAINABLE
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ABBREVIATIONS

AC	asbestos cement (pipe)
AMI	advanced metering infrastructure
CAM	continuous acoustic monitoring
CI	cast iron (pipe)
DI	ductile iron (pipe)
DMA	district metered area (also called demand management areas)
FCC	Federal Communications Commission
IL	Illinois
ISTC	Illinois Sustainable Technology Center
NRW	non-revenue water
PA	Pennsylvania
PVC	polyvinyl chloride (pipe)
POI	point of interest (potential leak suspect)
SCADA	supervisory control and data acquisition
WV	West Virginia

ABSTRACT

This project sought to further the Illinois Sustainable Technology Center's (ISTC) stated goal of reducing a billion gallons of water waste in the state of Illinois. This reduction can be directed in part at water utilities that transport billions of gallons from treatment and supply facilities to the customer through aging pipelines. Utilizing an advanced leak monitoring technique, this project has achieved measurable water savings in a water distribution system in less than a year, and has demonstrated the potential for significant water savings for other water systems. An economic analysis of the costs and benefits of the system has been provided to offer guidance to aid utilities considering this technology.

This pilot project sought to quantify the reduction of infrastructure leakage using active acoustic monitoring. The installation of advanced correlating continuous acoustic monitoring (correlating CAM) technology alerted the utility to water leaks close to the moment they started, rather than after they surfaced. A key to effective monitoring is the metering of the system supply to quantify leakage and determine the extent of non-revenue water losses. The economic analysis includes not only water production cost savings, but also identifies secondary benefits including projected reduction of overtime due to leak repair and damage caused by leaks. Because the system was put in place within 60 days of the start of the year-long project, there was sufficient time (including fall and winter months, when leaks are most prevalent) for leak equipment to be assessed and savings to be identified.

EXECUTIVE SUMMARY

OBJECTIVES

The objectives of the project were as follows:

- Provide a demonstration of the workability of an advanced correlating acoustic monitoring technology to effectively reduce water leakage in a water utility network.
- Evaluate the full financial benefits associated with the technology and provide a cost model to evaluate the expanded costs and benefits of operating such a system.
- Provide a forum for utility operators in Illinois to be made aware of the technology and the cost/benefit analysis through a workshop to discuss the technology and illustrate the cost model.

BACKGROUND

Utility water pipes leak and the aging pipe infrastructure is certain to make leakage control a vital element in water system management. A cost analysis has been provided in this report that will enable utilities to assess the benefit of finding individual leaks before they surface. The high cost to replace or rehabilitate aging pipe often far exceeds the cost of frequent leak repairs; it is less expensive to maintain the old than install the new. The precise location of future water leaks is unpredictable. There is not necessarily a direct correlation between pipe age and failure rate, and predicting weak points where the next failure will occur is impossible without employing costly condition assessment techniques.

The utility selected for the test, Illinois American Water, operates numerous water systems in the state including water supply priority areas (northeastern Illinois, east-central Illinois, and southwestern Illinois), which have been identified on the basis of limited water supply and projected growth (ISWS, 2006). Like other water utilities, Illinois American Water faces the issue of managing water loss. In 2013, Illinois American Water generated and purchased a net 43.4 billion gallons of water, of which 35.6 billion gallons were billed to customers. It is thought that 87% of the remaining 7.8 billion gallons of non-revenue water (NRW) is attributable to leakage. In 2013, the NRW water in the system studied in this project was 15 million gallons. Not all non-revenue water is leakage; some unsold water is used productively to flush and fill water lines and fight fires. Other NRW includes water lost to theft or inaccurate metering. Like other utilities, American Water seeks cost-effective ways to reduce non-revenue water with a focus on leakage. As is standard practice, the utility quantifies NRW by computing the difference between total meter water supply and the aggregate of customer-metered consumption on a periodic basis. This trial also provided the opportunity to employ a technique of examining minimum night flow that is used to estimate changes in leakage on a regular basis.

While the public is most aware of the spectacular leaks that flood streets or send water dozens of feet into the air, it is often the leaks that do not readily surface that have a greater impact on the NRW of the water utility. To find such leaks, utilities can choose between passive or active approaches. The passive approach is simply to endure losses from non-surfacing leaks and wait for them to surface and then respond. This approach is done most often when the cost of water loss does not offset the cost of active approaches. For systems with few hidden leaks or very low-cost water, this passive approach can be an appropriate strategy. But many systems experience leaks that take weeks or months to surface or have water that is either expensive or scarce. As a result, many utilities should consider an active approach of undertaking periodic leak surveys of the water system.

The science of finding leaks by listening for leak noise was developed over many years, beginning with manual methods and developing into today's sophisticated electronic devices. In 2005, American Water helped to initiate a first-of-its-kind listening system to address leakage and called it *continuous acoustic monitoring (CAM).* The process involves placing sensors throughout a water system that "listen" for the vibrations emanating from water leaks and carried by the pipe. The sensors are programmed to listen every day and report even the quietest sound through a sophisticated communication network. The network that communicates the information to the utility is an advanced metering infrastructure (AMI), the same system that transmits water meter readings daily. Today most AMI systems have some capacity to transmit acoustic monitoring information. American Water received funding from the Water Research Foundation to study results from this first system over three years (2006-2008). The system studied was a network of mostly aging pipe serving 5,000 customers in southwestern Pennsylvania. The results of the study documented the favorable results of the approach in reducing leakage and identifying non-surfacing leaks faster, which lowered the cost of repair when the leaks were quickly identified. However the study also pointed to deficiencies in the system, including the difficulty in separating true leaks from other sounds such as mechanical and electrical equipment, and the inability to detect leaks where plastic pipes, often used in repairs, were present.

The leak detection industry accepted the challenge and has made advances to overcome these issues. One way that non-leak noise (false positives) can be eliminated is through a technique known as correlating. With this technique, two sensors on either side of the leak can listen for the leak noise simultaneously. Using information about the size and material of the pipe, an accurate location of the leak can be provided and extraneous noise eliminated. This technique requires a communication system that works two ways: (1) sending data from the sensors, and (2) instructing the sensors to listen. Two-way communication is also needed to set the time on the sensors precisely, as simultaneous correlation requires millisecond accuracy. The issue of listening for leaks passing through plastic has been addressed with new technology as well. Cement and plastic pipes emit subsonic noise, but the sensitivity of sensors has overcome the problem. However, plastic still does not transmit vibration as well as metallic pipes.

APPROACH

With only one year to install and test the acoustic monitoring system, Echologics (the company chosen to supply the sensors) worked quickly to fabricate and install prototype sensors in selected fire hydrants in the Waycinden district of Des Plaines, Illinois. The devices are housed in modified hydrant caps and installation was relatively rapid. The Waycinden system contains over 130 hydrants and, based on the range of the sensors, 79 correlating CAM units were installed in September, 2014. The system took about a week to normalize and build a reasonable history on background noise before the system was fully ready to detect leak noises and perform the correlations on suspected targets.

The communication devices that relay the acoustic information were also housed in the hydrant caps. The devices work like a mesh network, relaying information to powered repeaters (if needed) and on to primary collectors placed on top of the Linneman Road standpipe and the Mount Prospect Street Tank building at the ends of the Waycinden system. Cellular communication forwarded data from the collector to the Echologics office near Toronto, Canada. Echologics managed the analysis of data during the project, but American Water staff accessed the data to evaluate the utility-managed option. The system is also currently in place at the Charleston district in West Virginia where American Water staff maintains the system. Results from the Charleston system have been impressive and are attached to this report in Appendix C.

RESULTS

As expected, especially with a cold winter, there were a number of leaks during the September 2014 - June 2015 study period. In all, 13 leaks occurred in the ten-month period, which was about the number anticipated. The majority of leaks in the winter were primarily breaks around the full circumference of the pipe, which was similar to the pattern observed for past leaks but were more numerous in this winter. It was suspected that these circumferential breaks would surface rapidly and that is what occurred. These leaks were not expected to be detected by the Echologics system if they began surfacing and were repaired before the sensors ran their nightly check. What was not expected was the behavior of the corrosion leaks, which were fewer in number than expected. With one notable exception, these leaks also surfaced rapidly. This means that the Echologics system had few chances to detect leaks that ran underground. Consequently, the economic case for the installation of the acoustic monitoring systems for a five-year program was not strong based on the initial study period.

The Echologics prototype system had issues that became apparent after the installation. A software issue led to the rapid consumption of batteries in at least 12 of the 79 units. Some of the battery issues coincided with periods of leaks and prevented some opportunities for initial detection. However, Echologics did restore some units during an interim period and confirmed that the units, if energized, would have detected leak noise. Ultimately, the prototype units were completely removed in January and February of 2015 and replaced with the marketed version that remains in operation. This led to a one-week delay in our ability to detect leaks, as the units are not activated until they have some time to gauge background noise.

CONCLUSIONS

It would appear that the leak noise correlating system is workable. Several problems occurred with the original prototype, but it is possible that over a longer working period the system may prove successful in the study location. Echologics verified that noises from undetected leaks were either detected by other units or would have been detected by a working unit. The use of SCADA (supervisory control and data acquisition) data to look at night volume confirmed that no significant leaks ran for any length of time in the system during the study period.

Since only one leak ran undetected for a prolonged time during the study period, the overwhelming conclusion was that there was no significant opportunity for major savings, at least from this system. Consequently, adopting a system of this type cannot be justified – at least on the basis of the ten-month study period. Historical records indicate that there are usually a higher number of corrosion (pinhole) leaks than the number that was observed in the study period. But it is not clear if these lower-level types of leaks would have found their way to the surface or not. It is noted that a significant number of mains are located in grass or sidewalk areas where it is easier for the pressurized water to run to the surface. An important consideration when considering an acoustic monitoring system is whether leaks (even frequent leaks) tend to remain hidden for a significant length of time.

RECOMMENDATIONS

American Water has observed in this and two other locations that the Echologics detection system is very good at detecting leaks where working correlating units are on either side of the leaking pipe. Consequently, it is recommended that utilities with leaky systems consider this technology. The selection of the study location in Illinois was primarily based on reports of numerous leaks and the high cost of water in the Waycinden system. What was not accounted for in the initial analysis was that many leaks in the system did surface rapidly, which impacted the results. So, it is further recommended that utilities understand the likelihood for leaks to remain undetected for extended periods. First, for systems where leak response time is very good, NRW should be relatively modest, owing to the relative absence of long-running leaks. Second, working knowledge of the location of water mains offers a significant clue. The Waycinden system was installed in the early 1960s which coincides with the time when water mains were beginning to be installed near the curb, rather than in the middle of the road. Roadways and good drainage are often cited as the cause for leaks that remain hidden. This was not the case in this study area.

It is recommended that utilities employ economic analysis to evaluate whether a sophisticated acoustic monitoring system might be effective. Although the economic analysis did not provide the expected outcome for a system with high water costs, acoustic monitoring can be a valuable tool for water utilities. An evaluation mechanism should consider water waste, repair costs, and damage related to long-running hidden leaks. It is hoped that this document will assist utilities in making this evaluation.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Utility water pipes leak routinely and, given the aging pipe infrastructure commonly found, leaks will likely increase in frequency. The cost to replace or rehabilitate aging pipe is often far greater than the cost of repairing leaks; it is less expensive to maintain the old than install the new. Consequently, the management of leakage is a vital part of water utility operations. But predicting the precise location of the next water leak is largely impossible. Pipes do not fail in the order of their age, and the weak points that are susceptible to leaks are difficult to find without employing costly assessment techniques.

The Illinois Sustainable Technology Center has recognized the value of water and the losses that result from a variety of causes, including physical and human factors. The grant they provided allowed American Water to perform and report on a pilot project, testing an advanced leakage control strategy for water utilities.

The American Water Works Association (AWWA) Water Loss Control committee is the primary AWWA group looking to reduce water waste; their goal is aimed at water utility performance. The AWWA manual on Water Loss Control has adopted the four key leakage control approaches as outlined in Figure 1.1 (Pearson, 1995). Active leakage control, shown by the blue arrow on the right side of Figure 1.1, was the focus of this project.

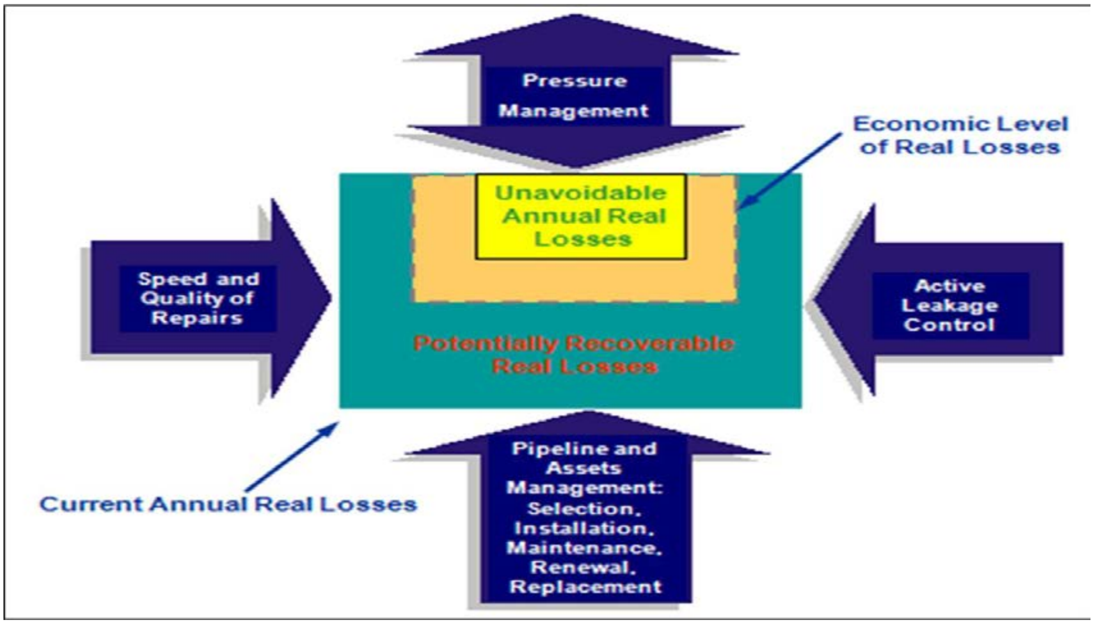

Figure 1.1 Methods to reduce leakage (Pearson 1995).

Illinois American Water operates numerous water systems in the state (Figure 1.2), including northeastern Illinois, east-central Illinois, and southwestern Illinois, areas which were prioritized for limited water supply and projected growth. Like other water utilities in the region, Illinois American Water faces the issue of managing water loss. In 2014, Illinois American Water generated or purchased more than 43.4 billion gallons of water, of which nearly 35.6 billion gallons were billed to customers. The remaining 7.8 billion gallons is termed non-revenue water (NRW); a portion of this NRW is used productively to flush and fill water lines and fight fires. Other NRW includes water lost to theft or inaccurate metering. However, approximately 6.8 billion gallons, or 87%, of NRW is thought to be lost to leakage. Similar to other utilities, American Water seeks cost-effective ways to reduce NRW with a focus on leakage. Per AWWA practice, American Water quantifies NRW by comparing total monthly meter water supply to the aggregate of monthly customer metered consumption in small systems such as the location of this project: the Waycinden subdivision in Des Plaines, a suburb of Chicago, Illinois.

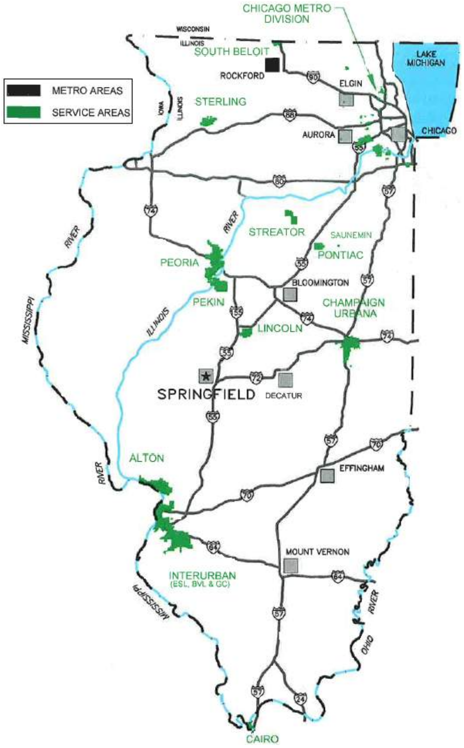

Figure 1.2 American Water systems in Illinois (shown in green).

The science of finding leaks by listening for leak noise has developed over many years, beginning with manual methods and advancing into today's sophisticated electronic devices. In 2005, American Water helped to initiate a first-of-its-kind listening system to address leakage and called it *continuous acoustic monitoring (CAM)*. The process involves placing sensors that "listen" for the vibrations from water leaks throughout a water system. The sensors listen every day and report the sound through the sophisticated communication network that currently transmits water meter readings daily. Today, most *Advanced Metering Infrastructure (AMI)* systems have some capacity to forward acoustic monitoring information.

Previously, American Water received funding from the Water Research Foundation of Denver, Colorado, to study results from this first CAM system over three years (2006-2008), following the 2005 installation (Hughes, 2010). The study area was a network of mostly aging pipe serving 5,000 customers in a river valley in southwestern Pennsylvania. The results of the study showed potential in terms of reducing leakage and identifying non-surfacing leaks faster, while lowering the cost of repair when leaks were quickly identified.

However, the first CAM system was not fully effective: a large number of false leads caused by other noise sources were encountered, leading to some fruitless searches. Equally troubling were occasions when the sensors were unable to hear leaks that occurred in plastic pipe found in many repairs. Subsequently, American Water has continued to encourage the industry to make improvements in continuous acoustic monitoring technology.

Since that time, American Water has tested new enhancements developed by vendors to overcome CAM deficiencies. Past research included the testing of a monitoring system from a German company, Gutermann, in the Valley View system of the Illinois American Metro Chicago district starting in 2008 (funded by the vendor and American Water). The system introduced a technique known as *correlating continuous acoustic monitoring (correlating CAM)* into the process. Correlation uses two or more sensors working together. Portable units have been used for decades to pinpoint leaks in the field. Like the portable correlation units, sensors are positioned on either side of a suspected leak area but within reasonable distance of each other. Both units are instructed to listen to a leak at exactly the same time. The time for the sound of a leak to travel between the two sensors allows the leak's location to be triangulated. Figure 1.3 illustrates how portable units are used today to pinpoint suspected leaks.

Correlation can confirm with high confidence that the leak exists and provide a fairly precise location of the leak as a function of distance between the two sensors. Correlation requires *two-way* AMI communications, allowing the sensors to be carefully synchronized and to issue the command to the sensors to correlate. The Gutermann system functioned but was very expensive and still experienced some missed leaks. The cost of the system could not be justified.

In 2010, American Water agreed to work with Echologics on a project funded by the Canadian government to build a better leak-detection device. Pennsylvania American Water systems in southwestern Pennsylvania were selected to "alpha" and "beta" test the developing product. The alpha test in Uniontown, PA began with primitive version of the device to evaluate and develop the acoustic monitor components. It took several years for the product to evolve from concept to prototype to a final product complete with software. Like the Gutermann device, it is a correlating CAM system. The beta prototypes were first tested in Liberty, Pennsylvania, and closely resemble the final version of the product. These prototypes were then installed in the Waycinden subdivision in Illinois for the ISTC project, a few months before the first commercially available product was manufactured. Some of the changes made between the beta monitors installed in Waycinden and the finished product came as a result of this project and are reported here.

A leak identified remotely from the Toronto office of Echologics in the beta test site of Liberty, Pennsylvania, demonstrated the potential of the system to be piloted for the ISTC project. Although monitored flow at night suggested that there were no significant leaks in the Liberty distribution system, Echologics determined that there was a leak between two monitors. The leak was not initially detected by on-site listening devices; although on-site correlation confirmed a leak in the area, microphones in contact with the road surface over the pipe failed to confirm the leak for two weeks. By the third week, the software indicated the noise continued to persist and was growing louder, so Echologics dispatched their best technician and American Water agreed to excavate the dimly heard suspected leak location. The leak matched the correlation of both the CAM system and the field correlation. Figure 1.4 shows the crack in the bottom of the excavated pipe. The location of the crack and the porous soils inhibited such a leak from surfacing; in fact, the top of the pipe was dry when initially excavated.

The location of the leak at the bottom of the pipe, coupled with the water pocket formed underneath, minimized the transmission of the leak noise to the ground surface. It is both the experience of our leak detection specialists and those around the world that a leak such as this might run undetected for months, leading to the pipe's eventual rupture under pressure, and resulting in a large flow with significant water loss.[1] This find likely saved the system from losing about half a million gallons of water.

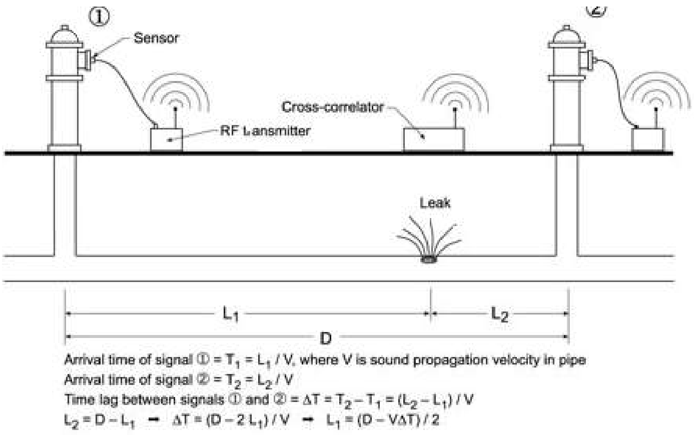

Figure 1.3 Correlation method and calculation

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[1] Farley, M. and Trow, P., 2003, Losses in Water Distribution Networks, IWA Publishing, London, UK

Figure 1.4 Cracked pipe from Liberty, PA. Leak found by acoustics.

Within American Water there are a number of technicians capable of interpreting and operating the acoustic monitoring system. The ISTC project in Waycinden exposed the Illinois American Water operations personnel to the value of both analyzing night flow and utilizing the Echologics correlating CAM system.

1.2 OBJECTIVES

The objectives of this project were as follows:

- Provide a demonstration on the workability of an advanced correlating acoustic monitoring technology to effectively reduce water leakage in a water utility network.
- Evaluate the full financial benefits associated with the technology and provide a cost model to evaluate the expanded costs and benefits of operating such a system.
- Provide a forum for utility operators in Illinois to be made aware of the technology and the cost/benefit analysis through a workshop to discuss the technology and illustrate a cost model.

The leaks identified to date at the alpha and beta locations are a small sample size and both the manufacturer and American Water understand the value of additional test locations and finding other types of leaks on various pipe materials. Echologics was a willing participant, owing in part to the challenge of a typical Chicago suburb with broad well-travelled highways over pipes more than 50 years old.

American Water utilized the research opportunity to further examine the economics of the early identification of leaks for this product and to assess the product for use in other systems based on the enhanced performance of this CAM system. This knowledge can be shared with other American Water systems and utilities in Illinois. It is essential to examine leakage control processes in financial terms. Reducing leakage by water utilities is an excellent but complex goal. It would not be practical for a utility to invest $50,000 to purchase a leak detection product when the net savings over a traditional reactive approach was only $2,500 annually, over the eight year life of the product. The economic value of this CAM system would be improved if it could be shown to be highly reliable and extremely fast in recognizing 90% of leaks.

The Illinois American Metro Chicago district consists of 24 separate systems where the cost to produce water is under $50 per million gallons in 10 groundwater systems, but well over $2,500 per million gallons in 14 systems where water is purchased (e.g., the Waycinden system). The selection of the Waycinden system in Mt Prospect, Illinois, was likely to be cost effective because of the high cost of water there. Typically, a water utility generates its own water from treatment facilities, and water tends to be even less expensive with groundwater sources. However, the Lake Michigan-sourced water in Waycinden is purchased by Illinois American Water via an adjacent water utility and serves 750 customers. Consequently, systems like Waycinden with a relatively significant NRW (about 20%), combined with the higher cost of water, are considered the best targets for CAM.

One of the major drivers for water main replacement is customer dissatisfaction when major breaks occur. These can result in interruption of traffic, loss of in-home water supply at inconvenient times, or notifications that customers must boil water until it is tested to be safe for consumption. If early detection means leaks can be repaired quickly with less damage and inconvenience, customer tolerance for interruptions will be higher and satisfaction will increase. This was not an economic consideration for a project of short duration (e.g., the Waycinden project, which ran for ten months), but should be accounted for to improve long-term water utility pipe management. It is not unusual for pipes to have only a few isolated weak spots that fail, rather than uniform failure throughout the entire pipe. In such cases, the quick repair of the selected weak spots may allow the pipe to remain in service for a longer period.

In 2014, the Waycinden water system experienced non-revenue water loss of over 18 million gallons; it was anticipated that up to 5 million gallons could be saved in the 10-month study period. Given that some leaks appear to run undetected for an extended period while others do not, several interesting questions concerning the evolution of leaks in this system were addressed:

- What proportion of leaks evolve slowly vs. erupt rapidly?
- Do most high-flow leak events develop quickly, meaning they cannot be eliminated by correlating CAM? Or, if high-flow leaks evolve slowly, can the pipe be excavated at an early stage to detect clues to a larger failure?
- What percentage of leaks would the correlating CAM locate in advance? This was of interest to the vendor, Echologics, in particular.
- What is the best strategy to conduct a review of data and field investigations – e.g., what are the best times to collect data, and with what frequency?

The correlating CAM system is expected to transmit data for a minimum of five years. In previous projects, the research began only after an initial “break in” of the acoustic monitoring system. That is, data collection had to be delayed until initial installation problems were resolved and until long-standing unattended leaks were identified and repaired. The Waycinden pilot project tested both initial leaks as well as how leaks continued to occur in a distribution network after a leak survey and the equipment from day one.

An opportunity provided by the correlating CAM technology that was not explored in this small pilot was the potential to track the sound pattern of a leak from start to repair. Knowing the start date of many leaks might permit better analysis of leaks in relation to external causes or triggers. Trigger factors include water temperature, pressure surges, and soil moisture. The CCAM technology offers the ability to follow the acoustic pattern of water main leaks as they change with time. Because the leak repair process included estimating leak flow at the time of repair, it might be possible to match the monitored leak frequencies to type of pipe and type of flow. However, the emphasis in the pilot project was to minimize NRW and make rapid repairs rather than study how leaks change over time.

While this research opportunity provided useful insights, it remains a case study in many respects. The aging infrastructure in the Waycinden study area may not be entirely representative of the average water utility. The Waycinden system is largely supplied through an adjoining municipal system that gets its water from the City of Chicago; many systems have their own supply that costs considerably less to produce. Waycinden uses modest pumps to deliver the water, so stresses from pump operations may be atypical. There are no major extremes in pressure in the system. The preponderance of ductile iron mains installed in the 1960's has led to discernable corrosion issues in recent years. Corrosion leaks were expected to be the source of hidden leaks, rather than sudden cold weather breaks.

Although this research should be viewed as a case study, some comments on the use of correlating CAM will apply to other water utilities. When the prevalent form of leakage for a utility is in the form of low-level non-surfacing leaks, the correlating CAM system appears to be appropriate. In order to be successful with correlating CAM, utility staff need to monitor for leak-probable sites, conduct field investigations, and follow through with repairs in a timely fashion.

Communicating information is part of the project. American Water coordinated with ISTC to disseminate the findings from this research. In addition to this report, presentations and a webinar were made[2]. As is the common practice of American Water researchers, the information will be communicated to an even broader audience at national conferences and workshops. This includes a successful abstract submission for a presentation at the AWWA annual conference in June 2016 in Chicago.

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[2] Results presented at ISTC's Sustainability Seminar Series on November 5, 2015. Seminar can be viewed at http://www.istc.illinois.edu/about/SustainabilitySeminar20151105.cfm

CHAPTER 2: METHODOLOGY

2.1 EQUIPMENT SELECTION

American Water identified the potential of Echologics as a developer of acoustic monitoring equipment in 2009 when most other vendors were struggling to make significant improvements in this technology. Echologics was well known for the leak detecting equipment it manufactured for plastic pipe and large transmission mains. American Water was one of the major participants in the development of the equipment, which was made possible through a grant from the Canadian government. Echologics was in discussion with Mueller Co., who used communication equipment for meter reading in fire hydrants. Ultimately, Mueller purchased Echologics and directly assisted in the development of the Echologics software. When American Water became aware of the funding mechanism from the Illinois Sustainable Technology Center, the project grant was immediately pursued. The Metro Chicago district of Illinois American Water had experience working with another vendor's acoustic monitoring system in the Valley View system in 2008. The conclusion was that the expense of the equipment demanded a periodic movement of the sensors which proved unsatisfactory. The units and software were not fully effective. . Results from the first Echologics prototype or "alpha" test in Uniontown, Pennsylvania, showed more promising results. The second or beta test in Liberty, Pennsylvania, used a model not unlike that installed initially for this project.

2.2 INSTALLATION OF EQUIPMENT

Illinois American Water provided Echologics with a GIS map of the project area in advance of the project start to strategize placement of acoustic monitoring units and estimate the quantity and costs of units. Immediately upon receiving the grant award, Echologics began work to fabricate and install sensors (Figure 2.1) in selected fire hydrants in the Waycinden system with field assistance from Metro Chicago staff. The original sensors were installed by August 29, 2014. The devices are easily set in replacement hydrant caps with threads that allow installation in a wide variety of systems. The Waycinden system contains over 130 hydrants and, based on the range of the sensors, it was decided that 79 CCAM units would be adequate. The communication device that relays the acoustic information is also housed in the Echologics-provided hydrant caps. The communication devices in the hydrants work like a mesh network, relaying information to the two primary collectors. The initial budget had anticipated a single collector to be placed on top of Waycinden's Linneman Road standpipe, pictured in Figure 2.2. The propagation study performed by Echologics determined that a second collector was needed to forward data from the hydrant sensors; the second collector and two repeaters were placed on top of the Illinois American Water Mount Prospect tank and pump station. Cellular communication forwarded data from the collectors to the computers in the Echologics office near Toronto.

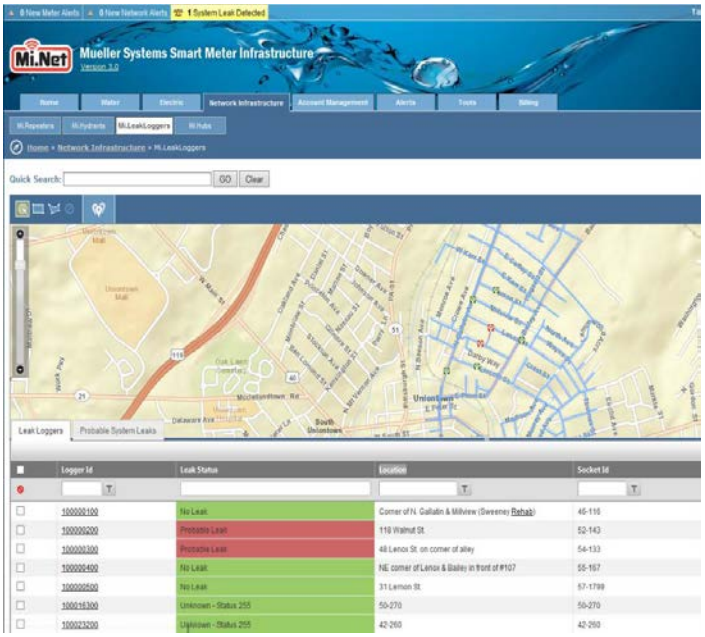
The acoustic monitoring units initially installed were prototype (beta) units. In 2014, Echologics was very interested in how various leaks appeared acoustically using their four-in-one hydrant sensor and new analytics technology. Echologics performed daily monitoring of the data in Waycinden. The Echologics field staff also made site visits to check on equipment and leaks as they were discovered.

Figure 2.1 Acoustic sensor inside hydrant cap.

Figure 2.2 Linneman Road standpipe, Waycinden, Illinois.

Due to equipment failure described in Chapters 3 and 4, all prototype units in the Waycinden study were replaced with improved second-generation units by February 10, 2015. Data collected before and after the replacement are included in this report. The new units had improved reception ability and corrected the software issue that ran down some of the batteries.

In the Waycinden test, Echologics monitored the data, checking for leaks on a daily basis (with success). Essentially, the software dashboard (Figure 2.3) highlights nodes with leaks within 500-1,000 feet of the sensor and calls them points of interest (POI). The system can then be instructed by the user to correlate data from the sensor with the most significant leak indication and adjacent units. This action helps to pinpoint the leak between two units. The software has a visual feature to display how sound changes at a particular location (by frequency and strength) day to day. When a leak is suspected, the software graphically records the leak noise correlation for view. The software also provides for notes to be added by the user. Echologics managed the analysis of data throughout the project, although American Water staff received training and gained access to the data in the last two months of the project.



☐	Logger Id	Leak Status	Location	Socket Id
☐	100000100	No Leak	Corner of N. Gallatin & Millview (Sweeney Rehab)	46-116
☐	100000200	Probable Leak	118 Walnut St	52-143
☐	100000300	Probable Leak	48 Lenox St. on corner of alley	54-133
☐	100000400	No Leak	NE corner of Lenox & Bailey in front of #107	55-167
☐	100000500	No Leak	31 Lemon St	57-1799
☐	100016300	Unknown - Status 255	50-270	50-270
☐	100023200	Unknown - Status 255	42-260	42-260

Figure 2.3 Echologics software display screenshot.

2.3 SYSTEM VERIFICATION OF NON-REVENUE WATER

American Water typically measures non-revenue water (NRW) using the traditional 12-month rolling averages calculation, which looks at the volume difference between water production and metered sales. A 12-month rolling average essentially looks at the difference between 12 months of water purchases and production and 12 months of water usage (in this case billed use based on customer meter readings in the same 12 months). Water purchases and production are tallied at the end of each month. However, meter readings occur at various times during the month, creating a lag in the data. The premise is that a lag of a few weeks is modest in comparison to a 12 month calculation. Nevertheless, it is far from an ideal way to evaluate water loss.

Night flow proved to be a useful indicator of NRW loss for this project. Night flow monitoring is employed as part of the international method for assessing leaks using *district metering areas* (DMA).[3] All small systems like Waycinden, or portions of a large system, can be metered around the clock. For the most part, Waycinden currently imports its water supply from a local water purveyor, after relying on wells for several years. The imported water is pumped as needed to maintain appropriate tank storage in the elevated Linneman standpipe.

Water use in the Waycinden system can be measured at any given time using a meter (Figure 2.4) to quantify the water pumped into the system plus any reduction in storage volume. Tank storage levels are also monitored through SCADA (supervisory control and data acquisition). American Water modified the system monitoring process to examine only the 3 AM to 4 AM period when pumps were usually inactive and when consumption is low and reasonably constant from night to night. With pumps off, only the change in storage needed to be monitored.

Figure 2.4 Master meter tracking flow into system from adjoining utility interconnection.

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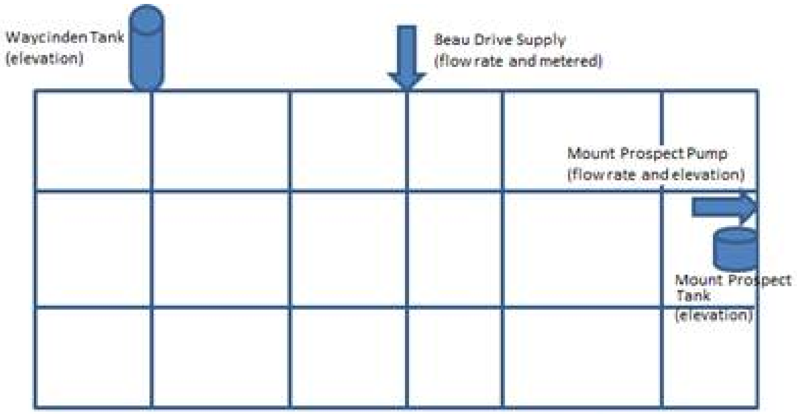
[3] AWWAWater Loss Control Committee, Applying Worldwide BMPs in Water Loss Control, JOURNAL AWWA, August 2003.

The change in storage approach had worked in the beta study area in Liberty, Pennsylvania, where operations were modified so that the system supply feed from a control valve was closed and tank storage was the only supply at night. The majority of data points from 3 AM to 4 AM in Waycinden suggested that tank storage change could be relied upon to measure night flow (Figure 2.5). Night flow monitoring served to demonstrate how effectively water loss was reduced by examining the lowest hour of consumption in the middle of the night when metered demand is predictably minimal. The researchers looked at changes in night flow over time; any sustained increase would suggest that a non-surfacing leak might be present. The night flow data could also be used to help quantify the size of ongoing identified leaks. The net difference between the master metered system flow the night before and the night after the repair provided a reasonable estimate of large leaks. Leaks were conventionally estimated on-site by a formula using two factors: the working pressure, and the size of the opening in the pipe.

The SCADA link was successful in providing pertinent information about flow into and out of the Waycinden system. Calculations were made for night flow using the most accurate times when pumps were off to avoid any calibration issues with rate of flow from pumping. On many nights each week pumps were off and tank elevation change was the only "consumption." The researchers used a period of zero known leaks to establish baseline night flow calculations.



Assuming auxilliary wells (not shown) are off in middle of night, the flow supplying water into the system equals *Drop in elevation x cross sectional area/foot in both tanks plus Beau Drive Supply*

Figure 2.5 Schematic of Waycinden system showing sources of supply and storage layout.

2.4 HISTORIC ANALYSIS OF SYSTEM BREAKS

Leak break data was provided by Illinois American Water from January 2011 through August 2014 to help identify the types and nature of leaks experienced in the system. (The data is summarized in Appendix A-2.) There were 44 leaks in those 44 months. The leaks were of two primary types and mostly occurred on 50-year old 6” cast-iron mains that are prevalent in the system. The common breaks that happened throughout the year were corrosion-related, and identified as pinholes, corrosion holes or, if the hole becomes large enough, blowouts of the pipe (23 cases). The other type of breaks – circumferential breaks – were common only in colder weather (18 cases), and are believed to be associated with thermal (freezing) stress on the pipes themselves and on surrounding soil. A third type – longitudinal breaks along the length of the pipe – was uncommon and may have been corrosion-related or impacted by traffic load (3 cases). It is also possible for breaks to occur on service lines, connections, valves, or hydrants.

The average leak in the system took the water main out of service for leak repair for over three hours and typically impacted over a dozen customers. The most severe break over the 44-month period left 24 customers without a pressurized water supply for nine hours. There were 11 leaks that lost water at a rate of 100 gallons per minute or more, including two at 500 gallons per minute. About half of the breaks occurred during overtime (after 4 PM and before 6 AM), based upon reports showing when water service was interrupted. Seven of the forty-four breaks were repaired on weekends or holidays. Most leaks were repaired with repair clamps, but seven required cutting out sections of corroded pipe and installing new pipe. Surface restoration was necessary, and included paving repair (state highways as well as suburban streets and driveways), sidewalk repair, lawn restoration, and tree replacements.

Estimates are provided for each break that occurred during the study period (see section 3.2). Estimates were based upon the estimated hours that the leak may have run and an estimate of the average water flow from the leak. Leak flow was observed at the time of repair and not at the start of the leak. But because most breaks appeared to surface quickly and were repaired relatively fast, the observed flow was used. Estimates of flow rate were based upon the experience of the staff in the field. For small breaks, flow rate was a function of the size of the leak opening in the pipe and the water pressure. Larger leaks are more difficult to estimate in the field and generally the impact on water use is employed to improve the estimate. In the last and largest leak, flow actually went through the customer meter.

2.5 ENVIRONMENTAL DATA

The most relevant environmental data was weather history, including daily temperatures and precipitation. Data was collected from Weather Underground’s website to look for unusual weather cycles and provide comparison with recent years. The observation for the study period was that the weather was colder than normal but precipitation was typical.

2.6 ECONOMIC ANALYSIS

An obvious cost-savings advantage of early leak detection is reduction of water loss with faster repair of hidden leaks. The traditional response is to wait for leaks to surface, a process that can take weeks or months. Some water utilities conduct conventional leak surveys in which utility personnel or consultants patrol the water system and listen on hydrants, valves, and curb stops to detect active leaks. Surveys usually take place at one-year intervals or more. The reductions in leakage from surveys can be short-lived as hidden leaks can begin soon after the survey is conducted. In fact, there is evidence from prior leak studies conducted by American Water that a leaky system that has had hidden leaks repaired attains higher pressures and may spring new leaks shortly after repairs are made.[4] If acoustic monitoring is successful and continually finds leaks that would otherwise remain hidden for an extended period, substantial savings can be realized. Based upon several American Water locations in Pennsylvania and New Jersey, where acoustic monitoring tracked leaks that had run for an extended time, it was determined that 90 days is a reasonable estimate for leaks to run without surfacing. This is a general rule for water systems with a history of hidden leaks and it is understood the time that individual leaks come to the surface can vary from a few days to years. The 90 day estimate can be reduced by factors such as shallow buried pipe (found in warmer climates) and pipe not buried under impervious surfaces. The estimate can be increased by factors such as steep topography, porous soils, or other subsurface conditions like limestone or shale.

Other savings to be considered include the potential of the leak repair to be more expensive if not addressed until it surfaced. Some leaks surface and create hazards (e.g., ice on the roads, flooding) and force worker overtime expenses, which are avoidable if leaks are found and repaired during normal work hours. A faster response time also tends to reduce damage caused by long-term underground leaks, eroding areas below ground and undermining the surface. Communication between the study researchers and Illinois American Water allowed for some of these costs to be evaluated in a few cases.

As noted, a review of leaks was conducted from January 2011 through August 2014 to evaluate the types of breaks and the expenses incurred in making repairs and restoration. This allowed certain baselines to be set, including a review of repair times, approximated by the duration of shutoff times (an hour was added for mobilization to the site and restoration performed after water was restored).

American Water identified potential cost savings for each leak detected by the acoustic monitoring system, based on the cost of repairing each leak. Immediate repair often involves working hours outside the 40-hour work week. From examining the repair events of prior years, it was established that three hours of overtime were incurred on average for all repair responses to breaks. Some leaks do not require immediate attention and can wait until the morning of the next work day, but others require an immediate response. For a cold climate area, winter leaks often fit the latter category.

The cost savings from acoustic monitoring alerts that reduce the time of a leak running are further summarized in the remainder of this section.

2.6.1 The Cost of Water Saved

Since the 2005 installation of the first continuous acoustic monitoring systems, American Water has learned a great deal about patterns of non-surfacing leaks. While operating about a dozen

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[4] Hughes, 2010. *Continuous Acoustic Monitoring: from Start to Repair*, AWWA Research Foundation, Denver, CO.

monitoring systems, American Water allowed some leaks to flow for extended time periods without surfacing. During the first continuous acoustic monitoring study in Connellsville, Pennsylvania, (funded by the Water Research Foundation then known as the AWWA Research Foundation [AWWARF]), several leaks were allowed to run until they surfaced. Most ran for one to four months; one leak – located under a concrete state highway – ran without surfacing for a year. Based on these patterns, it was determined that the average small leak ran for 90 days before surfacing. The three-year AWWARF study also determined whether the sound pattern was indicative of the growth of the leak with time; many leaks showed slow change, indicating that an underground water pathway tended to remain a path of least resistance, leading to extended periods in which leaks do not surface.

There are local differences that factor into the time it may take for a leak to surface: (1) the original Connellsville study area is in a river valley, while the study area in Illinois is flat; (2) the mains in Illinois are deeper and some run under the grass and sidewalk area, whereas most Connellsville pipes are about a foot shallower and located under roads. Additionally, loss depends on the type of leak. For example, catastrophic failure is assumed for longitudinal main leaks that result in high flow for a brief period of time when the leak surfaces. This leak type tends to represent a small proportion of water loss, however, confirming the importance of reducing the quantity from slow steady leaks. Of course there are exceptions to these generalizations. A major break in the Charleston, West Virginia, system identified Echologics monitors found a two million gallon per day leak that had been running into a storm sewer for an extended period.

2.6.2 Possible Reduction in Restoration Materials Expense

Long-running leaks typically erode subsurface materials, requiring replacement of unsupported surface materials (e.g., paving, sidewalk, etc.) and increased backfill. Restoration expenses for the past three years in the Waycinden system range from street and driveway paving restoration to restoration of sidewalks and landscaping in locations where the mains ran under unimproved areas.

2.6.3 Possible Reduction in Repair Material Expense

The materials required to repair mains can change as a pipe failure continues for a longer time. As illustrated in the Liberty, Pennsylvania, repair (Figure 1.4), a split at the pipe bell limited the repair to a small segment of the pipe instead of requiring replacement of the entire (20-foot) length. The City of Cleveland, Ohio, and other locations have reported that a simple joint leak in a cast iron main can lead to a bell fracture. [5] For many breaks, such as circumferential failures and most corrosion failures, an adjustment in the material requirements for repair is unlikely unless the pipe is severely undermined.

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[5] Margevicius, Alex, and Pierre Haddad. 2004. Catastrophic Failures of Cleveland's Large Diameter Water Mains. Presented at the ASCE Pipelines Conference, August 5, 2002. American Society of Civil Engineers, Reston, Virginia.

2.6.4 Possible Reduction in Repair Labor

There are two factors relating to costs of labor during pipe repair. First, a repair made early in the life of a leak will probably take less time to repair than one that has run for months and has caused substantial subsurface erosion. In addition to the costs of the laborers' time, these leaks require more extensive repair materials, as noted above. For example, in the AWWARF study, the cost of paving and backfill materials were 30% higher with surfacing leaks (Hughes, 2010). These repair and restoration material costs provide an estimate of the related labor expense. Second, leaks found early while they are not surfacing can typically be repaired during a repair crew's normal work hours, avoiding overtime. So, this calculation considers the virtual elimination of overtime.

Aspects of repair labor in the Waycinden study was undertaken by examining the main break repair history in the system since 2011. It was noted that shutdowns averaged almost three hours during "overtime hours" (between 4 PM and 6 AM, weekends and holidays). The time recorded on most leak repairs considers when the water line is turned on and off, when customers are without water. However, this does not reflect the hours that employees are on site. Normally water flow continues once the crew arrives to allow for pinpointing the leak location through excavation. Water service is typically restored as soon as the repair has been made, well before the crew has restored the excavation and cleaned up the site. Therefore, it would be reasonable to add at least another 30 minutes for workers to arrive on the job site before and after the shutdown. There would also be an allowance of approximately 45 minutes each way for workers to travel to Waycinden from the main office of the Metro Chicago district (34 miles) or their homes that are presumably within the area. Consequently, the difference between 4 hours at the regular rate and 4 hours at a 1½ overtime rate (4 x (1.5-1) = 2 crew hour equivalent) must be added to each repair, whereas the Echologics advance warning is meant to substantially reduce overtime repair.

2.6.5 Third Party Damage

Costs due to damage claims should be accounted for, as well. It can be challenging for water utilities to collect this data, however, as it is frequently handled by different personnel and it can take some time for the damage to be assessed and awarded. Damage to infrastructure and private property would also be accounted for on a case by case basis. In the Waycinden system, there appeared to be damages associated with lost trees and driveway repair.

2.6.6 Triple Bottom Line Costs

A research project[6] now underway for the Water Research Foundation is determining additional costs related to leaks that are not accounted for in third party property damage or direct costs to the utility. These include interruption of business, traffic disruption, and environmental impacts. While these costs are legitimate, their value can be somewhat speculative. No such events occurred during the Waycinden study period, but they would have been examined on a case by case basis. The Water Research Foundation is currently undertaking a project to examine such

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[6] Stratus Consulting, Utility Risk Management Methodologies for Buried Assets with Improved Triple Bottom Line Understanding of Pipe Failures, scope of work, Water research Foundation website, http://www.waterrf.org/ScopesOfWork/ScopeOfWork_4451.pdf

costs resulting from major main breaks. American Water is part of the project team and would have incorporated findings from that research, but that project has been delayed. Because many mains were off-road, traffic interruption appears to have been minimal.

2.6.7 Cost of Implementation

It is difficult to provide an exact cost for a product that is just hitting the market, but Echologics advises that a capital cost of about $1,000 per hydrant is a realistic estimate. Utilities should be aware that if hydrants are not at the ends of pipe lines, that additional monitoring may be required to pinpoint the exact location of leaks. The cost of the operating the installed system is more variable and depends on whether the utility wishes to perform the monitoring and leave system maintenance to the vendor, or allow the vendor to provide both monitoring of acoustic data and the system hardware. The equipment is expected to last at least 10 years, with battery replacement every 5 years. The range of annual operating cost is probably about $25 per node for a typical 1,000 node network that covers 10-12 square miles of buried infrastructure. The monitoring costs are reduced as the system scales upwards in size.

2.7 THE ACOUSTIC MONITORING PROCESS

The key element of the Echologics acoustic monitor is the preassembled smart node that is installed inside a standard steamer cap nozzle (Figure 2.6). Steamer caps are provided by Mueller, the parent company of Echologics, and are matched to the threading used by the local utility. The node includes an acoustic sensor, analysis software, network hardware (transmitter/mesh repeater), batteries, and an antenna. Unlike most other sensors, which are located in valve boxes underground, the Echologics node, being located in an above-ground location in the hydrant, provides a more stable and stronger radio signal.

Echologics studied the GIS layout of pipe and hydrants in the study area to determine optimal placement for acoustic coverage and radio transmission. Ultimately, signals from the nodes are sent to a central data collection hub. Nodes collect data at a pre-determined time of day – usually at the minimum night flow period. At the hydrant location, the acoustic values are filtered over a range of frequencies to separate leak sound from extraneous noise. The data is then compared to the historic baseline acoustic signatures from the location.

The acoustic monitors were placed on hydrants with the expectation that they could detect leak noise through approximately 1,000 feet of metallic pipe or 500 feet of plastic pipe. Consequently, about 40-80% percent of hydrants in a typical system are equipped with the acoustic unit to cover the distribution system. The percentage will vary by system depending on the density of hydrants, the pipe materials in use, and the distribution system layout. The acoustic monitor detects leak noise frequencies in the range of 1-4,000 Hz. The acoustic monitor is designed to provide data for five years and remain in one location. If batteries are replaced, the units are expected to last longer than the five years. FCC licensing of the mesh transmitter is not required.

Figure 2.6 Fire hydrant equipped with the acoustic monitor node.

When an acoustic anomaly between the new data and baseline is identified, the node sends a data file to the Echologics Analytical Module (EAM) located at Echologics office. This analytical module performs additional analyses. Once the anomaly is received, the EAM requests correlation data from adjacent nodes and automatically performs correlations in the immediate area in an effort to confirm a leak and target its location. The acoustic data review process is relatively straightforward. Every working day, new data is received and can be analyzed, compiling a list of probable leak suspects, known as points of interest or POI. When the leak is confirmed, Echologics notifies the customer. In this case, Echologics notified both the researchers and the Metro Chicago staff.

The acoustic monitoring units attempt to pinpoint the location of a leak through correlation. In a many cases, two acoustic monitors might detect the same leak sound and provide general information, but it is the correlating feature that enables a more precise location. The correlation results are displayed within the software. Field investigations are necessary to confirm the precise location in need of repair. These investigations typically involved the use of portable leak noise correlators and ground microphones not necessarily produced by the same vendor.

2.8 CUSTOMER METERING AND NON-REVENUE WATER

Customers in Illinois American Water are typically metered with readings collected monthly using an AMR (automatic meter reading or drive by) system. The meters in this individual Metro Chicago system of 720 customers is effectively read in a matter of a few hours. This offers a second method to evaluate non-revenue water: comparing the total water consumption on customer meters to the monthly consumption on the supply meter for the system. Before AMR, the meter reading processes often took days, so the conventional method for measuring water loss used the previously mentioned *12 month rolling average*. The AMR monthly analysis lacks some precision, as not every meter is read at precisely the same time. However, the few hours of timing error for readings over a 30-day billing period is small. This feedback, coupled with an estimate of leakage from night flow, provides information about the magnitude of other non-revenue water (NRW), such as authorized water use from hydrants, meter accuracy, and theft of water. A comparison of the information from the 12 month rolling average as of June 30, 2015 was made to that of the previous years. The results may help to confirm that NRW was reduced in the system over the previous year by a combination of Echologics devices and the rapid repair of quickly surfacing leaks.

The acoustic monitoring installation was completed prior to the September 1, 2014, the deadline set by American Water for the project. Illinois American kept records of repairs, rate of flow, and the nature of the breaks during the study period. The system was also tracked by 12 month rolling averages of NRW and this was compared to the estimated quantities of the leaks in the study period.

CHAPTER 3: RESULTS

3.1 THE DEPLOYMENT

Coverage of the entire Waycinden system was provided by the prototype acoustic monitors by the end of August, 2014. This allowed for a week of gathering baseline acoustic information, concluded by the end of the first week in September. Figure 3.1 shows the distribution of nodes (blue dots) and repeating nodes (red dots) and the collectors (large green dots).

Due to problems with the monitors, the prototype monitors were replaced by Echologics' second-generation system in late January and early February 2015. In addition, a few loggers received duplicate numbers which prevented detection of two leaks, as described later in this section.

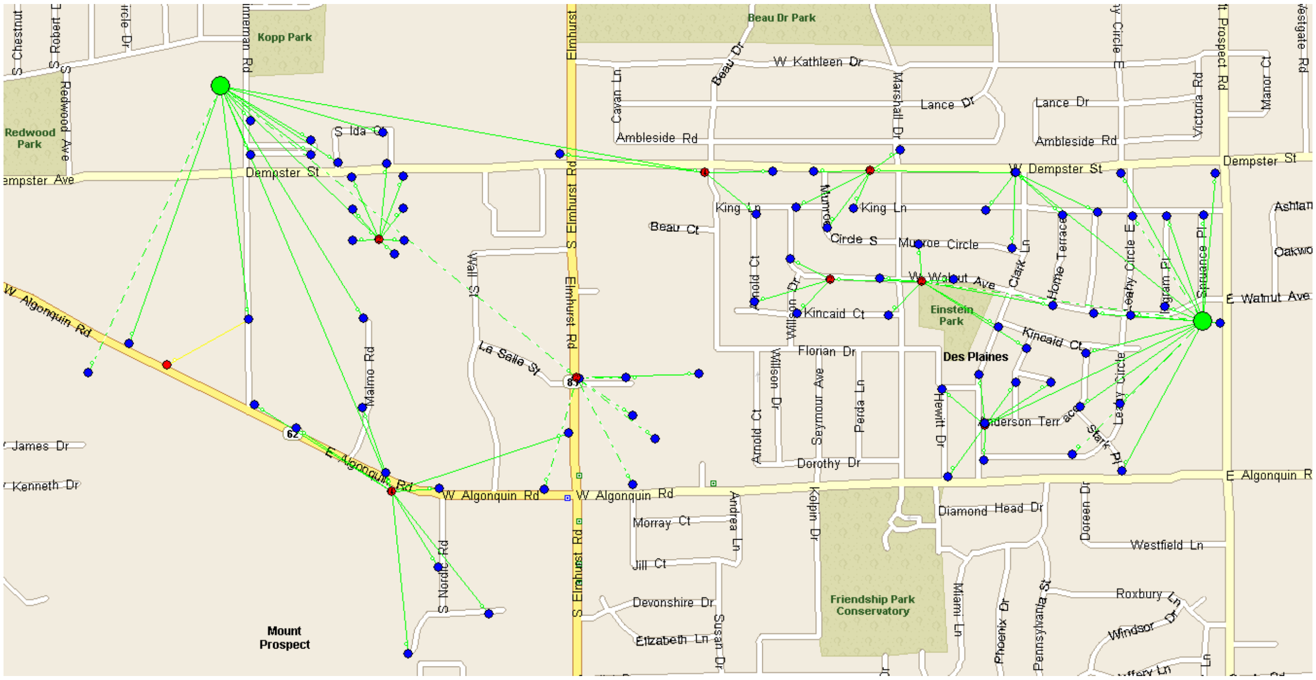


Figure 3.1 Layout of Echologics monitors, repeaters and collectors. Nodes (blue dots) and repeating nodes (red dots) and the collectors (large green dots).

3.2 LEAK DETAILS

This section describes leaks that occurred in the September 2014 - June 2015 study period. It should be noted that the reporting of leaks usually comes from customers in neighborhoods, drivers on the highway where water often appears, local public works departments, police, and utility workers. Leaks in winter are promptly reported as they are both common and hazardous. Water loss estimates are provided for each individual failure, along with possible savings if they could be identified. Repair data is not provided unless there was an identified clear savings.

Ideally, working correlating CAM units are positioned close enough to detect leaks and perform correlation. In this beta test, there were problems with some of the units. In some cases, units other than the closest units were checked to determine when a leak started, but this was not always successful. The detection of leaks by units at greater distance is not exact; there is no magic distance at which leaks will be heard. It is a function of the type of leak, the type and size of pipe, and the distance from the leak.

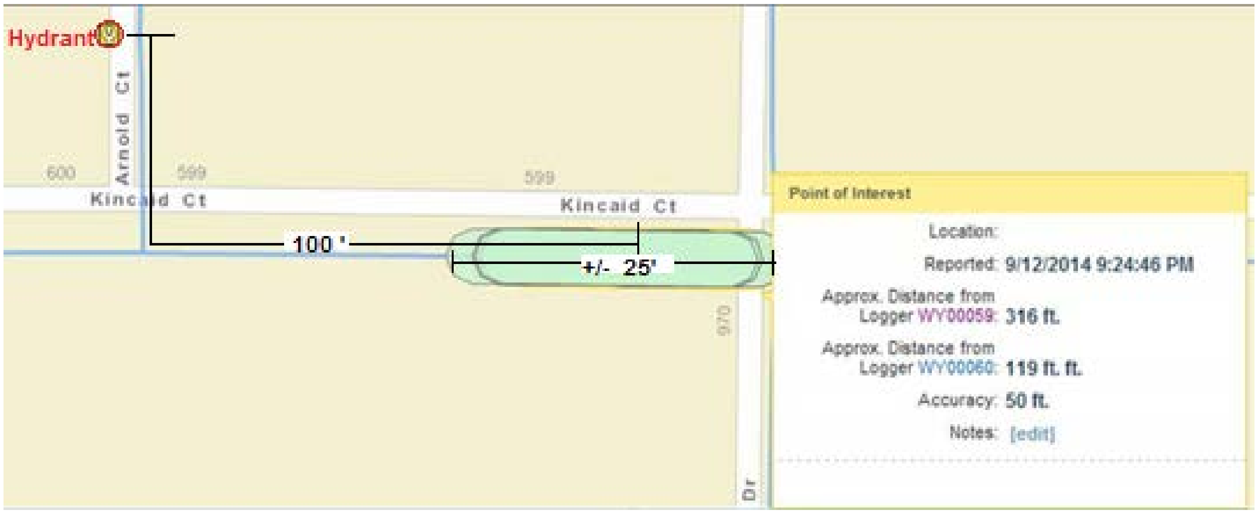
3.2.1 Leak 1 – Kincaid Court and Willson Drive

No leaks were identified at the start of the field work during the first week of September, but shortly after the initial analysis, a point of interest was identified. It was pinpointed through acoustic monitoring on Saturday, September 12, 2014, and confirmed as a leak by Illinois American Water staff the following Monday. The leak did not predate the start of monitoring. The leak was located on a 6” cast iron main on Kincaid Court at the intersection with Willson Drive in Mount Prospect. There was an audible sound of water running into an underground storm manhole when it was opened, but the sound was not loud enough to be noticed by the casual passerby. The easy discharge to the drain system strongly suggested the potential for this leak to continue without surfacing for an extended time in the absence of the acoustic monitoring provided by this project. There was some potential for the leak to only be detected once it increased substantially in flow largely because of the absence of paving cover.

The Kincaid Court leak location was approximated by the Echologics unit as 100 feet ± 25 feet from one of the sensors (Figure 3.2); the 50 foot location window allows for variation in correlation timing and for structural variations in the pipe. The leak was quickly found 82 feet from the hydrant/sensor (Figure 3.3); the 18-foot difference was within the expected range.

The break was a three-inch longitudinal crack on the top of the six-inch cast iron pipe, flowing at an estimated rate of 25 gallons per minute (gpm) (Figure 3.4). Despite permeable grass cover, the leak did not surface, due to direct flow into the nearby storm sewer manhole. The clear path to the drainage system would likely prevent this leak from surfacing for months. A 25 gpm leak running just one day would total 36,000 gallons, and that is assuming that the leak did not grow larger before detection. There was an expectation that the leak might eventually grow larger and surface, potentially reaching 100 gpm. A longitudinal crack left unrepaired is likely to continue propagating and breaking open with a large water discharge. It was surprising to find that a leak of this size could occur off the road and still not surface.

The leak continued to flow for twelve days without surfacing. The leak was allowed to run to help verify that the leak would not have surfaced even in a grass area. American Water’s experience with non-surfacing leaks of this size suggests that as the leak slowly grows, the pathway to the sewer manhole would likely become more defined and could leave the leak undetected for weeks or months. It is possible that the sounds of the leak splashing into the manhole could have alerted the public to the problem, but this was not evident at the time of repair.



Point of Interest

Location:

Reported: 9/12/2014 9:24:46 PM

Approx. Distance from Logger WY00059: 316 ft.

Approx. Distance from Logger WY00060: 119 ft. ft.

Accuracy: 50 ft.

Notes: [edit]

Figure 3.2 Echologics software display of suspected area of interest for Kincaid Court leak.

Figure 3.3 Location of hidden leak showing predicted location (blue) versus actual leak location (red).

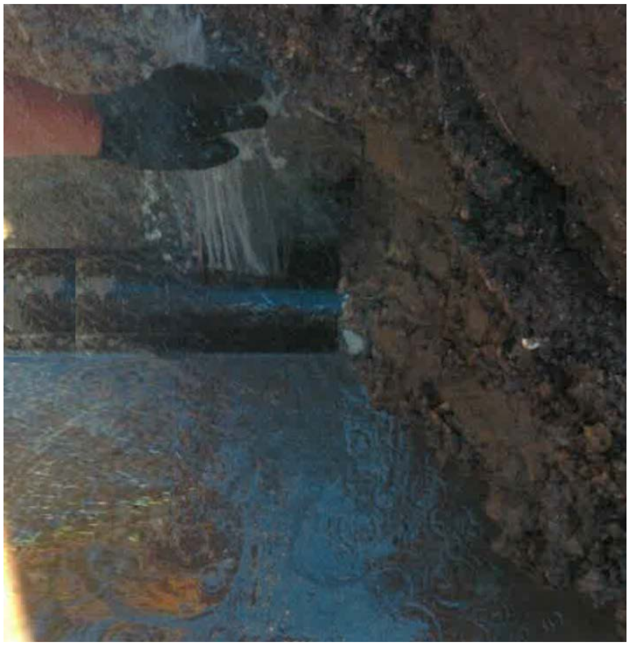


Figure 3.4 Leak on a six inch pipe Kincaid Court.

3.2.2 Leak 2 – Linneman Road

The leak on Linneman Road was reported the moment it started on Friday, October 31, 2014. The leak occurred when a shutoff valve was operated on a service line in the meter pit (Figure 3.5). The leak continued overnight and was reduced by a plumbing adjustment on November 1 and resolved on November 3. The Echologics alarm system did not respond to the leak because one of the two units that would have correlated the leak had a dead battery. A glitch in the prototype software caused the units' batteries to run down prematurely. An investigation into what was heard by the Echologics system confirmed that the leak was detected by another nearby unit and would have been reported the night after the leak started, if the failed unit was operating. The leak ran for about 3 days at an estimated average flow of 4 gallons per minute (higher at the start of the leak), expending about 13,000 gallons.

Echologics performed a high-sensitivity correlation with the working primary unit and a secondary unit more distant from the leak and confirmed that the system was able to find the leak through the local asbestos cement pipe. Figure 3.6 shows the location of the closest three units. The unit closest to the leak (WY00001) was the failed unit. Note that the closest working unit (WY00004) was more than 800 feet from the leak and the secondary correlating unit (WY00007) was more than 1,400 feet away. Leaks can be detected even from distant units such as these (Figure 3.7) if sensitive enough; however, too much sensitivity can lead to distracting data from multiple sources, including false positives. Had the failed unit been working, the leak would have been identified immediately. In any event, the time required to find this leak would not have changed the time required to repair it.

Figure 3.5 Linneman Road leak in meter pit on shutoff valve.

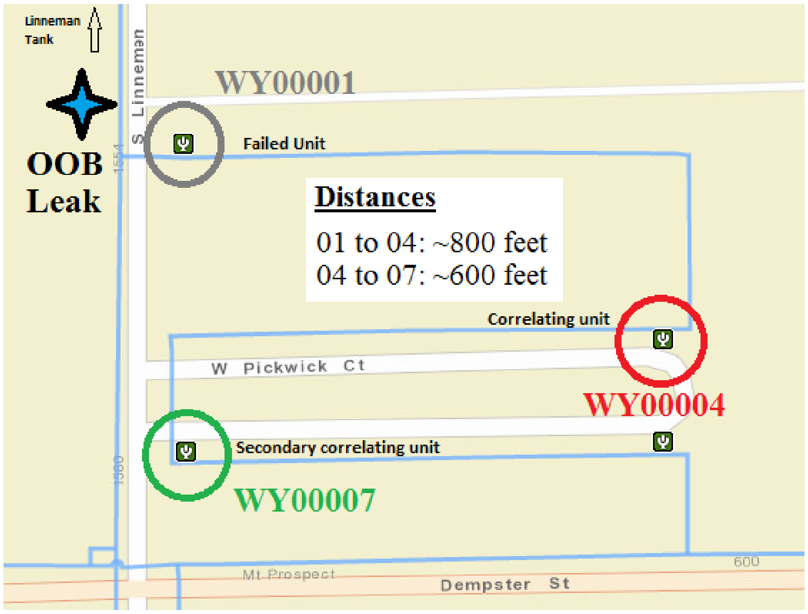


Figure 3.6 Acoustic monitors near Linneman Road leak.

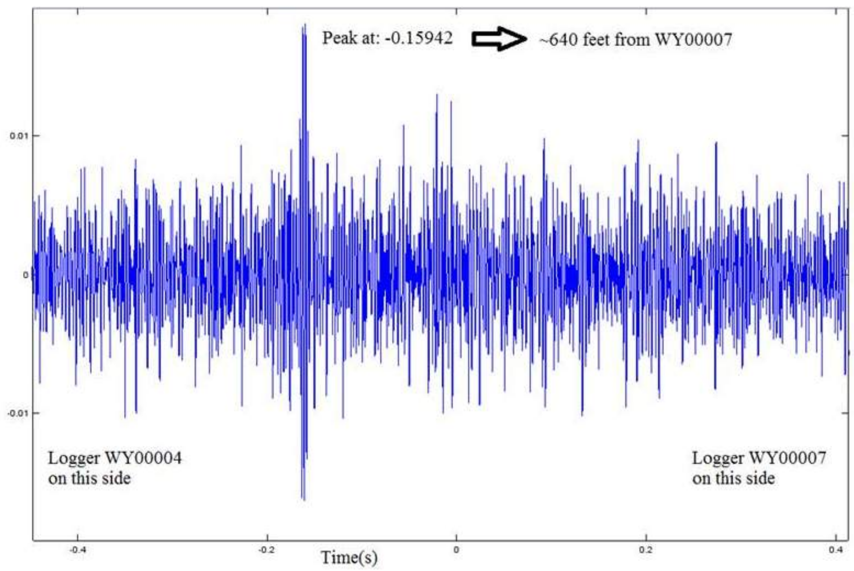


Figure 3.7 Correlation from more distant WY00004 and WY00007 acoustic monitors.

3.2.3 Leak 3 – Malmo Drive

The third leak was a customer service leak, which appeared to surface immediately through the customer shutoff curb box. Service leaks on both the utility and customer side of the pipe are common. This leak was on the customer side of the shutoff valve and, therefore, was their responsibility. In most, but not all, systems, the customer owns the pipe line on the property side of the shutoff valve and the utility owns the pipe from the water main to and including the shutoff valve. The leak raised an interesting monitoring issue for water utilities tracking customer service leaks. The leak appeared on November 20, 2014, and was flowing at a very modest rate (estimated at 1 gpm). The water flowed above ground along the gutter area to a storm drain. The Echologics system did not detect this small leak initially. It was thought to be below the threshold of detection because of the size of flow and its location off the main.

When customer-side leaks are discovered, the utility notifies the customer (usually supported with a letter of notification) and allows the customer a set number of days to make the repair. The issue for the utility is how to verify the leak has been repaired; customers respond at different rates when the leak is upstream of the water meter. Often, a visit or two is required by the utility to verify that it has been repaired. Successful acoustic monitoring of customer service leaks such as this could save at least the cost of making the verification trip. In this case, monitoring suggested that the leak was repaired in a timely fashion, as the acoustics dropped to the normal noise level after 8 days, with a loss of about 12,000 gallons in that time.

3.2.4 Leak 4 – 359 West Dempster Street

On January 1, 2015, a surfacing water main break was reported in front of 359 West Dempster Street. The leak was a modest road hazard due to cold weather icing along the curb line of Dempster Street; the road was treated to remove ice for several days. The leak location was difficult to pinpoint due, in part, to the snow and ice. Echologics assisted in pinpointing the leak using manual correlation on-site. The six inch cast iron main was repaired on January 6. The leak ran for at least 5 days at an estimated average flow of 20 gallons per minute, wasting about 144,000 gallons.

The location of this small leak was between the two logger units, WHY091 (200 feet from leak) and WYH093 (675 feet from leak), but it did not trigger an alarm from the correlating CAM system. WHY091, the closest unit, was inactive due to a failed battery. The next nearest loggers, WYH089 (1650 feet) and WYH053 (950 feet) (see Figure 3.8), were too far away from the leak for the noise they received to correlate or result in an alarm.

After repair, the Echologics team performed an acoustic investigation by inducing sound to verify that a properly operating unit would have heard the leak. This exercise is done by striking a valve near the leak with an impact hammer (Figure 3.9). Figure 3.10 displays the manual correlation responses of the replaced monitor (location 1, WYH091), as well as other units (location 3, WYH093 and location 5, WYH053)). According to these results, the sound source could be readily detected at the closest unit and one hydrant away from the source (location 3). Although the noise was barely noticeable at the units two hydrants away (location 3 and 5), it was concluded that, if the acoustic network was fully operational (WYH091 active), an alarm would have sounded and pinpointed the leak. It is not clear from the available data if the leak ran for any extended time prior to surfacing on January 1. Consequently, no economic value could be placed on this leak prior to surfacing. The leak – detected on a holiday – would not have been repaired any sooner than the following Monday. It would be unrealistic to assume a faster response time in this instance. The surfaced water caused road ice in the vicinity of the leak. Had the leak been detected earlier than January 1, the hazardous condition and the water loss could have been minimized, but this statement is hypothetical because it is not known if the leak started prior to the holiday.

Figure 3.8 Acoustic loggers near 359 Dempster Street leak.

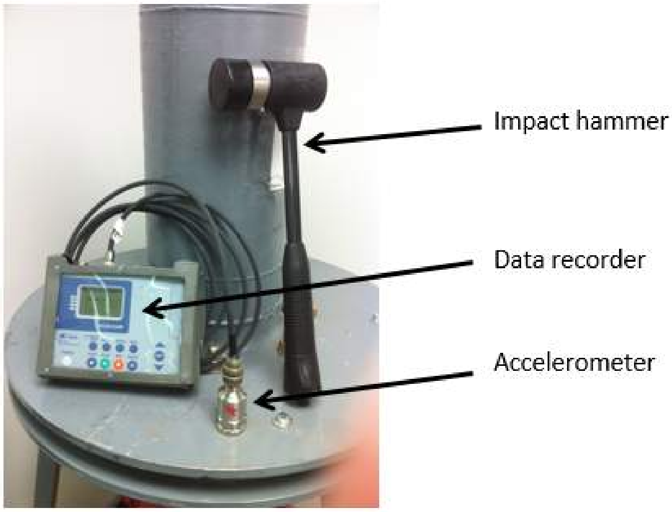


Figure 3.9 Impact hammer and recorder to test for acoustic transmission.

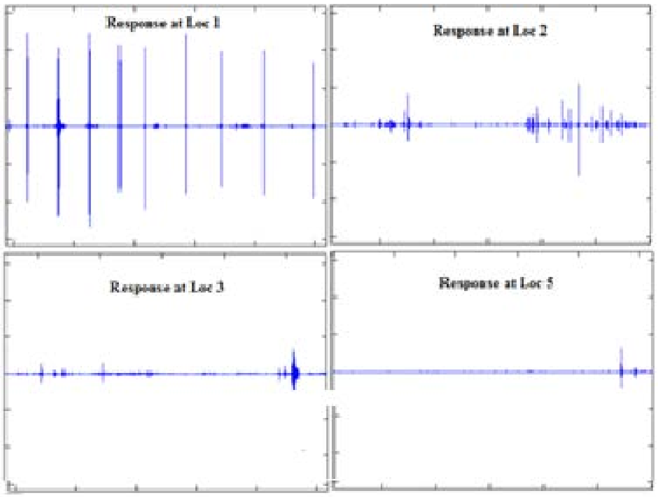


Figure 3.10 Responses at locations 1, 2, 3, and 5 from sound created at location 1 (diminishing sound with distance).

3.2.5 Leak 5 – 501 Carboy Road

On January 27, 2015, water surfaced from a leak at 501 Carboy Road. The excavation, repair, and restoration team arrived on site at 8 PM on January 27. Water was then shut off at 9 PM to repair the water main break. Water was off for 3.5 hours, so overnight monitoring would not have captured the leak. The leak was estimated at 50 gallons per minute (gpm) and ran for about 6 hours, losing about 18,000 gallons.

The Echologics alarm system did not respond. Figure 3.11 shows the location of the closest three units. The unit closest to the leak was location 2 WYH118 (50 feet) and the two next closest monitors were WYH116 (550 feet) and WYH119 (600 feet). The proximity of three sensors that appeared to be working suggests the leak should have been detected. There were several possible causes of the Echologics system failure: (1) the close sensors may not have been properly connected with the pipe network, (2) insufficient energy (noise) was generated by the leak, (3) the leak was very short term, or (4) there was a sensor issue. Under normal circumstances, if the energy from a leak is strong, it can be detected by the neighboring unit even if the unit closest to the leak has failed. Echologics performed a high-sensitivity correlation with the working primary unit and a secondary unit more distant from the leak and confirmed the ability of the system to find the leak.

The correlation responses to hammer blows at different locations are shown in Figure 3.12. According to these acoustic propagation results, the sound was detected one hydrant away from the source (response at Location 2). The sound dissipated noticeably at more distant locations (Locations 3 and 4), as expected. Even though the attenuation (noise dissipation) was significant, some minimal sound propagated through the pipes to the more distant hydrants. With a noise source at location 1 (hydrant WYH118), it was possible to clearly see the impacts on location 4. Because the leak could be found at a distance, the best theory is that the pipe break was a sudden surfacing leak.

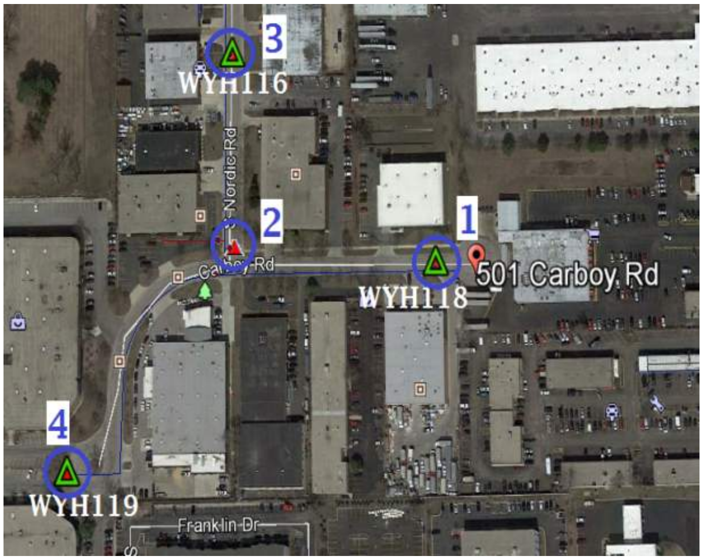


Figure 3.11 Location of acoustic monitors near 501 Carboy leak.

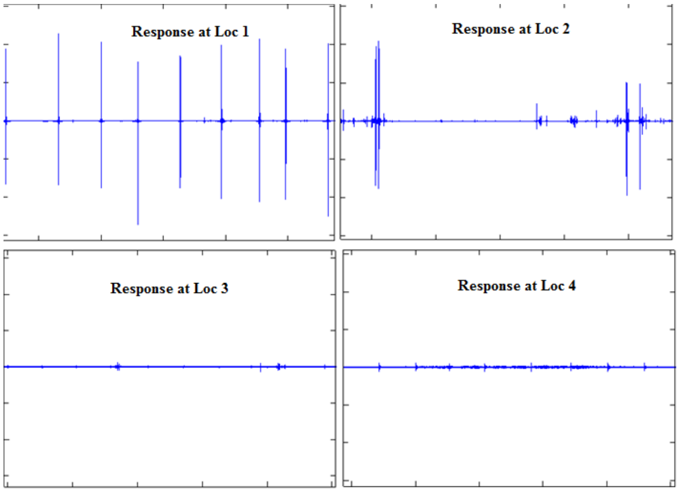


Figure 3.12 Responses at locations 1, 2, 3, and 4 from sound created at location 1 (diminishing sound with distance).

3.2.6 Leak 6 – 1181 Stark Place

The leak at Stark Place occurred on February 16, 2015. This was a circumferential break on a cast iron water main. The leak occurred not long after the prototype loggers had been replaced with the new second generation Echologics loggers due to the software/battery issue. Unfortunately, the logger closest to the leak location (WY127) was inactive due to the duplication of serial number with another device that was reporting in the system. The location of the leak was next to the driveway of a residential customer. If the leak, estimated at 150 gallons per minute (gpm), began running after it surfaced, about 54,000 gallons were lost. If it started smaller, the leak might have run a few more days. However, this would be atypical for a circumferential break, especially over a driveway that would not tend to hide the leak. Figure 3.13 shows the leak repair at Stark Place, and Figure 3.14 shows the layout of Echologics units in the area and the leak location. If the noise spectrum is strong from a main break like this one, an alarm would be triggered at the closest logger. The location of the leak occurred at the end of the network, so no acoustic unit was on the other side of the leak. The next closest units were WY122, WY112, and WY114. These distant loggers could not be counted upon to capture small changes that occurred due to this leak. A field spectrum investigation was conducted by Echologics to determine whether a fully functional system (with duplicate serial number loggers corrected and in active status) would have detected the leak. They found that the large leak with its strong leak energy spectrum could have triggered correlation with the next closest logger and would have confirmed the location of the leak.

However, the point of interest (POI) would have been outside the area between the two nodes, also referred to as “out of bracket.” The 15 gpm leak was repaired on the same day it surfaced. The circumferential break is in a class of leaks that tend to surface rapidly. There is no reason to believe that a fully-functioning Echologics system would have shortened the duration of this particular leak. For leaks at the ends of systems, Echologics should consider adjustments to minimize out of bracket finds that are currently not being reported by the software. This could be in the form of an acoustic monitor attached at the end of the system (on a curb stop or buried on the pipe) or a software modification that would provide for alarms when leaks occur out of bracket.

Figure 3.13 Leak repair at 1181 Stark Place.

Figure 3.14 Locations of acoustic monitors near 1181 Stark Place leak.

3.2.7 Leak 7 – 1101 Elmhurst Avenue

The leak at Elmhurst Avenue was spotted on February 17, 2015. The leak appeared shortly after the installation of second generation Echologics units. The units close to the leak location, WY039 and WY040 (Figure 3.15), were still being commissioned at the time of the leak, which means that the alarm mode was not activated. To validate that the system would have found the leak, Echologics performed high sensitivity manual correlation on February 18 and was able to spot the exact leak location. The circumferential leak was repaired later in the day on February 18. The leak occurred at about a 150 gpm rate for 18 hours, wasting 162,000 gallons. Circumferential breaks are generally categorized as sudden breaks, so it is likely the leak surfaced quickly with little advanced warning. Consequently, no theoretical economic benefit can be gleaned from detecting this break..

Figure 3.15 Acoustic monitors near 1101 Elmhurst leak.

3.2.8 Leak 8 – 183 West Walnut Street

The leak near 183 West Walnut Street was reported on February 25, 2015, and was estimated to be a 100 gpm circumferential break. The leak occurred next to the customer's driveway in a grassy area. The leak did not trigger the Echologics alarm system. At the time of the leak, the closest unit (WY107) (Figure 3.16) was inactive due to the duplication of serial number of the logger units. The subsequent field spectrum investigation by Echologics confirmed that the complete system (with duplicate serial number loggers corrected and in active status) would have detected that leak. But the Echologics system would have found a large leak another way; a strong leak energy spectrum could have triggered correlation between other working loggers (WY82 and WY102), had the leak run during an overnight period. The crew arrived at 3:00 PM on the day the leak surfaced, repaired the circumferential break, and restored service by 8:00 PM. It is estimated that the leak ran 16 hours and wasted 96,000 gallons. The combination of a circumferential break, fast repair, and absence of sound the previous night served to convince the researchers that the leak was sudden and could not have been detected sooner.

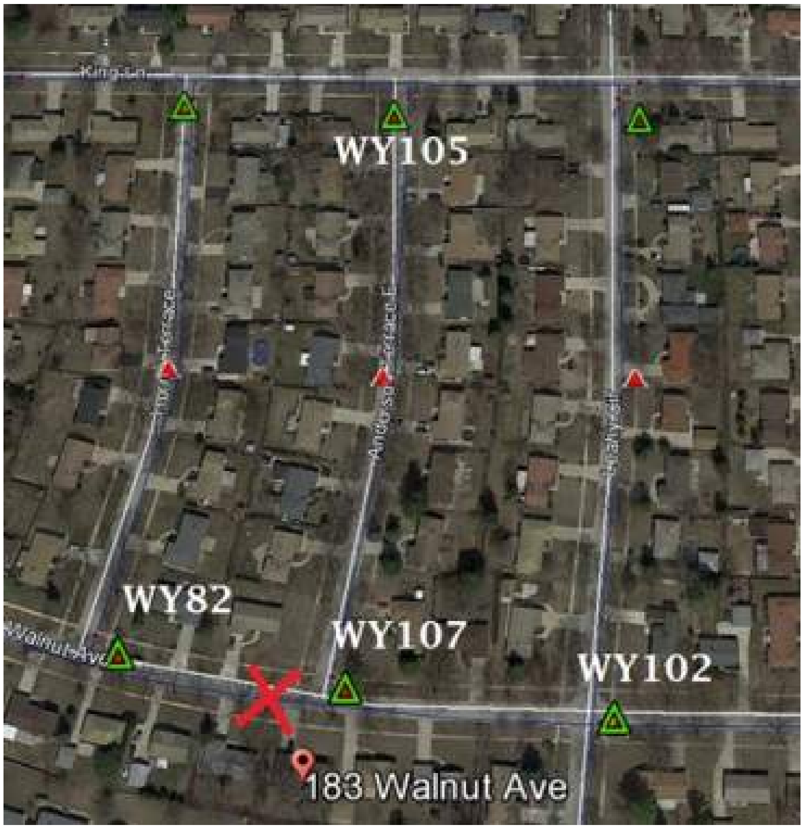


Figure 3.16 Acoustic monitors near 183 West Walnut leak.

3.2.9 Leak 9 – 963 Leahy Circle

The leak at 963 Leahy Circle was reported on March 1, 2015. This was a blowout leak on a 6” cast iron main adjacent to the customer’s driveway. The crew arrived on site at 11 PM, arrested the leaks using two clamps on the cast iron main, and discovered that a corroded section of pipe had to be removed. Service to 25 customers was interrupted for nearly three hours. The leak flow was estimated at 400 gallons per minute for 4 hours, losing 96,000 gallons. The loggers did not trigger leak alarms at this location, due to the short time window of the leak. The Echologics system reported 4 POIs the night before, but at different locations. The POIs were reported between the following pairs of nodes (Figure 3.17):

- WY099 & WY102
- WY099 & WY126
- WY100 & WY102
- WY126 &WY102

Manual correlations were run between five nodes (WY99, WY100, WY102, WY126 and WY123). The results pointed to a potential leak near node WY123. This hydrant was used during the repair to flush the line clean. It is possible that the flushing or a minor leak in the hydrant might have triggered the alarm. The leak took place on a Sunday, and was repaired by early Monday morning.

Figure 3.17 Acoustic monitors near 963 Leahy Circle leak.

3.2.10 Leak 10 – 724 Algonquin Road

On March 6, 2015, an 80 gpm leak was reported on a 6” cast iron main at 724 Algonquin Road. After the water surfaced, the circumferential break was repaired and restored on the same day. Thirty residents were without water for four hours during the repair. The water loss was estimated at 14,500 gallons with a fast response within four hours.

The Echologics monitors did not report this leak. Three loggers, WY046, WY047, and WY049 (Figure 3.18), were in the vicinity of the leak; the closest logger (less than 100 feet away) was WY046. Due to technical issues, the loggers (WY046, WY047 and WY049) failed to upload the acoustic files to the Echologics main server. The files, containing resonance information collected from the pipe, were saved and later uploaded to the server. These files were subsequently analyzed and studied by Echologics to provide leak information based on the acoustic data collected by the different nodes. Echologics was unable to confirm the root problem in its system. A few files were retrieved, but they were insufficient to allow a firm conclusion. But, given the nature of the leak and information that could be gathered prior to the leak surfacing, it is likely that the leak surfaced immediately.

Figure 3.18 Acoustic monitors near 998 Wilson Drive leak.

3.2.11 Leak 11 – South Malmo Drive and East Algonquin Road

A leak was reported in a parking lot near the intersection of South Malmo Drive and East Algonquin Road on March 28, 2015. The repair work on a corrosion hole leak was completed the following day, which means the Echologics system had the opportunity to hear the leak. The leak ran for about 36 hours at a 15 gpm rate, with a loss of about 32,500 gallons.

Hydrants WY31, WY33, and WY34 were the closest nodes to the site (Figure 3.19). Only WY33 and WY34 held files from March 28. Unfortunately, without the file from WY31, it was impossible to obtain a better estimate of the location. The system did not trigger. Although there was a change in the noise spectrum for loggers WY31, WY33, and WY34, it was below the leak alarm threshold. It would appear the leak was simply too small for detection and it surfaced before it grew worse. Using manual correlations for investigation, the system showed a correlation between loggers WY33 and WY34. Despite the absence of data from WY31, a correlation confirmed the leak likely began on March 28.

Figure 3.19 Leak surfacing 724 Algonguin Road.

3.2.12 Leak 12 – 998 Willson Drive

A leak of less than 5 gpm surfaced on Willson Drive near Kinkaid Court on May 4, 2015, close to the site of leak 1 (see section 3.2.1). The main break at the service connection for 998 Willson Drive was fixed that same day as it surfaced. It is estimated the leak ran for 10 hours, losing about 3,000 gallons.

The Echologics acoustic monitoring system did not detect the leak prior to the leak surfacing and being found. Echologics staff downloaded recordings from the surrounding nodes prior to the break to decipher whether the nodes heard the leak noise. There was no evidence of leak noise and the nodes were operating satisfactorily. Files from nodes WY00043, WY00059, WY00060, WY00062, WY00065, and WY00121 were downloaded and analyzed from May 1-5, 2015. None of the files showed any evidence of leaks, even a small one. Because a prior burst in the same area was detected earlier, most issues with possible equipment failure were ruled out. In this case, it is likely this leak surfaced rapidly.

3.2.13 Leak 13 – 1650 South Linneman Road

A sudden increase in water demand was noted in the Waycinden system beginning at approximately 11 PM on June 25, 2015. The issue continued through the early morning hours, until Illinois American Water staff asked Echologics to help find a suspected hidden leak. Before 5:00 AM and before Echologics could respond, the surfacing leak was found. The source was a broken pipeline on the internal metered piping serving the United Airlines computer building. The leak wasted 700,000 gallons of water.

Because the leak ran during the night, the Echologics system had opportunity to provide data about the acoustics of the leak, even though it was at some distance from the utility pipe network. Figure 3.20 shows the monitoring hydrants circled in orange. The hydrant near Linneman Road at the top of the map is the closest hydrant to the north (about 550 feet from the leak); the other acoustically-monitored hydrants in red at the upper right are in an apartment complex. Note the units in the apartment complex are actually farther from the leak because of the system layout. The closest hydrant to the south is on Linneman Road, 800 feet south of Dempster Avenue. Note also that there is no monitor on the western dead end of Dempster Avenue, 800 feet west of Linneman Road. This means the closest monitors on either side of the connection to the break were 1,350 feet apart, in addition to the distance along the service line of 250 feet. The pipe in this area is also asbestos cement, which does not carry sound nearly as well as cast iron. It has been suggested for critical water users who rely heavily on water supply for operation and fire protection that permission be secured to add monitors on their private hydrants (in green). After this event, it is likely at least this one customer will be willing to participate in leakage control in the future.

In Figure 3.20, the hydrant near Linneman Road at the top of the map is the closest hydrant to the north; the other acoustically-monitored hydrants in red at the upper right are in an apartment complex.

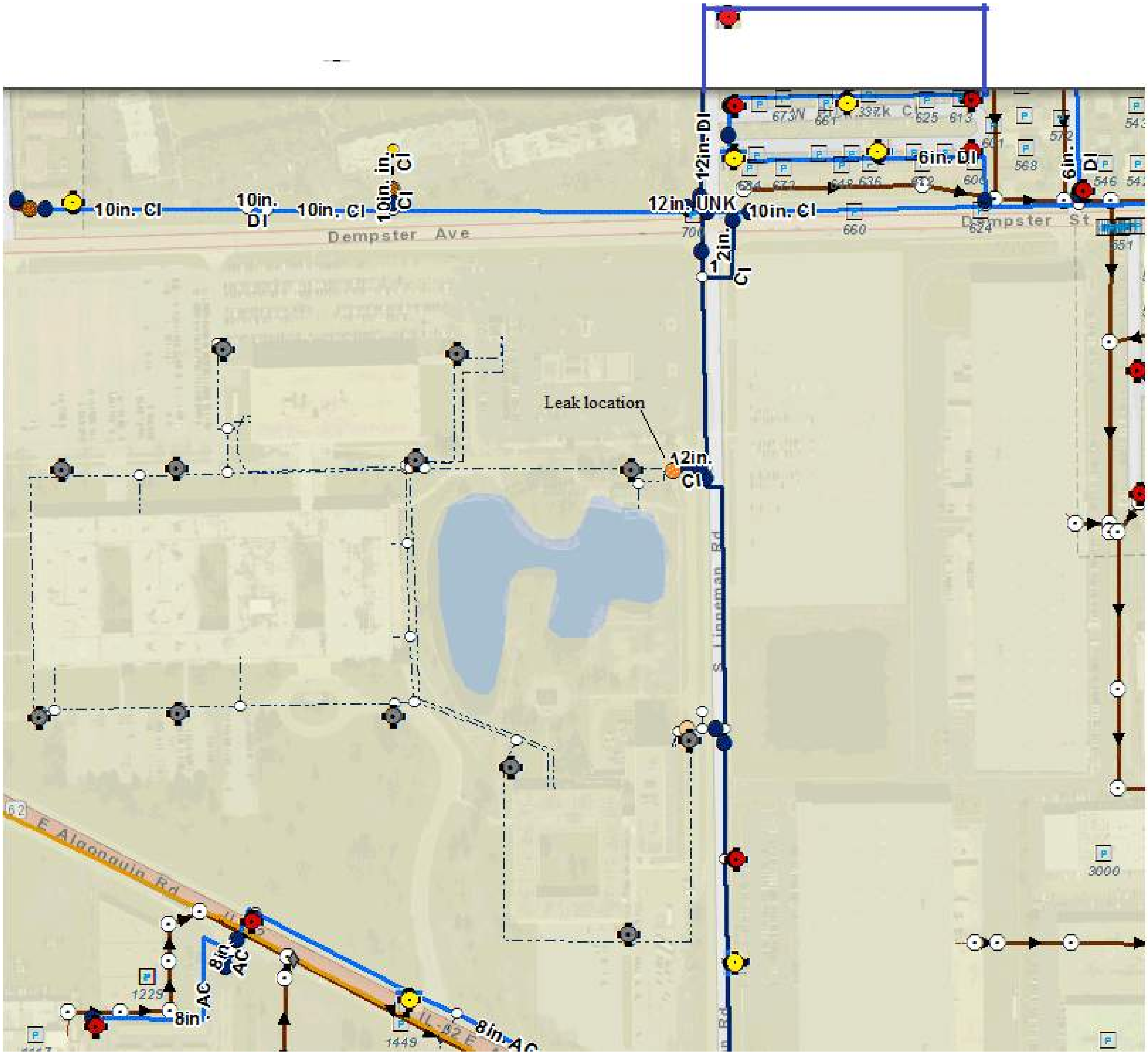


Figure 3.20 Acoustic monitors near 1650 South Linneman leak.

3.3 LEAK SUMMARY

Of the 13 leaks in the ten-month study period, only the first leak ran for any length of time before surfacing. Despite some irregularities in detection, Echologics documented that the remainder of leaks either came to the surface immediately or within a day or two of audible detection. While it was expected that half the leaks categorized as winter circumferential would surface quickly, it was not expected that the corrosion-related leaks would also surface quickly.

As anticipated, the influence of cold weather triggered new leaks in the Waycinden network in the winter months. The severe winter produced more leaks than expected: eight leaks (#4-11 listed in Table 3.1). This was more than double the number of leaks for a typical winter. Most of the leaks surfaced without Echologics monitors transmitting a leak alarm. In five of the winter events and seven of the total leaks (shaded in gray in Table 3.1), the sudden occurrences of the bursts were confirmed by Echologics analysis.

Unfortunately, technical issues interrupted the effectiveness of the acoustic monitoring. Issues included battery failure in first generation units, serial number duplicates in new loggers, and leaks occurring during the time of initialization of the new loggers, before they were "alarm ready." Two leaks (in italics in Table 3.1) of the five sudden winter events were detected by the correlating CAM when they began though they had no impact on speeding up repairs.

Table 3.1 Study period leak history.

#	**Location**	**Duration**	**Echologics detected**	**Days running**
1	*Kincaid Court and Willson Drive*	*ran 12 days after detection by Echologics*	*Echologics detected*	*12*
2	1567 South Linneman Road	leak identified immediately at site	battery issue	2
3	3001 Malmo Drive	service line surfaced at curb box	too small	5
4	359 Dempster St.	ran 4 days holiday weekend period	battery issue	4
5	501 Carboy	surfaced immediately, repaired same day	good coverage	<1
6	1181 Stark Place	surfaced immediately, repaired same day	serial # duplication	<1
7	1101 Elmhurst Avenue	surfaced immediately, repaired same day	no alarm in start up	<1
8	183 West Walnut Avenue	surfaced immediately, repaired same day	serial # duplication	<1
9	*963 Leahy Circle*	*surfaced, repaired second day*	*Echologics detected*	**2**
10	724 Algonquin Road	surfaced immediately, repaired same day	missing files	<1
11	Malmo Drive & Algonquin Road	ran one overnight period but too small	too small	2
12	998 Willson Drive	surfaced, repaired same day	good coverage	<1
13	Property near Linneman Road south of Dempster Avenue	service line surfaced, repaired same day	poor coverage	<1

Technical issues affected the detection of some leaks directly while other leaks were too small or out of range for the sensitivity of the equipment to be detected.

Most NRW experts agree that the effectiveness of acoustic monitoring leakage control depends on the nature and the types of breaks in the specific water network[7]. It is the overall consensus that the majority of water lost through water pipes is attributed to smaller leaks that typically develop slowly and remain hidden from view, as opposed to the more dramatic water main bursts that lose a significant volume over a comparatively brief time. The main issue for any water utility system considering acoustic monitoring will be the amount of water that can be saved by early detection and rapid repair of both small and large leaks.

American Water's experience in many water systems supports the idea that small non-surfacing leaks offer the most opportunity for savings, since many, but not all, large breaks appear to occur suddenly. In the Waycinden study system, however, many of the leaks – large and small – surfaced within hours of their apparent start.

Historically, the rapid surfacing of leaks in the Waycinden system may be attributed to the location of many mains in the system that are off road or along the road edge. Additional factors include the flat topography and poorly draining soils.

3.4 COST SAVINGS ANALYSIS

Cost savings for the project are mostly associated with the first leak on Kincaid Road, so this is discussed in detail here.

3.4.1 Leak 1 – Possible Savings from Water Loss Reduction

The first leak was a non-surfacing 25 gpm leak which ran for 12 days after initial detection but before it was confirmed as a leak. Had the leak run the normal estimate of 90 days for non-surfacing leaks, it would have leaked 3.24 million gallons at the observed rate. At Illinois American Water's 2014 purchase price of $5.342 per thousand gallons, this translates to a cost savings of $17,308 in water. This unit cost increased to $5.839 per thousand gallons in 2015.

3.4.2 Leak 1 – Possible Reduction in Restoration Materials Expense

Because the leak was in a grassy area, the cost of restoration materials was not significant. The direct flow into the manhole could have prevented damage to the road or sidewalk, but any additional cost here would be minimal.

3.4.3 Leak 1 – Possible Reduction in Repair Materials Expense

If the leak had not been detected for months, a substantial split in the pipe could have occurred, requiring an additional repair clamp and potential replacement of the full 20-foot length of pipe. These additional pipe materials could be conservatively estimated at $250.

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[7] Fantozzi, Marco et al, *Some International Experience in Promoting the Recent Advances in Practical Leakage Management,* Water Practice & Technology, Vol. 1, No. 2, IWA Publishing, 2006.

3.4.4 Leak 1 – Possible Reduction in Repair Labor and Equipment

Because of the early detection before the leak surfaced, the repair was made during the work week and repair costs were minimal. A sudden break after months of non-detection may have required overtime, or 1.5 times the normal rate (about $150/hour for a 3-man crew). In addition, the more complex repair noted above would add an additional hour to the crew's labor. This works out to the equivalent of 2.5 hours x $150/hour +1 hour x $100/hour (assume standard rate) for labor = $475.

3.4.5 Leak 1 – Possible Third Party Damage and Triple Bottom Line Costs

No damage was reported, though it is possible that the storm sewer manhole may have been damaged.

3.4.6 Leak 1 – Total Savings

The estimated total savings due to estimated water savings and potential additional costs were estimated at $18,250. This leak, as it turned out, was the most substantial and represented the majority of the savings during the study period. If a leak like this occurred annually, the cost savings would exceed the cost of the capital expenses over the five-year life of the equipment. It should be noted that the key to the large savings is the high cost of purchased water in the Waycinden area. If the cost of water was in a more typical range, the water savings might range between 5-15% of the $18,250 savings estimate. Such an adjustment clearly impacts the value of the leak and return on investment.

3.4.7 Savings Associated With Other Leaks

The cost savings realized from acoustic monitoring alerts depend upon identifying leaks that fail to surface for lengthy periods of time. While the researchers examined the history of prior leaks, they could not document the length of time that leaks stayed hidden until the acoustic monitors were set in place. Of the five leaks that did not surface on the same day they started, three leaks only stayed hidden for one day. The fourth surfaced on January 1, but a business decision was made to allow the modest leak to continue until the end of a long holiday weekend. It was of great interest to understand how common are high-flow, non-surfacing leaks (such as leak #1) in the system. Unfortunately, the ten-month study was too short to draw a definite conclusion. But if just one similar hidden event was detected annually, the acoustic system would likely be cost-effective. Considering its expected 5-year life, however, the cost-effectiveness of the system would depend on the cost of water in a particular utility area. This pilot project was in a system which had a high cost of purchased water. Many systems have water supplies of their own that cost 5-15% of the rate paid by Illinois American Water in the Waycinden system.

It was anticipated that there would be multiple hidden breaks during the study period which could be analyzed for economic impact, but this did not occur. Consequently, no further results on the cost of water saved, reduction in the nature of the repair, reduction in restoration expense, reduction of field labor, third party damage and third party costs (environmental, social, economic costs) are provided for the other leaks. The speed of the response to leaks by Illinois American Water staff was impressive. Most leaks were repaired the same day, even though the crew was not located in this system area. Response time was often minimized in the winter due to concerns about ice on local roads and sidewalks, but the quick responses also saved money on water losses.

3.5 MINIMUM NIGHT FLOW ANALYSIS

The SCADA link was successful in providing pertinent information about flow within the Waycinden system on most nights (between 3 and 4 AM). Data collection started in August and was stabilized in September, but the 12-day leak in September prevented examination of minimum night flow until October because it was adding to the night flow. For most days, the only source of supply between 3 and 4 AM was the Waycinden tank (Figure 3.21). The typical night flow was about 115 gpm (6,900 gph). It is noted that the granularity of the tank level is 0.1 feet, translating to 1,500 gallons. The margin of error (1,500 gallons per hour or 25 gpm) can be a significant portion of the hourly flow. The research team considered a more accurate reading approach using a more sensitive pressure data logger, but the use of night flow appeared sufficient with the use of existing equipment. There appeared to be a matchup with three leaks that ran overnight with the three highest peaks of night flow.

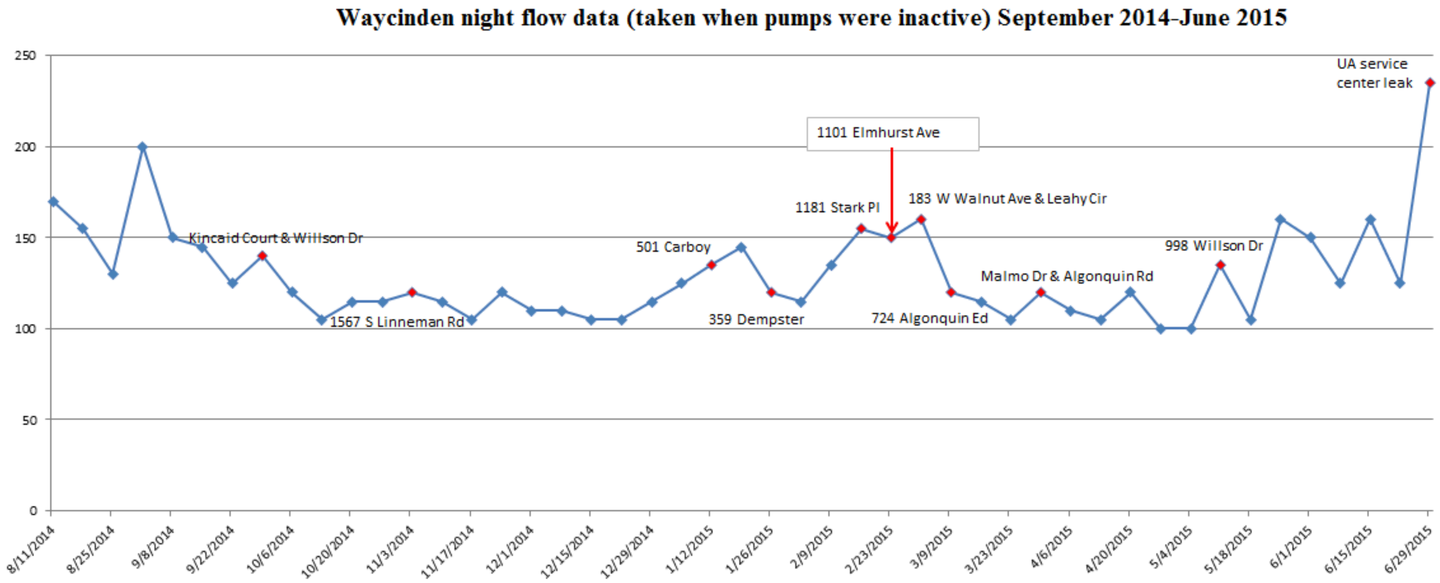

Figure 3.21 Night flow for project period.

The following can be concluded from the analysis of night flow:

- The average night flow (stored and pumped) for the system from August through April, 2015, was about 120 gpm (9,000 gph). Night flow during cold weather can be higher than average, since some customers try to prevent lines from freezing by continuously running water through taps. Night flow can be higher in the summer due to nighttime irrigation.

- Comparisons of the rate of flow of pumps with tank elevation changes showed an uneven transition, which is thought to be due to the calibration of the flow meters at the pumps. Consequently, the averages reported here reflect changes in tank elevation from selected days during each week. The researchers are also mindful that ice formation in the tank can cause skewed data. Ice at the top of the tank can either float on the water or become stuck along the walls of the tank, causing an irregularity in volume calculations.
- Some leaks in February were captured by the night flow system, suggesting that leaks may have lasted for a longer period than expected.

3.6 LEAK DATA COLLECTION

Illinois American Water provided their detailed leak reports, which include a full description of most aspects of the repair, including photographs (though higher-quality photos can be taken when breaks occur in daytime). Appendix B includes a representative excerpt from a leak report. There were instances in which the estimated flow of the pipe was not provided, as the form lacks a distinct place to enter a flow estimate. Reports can also lack information on the type of leak, which requires some speculation and close examination of the pipe. It is important to keep in mind that field crews often work in the dark and the cold, as many breaks occur during the winter. Their primary goal is to make the repair and ensure that water is properly restored, while minimizing the time that customers are out of service.

Often, the description of the repair materials will provide important clues to the pipe failure. For example, when two repair clamps and a section of PVC are listed under repair materials, this means a pipe section needed to be replaced. This is often required for issues with the connecting bell and spigot or, in the case of Waycinden, corrosion that has weakened an area of pipe to the extent that a piece of the pipe must be cut out and replaced. The fact that a saddle repair clamp was used to replace the connection at the main in Leak 10 suggests that the failure was either on the connection itself or on the water main that received the connection.

Two of the pipe failures noted in the report clearly involved a customer-side service leak. As described in the first such leak (Leak 3), the acoustic monitoring system could have been used to confirm if the repair had been made, assuming it was acoustically detectable. In the case of the second massive leak, in which a large commercial customer had major piping (Leak 13), it might make sense for the customer to extend the leak detection system into larger customer properties especially if they have significant pipe onsite.

The total volume of the unmetered leaks during the study period totalled roughly 1.3 million gallons. This is far less than the estimated 16 million gallons of nonrevenue water estimated to have occurred during the study period (based upon NRW figures provided by Illinois American Water). There are other sources of nonrevenue water besides main breaks. Major factors include authorized unmetered use such as hydrant operations for flushing mains, fighting fires and testing hydrants, apparent losses such as water theft, customer meter inaccuracy and billing errors, and unavoidable small leakage. Using AWWA water loss methodology, these factors may account collectively for about 7.3 million gallons, about half the water that has not been accounted for. The remainder may reside in some combination of error in flow measurement delivery into the system, an underestimation of other forms of non-revenue water and continuous leaks that have not been detected from the start of the project through to the end. Further work will be necessary to determine where the differences lie. There is some suspicion with the corrosive soils that the contribution from small (inaudible) leaks is underestimated. The unaccounted water flow if it ran during the entire ten month period would approximate 65 gallons per minute – well below the minimum night flow, per Figure 3.21.

3.7 CORRELATING CAM INVESTIGATION DATA

Very clearly, the Echologics prototype units did not perform as hoped. Battery failures prevented the timely confirmation of two rapidly-surfacing leaks. The manufacturer did respond promptly, first to replace the defective units and ultimately to equip the entire network with production-level versions of the sensors. In the haste to make a changeover, more issues arose: two leaks went undetected because of duplicate serial numbers on the units, and another went undetected because the new unit was still standardizing background noise during its first week of activation. In all of these cases, Echologics responded by making field verifications that the remaining system detected the leak and also conducted sound checks to verify that if the leak had occurred, the noise would have been detected. And in all of these cases there is evidence to suggest that the leaks ran for a very short period of time.

3.8 ENVIRONMENTAL DATA

The most significant environmental factors were air and water temperatures. Water temperature is speculated to be a contributing cause to circumferential breaks as the cold water would put thermal forces of contraction on the pipe in contrast to the weight of the cover and the joints holding the pipe in place. The source of water is the Chicago water supply from Lake Michigan. It is difficult to project the magnitude of temperature changes into the Waycinden system from Lake Michigan owing to the cribs that Chicago uses to extract water at depth from Lake Michigan. Moreover, the water must travel an estimated 25 miles underground where water can be warmed and then exposed to the cold at elevated water tanks in systems along the way. There were an insufficient number of breaks to justify a study with water temperature for this project, so the focus was placed on air temperature.

An examination was made of air temperatures from Mount Prospect. Figure 3.22 shows a plot of high, low, and median temperatures along with the time of breaks (vertical lines). As has been found in prior studies, leaks tend to occur at low and dropping temperatures. This phenomenon is not unknown to distribution operators. What is significant about data involving acoustic monitors is that the start of the leak (or at least when it becomes acoustically significant) is better known than in studies relating temperature to the surfacing leak.

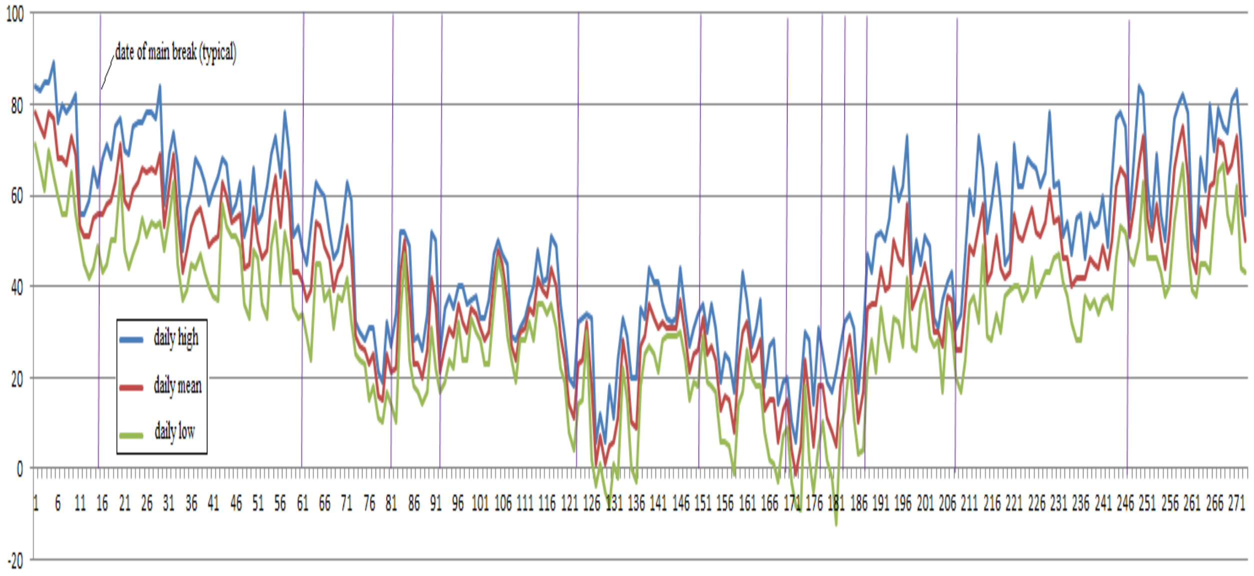

Figure 3.22 Area air temperatures and breaks through the project period.

3.9 METERING AND NRW

An investigation into metering information was conducted using the recently enhanced American Water meter data management (MDM) system. It was thought that the system might provide monthly feedback with reliable monthly customer readings, and that that this could be compared to monthly production values instead of the more cumbersome 12 month rolling average. One fortunate development is that the readings occur on or around the end of the month or start of the next month, so the timing of monthly production and meter readings would be favorable. The readings from the meter route that is the Waycinden system showed 785 meters to be read. The MDM data from readings for the month of June were taken on July 1 and 2. The system data shows that all but 13 meters were read and usage totalled 17,012,000 gallons. But the actual data used by Illinois American staff for June totalled 13,812,000 gallons, which suggests that the route includes meters outside the system or that substantial adjustments were made in the data that American Water uses internally to assess NRW. The issue with the MDM data since production is also in the area of 14 million gallons for the month of June. Additional analysis outside of the scope of this project would be required to determine the issues. It is noted that the largest user of water in June was the location of the last leak that was metered (Leak 13).

3.10 REPORTING

The findings of these trials have been and will continue to be shared with other utilities through presentations. The first presentation was made on June 4, 2015, at T-Con 2015: The Midwest Water and Wastewater Technology Conference. For the broader utility audience, the project is expected to demonstrate a truly effective and reliable acoustic monitoring system capable of identifying leaks the moment they start. The potential of the system, complete with an economic assessment of its benefits, will be outlined in this report. The effectiveness of finding significant leaks is verified through monitoring minimum night flow. If this approach proves fruitful, more utilities will be willing to engage in it.

CHAPTER 4: ANALYSIS AND DISCUSSION

4.1 ACOUSTIC MONTORING SYSTEM

As might be expected from a prototype system, there were issues that occurred during the project. While it appeared that the acoustic monitoring system was unable to detect many leak events, none of the prototype units had a negative effect on leak duration, because all of the relevant leaks surfaced immediately.

Adjustment was the theme of the acoustic monitoring system. The layout of the acoustic monitoring equipment was modified from the proposed layout to include a second data collector, at the Mount Prospect tank at the eastern end of the system, to complement the Linneman standpipe collector. Scheduling the installation of the antenna on the top of the Linneman Road tank was delayed by weather (thunderstorms in August), but the work was still completed on time. Two repeaters were also added to convey data from the hydrant sensors to the collectors. The additional cost of equipment was borne by Echologics and the cost of installation by Illinois American Water.

There were 79 loggers installed in the system – one more than originally estimated – to obtain full coverage. Two loggers were found to be not functioning correctly at start-up. These were immediately replaced by American Water and returned to Echologics for evaluation; production flaws or battery issues were suspected. Spare units were provided; therefore, there was no loss of coverage when the monitoring process began.

The first confirmed battery failure at the Linneman Street leak raised the first major concern about the equipment. Analysis of the failure suggested that a flaw in the program software might force the sensor to perform analysis and send transmissions unnecessarily, thereby exhausting the battery. At one point, 11 sensors lost battery power and were replaced after a few weeks. Echologics eventually decided to replace all units with their upgraded version, which was available at the end of 2014, to minimize the battery issue. Echologics learned from the technical failure of loggers; the timing of the unit change-outs was unfortunate but necessary. However, it did take some time to secure the new units, in part because a large order for the American Water system in Charleston, West Virginia, had priority.

There was a report on December 1, 2014, of damage to the face of the hydrant cap at 311 Kings Lane, Des Plaines (Figure 4.1). A lawn care company may have struck the hydrant with a weed whacker and taken off the face of the hydrant cap. Despite the surface damage, the unit continued to function. The cap was replaced as part of the change out in January, 2015.

Echologics experienced one more functional issue in their startup manufacturing process of the new units. An internal clerical error generated several units with duplicate serial numbers, which prevented transmissions from one of the duplicate units Illinois American Water received. Again, the locations of the problematic units overlapped with leak locations. To their credit, Echologics responded proactively by performing a thorough analysis of functional loggers and performing a local field analysis to verify that units were functioning when sudden leaks occurred.

Figure 4.1 Damage on hydrant cap.

The utility learned that installation of the acoustic monitors (prototype or second generation) does not mean that the system will instantly report leaks through the Echologics software. The system requires about one week to establish a background noise baseline before it can detect leaks and alert the utility. During wholesale replacements in January, the changeover prevented an alarm for a leak in one location.

Despite the equipment issues, there was very little impact on receiving early leak alerts and on the economic payback. The vast majority of the leaks during the report period surfaced immediately and provided no opportunity for the Echologics system to report leaks before the Chicago Metro crew was aware of a surfacing break. Echologics responded in the field to verify that a leak would have been detected if the units were functioning normally by simulating sound and confirming normal response.

For each leak reported, Echologics provided a write up on the coverage, issues with nearby units, and conclusions about the ability of the units to find the leak in advance. Many of the reports documented field visits made by Echologics to confirm that leak noise would transmit in cases where the units were unresponsive. Most of these descriptions are found within the description of each break in Chapter 3.

Of course, there is some evidence that the system did not hear every small leak and the last significant leak (Leak 13) was out of range because of hydrant coverage. In that instance the private hydrants of the customer were not considered as a resource and in hindsight should have been. There are limitations with hearing small leaks on service line possibly owing to the change to a much smaller pipe where sound can be easily absorbed by the size transition. There were some concerns about the correlating CAM system found in other pilot locations in Uniontown and Liberty, Pennsylvania. In the Liberty pilot, the use of correlation was stymied by the lack of hydrants at dead ends with reduced pipe sizes. It is possible for a leak to be “out of bracket” from monitors. Leaks outside the boundaries of hydrants cannot be correlated.

4.2 SCADA

The SCADA information about night flow provided a useful check against having undetected chronic leaks develop in the system. Calibration of the Waycinden pump units was not necessary given the frequent late night flow behavior where pumps were typically off and tank storage was the only source of water. It would be possible to further calibrate and refine the process but leaks less than 10 gpm would have been difficult to identify using the SCADA. This method has proven effective at other sites (like Liberty, PA). In other locations, American Water has found insertion flow meters to be effective, but such units cost about $5,000.

4.3 LEAKS REPORTED

There was good communication between Echologics and Illinois American Water whenever either party had a suspected leak to report. There was confusion only on one event because the Waycinden system encompasses two towns – Mount Prospect and Des Plaines – and identical street addresses of east-west streets could be found in both towns. The zip codes and municipal boundaries of the area do not match.

4.4 ENVIRONMENTAL DATA AND THE NATURE OF PIPE FAILURES

One of the factors in the surfacing of breaks in the Waycinden system is the location of many mains off the road in sidewalk or grassy areas of the right-of-way. This factor likely enhances the chance that a leak will surface. Water mains are deep in the Chicago area in order to be under the frost line but the location away from paved areas negates this effect.

The number of leaks in Waycinden (13) in ten months was above the yearly average for the prior three years. Temperature was a thought to be a reason for more failures than previous periods. Figure 4.2 shows a comparison of daily low temperatures through the September to June 2015 window for 2011 - 2015. It seems that 2013-2014 appears to have been colder than the study period in 2014-2015, but both periods were decidedly cooler than 2011-2013. The cold extended into February and March, when leaks continued to occur. As a consequence, the additional breaks tended to be circumferential breaks, the leak type associated with cold weather stresses.

The number of corrosion-related breaks was as expected, but the biggest surprise of the research was how rapidly all types of leaks surfaced. The majority of the breaks occurred on cast iron pipes, as expected. The two customer service leaks occurred on copper and asbestos cement pipe, respectively. For the most part, even the circumferential breaks were modest in size.

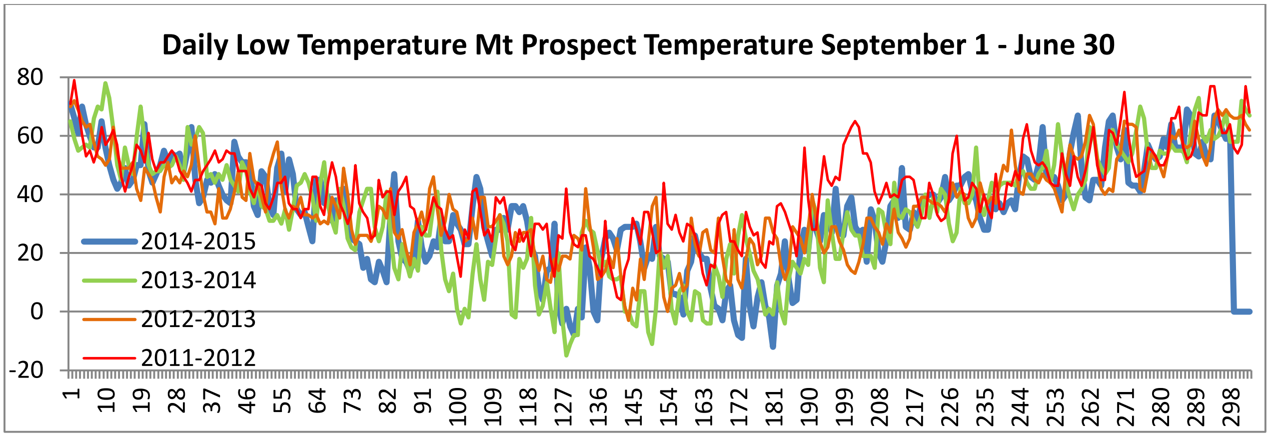

Figure 4.2 Daily temperatures over four years.

4.5 ECONOMIC ANALYSIS

The economic analysis was essentially centered on the very first leak. None of the other leaks would have been addressed any faster with a fully operational acoustic monitoring system in place. The repair crews were extremely responsive. With the exception of one leak that occurred over a holiday weekend, leaks were repaired within a day and sometimes within hours of being reported. The first leak occurred in an unimproved (grass) area, so other elements involving repair and restoration costs were minimal. But, largely owing to the high cost of water in the Waycinden system, the cost of the first leak (25 gpm, which could have run for 90 days) could account for more than 20% of the investment in this equipment. This is especially significant, given that the system is expected to last for at least 5 years (10 years with a battery replacement). Thus, this first leak would justify the investment in the acoustic monitors. One additional benefit realized in the study was the ability to monitor customer leaks to make sure the customer makes timely repairs without having to leave the office.

So the question then becomes what will the future of leaks be in Waycinden? Will most future leaks come to the surface quickly, making the first leak an anomaly? Given the high cost of water, the deployment of a correlating CAM system in Waycinden appears to be the correct one. But for other systems with a low cost of water, this may not be the prudent choice. Anecdotal information about the nature of leaks in a system can help to qualify the potential of hidden leaks. In the case of Waycinden, the amount of leakage seen in the ten-month period does not match the typical NRW amounts, suggesting that long running leaks could occur in the future.

The last leak, on the 12” service main of a customer (Leak 13), added another dimension to the potential of the acoustic monitoring system. This major leak was very large and was beginning to consume as much water as the system can generate. The risk of literally running out of water while looking for a subsurface leak is a distribution system operator’s nightmare. The acoustic monitor vendor has been encouraged to develop a method to scour the entire system for a possible major leak. This opportunity did not occur with this last leak, as it surfaced quickly and would not have worked with sensors out of range. But the potential to provide some insurance against such an occurrence has immense value.

CHAPTER 5: CONCLUSIONS

The acoustic monitoring of the Waycinden system was a successful effort in advancing an improved innovative approach to leak detection. The performance of the units over ten months provided sufficient results to justify the expense of the equipment, including installation, staff time, and maintenance of the system. Units originally provided were not satisfactory, but about 85% of the prototype units continued to function until they were replaced with a final product. Pilot efforts like this one do test the effectiveness of the monitors and the limitations of an acoustic system that relies on two units to detect and pinpoint leaks.

In this pilot, most leaks surfaced soon after they started. There was only one leak during the study period that failed to surface after a few days. Moreover, that leak could have gone undetected for a lengthy period of time. An otherwise undetected leak like this, running for an estimated duration of 90 days, would have cost a great deal of money. It is estimated that prevention of even one such leak per year could account for more than 20% of the cost of the correlating CAM system. Based on weather trends and aging infrastructure in the Waycinden system, a leak such as this will probably occur at least once per year in the future. Moreover, it became apparent from the last burst of a private water main that this small utility system is vulnerable to a major leak and, therefore, having this tool available will provide additional value.

The research must be considered a case study, as the Waycinden system has some atypical features for a water distribution system. The very high cost of water makes it far easier to justify the capital cost of monitoring equipment. As noted in the data, some of the pipe failures involved corrosion holes, which have the potential to leak steady quantities without surfacing for extended periods. While this pipe corrosion is not unusual in many systems in Illinois, it is not found everywhere. Other utilities considering this equipment will need to weigh the amount of leakage they have, the cost of water, and the magnitude of hidden leaks. The issue of non-surfacing leaks is the most significant in Waycinden. Though the ISTC project has concluded, monitoring will continue in the system and additional information will be forthcoming. What is most telling is that Metro Chicago will be installing the monitors in another leaky system in 2016.

Utilities considering acoustic monitoring should analyze the potential for long-running hidden leaks. The question is, how can this be done without installing the equipment? The analysis should examine field evidence from previous leaks; for example, a large sinkhole or other evidence suggesting water has flowed for a long time underground. Historical NRW data or night flow data can also be analyzed. For example, after the repair of a leak, does the NRW/night flow drop significantly from sustained higher levels? Waycinden loses about 10 to 20 million gallons to leakage annually. The calculated losses of the 13 leaks in the ten month study accounted for very little of the computed NRW. This suggests to the researchers that small undetected (inaudible) corrosion leaks may be occurring and it is only a matter of time before the leaks become audible to the acoustic monitoring system. Again, time will tell if these types of leaks will surface quickly when audible, or remain hidden. Finally, the use of a leak survey with correlation is another way to see if a system is a candidate for permanent acoustic monitors.

It is a challenge to predict how long a leak will go undetected. The topography, soils geology, proximity of drainage infrastructure, pipe depth, surface condition, pipe condition, and types of leaks all play a role in leak duration. In most cases, the experience of the system operators and repair crews can help predict the viability of the acoustic monitoring approach.

In light of the small number of non-surfacing leaks, the researchers travelled to the West Virginia American Water offices in Charleston, West Virginia, to check on the results of the first large-scale deployment of the Echologics equipment for comparison. That system uses the same technology that is now in place in Waycinden. It was put into operation in late February, 2015, with 386 sensors put in place. In the first four months of activity, the system detected 45 leaks that had been previously unreported and 40 that were repaired before they surfaced. The NRW water loss was reduced by 2 million gallons per day (mgd), and that does not include a leak found on a transmission main that added another 2 mgd in reduced NRW. Appendix C shows the types of leaks that were identified in Charleston. Correlating CAM installations are now being undertaken across American Water in Pennsylvania, Illinois, and California.

The use of night flow is useful to gauge the success of the correlating CAM system. For a small system like Waycinden, changes in water flow data or night flow help to suggest when to be vigilant. For larger systems, subdividing the system using the district-metered area approach of looking at patterns of nighttime water demand can support the correlating CAM system. An effort to utilize the meter data management (MDM) system for Waycinden to calculate water usage for NRW calculations was unsuccessful.

Evidence of significant elevated nighttime flow can suggest that the coverage of the CAM system is insufficient, as was the case with the last leak. Placement of another monitor on a private hydrant would have remedied that issue. That particular leak suggests the prime issue in Waycinden for the correlating CAM system was the coverage of units, dictated by hydrant placement. The spacing of hydrants can be unsatisfactory, especially at ends of the system where the hydrant spacing may not be adequate to perform correlation or register sufficiently in the analytics. Unmonitored space has been identified in other systems at dead ends that lack hydrants. American Water has communicated to the vendor the need to have a correlating CAM unit that can be connected to the pipe network using locations other than hydrants. Barring those changes, the utility can strategically add hydrants if that could improve coverage significantly.

While the issue of false reports of leaks was not evident in this study, this project did not provide significant testing of noise detection through changing pipe materials. Many leaks are not detected because leak noise does not travel well through some of the materials, or through repair clamps and couplings. For systems like Waycinden that employ PVC pipe for some corrosion repairs, this may be a significant issue. Pipe segments that already have sections removed for repair are likely to have future issues, so this concern needs further evaluation.

The acoustic identification of the start of only a dozen leaks provided little opportunity to look for possible leak triggers. A brief look at air temperature showed what has been seen in prior studies: colder air temperatures correlate with increases in leaks. In prior work, there was evidence that cooler water temperatures contributes to stress on the pipe that could cause a deteriorating pipe to fail (Hughes, 2010). However, a full investigation was dismissed, given the small water temperature variability from a distant deep lake source that travels many miles underground, coupled with the small sample of leaks generated.

SCADA and other NRW measuring tools were used to assess night flows and confirm the presence of leaks, providing an overall picture of the effectiveness of the leak detection system. Ironically, when the large leak occurred in the last week of the study, the system’s inability to maintain the tank level was the most telling and concerning form of alert. Small systems need to consider their vulnerability to such circumstances and weigh the effectiveness of the acoustic monitoring system to detect them. But this study and other small systems that have tested the developing Echologics acoustic monitoring system have determined that the evaluation of night flow is a valuable companion to the process.

CHAPTER 6: RECOMMENDATIONS

The major issue for analyzing the effectiveness of water leakage management tools is time. The study period for this research project was ten months; the number of leaks occurring within a short period often fails to be representative of the longer term. Fortunately, the cold winter in this case likely add to the number of breaks. However, the cold weather likely contributed to more serious circumferential breaks that are likely to surface quickly. A review of the history of leaks and the types of leaks bears this out. A logical recommendation to make as a result of this pilot project is to extend the study period to capture a more realistic long-term view of the economic benefit of deployment. The original acoustic monitoring project ran three years and appeared adequate.

At the core of this project is the effectiveness of the correlating CAM technology. Despite some issues with the detection units (resulting in replacement of the entire network), the system appears to be viable. This fact was borne out in monitoring of other American Water systems. An ongoing issue even in these other systems is the inability to correlate a dead end that has no hydrant. The manufacturer needs to develop a work-around for this issue. It should be noted that the Waycinden system had very few locations of this type.

Another issue is that the Echologics monitoring system does not easily locate leaks in non-metallic pipes. The distance between hydrants is generally sufficient for leak noise to travel through metallic pipe, but may be too far to correlate leaks on plastic and cement pipes that do not carry sound as far. The vendor will be encouraged to develop alternative tools to help close this gap for utilities.

Utilities face a decision of whether to deploy acoustic monitoring. There do appear to be more expensive monitoring systems that perform far better than original CAM systems, providing fewer false signals and a greater ability to locate leaks. Reducing leakage remains an economic decision. Deploying a $100,000 system with a five-year life only that reduces net system costs by $5,000 per year is not prudent. It is therefore recommended that utilities be fully informed of the following: (1) Know the true cost of the acoustic monitoring system to be installed, including initial costs and annual costs to maintain the system. (2) Take steps to reasonably quantify the amount of water leakage that could be reduced. This requires an understanding of the nature of breaks occurring in the system and other elements that determine whether a leak can run unseen for extended periods. Consider a leak survey using correlation to evaluate the significance of audible hidden leaks. (3) Apply this report outline of potential costs savings to see if a business case can be built. It appears that vendors are willing to run pilots, and targeting leaky portions of a utility service area may be the best approach to take.

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GLOSSARY

Advanced metering infrastructure (AMI) – A method of reading water meters using a transmission system that sends data through individual meter transmitters via radio or cellular means to the vendor or utility facility. Today's AMI generally generates 24 hourly reads per day for input into the meter data management system

Automatic meter reading (AMR) – A method of meter reading designed to be able to pick up reads by passing by in a vehicle. Since the AMR transmitter does not know when the receiving collector will pass by, AMR transmitters tend to send out a signal at regular intervals

Continuous acoustic monitoring (CAM) – The process of using noise monitoring sensors to listen at the quietest time of day to capture and report leak noise on a daily basis

Correlation – the use of two or more acoustic sensors typically placed in contact with the pipe network on either side of a suspected leak point. The two sensors on instruction from the correlating intelligence unit simultaneously track noise travelling along the pipe and then triangulate the distance between the noise heard as a function of the distance between sensors

District metered area (also called demand management areas or DMAs)

Non-revenue water (NRW) – the difference between water that is supplied into a system less the amount that is billed

Out of bracket – when a leak is not between the placement of the correlating sensors but to one direction or another of both sensors

Point of interest (POI) – potential suspected leak

APPENDIX A: DATA FROM LEAK INVESTIGATIONS

Table A-1 Leak history during monitoring.

Echologics	Notice Date	Repair Date	Address	Failure Mode	Type of Break	Pipe Material	Pipe Size (inches)	Water Leakage (GPM)	duration of leak (hours)	NRW volume	Material Used to Repair
alerted in advance	9/12/2014	9/24/2014	Kincaid Court & Willson Road	Longitudinal	Water Main Break	Cast Iron	6	25	288	432,000	6" X 15" Clamp
Closest logger defective	10/30/2014	11/3/2014	1567 South Linneman Road	**faulty valve**	Water Main Break	Brass	1"	4	100	24,000	**replace customer shutoff valve**
no alert burst	11/21/2014	customer to repair	3001 Malmo Drive	**customer service line**	**Service Break**	TBD	6	1	275	16,500	**customer responsibility**
Closest logger defective	1/1/2015	1/6/2015	359 Dempster St.	Circumferential	Water Main Break	Cast Iron	6	20	132	158,400	6" X 12" Clamp
no alert burst	1/27/2015	1/28/2015	501 Carboy	Pinhole(s)/Blowout		Cast Iron	6	50	6	18,000	6" X 12" and 6"X24" Clamp
no alert duplicate number	2/16/2015	2/17/2015	1181 Stark Place	Circumferential	Water Main Break	Cast Iron	6	150	6	54,000	6" X 12" Clamp
no alert commissioning burst	2/17/2015	2/18/2015	1101 Elmhurst Avenue	Circumferential	Water Main Break	Cast Iron	6	250	18	270,000	6" X 12" Clamp
no alert duplicate number	2/26/2015	2/25/2015	183 West Walnut Avenue	Circumferential	Water Main Break	Cast Iron	6	150	18	162,000	6" X 12" Clamp
message sent Sunday, also possible leaking hydrant after	3/1/2015	3/2/2015	963 Leahy Circle	Pinhole(s)/Blowout	Water Main Break	Cast Iron	6	400	5	120,000	6" X 12" Clamp
no alert burst (unable to retrive files from the nodes)	3/6/2015	3/6/2015	724 Algonquin Road	Circumferential	Water Main Break	Cast Iron	6	80	4	19,200	6" X 12" Clamp
no alert (due to missing logger file)	3/27/2015	3/28/2015	Malmo Drive & Algonquin Road	**Saddle Leakage**	Saddle Leak	Cast Iron	10	15	36	32,400	10" X 12" Clamp
	5/4/2015	5/5/2015	998 Wilson Dr	**Service Line Connection Leak**	Water Main Break	Cast Iron	6	4	10	2,400	3/4" corporation 3/4" copper tube, 6" PVC pipe and 6"X12"X1 CI clamp
no alert out of range	6/26/2015	6/27/2015	United Airline center customer leak	**service main burst**	metered service leak	Asbestos Cement	12	1800	7	750,000 gallons but metered	**by customer contractor**

Table A-2 Pre-monitoring leak history.

Repair Date	Address	Failure Mode	Type of Break	Pipe Material	Pipe Size (inches)	Water Leakage (GPM)	Material Used to Repair	Shut-off Duration (hours)	# Customer Affected
1/3/2011	905 & 915 Mount Prospect Rd	Pinhole(s)/Blowout	Water Main	Cast Iron	8		8" X 25" Clamp	3	-
1/18/2011	546 W Ida Court	Pinhole(s)/Blowout	**Saddle Leak**	Cast Iron	6	**100**	6"X12"X2" sleeve	2	8
3/5/2011	1449 E Algonquin Rd	Pinhole(s)/Blowout	Water Main	Cast Iron	8	**200**	8" X 12" Sleeve	5	-
5/24/2011	1100 Stark Pl and Leahy Circle	Pinhole(s)/Blowout	Water Main	Cast Iron	6	10	6" X 12" Sleeve	7	-
7/15/2011	381 Kings Lane	Pinhole(s)/Blowout	Water Main	Cast Iron	6	**200**	**6" X 12" Sleeve, 6" PVC pipe 8' length**	9	24
7/15/2011	449 Kings Ct	Longitudinal	Water Main	Cast Iron	6	80	2 - 6" X 12" & 6" X 25" sleeve	2.5	12
9/23/2011	720 Dempster St	Circumferential	Water Main	Cast Iron	10		10" X 30" Sleeve	3	
10/18/2011	722 Dempster St	Circumferential	Water Main	Cast Iron	10	5	10" X 12"Clamp	-	
11/25/2011	507 Walnut Ave	Pinhole(s)/Blowout	Water Main	Cast Iron	6	90	6" X 12" Clamp	-	
12/1/2011	508 Walnut Ave	Pinhole(s)/Blowout	Water Main	Cast Iron	6		**30' PVC pipe was installed**	8	18
3/10/2012	303 W Algonguin Rd	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	-	
5/9/2012	621 Kings Lane	Pinhole(s)/Blowout	Water Main	Cast Iron	6	**500**	6" X 12" Clamp	-	
5/11/2012	851 Manroe Circle	Pinhole(s)/Blowout	Water Main	Cast Iron	6	**500**	**20" PVC plus 6" couplings**	3	24
6/7/2012	591 & 621 Kings Lane	Pinhole(s)/Blowout	Water Main	Cast Iron	6		**35' Ductile Iron**	8	11
6/8/2012	887 Ingram Place	Other	Water Main service connection	Cast Iron & Copper	6 & 3/4		6" X 12" X 1" Clamp	2	18
7/12/2012	736 W Dempster St	Longitudinal	Water Main	Cast Iron	10	2	10" X 12"Clamp	-	
7/31/2012	887 Ingram Place	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 30" Sleeve	1	18
9/3/2012	621 Kings Lane	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 12" Clamp	5.5	10
9/13/2012	293 Walnut Ave	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 24" Sleeve	2	14
9/25/2012	1128 Leahy Circle	Circumferential	Water Main	Cast Iron	6	**200**	6" X 12" Clamp	1	9
9/26/2012	1129 Leahy Circle	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 12" Clamp	3.5	12
11/17/2012	839 Marshall Dr	Circumferential	Water Main	Cast Iron	6	75	6" X 12" Clamp	1	16
12/21/2012	998 Leahy Dr	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	0.5	20
12/12/2012	877 Spruance Pl	Other	Water Main	Cast Iron	6	50		0	

Table A-2 Pre-Monitoring Leak History (Continued).

Repair Date	Address	Failure Mode	Type of Break	Pipe Material	Pipe Size (inches)	Water Leakage (GPM)	Material Used to Repair	Shut-off Duration (hours)	# Customer Affected
1/30/2013	905 Willson Drive	Circumferential	Water Main	Cast Iron	6	**100**	6" X 12" Clamp	1	18
1/31/2013	437 Wallnut Ave	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	3.5	19
1/31/2013	546 Dempster Ave	Circumferential	Water Main	Cast Iron	6		6" X 12" X 2 Clamp	2.5	
3/10/2013	473 Kings Lane	Circumferential	Water Main	Cast Iron	6	**200**	6" X 12" Clamp	1.5	10
3/12/2013	1087 Leahy Circle	Circumferential	Water Main	Cast Iron	7	50	6" X 12" Clamp	1	18
3/22/2013	1551 E Algonquin Rd	Circumferential	Water Main	Cast Iron	4			3	3
4/18/2013	349 Eaker Pl	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 12" Clamp	0	5
4/19/2013	349 Eaker Pl	Pinhole(s)/Blowout	Water Main	Cast Iron	6		**7' 6" PVC plus couplings**	5	25
5/3/2013	925 Ingram Pl	Circumferential	Water Main	Cast Iron	6		**11', 6" DI plus couplings**	7.5	20
5/3/2013	W Dempster & S Elmhurst	Longitudinal	Water Main	Cast Iron	10			8	0
7/8/2013	720 Algonquin Rd	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 12" Clamp	4	0
8/20/2013	1160 Stark Pl	Pinhole(s)/Blowout	Water Main	Cast Iron	6			7.5	12
8/28/2013	1229 E Algonquin Rd	Pinhole(s)/Blowout	Water Main	Cast Iron	6		**3', 6" DI pipe plus couplings**	7	2
12/16/2013	547 IDA CT	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	-	-
12/24/2013	1125 Hewitt Dr	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	-	-
3/3/2014	526 IDA Ct	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	2.5	
3/13/2014	965 Willson Drive	Circumferential	Water Main	Cast Iron	6		6" X 12" Clamp	2	
7/23/2014	1051 Elmhurst Rd	Pinhole(s)/Blowout	Water Main	Cast Iron	6	300	6" X 12" Clamp	6	2
7/23/2014	760 Algonquin Road	Pinhole(s)/Blowout	Water Main	Cast Iron	6		6" X 15" Clamp	2	16
7/24/2014	760 Algonquin Road	Pinhole(s)/Blowout	Water Main	Cast Iron	6		**20', 6" DI pipe 6" valve plus couplings**	6	16

APPENDIX B: SAMPLE LEAK REPORT DATA

Customer:

Exc. #:

Project #:

EXCAVATION, REPAIR & RESTORATION REPORT

Excavation Date: 2/17/15 **J.U.L.I.E. Dig #:** ______ **Property:** Wayah

Address: 1181 Stark **City:** Des Plaines

Expense Code: R25-86H1.15-P-0001 **Work Order #:** 90177522

Type of Work

Water

- Water Main Break ☑
- Saddle Leak ☐
- Sample Station ☐
- Fire Hydrant #_____ ☐
- Fire Hydrant Aux. Valve #_____ ☐
- B-Box only ☐
- B-Box/Curb Stop ☒
- Water Service ☐
- Water Valve #_____ ☐
- Valve Box #_____ ☐
- Restoration Only ☐

Sewer

- Sewer Main ☐
- Sewer Service Lat. ☐
- Sewer Clean Out ☐
- Manhole ☐
- Service Line ☐
- Force Main ☐
- Backflow Preventer ☐
- Restoration Only ☐

☒ **Replace** ☑ **Repair** ☐ **New** ☐ **Abandon** ☐ **Line**

Other (explain): 10 GPM

45' away from FH# 127

Nearest Hydrant Make / Year: 1980 TC

Hydrant Replace. #______ New Make ______ Year ______

Old Make ______ Year ______

Ground Conditions: ☐ Dry ☐ Wet ☑ Slop ☐ Hydrodig

Arrive at job site: 8:00 [✓ AM] / PM

Leave job site: 2:00 AM [✓ PM]

Repaired under pressure? Y [✓ N]

Time water shut off: 9:00 AM

Time water turned back on: 12:30 PM

Duration water was off: 3 1/2 hours

Number of residential customers affected: 11

Number of commercial/institution customers affected: ______

Who: ______

Personnel performing repair work:

Operator - N. Beck

M. Prosch

J. Wonks

Equipment Used: ______

Materials Used: (**Complete Attached Inventory Parts Form if <u>ILAW</u> material.**) ______

RESTORATION

IS RESTORATION REQUIRED? [✓ **YES**] / **NO** **If complete same day, check box [**

<u>Show dimensions (length, width) of restoration area. Circle appropriate type(s).</u>

CONCRETE: (Sidewalk, Driveway, Approach, Street, Curb) ______ Handicapped Area: Y

ASPHALT: (Driveway, Approach, Street, Parking Lot, Walkway) ______

LAWN, [✓ PARKWAY], or EASEMENT: (Sod / [✓ Seed]) 15 x 8 Rear [✓ Front] S

OTHER: (Shrubs, Trees, Flower beds, mulch, etc.) – specify type, size & qty. Sprinkler Line Needs Repair

FENCE: Type: ______ **Ht.** ______ Rear Front S

Anything damaged other than above (explain): ______

BARRICADES LEFT ON JOB: ____ **ILAWC** ____ **OTHER** ____ **CONES** 1/16/14

TYPE OF PIPE: CI **SIZE:** 6"

NATURE OF BREAK: ☑ Circumferential ☐ Joint ☐ Longitudinal ☐ Blowout

PROXIMITY TO OTHER UTILITIES: Gas

VALVES OPERATED FOR SHUT DOWN: 3

VALVES OPERATED FOR TURN-ON: 3

C12 ( ) RESIDUAL FOR WATER MAIN SHUTDOWN: .5

FIRE HYDRANTS FLUSHED TO CLEAR SYSTEM: Frozen Hydrant [redacted]

BACKFILLED WITH Spoil **AT WHAT LEVEL** Grade

CU. FT. OF SPOILS HAULED AWAY: – **TO WHICH SITE:** –

HIT UTILITIES? Y / [✓ N] **IF YES, WHAT?**

WHY? ☐ Unmarked ☐ Mismarked ☐ No show ☐ Our Fault

ATTACH PHOTOS: ☑ Before dig ☑ Inside Shoring Box ☑ Showing shoring Box 5'-7' away ☑ J.U.L.I.E.S.

☐ Showing matting/plywood ☐ Backhoe Position ☑ After dig ☐ Any concerns that may develop

WAS RESTORATION DOOR HANGER (DH-110) LEFT FOR CUSTOMER? Y / N

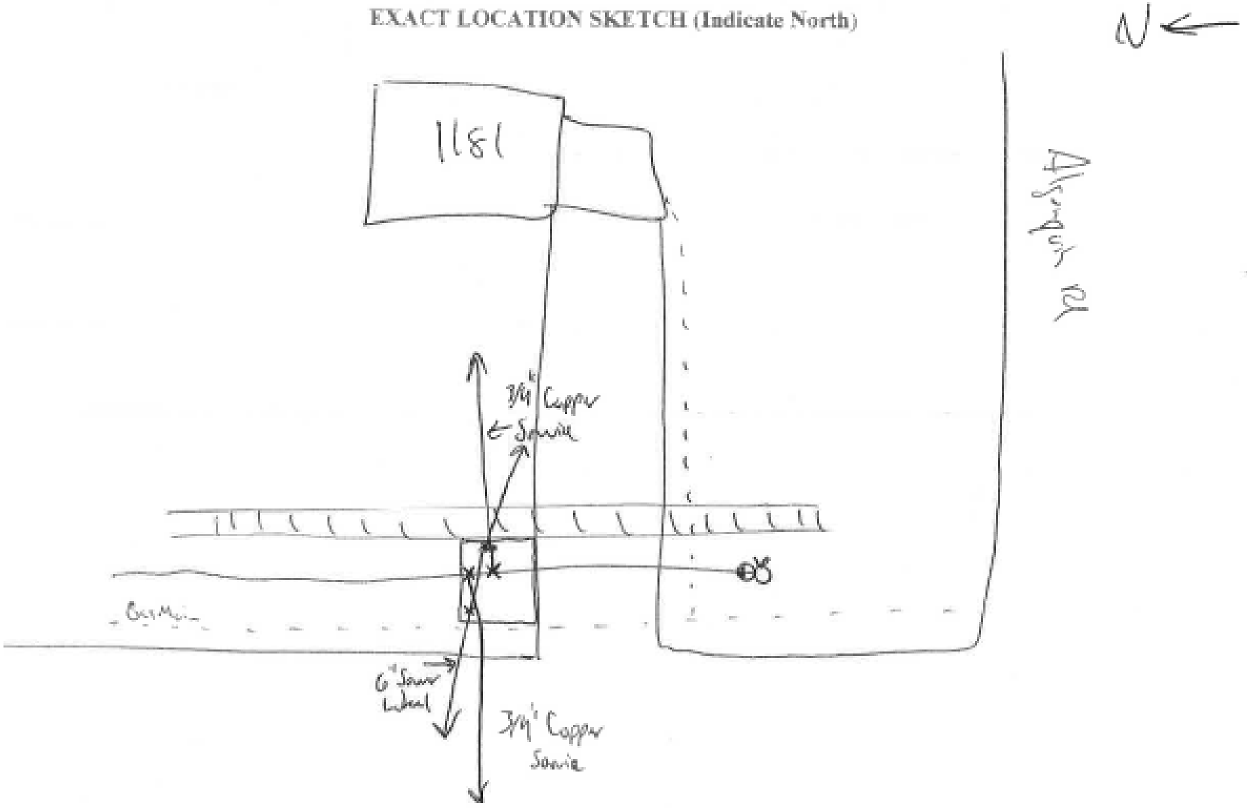
WHERE? ☐ Front Door ☐ Side Door ☐ Back Door ☐ Handed to Customer ☑ Other Talked to Customer

I understand and agree that my submission of this report and my signature below indicate that I certify that the above information is true and complete to the best of my knowledge.

Equipment Operator / Foreman

2/18/15
Date

EXACT LOCATION SKETCH (Indicate North)



INVENTORY PARTS

RESERVATION # / ISSUE DOCUMENT #

TRAILER # 21605

R25-86H1.15-P.001
WBS ELEMENT

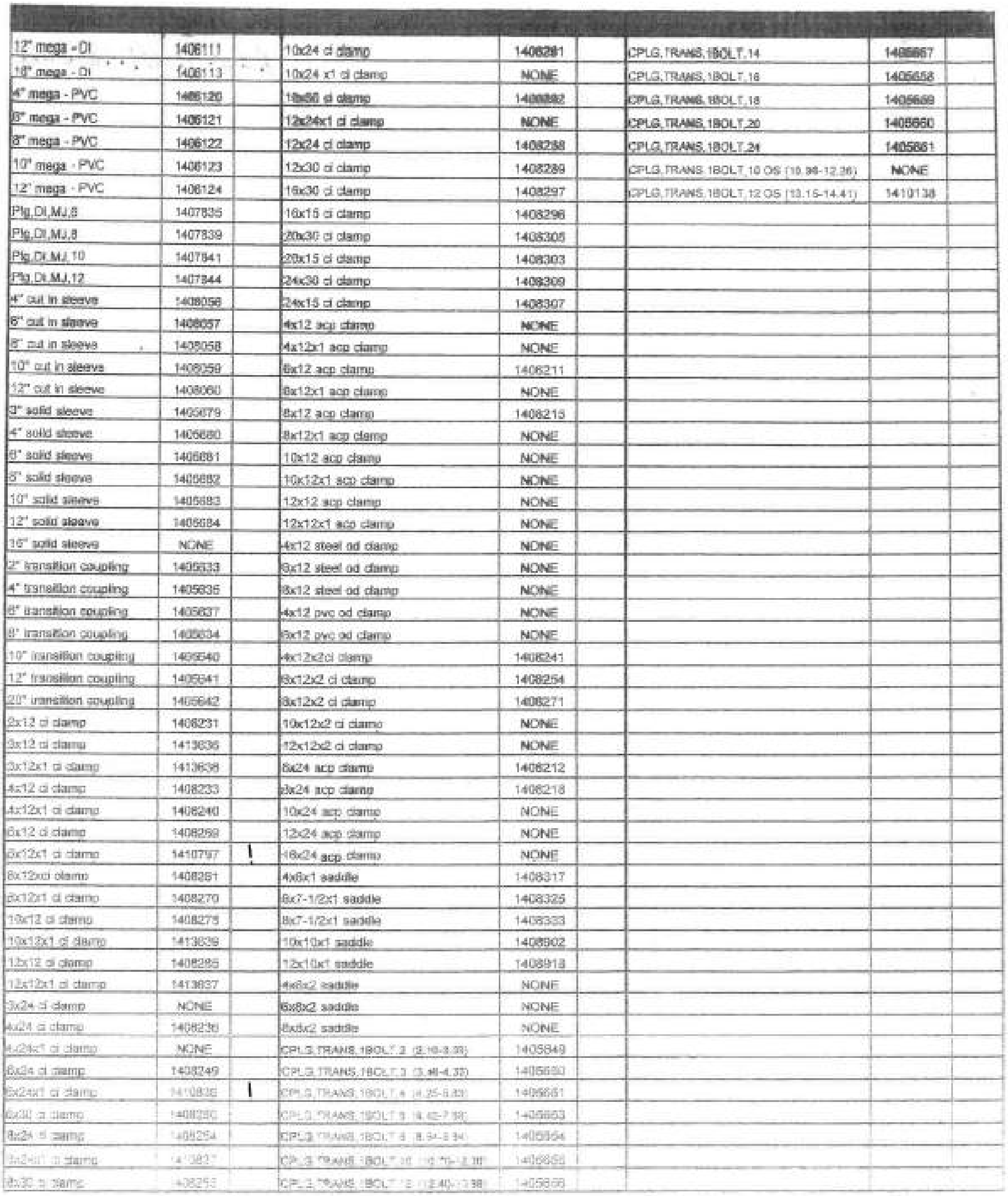
PART	INV #	QTY	PART	INV #	QTY	PART	INV #	QTY
b/box arch pattern	1413152		Cplg, NL 3/4	1412484		18" hydrant extension	1800669	
b/box minn thread	1405449	1	Cplg, NL 1	1412481		24" hydrant extension	1800670	
2x1-1/2 bushing	NONE		Cplg, NL 1-1/2	1412482		36" hydrant extension	1800672	
3/4" curb stop, nl	1411951	1	Cplg, NL 2	1412483		valve box lid only	1408177	
3/4" coupling, nl	1412009	1	4" tee/wye	1404177		T-BOLTS	NONE	
3/4" corp, nl	1411798	2	6" tee/wye	1404179		2" mj gasket	NONE	
3/4" copper	1406597	15'	4" vac-tee	1404212		3" mj gasket	NONE	
1" curb stop, nl	1411950		6" vac-tee	1404211		4" mj gasket	NONE	
1" coupling, nl	1412001		4" sdr 35 pipe	1404163		6" mj gasket	NONE	
1" corp	1404291		6" sdr 35 pipe	1404164		8" mj gasket	NONE	
1" copper	1406594		8" sdr 35 pipe	1404165		10" mj gasket	NONE	
1-1/4 curb stop, nl	1411904		10" sdr 35 pipe	1404166		12" mj gasket	NONE	
1-1/4 coupling, nl	1412004		12" sdr 35 pipe	1404167		16" mj gasket	NONE	
1-1/4 cplg, nl, CCXTNA	1413470		15" sdr 35 pipe	1404168		2" mj/mj valve	1407982	
1-1/4 corp, nl, TAPERXCF	1413471		Cplg,Swr Fernco,Shear,Str,CLAYXPVC,4	1413137		3" mj/mj valve	1407983	
1-1/4 copper	1406598		Cplg,Swr Fernco,Shear,Str,CLAYXPVC,6	1413139	1	4" mj/mj valve	1407984	
1-1/2 curb stop, nl	1411903		Cplg,Swr Fernco,Shear,Str,CLAYXPVC,8	1413140		6" mj/mj valve	1407985	
1-1/2 coupling, nl	1412002		Cplg,Swr Fernco,Shear,Str,CLAYXPVC,6X4	1413141		8" mj/mj valve	1407986	
1-1/2 corp, nl	1411801		Cplg,Swr Fernco,Shear,Str,ACXPVC,4	1413142		10" mj/mj valve	1407987	
1-1/2 corp, ball, nl, MIPXCC	1411856		Cplg,Swr Fernco,Shear,Str,ACXPVC,6	1413143		12" mj/mj valve	1407988	
1-1/2 copper	1406599		Cplg,Swr Fernco,Shear,Str,ACXPVC,8	1413144		16" mj/mj valve	1407990	
2" curb stop, nl	1411905		Cplg,Swr Fernco,Shear,Str,PVCXPVC,4	1413145		4" flange/mj valve	1408040	
2" union, nl	1412008		Cplg,Swr Fernco,Shear,Str,PVCXPVC,6	1413146		6" flange/mj valve	1408041	
2" corp, nl	1411802		Cplg,Swr Fernco,Shear,Str,PVCXPVC,6X4	1413147		8" flange/mj valve	1408042	
2" corp, ball, nl, MIPXCC	1411857		Cplg,Swr Fernco,Shear,Str,PVCXPVC,8	1413148		3" flange/flange valve	1408018	
2" copper	1406595		Cplg,Swr Fernco,Shear,Str,PVCXPVC,10	1413149		4" flange/flange valve	1408019	
3/4" curb stop, fem/fem	1411849		Cplg,Swr Fernco,Shear,Str,PVCXPVC,12	1413151		6" tap mj valve	1408002	
1" curb stop, fem/fem	1411848		Cplg,Swr Fernco,Shear,Str,CLAYXCIIPVC,10	1404237		8" tap mj valve	1408003	
3/4" corp, taper w/90 degree	1413589		Cplg,Swr Fernco,Shear,Str,CLAYXCIIPVC,12	1404238		4" insertion valve	1408119	
1" corp, taper w/90 degree	1413590		Hydrant 4' bury	1406682		6" insertion valve	1408120	
1x3/4 brass bush, nl, taper	1412865	2	Hydrant 5' bury	1406683		8" insertion valve	1408121	
2x1-1/2 brass rduc	NONE		Hydrant 5-1/2' bury	1406693		10" insertion valve	NONE	
2x1-1/4 brass rduc	NONE		Hydrant 5-1/2' flange	1406696		12" insertion valve	NONE	
Cplg, CCXFIP, 1	1412061		Sample station	1413317		4" di/cl52 water main	1406354	
Cplg, CCXMIP, 2	1412045		90 anchoring	NONE		6" di/cl52 water main	1406361	
Cplg, CCXMIP, 2x1-1/2	1412049		anchoring coupling	1407815		8" di/cl52 water main	1406369	
Cplg, CCXMIP, 1-1/4	1412040		#66B screw top	1409333		10" di/cl52 water main	1406376	
Cplg, CCXMIP, 1-1/2	1412038		5 1/4 rd lid water	1409358		12" di/cl52 water main	1406385	
Cplg, TNAXCC, 2	1411936		#64B screw bottom	1405496		16" di/cl52 water main	1406399	
Cplg, TNAXCC, 1-1/2	1411934		valve box stabilizer	1405544		4" pvc/cl150 c-900 main	1406546	
Cplg, CC, 1x3/4	1412007		18" extension	1405531		6" pvc/cl150 c-900 main	1406552	
Cplg, CC, 3/4x1/2	1404711		24" extension	1405532		8" pvc/cl150 c-900 main	1406558	
Cplg, NL, CCXMIP, 1	1412037		30" middle extension	1409380		10" pvc/cl150 c-900 main	1406563	
Cplg, NL, CCXMIP, 3/4	1412047		12" valvebox top screw	1405485		12" pvc/cl150 c-900 main	1406568	
Cplg, NL, CC, 5/8x3/4	1413472		12" valvebox top slip	1409354		3" mega - DI	1408106	
Cplg, NL, CC, 1-1/4x1	1412005		3/4 - 90 mip/compression	1412493		4" mega - DI	1408107	
Cplg, NL, CC, 1/2x3/4	1412006		Plg, NL, Taper, 1	1800947		6" mega - DI	1408108	
Cplg, NL, RICIPSPEXMIP, 3/4	1411909		6" hydrant extension	1800667		8" mega - DI	1408109	
Cplg, NL, RICIPSPEXMIP, 1	1411906		12" hydrant extension	1800668		10" mega - DI	1408110	

Fernco - 8" Clay × 6" PVC - 1

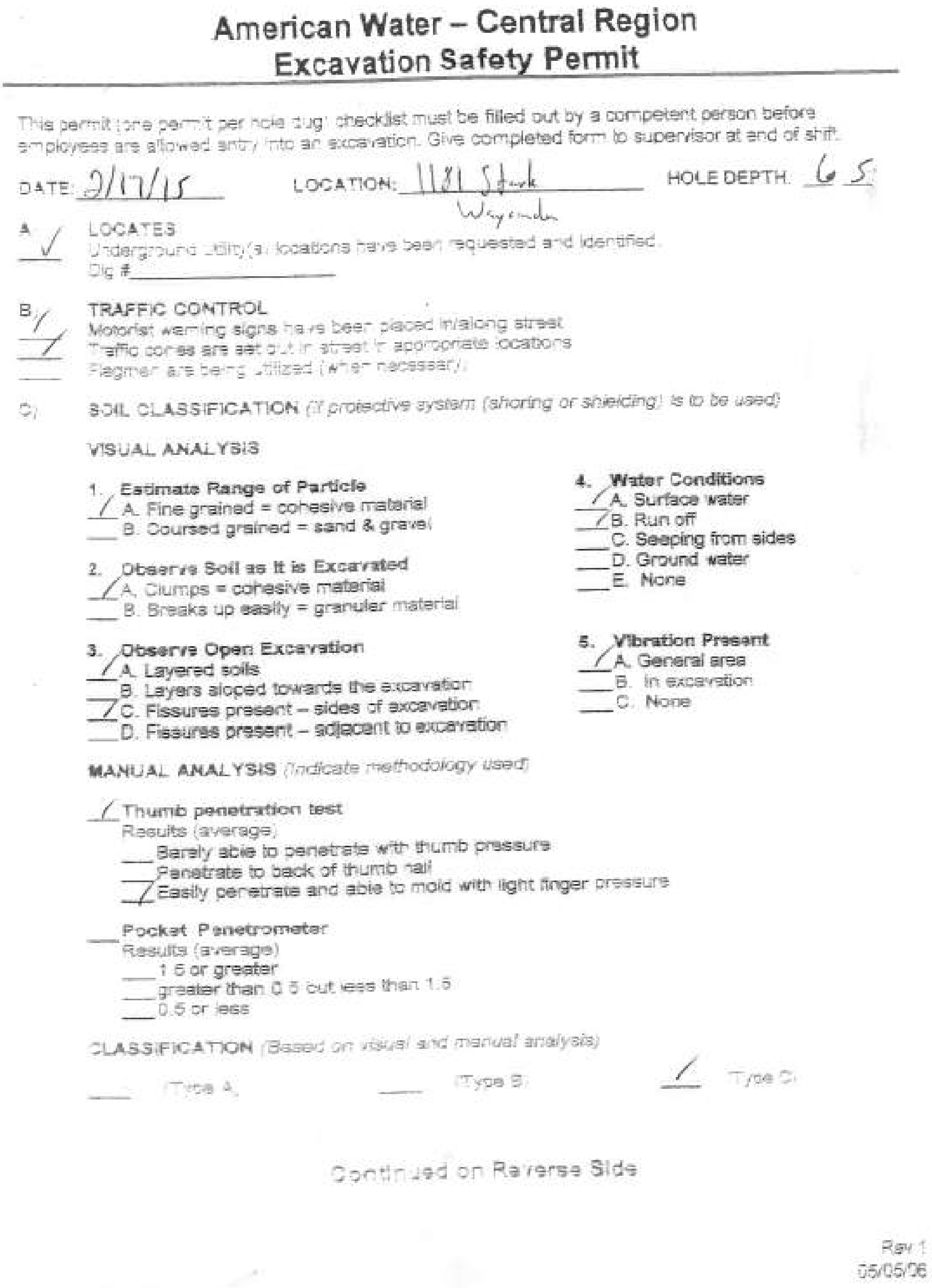
Initials: MJB 2
E.O./INV. COORDINATOR DATE

See BACK

Initials: ______________________
OPERATIONS COORDINATOR



12" mega - DI	1406111		10x24 ci clamp	1408281		CPLG,TRANS,1BOLT,14	1405657	
16" mega - DI	1406113		10x24 x1 ci clamp	NONE		CPLG,TRANS,1BOLT,16	1405658	
4" mega - PVC	1406120		16x56 ci clamp	1408292		CPLG,TRANS,1BOLT,18	1405659	
6" mega - PVC	1406121		12x24x1 ci clamp	NONE		CPLG,TRANS,1BOLT,20	1405660	
8" mega - PVC	1406122		12x24 ci clamp	1408288		CPLG,TRANS,1BOLT,24	1405661	
10" mega - PVC	1406123		12x30 ci clamp	1408289		CPLG,TRANS,1BOLT,10 OS (10.96-12.26)	NONE	
12" mega - PVC	1406124		16x30 ci clamp	1408297		CPLG,TRANS,1BOLT,12 OS (13.15-14.41)	1410138	
Plg,DI,MJ,6	1407835		16x15 ci clamp	1408296				
Plg,DI,MJ,8	1407839		20x30 ci clamp	1408305				
Plg,DI,MJ,10	1407841		20x15 ci clamp	1408303				
Plg,DI,MJ,12	1407844		24x30 ci clamp	1408309				
4" cut in sleeve	1408056		24x15 ci clamp	1408307				
6" cut in sleeve	1408057		4x12 acp clamp	NONE				
8" cut in sleeve	1408058		4x12x1 acp clamp	NONE				
10" cut in sleeve	1408059		6x12 acp clamp	1408211				
12" cut in sleeve	1408060		6x12x1 acp clamp	NONE				
3" solid sleeve	1405679		8x12 acp clamp	1408215				
4" solid sleeve	1405680		8x12x1 acp clamp	NONE				
6" solid sleeve	1405681		10x12 acp clamp	NONE				
8" solid sleeve	1405682		10x12x1 acp clamp	NONE				
10" solid sleeve	1405683		12x12 acp clamp	NONE				
12" solid sleeve	1405684		12x12x1 acp clamp	NONE				
16" solid sleeve	NONE		4x12 steel od clamp	NONE				
2" transition coupling	1405633		6x12 steel od clamp	NONE				
4" transition coupling	1405635		8x12 steel od clamp	NONE				
6" transition coupling	1405637		4x12 pvc od clamp	NONE				
8" transition coupling	1405634		6x12 pvc od clamp	NONE				
10" transition coupling	1405640		4x12x2ci clamp	1408241				
12" transition coupling	1405641		6x12x2 ci clamp	1408254				
20" transition coupling	1405642		8x12x2 ci clamp	1408271				
2x12 ci clamp	1408231		10x12x2 ci clamp	NONE				
3x12 ci clamp	1413636		12x12x2 ci clamp	NONE				
3x12x1 ci clamp	1413638		6x24 acp clamp	1408212				
4x12 ci clamp	1408233		8x24 acp clamp	1408218				
4x12x1 ci clamp	1408240		10x24 acp clamp	NONE				
6x12 ci clamp	1408259		12x24 acp clamp	NONE				
6x12x1 ci clamp	1410797		16x24 acp clamp	NONE				
8x12xci clamp	1408261		4x6x1 saddle	1408317				
8x12x1 ci clamp	1408270		6x7-1/2x1 saddle	1408325				
10x12 ci clamp	1408275		8x7-1/2x1 saddle	1408333				
10x12x1 ci clamp	1413639		10x10x1 saddle	1408902				
12x12 ci clamp	1408285		12x10x1 saddle	1408918				
12x12x1 ci clamp	1413637		4x6x2 saddle	NONE				
3x24 ci clamp	NONE		6x8x2 saddle	NONE				
4x24 ci clamp	1408236		8x8x2 saddle	NONE				
4x24x1 ci clamp	NONE		CPLG,TRANS,1BOLT,2 (2.16-3.33)	1405649				
6x24 ci clamp	1408249		CPLG,TRANS,1BOLT,3 (3.46-4.32)	1405650				
6x24x1 ci clamp	1410836		CPLG,TRANS,1BOLT,4 (4.25-5.83)	1405651				
6x30 ci clamp	1408250		CPLG,TRANS,1BOLT,6 (6.42-7.56)	1405653				
8x24 ci clamp	1408254		CPLG,TRANS,1BOLT,8 (8.54-9.84)	1405654				
8x24x1 ci clamp	1410837		CPLG,TRANS,1BOLT,10 [illegible]	1405655				
8x30 ci clamp	1408253		CPLG,TRANS,1BOLT,12 (12.40-13.38)	1405656				



American Water – Central Region
Excavation Safety Permit

This permit (one permit per hole dug) checklist must be filled out by a competent person before employees are allowed entry into an excavation. Give completed form to supervisor at end of shift.

DATE: 2/17/15 LOCATION: 1181 Stark [illegible] HOLE DEPTH: 6 5

A. ✓ **LOCATES**
Underground utility(s) locations have been requested and identified.
Dig # __________

B. **TRAFFIC CONTROL**
✓ Motorist warning signs have been placed in/along street
✓ Traffic cones are set out in street in appropriate locations
___ Flagmen are being utilized (when necessary)

C) **SOIL CLASSIFICATION** *(if protective system (shoring or shielding) is to be used)*

VISUAL ANALYSIS

1. **Estimate Range of Particle**
✓ A. Fine grained = cohesive material
___ B. Coursed grained = sand & gravel

2. **Observe Soil as It is Excavated**
✓ A. Clumps = cohesive material
___ B. Breaks up easily = granular material

3. **Observe Open Excavation**
✓ A. Layered soils
___ B. Layers sloped towards the excavation
✓ C. Fissures present – sides of excavation
___ D. Fissures present – adjacent to excavation

4. **Water Conditions**
✓ A. Surface water
✓ B. Run off
___ C. Seeping from sides
___ D. Ground water
___ E. None

5. **Vibration Present**
✓ A. General area
___ B. In excavation
___ C. None

MANUAL ANALYSIS *(indicate methodology used)*

✓ **Thumb penetration test**
Results (average)
___ Barely able to penetrate with thumb pressure
___ Penetrate to back of thumb nail
✓ Easily penetrate and able to mold with light finger pressure

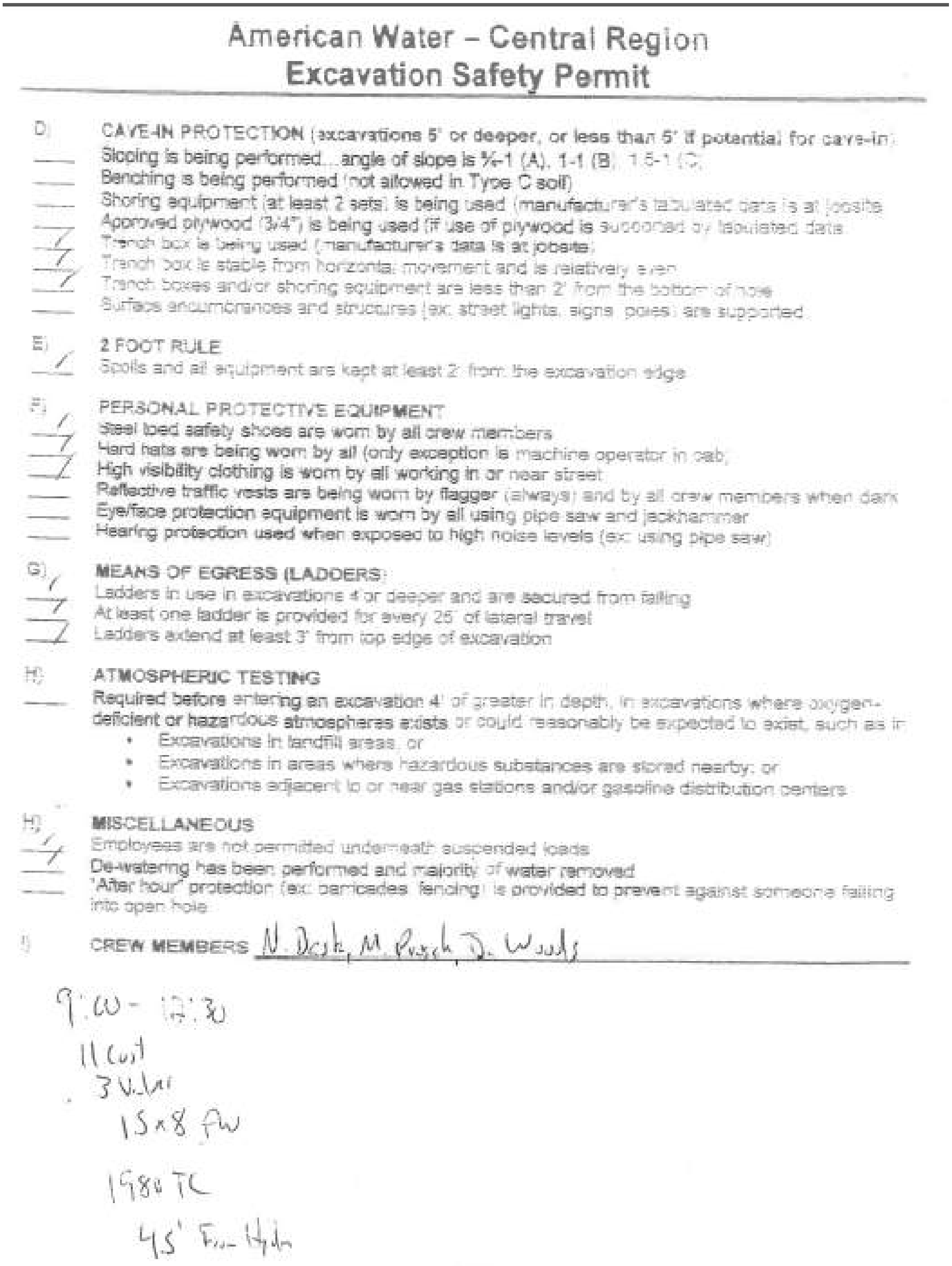
___ **Pocket Penetrometer**
Results (average)
___ 1.5 or greater
___ greater than 0.5 but less than 1.5
___ 0.5 or less

CLASSIFICATION *(Based on visual and manual analysis)*

___ (Type A) ___ (Type B) ✓ (Type C)

Continued on Reverse Side

Rev 1
05/05/06



American Water – Central Region
Excavation Safety Permit

D) **CAVE-IN PROTECTION** (excavations 5' or deeper, or less than 5' if potential for cave-in)
___ Sloping is being performed...angle of slope is ¾-1 (A), 1-1 (B), 1.5-1 (C)
___ Benching is being performed (not allowed in Type C soil)
___ Shoring equipment (at least 2 sets) is being used (manufacturer's tabulated data is at jobsite)
___ Approved plywood (3/4") is being used (if use of plywood is supported by tabulated data)
✓ Trench box is being used (manufacturer's data is at jobsite)
✓ Trench box is stable from horizontal movement and is relatively even
✓ Trench boxes and/or shoring equipment are less than 2' from the bottom of hole
___ Surface encumbrances and structures (ex: street lights, signs, poles) are supported

E) **2 FOOT RULE**
✓ Spoils and all equipment are kept at least 2' from the excavation edge

F) **PERSONAL PROTECTIVE EQUIPMENT**
✓ Steel toed safety shoes are worn by all crew members
✓ Hard hats are being worn by all (only exception is machine operator in cab)
✓ High visibility clothing is worn by all working in or near street
___ Reflective traffic vests are being worn by flagger (always) and by all crew members when dark
___ Eye/face protection equipment is worn by all using pipe saw and jackhammer
___ Hearing protection used when exposed to high noise levels (ex: using pipe saw)

G) **MEANS OF EGRESS (LADDERS)**
✓ Ladders in use in excavations 4' or deeper and are secured from falling
✓ At least one ladder is provided for every 25' of lateral travel
✓ Ladders extend at least 3' from top edge of excavation

H) **ATMOSPHERIC TESTING**
___ Required before entering an excavation 4' or greater in depth, in excavations where oxygen-deficient or hazardous atmospheres exists or could reasonably be expected to exist, such as in:
- Excavations in landfill areas, or
- Excavations in areas where hazardous substances are stored nearby; or
- Excavations adjacent to or near gas stations and/or gasoline distribution centers

H) **MISCELLANEOUS**
✓ Employees are not permitted underneath suspended loads
___ De-watering has been performed and majority of water removed
___ "After hour" protection (ex: barricades, fencing) is provided to prevent against someone falling into open hole

I) **CREW MEMBERS** N. Dick, M. Pusch, D. Woods

9:00 - 12:30
11 Cut
3 Valve
15x8 FW
1980 TC
4.5' Fire Hydr

02-17-15

02-17-15

Figure B.1 Sample photos taken by staff at locations of leaks.

Figure B.1 Sample photos taken by staff at locations of leaks (continued).

Figure B.1 Sample photos taken by staff at locations of leaks (continued).

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MBRCDE 00000 JULIE 2/16/2015 07:23PM A000470687-00A NEW RUSH GRID LREQ

Ticket : A000470687 Date:  Oper: PICLB Chan: RTE Rev: 00A
Old Tkt:  Date:  Oper:  Chan:

State: IL Cnty: COOK          Place: DES PLAINES CIT
Address : 1181
Street  : STARK PL                                   Intersection: Y
Cross 1 : W ALGONQUIN RD                             Sub-division:
Location: IN THE CITY OF DES PLAINES,

Grids   : T41NR11E24NE T41NR11E24SE

Work type: WATER MAIN BREAK
Boring   : N  Depth>7ft: U
Extent   : LOCATE ENTIRE FRONT OF PROPERTY INCLUDING THE PARKWAY
Work date: 02/17/15 07:00 AM Hours Notice:  Priority: RUSH
Ug/Oh/Both: U Railroad:
Done for:   Pre-marked: N

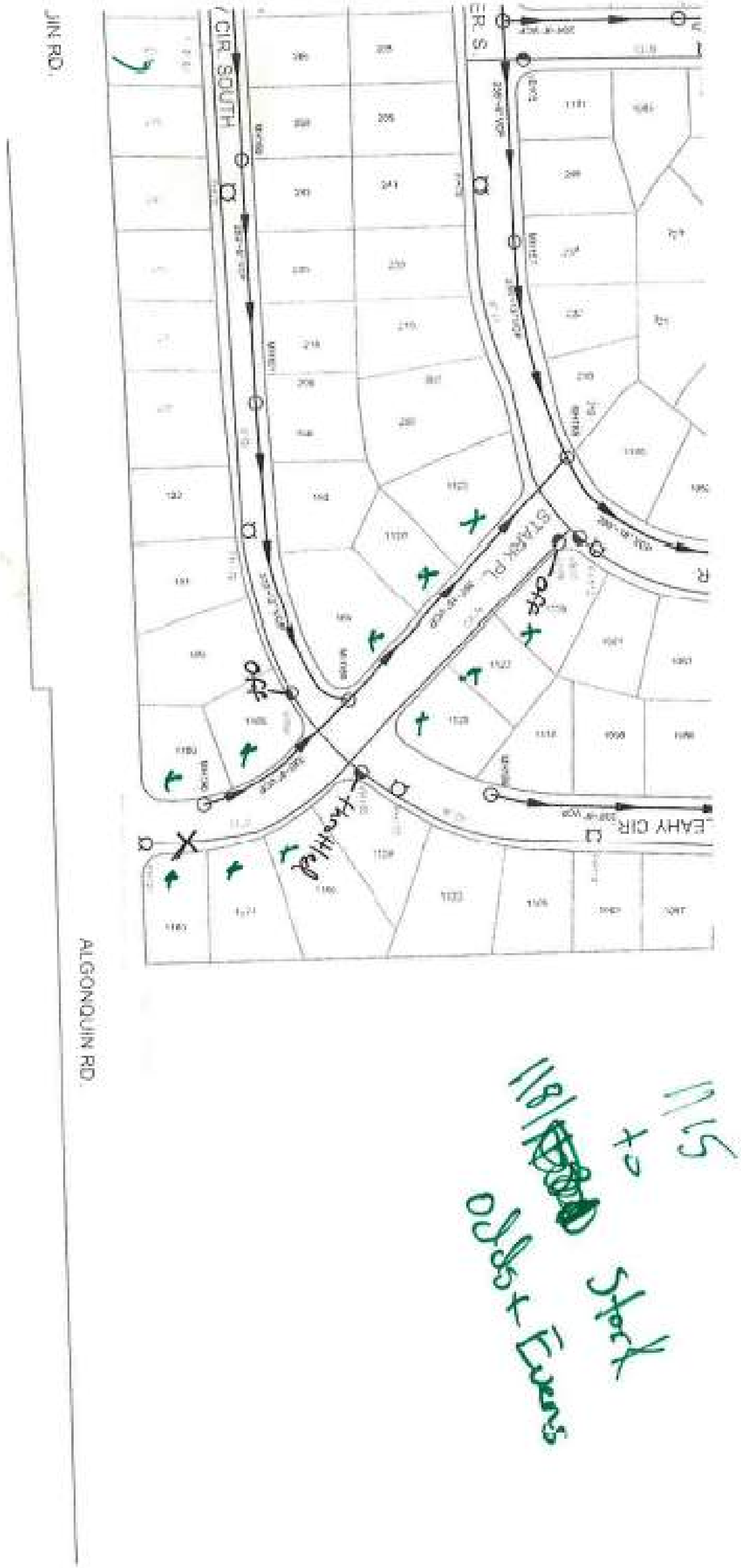
Company : ILLINOIS AMERICAN WATER                    Type: UTIL
Co addr : 1000 INTERNATIONAL PARKWAY
City    : WOODRIDGE                        State: IL Zip: 60517
Caller  : BRIAN PICL                       Phone: 630-739-8857 Ext:
Contact : SAME                             Phone:  Ext:
BestTime:
Fax     : 630-739-0488

Remarks : CREW WILL BE DIGGING FIRST THING IN THE MORNING

Members : ATTD5A CECO0A COMC4A CTZN0A DPLN0A DPLN0B MCI0A NEXT0A NICR0A SCL0A
USIC0A

Member     Name
====================================
ATTD5A     ATT/DISTRIBUTION
CECO0A     COMED
COMC4A     COMCAST
CTZN0A     IL AMERICAN WTR - CHICAGO METRO DIV.
DPLN0A     DES PLAINES CITY OF
DPLN0B     DES PLAINES CITY OF
MCI0A      MCI
NEXT0A     XO ILLINOIS INC
NICR0A     NICOR GAS
SCL0A      STAKE CENTER LOCATING
USIC0A     USIC LOCATING SERVICES
```

Basta
Prosek
Woods



1115 to 1181 Stark Odds + Evens

APPENDIX C: SUMMARY OF BREAKS FOUND BY CORRELATING CAM IN CHARLESTON WEST VIRGINIA INSTALLATION FEBRUARY – MAY 2015

Table C.1 Leaks Found by Correlating CAM, Charleston, WV.

Address	Date and Time Leak Reported	Response Time Leak report to repair (days)	Leak Type	Main or Service Material	Pipe Size	REPAIR METHOD	Time Leak ran days	Leak Rate, GPM
303 89th St	2/6/15 8:00 AM	6.17	corrosion hole	cast iron	2	clamp	6.0	112.1
200 Park Ave	2/20/15 8:00 AM	2.29	circumferential break	cast iron	6	clamp	2.0	291.3
508 Elizabeth St	2/23/15 8:00 AM	0.38	circumferential break	cast iron	2	clamp	1.0	56.1
1114 Beech Ave	2/25/15 8:00 AM	0.44	circumferential break	cast iron	6	clamp	2.0	368.5
12952 Ohio Ave	2/27/15 12:30 PM	3.00	circumferential break	cast iron	2 1/4	clamp	3.0	25.0
intersection Elizabeth St & Kanaw	2/27/15 1:15 PM	4.00	corrosion hole	galvanized main	1	remove service	3.0	20.0
400 Highland Ave	2/28/15 4:45 PM	9.00	circumferential break	cast iron	4	clamp	10.0	15.0
414 6th St	3/1/15 8:00 AM	0.22	circumferential break	cast iron	2 1/4	clamp	0.2	125.0
1514 Lewis St	3/4/15 8:00 AM	0.21	circumferential break	cast iron	6	clamp	1.0	300.0
239 Stauton Ave	3/5/15 9:00 AM	0.25	corrosion hole	cast iron	2	clamp	0.2	212.7
intersection MacCorkle Ave & F S	3/7/15 8:00 AM	18.35	valve packing	cast iron	12	replace valve	18.4	20.0
1011 Cleveland Ave	3/7/15 8:00 AM	0.33	service connection	cast iron	2	clamp	4.3	12.5
220 Highland Ave	3/7/15 10:00 PM	2.03	circumferential break	galvanized main	2	clamp	2.0	103.4
6901 MacCorkle Ave	3/9/15 11:00 AM	1.00	corrosion hole	galvanized main	2	clamp	1.0	75.0
6901 MacCorkle Ave	3/9/15 1:00 PM	2.00	circumferential break	galvanized main	2	replace pipe	3.0	5.0
141 Valley Dr	3/12/15 8:00 AM	0.17	circumferential break	cast iron	4	clamp	0.2	132.3
intersection Washington & Delewa	3/12/15 8:00 AM	32.31	valve bonnet	cast iron	6	replace gasket	32.3	56.1
Virginia Ave	3/16/15 12:30 AM	0.33	Contractor	cast iron	2	replace pipe	0.3	10.0
9114 Oregon Ave	3/16/15 8:00 AM	0.33	corrosion hole	PVC main	3/4	clamp	3.0	10.0
5711 MacCorkle Ave	3/16/15 8:00 AM	2.17	circumferential break	copper service	1	replace pipe	2.0	90.0
12970 Ohio Ave	3/16/15 12:00 PM	2.00	longitudinal break	cast iron	2 1/4	clamp	2.0	20.0
517 18th st	3/16/15 1:15 PM	3.00	corrosion hole	cast iron	6	clamp	3.0	112.1
222 Kanawha Blvd East	3/19/15 8:00 AM	0.52	joint leak	cast iron	20	replace gasket	0.5	116.3
intersection MacCorkle Ave & E S	3/23/15 8:00 AM	0.33	corrosion hole	cast iron	2	clamp	0.3	30.0
4860 MacCorkle Ave	3/24/15 8:00 AM	3.19	circumferential break	cast iron	2		3.0	67.7
612 Hall Street	3/25/15 9:00 AM	15.29	longitudinal break	polyethylene service	3/4	replace pipe	15.3	75.0
5827 MacCorkle Ave	3/30/15 8:00 AM	1.29	Contractor	copper service	3/4	replace pipe	1.5	5.0
5825 MacCorkle Ave	3/30/15 8:00 AM	1.33	Contractor	cast iron	3/4	replace pipe	1.4	60.0
370 Central Avenue	3/31/15 9:23 AM	16.13	circumferential break	cast iron	6	clamp	16.0	10.0
5811 MacCorkle Ave SW	4/6/15 8:00 AM	0.33	valve bonnet	cast iron	2	replace pipe	0.3	60.0
5828 B MacCorkle Ave SW	4/11/15 3:00 PM	0.19	corrosion hole	ductile iron	6	clamp	1.0	2.0
1021 Hendrix Ave	4/13/15 9:30 AM	3.13	valve packing	cast iron	8	replace gasket	3.0	10.0
1325 Washington Street W	4/16/15 8:00 AM	5.19	corrosion hole	galvanized main	1	replace pipe	5.0	10.0
837 Watts St	4/20/15 8:00 AM	4.21	circumferential break	galvanized main	2	clamp	4.2	150.0
248 Staunton Ave	4/20/15 9:29 AM	3.27	valve packing	cast iron	6	replace gasket	4.0	2.2
907 2nd Ave West	4/21/15 9:30 AM	8.27	circumferential break	PVC main	3/4	replace pipe	8.3	5.0
1508 Mountain Road	4/22/15 12:43 AM	0.53	longitudinal break	ductile iron	8	replace pipe	1.0	20.0
2331 Woodland Ave	4/30/15 3:30 PM	21.00	circumferential break	cast iron	6	clamp	21.0	56.1
5109 Staunton Ave	5/1/15 10:00 AM	0.13	corrosion hole	galvanized main	1/2	clamp	1.0	200.0
3000 Washington Street	5/4/15 8:30 AM	0.25	circumferential break	cast iron	8	clamp	1.0	58.8
5109 51st Street	5/4/15 3:30 PM	0.13	corrosion hole	galvanized main	1/2	replace pipe	1.0	10.0
601 Park Ave	5/11/15 12:00 PM	0.25	corrosion hole	PVC main	1	clamp	0.3	33.1
intersection Maryland Av & Rando	5/15/15 8:00 AM	4.42	corrosion hole	galvanized main	2	replace pipe	14.0	10.0
220 Highland Ave	5/19/15 8:00 AM	7.31	corrosion hole	cast iron	2	replace pipe	7.3	10.0