Pacific Northwest NATIONAL LABORATORY

PNNL-28885

Overview of Available Leak Detection Technologies

A Summary of Capabilities and Costs

July 2019

Megan A. Kilinski

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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As droughts and changing climate patterns cause water shortages and potential water system disruptions, there is a growing need for water resilience, which is the ability to withstand, adapt to, and recover from disruption. The Environmental Protection Agency's (EPA) report on Water Audits and Water Loss Control for Public Water Systems [EPA, Water Audits and Water Loss Control for Public Water Systems] states that average water loss in distribution systems is 16%, 75% of which is lost through leaks. Commercially available leak detection technologies were researched to identify current capabilities and average use costs, including operation and management (O&M) considerations, how to operate the devices, and current limitations. It was found that the cost-effectiveness of leak detection technologies is not ubiquitous across all systems. Factors that must be taken into account include the size of the water system, the amount of water use, and the currently known water losses in the system. A variety of technologies are summarized to give water managers a basic understanding of the tools available to them, and help enable them to make a more informed choice of how to reduce water losses in their water systems.

I INTRODUCTION

The United States loses 2 trillion gallons of treated drinking water each year from water main breaks that are often caused by undetected leaks.[1] This unused water is a growing concern, as 80% of state water managers expect water systems to be strained because of population growth and changing weather pattern events over the next decade.[2] Reducing leakage can help alleviate water shortages by mitigating losses and increasing the ability of the water provider to adequately anticipate water needs, leading to a more resilient water system that is better able to withstand, adapt to, and recover from disruption.

Water lost through leaks strains capital and natural resources while creating health and safety risks. Leaks cause capital loss and high operational costs in multiple ways. First, the upfront cost of paying for treating and delivering an unused resource or buying potable water from a provider, also a capital loss, is generated from damages caused by leaks that can also create safety risks, require costly repairs, and delay operations. Large, leak-caused failures are more prevalent if the facility/distribution system was built at least 50 years ago, as the service life of the pipe infrastructure may be nearing its end.[3] Significant leaks can also cause health and safety risks by increasing the chances of contaminating the drinking water. Leaks cause low pressure in pipes, which draws in pollutants from the surroundings and fouls drinking water.[4] The first step to mitigating these losses and risks is detecting leaks. Emerging technology has enabled leak detection with pinpoint accuracy, fewer staff hours, and less capital investment over the life of the product.

II REVIEW OF TECHNOLOGIES

Currently utilized leak detection technologies were researched to determine the variety of devices and services, including how they work, cost-effectiveness of each, and their limitations. The most common detection methods use acoustic sensors that detect the vibrations associated with leaks in pressurized pipes; they are, in essence, listening for leaks. It was also found that various types of imaging, fiber optics, and meter measurements were used to identify leaks. A summary of leak detection technologies is provided in Table 1 and covers the operation of each technology, what size of water system it applies to, the cost of the service or device, how accurate the technology is, and special considerations when using a particular type of technology. No one technology is the most cost-effective, as each water system has its own specific needs.

Table 1. Summary of Leak Detection Technologies

	Operation	System Size[1]	Cost[2]	Considerations
Noise Loggers	Loggers collect acoustic data during low-use hours; technician or software then analyzes data to determine if and where there is a leak	Medium to Small	$ - $$$	· More time needed to analyze PVC pipe · More expensive the broader the area to be covered · Can be semi-permanently or permanently placed in system
Listening Sticks	Handheld devices enable technicians to listen for the acoustic signature of a leak in a pipeline	Small	$ - $$	· Technician must be highly trained to determine presence of a leak
Smart Water Meters	Meters remotely send actual water-use data to be analyzed against expected water use	All	$$	· Network connected meters can have a shorter battery life · No location given for detected leak

Table 1. Summary of Leak Detection Technologies				
	Operation	**System Size[1]**	**Cost[2]**	**Considerations**
Advanced Metering Infrastructure (AMI)	The combination of smart meters, noise loggers, and analytic software to remotely monitor complete water systems	All	$$$$	· High upfront capital is mitigated by high savings over the life of the system · Network security is a priority to prevent hacking of water infrastructure
Thermal Imaging	Handheld cameras or drones are used to examine pipes through walls or the ground; abnormal temperature readings indicate a leak	Small	$ - $$$	· Leak water must be a different temperature than surroundings · In-ground leaks may be masked by water table
In-Pipe	Sensor deployed inside pipes uses either acoustic, pressure, or electromagnetic sensors to detect leaks	Large	$$$$	· Some types require temporarily closing the pipes, emptying them of water for testing, and subsequent sanitation before reopening · Pipes 8” or larger · Creates Geographic Information System (GIS) maps of pipe networks
Fiber Optics	Acoustic-sensing fiber optic cables are used to sense leaks along pipeline or breakage of wires imbedded in Pre-stressed Concrete Cylinder Pipes (PCCP)	Large	$$	· Limited commercial options for in-pipe use · PCCP application only cost-effective when putting in new pipe
Satellite	Satellite uses radar to detect the chemical makeup of treated drinking water, up to 12’ below ground	Large	$$$$	· Provides a snapshot of system leaks · Other leak detection technologies needed after service

Table 1. Summary of Leak Detection Technologies				
	Operation	**System Size[1]**	**Cost[2]**	**Considerations**
Ground Penetrating Radar	Walk behind unit uses microwaves to image subsurface structures; can detect leaks within pipes up to 12' below ground	Large to Medium	$$$	· Pipe 1" or larger · Ground above pipes must be clear of buildings and vegetation · Pipeline must be marked above ground

1. *System Size:*
   - *Large: Distribution systems with miles of long run pipe*
   - *Medium: Campuses with inter-building distribution piping and in-building monitoring*
   - *Small: Single building site and industrial use monitoring*
   - *All: Can be used in all size systems*
2. *Cost:*
   - *$ - < $200 per device (the larger the system the more devices required)*
   - *$$ - $200-$5,000*
   - *$$$ - $5,000-$20,000*
   - *$$$$ - >$20,000*

A Noise Loggers

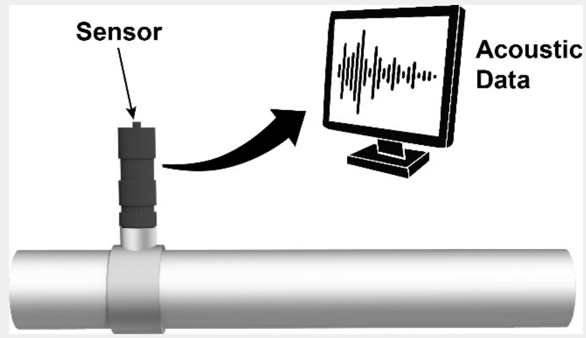

Figure 1. Noise Loggers

Noise loggers are acoustic-based sensors placed either on the outside of pipes or through a valve in water (Figure 1). Loggers can be placed temporarily and moved to analyze an entire system or placed on a permanent basis to continuously monitor a specific area. Sensors are placed on 100-300 ft intervals dependent on pipe material; PVC pipes require loggers to be closer together. Sensors listen for the high-frequency signature of leaks. Loggers can be moved around large systems for system inspection, or left in place as a part of a continuous monitoring system. Loggers are scheduled to run scans during low-use hours to minimize acoustic interference. Different models have a variety of features, such as frequency filters,[1] wireless connectivity, and digital or graphic readouts. Correlating loggers are a type of noise logger that analyze data between multiple loggers to detect the exact location of a leak; although efficient, such features increase the cost.

Cost Estimate:

- Variable $100 - $5,000 per logger (vendor quote)
- Installation, maintenance, and gathering and interpretation of data

Required Training:
- A trained technician to interpret data

Considerations:
- PVC pipes need to record acoustic data for longer and sensors must be closer together
- Lower-end models need more personnel training to interpret data, as higher end models provide more interpretation of data
- More efficient features will increase cost (e.g. frequency filters, correlating analysis, or digital/graphic readouts)
- Application to large systems may not be cost effective, placing on small sections with multiple leak possibilities may be more appropriate

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[a] Frequency filters will disregard ambient sounds, reducing false positives

B Listening Sticks


Figure 2. Acoustic Listening Sticks

One of the oldest types of leak detection technologies are listening sticks, which are acoustic-based devices that consist of a metal rod attached to either a diaphragm and resonance chamber or a digital readout (Figure 2). These handheld devices are placed on the pipe to access the acoustic vibrations within the pipe. While these devices require no modification to existing infrastructure, they can only be used on accessible pipes. Simple acoustic sticks require training and experience to detect leaks accurately. Digital models have various frequency filters and are much easier to operate correctly. These devices can be used with any size system, but with the intensive staff hours required to analyze a system it may only be cost effective on small systems.

Cost Estimate:
- $100 - $2000 per device (vendor quote)
- Additional staff-hours needed for detection

Required Training:
- Technician training, amount of training depends on model of device

Considerations:
- Requires every pipe to be physically inspected by a technician, resulting in many staff hours
- Pipe must be accessible (e.g., above ground or easily accessible underground pipe)
- Leaks may go unnoticed if large and established (create less of an acoustic signature)
- More efficient features will increase cost (e.g., digital or graphic readouts)

C Smart Water Meters

Figure 3. Smart Water Meters

Smart water meters (also known as advanced meters) are meters connected to a wireless, Wi-Fi, cellular, radio, or hardwired network to communicate water usage to a remote analytic monitoring service (Figure 3). Smart meters do not directly monitor for leaks, but the data gathered by them can help identify potential leaks. For example, if water usage data shows that water use never reaches zero, the likelihood of a leak is high if the facility has no continuous water processes or end-uses. Also, night-time water use in facilities that do not have 24-hour operation may also indicate a leak. The smart meters' remote transmission of data reduces operating costs over their lifetimes, as there are no staff hours or vehicle deployments necessary to collect data. Smart meters come in a variety of different types; some require fluid interaction while others do not. Installation and maintenance costs will vary depending on the type of meter. Deployment of smart water meters can be applicable to a variety of system sizes, e.g., sub-metering within a campus between buildings or inside a building to quantify water use in a specific process.

Cost Estimate:

- $400-$800 per meter (vendor quotes)
- Installation, maintenance, gathering, hosting, and interpretation of data

Required Training:

- Installed by the vendor, and monitored by facility technicians or analytic software

Considerations:

- Network security required for critical locations
- Analytic monitoring service is an added cost
- Variable battery life, give special attention when selecting meters
- Meters do not provide a precise location of leaks
- Secondary leak detection team must be highly trained to detect leaks accurately

D Advanced Metering Infrastructure

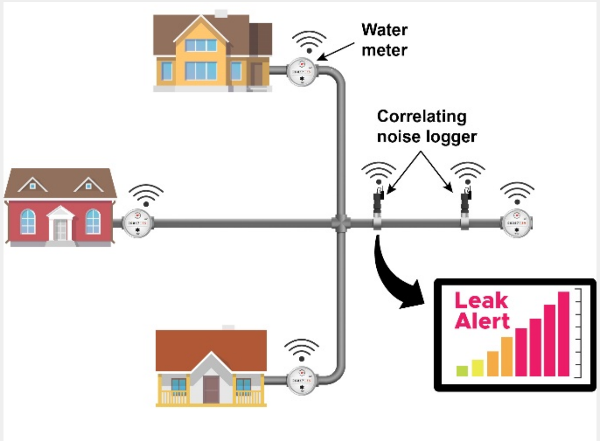

Figure 4. Advanced Metering Infrastructure

Advanced Metering Infrastructure (AMI), is the combination of smart meters and the analytic software needed to automate the monitoring of a water system (Figure 4). AMI can use data analytics or machine learning to analyze input data from connected devices to give water managers an efficient and comprehensive monitoring system in a central location. The analytic software automatically processes usage data against established norms and alerts water managers if there is an abnormality that may indicate a leak. Noise loggers can also be integrated into an AMI system; if done, the software will analyze the acoustic data from the loggers and alert managers if there is a possibility of a leak. AMI systems increase the real-time knowledge of a water system while using fewer staff hours. However, applying AMI may only be cost-effective for larger systems because of the upfront costs.

Cost Estimate:

- $400-$800 per meter (vendor quotes)
- $100 - $5,000 per logger (vendor quote)
- $25 per meter per year for software and data hosting (vendor quote, some vendors do not have an annual fee)
- Additional costs per meter or logger included in the system

Required Training:

- Training from a vendor for the user interface; AMI is connected by the vendor

Considerations:

- Cost of AMI will vary depending on how large the water system is
- Network security required for critical locations
- Facilities with software engineers may be able to design an in-house AMI system for less investment
- Overall savings reduce high upfront capital investment over the life of the product

E Thermal Imaging

Figure 5. Thermal Imaging

Thermal imaging cameras are used to detect hot or cold spots within buildings or fields (Figure 5). Devices can be handheld cameras, which are best suited for leaks in walls or around structures, or cameras that are mounted to drones for long transmission mains under roads or fields. Handheld cameras have a variety of price points; high-end models have Wi-Fi connectivity and high screen resolution. Drone applications are best suited for rural areas that are relatively clear of vegetation. Thermal imaging is commonly used in steam systems, so steam traps can be easily monitored and maintained. Leaks will be warmer than the surroundings during cold months, and cooler than the surroundings during warm months, assuming the average temperature of the water is 50-60°F. Temperature differences will vary for heated water.

<u>Cost Estimate:</u>

- Handheld device $150-$1,000, drone camera $7,000 - $16,000 (vendor quotes)
- Additional staff-hours needed for detection

<u>Required Training:</u>

- Handheld device, none; drone devices require flight training

<u>Considerations:</u>

- Must have a 20°F difference between ambient air and temperature of the water
- In-ground pipe leaks may be masked by groundwater or vegetation
- No indication of leak’s size

F In-Pipe

In-pipe leak detection technologies work as a one-time service from a vendor by running a device with either acoustic, pressure, or electromagnetic sensors through pipes to detect leaks. Devices can be tethered or free floating in watered lines; they can also be a robotic crawler if lines have been completely de-watered (Figure 6). Tethered versions are necessary for complex urban systems. These devices can use acoustic, pressure, or electromagnetic sensors to detect leaks in the pipeline. The utilization of Geographic Information System (GIS) sensors in these devices enables the digital mapping of pipe systems during the inspection process. Detected leaks are marked on a pipe map to represent their exact locations. Use of in-pipe detection methods is reserved for large transmission pipes, because of costs and the method's pipe size requirements.

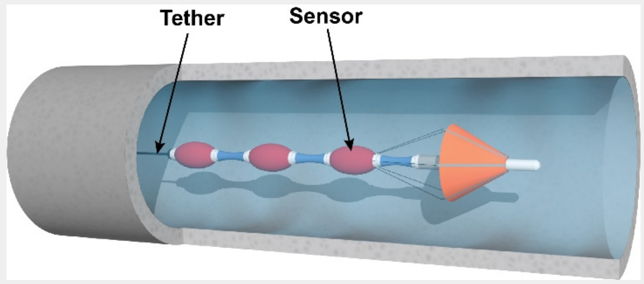

Figure 6. In-Pipe Leak Sensor

Cost Estimate:

- Deployment, $50,000; additional charges, $10,000-$15,000 per mile (vendor quote)

Required Training:

- Company-trained technician needs to be hired to inspect the area.

Considerations:

- If the line must be shut off for inspection, the pipe must be thoroughly cleaned after assessment
- One-time service from a vendor
- Small leaks of less than 1 gal/min, may not be detected
- Pipes must generally be 8 in or larger

G Fiber Optics

Acoustic Fiber Optic (AFO) monitoring lines may be placed in-line or outside PCCP channels (Figure 7). Although there is research on the in-line application of AFO, commercial application is limited.[6] In-line AFO monitoring acoustically listens for the high-frequency signature of leaks. AFO systems on the outside of PCCP lines listen for the breakage of the reinforcing steel wires within the structure of the pipe. AFO systems outside of PCCP lines can detect wear on the pipes but do not detect leaks.

Figure 7. Acoustic Fiber Optic Lines

Cost Estimate:

- Deployment $2,000 - $10,000,[a] monitoring costs $20 per mile

Required Training:

- A vendor-trained technician needs to be hired to install the technology; remote monitoring service alerts water managers to possible leaks.

Considerations:

- Most water applications are used with large-diameter PCCP lines; not applicable to other materials
- Remote monitoring service is an additional ongoing cost
- Outer diameter application is not cost-effective as a retrofit but can be used for new construction and pipe replacement

[a] Cost Estimate from 2010, may have changed[5]

H Satellite

Satellites carrying radar sensors scan an area of about 1,200 mi^2 looking for the specific signature of treated drinking water. Synthetic Aperture Radar (SAR) sensors can detect water up to 12 ft below the surface of the ground and leaks as small as 0.026 gal/min. Algorithms process the data and reports are generated from client provided GIS pipeline maps. If a water manager does not have a complete GIS map of pipes, the report can be generated from paper maps but will take more time and money. The report indicates Points of Interest (POI), which are roughly the size of a city block; these signify a high likelihood of a water leak (Figure 8). A secondary leak detection team is deployed to pinpoint leaks and repair them. Having targeted POIs to inspect can mitigate the staff-hours required for secondary leak detection teams in large systems.

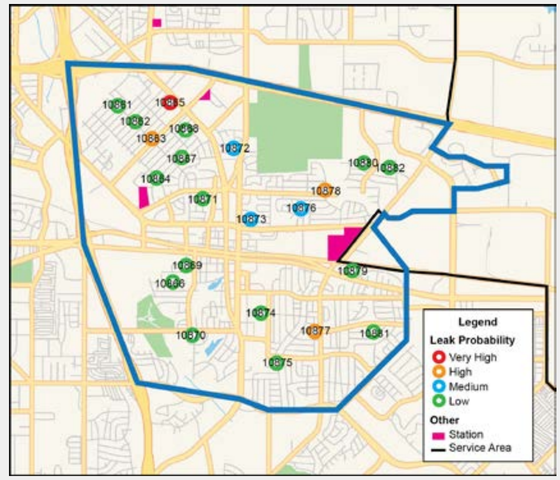

Figure 8. Satellite

Cost Estimate:

- $40,000 per 1,200 mi^2 (vendor quote)
- Additional staff hours needed for detection

Required Training:

- Secondary leak detection team must be highly trained to detect leaks accurately

Considerations:

- One-time service from a vendor
- Only works on treated drinking water
- Only price-effective for 100-200 miles of pipe systems

I Ground Penetrating Radar

Ground Penetrating Radar (GPR) sends electromagnetic waves into the ground; these waves are reflected off objects and returned to the device which creates a picture of subsurface objects. The image depicts pipe breaks and underground pools of water. Some models can create 3D models of underground substances. GPR requires trained-technician hours to operate the device by walking directly over the pipe system and significant experience is needed to interpret returned data to detect leaks (Figure 9).


Figure 9. Ground Penetrating Radar

Cost Estimate:

- $15,000 - $30,000 for device (vendor quotes)
- Additional staff hours needed for use

Required Training:

- Moderate training necessary to use the system, significant experience needed to interpret data to detect leaks

Considerations:

- The pipeline (greater than 1 in) must be marked on the ground before use
- The pipeline must be unobstructed by vegetation and buildings
- Naturally occurring groundwater can interfere with leak detection
- Extensive staff hours needed for a comprehensive system inspection

III SELECTING A TECHNOLOGY

Before deciding on which leak detection technology is best for a specific water system, a water manager must have a set of overarching policy goals, an assessment of current water use and costs, and a developed water balance.[7] The water balance gives an approximation of the current leaks in the system; combining this quantity with the water rate provides the value of calculated leaks and enables a total account of potential savings for a considered technology. With this information, a water manager can identify potentially applicable technologies based on the size of the system, cost, and required accuracy of the technology and then generate a life-cycle cost analysis (LCCA) of each potential technology. When completing an LCCA, the sum of the present values of capital investment costs, installation costs, and longer-term costs, such as associated energy, O&M, and disposal costs, are compared against the estimated cost savings over the lifetime of the product.[8] Performing a complete LCCA with a developed water management plan and current water balance will allow for an informed decision when choosing which leak detection technology to implement.

IV CONCLUSION

Leaks cause a significant amount of water loss each day across the United States; this is a significant concern, as water managers expect water systems to be strained because of population growth and changing weather pattern events over the next decade. Water loss strains natural and capital resources and creates health and safety risks. One way to significantly reduce water loss is to find and repair leaks. Currently utilized leak detection technologies were researched to discover the variety of devices and services, including how they work, cost-effectiveness of each, and their limitations. The leak detection methods discussed apply mainly to potable water systems; future work might look into other water systems such as non-potable water, wastewater, or specific industrial systems. Applying leak detection technology requires careful analysis of the current system and a complete LCCA of considered technology to determine cost-effectiveness. Using modern leak detection methods decreases costs and risks, ensures an efficiently running organization, and creates a more resilient system that is more able to withstand, adapt to, and recover from disruption.

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