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Energy Research and Development Division

FINAL PROJECT REPORT

Demonstrating Innovative Water Leakage Reduction Strategies

Correlating Continuous Acoustic Monitoring, Satellite Imagery, and Flow Sensitive Pressure Reducing Valve System

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Demonstrating Innovative Leakage Reduction Strategies is the final report for Contract Number EPC-15-096 conducted by Hazen and Sawyer and American Water. The information from this project contributes to Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

ABSTRACT

The project team installed and evaluated the latest in advanced correlating continuous acoustic monitoring technology, satellite imagery leak detection, and flow sensitive pressure reducing valve systems to reduce water leakage and prevent water loss in California water utility networks. Because of the embedded energy in water pumping and treatment, reduced water loss directly correlates with reduced energy loss. Evaluation was a cooperative effort with the vendors to improve the developing tools. During the project, the team also evaluated the financial and water/energy saving benefits associated with the technologies and provided guidance for utilities to evaluate the technologies for applicability to other systems.

The project team compared the performance of continuous acoustic monitoring technology and satellite imagery leak detection, but a key conclusion was that both technologies are effective in locating subsurface leaks that would have been invisible to the casual observer and should be considered for future applications. Based on budget, resources, schedule, system characteristics, and other factors, future users should consider what is best for their systems. Using both technologies in the same system may be an effective way to take advantage of the strengths of each method. The two technologies found leaks that would have resulted in 57-170 million gallons of lost water, equal to 140-419 megawatt-hours of energy savings.

Keywords: water loss, leak detection, energy intensity, embedded energy, pipe break, water energy nexus, satellite imagery, acoustic monitoring, pressure management

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EXECUTIVE SUMMARY

Introduction

Water utilities struggle with identifying leaks in buried pipe infrastructure. The cost of repairing pipe leaks is relatively low when compared to replacement, but water utilities often do not know a pipe is leaking until the water reaches the surface. When leaks do not surface immediately, substantial water loss and subsurface damage can occur. While reported leakage tends to be associated with major surface expression of water and infrastructure damage, hidden leakage and unreported leakage are a challenge to detect and manage. Along with the waste of water, is the waste of energy associated with producing that water.

Water-related energy use in California consumed 19 percent of the state's electricity, 30 percent of its natural gas, and 88 billion gallons of diesel fuel annually, and the demand is growing. Water is provided to users from different resources including surface water (mostly in Northern California), conveyed water (mostly in Southern California), desalinated water, groundwater, and recycled water. The common theme among these water resources is the intensive embedded energy required for conveying, treating, and distributing the water. The California Energy Commission (CEC) released a report on the range of energy intensity among the water segments in 2006 that indicates that in California, water supply and conveyance consume up to 14,000 kilowatt-hours per million gallons (kWh/MG), water treatment consumes up to 16,000 kWh/MG, and water distribution consumes between 700 to 1,200 kWh/MG.

Significant water loss associated with aging infrastructure and long lag times from leak inception to detection results in not only wasted water but also wasted energy due to the high level of energy required to treat and deliver water intended for consumption. It is estimated that leak detection saves as much as 16,000 kWh/MG, based on the average energy intensity required for conveying (7000 kWh/MG), treating (8050 kWh/MG) and distributing water (950 kWh/MG) in California. This amount of energy saving mitigates 3,872 kilograms of carbon dioxide equivalent per million gallons (kg CO_2eq/MG) prevented loss (8,606 lbs. CO_2eq/MG prevented loss). State authorities estimate that California's water distribution systems lose up to 228 billion gallons of potable water annually from leakage or broken underground pipes, translating to 3,648 million kWh/year and 1,207,500 metric tons of greenhouse gas emissions/year. Deploying technologies to identify leaks as soon as they occur would not only facilitate the task of water leak detection in distribution systems, but also assist water agencies in more efficient loss control strategies.

Project Purpose

The purpose of this project was to evaluate technologies that could mitigate the formation of distribution system leaks and detect any leaks that do occur early enough to minimize water loss and damage. Specifically, this project aimed to provide a means by which water utilities could minimize wasted energy associated with the energy intensity of water due to leaks in the system, providing a net benefit to water and electricity ratepayers. For example, a system that experienced more than 200 detected leaks in 2018, scaling this leak reduction would be equivalent to 24 million gallons to 72 million gallons of leak reduction savings and an equivalent of 149,000 kWh - 446,000 kWh of energy saved.

For this project, American Water, with support from Hazen and Sawyer for field supervision, detailed analysis, and project coordination, evaluated four technologies and methods to detect and prevent leaks:

1. Correlating continuous acoustic monitoring (CCAM) technology for leak detection is based on a series of sensors that are installed on fire hydrants throughout the distribution system to cover as wide an area as possible. The sensors listen to and record sounds and through post-processing of the data, leaks are identified for follow-up investigation by a leak investigation crew.
2. Satellite imagery for leak detection requires no special installation in the system, instead uses existing satellite systems to collect microwave-based images of the entire distribution system. The images are processed by proprietary algorithms to identify underground leaks from a drinking water system. Leaks identified during post-processing are sent for follow-up investigation by a leak investigation crew.
3. Flow sensitive pressure reducing valve system (FSPRV) for pressure management and leak prevention use smart sensors to moderate pressure within a system based on flow and demand patterns. FSPRV devices have the potential to prevent leaks by minimizing the number and duration of high-pressure events that can often lead to pipe breaks during low-flow night time hours.
4. District metered areas (DMAs) observe system flow patterns using flow meters for leak detection and allow utilities to monitor flow to specific portions of the distribution system.

Project Goals

The goals of this project were to:

- Use, evaluate, and collaborate with the vendor to improve correlating continuous acoustic monitoring technology to reduce water leakage and prevent water loss in water utility networks.
- Use, evaluate, and collaborate with vendor to improve the state-of-the-art satellite imagery leak detection technology. Satellite imagery leak detection and correlating continuous acoustic monitoring were deployed in the same location for purposes of comparing the values and performance of each technique.
- Explore the relative value of flow sensitive pressure reducing valve system and work with the technology vendor to develop a finished product designed for the United States market.
- Evaluate the full financial and water saving benefits associated with the proposed technologies.
- Present the potential savings in water and energy consumption, and greenhouse gas emission mitigation achieved through water loss control.

Project Approach

Technology Deployment

American Water is the largest privately-owned water utility in the United States and its California American Water subsidiary provides water and wastewater services to nearly

700,000 people. Given its large footprint across the state and its innovative approach to water conservation, California American Water provided an ideal candidate for implementation and evaluation of the four leak detection and prevention technologies in three California American Water systems: the Ventura County District, the Duarte System in Los Angeles County, and the San Diego County District. These systems were selected due to their different pipe materials, increasing historical pipe break rates, and the availability of district meter areas for monitoring and evaluation. The team implemented flow sensitive pressure reducing valve (FSPRV) and district metering in the Ventura County District and the San Diego County District to determine if FSPRVs could provide meaningful prevention or reduction in leakage in these two districts. To compare the two leak detection technologies, the research team implemented correlating continuous acoustic monitoring and satellite imagery leak detection only in the Duarte System. Table ES-1 summarizes the technologies and their corresponding California American Water systems.

Table ES-1: Summary of Technologies Implemented

California American Water System	Correlating Continuous Acoustic Monitoring (Echologics)	Satellite Imagery Leak Detection (Utilis)	Flow Sensitive Pressure Reducing Valve (Aqua-Guard by Stream Control)	District Metering
Duarte System	X	X		
Ventura County District			X	X
San Diego County District			X	X

Source: Hazen and Sawyer, American Water

Key vendors used in this project included:

- Echologics for correlating continuous acoustic monitoring.
- Utilis for satellite imagery leak detection.
- Stream Control for flow sensitive pressure reducing valve.

Technology Evaluation

The team evaluated CCAM and satellite imagery leak detection in the Duarte System. Each technology identified points of interest or possible leak locations. Pertinent leak investigation data such as leak location, the technology that found the leak, and leak size was collected in a project database. CCAM is applicable to any size system or portion of a system provided it has metallic or asbestos cement pipe materials. The satellite imagery leak detection technology is generally best suited for systems with greater than 50 miles of pipe and it can work on systems with any type of pipe materials. The CCAM needs to be able to adapt the technology to PVC/plastic pipes, reduce the number of false positives, and provide greater vendor support to the leak detection teams. The satellite imagery leak detection needs to further reduce the area for investigation to provide more efficiency to the field crews, publish data to diminish the perception of randomness of points of interest, provide vendor support as the company grows, and consider using the technology for more than just drinking water leak detection.

The flow sensitive pressure reducing valve technology was in the Aqua-Guard system by Stream Control. The researchers evaluated this system for its applicability and market readiness for the United States market. The evaluation included assessing implementation and ability to reduce downstream pressures during periods of low demands (for example, nighttime). The Aqua-Guard system is still in development and encountered several challenges including needing advancements in the software and provision of reliable data transmission (for example, cellular) from the field units to a central data processing location. Other barriers to overcome include developing a packaged system approach, improving performance of the product, developing a greater presence in the United States, and providing more detailed training and documentation. This type of system will be useful for systems with defined pressure zones with varied diurnal demand patterns of water use and frequent leaks or high amounts of non-revenue water.

The team created five DMAs for this project – four in Ventura and one in San Diego — and evaluated them weekly by analyzing the flow data for any inconsistent patterns that could result from leakage. Using DMAs in a water system is a traditional yet effective way to manage water loss and becomes more effective as the district metered area size is reduced.

Project Results

The researchers used CCAM and satellite imagery leak detection technologies in Duarte during the same period to evaluate their effectiveness at locating leaks. The team used parameters such as number of leaks found, miles of pipe investigated, and embedded energy savings to evaluate the two technologies. Both technologies performed comparably, finding between 2.6 and 3.8 leaks per mile of pipe in the distribution system and average labor per leak found was 4.9 hours/leak for CCAM and 5.6 hours/leak for satellite imagery leak detection. Each technology was able to find leaks, with the satellite imagery leak detection being able to scan a broader area and CCAM providing a more pinpoint approach to finding a higher density of leaks in the portion of the distribution system covered by the installed sensors.

Although the researchers compared the two technologies for effectiveness, a key conclusion was that there are applications for both technologies with energy and cost savings associated with proactive leak detection and repair, including benefits to employing both within the same system. For example, using both technologies in a very large system could be advantageous because a large system may include thousands of miles of distribution pipeline and thousands of hydrants. Both CCAM and satellite imagery leak detection found leaks missed by the other technology, providing a complimentary approach to leak detection. While the data show a number of leaks "missed" by both technologies (that is, leaks were found/observed in the system that neither technology identified), part of this may have been due to the limitation of the team to investigate all points of interest provided. For example, the team was only able to investigate 29 percent of the more than 500 points of interest provided by the satellite imagery leak detection vendor while the CCAM vendor provided to the team with only 77 out of all their points of interest identified, of which 64 percent were investigated. Thus, providing and investigating more points of interest could improve the number of leaks found and eliminate many of the "misses" observed by both technologies.

Benefits to California

Using the satellite technology and the continuous correlating technology could save as much as 419,000 kWh of energy per year at an energy cost savings of up to $101,000 in the Duarte System alone, as shown in Table ES-2. These figures represent only limited-scale use in California and would be significantly larger if implemented statewide.

Table ES-2: Combined Impact of Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection Performance Metrics

Parameter	Value
EI (kWh/MG)	2,464
Leak Volume (MG, based on duration)	57 to 170
Cumulative Energy Saved (kWh)	140,000 to 419,000
Cumulative Energy Savings	$33,000 to $101,000
Energy Savings (% of system use)	3.1% to 9.0%
Nitrogen oxide reduction (lbs)*	112 to 336
Carbon dioxide reduction (lbs)*	73,541 to 220,120

Source: U.S. Energy Information Administration Webpage: https://www.eia.gov/electricity/state/california

When fully functional, a flow sensitive pressure reducing valve technology with the potential to decrease flow to leaks during low use periods could also provide additional benefit to the state. Assuming the leak flow reduction when the system is at 60 pounds per square inch (psi) compared to 70 psi could potentially lower water loss to 0.36 million gallons per leak during the leak, thereby saving between 744 kWh and 2,232 kWh per leak when converted to energy for the San Diego County District. These values would clearly be magnified when projected across multiple leaks in a system over years of operation. For a system like Duarte that experienced more than 200 detected leaks in 2018, scaling this leak reduction would be equivalent to 24 million gallons to 72 million gallons of leak reduction savings and an equivalent of 149,000 kWh - 446,000 kWh of energy saved.

Each technology could minimize water loss with the added benefit of providing a reduction in energy and greenhouse gas emissions. Benefits, successes, challenges, and recommended upgrades/updates for each technology are discussed in the report and its important no conclusions are drawn regarding the favorability or success of one technology over the other.

Instead, utility manager and decision makers are urged to seek guidance in evaluating the applicability of each technology with their site-specific constraints, staff needs, water loss goals, accessibility, and use in mind.

Marketing and Knowledge Transfer

The types of communication used for knowledge transfer activities include conference presentations, panel discussions, webinars, luncheons, online/digital media, and magazines.

The primary publication associated with this project is this final report, made available by the CEC. The research team is currently preparing a manuscript for publication in one of the American Water Works Association publications. Additionally, a fact sheet was developed to provide utilities attending presentations on the project with additional information about the project.

At the time of writing, several presentations had already been given on the project, and several were planned or submitted for acceptance at future conferences. Presentations previously given at conferences include:

- 2017 AWWA Water Loss Conference
- 2018 AWWA ACE Conference (2 presentations given)

- 2018 Arizona Water Annual Conference
- 2018 Rocky Mountain Water Environment Association Joint Technical Annual Conference
- 2018 Arizona Water Energy and Sustainability Webcast
- 2018 Utilis Innovation Summit
- 2019 California/Nevada/AWWA Conference
- 2019 AWWA ACE Conference
- 2019 CEC Workshop: Energy Research Innovations in Water Treatment, Delivery, and Energy Recovery

A technical advisory committee was also formed to provide monthly review and input on various topics throughout the project's implementation. The committee included leaders from prominent California water agencies including Los Angeles Department of Water and Power, Metropolitan Water District of Southern California, San Jose Water Company, and California American Water. The committee meetings typically consisted of a presentation given by the research team on a certain project topic, with discussion and questions from the members. In addition to the members providing valuable input to the research team throughout the project, the research team was able to transfer knowledge gained from the technologies to the members. Some committee members had experience from implementing the same or similar technologies, while some were considering future deployment in their systems.

As of January 2021, Echologics has installed 23,335 acoustic sensors and located more than 1,200 leaks. The Echologics CCAM technology has been used for various projects in North American and around the world. Recent projects have included detecting leaks on critical transmission mains and airport water supply lines. Echologics is currently working on upgrading their technology with the ability to detect leaks on prestressed concrete cylinder pipe.

As of December 2020, Utilis had completed more than 400 leak detection projects in 55 countries that resulted in 28,000 verified leaks found. Once the leaks are repaired, this will save over 7,200 million gallons pf potable water and 17,000 mega-watt hours of energy per year.

Stream Control was not available for comment on the current status of their technology in the United States.

CHAPTER 1: Technology and Equipment Deployment

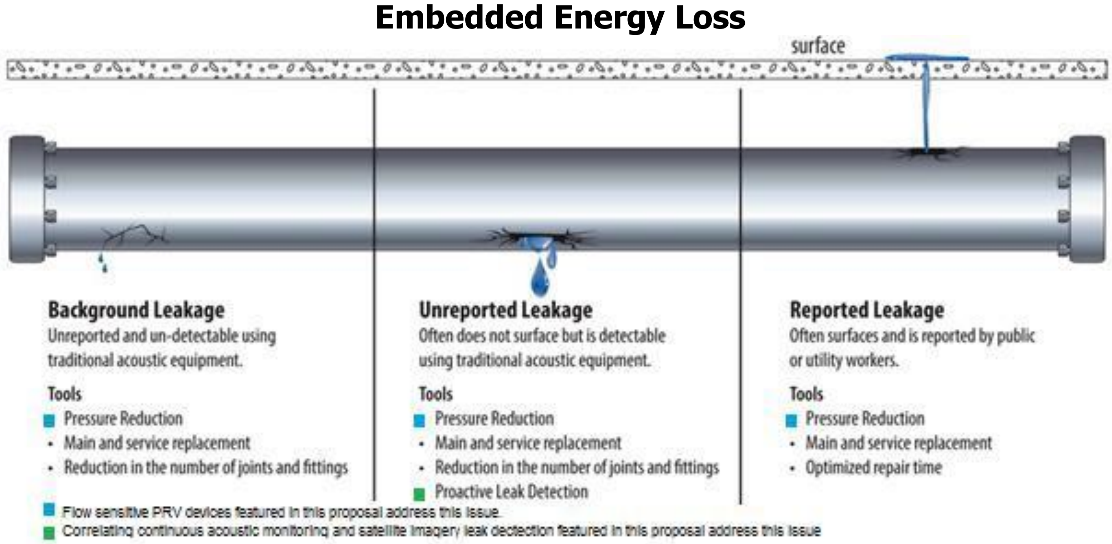
Introduction

The efforts of this project developed and deployed technologies that detect water leaks and prevent water loss in water distribution systems. A primary driver behind this leak detection research is to determine how much energy can be saved by reducing water loss within a system, because lost water is lost energy.

Specifically, the efforts during this project advanced reducing water system waste in California and consequently cutting electrical energy consumption (and greenhouse gas [GHG] emissions) by lessening the amount of energy used for treatment and conveyance. The project efforts provided a demonstration-scale validation and improvement of a suite of technologies that work (a) to reduce leakage in distribution systems via intelligent monitoring with active flow management and (b) to detect hidden leaks using remote sensing (satellite) technology and in-situ monitoring devices.

Water utilities struggle with identifying leaking pipe infrastructure. The cost of repairing pipe leaks is relatively low when compared to replacement, but water utilities often do not know a pipe is leaking until the water reaches the surface. Pipes fail at their weakest point which, unfortunately, is not solely dictated by age and therefore predicting leak location in buried infrastructure/pipe networks is impractical. When leaks do not surface immediately, substantial water loss and subsurface damage can occur. While reported leakage tends to be associated with major surface expression of water and infrastructure damage, hidden and unreported leakage are a challenge to detect and manage (Figure 1). The significant loss of drinking water before it reaches the customer is especially acute in California where water scarcity and drought, along with the embedded energy of treatment and conveyance compound the value of water lost.

Figure 1: Types of Leakage Leading to Water and Embedded Energy Loss



Source: Adapted from Water Research Foundation, Advances in Water Research, June-Sept, 2014.

The American Water Works Association (AWWA) water loss control committee recommends a multi-faceted approach to managing and reducing leakage (Figure 2). The project team sought to demonstrate technologies and improve their performance in managing two of the four parts of the approach: reducing leak formation through pressure management and reducing water loss through proactive leak detection strategies that are relatively new to most water utilities in the U.S. The technologies included correlating continuous acoustic monitoring (CCAM), satellite imagery leak detection (SILD), district meter areas (DMA) and flow sensitive pressure reducing valves (FSPRVs). The technologies had been through validation testing but had yet to be commercialized at full scale and in conjunction with each other.

Figure 2: American Water Works Association-Recommended Strategies to Prevent and Reduce Leakage

Source: Hazen and Sawyer, American Water

For this project, American Water deployed and evaluated the following technologies and methods for leak detection, leak prevention and energy savings:

- Physical CCAM technology for leak detection
- Remote sensing, SILD for leak detection
- Physical FSPRV for pressure management and for leak prevention
- Development and assignment of DMAs programs to observe system flow patterns utilizing flow meters for leak detection

The benefits of this project have been quantified through the volume of water saved by proposed technologies, the embedded energy in the saved water, and the GHG emission reduction associated with the saved energy. The water savings was calculated directly based on the generated data during the project from detected leaks, the volume of the leak, and consequently the volume of prevented loss. The energy savings was calculated based on the embedded energy in the water saved by the presented leak detection and loss prevention technologies. Carbon emission (GHG) reduction was calculated based on the emission that is associated with electricity generation, and the energy saved from water loss prevention.

Goals and Objectives

The goals of the project were to:

- Deploy, evaluate, and collaborate with vendor to improve the acoustic CCAM technology to effectively reduce water leakage in water utility networks.
- Deploy, evaluate, and collaborate with vendor to improve the state-of-the-art remote sensing SILD technology.
- Compare the performance of satellite and acoustic technologies by using and evaluating their use in the same locations.
- Explore the relative value of a smart pressure management (FSPRV) system and work with the technology vendor to develop a finished product designed for the U.S. market.
- Evaluate the full financial and water saving benefits associated with the proposed technologies.
- Present the potential savings in water and energy consumption, and GHG emission mitigation achieved through water loss control.

Ratepayer benefits resulting from the project include greater system reliability, lower emergency and repair costs, increased safety, and water and electricity savings by managing and minimizing water leakage in California water systems.

This project will lead to future technological advancement to overcome barriers to the achievement of the California's statutory energy goals by improving leak detection/prevention strategies, and commercializing the proposed technologies (CCAM, SILD, and FSPRV). Furthermore, the results help to introduce the employed technologies to California water agencies as successful water/energy savings and GHG mitigation solutions.

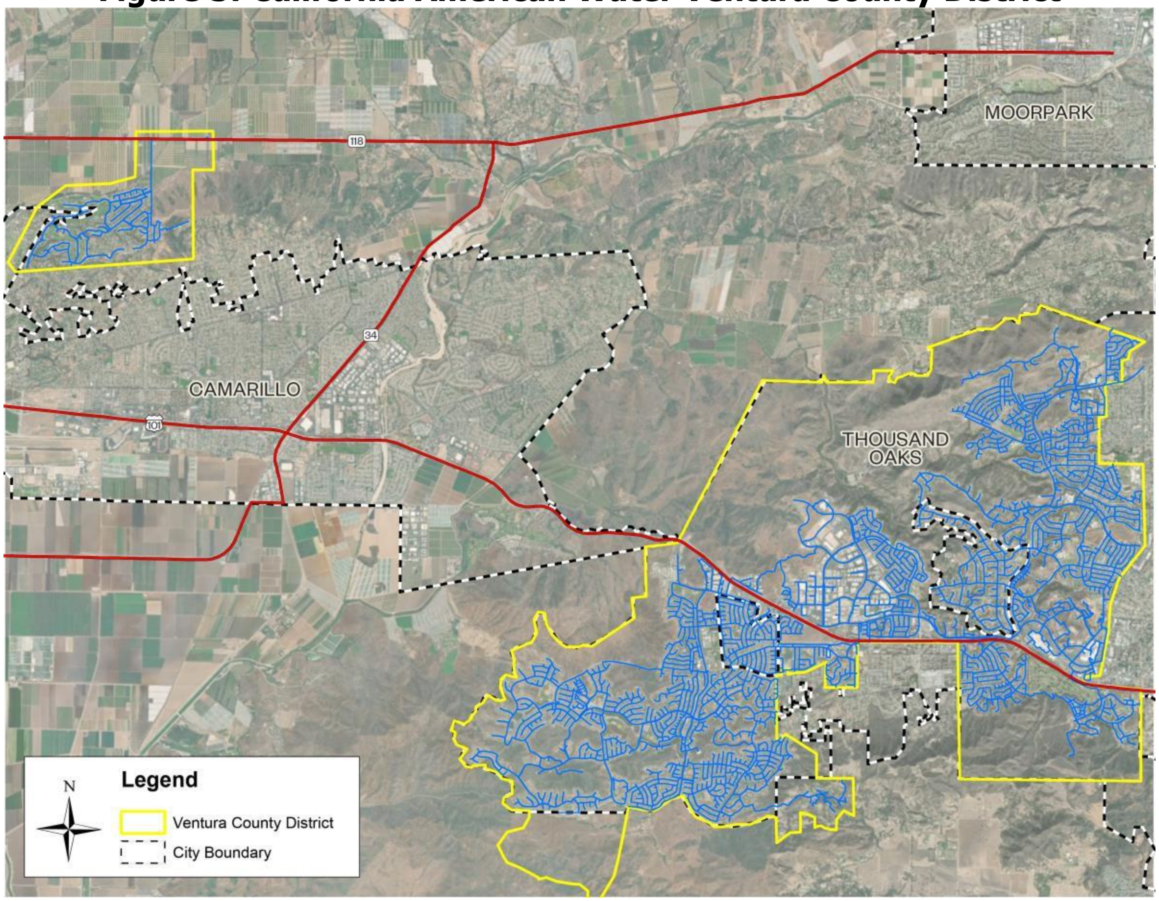
Demonstration Sites

The technologies (described in later sections of this report) were implemented in three California American Water (CAW) systems: Ventura County District, Duarte System in Los Angeles County, and San Diego County District. A brief description of each site is included in the following sections.

Ventura County District

The Ventura County District is comprised of hilly topography with more than 380 miles of water pipelines, a majority of which are plastic or asbestos cement pipe (Figure 3). Additionally, the district experiences relatively few main breaks. In this system district meter areas were established with testing of the satellite and pressure reducing FSPRV technologies.

Figure 3: California American Water Ventura County District

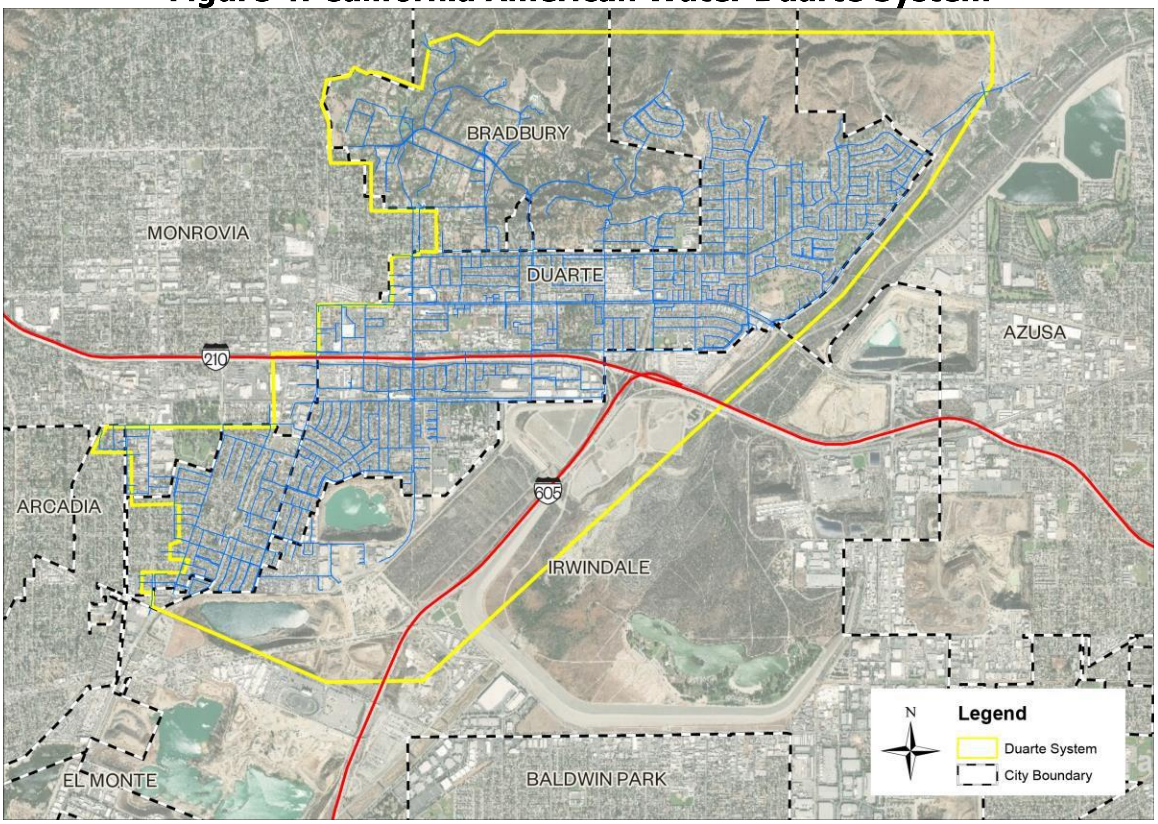


Source: American Water

Duarte System

The Duarte System is in the San Gabriel Mountain foothills and is comprised of 100 miles of mains, which are a mix of steel, asbestos cement, and plastic pipes (Figure 4). Historically the system has averaged about 60 leaks per year, but this rate has escalated in the last two years. In 2016 and 2017 the system experienced 87 and 140 breaks, respectively. In this system acoustic CCAM and remote sensing SILD technologies were implemented. Additionally, an embedded energy analysis was performed using the Duarte system.

Figure 4: California American Water Duarte System

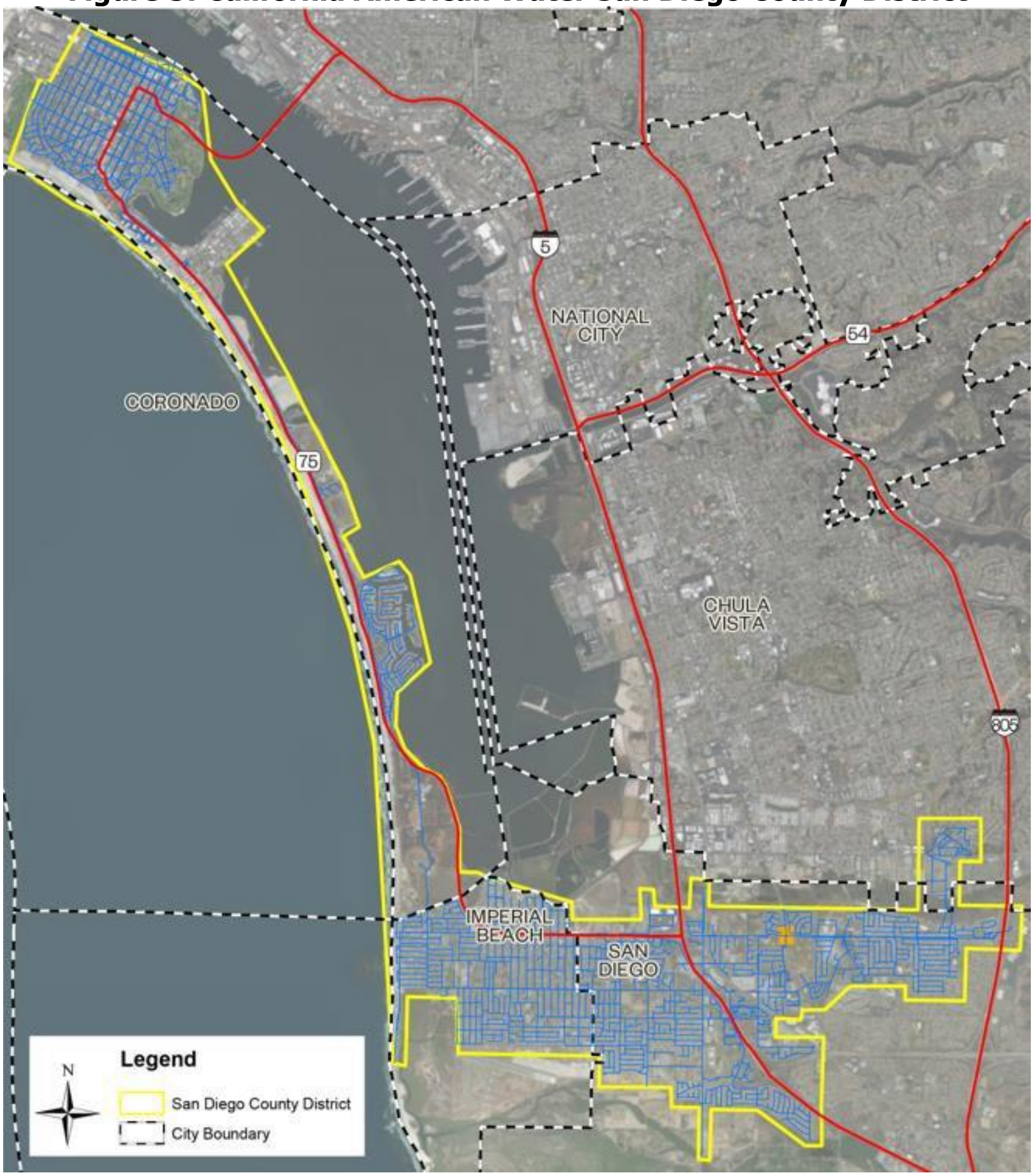


Source: American Water

San Diego County District

San Diego County District encompasses portions of the Cities of Coronado, Imperial Beach, Chula Vista and San Diego (Figure 5). It is also bordered by the North Island Naval Air Station in the north and Mexico in the south. The water system is comprised of 156 miles of mains, which are a mix of metallic, asbestos cement, plastic pipes, and galvanized steel pipes. This system experiences very few pipe breaks. Smart pressure FSPRVs and DMAs were implemented in this system to prevent leak formation.

Figure 5: California American Water San Diego County District



Source: American Water

Table 1 summarizes the technologies and analysis deployed in the three CAW systems in this project.

Table 1: Summary of Technologies Implemented and Where Deployed

CAW System	Acoustic CCAM (Echologics)	Remote SILD (Utilis)	Smart FSPRV (Stream Control)	District Metering	Embedded Energy Analysis
Duarte System	X	X			X
Ventura County District			X	X	
San Diego County District			X	X	

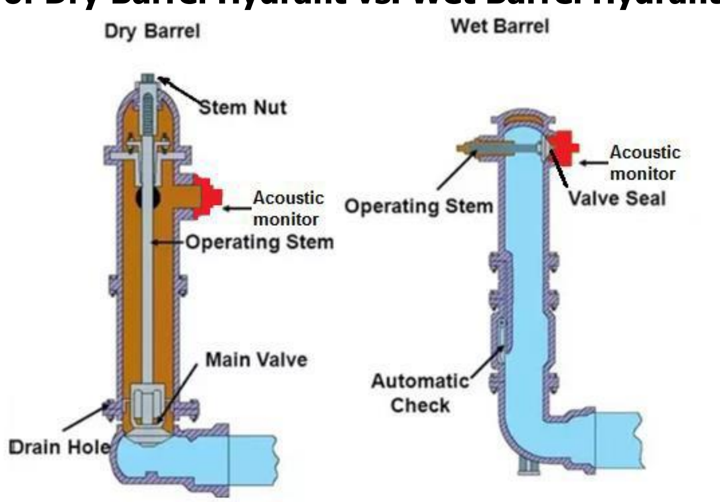
Source: Hazen and Sawyer, American Water

Correlating Continuous Acoustic Monitoring

Technology Summary

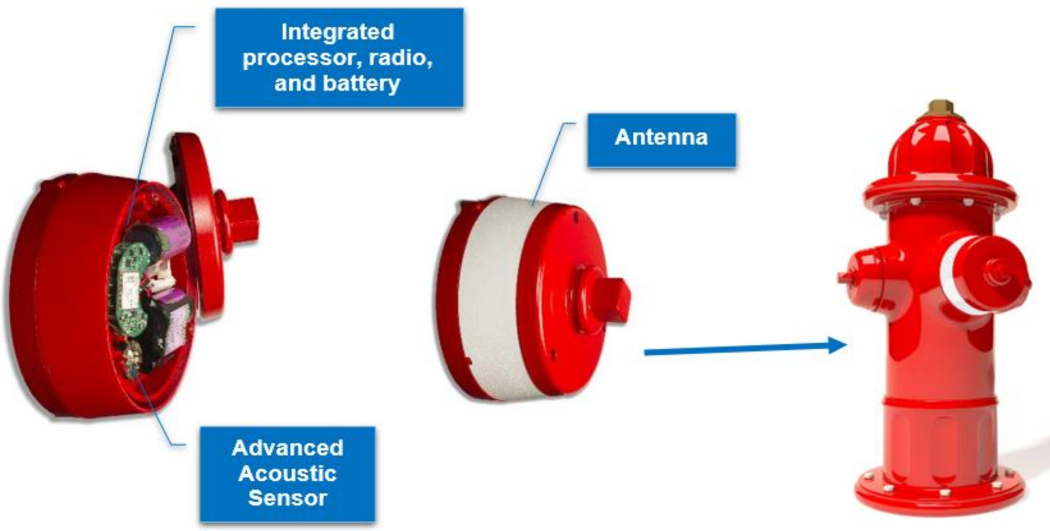
The Echologics CCAM technology used acoustic sensors placed on dry or wet barrel fire hydrants (Figure 6) and generates a daily report containing acoustic data it collects from the hydrant sensors. The acoustic sensors (Figure 7) recorded data between 2 a.m. and 4 a.m. Each device transmits a data package containing sensor health metrics and a sound file for further processing. The host cloud-based software cross-correlates between sensors with an elevated noise spectrum to pinpoint possible leak locations. Echologics analyzed the data generated by the technology to determine if a positive correlation is persistent and thus should be investigated as a point of interest using advanced algorithms not yet implemented into the cloud-based processor. If a point of interest (POI) is detected, the point will be logged and stored. POIs are generated based on readings from the acoustic sensors that may be indicative of a pipeline leak. While large volumes of data were produced from the acoustic monitors, only POIs recommended for field investigations are reported in this document.

Figure 6: Dry Barrel Hydrant vs. Wet Barrel Hydrant Design



Source: Hazen and Sawyer, American Water

Figure 7: Echologics Acoustic Sensors

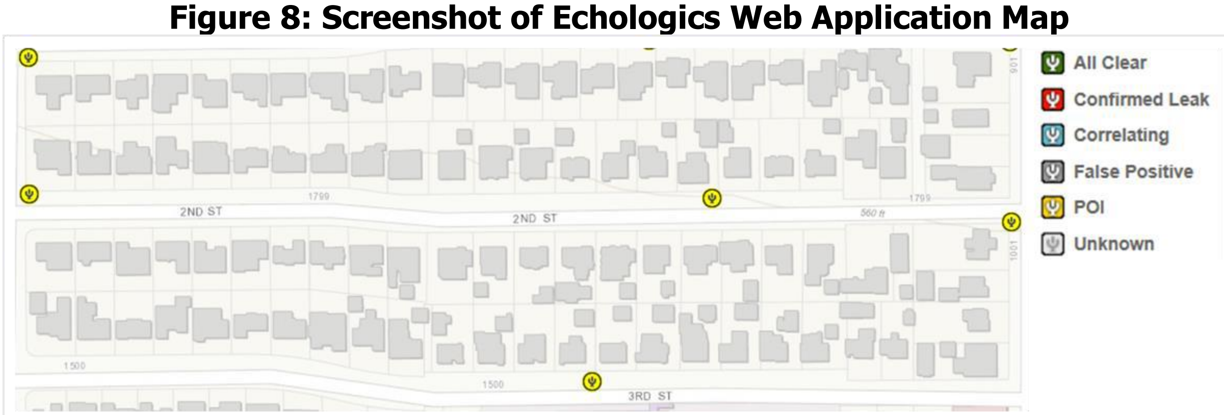


Source: Hazen and Sawyer, American Water

Noise generated from a pipeline leak is different from noise generated from another source, such as a car driving by, or water usage by the customer. Pipeline leak noise is a consistent noise source that can be detected during a time when noise wouldn't normally be expected (such as between 2 a.m. and 4 a.m.). It is consistent and constant across multiple days, whereas other noise like water usage or traffic noise is intermittent. The difference between constant and consistent noise, versus intermittent noise, is how a POI is generated as a potential pipeline leak.

Once a day, the Echologics team reviewed the POI list and manually analyzed the data for repeat locations across multiple days, or POIs with high correlation strength based on their algorithm. Echologics maintains a web application (Figure 8) that can be viewed and used to download applicable data.

Figure 8: Screenshot of Echologics Web Application Map



Source: Hazen and Sawyer, American Water

An online Google document (Figure 9) was maintained with live data of the prioritized list of POIs recommended for investigations due to high correlation strength or repeated findings across multiple days. The intent of such a data management system was that the prioritized list of POIs could then be investigated by field crews on a regular basis, followed by confirmation and repair of leaks before major infrastructure damage or significant water loss could occur.

Figure 9: Screenshot of Echologics Online Google Document with Identified Points of Interest

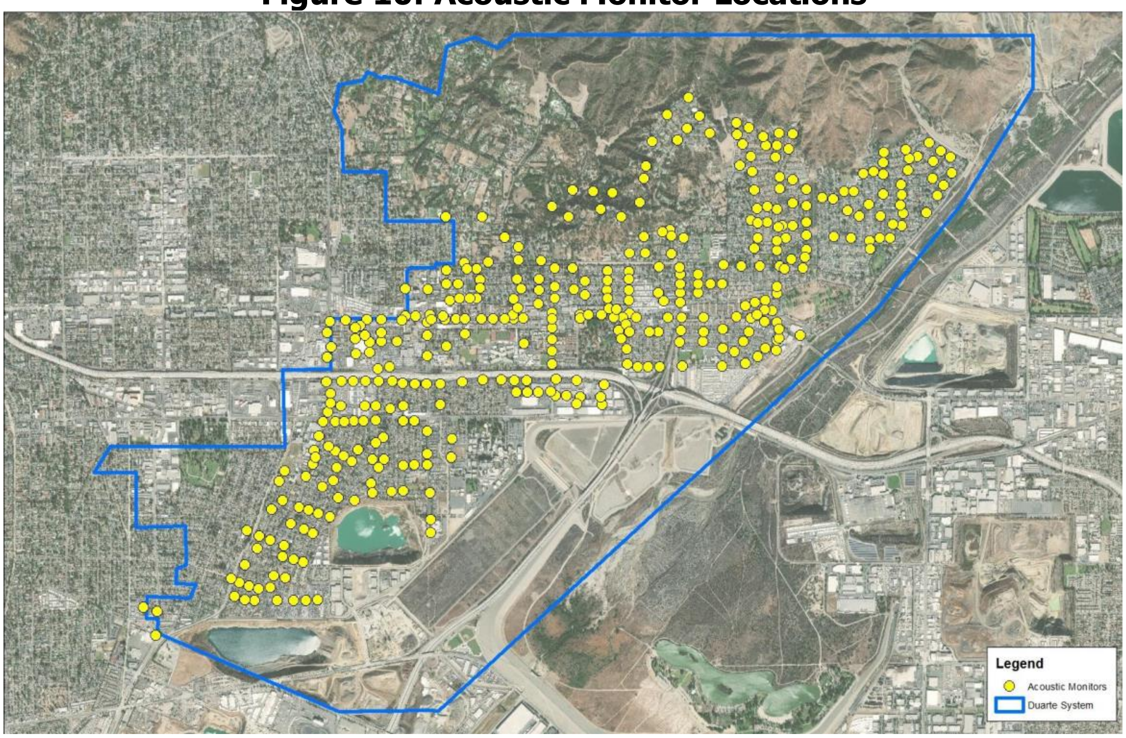
SocketID1	SocketID2	Address	Date	Comments	Record ID	Investigation State
FH2282	FH2277	3161-3199 Fish Canyon Rd, Duarte, CA 91010, USA	2017-09-20	POI	E001	
FH1748	FH1749	1931 Warrington Ave, Duarte, CA 91010, USA	2017-10-03	POI	E002	Leak Located and Repaired
FH1922	FH1851	3218-3224 Tannencrest Dr, Duarte, CA 91010, USA	2017-10-03	POI	E003	
FH1920	FH1919	3323 Shadylawn Dr, Duarte, CA 91010, USA	2017-10-10	uggests a higher frequen	E004	

Source: Hazen and Sawyer, American Water

Demonstration Site

The Echologics CCAM technology was deployed in the Duarte System due to its moderate but increasing historical leak rate. Leaks historically averaged about 60 per year prior to 2015, but increased to 87 in 2016, and 140 in 2017. The system has asbestos cement, PVC and predominantly metallic distribution system piping, and several pressure zones. The CCAM technology is appropriate for metallic piping and was in development for plastic pipe systems at the time of this project. The locations of acoustic monitors located within Duarte are shown in Figure 10.

Figure 10: Acoustic Monitor Locations



Source: Hazen and Sawyer, American Water

Deployment Details

Echologics sensors were deployed on non-plastic pipe starting in April/May 2017 and commissioning began in June/July 2017. Sensors were installed on 383 wet barrel hydrants (Figure 11), throughout the Duarte System and actively generated readings that were analyzed by Echologics. The Echologics standard unit was designed to fit hydrants with 4-inch diameter nozzles. However, there were several nozzle hydrants with 2.5-inch connections where Echologics fabricated custom hydrant caps used to house the sensors. The study occurred from June 2017 to June 2018.

Figure 11: Echologics Sensor on Fire Hydrant

Source: Hazen and Sawyer, American Water

Satellite Imagery Leak Detection

Technology Summary

SILD technology by Utilis uses satellite imagery to detect subsurface leaks. A microwave sensor on board a satellite is used to acquire an image of a specified area. The microwave sensor can take images that cover up to 1,350 square miles. The type of satellite used orbits the earth at 434 miles above the ground surface. This distance allows the satellite to receive images of large areas relatively quickly, as well as taking multiple readings of the same area as often as every two weeks. The Utilis technology uses a satellite called ALOS-2 which carries a synthetic aperture radar (SAR) sensor. The SAR sensor on the ALOS-2 satellite transmits electromagnetic waves which can penetrate the earth's surface to a depth of approximately 10 feet depending on soil conditions. The waves are reflected back towards the satellite and a sensor on-board measures the interaction between the electromagnetic waves and potentially saturated soil.[1]

Utilis employs an algorithm that identifies drinking water below the surface. Drinking water is treated with chemicals like chlorine which has a specific "signature" when in contact with soil that is recognized as a possible subsurface leak by the Utilis algorithm. The technology can sense other sources of water, but the analysis process and algorithm allow the differentiation from drinking water to other types of water. Utilis also employs multiple factors in their

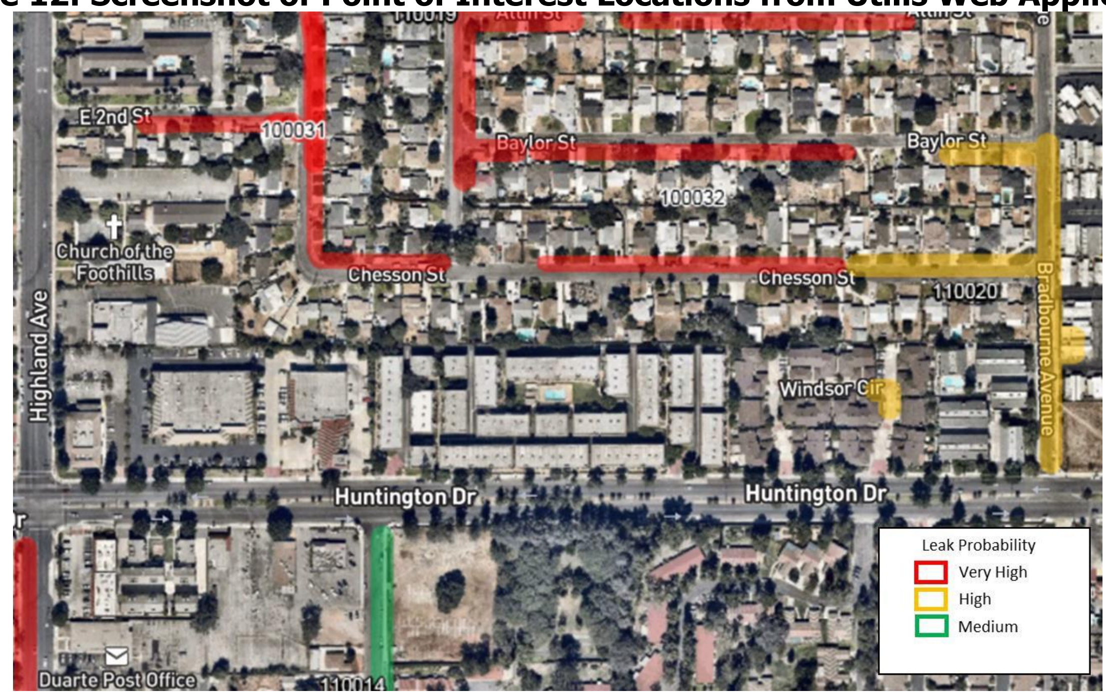
[1] Hoober, D., & Gondor, D. (2018). Using Satellites to Detect Leakage and Reduce Non-Revenue Water in the 21st Century. Presentation, Webinar.

analysis to locate potential leaks of varying probability levels, including a study of the distribution system including layout and configuration of pressure zones, pipe material distribution across the system, and installation year. Utilis also analyzes the area's previous leak history, and recent field investigation findings.

Utilis generates POIs for field investigations. A Utilis POI is based on a 265-foot radius circle and can either be shown as a circle or a group of highlighted distribution system pipes that fall within that circle. A set of POIs are delivered for every satellite image (flyover) that is analyzed. Utilis recommends conducting multiple flyovers on a periodic basis (monthly, quarterly, biannual, and so on) based on the complexity and size of the system. Multiple flyovers allow the Utilis team to become more familiar with a distribution system, and to increase probability of leak finds based on comparison of results to field leak investigations.

Utilis maintains a web application where their data and findings can be viewed, accessed, and downloaded as shown in Figure 12. They also provide compiled reports summarizing their work efforts and findings.

Figure 12: Screenshot of Point of Interest Locations from Utilis Web Application



Source: Hazen and Sawyer, American Water

Demonstration Site

The SILD technology by Utilis was used in the Duarte System due to a moderate but increasing historical leak rate, and as an opportunity to directly compare the SILD technology with Echologics' CCAM within the same area.

Deployment Details

Since SILD technology does not require installation of equipment within the system, deployment of the technology is relatively quick. Utilis requires a GIS shapefile of the area of interest, such as the system boundary, as well as a shapefile of the pipe distribution network. Once those items are provided to Utilis, they will initiate the process of acquiring a satellite image and conducting the analysis. For this project, the duration of time between initially providing the GIS data and receipt of findings and recommended POIs for field investigation from Utilis was approximately one month. The period for the study was from June 2017 to June 2018, to the same as the CCAM study. A total of 504 POIs were provided by Utilis for the Duarte system during this period (average 42 per month).

Flow Sensitive Pressure Reducing Valves

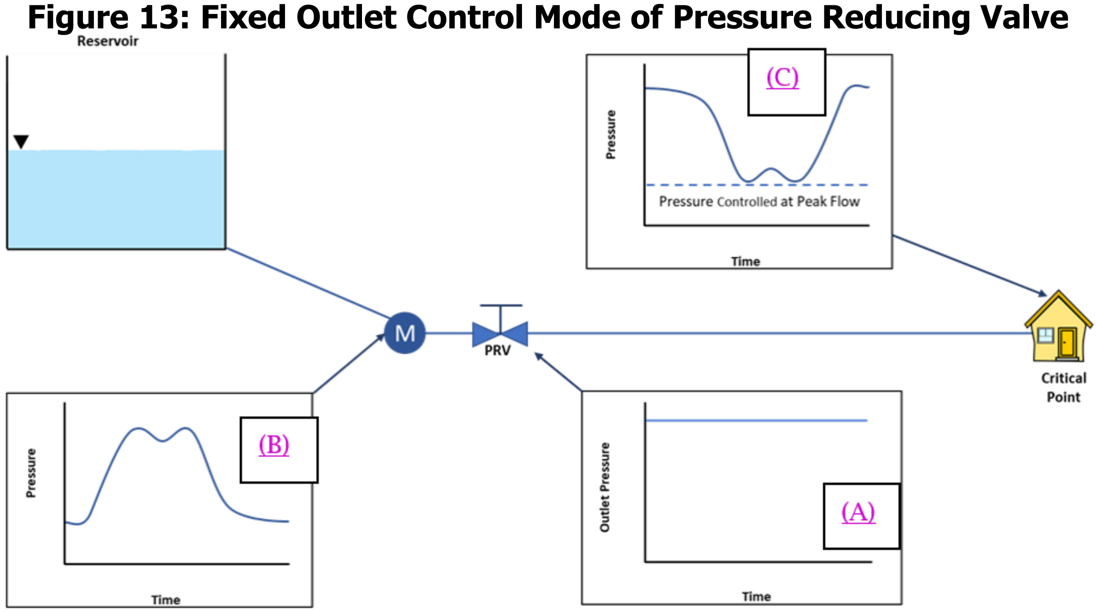
Technology Summary

Pressure management is one of multiple strategies for leakage control for water utilities. Within the category of pressure management, there are specific methods including utilizing pump controls, pressure zones, and pressure reducing valves (PRVs). Within the category of PRVs, there are sub-categories including fixed outlet control, time-based modulation, remote node control, and flow-based dynamic modulation. Flow-based dynamic modulation of PRVs – or flow sensitive pressure reducing valves (FSPRVs) was the strategy in this project.

Fixed outlet control of PRVs is more commonly used in water systems as opposed to FSPRVs. The difference between fixed outlet control of PRVs and FSPRVs can be understood using two graphics from AWWA M36 as shown in Figure 13 and Figure 14 illustrates FSPRVs. FSPRVs vary the downstream pressure at the PRV (A), based on system demands into the service area (B), measured by a flow meter. The pressure settings are modulated to provide a minimum pressure throughout all system demand conditions at the critical point in the service area (C), or also to allow lower pressures in the system when demands are lowest, such as the middle of the night for residential areas. For example, a typical diurnal curve is shown in Figure 15. The areas shaded represent the lower demand periods when the downstream pressure setting at PRVs can be reduced and still provide sufficient service to the critical point in the system.

Figure 14.

Figure 13: Fixed Outlet Control Mode of Pressure Reducing Valve

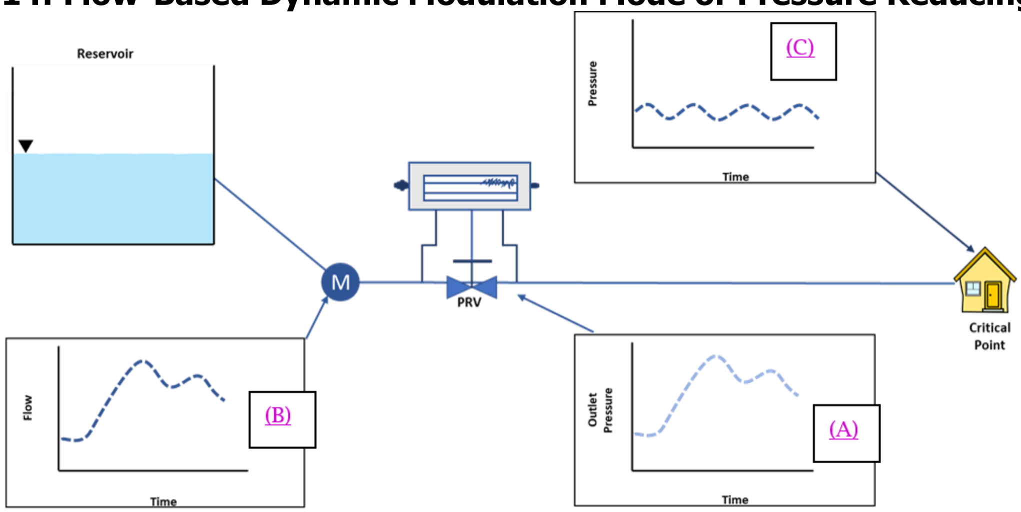


Source: Adapted from Water Audits and Loss Control Programs, 4th Ed. (M36) by G. A. Kunkel, Jr., 2016, Denver: American Water Works Association. Copyright 2016 by the American Water Works Association.

Fixed outlet control of PRVs sets a constant downstream pressure at the PRV (A), regardless of upstream conditions (B). The pressure setting is typically set to provide the desired or minimum pressure during peak flows at the critical point in the service area (C), which could either be the highest elevation point or furthest point from the PRV. The constant downstream pressure at the PRV, results in varying pressure at the critical point depending on system demands, with higher pressures seen when system demands are low, and lower pressures seen when system demands are high. Pressures can vary greatly depending on the hydraulic characteristics of the PRV service area.

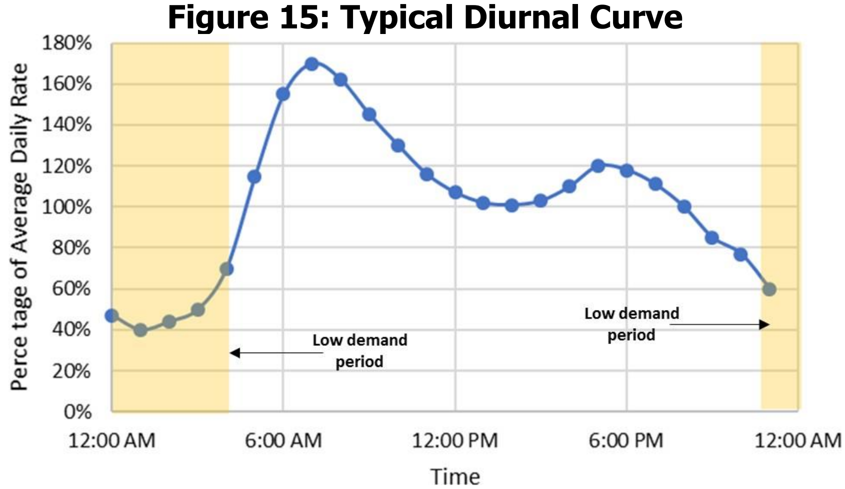
Figure 14 illustrates FSPRVs. FSPRVs vary the downstream pressure at the PRV (A), based on system *demands* into the service area (B), measured by a flow meter. The pressure settings are modulated to provide a minimum pressure throughout all system demand conditions at the critical point in the service area (C), or also to allow lower pressures in the system when demands are lowest, such as the middle of the night for residential areas. For example, a typical diurnal curve is shown in Figure 15. The areas shaded represent the lower demand periods when the downstream pressure setting at PRVs can be reduced and still provide sufficient service to the critical point in the system.

Figure 14: Flow-Based Dynamic Modulation Mode of Pressure Reducing Valve



Source: Adapted from Water Audits and Loss Control Programs, 4th Ed. (M36) by G. A. Kunkel, Jr., 2016, Denver: American Water Works Association. Copyright 2016 by the American Water Works Association.

Figure 15: Typical Diurnal Curve



Source: Hazen and Sawyer, American Water

The FSPRV technology employed as part of this project the Aqua-Guard (AG) system by Stream Control. Compared to products by Echologics and Utilis, the AG system is a relatively new product with few deployments within the U.S. Whereas Echologics and Utilis have established products, case studies, and documentation, there is relatively little documentation related to the AG system. One of the purposes of this report is to provide details of the technology, product, and deployment to assist future users and applications.

The AG system integrates with the hydraulic pilot pressure control of PRVs and based on adjustable settings, can modify the downstream pressure based on different flow rates. Typical settings include "steps" or "corridors" that have an associated pressure setting with an associated flow range. The AG system is typically set to reduce the downstream pressure setting during low demand periods (nighttime) to reduce the stress on the pipe. Typical downstream pressure reduction can be as little as 5 psi to up to 20 psi or more depending on the system characteristics.

The requirements of CPUC General Order 103-A must be considered when making the AG system settings. For example, the AG system settings must ensure minimum pressures meet the average 40 psi requirement throughout the day, and 30 psi requirement during peak hour demands. A typical example of how the AG system settings would be configured is shown in Table 2.

Table 2: Flow Sensitive Pressure Reducing Valves Example Settings

Flow Condition	PRV Setting Without AG System	PRV Setting With AG System
Flow ≤ 60 GPM	70 psi	60 psi
Flow > 60 GPM	70 psi	70 psi

Source: Hazen and Sawyer, American Water

Table 2 provides an example of how a typical fixed-outlet control PRV would be modified with the use of the AG system. The example is based on the actual settings employed at the Beyer PRV in the San Diego County District. Typical flows range from 20 gpm to 180 gpm. The flows drop below 60 gpm starting around midnight and stay below 60 gpm until around 5:00 am when flows increase steadily up to the 180 gpm range. The AG system was set to reduce the downstream pressure by 10 psi during the low demand period from midnight to 5:00 am, avoiding nighttime pressure spikes previously depicted.

A 4-20 milliamp signal from the upstream flow meter is transmitted to the FSPRV controller and reveals when a low flow scenario initiates a control override of the PRV pilot system. The same flow meter indicates when a higher demand scenario occurs, placing the hydraulic pilot control back into the higher default pressure setting.

Nighttime distribution system pressures are typically higher than daytime pressures due to less demand in the system and less pressure loss through the system.

Pipe breaks for municipalities often occur at night due to this condition; therefore, using a flow sensitive PRV to decrease the pressure set point could have an impact on water loss due to pipe breaks by reducing the stress on the pipe.

One potential disadvantage of the AG unit is that it requires a small power source to operate. The power source charges a battery that then powers the AG unit motor which modulates the

PRV setting, as well as downloads and transmits data points associated with the operation of the AG unit. Options for powering the AG unit include a power supply from the local utility, solar power, turbine, or generator power. A turbine generator with the flow and differential pressure was used to generate the power source for the AG unit.

The AG unit operates automatically but can be monitored through an independent cloud-based data monitoring system. The AG unit uses a SIM card with ftp protocol data transmission. A small antenna (less than 6”) is connected to the unit and is placed in a location where a signal can be sent and received. For the San Diego County District, the antenna was placed within the vault. The data collected includes flow, upstream pressure, and downstream pressure. It should be noted that the data transmission component is only used for data collection and monitoring, but control and settings adjustments cannot be made remotely.

Demonstration Sites

There were three demonstration sites for the FSPRV units: one site in the San Diego County District, and two sites in the Ventura County District. The site in the San Diego District is called the Beyer PRV which serves the Beyer pressure zone. The two sites in Ventura are PRVs that serve the same Dos Vientos PRV zone. The two PRV sites serving the Dos Vientos PRV zone are called the Del Prado PRV and the Via Estrella PRV.

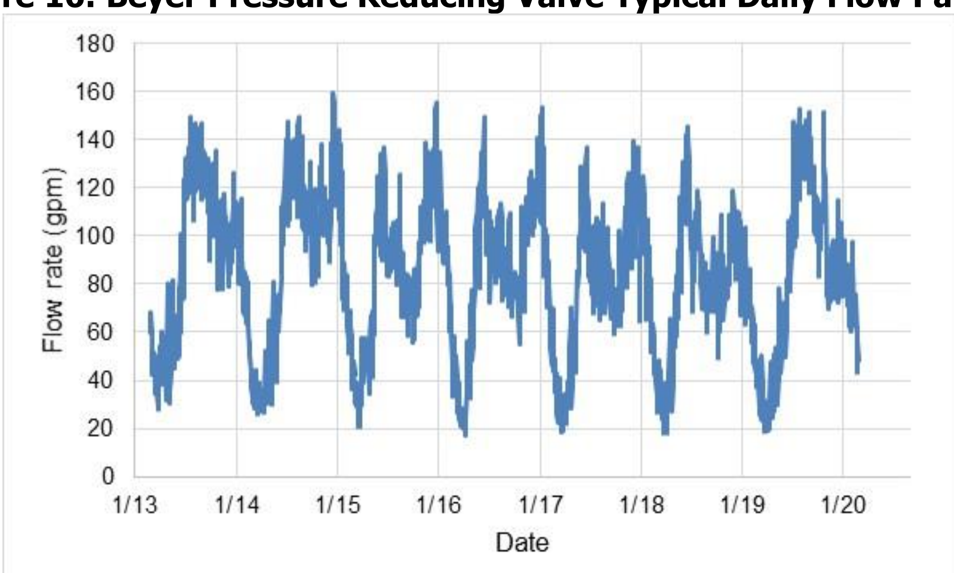
San Diego County District – Beyer Pressure Reducing Valves

One AG unit was installed at the Beyer PRV, located within CAW’s San Diego County District. The Beyer PRV serves the Beyer pressure zone and acts as the sole supply point into the closed zone. The primary land use of the zone is single-family residential.

Typical flows into the zone range from 20 gpm to 180 gpm and they follow the typical residential diurnal curve.

Figure 16 shows a typical daily flow pattern into the Beyer PRV zone, and Figure 17 shows key characteristics of the zone.

Figure 16: Beyer Pressure Reducing Valve Typical Daily Flow Pattern



Source: Hazen and Sawyer, American Water

Figure 17: Beyer Pressure Reducing Valve Zone

Source: Hazen and Sawyer, American Water

Ventura County District – Del Prado and Via Estrella Pressure Reducing Valves

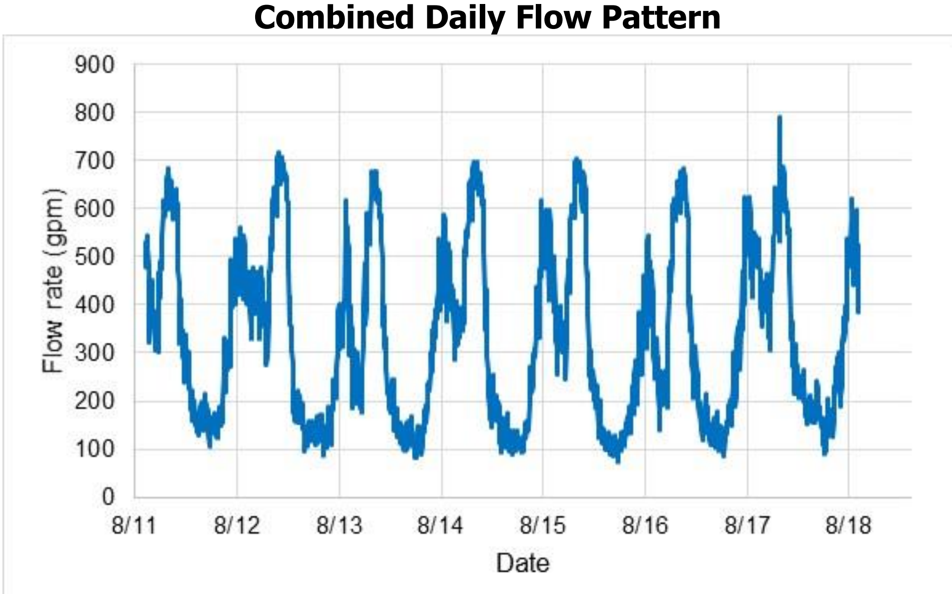
The two locations in Ventura are the Del Prado PRV and the Via Estrella PRV. The two PRVs, along with another PRV supply the Dos Vientos PRV zone. The primary land use of the zone is single-family residential, but also includes a park and a school. Typical flows into the zone range from 100 gpm to 700 gpm and they follow a repeatable diurnal curve.

Figure 18 shows key characteristics of the Dos Vientos PRV zone including the locations of each PRV, and Figure 19 shows a typical daily flow pattern into the zone.

Figure 18: Del Prado and Via Estrella Pressure Reducing Valve Zone

Source: Hazen and Sawyer, American Water

Figure 19: Del Prado and Via Estrella Pressure Reducing Valve Combined Daily Flow Pattern



Source: Hazen and Sawyer, American Water

Deployment Details

Using the AG units require a flow meter, a power supply, and space with access for the AG unit and associated components. Additional considerations include a way to transmit the data, which is recommended, but not required. Details for each of the required components and deployment of the AG units are described in the following sections. The AG unit was originally installed in May 2018 and monitored through October 2018.

Flow Meter

The AG unit functions by modulating the downstream pressure based on flow. Therefore, a flow meter is required adjacent to the AG unit installation. The flow meter must be capable of providing a dry contact that provides the flow signal as a pulse output to be recognized by the AG unit. Flow meters are typically provided with variable settings: one pulse per one gallon, one pulse per 10 gallons, one pulse per 100 gallons, and so on. The pulse output setting should be such that it is not sending a pulse more often than one per second because it would be too fast to be recognized by the AG unit. For example, flow rates through the Beyer PRV ranged from 20 to 160 gpm, and the flow meter was set to one pulse per 10 gallons.

For this project, a propeller flow meter was used - Sensus Omni T2 (Figure 20). Possible flow meter types could include electromagnetic flow meters, or insertion magnetic flow meters.

Figure 20: Flow Meter at Del Prado Pressure Reducing Valve in Ventura County District

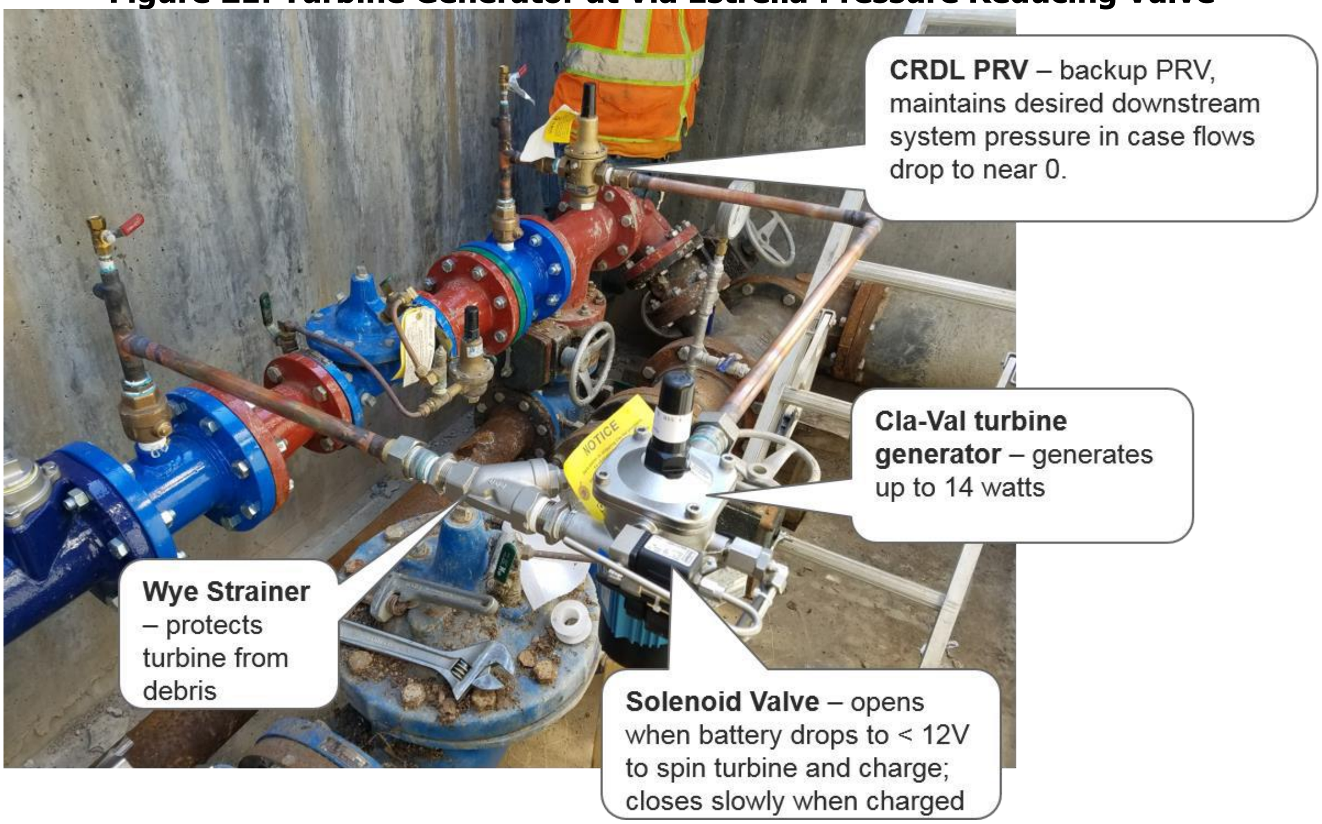
Source: Hazen and Sawyer, American Water

Power Supply

The AG unit requires a small power supply to continually charge a battery used to modulate the PRV setting, save the data and transmit the data via file transfer protocol (FTP). Power supply options include the local utility service provider, solar power, or a Pico (mini) hydro-turbine generator. Each of the three locations for this project did not have a power supply from the local utility within the existing PRV vault. As a result, an alternative power source was used. A turbine generator was chosen as the power supply. The product used was Cla-Val X143IP Intermediate Power Generator which can produce up to 14 watts of continuous power with a minimum 15 gpm flow and 12 psi differential pressure. The turbine generator was installed at each location to provide power for the AG system. On the piping branch with the turbine generator is a Cla-Val CRDL PRV. This PRV maintains the required downstream pressure in the system if flows through the station are less than 15 gpm, in which case all flow would be going through the turbine generator pipe branch and the regular station PRVs would be bypassed.

However, flow data throughout the use showed flows never dropped below this level.

Figure 21: Turbine Generator at Via Estrella Pressure Reducing Valve



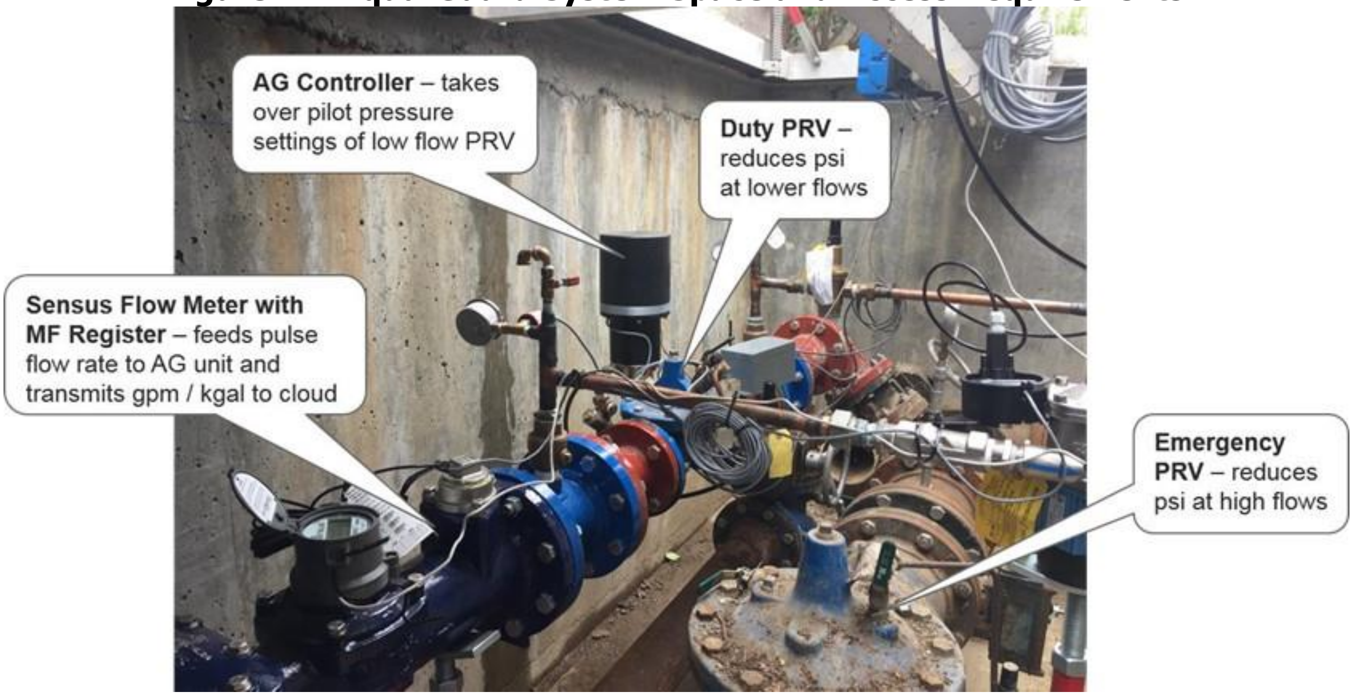
Source: Hazen and Sawyer, American Water

Space and Access Requirements

Sufficient space and access are required to install the AG system and the associated components at a PRV. A propeller flow meter has the largest space requirement on the upstream pipe. The flow meter must be located within the vault or building where the PRV is located so it can be hard-wired to the AG unit. The power supply components such as the turbine generator in this project requires piping, isolation valves, and fittings. The AG unit itself is mounted next to the PRV as shown in Figure 22.

Locations where PRVs and piping have very limited additional space are not good candidate locations for AG unit deployments.

Figure 22: Aqua-Guard System Space and Access Requirements

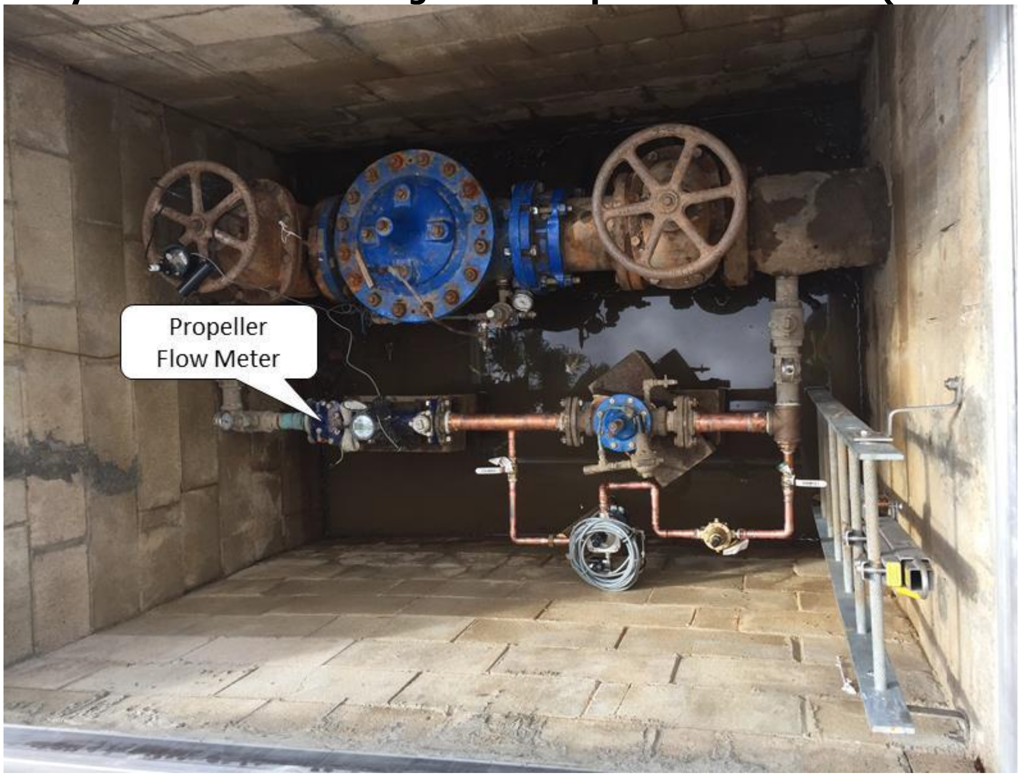


Source: Hazen and Sawyer, American Water

San Diego County District – Beyer Pressure Reducing Valve Deployment

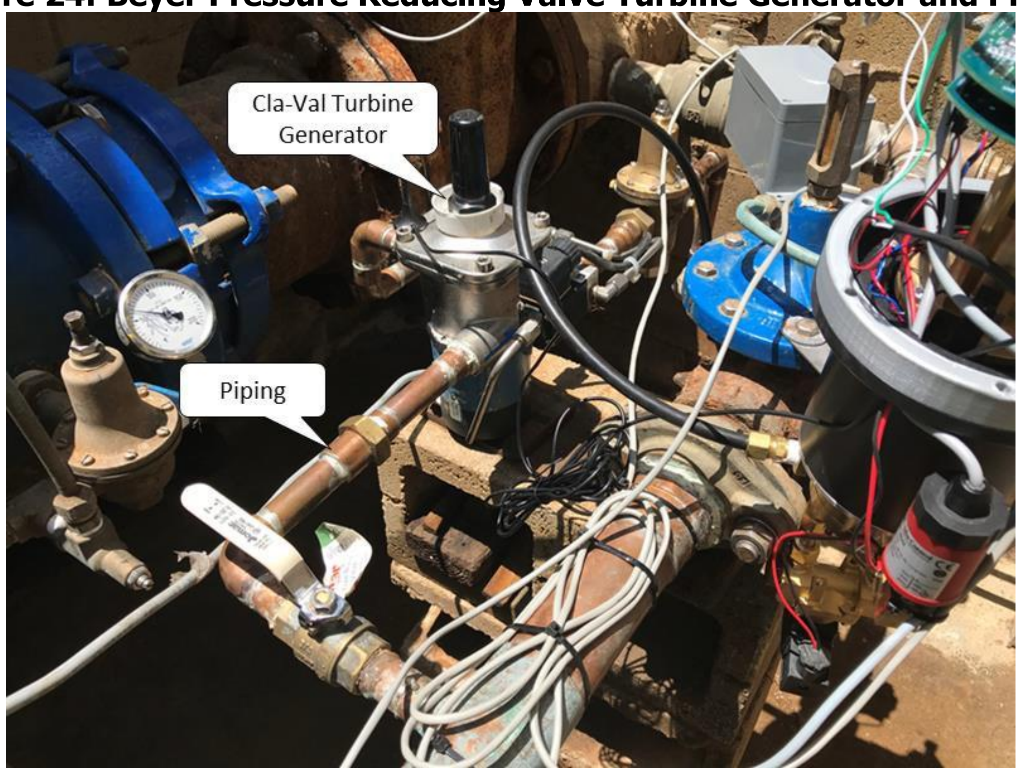
The Beyer PRV deployment occurred in three phases. First, the propeller flow meter (Sensus Omni T2) was installed and enabled with flow transmitting capabilities through a cloud-based system set up by Metron Farnier. Second, the turbine generator and associated piping and valves were installed. Third, the AG unit was installed and started up. Since the AG unit manufacturer was providing the installation and start-up services, it was efficient to ensure the flow meter and power supply were in place prior to the AG unit installation and startup. Pictures from the Beyer PRV AG unit deployment are shown in the subsequent figures.

Figure 23: Beyer Pressure Reducing Valve Propeller Flow Meter (Sensus Omni T2)



Source: Hazen and Sawyer, American Water

Figure 24: Beyer Pressure Reducing Valve Turbine Generator and Piping



Source: Hazen and Sawyer, American Water

Figure 25: Beyer Pressure Reducing Valve Aqua-Guard Controller (Cover Removed)

Source: Hazen and Sawyer, American Water

Ventura County District – Del Prado and Via Estrella Pressure Reducing Valve Deployment

The Del Prado and Via Estrella PRV deployment occurred in two phases. A mechanical contractor was hired to install the propeller flow meters and the turbine generator and associated piping and valves. After the first phase was completed, the AG unit was installed and started up at each PRV (Figures 26 and 27). Since both PRVs serve the same pressure zone, the settings for each PRV had to be set to make one PRV the primary PRV where all regular demands were supplied, and the other PRV as a backup that only opened during very high demands within the zone. The details for this arrangement are further discussed in Chapter 2.

Figure 26: Del Prado Pressure Reducing Valve Turbine Generator

Source: Hazen and Sawyer, American Water

Figure 27: Del Prado Pressure Reducing Valve Aqua-Guard System

Source: Hazen and Sawyer, American Water

Startup

Once the AG units were installed, start-up included:

- Optimizing AG unit settings, including upper and lower flow bands and corresponding pressure settings
- Ensuring adequate operation and sufficient flow through the turbine generator
- Monitoring data transmission component
- Monitoring system pressures through low and high demand periods

The total duration of the AG unit installation and startup typically took 2-3 days. The first portion was spent installing and ensuring all components are working properly (about 1 day). The second portion was spent monitoring the operation of the unit and the system to ensure proper settings, adequate pressures in the system, and data transmission is functioning properly (1-2 days). Additional time would be required in cases where the flow meter and power supply (generator or another source) were not already in place.

District Metered Areas

Technology Summary

A traditional approach to reducing leakage in a water distribution system is the creation of district metered areas (DMAs). DMAs help to identify, define, and manage water loss within a distribution system. A DMA is a hydraulically discrete part of a water distribution system, with water supplied by one or more open supply mains that are metered and closely monitored on a permanent basis[2]. The goal is to analyze flows during minimum consumption periods (night flow) and distinguish legitimate consumption from leakage occurring within the DMA. When there's a discrepancy, leak detection activities are undertaken to find these leaks and quickly repair them. The use of DMAs allows for a more accurate localization of leakage within the water distribution system by allowing the agency to focus on smaller areas.

Demonstration Site

DMAs are typically smaller areas with repeatable flow patterns that are often created by closing valves or by providing other means of isolation from the rest of the system.

Isolation is often a challenge when creating DMAs as it can constrict a pipe network.

Criteria for choosing DMA demonstration sites require that the DMA must not alter the pressure zone boundaries or create sub-pressure zones. The goal was to identify demonstration sites where a DMA could be created by metering a point in the system that was not previously metered.

For this project, candidate locations included unmetered PRVs and pump station discharges, particularly where construction of new vaults or structures would not be required to house the new flow meter. A total of five demonstration sites were created as part of this project – four in Ventura, and one in San Diego. Two flow meter sites in Ventura served the same zone so the five flow meter sites created four DMAs.

[2] Kunkel, G. A. (2016). *M36 Water audits and loss control programs (4th ed.).* Denver: American Water Works Association, p.382

Three of the flow meter sites were located at the FSPRV technology sites – the Beyer PRV in the San Diego County District, and the Del Prado and Via Estrella PRV sites in the Ventura County District. As described previously, the Del Prado and Via Estrella sites serve the same zone, thus comprising one DMA. Two additional locations in Ventura are described below – the Dos Vientos Booster Station (DVBS) and the Dos Vientos Zone 3 Booster Station (DV3BS).

Ventura County District

In addition to the Del Prado and Via Estrella PRVs, two additional DMAs were analyzed in the Ventura County District by installing flow meters at the DVBS and the DV3BS.

DVBS is situated near the homes along Camino De La Rosa in Thousand Oaks, California, in the Ventura County District. The booster station can only be accessed through a gated pathway at the end of Mountain Creek Drive. DVBS pumps from the Potrero Reservoir in the Main Gradient to the Dos Vientos 2A and 2B tanks. DVBS was chosen as a location to install a flow meter because it did not have an existing flow meter and there was adequate space on the discharge piping.

DV3BS is located off Via El Cerro in Thousand Oaks, California, in the Ventura County District, near Dos Vientos Zone 3 tank. It pumps from Dos Vientos 2A and 2B tanks into Dos Vientos Zone 3 tank. DV3BS was chosen as a location to install a flow meter because it did not have an existing flow meter and there was adequate space on the discharge piping. Figure 28 shows the location of DVBS and DV3BS.

Figure 28: Dos Vientos Booster Station and Dos Vientos Zone 3 Booster Station Locations

Source: Hazen and Sawyer, American Water

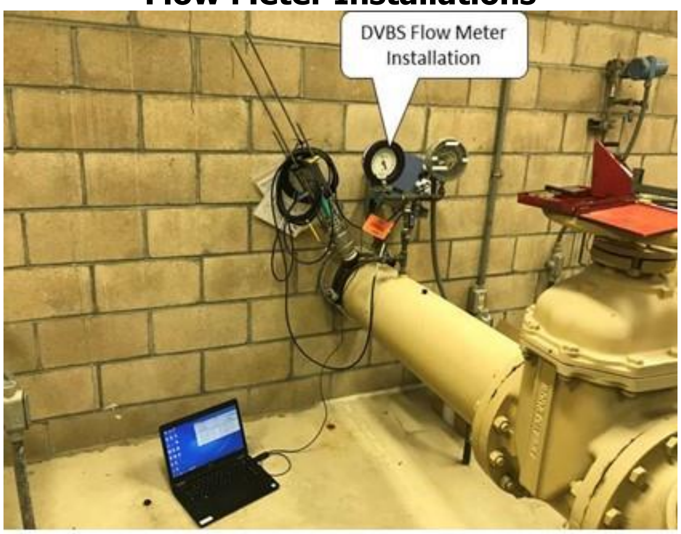
Deployment Details

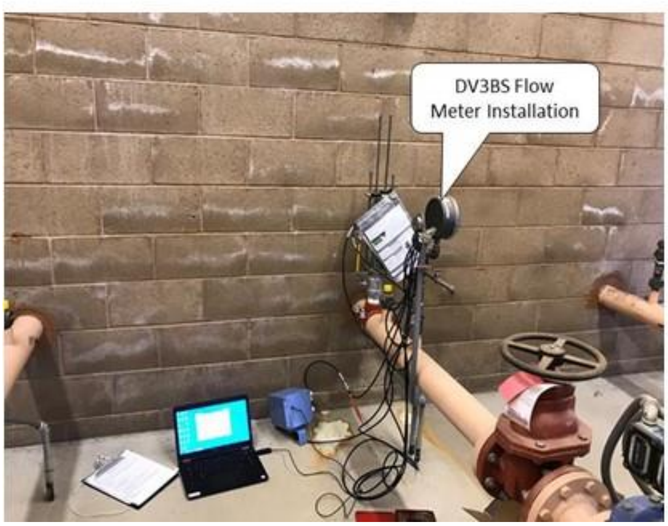
A contractor was hired to install the flow meter on the discharge pipe of one of the pumps at both the DVBS and DV3BS. The flow meter manufacturer was onsite the same day with the flow meters to install and complete the startup. The pump with the flow meter was programmed as the primary/lead pump at each booster station so that flow would be measured as much as possible.

The flow meters used were insertion electromagnetic flow meters by McCrometer – Model 395L. Each flow meter included the datalogger and software that could be downloaded to a laptop. Pictures of each flow meter installation are included in Figure 29.

For data acquisition, McCrometer provides a software to be downloaded onto a field laptop, along with a cable to connect to the datalogger at each flow meter location. Flow data is manually downloaded during periodic visits using the software and then the data can be monitored and analyzed as needed. The DMAs in this project were studied from May 2017 to October 2018.

Figure 29: Dos Vientos Booster Station and Dos Vientos Zone 3 Booster Station Flow Meter Installations





Source: Hazen and Sawyer, American Water

CHAPTER 2: Technology Monitoring and Response

Introduction

Chapter 1 provided details on the technology. Chapter 2 discusses next steps after use. For the acoustic CCAM and remote sensing SILD technologies, next steps included beginning the leak detection process for each technology, including leak investigations, review of false positives, and ultimately leak repairs. For the pressure managing FSPRVs and non-revenue water tracking DMAs, next steps included monitoring the technology, monitoring the data, and implementing adjustments to the technology if necessary.

While enormous volumes of data were produced as part of this study, the technology providers handled the processing and reporting of data as "points of interest." A full discussion of the processing of data is beyond the scope of this project and in most cases uses proprietary algorithms. As such, data discussion is limited to what would be reported to utilities from each of the technology providers and what data were available from the participating utility locations.

Correlating Continuous Acoustic Monitoring

Duarte System

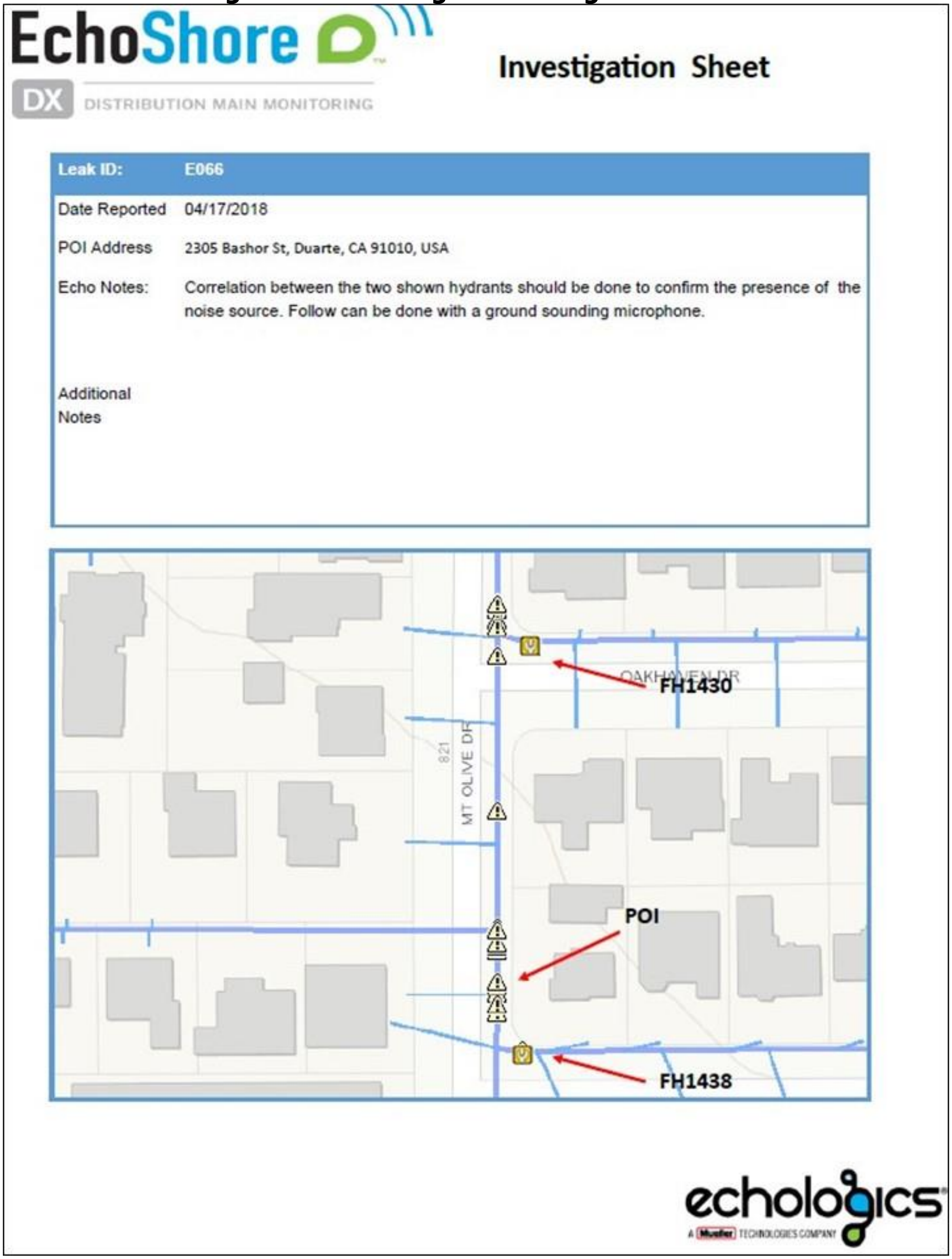
Leak Detection

Echologics technology generated a daily report with points of interest (POIs), which were analyzed by the Echologics team and sorted into a prioritized list recommended for investigations. The Echologics web application shows all POIs, but the locations recommended for investigation were shown on an online Google document. Echologics recommended that the leak investigation team only focus on the prioritized locations on the Google document.

Echologics would alert the leak investigation team whenever POIs were recommended for field investigation. In addition, Echologics would provide leak sheets (Figure 30) which showed the exact location of the POI and the hydrants that were to be used for correlation (leak pinpointing). The prioritized list, along with the leak sheets, were then used to conduct leak investigations.

From July 2017 to June 2018, Echologics identified POIs daily, with a total of 77 POIs recommended for investigation. POIs for investigations needed to show a repeatable, consistent, and atypical noise pattern. For example, on a residential street in the middle of the night, the sensors may pick up intermittent noise from a car driving by, but that is not characteristic of a pipe leak. In comparison, pipe leak noise would be a constant noise received by the sensor during a time when a constant noise would not be expected. Only these qualifying results were recommended for further investigation by Echologics.

Figure 30: Echologics Investigation Sheet


EchoShore DX DISTRIBUTION MAIN MONITORING

Investigation Sheet

Leak ID:	E066
Date Reported	04/17/2018
POI Address	2305 Bashor St, Duarte, CA 91010, USA
Echo Notes:	Correlation between the two shown hydrants should be done to confirm the presence of the noise source. Follow can be done with a ground sounding microphone.
Additional Notes	

Source: Hazen and Sawyer, American Water

Leak Investigations

After leaks were detected by the technology, on-site leak investigations were done by a leak detection team to pinpoint the leak and identify the area to be excavated for repair.

A typical leak investigation team consists of a 2-person crew equipped with a laptop computer and leak correlation equipment (Figure 31) including sensors, receivers/transmitters, ground microphone, "listening rod" or microphone with a long handle, and head phones. This equipment can be purchased from companies including Echologics, FCS, and Sewerin.

Figure 31: Leak Locating Equipment

Source: Hazen and Sawyer, American Water

Properly training a leak investigation crew on how to use the leak correlation equipment and leak pinpointing best practices is an important component of leak investigations (Figure 32). A typical training course consists of classroom and field training and usually taking three days. Training can be provided by the leak correlation equipment manufacturers or by third-party training services.

Figure 32: Leak Correlation Training

Source: Hazen and Sawyer, American Water

The Echologics leak sheets show the location of each POI, including the subject pipeline if there are multiple pipelines in the same street. The correlation equipment includes sensors that are placed on hydrants or valves on either side of the POI and correlation software is used to pinpoint the precise location of the leak noise as a distance from one of the sensors (Figure 33). A ground measuring wheel is used to find the distance in the field and mark the spot of the leak (Figure 34). Once the leak is marked, an area is spray-painted to call in a DigAlert notification for the leak repair investigation.

Figure 33: Field Leak Investigations Using Correlation Software

Source: Hazen and Sawyer, American Water

Figure 34: Leak Pinpointing Investigation

Source: Hazen and Sawyer, American Water

Data was collected in the field on forms documenting the correlation process and key information, including the precise location of the leak. These forms were filled out and information was entered into a database.

The total time to investigate a POI and either pinpoint the leak or conclude it is a false positive typically takes a 2-person crew about 1 to 3 labor-hours or 0.5 to 1.5 labor-hours per person. Echologics directed the team to only correlate based on the POI location shown on the leak sheet. If there was no leak found at that location, then it was considered a false positive and the team moved on to the next POI. Limiting the investigation to this small area allowed the leak investigations to proceed relatively quickly. Additionally, Echologics providing the leak sheets that showed exactly where to correlate between was an improvement to their data deliveries which reduced the leak investigation time per POI.

Leak Repairs

When the leak investigation team completed their investigation and was able to pinpoint a leak, the area boundary was spray-painted, and a DigAlert notification was issued.

Depending on the availability of CAW operations staff, leaks were either excavated and repaired by CAW staff, or an on-call contractor was used. If the leak was estimated to be a substantial mainline leak, an on-call contractor was usually brought in. Main line leaks were repaired with clamps or partial pipe replacement. For service line leaks, the broken portion was replaced. For leaks at the service connection to the main, which according to operations staff tend be the most common type of leak, a new service line connection was installed to the main and reconnected to the existing service line. Figures 35, 36 and 37 show the leak repairs.

Figure 35: Service Line Leak

Source: Hazen and Sawyer, American Water

Figure 36: Distribution Pipe Leak Repair

Source: Hazen and Sawyer, American Water

Figure 37: Contractor Fixing a Leak

Source: Hazen and Sawyer, American Water

False Positives

A POI was identified as a false positive if it was recommended for investigation, and no leak was found. Readings gathered by the Echologics sensors can be the result of noise caused by a leak or noise from the surrounding conditions that propagates into the pipeline and is picked up by the sensors. Echologics protocol for recommending investigations required the noise to be consistent and atypical from the usual readings across a multiple-day period. For example, a one-time noise reading on a sensor is not enough evidence to recommend a field investigation, but when the same readings show up for 3 to 4 nights in a row, that is characteristic of a potential leak and an investigation is recommended.

False positives can occur for several reasons. One type of false positive observed from the Echologics findings was electrical interference. When conducting leak pinpointing, electrical equipment such as overhead power lines and transformers can emit an audible "humm" that can be interpreted as a leak.

Another type of false positive was a result of system facilities such as pressure reducing valves, pump stations, or throttled valves. These facilities cause noise in a water system that is then recorded by the sensors.

False positives were also created by noise from buildings and residences that was recorded by the sensors. Large motor-driven equipment at industrial sites were also picked up by sensors.

Noise recordings were only taken between 2 am and 4 am when other ambient noise should be at a minimum, however, noise sources such as electrical interference, water system facilities, industrial sites, and other private noise sources can be picked up by the Echologics sensors and generate a false positive. Depending on location-specific objectives and/or constraints, additional recordings can be made outside of the 2 am – 4 am time frame to further evaluate noise consistency.

Finally, false positives can also occur because a leak simply could not be located in the field for various reasons. This would be considered the "human element," and is consistent in any technology deployment.

For this project, there were a total of 49 Echologics POIs investigated. Of the total 49 POIs, 20 leaks were found, and 29 POIs were false positives. Echologics results are further discussed in Chapter 3.

Satellite Imagery Leak Detection

Duarte System

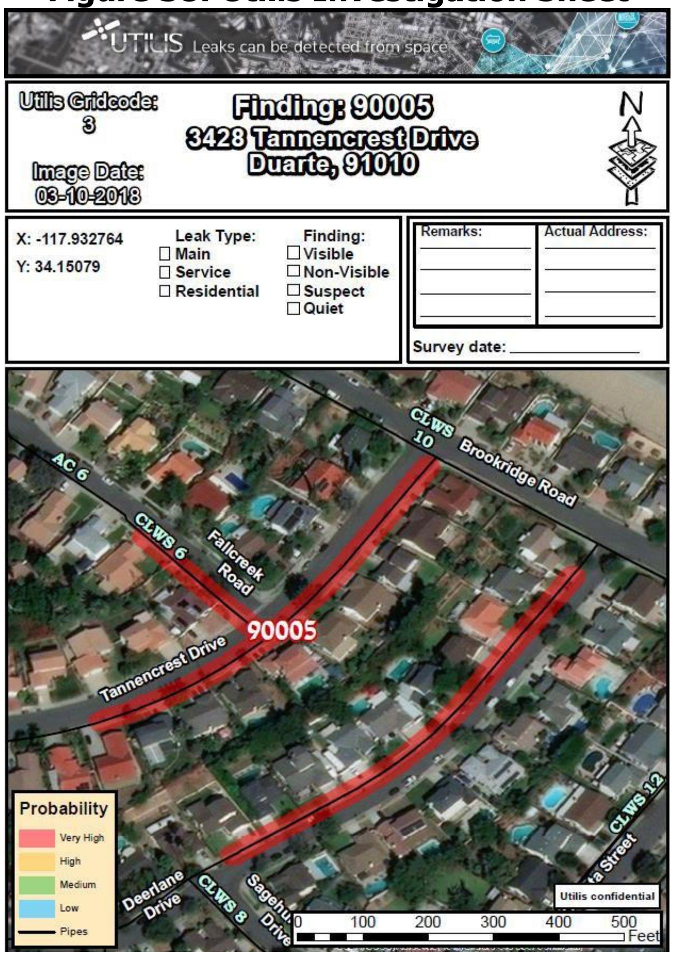
Leak Detection

Utilis conducted a total of 12 monthly flyovers from May 2017 to June 2018. After each flyover, the data was collected and analyzed by the Utilis team. The result of their analysis yielded approximately 40 POIs per month, with each set of POIs broken down with different confidence levels from low to very high. Since the leak investigation team did not have availability to investigate all 40 POIs per month, Utilis provided an ordered list of recommended field investigation locations based on the availability of the crew.

Utilis identified a total of 504 POIs. Of those 504 POIs, a total of 146 were investigated in the field, with the majority of the investigations conducted from December 2017 to June 2018.

With each data delivery, Utilis provided their POIs in multiple formats: GIS shapefiles, web application (online and mobile device application), and leak sheets. Leak sheets are a 1-page map for each POI that identifies the limits of the investigation overlaid on the water system pipe network. An example is shown in Figure 38. At the beginning of the project the leak sheets showed a circle or radius of investigation, with the additional direction from Utilis to continue to investigate for a certain area beyond the radius. An improvement Utilis made in their data deliveries is switching to highlighting the pipe investigation limits so it is clear how much pipe length is to be covered.

Figure 38: Utilis Investigation Sheet

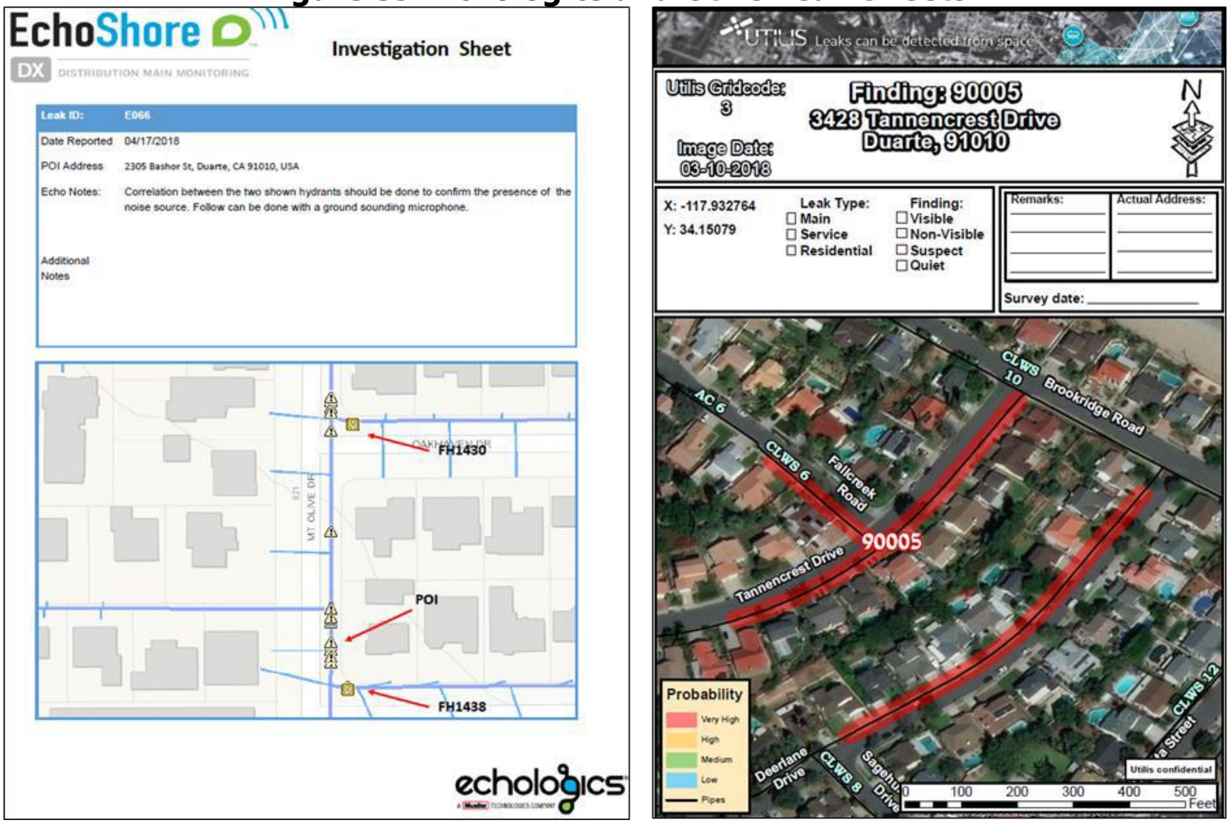


Source: Hazen and Sawyer, American Water

Leak Investigations

After leaks were detected by the technology, leak investigations took place to pinpoint the leak and identify the area to be excavated for leak repair. The equipment, training, and data collection process of leak investigations for Utilis POIs are substantially the same as Echologics POIs. However, the leak investigation process is slightly different. To illustrate the difference, the leak sheets from both technologies are shown in Figure 39.

Figure 39: Echologics and Utilis Leak Sheets

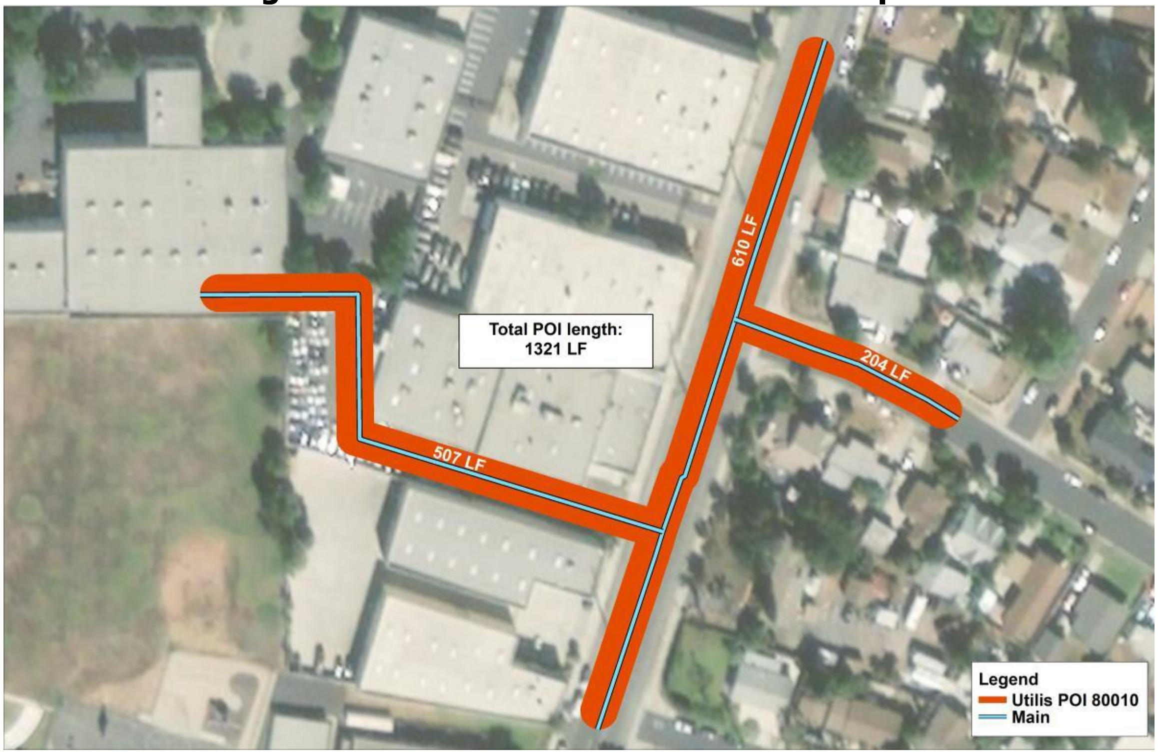


Source: Hazen and Sawyer, American Water

The leak sheet from Echologics identifies the POI as a point. As discussed previously, Echologics directed the team to only focus on that point and the immediate adjacent area (approximately 20 feet on either side of the POI) and if the leak was not found in that area, consider it a false positive and move on to the next POI.

The leak sheet from Utilis identifies the POI as an area to be investigated. Utilis POIs encompassed an area that included an average of 1,200 feet of pipe to be investigated. The Utilis team considers a leak investigation complete only when the entire area has been investigated. An example of a Utilis POI and the total length of pipe to be investigated within the POI is shown in Figure 41.

Figure 40: Utilis Points of Interest Example



Source: Hazen and Sawyer, American Water

The leak investigation process typically involves walking the pipeline alignment and opening every meter box and putting the microphone up to the service line and listening for leak noise (Figure 41).

Figure 41: Utilis Leak Investigation With 2-Person Crew Plus Engineer

Source: Hazen and Sawyer, American Water

The team member listened to each meter box for 5 to 10 seconds. If no noise was heard, then the field crew moved on to the next meter box and continued until the entire POI area was covered as shown on the leak sheet. If a noise was heard, the meter was checked to see if the resident was using water. If water noise is heard and there is no sign of use, then that may be indicative of a leak and pinpointing efforts were conducted.

The total time to investigate a Utilis POI and either pinpoint the leak or conclude it as a false positive typically took 3.8 labor-hours (or 1.9 labor-hours per 2-person crew). The investigation duration varied for each Utilis POI due to the nature of the POI size, accessibility of the meter boxes, and the speed and experience of the leak investigation team. If a leak was found within a POI, the Utilis team recommended that the entire POI continue to be investigated since it was possible that their technology might have found multiple leaks within one POI.

Leak Repairs

The process for leak repairs is the same regardless of the technology used to find the leak. The leak repair process is discussed in the previous section for the Echologics technology.

False Positives

False positives also occurred with SILD, but for different reasons than Echologics. A false positive occurred when Utilis recommended a POI for an investigation, and no leak was found in the field.

Leaks located on the private side of the meter, such as on a residential irrigation system, can be a cause for a false positive. SILD does not differentiate between a private and public system. Therefore, leaks can occur in an irrigation system and generate a POI from Utilis. Some of the neighborhoods within the Duarte system had evidence of irrigation systems that were not maintained and had leaks that could be detected by Utilis.

SILD identifies leaks in the ground for all pipe materials. Pinpointing the leaks in the field requires the use of acoustic tools like a correlation set. If trying to pinpoint a leak on a plastic pipe system like PVC, the acoustics of leaks are less pronounced making them harder to locate. In some instances, a POI was identified in a non-metallic pipe area, but leak noises were not detected by field investigation crews, meaning that a background leak in the area may exist but could not be identified using acoustic tools. Thus, additional monitoring tools and/or advancements in monitoring technology could assist with identifying leaks in distribution system with multiple types of pipe material.

Topography can also play a role with SILD in two ways. First, steep slopes in a distribution system can affect where the water is found. If a leak were to occur at the top of a hill, the water may flow downhill underground to a distant location where the POI would be generated. In locating the source of the leak, field crews may need to observe their surroundings, use their experience and judgment, and deviate from the limits of the POI boundary to find the leak. Second, mountains and tall buildings can also create false positives by creating a shadow effect when a satellite image is acquired. A shadow effect is a result of shadows cast by buildings, mountains, or large objects that obscure much of the information in the satellite image leading to potentially corrupted classification of results or blunders in information[3]. A shadow effect may cause radar responses to be shifted geographically. This is the primary reason Utilis POIs are given as an area to investigate, rather than a single point location.

Finally, false positives can also occur because a leak simply could not be located in the field for various reasons. This would be considered the "human element," and is part of any technology deployment.

Flow Sensitive Pressure Reducing Valves

San Diego County District

The flow-sensitive pressure reducing valve technology Aqua-Guard (AG) System by Stream Control was deployed at the Beyer PRV in the San Diego County District. The following section includes a discussion on the technology monitoring and adjustment phase of that deployment.

Technology Monitoring and Adjustments

Installation and start-up of the AG system by Stream Control includes optimizing the AG system settings, ensuring adequate power supply by a generator or other means, monitoring the data transmission component, and initial monitoring of system pressures through high and low demand periods. This initial start-up and monitoring period usually take about 2-3 days.

The next step in the process is continual monitoring of the AG system. For the Beyer PRV deployment in the San Diego County District, continual monitoring took place in multiple ways. First, the flow and upstream and downstream pressure readings were remotely monitored on a weekly basis. Since the data were transmitted daily to the online web application, all the key system performance characteristics could be easily monitored.

Second, CAW staff installed pressure recorders at two points in the pressure zone – one near the high point in the zone, one near the low point in the zone (Figure 42). The purpose was to compare pressures seen at the extreme ends of the pressure zone with the pressures within the Beyer PRV Zone that were being controlled by the AG system.

If the system is in an area that experienced a high leak rate or high non-revenue water quantity, these additional characteristics should be monitored.

As a result of the continual monitoring period of the AG system, important findings regarding the installations were made. Early in the project it was observed that higher than expected flows were entering the zone. After investigation, it was discovered that there was a broken valve in the system allowing flow to enter the zone. The valve was located and replaced, and then flows returned to the expected pattern and quantity. Figure 43 highlights flows in the system before and after the valve was replaced.

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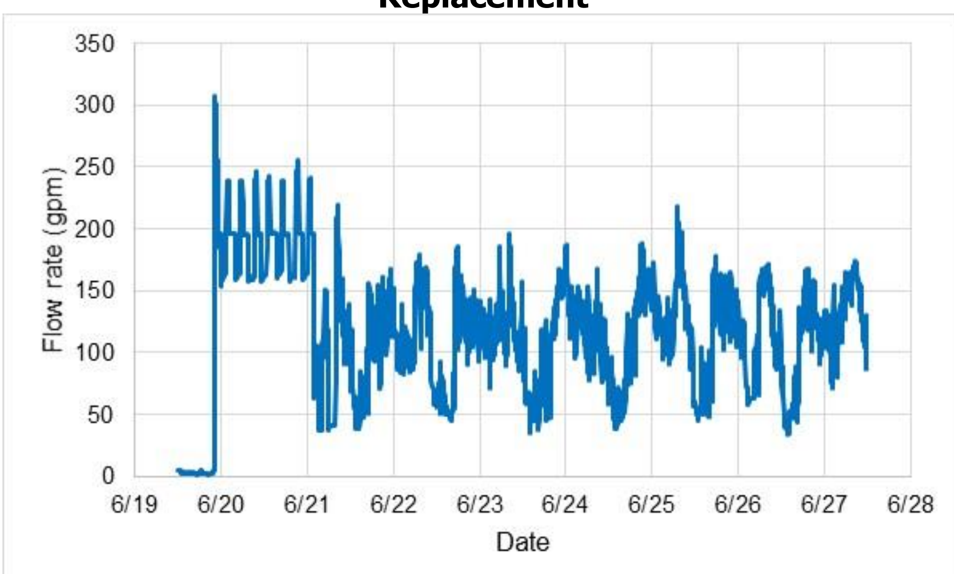
[3] Dare, P. M. (2005). Shadow Analysis in High-Resolution Satellite Imagery of Urban Areas. *Photogrammetric Engineering & Remote Sensing,* 71(2), 169-177.

Figure 42: Pressure Recorder Locations

Source: Hazen and Sawyer, American Water

Figure 43: Beyer Pressure Reducing Valve Flows Before and After Valve Replacement

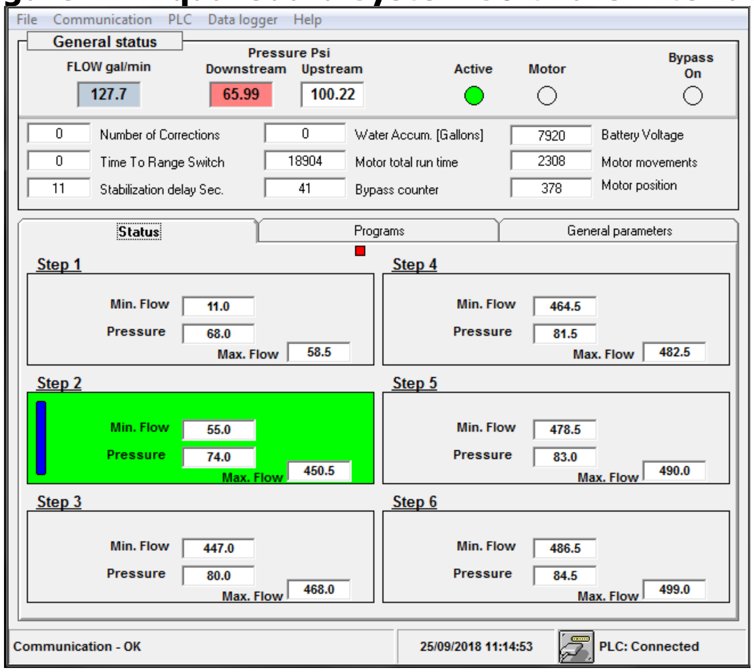


Source: Hazen and Sawyer, American Water

Since the AG system includes pressure transducers on the upstream and downstream branches of the PRV, it was confirmed that the downstream pressure gauge was malfunctioning and needed replacement. The reading it provided was significantly different from the pressure transducer reading from the AG system.

Based on the readings from the pressure recorders, it was determined that the high point in the pressure zone should have a minimum pressure 4 psi higher than what it was currently experiencing. The AG system settings were adjusted to raise the low setting by 4 psi.

Figure 44: Aqua-Guard System Software Interface



Beyer Pressure Reducing Valve Settings.

Source: Hazen and Sawyer, American Water

In addition to pressure adjustments, sometimes the flow bands of the AG system had to be adjusted when pressure was higher or lower in the zone. These adjustments are system specific depending on the goals and preferences of the utility. Pressure complaints or leaks did not occur in the system during the monitoring period for this project, however, they could be a motivating factor for making adjustments in other deployments.

Monitoring also took place by meeting in the field at the Beyer PRV and connecting a laptop to the AG system to confirm the data transmission, settings, and operation of the AG system were as desired. Although data can be remotely monitored, adjustments of settings can only be made on-site, when connected to the AG system with a laptop and AG system software.

Just as a utility's operations staff continually monitor mechanical equipment such as pumps and treatment facilities, the AG system needs to be continually monitored for proper performance. A once per week monitoring schedule is a sufficient frequency.

Ventura County District

The FSPRV technology AG system was used at the Dos Vientos Via Estrella PRV and Dos Vientos Del Prado PRV in the Ventura County District. The following section includes a discussion on the technology monitoring and adjustment phase.

Technology Monitoring and Adjustments

Monitoring the two installations in the Ventura County District required a different approach compared with the San Diego County District. The two installations were at the Del Prado PRV and the Via Estrella PRV, with both PRVs supplying the same pressure zone. The pressure zone being supplied was relatively new and had not had a history of leaks or excessive non-revenue water.

As described in Chapter 1, installation and startup of the AG systems at each PRV was completed. Based on demands into the zone, one PRV was sufficient to supply the entire pressure zone during normal demands, so the Via Estrella PRV was initially set as the primary and the Del Prado PRV was set as the backup.

The transmission component of the AG system was not successfully completed at the two installations. Multiple attempts were made with different subscriber identification module (SIM) cards and different antenna placements, all with the same result. The team concluded that since the data transmission component could not be set up properly, the AG system data would have to be downloaded on location in the field at periodic intervals. The data transmission component is not mandatory for the operation of the AG system, but it is preferred to allow remote monitoring of the performance.

At one of the initial field visits, the team discovered that both AG systems had gone into bypass mode due to a loss of power supplied through the turbine generator. After some troubleshooting in the field, it was confirmed that the turbine generator at the Via Estrella PRV was malfunctioning due to a manufacturing defect. Without the turbine generator properly functioning to provide power, the AG system could not operate as it was intended to. Therefore, the Via Estrella PRV was returned to normal system operation based on the initial pressure settings of the PRV prior to the deployment of the AG system and the AG system was left in bypass mode.

With the AG system at the Via Estrella PRV not operating, the Del Prado PRV was set as the primary PRV serving the zone, and the AG system was set to control the PRV.

Operating multiple AG systems on PRVs that supply the same pressure zone can present a challenging situation, especially when turbine generators are used as the power supply. Settings for the turbine generator, duty PRV, AG system, and large PRV all need to be coordinated so that they do not counteract the operation of each other. This is further discussed in Chapter 4. Like the Beyer PRV in the San Diego County District, continual monitoring of the AG system performance is required.

District Metered Areas

Ventura County District

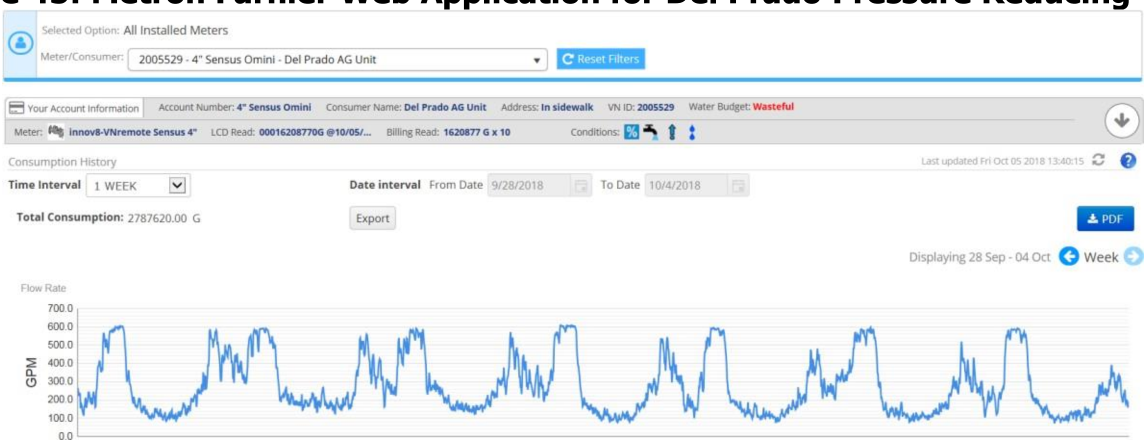
DMAs were deployed in the Ventura County District at four locations: the two AG system installation sites, (Via Estrella PRV and Del Prado PRV serve the same pressure zone), the Dos Vientos Booster Station (DVBS), and the Dos Vientos Zone 3 Booster Station (DV3BS). DMAs were set up to monitor flow and determine if there were irregular flow patterns or quantities that would have been indicative of a leak. During the monitoring period for this project, there were no irregularities in flow patterns or volumes that indicated a leak in the system, however, important data on consumption within the DMAs was obtained.

The following section includes a discussion of the technology monitoring and response phase of the DMA deployments.

Technology Monitoring and Response – Via Estrella and Del Prado Pressure Reducing Valves

Flow data from the Via Estrella PRV and the Del Prado PRV were transmitted to an online web application set up by Metron Farnier, who was the vendor that set up and maintained the flow meter data for the DMA analysis. The website showed flow readings every 5-minutes, updated daily with the latest data. The data could be simply viewed on the website or downloaded to an excel file. A screenshot of the website displaying the flow data is shown in Figure 45.

Figure 45: Metron Farnier Web Application for Del Prado Pressure Reducing Valve

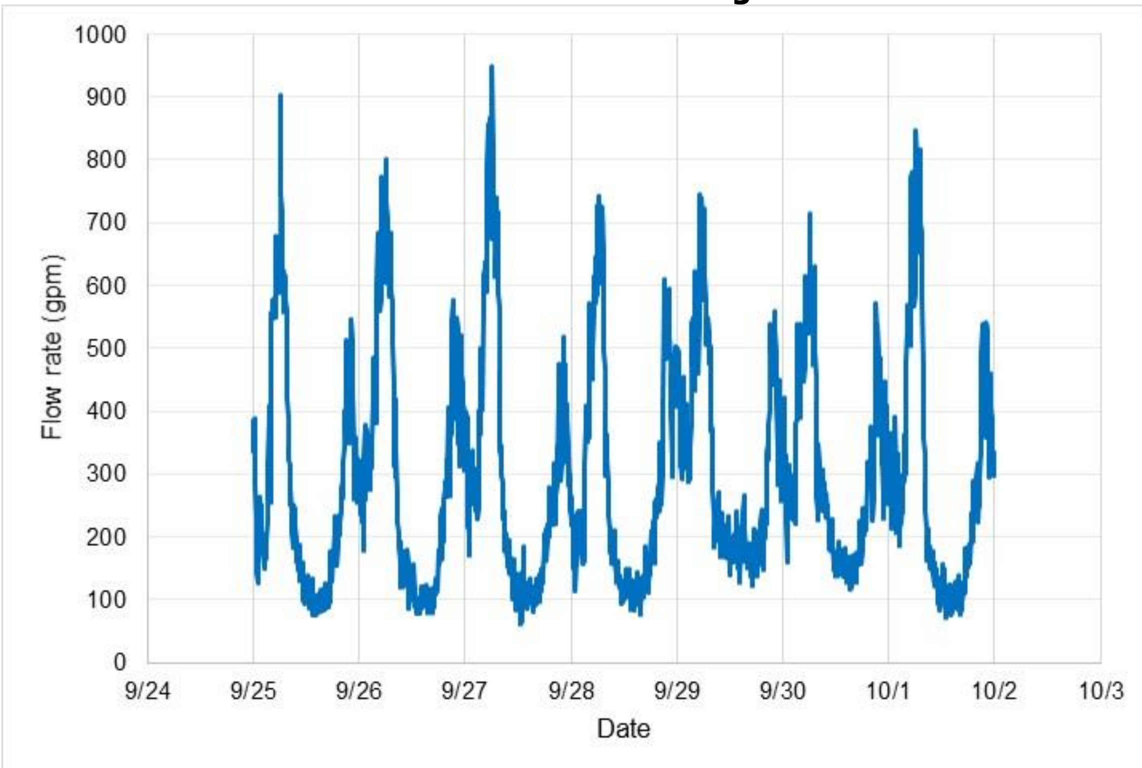


Source: Hazen and Sawyer, American Water

The DMA for the Via Estrella PRV and Del Prado PRV is an entire pressure zone. The size of the DMA is 783 metered connections which is considered a small DMA based on AWWA M36. A medium DMA would consist of 1,000 to 3,000 connections, and a large DMA would have 3,000 to 5,000 connections.

Flow data for the DMA was typically monitored on a weekly basis. Since leaks were not prevalent in this DMA, the weekly monitoring period was appropriate. Flow data from both PRVs was combined since they both serve the same DMA. Data was monitored and reviewed, and when an irregular flow pattern, flow spike, or flow drop was observed, it was brought up to CAW. A substantial leak in the DMA would be seen in the flow data through a consistently high shift up in the graph from the typical flow pattern. If it was something related to the operation of the AG system (discussed in the previous section), then correspondence was conducted with the manufacturer on their review of the data. Typical flow data is shown in Figure 46.

Figure 46: Combined Flow Data for Via Estrella and Del Prado Pressure Reducing Valve Sites



Source: Hazen and Sawyer, American Water

Billing data from January 2018 to September 2018 was used to determine the DMA's top 10 percent water users. The largest water users within the DMA were identified because their water usage can significantly impact total usage volume and pattern for the entire DMA. If an irregular flow pattern was observed when monitoring the DMA, the meters for the largest users can be checked to see if their usage was contributing to the irregular flow pattern. If usage was abnormal, then the irregular flow pattern could be indicative of a leak somewhere in the DMA. Table 3 and Figure 47 highlight locations that account for 10 percent of the DMA's consumption.

Table 3: Via Estrella and Del Prado Pressure Reducing Valve District Meter Area Top 10 Percent Water Use Meters

Location	Consumption (gallons/day)
Sycamore Canyon School	13,675
Via la Jolla, Thousand Oaks, CA	9,288
Via Katrina, Thousand Oaks, CA	7,550
Via del Prado, Thousand Oaks, CA	7,493

Note, addresses of private residences have been removed.

Source: Hazen and Sawyer, American Water

Figure 47: Via Estrella and Del Prado Pressure Reducing Valve District Meter Area Top 10 Percent Water Consumption Locations

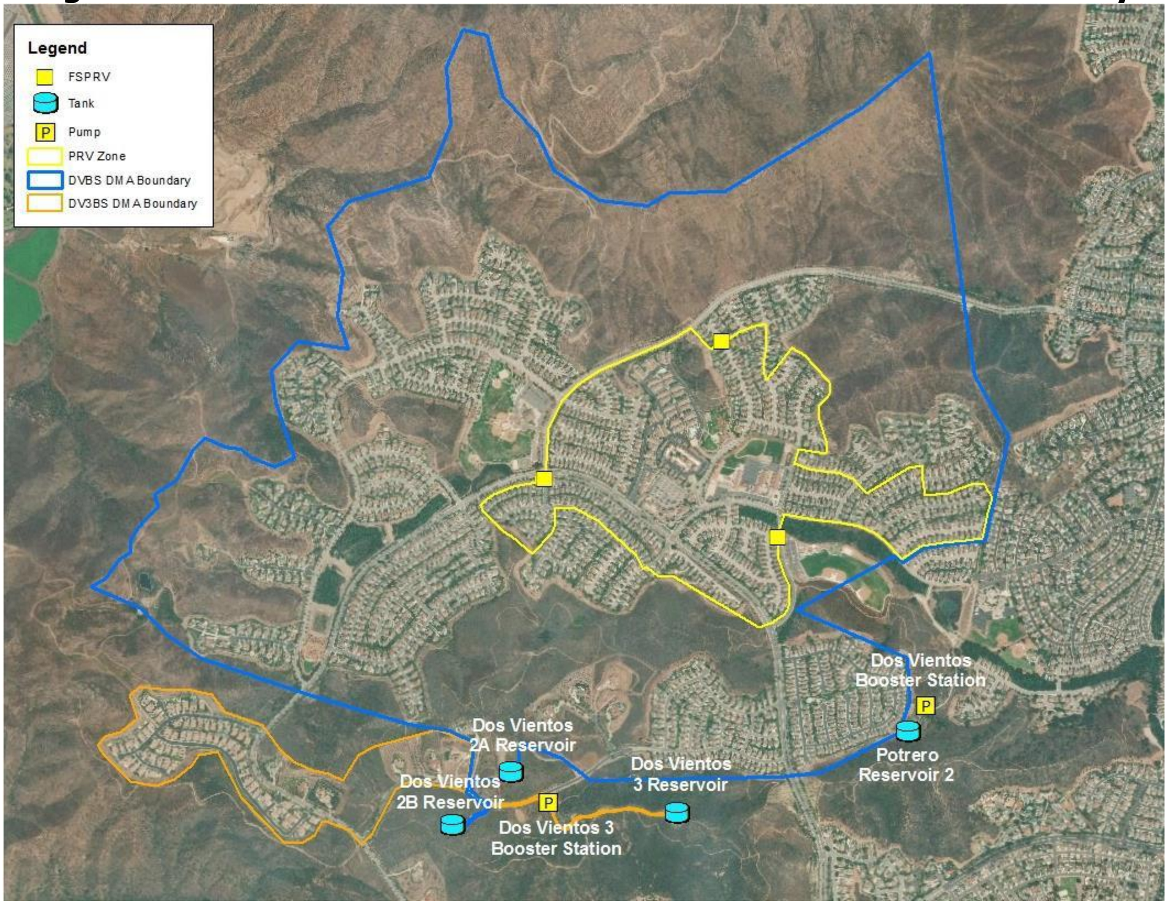
Source: Hazen and Sawyer, American Water

Technology Monitoring and Response – Dos Vientos Booster Station and Dos Vientos Zone 3 Booster Station

Flow data from the DVBS and the DV3BS was downloaded manually at the flow meter site on an approximate monthly schedule. Flow readings were taken every 5-minutes on the primary pump at each booster station. The data was downloaded to an Excel file.

The DVBS pumps from the Main Gradient (Potrero Reservoirs) into the Dos Vientos 2A and 2B Reservoirs. The DMA for the DVBS is the area served exclusively by the Dos Vientos 2A and 2B Reservoirs (Figure 48). The total size of the DMA is 1,971 connections.

Figure 48: Dos Vientos Booster Station District Meter Area Boundary



Source: Hazen and Sawyer, American Water

Billing data from January 2018 to September 2018 was used to determine the DMA's top water users. The Via Estrella PRV/Del Prado PRV DMA is within the DVBS DMA, as shown in Figure 48. Table 4 highlights locations within the DVBS DMA that account for top 5 percent of the DMA's consumption. Figure 49 highlights locations within the DVBS DMA that account for top 10 percent of the DMA's consumption.

Table 4: Dos Vientos Booster Station Top 5 Percent Water Use Meters

Location	Consumption (gallons/day)
Rancho dos Vientos, Thousand Oaks, CA	45,653
Calle del Prado, Thousand Oaks, CA	15,439

Addresses of private residences have been removed.

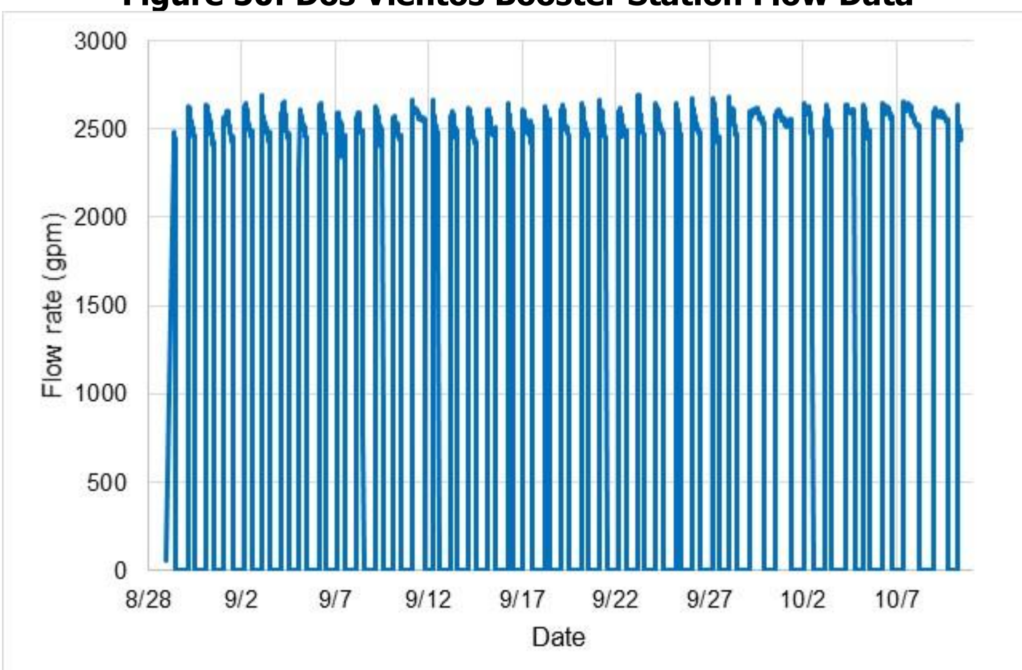
Source: Hazen and Sawyer, American Water

Figure 49: Dos Vientos Booster Station Top 10 Percent Water Consumption Locations

Source: Hazen and Sawyer, American Water

Like the Via Estrella PRV/Del Prado PRV, leaks were not prevalent in this area. A graph charting the data from the flow meter site is shown in Figure 50.

Figure 50: Dos Vientos Booster Station Flow Data



Source: Hazen and Sawyer, American Water

The DV3BS pumps from the Dos Vientos 2A and 2B Reservoirs into the Dos Vientos 3 Reservoir. The DMA for DV3BS is the area served by the Dos Vientos 3 Reservoir. The DMA for DV3BS is only 77 connections. The DV3BS and DVBS DMAs are independent of each other.

Figure 51: Dos Vientos Zone 3 Booster Station District Meter Area Boundary

Source: Hazen and Sawyer, American Water

The flow meters were installed at pump stations on the primary pump, however, when the other pumps were operating the flow was not captured. Like the Via Estrella PRV/Del Prado PRV, leaks were not prevalent in this area. A graph charting the data from the flow meter site is shown in Figure 53.

Billing data from January 2018 to September 2018 was used to determine the DMA's top 10 percent water users. Table 5 and Figure 52 summarize locations within the DV3BS DMA that account for top 10 percent of the DMA's consumption.

Table 5: Dos Vientos Zone 3 Booster Station Top 10 Percent Water Consumption Locations

Location	Consumption (gallons/day)
Rancho dos Vientos, Thousand Oaks, CA	8,562
Via Sedona, Thousand Oaks, CA	5,217

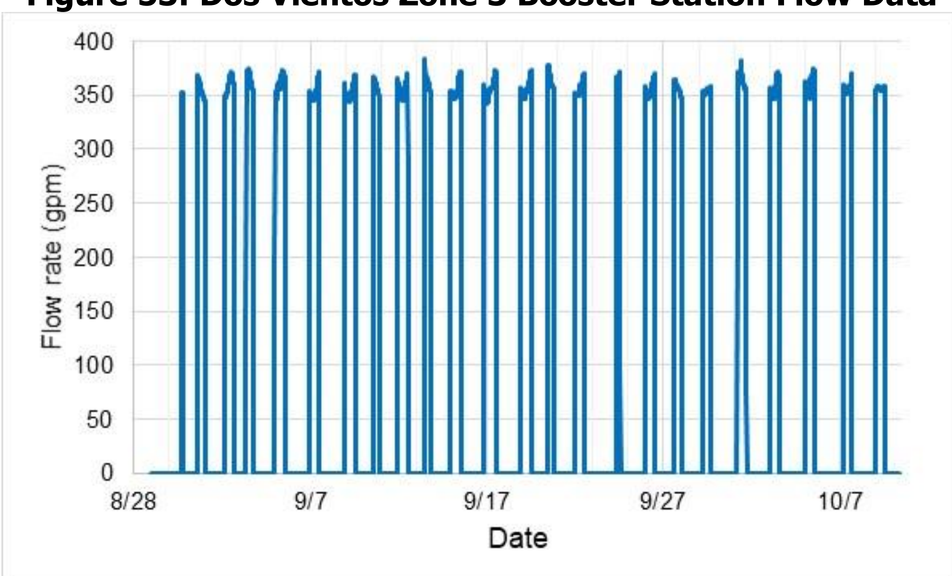
Addresses of private residences have been removed.

Source: Hazen and Sawyer, American Water

Figure 52: Dos Vientos Zone 3 Booster Station Top 10 Percent Water Consumption Locations

Source: Hazen and Sawyer, American Water

Figure 53: Dos Vientos Zone 3 Booster Station Flow Data



Source: Hazen and Sawyer, American Water

Areas with zero flow correspond to periods when the pumps were not in operation. Furthermore, the flow data correlates to the DMA sizes, with DVBS having significantly more flow than DV3BS.

San Diego County District

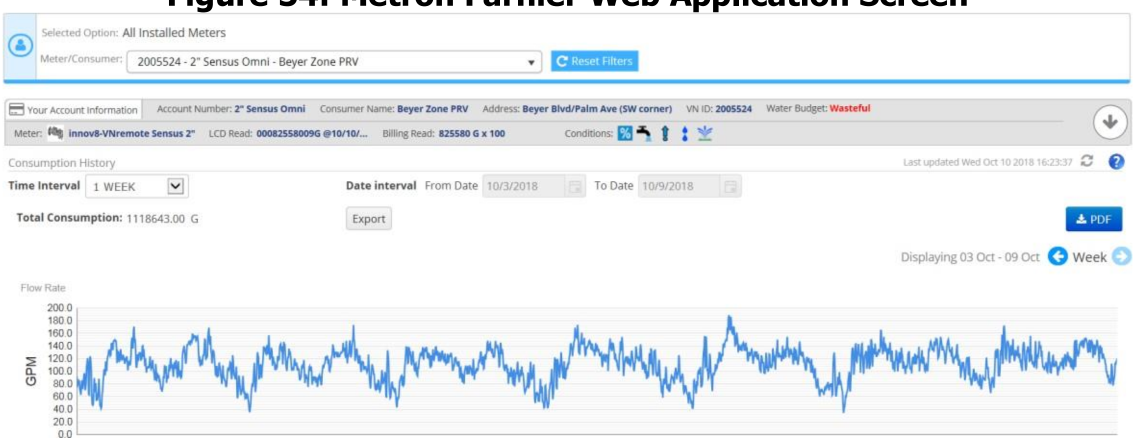
The DMA in the San Diego County District was deployed at the AG system installation site at the Beyer PRV. DMAs were set up to monitor flow and determine if there were irregular flow patterns or quantities that would have been indicative of a leak. During the monitoring period, one of the key discoveries from the DMA was identifying a broken valve in the system which resulted in higher flows into the DMA that should have been occurring during normal conditions. The discovery of the broken valve was discussed in the earlier FSPRV section. There were no additional irregular flow patterns or quantities into the DMA, however, important data on consumption within the DMA was obtained.

The following section includes a discussion of the technology monitoring and response phase of the DMA deployment.

Technology Monitoring and Response – Beyer Pressure Reducing Valve

The Beyer PRV flow data was transmitted to an online web application set up by Metron Farnier, in the same way as the Ventura County District DMA deployments. The website showed flow readings every 5-minutes, updated daily with the latest data. The data could be simply viewed on the website or downloaded to an excel spreadsheet file. A screenshot of the website displaying the flow data is shown in Figure 54.

Figure 54: Metron Farnier Web Application Screen

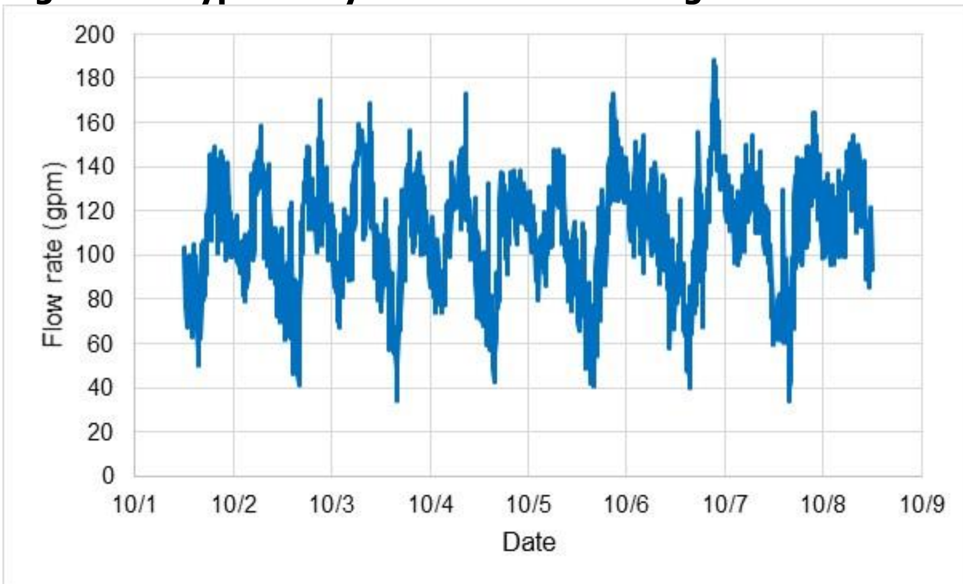


Source: Hazen and Sawyer, American Water

The DMA for the Beyer PRV contains the entire pressure zone, which equates to 621 connections (or meters), and is considered a small DMA based on AWWA M36. The Beyer PRV DMA contains only single-family residential customers.

Flow data for the DMA was typically monitored on a weekly basis since leaks were not prevalent. Data were monitored and reviewed, and when an irregular flow pattern, flow spike, or flow drop was observed, CAW was notified. If it was something related to the operation of the AG system (discussed in the previous section), then the manufacturer was also consulted on their review of the data. An example of typical Beyer PRV flow data is shown in Figure 55.

Figure 55: Typical Beyer Pressure Reducing Valve Flow Data



Source: Hazen and Sawyer, American Water

The Beyer PRV DMA follows a typical residential diurnal pattern, where flows are greatest in the morning when people wake up and get ready for their day, then drop down during the middle of the day, then increase as people get home from work in the evening, then stay relatively low through the night until the next morning. The Beyer PRV DMA has been monitored since May 2017 and has shown a consistent pattern throughout the monitoring period. Flows range from a low of 20-40 gpm to a high of 160-180 gpm and follow that same pattern every day.

CHAPTER 3:
Data Analysis

Introduction

Data analysis associated with this project was related to the performance of the technologies through evaluation of different metrics. These metrics included:

- Quantities of leaks located
- Results of leak investigations
- Correlations to the system characteristics

Additionally, the technologies were evaluated based upon an energy analysis, including calculated water and energy savings, and estimated greenhouse gas emission reductions. The specifics of the energy analysis are described below, followed by an overall data analysis evaluation for each technology.

Energy Intensity Analysis

System leaks result in water loss, and water loss is energy loss. This results in a correlated loss of embedded energy in the water distribution system. Embedded energy in a water system is the sum of all energy that is used to collect, convey, treat, and distribute water to end users.

Embedded energy can be calculated in two ways:

1. kWh/MG – consumptive weighted, and
2. kW/MGD – demand weighted.

Since the instantaneous flow rate of a subsurface leak will likely be small in comparison to the totalized volume of water lost over a prolonged timeframe, only the consumptive energy intensity (EI) was evaluated. EI is the unit of energy required to transport or treat water on a per unit basis.[4]

GHG emission mitigation can also be calculated based on EI calculations associated with leaks. A greenhouse gas is a gas that traps heat in the atmosphere, causing the greenhouse effect. The state of California published rates for nitrogen oxide and carbon dioxide emissions are provided in pounds per megawatt hours (lbs/MWh) as shown in Table 6.

[4] Molinos-Senante, M., & Sala-Garrido, R. (2017). Energy intensity of treating drinking water: Understanding the influence of factors. *Applied Energy,* 202, 275-281.

Table 6: California Greenhouse Gas Emission Data (2016)

Emission Type	Sulfur dioxide (short tons)	Nitrogen oxide (short tons)	Carbon dioxide (thousand metric tons)
Coal	373	892	1,407
Natural gas	229	47,864	44,642
Other	868	25,934	612
Petroleum	1,227	1,529	346
Total	2,697	76,219	47,008
Total emission rate (lbs/MWh)	0.0	0.8	525

Source: U.S. Energy Information Administration Webpage: https://www.eia.gov/electricity/state/california

The three CAW distribution systems were evaluated for EI and GHG associated with water loss and water loss prevention: Duarte System, San Diego County District, and Ventura County District. The Duarte System was the primary focus of the energy intensity evaluation because it:

1. Experienced a high historical leak rate.
2. Had data available regarding electrical costs for water delivered to customers and a good historical record of these costs.
3. Was able to adjust the SCADA flow data cycle to match electric billing cycle to get true kWh/MG early in the process.
4. Included Utilis and Echologics non-invasive subsurface leak detection deployed, that geographically detected leaks with reasonable accuracy prior to surfacing.

EI calculations for the Coronado and Ventura System were also evaluated, but the extent of this investigation was limited to what was publicly available in the Urban Water Management Plans for the water utility supplying water to these systems.

Duarte System

Since CCAM and SILD technologies reveal where the subsurface leak is occurring, the embedded energy/water savings can be calculated from the leak flow rate and duration.

The EI value for Duarte relies on the energy consumption, in kWh, used to deliver water to the customer, including groundwater wells and pump stations, and the total water volume produced (MG). In Duarte, eight well locations are in operation. Their primary power use is to extract the groundwater from the aquifer, treat the water and pump it into the system. There are also additional water pumping stations that use power to pump water to higher pressure zones. Based on total energy consumption and total water produced, the system EI value is shown in Table 7.

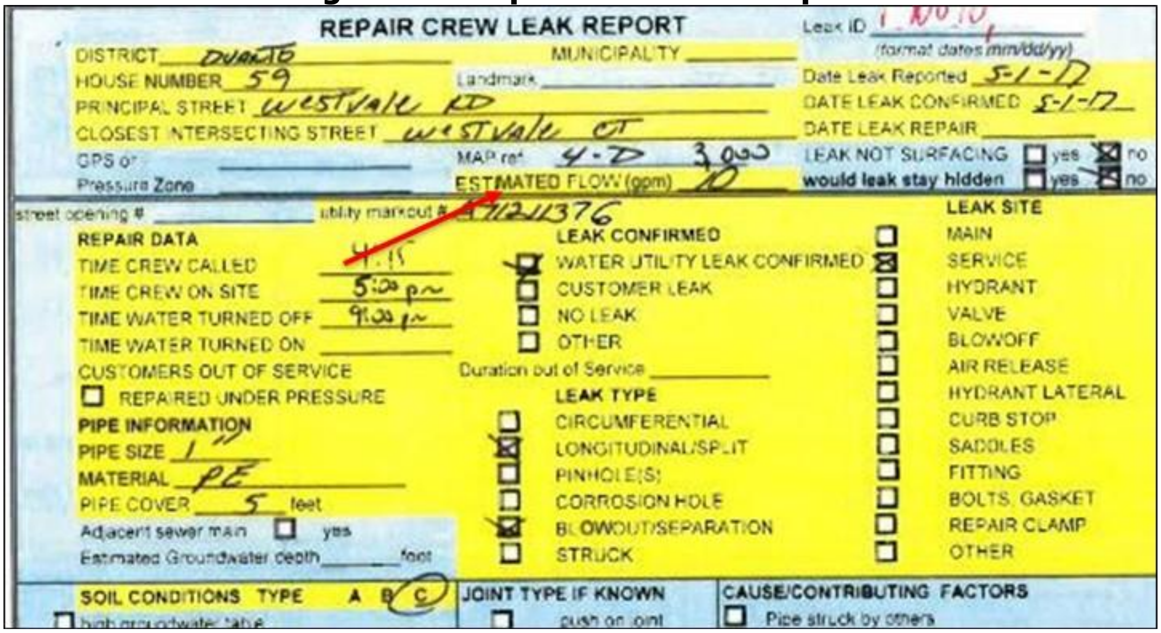
Table 7: Energy Intensity Calculation for Duarte System

Well Name	Sum of Energy Use (kWh)	Water Produced (MG)
Bacon Well	7,647	2
Buena Vista Well	890,254	379
Crownhaven Well	242,510	88
Encanto Well	228,482	79
Las Lomas Well	321,741	148
Santa Fe Well	547,450	225
Wiley Well	1,095,081	714
TOTAL WELL	3,333,165	1,635
Bliss Canyon Hydro Station	10,039	0
Bradbury Tank	4,853	0
Brookridge Booster Station	625	0
Las Lomas Booster	39,542	0
Scott Booster	567,685	0
Spinks Booster	12,035	0
Vineyard Booster Station	4,851	0
Woodlyn Lane Booster	56,377	0
TOTAL BOOSTER	696,007	0
Sum	4,029,172	1,635
	EI Value (kWh/MG)	2,464

Source: Hazen and Sawyer, American Water

Once the EI value is determined, the two additional components needed are the leak flow and leak duration. For leak flow rates, data was determined using two options. The first option was based on leak flow rate estimates reported by field staff on their "repair crew leak report." As shown in Figure 56, a form is filled out in the field when a leak repair is conducted, and the crew estimates the leak flow. Leak flow estimates from field staff ranged from negligible leak flows up to 240 gpm. For all leak repairs where a flow was estimated by field staff, this value was used. Leak flow is difficult to estimated and the estimates are highly subjective.

Figure 56: Repair Crew Leak Report



REPAIR CREW LEAK REPORT

DISTRICT Duarte
MUNICIPALITY
HOUSE NUMBER 59
Landmark
PRINCIPAL STREET Westvale RD
CLOSEST INTERSECTING STREET Westvale CT
GPS or
Pressure Zone
MAP ref 4-D 3,000
ESTIMATED FLOW (gpm) 10

Leak ID
(format dates mm/dd/yy)
Date Leak Reported 5-1-17
DATE LEAK CONFIRMED 5-1-17
DATE LEAK REPAIR
LEAK NOT SURFACING ☐ yes ☒ no
would leak stay hidden ☐ yes ☒ no

street opening #
utility markout # 171211376

REPAIR DATA
TIME CREW CALLED 4:15
TIME CREW ON SITE 5:00 pm
TIME WATER TURNED OFF 9:00 pm
TIME WATER TURNED ON
CUSTOMERS OUT OF SERVICE
☐ REPAIRED UNDER PRESSURE

PIPE INFORMATION
PIPE SIZE 1"
MATERIAL PE
PIPE COVER 5 feet
Adjacent sewer main ☐ yes
Estimated Groundwater depth ____ foot

LEAK CONFIRMED
☒ WATER UTILITY LEAK CONFIRMED
☐ CUSTOMER LEAK
☐ NO LEAK
☐ OTHER
Duration out of Service

LEAK TYPE
☐ CIRCUMFERENTIAL
☒ LONGITUDINAL/SPLIT
☐ PINHOLE(S)
☐ CORROSION HOLE
☒ BLOWOUT/SEPARATION
☐ STRUCK

LEAK SITE
☐ MAIN
☒ SERVICE
☐ HYDRANT
☐ VALVE
☐ BLOWOFF
☐ AIR RELEASE
☐ HYDRANT LATERAL
☐ CURB STOP
☐ SADDLES
☐ FITTING
☐ BOLTS, GASKET
☐ REPAIR CLAMP
☐ OTHER

SOIL CONDITIONS TYPE A B C
☐ high groundwater table

JOINT TYPE IF KNOWN
☐ push on joint

CAUSE/CONTRIBUTING FACTORS
☐ Pipe struck by others

Source: California American Water – Duarte System

The second option for leak flow was using industry accepted values when a leak flow estimate was not provided by field staff. Based on feedback from field staff, most leaks found as part of this project occurred at the connection of the service line to the main line. For these types of leaks, an accepted estimate for leak flow is 7 gpm based on AWWA M36 and other technical papers. A leak-flow estimate of 7 gpm was used for all leaks where field staff did not provide an estimate of leak flow from the field observation.

The other component needed for energy loss calculations associated with leaks is leak duration. Per AWWA M36, the total runtime of a leak consists of awareness time, location time, and repair time. It is assumed the location time and repair time would be the same whether a proactive leak detection program was implemented or not. Leak location time may vary slightly, but the assumption was that the differences are negligible. The true difference is in the awareness time or the time it takes to discover a leak in the system. For small background leakage, total leak duration could be "…weeks, months, even years…[5]", with of that being awareness time.

For this project, the total leak durations assumed for distribution systems without a leak detection program are shown in Table 8. The leak duration estimates are appropriate for the Duarte System considering that some leaks surface quickly, and some leaks can go an extended amount of time before surfacing. The smaller the leak, the longer the leak duration might have been had this leak detection program not been in place. Thus, duration values were assigned according to leak size. These values are assumptions based on general feedback from field staff.

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5 Hughes, D. M., Kleiner, Y., Rajani, B., & Sink, J. (2011). Continuous System Acoustic Monitoring: From Start to Repair (Project #3183). *Water Research Foundation;* Kunkel, p.266.; Laven et al, *What Do We Know About Real Losses on Transmission Mains?* (Presentation at IWA WaterLossEurope), 2012.

Table 8: Leak Flow Duration Assumptions

Flow (gpm)	Min (days)	Max (days)
< 10	60	180
10 to 30	10	60
30 to 60	3	10
> 60	1	3

Source: Hazen and Sawyer, American Water

San Diego County District

Water supplied to the San Diego County District is 100 percent imported water with a tremendous amount of energy associated with conveyance of the water to San Diego. The water comes from the Colorado River Aqueduct through Metropolitan Water District of Southern California (MWD). Based on the 2015 City of San Diego Urban Water Management Plan (Final June 2016), and the Metropolitan Water District of Southern California 2015 Urban Water Management Plan (June 2016), the total EI value for the San Diego County District is 6,201 kWh/MG (2,021 kWh/AF)[6]. This EI value does not include energy used by MWD to deliver water to the City of San Diego. Table 9 provides a summary of how the San Diego County District EI value was calculated. The 214 kWh/MG value pertains to the energy intensity required to deliver water within the San Diego County District and 5,987 kWh/MG captures the energy intensity required to pump water from the Colorado River Aqueduct by MWD.

Table 9: San Diego County District Energy Intensity Calculations

Source	EI (kWh/MG)	EI (kWh/AF)
Table 10-3 of the 2015 City of San Diego Urban Water Management Plan	214	69.9
Appendix 9 of the Metropolitan Water District of Southern California 2015 Urban Water Management Plan	5,987	1,951
Total EI	6,201	2,021

Source: Hazen and Sawyer, American Water

Ventura County District

Water supplied to the Ventura County District is also 100 percent imported water. Based on *The Metropolitan Water District of Southern California 2015 Urban Water Management Plan* (June 2016), the EI value for the Ventura County District is 10,795 kWh/MG (3,528 kWh/AF), as identified in Table A.9-2[7] of the plan. Metropolitan Water District uses energy to deliver

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[6] City of San Diego. (2016)*. 2015 City of San Diego Urban Water Management Plan.* San Diego, CA.; Metropolitan Water District of Southern California. (2016). 2015 *Urban Water Management Plan.* Los Angeles, CA.

[7] Metropolitan Water District of Southern California. (2016). *2015 Urban Water Management Plan.* Los Angeles, CA.

water to Calleguas Municipal Water District, which delivers water to California American Water's Ventura County District via a gravity system.

The three systems have very different EI associated with water, resulting in vastly different impacts related to energy loss through nonrevenue water/water leaks (Table 10).

Table 10: California American Water System Energy Intensity Values

CAW System	EI (kWh/MG)	EI (kWh/AF)
Duarte System (Los Angeles County)	2,464	803
San Diego County District	6,201	2,021
Ventura County District	10,795	3,528

Source: Hazen and Sawyer, American Water

Correlating Continuous Acoustic Monitoring (Echologics)

Duarte System

Leak Investigations

Echologics analyzed their acoustic sensor data daily looking for potential leak locations. Although the technology continually identifies various types of noise picked up by the sensors, the analysis protocol includes waiting for continuous noise across multiple days before recommending the location for a field leak investigation.

Echologics identified 77 points of interest (POIs) that were recommended for field investigation. Of those 77 POIs, a total of 49 were investigated in the field. In general, the POIs provided by Echologics were prioritized for field investigation as soon as possible. Since the leak investigation crews also had operations and maintenance responsibilities for the system, there were times when leak investigations could not be conducted. The performance metrics associated with the Echologics technology is based on the 49 field investigations.

Performance Metrics

The acoustic sensors were installed and operational as of July 2017, however a regular leak investigation program was initiated starting in December 2017 and continued through May 2018. Most of the data collected is from that time period. In addition to leak investigations recommended by the technology, there were also additional leaks that had surfaced and were repaired by CAW staff. This leak data was reviewed to determine if the technology had identified this location as a potential leak prior to it surfacing, but the leak investigation team had not been available to investigate it due to availability. These instances were also included in the performance metrics.

The data associated with the Echologics technology deployed in Duarte are shown in Table 11. It should be noted that labor estimates associated with leak investigations were approximated based on POIs investigated throughout the project duration.

Table 11: Echologics Leak Data from Duarte Deployment

Parameter	Value
POIs Provided	77
POIs Investigated	49
Total Leaks Found	20
Leaks Found per POIs Investigated	41%
Leaks Found per Mile Investigated	3.8
Miles of Pipe Investigated	5
Labor per POI Investigated (hours)	1 to 3
Average Labor per Leak Found (hours)	4.9

Source: Hazen and Sawyer, American Water

Energy and Greenhouse Gas Emissions Metrics

Based on the energy intensity and GHG emission estimates for the Duarte System with the range of leak duration before the leak would have surfaced, the leak volume and associated energy and GHG emission savings from the early detection of leaks by the Echologics technology is summarized in Table 12.

Table 12: Correlating Continuous Acoustic Monitoring Energy Calculations Based on Leaks Found

Parameter	Value
EI (kWh/MG)	2,464
Miles of Pipe Investigated	5
Average Flow per Leak (gpm)	17
Total Leaks Found	20
Cumulative Leak Volume (MG, based on duration)	10 to 31
Cumulative Leak Volume per mile (MG/mi, based on duration)	2 to 6.2
Cumulative Energy Saved (kWh) [1]	25,000 to 76,000
Cumulative Energy Saved per mile (kWh/mi)	5,000 to 15,000
Cumulative Energy Cost Savings [2]	$6,000 to $18,000
Cumulative Energy Savings per mile	$1,200 to $3,600
Energy Savings (% of system usage)	0.1 % to 0.5%
Nitrogen oxide reduction (lb) [3]	20 to 61
Nitrogen oxide reduction per mile (lb/mi)	4 to 12
Carbon dioxide reduction (lb) [3]	13,000 to 40,000
Carbon dioxide reduction per mile (lb/mi)	2,600 to 8,000

[1] Calculation example: (2,464 kWh/MG) x (10.2 MG) = 25,156 kWh

[2] Based on average electric rates for CAW Duarte System at $0.25/kWh

[3] Source: U.S. Energy Information Administration Webpage: https://www.eia.gov/electricity/state/california

Source: Hazen and Sawyer, American Water

When only looking at energy costs per leak found and repaired, up to $900 per leak can be saved in energy costs. Additional savings would also be accounted for from savings in water supply and treatment, plus the potential for electric utility credits such as Southern California Edison's WISE program. However, this number should not be taken out of context to compare technologies as it would be expected to vary based on size of leaks found and duration of leaks before detection if no advanced technology were used.

Satellite Imagery Leak Detection

Duarte System

Leak Investigations

Utilis conducted a total of 12 monthly flyovers from May 2017 to June 2018. After each flyover, the data was collected and analyzed by the Utilis team. The result of their analysis yielded approximately 40 POIs per month, with each set of POIs broken down with different confidence levels from low to very high. Since the leak investigation team didn't have availability to investigate all 40 POIs per month, Utilis provided an ordered list of recommended field investigation locations based on the availability of the crew. After each round of investigations, the results were provided to Utilis to review and use in their analysis for the next month's POIs.

Utilis identified a total of 504 POIs. Of those 504 POIs, a total of 146 were investigated in the field, with most of the investigations conducted from December 2017 to June 2018. The POIs provided by Utilis were prioritized for field investigation based on the leak investigation team's availability. The performance metrics associated with the Utilis technology is based on the 146 field investigations.

Performance Metrics

Monthly flyovers began in May 2017; however, a regular leak investigation program was initiated starting in December 2017 and continued through June 2018. Most of the data collected is from that time period. In addition to leak investigations recommended by the technology, there were also additional leaks that had surfaced and were repaired by CAW staff. This leak data was reviewed to determine if the technology had identified this location as a potential leak prior to it surfacing, but the leak investigation team had not been available to investigate it due to the lack of crew availability. These instances were also included in the performance metrics.

Energy and Greenhouse Gas Emissions Metrics

The data associated with the Utilis technology deployed in Duarte is shown in Table 13.

Based on the energy intensity and GHG emission estimates for the Duarte System along with the range of leak duration before the leak would have surfaced, the leak volume and associated energy and GHG emission savings from the early detection of leaks by the Utilis technology is summarized in Table 14.

Table 13: Utilis Leak Data

Parameter	Value
Miles of Pipe Investigated (mi)	45
Total POIs Provided (#)	504
POI Provided per mile (#)	11
Total POIs Investigated	146
POIs Investigated per mile (#)	3
POI Investigated per POI Provided	29%
Total Leaks Found (#)	117
Leaks Found per Mile Investigated (#)	2.6
Leaks Found per POIs Investigated	80%
Leaks Found per POI Provided	23%
Labor per POI Investigated (hours)	3.8
Average Labor per Leak Found (hours)	5.6

Source: Hazen and Sawyer, American Water

Table 14: Satellite Imagery Leak Detection Energy Calculations Based on Leaks Found

Parameter	Value
EI (kWh/MG)	2,464
Miles of Pipe Investigated	45
Average Flow per Leak (gpm)	7
Total Leaks Found	117
Cumulative Leak Volume (MG, based on duration)	47 to 139
Cumulative Leak Volume per mile (MG/mi, based on duration)	1 to 3
Cumulative Energy Saved (kWh) [1]	116,000 to 342,000
Cumulative Energy Saved per mile (kWh/mi)	2,578 to 7,600
Cumulative Energy Savings [2]	$28,000 to $82,000
Cumulative Energy Savings per mile	$622 to $1,822
Energy Savings (% of system usage)	3.0% to 8.5%
Nitrogen oxide reduction (lbs) [3]	92 to 275
Nitrogen oxide reduction (lbs/mi)	2 to 6.1
Carbon dioxide reduction (lbs) [3]	60,000 to 180,000
Carbon dioxide reduction (lbs/mi)	1,333 to 4,000

[1] **Calculation example: (2,464 kWh/MG) x (47 MG) = 115,808 kWh**

[2] **Based on average electric rates for CAW Duarte System at $0.25/kWh**

[3] **Source: U.S. Energy Information Administration Webpage: https://www.eia.gov/electricity/state/california**

Source: Hazen and Sawyer, American Water

When looking at energy costs per leak found and repaired, up to $700 per leak can be saved in energy costs alone. Additional savings would also be accounted for from savings in water supply and treatment, plus the potential for electric utility credits such as Southern California Edison's WISE program.

However, this number should not be taken out of context to compare technologies as it would be expected to vary based on size of leaks found and duration of leaks before detection if no advanced technology were used.

A leak flow of 7 gpm (based on AWWA M36 and other technical papers), was used for all leaks that were not estimated by field staff. It is emphasized that leak flow estimates in the field are highly subjective. When a leak is excavated and discovered, there are often other circumstances that have already altered the actual leak flow, such as closing valves to isolate the leak. However, leak flow estimates are a required value in ultimately calculating energy savings associated with the early location of leaks in a water system. Therefore, leak flow estimates were an important value required for this analysis.

Duarte System Analysis

Comparison of Correlating Continuous Acoustic Monitoring to Satellite Imagery Leak Detection

As discussed, the CCAM and SILD technologies were used in the Duarte System across the same time period to evaluate their effectiveness in locating leaks. The performance metrics for each technology were discussed independently in previous sections but are shown side-by-side for comparison in Table 15.

Table 15: Comparison of Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Performance Metrics

Parameter	Echologics (CCAM)	Utilis (SILD)
Miles of Pipe Investigated (mi)	5	45
Total POIs Provided (#)	77	504
POI Provided per mile (#)	15	11
Total POIs Investigated	49	146
POIs Investigated per mile (#)	10	3
POI Investigated per POI Provided	64%	29%
Total Leaks Found (#)	20	117
Leaks Found per Mile Investigated (#)	3.8	2.6
Leaks Found per POIs Investigated	41%	80%
Leaks Found per POI Provided	26%	23%
Labor per POI Investigated (hours)	1 to 3	3.8
Average Labor per Leak Found (hours)	4.9	5.6

Source: Hazen and Sawyer, American Water

Utilis provided significantly more POIs for investigation compared to Echologics. It should be noted that the Echologics technology also generates a very high volume of POIs, but what is recommended for investigation is a much lower number because the Echologics team filters out what they believe are false positives. Since Echologics POIs were based on acoustic readings within the previous few days, the leak investigation team typically prioritized going out to those locations first. The POIs that weren't investigated were generated in the early stages of the project before a field leak investigation team was mobilized for scheduling regular investigations.

Echologics technology identifies specific locations for emerging leaks. During the study, field crews investigated the leak point identified and the immediate area surrounding (approximately 20 feet on either side of the POI). If a leak was not found in that area, the POI leak alert was recorded as a false positive.

The leak sheet from Utilis provides points of interest over an area, that results in an average of 1,200 feet of pipeline (at a standard deviation of 550 feet), that should be investigated. The Utilis team considers a leak investigation complete only when the entire area has been investigated.

The leak investigations conducted to investigate the leak alerts delivered by each technology used different approaches. Because the Utilis POI represents an area of approximately 265 ft radius or an average of 1,200 feet of distribution pipe, the likelihood of finding a leak is improved compared to an Echologics POI that is a specific point. The durations to investigate POIs are naturally higher for Utilis POIs compared to Echologics POIs, but as noted previously, the leak investigation durations are approximate.

Although the two technologies were compared for effectiveness, a key conclusion is there are applications for both technologies with energy and cost savings associated with proactive leak detection and repair, including benefits to employing both within the same system. For example, deploying both technologies in a very large system could be advantageous: A large system may include thousands of miles of distribution pipeline and thousands of hydrants. Although using the Echologics hydrant sensors on the entire system may be worthwhile, there may be portions of the system with high water efficiencies and low leakage rates, where other parts of the system are just the opposite. Deploying the Utilis technology on the entire system would help identify where the "trouble spots" are located. Using the Echologics technology in only these trouble spots would be a better investment and yield quicker results and optimize staff time in only focusing on the areas with high leakage rates.

Pipe Leak Metrics

In addition to metrics associated with the CCAM and SILD leak detection technologies, metrics were also evaluated with the leaks compared to different system related parameters. The first metric was an evaluation of pipe leaks found relative to the pipe material (Table 16) throughout a 14-month study period. Pipe leak data included leaks located by the CCAM and SILD technologies, as well as other system leaks provided by CAW.

Table 16: Pipe Material Leak Metrics

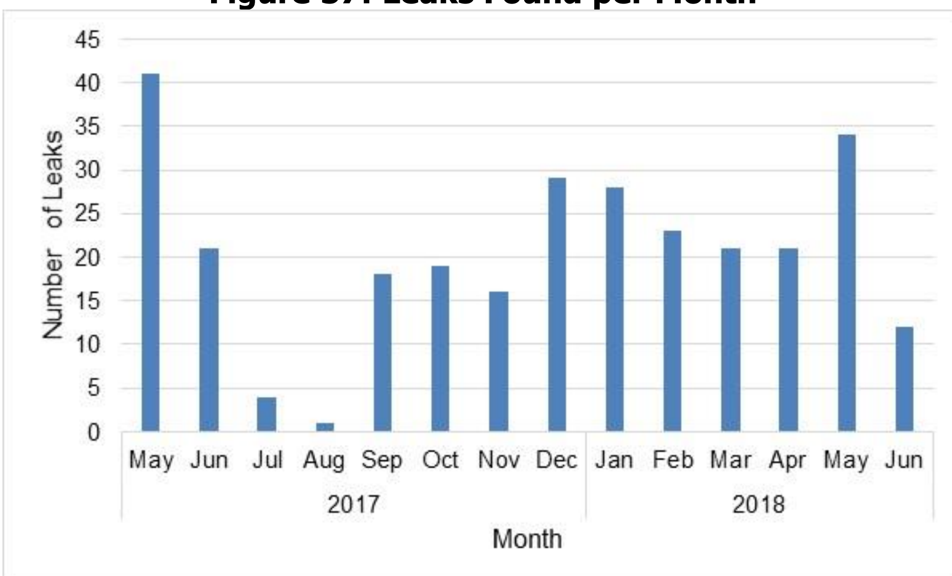
Pipe Material	Total LF in System	% of Total System	# Leaks	% of Total Leaks
AC	75,092	13%	24	8%
PVC	137,121	24%	36	13%
Metallic	353,351	62%	228	79%
Total	565,564	100%	288	100%

Source: Hazen and Sawyer, American Water

Several conclusions to pipe material and leaks were drawn based on the data in Table 16. Metallic pipe is the predominant pipe material in the system (62 percent of system), and the predominant pipe material where system leaks were found (79 percent of leaks). However, the percentage of leaks found on metallic pipe is 17 percentage points higher compared to its representation within the system (79 percent versus 62 percent). Along the same lines, the percentage of leaks found on PVC pipe is 11 percentage points lower compared to its representation within the system (13 percent versus 24 percent). One reason for this was the Echologics sensors were not installed in parts of the system that had a high concentration of PVC pipes. Another reason is leak locating and pinpointing is more difficult in PVC systems due to the acoustics of a leak in PVC pipe compared to metallic pipe.

A graph of pipe leaks broken down by month is also included in Figure 57. It is important to note that more leaks were found on the months where leak investigations were conducted on multiple days, allowing the field crew to investigate more POIs.

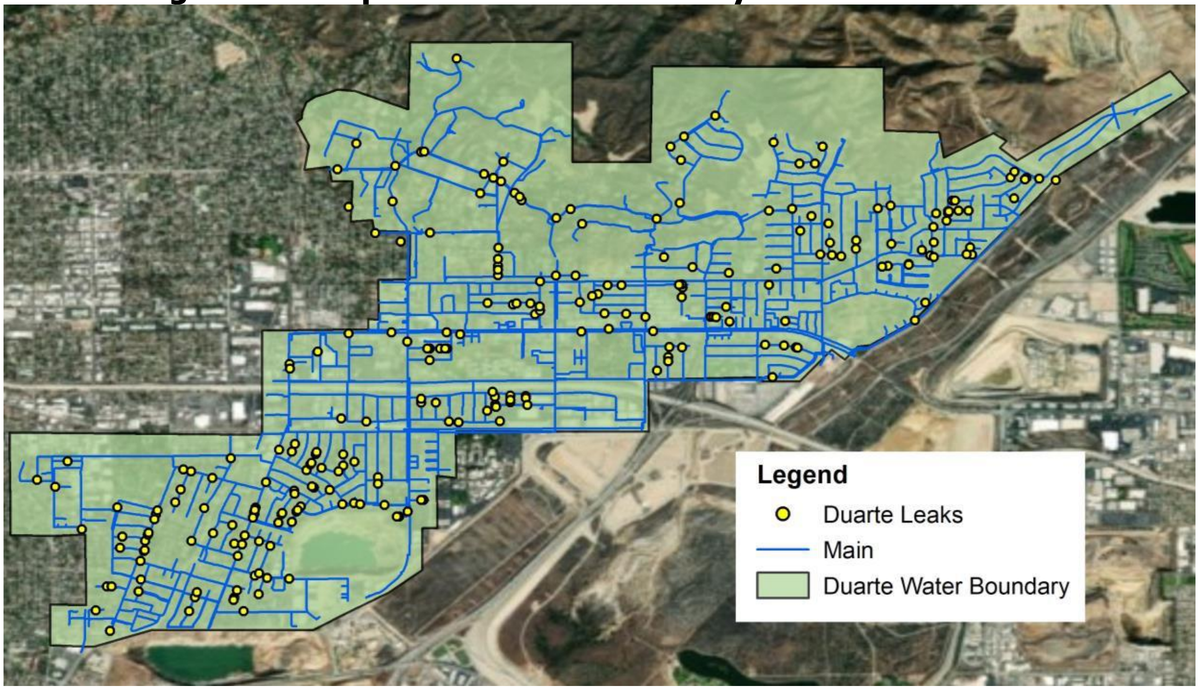
Figure 57: Leaks Found per Month



Source: Hazen and Sawyer, American Water

Figure 58 highlights leak locations within Duarte from May 2017 to June 2018. Although there is a fairly even distribution of leaks geographically across the system, it is interesting to note that leaks often occur in clusters: either multiple leaks in a line along the same street, or within a tight grouping of parallel streets. This could potentially be attributed to similar issues such as a consistent soil type causing corrosion or settlement, a bad pipe batch installed at the same time, poor construction technique, or simply pipe age and reaching the end of its useful life at the same time.

Figure 58: Map of Duarte Leaks – May 2017 to June 2018



Source: Hazen and Sawyer, American Water

Leak "Hits and Misses" Analysis

Additional analysis was conducted on the 288 leaks found in the Duarte system from May 2017 to June 2018. The additional analysis looked closer into both the "hits" and "misses" of each technology. The questions investigated in the additional analysis on "hits and misses" include:

- Where did both technologies find the same leak?
- Where did Utilis find a leak and Echologics did not?
- Where did Echologics find a leak and Utilis did not?
- Where did both technologies miss the same leak?

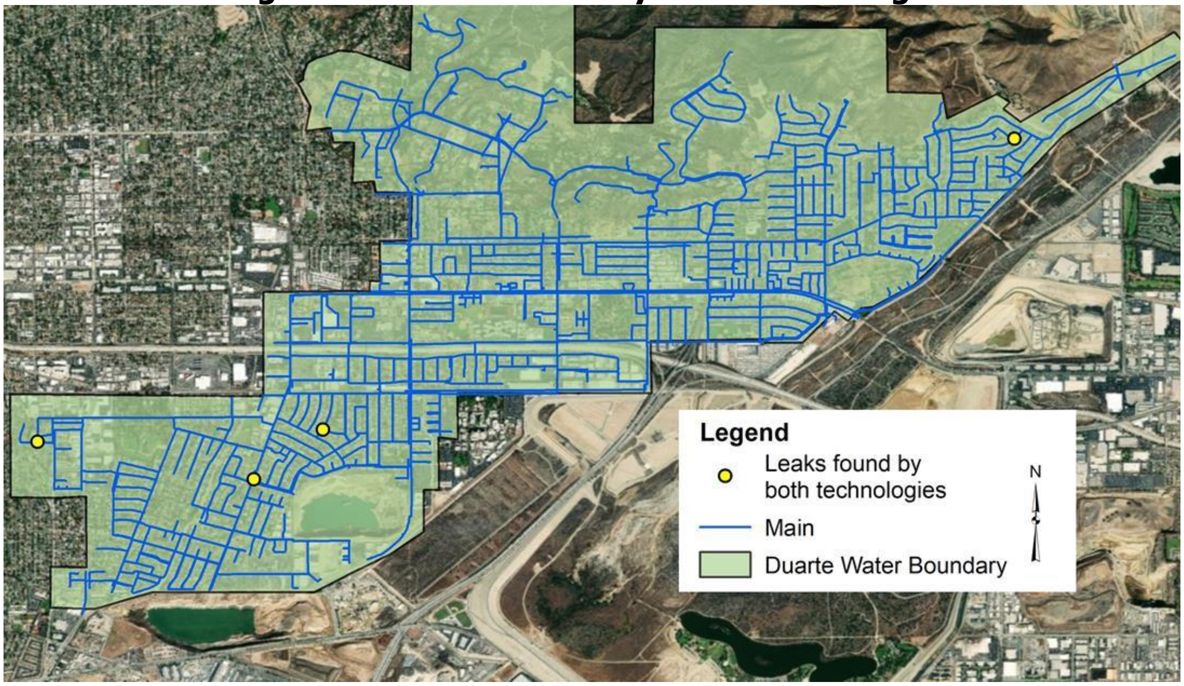
Figure 59 shows four leaks found by Utilis and Echologics. These leaks were found during the second half of the study period when field investigations were more frequent. Beyond that, there was no notable common characteristics among these three points such as leak flow, pipe material, or vicinity.

Table 17: Leaks Found by Both Technologies

Investigation ID	Investigation Date
H153	1/30/2018
H181	2/7/2018
H270	2/22/2018
H315	4/19/2018

Source: Hazen and Sawyer, American Water

Figure 59: Leaks Found by Both Technologies



Source: Hazen and Sawyer, American Water

Utilis found 117 leaks during the study period. Table 18 contains a breakdown of the confidence interval for these 117 leaks.

Table 18: Confidence Interval for Leaks Found by Utilis

POI Confidence Interval	Leaks Found (%)
Low	8%
Medium	9%
High	40%
Very High	41%

Source: Hazen and Sawyer, American Water

Utilis missed 171 leaks in the Duarte system during the study period, which includes 155 surfaced leaks not found by either technology plus 16 leaks found only by Echologics. Table 19 represents the confidence interval for POIs generated by Utilis, but upon investigation no leak was found.

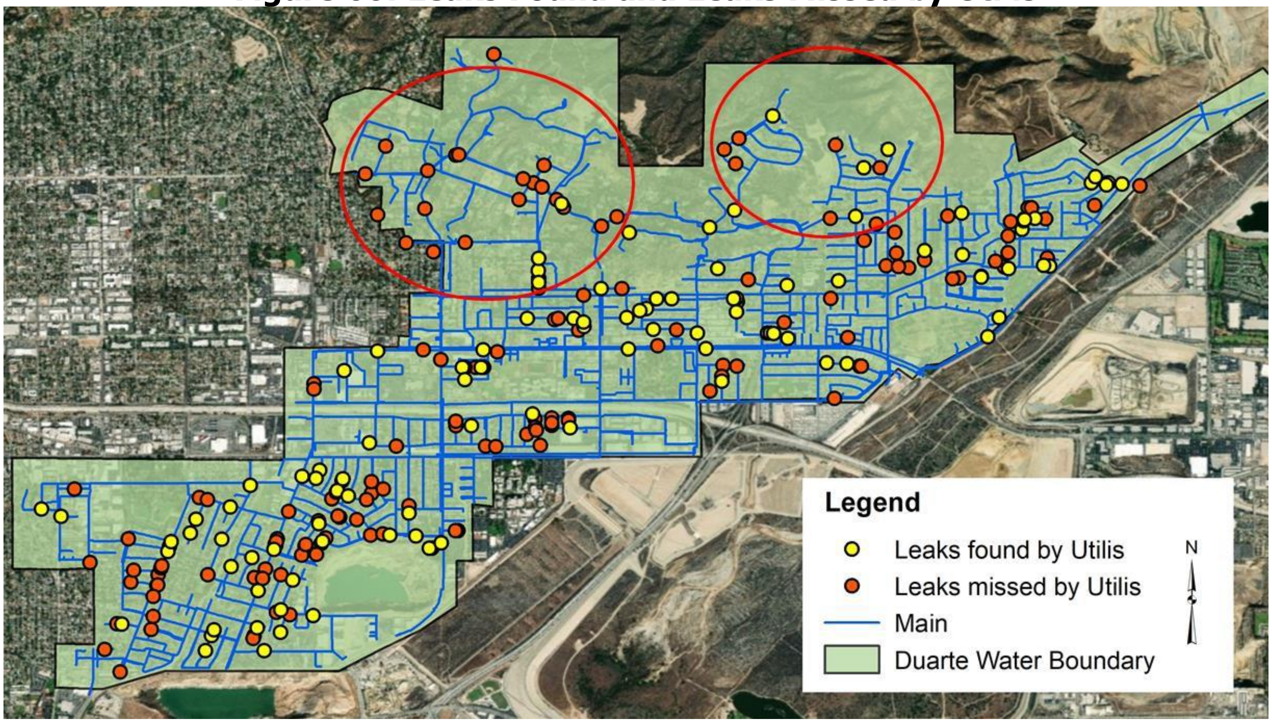
Table 19: Confidence Interval for Utilis False Positives

POI Confidence Interval	No Leaks Found (%)
Low	7%
Medium	20%
High	27%
Very High	47%

Source: Hazen and Sawyer, American Water

Figure 60 summarizes the leaks found and leaks missed by Utilis. The red circles in the figure indicate the hilly areas within the service area. It is understood that the technology can have challenges in pinpointing leaks in hilly areas due to the potential for the underground leakage to migrate away from the leak down the hill.

Figure 60: Leaks Found and Leaks Missed by Utilis



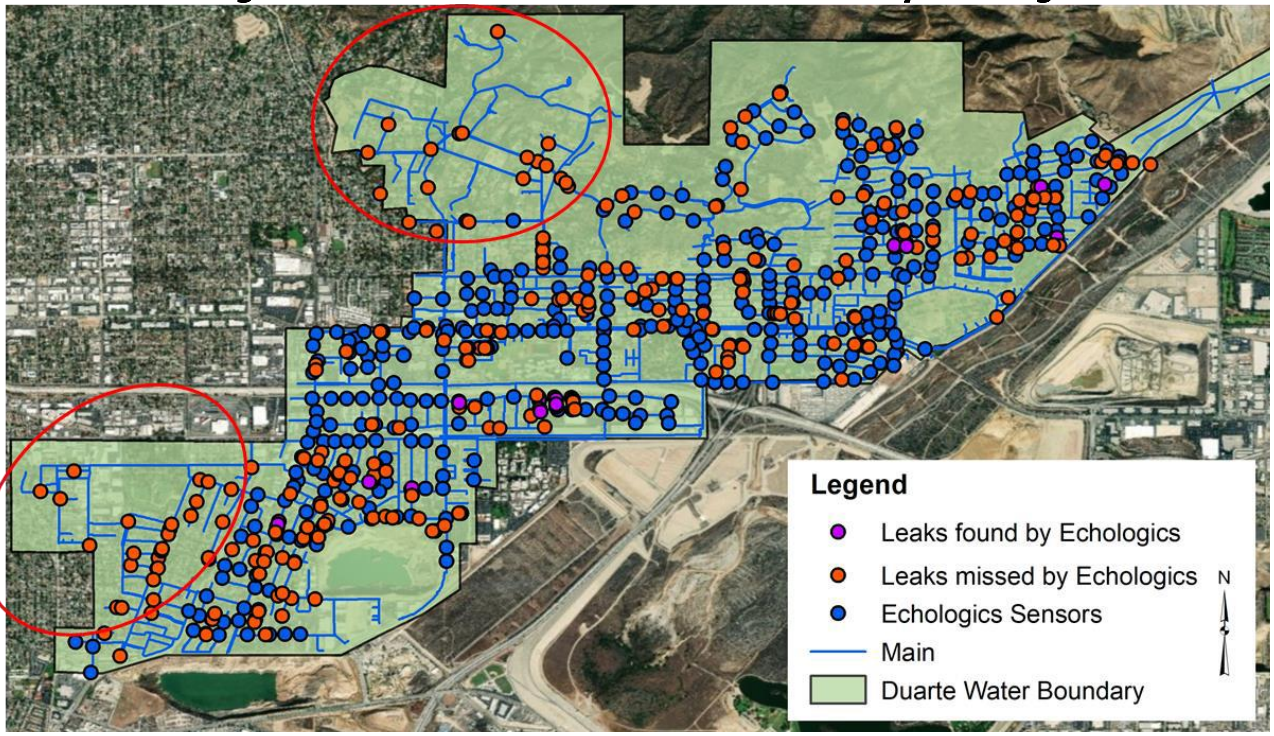
Source: Hazen and Sawyer, American Water

Echologics missed 268 leaks within the Duarte system, which includes the 155 leaks missed by both technologies, plus 113 leaks found only by Utilis. Figure 61 depicts leaks found and leaks missed by Echologics along with the sensor locations. The red circles in the figure are areas where Echologics did not have sensors installed, so it is expected that leaks would not be found by Echologics in those areas.

Both technologies missed a total of 155 leaks. Figure 62 shows the 288 leaks found during the study period including those found and missed by the technologies.

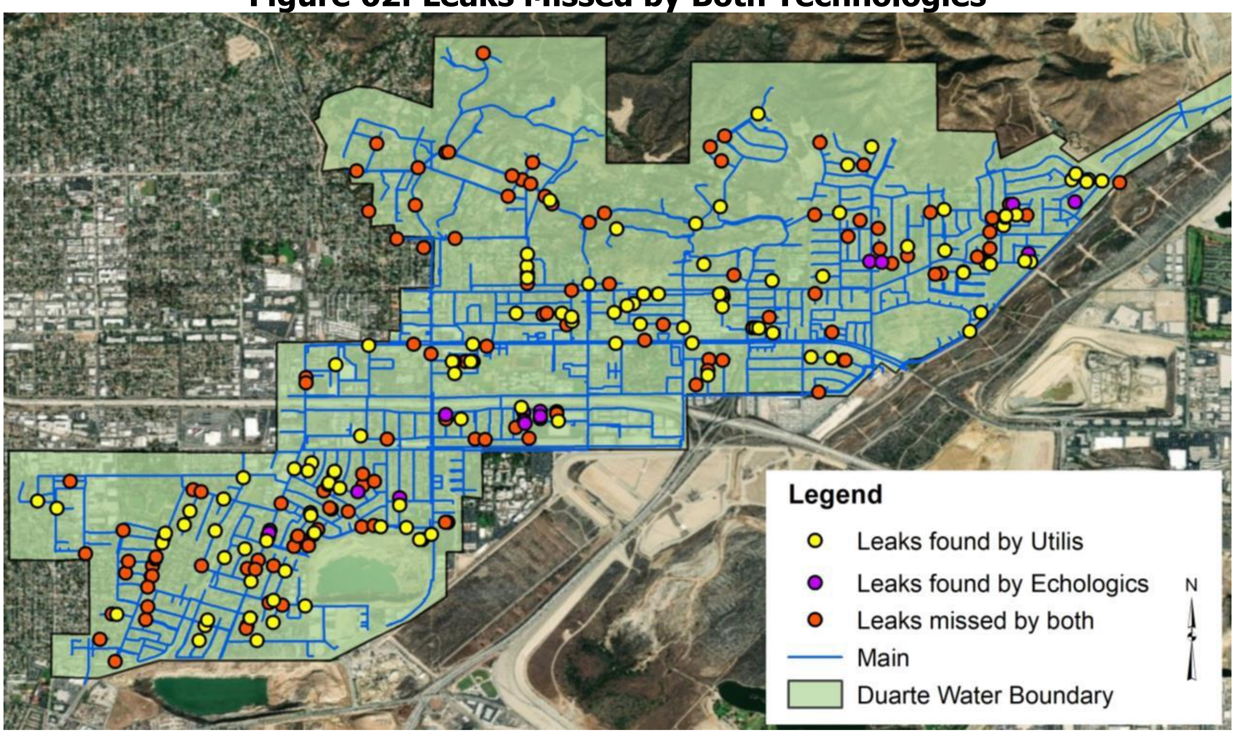
Additional statistical analysis was performed on the Utilis and Echologics leak investigation data to quantify the probability of finding a leak when an investigation occurred. This analysis was based on conditional probability theory described by Bayes' Theorem. Although the analysis provided insights about metrics such as false positives (specifically the probability of finding no leaks when an investigation occurred), it did not provide meaningful insights beyond those described by simpler analyses.

Figure 61: Leaks Found and Leaks Missed by Echologics



Source: Hazen and Sawyer, American Water

Figure 62: Leaks Missed by Both Technologies



Source: Hazen and Sawyer, American Water

Financial Metric Discussion for Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection

A financial metric analysis on payback duration or return on investment (ROI) for both technologies is not included in this report due to the limited nature of the study and the subsidized cost of implementation from the vendors. These analyses should identify investment costs for each technology including costs of technology deployment, leak detection equipment and training, and staff labor in locating leaks. The return or savings component of the calculations should look at energy savings and cost of water savings. However, the savings associated with avoidance of major leaks and potential damages would have to be estimated and would be a large source of error in any such estimates of ROI.

Using CCAM and SILD results in the early detection of leaks before they surface. Some leaks surface in the form of small leaks that slowly pool at the surface and result in minimal damage and community disruption. However, some leaks can result in major disruptions including sinkholes, property damage, street closures, and numerous staff and construction resources before the leak is fixed and the area returned to normal.

Estimating the savings associated with the avoidance of these events is difficult, which is a primary reason why financial metrics like payback duration and ROI are not included in this report.

Flow Sensitive Pressure Reducing Valves

FSPRV technologies such as the Stream Control AG system use the pressure management strategy. These technologies allow for pressures in a zone or system to be lowered as demands decrease. The Stream Control AG System data analyses discussed in this chapter include:

- Reduced stress on pipes due to lower pressure.
- Reduced water lost during pipe breaks due to lower pressure.
- Reduced water use during decreased demand periods.

The following sections include data analysis discussions based on the AG system deployments in the San Diego County and Ventura County Districts.

San Diego County District

The AG system was deployed in the San Diego County District at the Beyer PRV. The details for the deployment and the system served by the Beyer PRV are included in Chapter 1.

Elevations in the Beyer PRV zone range from 60 to 155 feet. Due to the large difference in elevation within the zone, downstream pressure at the PRV cannot be reduced more than 10 psi to maintain required minimum pressures at the highest elevation in the zone.

Reduced Stress on Pipes

At the Beyer PRV, the AG system settings reduced pressure in the zone by 10 psi during low demand periods – approximately midnight to 5 am. However, results from this deployment were inconclusive as to whether reduced pressure in the zone would lead to fewer pipe breaks. The inconclusive findings were because the area had not experienced significant pipe breaks and leaks before the AG deployment. As a result, a "before/after" comparison could not be made. However previous studies have shown that pipe break frequency increases exponentially with a rise in pressure, therefore this technology should be further investigated in areas where there are high pressure changes at night and/or where there is a history of nighttime pipe breaks.[8]

Reduced Water Lost During Leaks

When pipe breaks occur, the leak flow is a function of pressure in the pipeline, and the size (area) of the leak. Assuming the size of the leak is the same, the leak flow at a higher pressure can be directly compared with the leak flow at a lower pressure. For the Beyer PRV, the typical pressure at a point in the zone is 70 psi and the AG system reduced the pressure to 60 psi during the low demand periods. The following formulas, adapted from AWWA M36, can be used to calculate break flow and leak flow. Equation 1 (Table 20) can be used to determine leak flow as a function of flow rate. Equation 2 (Table 21) is used to find leak flow as a function of leak size.

$$Equation\ 1\text{: } \boldsymbol{Q\ at\ actual\ pressure\ P_a} = (\boldsymbol{Q\ at\ 70\ psi})\left[\left(\frac{\boldsymbol{P_a}}{\boldsymbol{70}}\right)^{\boldsymbol{0.5}}\right]$$

Where:

Q = flow (gpm)
P_a = actual pressure (psi)

$$Equation\ 2\text{: } \boldsymbol{Q} = (\boldsymbol{22.796})(\boldsymbol{A})(\boldsymbol{P^{0.5}})$$

Where:

Q = flow (gpm)
A = the cross-sectional area of the leak (in.^{2})
P = pressure (psi)

Table 20: System Leak Flow Reduction

Parameter	Value
Q at 70 psi	10 gpm
Actual pressure P_a	60 psi
Q at actual pressure P_a	9.3 gpm
Flow Reduction (%)	7%

Source: Hazen and Sawyer, American Water

Table 21: Leak Flow at 70 psi vs 60 psi

Parameter	Value
Leak Diameter	0.5 in
Q at 70 psi	37.4 gpm
Q at 60 psi	34.7 gpm
Flow Reduction (%)	7%

Source: Hazen and Sawyer, American Water

[8] Lambert, A. (2013, March). Leakage Reductions – The Fundamental Role of Pressure Management. *Water World Magazine*.; Kunkel, p.259

The theoretical leak flow reduction when the system is at 60 psi compared to 70 psi would be approximately 0.7 gpm or 7 percent of the original flow. As discussed in the Energy Analysis section, leaks can conservatively go on for 60 to 180 days of awareness time, so the corresponding reduction in leak flow equates to a total volume of 0.06 MG to 0.18 MG per leak.

It should also be noted that additional research has been conducted on the pressure- leakage relationship including the theory of fixed and variable area discharge paths (FAVAD)[9]. The FAVAD theory states that the exponent in Equations 1 and 2 is not fixed at 0.5 but can vary up to 2.5 for certain types of leaks. It is now common to assume an exponent of 1.0 (rather than 0.5) for background leakage.

With the FAVAD theory assumptions, the leak flow reduction when the system is at 60 psi compared to 70 psi would be 1.4 gpm per leak. With leak durations from 60 to 180 days, the corresponding reduction in leak flow equates to a total volume of 0.12 MG to

0.36 MG per leak, and 744 kWh to 2,232 kWh per leak when converted to energy for the San Diego County District. These values would clearly be magnified when projected across multiple leaks in a system over years of operation. For a system like Duarte that experienced more than 200 detected leaks in 2018, scaling this leak reduction would be equivalent to 24 MG to 72 MG of leak reduction savings and an equivalent of 149,000 kWh to 446,000 kWh of energy saved.

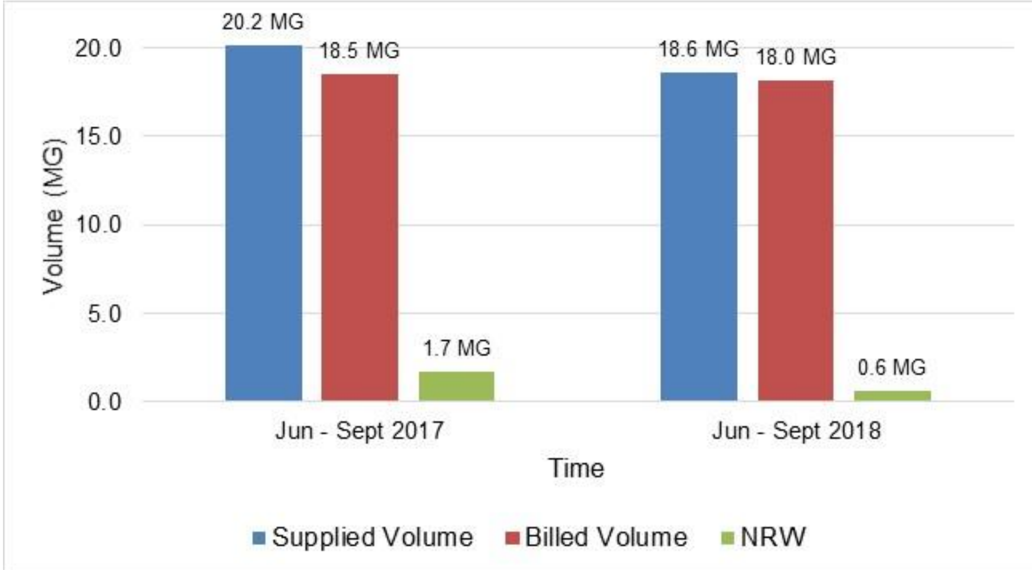
Reduced Water Use During Decreased Demands

The relationship between pressure and consumption is discussed in AWWA M36. For residential customers, more than half of consumption is volumetric, meaning water is used to fill a toilet, or fill a washing machine, or fill a pot. Therefore, total consumption for these activities would not be changed as pressure decreases. Also, it is important to note that the AG system lowers pressures only during lower demand periods, so any change in total consumption due to lower pressures would be less noticeable. If irrigation is the predominant component of consumption, however, reduced pressures could have a small impact on total consumption.

Another metric investigated was non-revenue water totals before and after the AG system installation for the Beyer PRV zone. Monthly billing data was obtained and compared with the actual flows into the zone to determine non-revenue water (NRW), shown in Figure 63. Beyer AG system was fully operational in June 2018, so data from June to September 2017 and 2018 were used for comparisons. The higher flows supplied to the zone in 2017 compared to 2018 was most likely attributed to the broken valve discovered in the zone after the flow meter was installed and flows were being monitored.

[9] Kunkel, p.178

Figure 63: Supplied vs Billed Water Comparison in Beyer Pressure Reducing Valve Zone



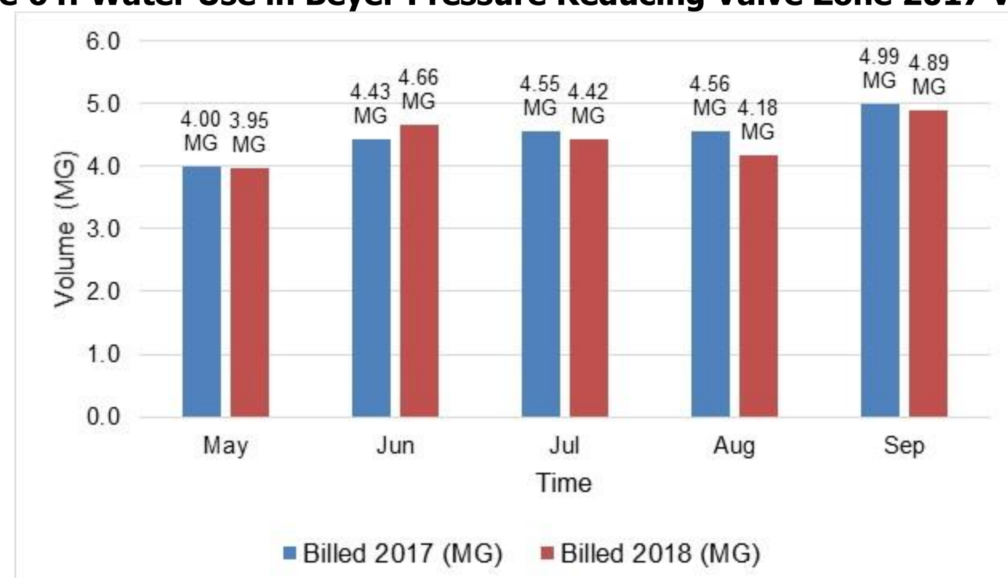
Source: Hazen and Sawyer, American Water

Water Use

Water use data from 2017 and 2018 was compared to check if the implementation of the AG system lead to a decrease in the amount of water consumed in the system.

Billing data from May through August 2017 was used for comparison to the same period in 2018, since the AG system was first installed in May 2018 (Figure 64).

Figure 64: Water Use in Beyer Pressure Reducing Valve Zone 2017 vs 2018



Source: Hazen and Sawyer, American Water

Ventura County District

The Aqua-Guard system was also deployed in the Ventura County District at the Dos Vientos Del Prado PRV and the Dos Vientos Via Estrella PRV. The details for the deployment and the system served by the PRVs are included in Chapter 1. Since both PRVs serve the same zone and the AG system was configured to make the Del Prado PRV the primary supply point into the zone, the focus of this discussion will be on the Del Prado PRV.

Elevations in the Del Prado PRV zone range from 757 to 884 feet. When downstream pressure at the Del Prado PRV is 90 psi, the pressures in the zone range from 43 to 99 psi. Due to the large difference in elevation within the zone, downstream pressure at the PRV cannot be reduced more than 8 psi, which equates to a modified range of 35 to 91 psi.

Reduced Stress on Pipes

At the Del Prado PRV, the AG system settings reduced pressure in the zone by 8 psi during low demand periods – approximately 10 am to 5 pm. The interesting aspect of this pressure zone is it seems to follow an "inverse diurnal pattern" where the consistent low flow period is for an extended time during the day rather than at night. It is estimated that residential irrigation and school/park irrigation push demands higher in the evening and early morning hours. Flows consistently drop to below 150 gpm around 10 am and stay below until around 5 pm.

Similar to the San Diego County system, the rationale that reduced pressure in the zone leads to less pipe breaks could not be supported based on this deployment because the area had not previously experienced significant pipe breaks and leaks, so a "before/after" comparison could not be made.

Reduced Water Lost During Leaks

Like the Beyer PRV calculations, a corresponding rate of leakage was calculated for a reduction of pressure from 80 psi to 72 psi. The calculated leak flow reduction when the system is at 72 psi compared to 80 psi is 0.51 gpm. Given the conservative assumption of 60 to 180 days leak duration, the corresponding reduction in leak flow equates to a calculated total volume of 0.04 MG to 0.13 MG per leak.

With the FAVAD theory assumptions, the leak flow reduction when the system is at 72 psi compared to 80 psi is 1 gpm. With leak durations from 60 to 180 days, the corresponding reduction in leak flow equates to a total volume of 0.09 MG to 0.26 MG per leak, and 972 kWh to 2,807 kWh per leak when converted to energy for the Ventura County District.

District Metering

Key statistics associated with DMAs implemented in both the San Diego County System and Ventura County System are included in the following sections.

San Diego County System

Beyer PRV DMA

Table 22 shows some key metrics associated with the Beyer PRV DMA. The Beyer PRV DMA consists of 629 residential meters and has been established for more than a year allowing data to be compared across different seasons.

Table 22: Beyer Pressure Reducing Valve District Meter Area Average Flow Data

Monitoring Period 10/1/17 to 10/1/18	Value
Total Meters (#)	629
Daily Flow - All Year (gpm)	99
Daily Flow - June to Sept (gpm)	106
Daily Flow - Dec to Mar (gpm)	91
Gallons per meter per day - All Year	226
Gallons per meter per day - June to Sept	242
Gallons per meter per day - Dec to Mar	208
Gallons per day - All Year	141,854
Gallons per day - June to Sept	152,403
Gallons per day - Dec to Mar	130,647

Source: Hazen and Sawyer, American Water

The data shows the variation in consumption between the winter and summer months is not substantial, with the winter months being approximately 8 percent below average, and the summer months being 7 percent above average. This is most likely attributable to the mild climate associated with proximity to the ocean.

Ventura County System

Via Estrella PRV and Del Prado PRV DMA

Table 23 shows some key metrics associated with the Via Estrella and Del Prado DMA. The DMA includes a total of 783 meters. Although primarily single-family residential land use, the DMA includes an elementary school and commercial meters (restaurants). The elementary school and non-residential customers have a significant impact on the total flow into the DMA.

Table 23: Via Estrella and Del Prado Pressure Reducing Valve District Meter Area Average Flow Data

Monitoring Period 5/23/18 to 10/21/18	Value
Total Meters (#)	783
Daily Flow - (gpm)	315
Daily Flow - June to Sept (gpm)	324
Gallons per meter per day - Average	579
Gallons per meter per day - June to Sept	596
Gallons per day - Average	453,356
Gallons per day - June to Sept	467,002

Source: Hazen and Sawyer, American Water

Dos Vientos Booster Station and Dos Vientos Zone 3 Booster Station DMAs

Table 24 and Source: Hazen and Sawyer, American Water

Table 25 show some key metrics associated with these Dos Vientos Booster Station and Dos Vientos Zone 3 Booster Station DMAs. As described in Chapter 2, the DMAs are set up by metering flow on the primary pump discharge line that serves the DMA. With this configuration, the data captured is different than a traditional DMA like the Via Estrella and Del

Prado PRV DMA. The Dos Vientos Booster Station DMA includes the Via Estrella and Del Prado PRV DMA.

Table 24: Dos Vientos Booster Station District Meter Area Average Pump Flow Data

Monitoring Period 8/29/18 to 10/10/18	Value
Total Meters	1,971
Daily Flow When Operating (gpm)	2,525
Pump Run Time (hrs)	10.7
Water Volume Delivered Per Pump Run (MG)	1.61

Source: Hazen and Sawyer, American Water

Table 25: Dos Vientos Zone 3 Booster Station District Meter Area Average Pump Flow Data

Monitoring Period 8/29/18 to 10/10/18	Value
Total Meters	77
Daily Flow When Operating (gpm)	355
Pump Run Time (hrs)	11.9
Water Volume Delivered Per Pump Run (MG)	0.25

Source: Hazen and Sawyer, American Water

CHAPTER 4:
Technology Evaluation and Improvement

Introduction

Four leak detection and mitigation technologies and strategies were used for this project: correlating continuous acoustic monitoring (CCAM), satellite imagery leak detection (SILD), flow sensitive pressure reducing valves (FSPRVs) and district metered areas (DMAs). This chapter focuses on the technologies: CCAM, SILD, and FSPRV, and includes a discussion on the use of DMA as a leak detection strategy.

Included in this chapter is an evaluation of each technology, discussion of technology improvements that were made during the implementation of the project, a discussion of barriers to overcome for each technology and strategies for overcoming those barriers, and a comparison of the performance of CCAM with SILD in the Duarte system.

Correlating Continuous Acoustic Monitoring

Technology Evaluation

The CCAM technology by Echologics was evaluated based on the primary topics of deployment and field investigations, vendor support, and technology performance. The details of each of those topics are included in other chapters, so the focus of this discussion is on the evaluation of the technology related to those topics.

Deployment and Field Investigations

Echologics sensors were deployed in May 2017 and commissioning began in late June 2017. The Chapter 1 discussion on deployment described how Echologics needed to modify their sensor to fit on some of the hydrants within the Duarte system. Another issue encountered was the presence of PVC in the system. Acoustics in a PVC system are different than a metallic system and both the sensors and algorithms for generating POIs needed to be modified. Echologics conducted research and development with the goal of developing a product to test leak locating in a PVC system, however it was not able to be developed within the project schedule.

After the deployment of the technology, field investigations were conducted to pinpoint leaks. Details of how field investigations take place are included in Chapter 2. As described in Chapter 2, successful field work requires the right equipment, the proper training, and staff resources allocated to leak detection and pinpointing. In addition, the following topics are further discussed in Chapter 2 and should be considered when others deploy this technology in the future:

- The use of leak sheets in pinpointing leaks.
- Timing and logistics of field investigations.
- Factors that can create false positives.
- Data collection.

The timing and logistics of field investigations must be considered. Field investigations should only be conducted during periods of minimal ambient noise and water usage.

This includes essentially zero noise from traffic or other noise sources that would be picked up by the sensors. For a residential neighborhood, the middle of the day works well because most people have left their homes for work in the morning, so traffic and water use are at a minimum. For areas like busy streets, field investigations must take place in the middle of the night because any traffic noise will make it very difficult to identify leaks.

Causes of false positives should be considered when others use this technology. As described in Chapter 2, false positives can be caused by electrical interference, noise created by distribution facilities like pressure reducing valves and pumps, or vibrations or other noise coming from private facilities. The acoustic sensors are highly sensitive and will pick up noise from any of those nearby sources, and that noise would interfere with field investigations of leak pinpointing as well.

Managing the data from POIs, leak investigations, and leak repairs is a factor that should be considered for future deployments. This data can provide valuable insights on leak trends in a system or planning pipe replacement projects, as well as data to report to management. Collecting and managing the data from implementing a leak detection program could be led by internal staff, an outside consultant, or Echologics, based on the service contract in place.

Vendor Support

Once the technology was installed, Echologics supported the leak investigation phase by:

- Daily monitoring of acoustic sensors for POIs and leak investigation recommendations.
- Maintaining their online web application showing POIs and system parameters.
- Maintaining a Google Document listing the recommended POIs for field investigations, including providing leak sheets for the latest field investigations.
- Weekly reports on key acoustic sensors on transmission mains.
- Email/phone correspondence as needed to support the work.
- Occasional field visits to support the leak investigations and equipment maintenance.

Echologics assigned a project manager to support the leak investigations and acoustic sensor monitoring throughout the project. The project manager was responsive in answering questions on leak investigation findings, maintaining the Google Document with POI recommendations, and supporting the local team in various ways throughout the project. The Echologics project manager was not local, so support in the field was limited. However, when support in the field was provided, it was beneficial to the leak detection team in providing further training on operating the leak detection correlation equipment and helping to interpret findings.

Different levels of support from the vendor are available based on the services contract set up by the end user.

Performance Metrics

Performance metrics for the Echologics CCAM technology deployed in the Duarte System are included in Chapter 3 and summarized in Table 26.

Table 26: Echologics Leak Data

Parameter	Value
Miles of Pipe Investigated (mi)	5
Total POIs Provided (#)	77
POI Provided per mile (#)	15
Total POIs Investigated	49
POIs Investigated per mile (#)	10
POI Investigated per POI Provided	64%
Total Leaks Found (#)	20
Leaks Found per Mile Investigated (#)	3.8
Leaks Found per POIs Investigated	41%
Leaks Found per POI Provided	26%
Labor per POI Investigated (hours)	1 to 3
Average Labor per Leak Found (hours)	4.9

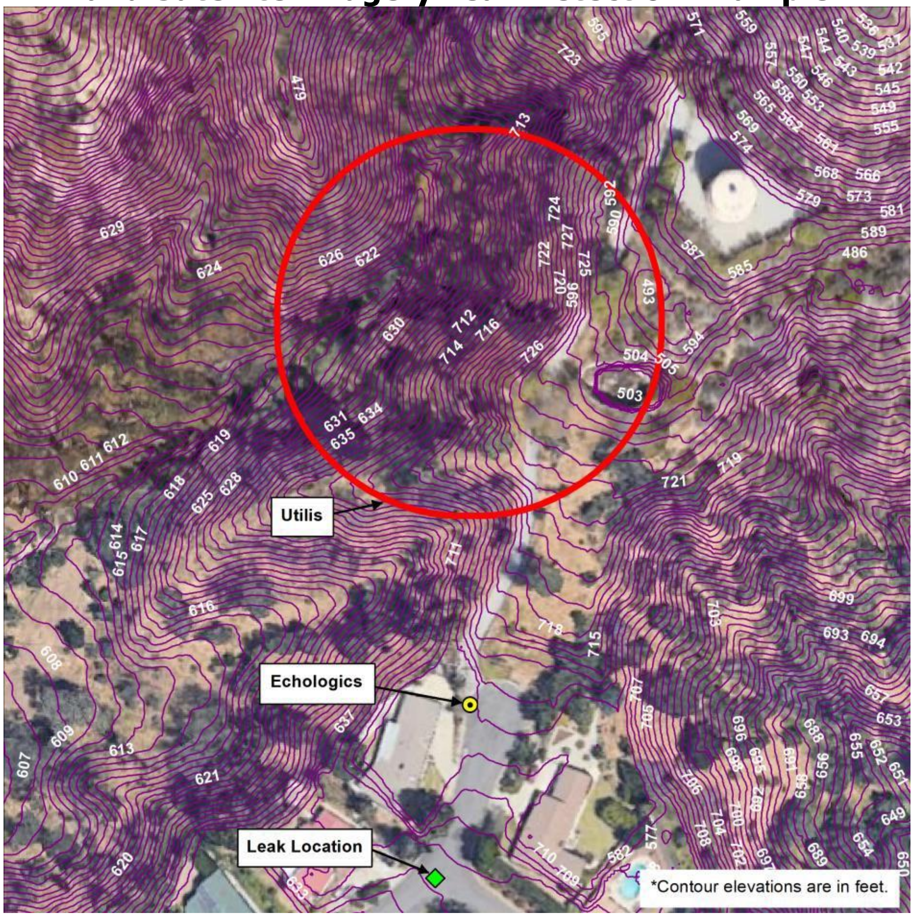
Source: Hazen and Sawyer, American Water

One finding from the field investigations was the prevalence of false positives created by non-leak noise sources. The noise was often caused by sources such as electrical harmonics or water system distribution facilities, like pressure reducing valves.

Another finding was the relatively low quantity of leaks found, a result of not investigating POIs in areas with a prevalence for non-leak noise getting recorded by the sensors. POIs recommended for investigations had to pass a series of criteria developed by the Echologics team including a consistent noise pattern for a multiple-day period that was not at a location impacted by false positive influences.

A key feature of Echologics CCAM technology, is its ability to provide more precise locations of the possible leaks as illustrated in Figure 65.

Figure 65: Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection Example



Source: Hazen and Sawyer, American Water

Figure 65 is an example of possible leak locations predicted by CCAM and SILD technologies compared to the actual location of the leak found during field investigations. Although the example depicted above was not a frequent occurrence, it does capture a key difference between the technologies where topography and other factors can influence findings. A comparison of the Echologics CCAM performance to the Utilis SILD performance is included later in this chapter.

Technology Enhancements and Improvements

As the project progressed the leak investigation team would regularly correspond with the Echologics project manager on the field investigations, including challenges and findings. One of the challenges brought up to the Echologics team was the need for more refinement of the POI and the specific hydrants to correlate to when conducting field investigations.

Initially the POIs were provided in the form of an address and a coordinate. If an address brought the team to a 3-way or 4-way intersection with multiple pipelines in each street, the field investigation team had to correlate between multiple sets of hydrants before being able to locate the leak. If the findings were difficult to interpret, it was unclear if the point was the POI intended by the Echologics team, or if this was an additional finding. This added to the duration of field investigations, and potentially hindered the results.

Echologics' response to this challenge was creating leak sheets to accompany the POI recommendations. The leak sheets would show the pipelines in the area, the exact location of the POI on a particular pipeline, and the hydrants to correlate between.

Although not altering the technology itself, this was a significant improvement in the services provided by Echologics because it reduced the field investigation time at each POI and made it more efficient.

Key improvements implemented in the span of this project included:

1. Refinement of the correlators such that "leak noise", typically 10-1000 Hz, could be detected more easily above other sources of noise in the same frequency.
2. Development of "leak sheets" with POI locations and map facilitated in the reduction of labor-hours per POI.
3. Modified acoustic sensors to fit the hydrants in the Duarte System. This will allow Echologics to implement future installations in different types of hydrants.

Barriers to Overcome

Three primary areas of improvement were identified for Echologics' CCAM technology:

- Adaptation to PVC/plastic pipes
- Reduction of false positives, increased quantity of leaks
- Increasing local vendor support

The CCAM technology by Echologics is currently only intended for metallic piping systems, with the sensors and algorithms for PVC and other plastic pipes currently in research and development phase. PVC pipe is the predominant pipe material of choice for many systems in California, especially newer ones. For Echologics to be able to serve these systems with leak detection services, acoustic sensors and algorithms for PVC systems must be developed.

For this project, there was a high quantity of false positives and a relatively low quantity of leaks found. Based on the level of investment of installing acoustic sensors on hydrants and daily monitoring of the results, there was an expectation that the deployment would result in both a higher quantity of leaks, and a higher success rate based on POIs investigated. This is a barrier that must be overcome for future deployments, however one of the ways to improve in this area would be to provide local vendor support during the field investigations.

Local vendor support provides first-hand experience in understanding a system and the surrounding conditions. It allows the vendor to make better informed decisions on which POIs are worth investigating and which are most likely false positives. It was concluded that a higher success rate in the field and a higher quantity of leaks would have been achieved if the Echologics project manager were local and could be out in the field with the leak investigation team more often. For future deployments, providing local vendor support is highly recommended. It is recommended that Echologics include service contracts with their technology deployment that allow a local project manager to spend a significant amount of time with the leak investigation team and in the field.

Applicability to Other Systems

There are some key factors to consider when assessing the applicability of the Echologics CCAM technology to other systems. First, a system must be able to justify the capital expenditure to deploy the technology, purchase the leak locating equipment, conduct training, and have staff availability to conduct leak investigations. In addition to the leak investigation field team, at least one additional person should be assigned to coordinate/manage the crew, lead data collection and analysis, and be the primary contact with the vendor. If the acoustic sensors are going to be deployed in an area where there is a lot of ambient noise during the day, then leak investigations will need to be conducted late at night.

For the Duarte system, which is approximately 100-miles of distribution pipe, a leak investigation team of two people was available for 3 to 6 days per month which was appropriate for the number of leak investigations that were occurring monthly.

It should be noted that this technology can be used on a portion of the system, and not necessarily the entire system. It can be deployed in an area where there is historically a high leak rate, or high probability of failure/consequence of failure ratings.

It can also be used in conjunction with the SILD technology by Utilis. SILD can be used to identify potential high leak areas within a system, and Echologics CCAM technology can be deployed in certain areas based on the SILD results. This leverages the advantages of both technologies since SILD can cover a large area and doesn't require any equipment deployment, and CCAM deployment can be limited to only the areas where there is a high leakage rate in the pipelines.

Regarding the system characteristics, a predominantly metallic pipe system is preferred for deployment of the acoustic sensors until Echologics develops the technology for PVC/plastic pipe systems. As far as system size, any size is feasible if there is a network of hydrants available to install the acoustic sensors. There is no minimum size, and a maximum size is based on available budget and resources but as stated previously it can be advantageous to focus on specific areas of a large system.

Summary of Technology Evaluation and Improvements

Table 27 summarizes key takeaways regarding CCAM technology evaluation and improvements.

Table 27: Echologics Technology Evaluation Summary

Performance Metrics	Applicability to Other Systems	Barriers to Overcome
• POIs Provided: 77 • POIs Investigated: 49 • Total Leaks Found: 20 • Leaks Found per POIs Investigated: 41% • Average Flow per Leak (gpm): 17 • Leaks Found per Mile Investigated: 3.8 • Miles of Pipe Investigated: 5 • Average Labor per POI Investigated (hours): 1 to 3 • Average Labor per Leak Found (hours): 4.9	• Any size system or portions of systems • Metallic pipe system	• Adaption to PVC/plastic pipes • Reduction of false positives • Increasing local vendor support

Source: Hazen and Sawyer, American Water

Satellite Imagery Leak Detection

Technology Evaluation

The CCAM technology by Echologics and SILD technology by Utilis were both deployed in the Duarte System. The Utilis SILD technology was also evaluated based on the primary factors of deployment and field investigations, vendor support, and technology performance. The details of each of those topics are included in other chapters, so the focus of this discussion is on the evaluation of the technology related to those topics.

Deployment and Field Investigations

The Utilis SILD technology was evaluated based on deployment logistics and field investigations. Utilis monthly scans covered the entire Duarte system. Since there is no equipment to be installed, Utilis only requires basic system information: GIS shapefiles of the area of interest (system boundary), and the pipe network. The first data delivery provided by Utilis was in May 2017 and continued for 12-months with Utilis providing monthly data deliveries of POIs.

Monthly data deliveries of POIs are prioritized from low, to medium, to high, to very high confidence levels. In addition, the leak investigation team would request Utilis to identify a prioritized list of POIs to focus the field investigation effort for the month, depending on the number of days available to conduct the investigations. Details of how field investigations take place are included in Chapter 2. Successful field work requires the right equipment, proper training, and staff resources allocated to leak detection and pinpointing. In addition, the following should be considered in future deployments of this technology:

- The use of leak sheets in pinpointing leaks (different from Echologics).
- Timing and logistics of field investigations (same considerations as Echologics).
- Factors that can create false positives (different from Echologics).
- Data collection (same considerations as Echologics).

Leak sheets and the field investigation process are different for Utilis POIs compared with Echologics POIs. Utilis leak sheets are 1-page summaries of the Utilis POI that show the POI limits and the system pipelines overlaid on an aerial map. The Utilis leak sheets are available on their online web application, the mobile application, or as pdfs and hard copies. The leak investigation process for Utilis POIs is to walk the complete limits of the POI and open every meter box and listen for leak noise. Each POI for the Duarte system took an average of 3.8 labor-hours or 1.9 labor-hours per 2-person for each POI (see Chapter 3 for further explanation on this).

The leak sheets were a valuable tool in conducting the field investigations in that they confirmed the limits to be covered for each POI investigation. Even when a leak was found, the recommended methodology was to complete the investigation for the entire limits of the POI because multiple leaks could be found, which was the case for some POIs in the Duarte system.

Timing and logistics of field investigations is the same for SILD as it is for CCAM. Field investigations should only be conducted during periods of minimal ambient noise and water usage. This includes essentially zero noise from traffic or other noise sources that would get picked up by the sensors. Any cars driving by would hinder the ability to hear leak noise. For areas like busy streets, field investigations must take place in the middle of the night to minimize traffic noise.

Causes of false positives should be considered when others deploy this technology. As described in Chapter 2, the SILD technology detects treated water saturating the below grade soil. Although finding leaks on the public water system is the priority, the technology will also pick-up private leaks, such as irrigation line leaks. If the technology is being deployed in areas where there may be a high quantity of private system leaks, locating leaks on the public system may be a challenge. Another consideration regarding false positives is the pipe material. Although the SILD technology of identifying POIs is not dependent on pipe material, pinpointing the leaks using acoustic correlation equipment will be challenging if the system is predominantly non-metallic material. This should be a consideration when deploying this technology.

Managing the data from POIs, leak investigations, and leak repairs has the same considerations as CCAM. Collecting and managing the data from implementing a leak detection program could be led by internal staff, or an outside consultant, or Utilis based on the service contract in place.

Vendor Support

Utilis provided monthly data deliveries associated with each flyover which included providing their total POIs for the month, and prioritized POIs for investigation based on field crew availability. In summary, Utilis supported the project in the following primary ways:

- Monthly data deliveries (12 total) for POIs and leak investigation recommendations.
- Maintaining their online web application showing POIs and system parameters.
- Maintaining their mobile application showing POIs and system parameters.
- Email/phone correspondence as needed supporting the work.
- Frequent field visits to support the leak investigations.

Utilis provided a very high level of support to the project team throughout the duration of the project. The Utilis project manager or supporting staff was regularly in the field alongside the leak investigation team, typically for multiple days each month, assisting the leak investigation team. The Utilis project manager also conducted multiple meetings with the research team making available key staff from their company including technology leads, marketing staff, and management. Utilis supported the research team through providing technical reports and presentations on their technology and supporting various efforts including conference presentations.

Performance Metrics

Performance metrics for the Utilis SILD technology deployed in the Duarte System are included in Chapter 3 and summarized in Table 28.

Table 28: Utilis Leak Data

Parameter	Value
Miles of Pipe Investigated (mi)	45
Total POIs Provided (#)	504
POI Provided per mile (#)	11
Total POIs Investigated	146
POIs Investigated per mile (#)	3
POI Investigated per POI Provided	29%
Total Leaks Found (#)	117
Leaks Found per Mile Investigated (#)	2.6
Leaks Found per POIs Investigated	80%
Leaks Found per POI Provided	23%
Labor per POI Investigated (hours)	3.8
Average Labor per Leak Found (hours)	5.6

Source: Hazen and Sawyer, American Water

The success rate of finding leaks based on the POIs investigated was 80 percent, with a total quantity of 117 leaks found. This represents a high success rate and a relatively high quantity of leaks found, which has been a consistent trend for the Duarte System in recent years. The methodology for investigating POIs was to cover the entire limits even once a leak is found. There were instances where multiple leaks were found in a single POI, which increased the success rate of the technology. Since each POI represented an area or mileage of pipeline to cover when looking for leaks, it took more time than the CCAM technology to investigate a POI, but it also resulted in locating more leaks.

Several conclusions can be drawn based on the performance of the Utilis technology. The Duarte System was an optimal location to deploy this technology. It was an area experiencing a high quantity of leaks for the size of the system. The neighborhoods were good candidates for leak listening and pinpointing in that the meters were easy to access, usage was at a minimum during the day, ambient noise was at a minimum, and the system was predominantly metallic piping material which helps when using the correlation equipment.

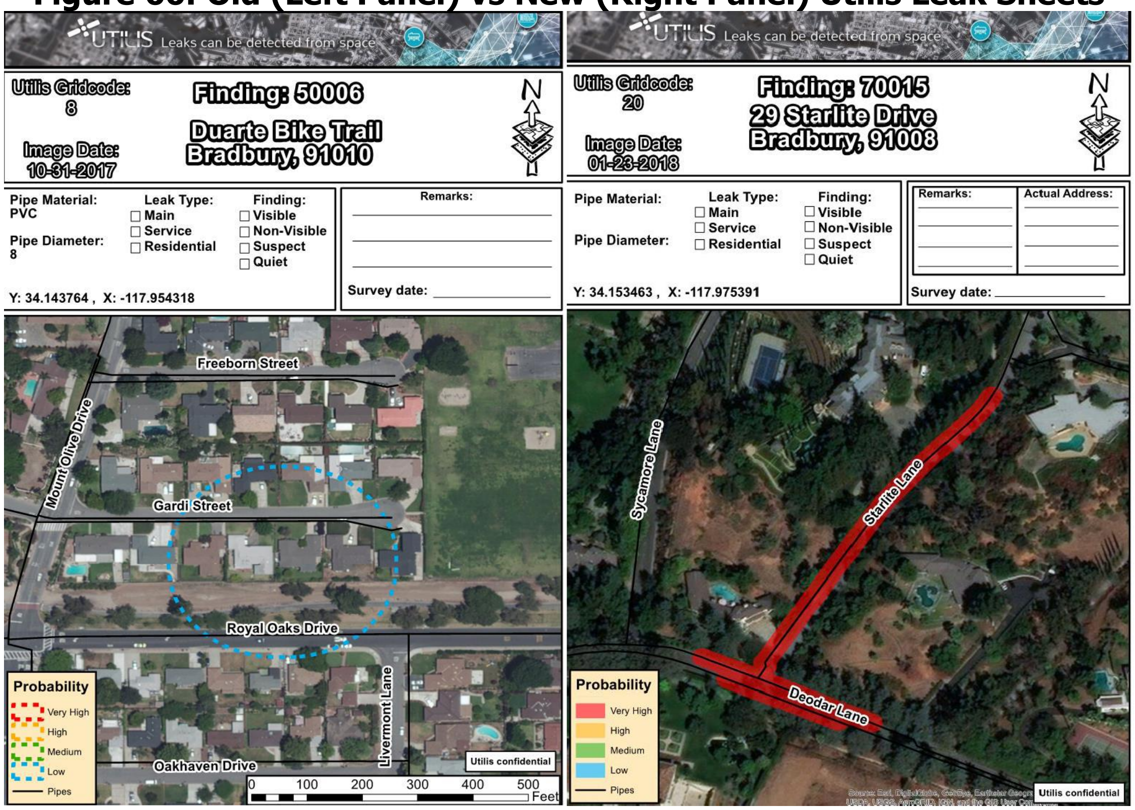
Multiple and frequent flyovers, along with monitoring results of leak investigations, allowed the Utilis data team to gain a better understanding of the system and refine their POI methodology as the project moved forward, which yielded positive results. Many of the highest confidence level POIs were established based on repeated and overlapping POIs from multiple flyovers, indicating the technology continues to see the same result for a particular area. As a greater understanding of the system and area characteristics was gained, the Utilis team's methodology for POI recommendations also improved.

The high level of involvement from Utilis had a positive impact on the results. Representatives from Utilis were regularly in the field with the leak investigation team, helping them investigate POIs and pinpoint leaks. Through this support, additional leaks were able to be located that may not have been located without their support. Leak listening and pinpointing is a skill developed based on experience, and the occurrence of false positives can sometimes be a result of the "human factor," simply not being able to locate a leak. The experience provided by the Utilis representatives in leak locating provided a positive impact on the results.

Technology Enhancements and Improvements

There were two primary areas through the project progress where Utilis enhanced and improved their technology. First, was the creation of improved leak sheets. Utilis originally provided POIs as 165-foot radius circles. In addition to the circles, the investigation methodology was to not only investigate all pipelines within the circle, but also to extend the search beyond the circle for an additional 100 feet, which essentially made the search area a 530-foot diameter circle. When the leak investigation team was in the field, it was difficult to ascertain the exact limits of the larger diameter circle, and when a leak was found it was unclear whether that leak should be attributed to the POI, or if it should be considered beyond the POI. This challenge was discussed with the Utilis team and their response was to create an improved leak sheet. The new leak sheet clarified the pipelines to be investigated rather than a circle overlaid on the system. The new leak sheet is still based on the same circle methodology, but it makes it clearer for the field investigation team. Figure 66 provides a comparison of the old leak sheet to the new leak sheet.

Figure 66: Old (Left Panel) vs New (Right Panel) Utilis Leak Sheets



Source: Hazen and Sawyer, American Water

Although it is understood the technology is still basing the POI on the original circle method, it makes it easier for the leak investigation team to confirm the limits of the POI investigation using the new leak sheet. This improvement made POI investigations more efficient, and data collection of attributing leaks to POIs more accurate.

Another improvement was based on their level of support to the project team. Utilis provided a high level of support through regular trips of being with the leak investigation team in the field and frequent correspondence with the team collecting and managing the data and monitoring results. Through this involvement, Utilis was able to improve the success rate of the POI investigations by gaining a better understanding of the system and helping the leak investigation team to locate leaks.

Barriers to Overcome

Barriers to overcome for the Utilis SILD technology include the following:

- The perception of randomness of POIs (though Utilis is working with an agency on a study comparing random POIs to Utilis POIs and found significant improvement in ability to find leaks with SILD compared to random investigation).
- The size of POIs and duration to investigate them.
- Providing vendor support as the company grows.
- Using the technology for more than just leak detection.

Radar and other remote sensing technologies are relatively new to the utility sector. Some additional education and care may be appropriate to prepare utility employees to understand the results. Upon quick view of a set of Utilis POI findings within a system, a perception can be that the areas are random, and the same results would be realized if locations were randomly selected like throwing darts on a map. It is understood that Utilis is aware of this perception and has an on-going case studies currently in development that show randomness is not the case. However, this is still a possible perception of the results nonetheless and Utilis should continue to actively market that the findings are based on sound engineering principles and multiple case studies prove this point.

Utilis POIs are areas where the full limits need to be investigated. A desire from future users of the technology would be to reduce the size of the POIs in order to reduce the investigation time (which averaged 3.8 labor-hours per POI for this project), especially those in highly concentrated environments where multiple overlapping POIs are occurring. According to Utilis, the current POI area extent is based on both theoretical and empirical factors. As discussed earlier, a Utilis POI is an area rather than a point location due to georeferencing and radar effects, such as shadow effects. In addition, Utilis routinely reviews the location of identified leaks from projects around the world. The Utilis POI size is intended to balance investigation time and opportunity to identify the leak triggering the radar response.

The vendor support provided on this project yielded positive results. The presence of Utilis staff in the field during leak investigations assisted the investigation team in finding leaks that may not have been located without their assistance. As the company grows and expands its client base, continuing to provide a high level of support may be challenging. For clients with experienced leak investigation teams and staff to dedicate to a leak detection program, extensive vendor support may not be required. But for systems where a program like this is relatively new, the vendor support may make a big difference in the results.

Finally, there are other applications for this technology beyond typical deployments used for direct leak detection in a distribution system, but also provide the benefits of the ultimate goals of preventing and minimizing water loss. Other applications include long runs of isolated transmission mains or adding to other criteria to develop a pipe replacement program. A conclusion of this project is SILD can be coupled with CCAM technology in the same system to leverage the strengths of both – it is not necessarily an “either/or” decision.

Applicability to Other Systems

There are some key factors to consider when assessing the applicability of the Utilis SILD technology to other systems. These conclusions are similar and related to the applicability of the Echologics CCAM technology. First, a system must be able to justify the capital expenditure to deploy the technology, purchase the leak locating equipment, conduct training, and have staff availability to conduct leak investigations and manage the data. Since there is no actual equipment to install in a system, costs are driven by the quantity and frequency of flyovers and data deliveries, as well as the service and vendor support desired.

Another consideration is predominant pipe material. Although the technology is not dependent on pipe material, leak pinpointing is much more difficult in a plastic pipe system using acoustic leak correlation equipment.

Regarding the system characteristics, if a system is less than 50 miles of distribution pipe, it is probably too small of a system to be effective (unless the focus is a long transmission main). There is no maximum size limit on a system. One of the benefits of this technology is the ability to cover large areas without any equipment deployment or extensive upfront mobilization efforts. However, the larger the system, the higher quantity of POIs that will require field investigation. To fully realize the technology benefits, resources must be available to conduct POI field investigations.

Summary of Technology Evaluation and Improvements

Table 29 summarizes key takeaways regarding SILD technology evaluation and improvements.

Table 29: Utilis Technology Evaluation Summary

Performance Metrics	Applicability to Other Systems	Barriers to Overcome
• POIs Provided: 504 • POIs Investigated: 146 • Total Leaks Found: 117 • Leaks Found per POIs Investigated: 80% • Leaks Found per Mile Investigated: 2.6 • Miles of Pipe Investigated: 45 • Average Labor per POI Investigated (hours): 3.8 • Average Labor per Leak Found (hours): 5.6	• Systems > 50 miles of pipe • Metallic and non-metallic pipe systems	• Perception of randomness of the POIs • Size of POIs and duration to investigate them • Providing vendor support as the company grows • Using the technology for more than just leak detection

Source: Hazen and Sawyer, American Water

Flow Sensitive Pressure Reducing Valves

Technology Evaluation

The AG system by Stream Control is still a product in development. Although the work on this project deployed the product in three different locations, the product is still a work in progress. The actual performance of the product as a pressure management strategy encountered several challenges.

One of the goals of this project was to assist the vendor (Stream Control) in developing a finished product for the U.S. market. Through this project, the vendor and utility staff were able better understand the details of deployment, start up, and operation of the AG system. This section provides an evaluation of the AG system product and technology based on the field work conducted for this project. Included is an evaluation of the product, along with details on barriers to overcome and considerations for applicability to other systems.

Deployment and Operations

Deployment of the technology was conducted in two phases. The first phase was to install the associated components at each PRV that are needed to operate the AG system, including the flow meter and the turbine generator which was the power supply for the unit. This first phase required extensive coordination and correspondence.

The second phase was the installation and startup of the AG system. Stream Control staff brought the AG system components and the installations and startup took place over a couple days. In the end, the units were installed and started up successfully, but only through diligent coordination between all parties and the right resources available to adapt to the circumstances.

Operations of the units consisted of weekly monitoring the data and functionality of the AG system. Monitoring primarily consisted of weekly remote monitoring, with monthly field visits and correspondence with the Stream Control team. If issues arose that required work beyond system monitoring, an outside specialist was brought in with experience with the AG system, and a longer field visit was coordinated with the research team, CAW staff, and remote correspondence with Stream Control.

Several challenges with the operation of the product were encountered. A loss of power caused the AG system to go into "bypass mode" which required a manual restart. The loss of power was sometimes a result of the malfunction of the turbine generator which provided the power for the unit, but it posed a problem none the less. When the AG system was in operation, the unit seemed to not always adhere to the pressure corridor settings that were input into the unit based on demand. This challenge was brought to the manufacturer and often required manual adjustment of the settings.

Substantial lessons were learned through this process of deployment, startup, and operations. The results of these lessons learned are described in the subsequent sections.

Vendor Support

Stream Control supported the installation, startup, and operations of the AG system in the following primary ways:

- Email/phone correspondence to coordinate the requirements for each installation.
- Physically installing and starting up the AG system at the three installation sites.
- Data monitoring and correspondence.
- Remote field support to monitor and adjust installations.

With all Stream Control staff located in Israel, they provided as much support as feasible. Their site visits to install and start up the units was beneficial to the project and team members to discuss and coordinate the operation and monitoring phase of the project.

Performance Metrics

The primary areas of data analysis for the AG system discussed in Chapter 3 include reduced stress on pipes during lower demand periods which lead to less leaks, reduced water lost during leaks, and reduced overall water use. Reduced pressures in a zone also result in lower non-revenue water and potentially lower overall usage. Conclusions related to leaks could not be made because all three installations were in areas that did not have a history of leaks and continued to not have any leaks during the study period for this project. As mentioned previously, the performance of the product encountered several challenges in not operating as intended, which prohibited the ability to extract system data for a sustained study period.

The emphasis of this technology evaluation is based on development and improvement of the technology, not based on performance metrics. Subsequent sections discussing barriers to overcome and applicability for other systems elaborate on ways to improve this product for future installations.

Technology Enhancements and Improvements

The AG system technology did not improve or change over the course of this project, but valuable information was learned from the Beyer PRV installation in the San Diego County District, and the Del Prado and Via Estrella PRV installations in the Ventura County District. The lessons learned from this deployment are summarized in the Barriers to Overcome and Applicability to Other Systems sections. Furthermore, this information will allow the product to be enhanced and improved for future installations.

Barriers to Overcome

Technology and product advancements for Stream Control and the AG system to become a more marketable product in the U.S. include:

- U.S. presence
- Technical training
- Technical documentation
- Software advancement
- Reliable data transmission
- Packaged system approach
- Product performance improvement

Stream Control is an Israeli-based company with all staff residing outside the U.S. For this product to gain a share in the market, it might be beneficial to have permanent staff based in the U.S., including technical and sales. Based on experience gained in this project, any new installations will likely require on-site support from the technical team ensuring the local operations group is fully trained in the operation of the AG system.

Related to having local staff, technical training should be made available for installation, maintenance, adjustments, commissioning, and monitoring. For this project, the AG systems were installed and started up by Stream Control staff. However, the product should be developed to allow installation and start-up by contractors and operations staff.

Additional technical documentation needs to be developed for the AG system, including engineering data sheets, installation manual, Operation & Maintenance manual, and PRV design best practices for AG systems. The installation manual should address retrofitting existing PRV stations with AG systems as well as new installations. The PRV design best practices should address design considerations for new PRV stations that will include an AG system. At the time there was no technical documentation on the product besides promotional material on the website.

The AG system settings are adjusted through a proprietary software that must be installed on a field laptop. The software allows the pressure settings at the PRV to be adjusted, which can only be done when the field laptop is connected to the AG system in the field. Advancements in this software are required to make this a more marketable product in the U.S. It must be further developed to improve ease of installation and operation on U.S. computers and the latest operating systems.

The data transmission component could be improved to provide a more reliable system for communicating with the devices. The communication system currently uses a file transfer protocol. The system worked as intended at the San Diego County installation but did not work at the Ventura County installations. This data transmission system needs to be simplified and made more reliable.

Partnerships could be developed with other manufacturers that supply the other components needed for the AG system operation, including flow meters, power supply, and data transmission components. This is considered a packaged system approach. For example, a flow meter is required at each installation, but must be configured to provide a pulse output to the AG system that is not too frequent and must also include a dry contact. The flow meter for the Beyer PRV was removed and taken back to the manufacturer because it was originally set up to provide 1 pulse per 1 gallon which resulted in a pulse output that was too frequent. It needed to be adjusted to 1 pulse per 10 gallons. In addition, it was not set up with a dry contact so additional field personnel were required to configure a dry contact. Future installations would be simplified if Stream Control had partnerships with manufacturers that allowed them to provide all needed components configured for the AG system.

Finally, the product simply requires performance improvements. There were multiple periods where the product was deployed and operating but did not manage the pressure in the zone as intended. This occurred at both the San Diego County District and the Ventura County District deployments and the full understanding of the reasons for the performance issues were not resolved during the study period.

Applicability to Other Systems

Assessing the applicability of the AG system to other systems includes big picture applications, and specific logistical considerations for each installation. The optimal applications for the AG system should meet both sets of requirements.

System Applications

There are several system considerations when determining if the AG system is the right product in other systems. This section identifies and discusses those system considerations.

The AG system is only applicable for a pressure zone or service area with demands supplied through a PRV. Sometimes PRVs are used within a system at pump stations, treatment plants, or reservoirs, but not necessarily directly supplying a pressure zone with demands. The AG system controls the settings of a PRV supply into a pressure zone based on demands, so other locations where PRVs are installed and not serving this purpose are not the right application for the AG system.

The pressure zone must have a low flow and high flow period. The AG system modulates the downstream pressure setting based on varying flow (demand). If demand is constant across a 24-hour period like for an industrial customer, then the AG system wouldn't have a period to modulate the downstream pressure. There must be a diurnal pattern of flow into the zone that varies from high to low throughout the day.

The pressure zone characteristics must allow for a reduction of pressure in the zone. The primary function of the AG system is to lower downstream pressure when demand in a pressure zone is lower. If a pressure zone is configured where it already operates as low as allowable and there is no allowance for any reduction in pressure, then it is not the right application for the AG system.

Finally, optimal applications are pressure zones that also have frequent leaks, or high non-revenue water volumes. A purpose of the AG system is to reduce leaks and reduce non-revenue water so pressure zones that are impacted by these are the optimal locations for AG system installations.

In summary, the primary system attributes for successful application of the AG system include:

- PRV supplied pressure zones.
- Pressure zones with varied diurnal demand patterns (not constant demands).
- Pressure zones that allow a reduction in pressure during low demands.
- Pressure zones with frequent leaks or high non-revenue water.

In addition to system application considerations, there are also specific logistical considerations discussed in the next section.

Logistical Considerations

In deploying, starting up, and monitoring the operation of the AG system for this project, extensive lessons were learned on the specific logistics that need to be considered for AG system installations. These include:

- A single PRV station supplied zone.
- Reliable power supply.
- Space for the equipment.
- Assigning key staff to be responsible for ownership of tasks and equipment.

One outcome learned was that the optimal application was a single PRV station supplying a zone, rather than multiple PRV stations supplying a zone. This was directly learned comparing the San Diego County installation (Beyer PRV) where there was a single PRV station, with the Ventura County installation (Del Prado and Via Estrella PRVs) where there were multiple PRV stations supplying the zone.

The AG system includes different pressure corridor settings that modulate downstream pressure based on demand. In addition, a PRV station often has a smaller duty PRV, and a larger backup PRV used when demands are atypically high like during a fire flow event. Some PRV stations also have a pressure relief valve. The AG system, duty PRV, large PRV, and pressure relief valve settings all need to be coordinated to not overlap.

When a zone is supplied by multiple PRV stations with AG systems, there are more components to coordinate the settings with. Although it’s possible, this adds a level of complexity in operating the system that is most likely not desired by an operations team. For this reason, it was concluded that the optimal application for the AG system is on pressure zones with a single PRV station supplying the demands.

Another logistical consideration is a reliable power supply. There was no power supply at the three installations in this project. As a result, a turbine generator was used to provide power for the AG system. However, for future applications, a turbine generator is not recommended as the optimal power supply for the following reasons: A turbine generator is another mechanical component that is added to the installation, and requires space for the piping, and requires the setting to be coordinated to ensure sufficient flow is always going through the unit so it can provide power. It is also one more component to be maintained. Due to the turbine generator adding another layer of complexity to the AG system operation, adding another component to be maintained, and a component that can possibly fail, it is not recommended to consider a turbine generator as a reliable power supply for future AG system installations. A reliable power supply should be either from the local electric utility, or another source that the owner feels is an acceptable and reliable power supply.

Each AG system needs sufficient space to install the AG system components, including the flow meter, power supply component, and AG system and the associated components. There also needs to be sufficient space for an operator to stand near the components and make setting adjustments or conduct maintenance. The AG system includes electrical components that are designed for operating in temperatures between 30- and 120-degrees Fahrenheit. If the installation is in a location with temperatures beyond this range, then a temperature-controlled environment is required. Furthermore, if installation is in a location that is prone to cold weather, steps must be taken such that there is constant flow through the AG system to prevent freezing within the pipe.

A final consideration for the AG system is personnel that takes responsibility for the monitoring and maintenance of the system. A hydraulically controlled PRV is a component of the system that once installed only requires intermittent checks. An AG system includes a power supply, a small motor, and a data transmission component. Like the monitoring and maintenance schedule of a distribution system pump station, the AG system requires regular and continual monitoring. Monitoring efforts include confirming status of power supply, confirming downstream pressure adjustments, and confirming optimal operation of the system. A weekly monitoring schedule is recommended.

Summary of Technology Evaluation and Improvements

Table 30 summarizes key takeaways regarding Stream Control technology evaluation and improvements.

Table 30: Stream Control Technology Evaluation Summary

Applicability to Other Systems	Logistical Considerations	Barriers to Overcome
• PRV supplied pressure zones • Pressure zones with varied diurnal demand patterns (not constant demands) • Pressure zones that allow a reduction in pressure during low demands • Pressure zones with frequent leaks or high non-revenue water	• A single PRV station supplied zone • Reliable power supply • Space for equipment • Personnel to “own it”	• Developing a greater U.S. presence • Providing technical training and software documentation • Software advancement and reliable data transmission • Developing a packaged system approach • Technology performance issues

Source: Hazen and Sawyer, American Water

District Metered Areas

A traditional approach to reducing leakage in a water distribution system is creating DMAs to identify, define, and manage water loss within a distribution system. Using DMAs allows for a more accurate localization of leakage within the water distribution system by allowing the agency to focus on smaller areas. Per AWWA M36, a small DMA is less than 1,000 connections (or meters), a medium DMA is 1,000 to 3,000 connections, and a large DMA is 3,000 to 5,000 connections.

A conclusion of the research team is that if a utility is using DMAs for leak detection, then DMAs should only be of the “small category” as defined by AWWA M36 which is less than 1,000 connections. The smaller the DMA, the less time it will take to investigate and locate the leak. A DMA in the medium or large category would encompass too large of an area to make leak detection effective and efficient for most systems.

CHAPTER 5: Evaluation of Project Benefits

This project deployed and evaluated the latest in advanced Correlating Continuous Acoustic Monitoring technology (CCAM) by Echologics, Satellite Imagery Leak Detection (SILD) by Utilis, and flow sensitive pressure reducing valves (FSPRV) by Stream Control. District metered areas (DMAs) were also implemented. The focus of this chapter is the evaluation of project benefits related to the new technologies: CCAM, SILD, and FSPRV.

Technology Demonstrations

A benefit of this project was the successful demonstration of CCAM technology by Echologics and SILD technology by Utilis, both in the CAW Duarte System in the Los Angeles County District. Each technology was deployed for at least a year period, which included 7-months of regularly conducted leak investigations based on the technology findings. The deployment period and leak investigations provided sufficient data to draw key conclusions.

The parallel deployment of CCAM and SILD in the Duarte System also allowed evaluation to include a comparison of the two technologies. Other systems can use the comparison to determine if either technology is right for their system or consider using both.

Another benefit was the demonstration of the FSPRV technology by Stream Control, where their Aqua-Guard (AG) system was deployed at three locations – one in San Diego County, two in Ventura County. Both systems had different logistical considerations, including different installation and operational characteristics, which the Stream Control and project team had to adapt to and learn from.

All technologies were demonstrated in CAW systems. CAW is a significant water system owner in California with substantial influence. CAW owns and operates systems throughout California from San Diego County in the south to Sonoma and Sacramento Counties in the north and several systems in between including in Los Angeles, Ventura, and Monterey Counties. As a result, they are recognized across the state for understanding the regional challenges of Southern California and Northern California.

American Water and CAW are recognized as prioritizing innovation to provide the greatest value to their rate payers. With the technologies demonstrated in CAW systems, it provided a testing ground that will be recognized throughout the state.

Technology Development

Related to the substantial technology demonstrations for CCAM, SILD, and FSPRV, the project allowed the technology vendors to further understand their products and develop strategies for improvements. Areas identified for technology improvements are included in Chapter 4 with key topics discussed in the following sections.

With the CCAM technology, Echologics developed an adapted sensor for the hydrants in the Duarte System. Being able to adapt their sensors to different hydrants improves their ability to serve different customers. Echologics also improved their service to the field investigation team by creating leak sheets to make the field investigation more efficient. Echologics prioritized 77 POIs and the team was able to investigate 49 of them.

Utilis further developed their technology and service through this product demonstration. The creation of leak sheets showing the full limits of investigation as the POI rather than a circle was an improvement that helped the field investigations.

Conducting monthly flyovers for a year duration also allowed Utilis to analyze their technology and refine their confidence intervals of their POIs. Monthly flyovers for a system of 100-miles of pipeline is a relatively frequent occurrence for the size of the system, however it allowed them to analyze clusters of findings across multiple months, conduct false positive analysis, conduct false negative analysis (surfacing leaks not identified by the technology), and refine the confidence level of their POIs. Utilis prioritized 504 POIs and the team was able to investigate 146.

Stream Control's AG system is a new product without extensive product demonstration experience in the U.S. They were able to gain valuable information on the deployment, startup, and operation of their product from the three deployments. Several barriers to overcome to make the product more marketable in the U.S. are described in Chapter 4.

Energy, Water, and Cost Savings

A summary of the energy, water, and cost savings directly related to the implementation of CCAM and SILD leak detection is included in Table 31.

Table 31: Combined Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection Duarte System Energy Calculations

Parameter	Value
EI (kWh/MG)	2,464
Leak Volume (MG, based on duration)	57 to 170
Cumulative Energy Saved (kWh)	140,000 to 419,000
Cumulative Energy Savings ($)	$33,000 to $101,000
Energy Savings (% of system usage)	3.1 % to 9.0%
Nitrogen oxide reduction (lbs)*	112 to 336
Carbon dioxide reduction (lbs)*	73,541 to 220,120

*** U.S. Energy Information Administration Webpage: https://www.eia.gov/electricity/state/california**
Calculations based on a combination of Table 3-7 and Table 3-9.

Source: Hazen and Sawyer, American Water

Another benefit of this project is related to the early detection of leaks and being able to better plan for repairs. When leaks come to the surface, repairs must be conducted immediately, often at night or on the weekends. CAW often uses one of their on-call contractors to fix the leak unless they have operations staff availability. When small leaks are found below the surface, the leak repairs can be planned out and scheduled. When leak repairs can be conducted by CAW staff, it eliminates the cost of hiring on-call contractors to perform the leak repair.

The technology deployments for this project were in 2018. Leak repair data from 2017, which was prior to the full technology deployments, was compared to 2018. Table 32 shows a comparison of the quantity of leak repairs conducted by CAW staff compared to contractors for 2017 and 2018.

The data shows that although there was a similar quantity of leaks for both years, in 2018 CAW was able to repair more than twice as many leaks as they did in 2017. The conclusion drawn is that the early detection of leaks from the technology deployments from this project allowed CAW staff to better plan and schedule leak repairs. More leak repairs could be performed internally, which provided cost savings from hiring on-call contractors.

Table 32: 2017 vs 2018 Duarte Leak Repairs

Year	Leaks Repaired by CAW	Leaks Repaired by Contractor	% CAW Repairs
2017	24	283	8%
2018	56	253	18%

Source: Hazen and Sawyer, American Water

Although there was a substantial energy, water loss, and cost savings in the Duarte System related to directly implementing these technologies, the true benefits will be realized in the future as other agencies continue to deploy leak detection and water loss prevention technologies.

Other Related Benefits

Direct benefits from this project include energy and water savings resulting directly from the deployment and implementation of CCAM, SILD, FSPRV, and DMAs in CAW systems. Direct benefits also include the subsequent energy and water savings that will result as other agencies deploy these technologies in their systems, and these technologies continue to grow, improve and help water agencies reduce leakage and prevent water loss in California and nationwide. There are also other benefits resulting from this project that are related, but less obvious.

Deploying these technologies improves system reliability. If a water system can locate small leaks below the surface and fix them, they are improving the reliability of their system. They are finding the weak points in their system and fixing them before they become a major problem that could result in creating a sinkhole or a large leak that puts people out of water for a significant time period. Finding and fixing small leaks avoids larger impactful leaks and makes a system more reliable for their customers.

Deploying these technologies improves public safety. Large pipe breaks are not only a great nuisance due to community impacts, property damage, and construction to fix the problem, but they can also pose a public safety issue. Large breaks can expose the distribution system to contamination. The early locating of small leaks and fixing the issue reduces the risk of public safety issues resulting from large leaks.

Deploying these technologies will lead to improved operations of water systems. When small leaks are detected, the fixes can be planned out and repaired in an efficient manner, ensuring the right materials are on hand and fixing the leak during normal business hours. When a large leak surfaces, it must be repaired immediately, often requiring extensive staff resources, using an on-call emergency contractor, and possible insurance claims from property damage. Emergencies like this take staff away from their normal operations duties. Pipe breaks and emergency fixes can also lead to poor consumer confidence and complaints from the community.

Figure 67: Pipe Break in Duarte System

Source: Hazen and Sawyer, American Water

All these factors result in ultimate cost savings to rate payers by deploying these technologies. As leakage and water loss is reduced in a water system, the water agency's cost of distributing water is decreased. As large leaks are reduced, and the associated costs of emergency repairs are reduced, the water agency's cost of distributing water is decreased. As operations improve and are made more efficient, the water agency's cost of distributing water is decreased. Reduced costs of operating a water system allow reduced rates for rate payers.

Outreach

A goal of this project was to make the knowledge gained, lessons learned, data analysis, and key conclusions available to the public and most importantly the end users of these technologies, for the ultimate goal of reducing water loss in water systems. Progress towards this goal was made throughout the project's implementation and will continue in the immediate years after the project is completed through presentations at conferences and publications. The details of the outreach efforts are included in Chapter 6.

The primary publication associated with this project is this final report, made available by the CEC. Future efforts will include working with professional magazines and publications for articles on this project.

Presentations have been given at several venues to date, and several are planned or submitted for acceptance at future conferences. At the time of this writing, six presentations have been given at conferences, with several more presentations to be given within a year.

Project Outcomes

The goals of the project were to:

- Deploy, evaluate, and collaborate with vendor to improve CCAM technology to effectively reduce water leakage in water utility networks.
- Employ, evaluate, and collaborate with vendor to improve the state-of-the-art SILD technology. The SILD and CCAM will be employed in the same location for purposes of comparing the values and performance of each technique.
- Explore the relative value of FSPRV system and work with the technology vendor to develop a finished product designed for the U.S. market.
- Evaluate the full financial and water saving benefits associated with the proposed technologies.
- Present the potential savings in water and energy consumption, and GHG emission mitigation due to the water loss control.

The research team concludes that each of the listed goals were fully met through the implementation of this project. The technologies were deployed, evaluated, improved, and demonstrated towards the goal of reducing water leakage, preventing water loss, and enhancing water/energy efficiency in water systems.

CHAPTER 6: Knowledge Transfer, Marketing, and Commercialization

Introduction

A goal of this project was to make the knowledge gained, lessons learned, data analysis, and key conclusions available to the public and most importantly the end users of these technologies, for the ultimate goal of reducing water loss in water systems. The end users of the technologies are primarily water system owners including cities, counties, water districts, and private water companies. This chapter describes the strategies used for making that information known, both previously, on-going, and future planned activities.

Targeted Market of Knowledge Transfer

The primary target of the knowledge transfer are the end users of the technology. The end users of the technology are primarily water agencies including cities, counties, water districts, and private water companies. Water agencies have the most to gain from this information because they are evaluating the technologies and applicability to their water system.

- Targeted water agencies include:
- Agencies with current water loss programs who want to keep up with the latest technologies.
- Agencies who do not have a water loss program but are interested in starting one.
- Agencies who are focused on energy efficiency.
- Agencies who have previously implemented these or similar technologies.

The groups of people targeted include asset management specialists, GIS specialists, operations staff, design consultants, technology developers, and elected officials.

Knowledge Transfer Information

Key information that is intended to be conveyed through the knowledge transfer activities include applicability to other systems, deployment details, field investigations, and technology performance.

Regarding applicability to other systems, example key questions that water agencies should be able to answer include:

- Is CCAM right for my system?
- Is SILD right for my system?
- Should I consider both?
- Do we have a location where pressure management like FSPRVs would be applicable?
- Do I know the extent of non-revenue water and real losses in my distribution system?

For each technology, water agencies should understand the full details of deploying the technology including logistics, schedule, vendor support, staff support needed, and challenges.

For each technology, water agencies should also understand the full details of field investigations and follow up work needed including training, new equipment, labor hours, data collection, support from vendors, and monitoring and troubleshooting strategies.

Finally, water agencies should understand how each technology performed in this project. For CCAM and SILD, they should know the success rate of finding leaks versus POIs, quantity of leaks found, and other important metrics included in the data analysis.

Knowledge Transfer Activities

Communication Types and Venues

The types of communication used for knowledge transfer activities include conference presentations, panel discussions, webinars, luncheons, online/digital media, and magazines.

The venues used include national conferences, California conferences, and local and specialized group meetings. National and statewide groups include AWWA, ASCE, APWA, ACEC, Water Asset Management, Water Smart Innovations, and California Rural Water Association. Local groups often focus on the specific interests of a region and are often well attended by local end users. Examples of local groups include Orange County Water Association and Association of Water Agencies of Ventura County.

In addition to large group format activities, there have also been multiple meetings between members of the project team and other agencies discussing the project and the technologies deployed.

Publications

The primary publication associated with this project is this final report, made available by the CEC. The research team is currently preparing a manuscript for publication in one of the American Water Works Association publications. Additionally, a fact sheet (Figure 69) was developed to provide utilities attending presentations on the project with additional information about the project.

Presentations

Several presentations have already been given on the project, and several are planned or submitted for acceptance at future conferences. Presentations previously given at conferences include:

- 2017 AWWA Water Loss Conference
- 2018 AWWA ACE Conference (2 presentations given)
- 2018 Arizona Water Annual Conference
- 2018 Rocky Mountain Water Environment Association Joint Technical Annual Conference
- 2018 Arizona Water Energy and Sustainability Webcast
- 2018 Utilis Innovation Summit
- 2019 California/Nevada/AWWA Conference
- 2019 AWWA ACE Conference
- 2019 CEC Workshop: Energy Research Innovations in Water Treatment, Delivery, and Energy Recovery

A technical advisory committee (TAC) was formed to provide monthly review and input on various topics throughout the project's implementation. The TAC included leaders from prominent California water agencies including Los Angeles Department of Water and Power, Metropolitan Water District of Southern California, San Jose Water Company, and California American Water. The TAC meetings typically consisted of a presentation given by the research team on a certain project topic, with discussion and questions from the TAC members. In addition to the TAC members providing valuable input throughout the duration of the project, the research team was able to transfer knowledge from the technologies to the TAC members. Some of the TAC members had experience from implementing the same or similar technologies, while some were considering future deployment in their systems.

Market Adoption

The statements below address the current status of the technologies in the leak detection and asset management industry since this project started.

As of January 2021, Echologics has installed 23,335 acoustic sensors and located over 1,200 leaks. The Echologics CCAM technology has been used for various projects in North American and around the world. Recent projects have included detecting leaks on critical transmission mains and airport water supply lines. Echologics is currently working on upgrading their technology with the ability to detect leaks on prestressed concrete cylinder pipe (PCCP).

As of December 2020, Utilis has completed more than 400 leak detection projects in 55 countries that resulted in 28,000 verified leaks found. Once the leaks are repaired, this will save over 7,200 million gallons pf potable water and 17,000 mega-watt hours of energy per year.

Stream Control was not available for comment on the status of their technology in the United States.

Figure 68: Project Fact Sheet

Project Fact Sheet

Demonstrating Innovative Leakage Reduction Strategies

PROJECT DESCRIPTION

The purpose of this project was to fund the development and deployment of technologies that detect water leaks and prevent water loss in water distribution systems. A primary driver behind this leak detection research is to determine how much energy can be saved by reducing water loss within a system, with the premise that lost water is lost energy.

Water utilities struggle with identifying leaking pipe infrastructure. The cost of repairing pipe leaks is relatively low when compared to replacement, and utilities often wait for leaks to surface before taking substantial water loss and subsurface damage can occur. While reported leakage tends to be associated with major surface expression of water and infrastructure damage, hidden leakage and unreported leakage are a challenge to detect and manage. The following technologies/methodologies for leak detection and prevention were deployed and evaluated in this project:

1. **Correlating continuous acoustic monitoring** (CCAM) technology for leak detection.
2. **Satellite imagery leak detection** (SILD) for leak detection.
3. **Flow sensitive pressure reducing valve** (FSPRV) for pressure management and for leak prevention.
4. **District metered areas (DMAs) program** to observe system flow patterns utilizing flow meters for leak detection.

The four technologies were deployed and implemented in three California American Water (CAW) systems: Ventura County District (Ventura), Duarte System (Duarte) in Los Angeles County, and San Diego County District (San Diego). FSPRV and DMAs were implemented in Ventura and San Diego. For the purpose of comparing the two technologies, both CCAM and SILD were implemented in the same area (Duarte).

BENEFITS TO CALIFORNIA

This project will lead to future technological advancement to overcome barriers to the achievement of the State of California's statutory energy goals by improving leak detection/prevention strategies, and commercializing the proposed technologies (CCAM, SILD, and FSPRV). Furthermore, the results help to introduce the employed technologies to California water agencies as successful water/energy savings and GHG mitigation solutions.

PROJECT RESULTS

Although the scope of this project included comparing the performance of CCAM and SILD, a key conclusion is that both technologies are effective in locating subsurface leaks, and both should be considered for future applications. Based on budget, resources, schedule, system characteristics, and other factors, future users should consider what is best for their system. Using both technologies in the same system can be an effective strategy in capitalizing on the strengths of each method.

The FSPRV technology Aqua-Guard System by Stream Control is an effective pressure management approach to leak prevention. There are improvements and barriers to overcome for the product to be more marketable in the U.S.

DMAs are a traditional yet effective approach to managing water loss in a system. They provide valuable information on specific user-types in a small area and can also help systems identify leaks and problem areas efficiently.

PROJECT SPECIFICS

Contractor: American Water Works Company (American Water)

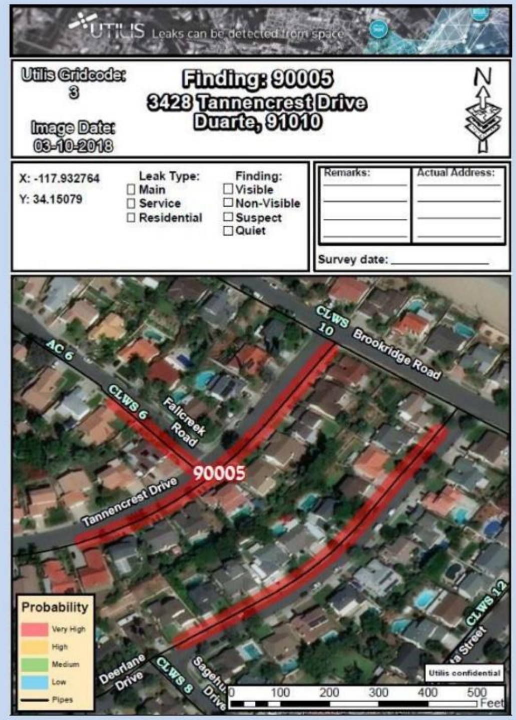
Major Subcontractor: Hazen and Sawyer

Other Subcontractors: Echologics, Utilis, Stream Control

Amount: $1,517,780

Co-funding: $470,236 from American Water and Subcontractors

Term: November 2016 to June 2019



Source: Hazen and Sawyer, American Water

CHAPTER 7:
Summary and Conclusions

Introduction

The purpose of this project was to fund the development and deployment of technologies that detect water leaks and prevent water loss in water systems.

For this project, American Water (AW) deployed and evaluated two primary technologies for leak detection: 1) correlating continuous acoustic monitoring (CCAM), and 2) satellite imagery leak detection (SILD). The technologies were assessed on their effectiveness in detecting leakage. The project also deployed 3) flow sensitive pressure reducing valve (FSPRV) systems, and 4) district metered areas (DMAs). The FSPRV system is a pressure management strategy used to prevent leaks, and DMAs are used to prevent and locate leaks at a higher level through observing daily flow patterns and quantities.

Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection

Comparison of Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection

Both the CCAM and SILD technologies were deployed in the Duarte System across the same time period to evaluate their effectiveness in locating leaks. The performance metrics are shown side-by-side for comparison in Table 33.

Table 33: Comparison of Correlating Continuous Acoustic Monitoring and Satellite Imagery Leak Detection Performance Metrics

Parameter	Echologics (CCAM)	Utilis (SILD)
POIs Provided	77	504
POIs Investigated	49	146
Total Leaks Found	20	117
Leaks Found per POIs Investigated	41%	80%
Leaks Found per Mile Investigated	3.8	2.6
Miles of Pipe Investigated	5	45
Average Labor per POI (hours)	1 to 3	3.8
Average Labor per Leak Found (hours)	4.9	5.6

Source: Hazen and Sawyer, American Water

Correlating Continuous Acoustic Monitoring Barriers to Overcome

Three primary areas of improvement were identified for Echologics' CCAM technology:

- Adaptation to PVC/plastic pipes.
- Reduction of false positives, increased quantity of leaks.
- Increasing local vendor support.

Further descriptions on each of these barriers is included in Chapter 4.

Correlating Continuous Acoustic Monitoring Applicability to Other Systems

The CCAM technology can be used on a portion of the system or an entire system. It can be deployed in an area where there is a historically high leak rate, or high probability of failure/consequence of failure ratings.

It can also be used in conjunction with the SILD technology by Utilis. SILD can be used to identify potential high leak areas within a system, and CCAM technology can be deployed in those prioritized areas based on the SILD results. This leverages the strengths of both technologies since SILD can cover a large area and does not require any equipment deployment, and CCAM deployment can be limited to only the areas where there is a potential high leakage rate in the pipelines.

Regarding the system characteristics, it must be a predominantly all-metallic pipe system where the acoustic sensors are deployed, until Echologics develops the technology for PVC/plastic pipe systems. As far as system size, any size is feasible if there is a network of hydrants available to install the acoustic sensors. There is no minimum size, and a maximum size is based on available budget and resources, but it is advantageous to focus on specific areas of a large system.

Satellite Imagery Leak Detection Barriers to Overcome

Barriers to overcome for the Utilis SILD technology include the following:

- The perception of randomness of POIs.
- The size of POIs and duration to investigate them.
- Providing vendor support as the company grows.
- Using the technology for more than just leak detection.

Further descriptions on each of these barriers is included in Chapter 4.

Satellite Imagery Leak Detection Applicability to Other Systems

There are some key factors to consider when assessing the applicability of the Utilis SILD technology to other systems. One consideration is predominant pipe material. Although the technology is not dependent on pipe material, leak pinpointing is much more difficult in a plastic pipe system using acoustic leak correlation equipment.

Regarding the system characteristics, if a system is less than 50 miles of distribution pipe, it is probably too small of a system to be effective (unless the focus is a long transmission main). There is no maximum size limit on a system. One of the benefits of this technology is the ability to cover large areas without any equipment deployment or extensive upfront mobilization efforts. However, the larger the system the higher quantity of POIs that will require field investigation. Resources must be available to conduct the field investigations to realize the benefits.

Flow Sensitive Pressure Reducing Valve

The FSPRV technology employed as part of this project is known as the Aqua-Guard system by Stream Control. The Aqua-Guard (AG) system integrates with the hydraulic pilot pressure control of PRVs and based on adjustable settings, can modify the downstream pressure based on different flow rates. The AG system is typically set to reduce the downstream pressure setting during low demand periods (nighttime) to reduce the stress on the pipe and ultimately prevent damage to the pipe which could result in a leak. Typical downstream pressure reduction can be as little as 5 psi to up to 20 psi or more depending on the system characteristics.

There were three demonstration sites for the FSPRV units. One site in the San Diego County District, and two sites in the Ventura County District. The site in the San Diego District is called the Beyer PRV which serves the Beyer pressure zone. The two sites in Ventura are PRVs that serve the same Dos Vientos PRV zone. The two PRV sites serving the Dos Vientos PRV zone are called the Del Prado PRV and the Via Estrella PRV.

The AG system is still a product in development. One of the goals of this project was to assist the vendor (Stream Control) in developing a finished product for the U.S. market. Fully understanding the details of deployment, start up, and operation of the AG system was achieved through this project.

Flow Sensitive Pressure Reducing Valve Barriers to Overcome

Technology and product advancements for Stream Control and the AG system to become a more marketable product in the U.S. include:

- U.S. presence
- Technical training
- Technical documentation
- Software advancement
- Reliable data transmission
- Packaged system approach

Further descriptions on each of these barriers is included in Chapter 4.

Flow Sensitive Pressure Reducing Valve Applicability to Other Systems

The optimal applications for the AG system should meet both system and logistical requirements. The primary system applications for the AG system include:

- PRV supplied pressure zones.
- Pressure zones with a varied diurnal demand pattern (not constant demands).
- Pressure zones that allow a reduction in pressure during low demands.
- Pressure zones with frequent leaks or high non-revenue water.

In addition to system application considerations, there are also specific logistical considerations. The specific logistics that needs to be considered for AG system installations include:

- A single PRV station supplied zone
- Reliable power supply
- Space for the equipment
- Personnel to monitor and maintain the equipment

Future applications of the AG system should account for both system and logistical considerations.

District Meter Areas

A traditional approach to reducing leakage in a water distribution system is the creation of DMAs. DMAs help to identify and manage water loss within a distribution system.

A total of five demonstration sites were created as part of this project – four in Ventura, and one in San Diego. Two of the flow-meter sites in Ventura served the same zone so the five flow meter sites created four DMAs.

Key metrics associated with each DMA are included in Chapter 3.

Summary and Conclusions

The goals of this project were accomplished:

- The CCAM technology by Echologics was successfully deployed and evaluated in the Duarte system. The project provided valuable data and information allowing the vendor to further improve their technology.
- The SILD technology by Utilis was successfully deployed and evaluated in the Duarte System. The project provided valuable proving ground showing the effectiveness of the technology in locating subsurface leaks.
- The FSPRV technology Aqua-Guard System by Stream Control was successfully deployed at three locations. This project was one example of introducing the product to the U.S. market and providing valuable information on the applicability and product improvements for future installations.
- Water, energy, and greenhouse gas savings associated with the leak detection technologies were analyzed.

Key conclusions from this project include:

- CCAM and SILD are effective technologies in locating subsurface leaks. They each have advantages and disadvantages, and each have a place in the market with the right application.
- The FSPRV technology Aqua-Guard System by Stream Control is an effective pressure management approach to leak prevention when used with the right applications. There are improvements and barriers to overcome for the product to be more marketable in the U.S.
- Using DMAs in a water system is a traditional yet effective approach to managing water loss. It provides valuable information on specific user-types in a small area.
- Although the scope of this project included comparing the performance of CCAM and SILD, a key conclusion is that both technologies are effective in locating subsurface leaks, and both should be considered for future applications. The needs of one system are different from the needs of others. Based on budget, resources, schedule, system characteristics, and other factors, future users should consider what is best for their system.
- Using both technologies in the same system can also be an effective strategy in capitalizing on the strengths of each method. SILD can be used to cover a large area to locate potential "trouble spots" and prioritize specific areas where CCAM can be deployed. The decision to deploy leak detection technologies in a system can be based

on several factors. One important consideration is determining how important is leakage reduction, energy savings, and water savings to the operation of the system.

- Another consideration is determining how important is the avoidance of major leaks to the operation of the system.
- The FSPRV technology Aqua-Guard System by Stream Control can be an effective pressure management approach to leak prevention. There are improvements and barriers to overcome for the product to be more marketable in the U.S. The three deployments in this project provided the vendor valuable information to improve their product and understand future application, installation, and operational considerations.
- Utilizing DMAs in a water system is a traditional yet effective approach to managing water loss in a system. It provides valuable information on specific user-types in a small area and can also help systems identify leaks and problem areas efficiently.
- The research team concludes that each of the listed goals were fully met through the implementation of this project. The technologies were deployed, evaluated, improved, and demonstrated towards the goal of reducing water leakage, preventing water loss, and enhancing water/energy efficiency in water systems.

LIST OF ACRONYMS

Term	Definition
AC	Asbestos Cement
ACE	Annual Conference and Exposition
ACEC	American Council of Engineering Companies
AF	Acre-Foot
AG	Aqua-Guard
ALOS	Advanced Land Observing Satellite
APWA	American Public Works Association
ASCE	American Society of Civil Engineers
AW	American Water
AWWA	American Water Works Association
CA	California
CAW	California American Water
CCAM	Correlating Continuous Acoustic Monitor
CEC	California Energy Commission
CPUC	California Public Utility Commission
CRDL	Model Number for Cla-Val PRV Product
DMA	District Meter Area
DVBS	Dos Vientos Booster Station
ECC	European Control Conference
EI	Energy Intensity
EPA	Environmental Protection Agency
EPIC	Electric Program Investment Charge
ES	Executive Summary
FAVAD	Fixed and Variable Discharge (Path)
FCS	Fluid Conservation Systems (Parts Vendor)
FSPRV	Flow-Sensitive Pressure Reducing Valve
FTP	File Transfer Protocol
GHG	Greenhouse Gas
GIS	Geographic Information System

Term	Definition
GPM	Gallons Per Minute
ID	Identification
IEPR	Integrated Energy Policy Report
IWA	International Water Association
LF	Linear Feet
MG	Million Gallons
MGD	Million Gallons Per Day
MWD	Metropolitan Water District
NRW	Nonrevenue Water
POI	Point of Interest
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride (Pipe)
ROI	Return on Investment
SAR	Synthetic Aperture Radar
SCADA	Supervisory Control and Data Acquisition
SILD	Satellite Imagery Leak Detection
SIM	Subscriber Identification Module
TAC	Technical Advisory Committee
WISE	Water Infrastructure System Efficiency

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