Identifying Operational Risks in Water Distribution Systems (Part 1 of 2)

White Paper

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Overview

A multitude of operational challenges exist in today's water infrastructure. To mitigate these challenges while at the same time expanding infrastructure to accommodate new customers, utilities must invest ample time and resources in new solutions. While water utilities continue to seek funding to upgrade, repair and build systems for the future, research and development has moved forward and led to the creation of new technological solutions. This paper, the first in a two-part series, will examine the problems that impact all potable water distribution systems and outline the steps necessary to implement solutions.

The Problem

The most significant challenges currently facing water distribution systems are aging infrastructure, increasing demand for potable water, maintaining potable water quality, weakened infrastructure as a result of system inefficiencies, environmental considerations and the cost of energy. Another major challenge faced by water utilities is leakage; however, until very recently, the majority of efforts to mitigate this challenge took place after the occurrence of a break or leakage.

When it became apparent that significant fluctuations in pipe pressure within a water distribution system were the main cause of breaks and leakages, research was conducted to improve water pressure monitoring; the resulting improvements allow a system to reduce their risk factor, protect system components prone to leakage, and provide safer and cleaner potable water. Technological advances that have occurred as a result of this research have led to the development of Intelligent Water Networks. The implementation of this technology allows a water distribution system to use preventative measures to address leakage and other challenges; this strategy of addressing challenges before they occur is more cost-effective and improves the longevity of infrastructure elements.

What Intelligent Water Networks Could Have Prevented

In the summer of 2009, the city of Los Angeles experienced a series of pipe breaks and leaks, causing significant disruption. Although a lack of specific water system data exists on the incident, a review conducted by experts pinpointed unnecessarily high water pressures as the cause of the catastrophe. The abnormally high pressures were a result of low demand due to a series of water rationing measures.*

*The lack of data was due to the absence of accurate, real-time direct pressure monitoring, which could have predicted and prevented problems.

Exploring Leakage and the Benefits of Pressure Management

Leakage is most often found in pipelines where unaddressed fluctuations in pressure continually take place. This causes excessive stress on the pipes; when frequent fluctuations are compounded with a lack of accurate monitoring, the result is eventual pipe failure. The risk of system failure is exacerbated when pipe pressures are unmonitored; conversely, the continuous management along with the leveling of water pressure and its anticipated fluctuations allows a water utility to reduce and prevent leakage. As leakage is driven by pressure, comprehensive efforts to reduce water pressure for even part of the day will reduce leakage to some extent.

Many water utilities have only limited on-line monitoring capabilities within their systems and subsystems; however, this compounds the risk of leakage. Hydraulic pressure and flow are typically collected continuously only at inlets and outlets of the distribution system. At this level, it is difficult to determine the specific problem areas where leakage could occur.

Pressure management can reduce leakage from existing and new burst pipes in addition to reducing often overlooked background leakage. In some circumstances, pressure management can also result in a significant reduction of so-called normal water consumption; this carries with the substantial residual benefit of extending the lifespan of a water distribution system.

The Case for Continuous Pressure Management

In 2011, an incident in the city of Boston caused two million residents to lose access to clean drinking water. Though a backup water supply was considered, it did not meet U.S. EPA standards, and citizens were left without potable water for several days. Had real-time pressure monitoring been available, analysis of the existing contaminated water would have been completed more quickly, allowing faster delivery of safe drinking water to residents.

High Water Pressure Risks

High water pressure incidents originate from a number of possible sources and can wreak havoc on pipelines.

Water hammer is one of the most common causes of high pressure incidents. Water hammer is an anomalous pressure event which occurs when a valve is closed quickly and suddenly stops the flow of water in a pipeline; this action results in shock waves which travel back and forth through the piping system.

Sudden valve closure can also cause water column separation and rejoining, which are the results of differing pressures in two separate columns of water. These differences can create a pressure vacuum that is extremely harmful to pipes and can result in implosions and reverse leakages.

Additional problematic high pressure incidents are check valve slam, rapid pump startups and rapid pump shutdowns; these incidents can all result in significant damage to pipelines.

Hazardous Low Pressure Conditions

Low and negative pressure events can be as challenging to a water distribution system as high pressure events. A primary danger of low pressure in a water distribution system is the occurrence of a vacuum or negative pressure on the suction side of a pump when a positive pressure of 10 psi or less occurs on the same side. In these cases, a low-pressure cutoff is usually installed on booster pumps in the water pressure booster system to prevent the occurence of a vacuum or negative pressure.

Contamination can occur as a result of pressure transients that create low pressure scenarios. This can occur secondarily to pipe breaks, main breaks, or as a result of low pressures due to pipe failure, especially as a result of a power outage. Contamination of a potable water supply is a residual effect of low or negative pressure and remains one of today's most significant health hazards. For example, low pressure in a water pipe underlying a sewage leach field may result in the movement of contaminants into the water supply.

Surge events can occur when pumps are switched or when valves and hydrants are operated. While any change in flow can cause a surge event, the most common causes are the operation of pumps, valves and hydrants. A surge in pressure of flow can result in a deterioration of water quality, as the surge can disturb deposits in the pipe or on the pipe wall. Additionally, changes in flow can result in low pressures that allow ingress of contaminants.

The risk of significant surge is greater in long un-branched pipes than in branched pipes, as branched pipes reduce surge. Other events that can cause surges are firefighting, bursts, and sudden increases in demand.

Other low pressure issues include backflow, backsiphonage and cross-connection. Backflow is the undesired flow of used water, non-potable water, or substances from any domestic, industrial or institutional piping system into the pure, potable water distribution system. The direction of flow in these conditions is the reverse of that intended by the system and could be caused by any number of specific conditions. The reverse pressure gradient is often due to either a loss of pressure in the supply main called backsiphonage, or by the flow from a customer's pressurized system through an unprotected cross-connection, which is called backpressure. A reversal of flow in a distribution main or in the customer's system can be created by any change of system pressure wherein the pressure at the supply point becomes lower than the pressure at the point of use. These low pressure or negative pressure conditions introduce the possibility of contaminated or polluted water backflowing into the water distribution system; the point at which it is possible for a non-potable substance to come in contact with a potable drinking water system is called a cross-connection.

Basics of Water Pressure and Pressure Management

Water supply systems are generally designed to provide water to consumer at some agreed-upon level of service or with a minimum level of pressure at the critical point - the point of lowest pressure in the system. The system may also provide minimum pressures for needed municipal fire protection or fire flow, which would override everyday requirements to the consumer.

Water distribution systems are designed to accommodate the pressure and flow requirements during periods of peak demand, determined from factors affecting the involved municipalities. Water distribution systems are designed to provide the appropriate water supply during a very short period of time; for the remainder of the time, the systems tend to operate at pressures significantly higher than required.

Within the same system, there will also be areas of high pressure due to topography and/or distance from the supply point; the result is that many parts of a supply area will operate at pressures higher than required. The purpose of this surplus of pressure is to ensure sufficient pressure at the one critical point where it will be needed.

Managing water pressures in a supply area is not a simple issue, and there are several details to consider. No two systems react in the same way to pressure, and it is often difficult to accurately predict the reduction in leakage due to a decrease in pressure.

Determining Pressure-Leakage Relationships

Many theories exist regarding pressure-leakage relationships in a municipal water supply system. The most widely accepted theory is that of Fixed and Variable Area Discharges (FAVAD).

FAVAD describes the relationship between pressure and leakage, wherein two components will conform to a square-root relationship (N1 = 0.5) in cases where the size of the leakage path remains constant during the change in pressure. This is the typical situation when the leak is a fixed area leak, such as a small hole in an iron or steel pipe. In these cases, doubling the pressure results in a leakage increase of about 41%.

In variable area leaks, doubling the pressure results in a greater leakage increase than in fixed area leaks. In general, large leaks from metal pipes have N1 exponents close to 0.5. Small "background" leaks at joints and fittings, however, usually have N1 exponents of 1.5 or greater; this also applies to large leaks from flexible non-metal pipes. While the N1 exponent may range from 0.5 to 2.5 for small individual zones, the average pressure-leakage rate relationship for large systems with mixed pipe materials is usually close to linear (N1 = 1.0). In some cases, leakage will increase by as much as eight times the original level (N1 - 3).

In reality, there is most often a mix of fixed and variable area leaks within a water distribution system; this is due at least in part to the different composition types of pipes within the system. Inferior workmanship in the laying of pipes is also a frequent factor influencing leakage. Two similar systems laid next to each other can have significantly different leak characteristics simply because one system was laid properly, while the other system was laid by a poorly qualified contractor.

Average Pressures in Water Distribution Systems

Most water distribution systems provide a specific minimum level of service during peak demand periods, such as a required minimum pressure of 20m. Pressures at the pump head may be as high as 100m at peak demand. During off-peak periods, pressures tend to be much greater than during peak demand periods; the resulting water pressure is significantly higher than necessary.

Typical Optimized Pressure Management Goals

- >0 psi during emergencies
- >20 psi under max day and fire flow conditions
- >35 psi under normal conditions
- <100 psi under normal conditions
- Within +/-10 psi of average >95% of the time

Summary

Pressure management interventions protect water distribution systems by controlling potentially harmful changes in pressure. Continuous, unmonitored pressures can wreak havoc on a water distribution system by destroying pipes, joints, and operational equipment within the system; this degradation can introduce leakages leading to water loss, threatening possible water contamination, and necessitating the interruption of water delivery to the consumer. Loss of revenue will inevitably follow.

In the second paper of this two-part series, we will explore methods of pressure management and control as well as products which are used to lessen or eliminate pressure-driven challenges.

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Examining Pressure Management Methods in Water Distribution Systems (Part 2 of 2)

White Paper

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Overview

The first paper in this two-part series identified the key pressure management problems faced by water utilities. Uncontrolled water pressure can result in increased system leakage, shortened pipe life, and an increase in line breakages. This paper outlines methods used in helping to curb pressure-driven problems, including remote wireless pressure monitoring. By monitoring multiple points throughout a potable water system, remote wireless pressure monitoring anticipates and helps to mitigate dangerous pressures that could denigrate the water system.

Methods of Reducing Water Pressure

A broad range of pressure management methods have been developed over the course of several decades. Each method offers a specific set of advantages and disadvantages depending on the needs, priorities, and budget of a water utility.

Fixed Outlet Pressure Control typically employs a pressure reducing valve (PRV) with no additional equipment; it is considered to be the most straightforward form of pressure management. PRVs are easy to install and require little with regard to operation and maintenance. However, most PRVs lack the flexibility to adjust water pressures at different times of day. Excessive pressure in pipes downstream of the PRV can increase the chance of leakage or breakage if pressures are not decreased when necessary. This leads to diminished savings due to water loss, potential contamination, and expenditures related to repairing leaks and breaks.

Similar to fixed-outlet pressure control, **Time-Modulated Pressure Control** includes an additional control which provide a further reduction in pressure during off-peak periods. This method is particularly useful in areas where water pressures build during off-peak, non-use periods. The controller provides greater flexibility by allowing for the reduction of pressures at specific times of day, resulting in greater savings. Additionally, the system's components are less expensive than those used in flow-modulated pressure control. Because time-modulated pressure control does not react to the demand for water, it can present a significant liability in times of needed fire flow; this problem can be mitigated by the installation of a flow meter. When compared with fixed outlet pressure control, time-modulated pressure control is more expensive and requires a higher level of expertise to operate maintain.

Flow Modulated Pressure Control provides greater control and flexibility than time-modulated pressure control. This method uses an electronic controller which interacts with a properly-sized meter and PRV to ensure adequate water pressure in the event of needed fire flow. The increased flexibility of flow modulated pressure control offers more savings than fixed outlet and time-modulated control methods; these savings may be offset by the increased equipment expense associated with the electronic controller and properly-sized meter. Flow modulated pressure control is often beyond the employee skills base of many water utilities.

In **Closed-Loop Pressure Control**, a flow modulated controller is employed with the water meter and PRV. Additionally, beyond the supply area, a pressure sensor is placed at the critical node of the system; live data is supplied to the pressure controller at the inlet to the zone via a communications link. Closed-loop pressure control has historically been considered the best available form of pressure control, resulting in maximum savings to the water utility and consumer. This method is the most complicated form of pressure control, involving many integrated components; this presents a greater likelihood of equipment failure and requires a level of skill for maintenance and operation that is often too challenging for a water utility.

The most advanced solution for every water distribution system is **Remote Wireless Pressure Monitoring**. As indicated by increasing numbers of reticulation system failures, real-time monitoring is critical to prevent costly and often unnecessary water system interruptions. Developed as a result of intensive research, remote wireless pressure monitoring offers an end-to-end integrated hardware and software system for monitoring, analyzing and modeling a water distribution system in real-time.

Understanding Remote Wireless Pressure Monitoring

The typical remote wireless pressure monitoring system consists of:

- **Sensor Node or Controller and Reporting Unit:** A remote pressure sensor consisting of an embedded single-board computer with custom-designed sensor hardware is attached to a port in the water distribution system, enabling the continuous collection and analysis of data. The device provides real-time reporting of pressure conditions outside of user-defined parameters. Sensor nodes at critical locations in the field are able to communicate along the network and provide full data sets suitable for centralized online and offline analysis.

- **Remote Servers:** Connected to the entire network, remote servers consist primarily of a browser-based user interface and an Integrated Data and Alerts System (IDEA). The IDEA server performs data acquisition, analysis, and other integral tasks to modulate pressures within the water distribution system and keep them at safe levers; the wireless sensor network supplies data to the remote servers. The browser interface provides users with a way to interact with the functions of the remote servers and reconfigure the sensor nodes. The remote wireless pressure monitoring system may be used either as a stand-alone system or as a unit of an integrated water distribution system. When used as a stand-alone system, a map-based web user interface and dashboard are provided; this interface is accessible via web browser on desktop PCs or via tablet or smartphone, enabling in-field analysis and validation. No special hardware or software is required.

- **Transmission & Reception Platform for Wireless Data:** This platform can be integrated into a network's existing supervisory control and data acquisition systems. The wireless system can also be used as a stand-alone monitoring platform hosted either locally within a water utility or in the Cloud.

Remote wireless pressure monitoring is an intelligent technology that outperforms all other pressure control methods available on the market. Proprietary technology is retrofitted easily to existing pressure ports or dedicated corporation valves; combining the latest advances in sensor technology with a user-friendly web interface, remote wireless pressure monitoring provides an intelligent, proactive operations base.

Advantages of Remote Wireless Pressure Monitoring

- Can monitor pressures anywhere along the pipe distribution network.
- Is integrated with existing network infrastructure.
- Allows for customizable pressure and condition alerts to field and office personnel.
- Provides constant intelligent monitoring for out-of-normal pressure conditions.
- Offers immediate communication of data via the most reliable cellular services.
- Includes pressure sensor and communication system in one box.
- Operates safely and securely, making data available to as few or as many personnel as desired.

The Profile of an Intelligent Water Distribution System

Monitoring real-time water pressures can produce benefits across the entire spectrum of a water distribution system:

- **Pump operations:** The knowledge of monitored pressures in specific pipelines directly impacts pump operations through the transmission of accurate pressure data which may pinpoint the pump as a source of pressure-driven problems. Additionally, any analysis conducted alongside critical pump operations in an intelligent water distribution system will help to determine whether a pump is robust enough for a job, or if a higher-pressure pump is needed.

- **Water Quality Management (WQM):** A real-time remote wireless pressure monitoring system and associated analytics help to provide crucial water quality parameters, enrich distribution processes, and paint a fuller picture of water quality management within the infrastructure. Intelligent WQM software establishes a baseline pattern of expected parameters under normal conditions in the distribution network. These parameters can include quality markers such as pH, turbidity and conductivity, and they are measured both individually and in correlation to one another; certain cases of contamination can be detected through this software.

- **Reduced Operating and Maintenance Costs:** The adoption of an intelligent water system leads directly to improved operating efficiency and reduced costs. Smart solutions for leakage reduction allow utilities to easily identify the location of water losses, reducing the cost of field personnel deployment. Additionally, water utilities are able to reduce energy costs and emissions through the optimization of operations.

- **Expedited Compliance in Regulatory Matters:** Local, state and federal regulatory bodies constantly seek to improve the level and quality of services to consumers; water utilities are front and center with respect to such initiatives. Performance benchmarks and water quality standard targets can occasionally be delivered with a short timeline for compliance; in these cases, intelligent water technology is vital to identifying and implementing the adjustments needed for fast compliance.

- **Security:** As demand grows and water resources become more scarce, water distribution systems are tasked with ensuring the security of their water supplies. Intelligent water technology empowers managers and planners to make decisions for the future, helping to reduce waste, improve efficiency, and plan for the expansion and revitalization of a system while avoiding unnecessary costs.

Conventional monitors do not capture the full range of pressures within a water distribution system

Eight months (August 2011 to February 2012) of test monitoring was conducted to determine the effectiveness of remote wireless pressure monitoring technology at zones varying from high-pressure/low elevation to low pressure/high elevation. Both conventional (using SCADA) and newer, wireless optimized pressure monitoring methods were employed in the testing. The following was observed: Conventional monitoring showed an average of 55 psi, while optimized monitoring ranged from 40 to 120 psi. When testing was concluded, the hosting utility determined that the following benefits would be realized with the new, more accurate technology in place:

1. *The cost to implement the new pressure reduction technology was minimal*
2. *A water loss reduction of ~10-15% was easily assumable*
3. *The new technology would help reduce main break frequency*
4. *Due to lowered pumping energy usage, costs could be further reduced*

Testing within other District Metered Areas (DMAs) using the same conditions and criteria was conducted between April 2005 and December 2009. The result: remote wireless real-time distributed pressure monitoring turned the water pressure profile upside-down — leakages were effectively eliminated, outlay of funds for maintenance were no longer a significant factor, and water pressures were minimized, resulting in further cost savings through less energy use.

Conclusions

Through the implementation of remote wireless pressure monitoring technology, a water utility is able to enjoy significant gains in a variety of areas. When combined with appropriate data processing techniques, the increased density and availability of accurate pressure monitoring with real-time data and remote sensing results in:

- Improved management, prediction of, and response to infrastructure failures
- Improved public safety
- Reductions in energy costs, including pumping costs, system maintenance costs, water quality problems, unaccounted-for non-revenue water and customer complaints

Water distribution systems are essential components of civic infrastructure, and each one must competently managed and maintained to provide optimal service to consumers. Because of this, each water distribution system has the immediate need for online decision-support systems based on the continuous, accurate monitoring of parameters within the system. By deploying the type of monitoring, water utilities can begin to improve system operations, manage leakage control more effectively, and reduce the duration, cost and disruption of repairs and maintenance.

The state of water safety, quality and delivery hinges upon the ability of each water utility to consistently meet customers needs. If water qualities can commit to updating and optimizing the potable water infrastructure in a manner similar to that of the recent trend towards bolstering and updating the power grid, we can continuously serve the best interests of every water customer for decades to come.

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