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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