Surge Protection of a Wellfield Pipeline System Through Hardening and Risk Analysis

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ABSTRACT

Utilities have several options for protecting pipeline systems from the effects of transients and surges. The most common methods include installation of surge protection devices, such as surge chambers, air release valves, etc., and to design the system to withstand the stresses of transients (hardening of the system).

The San Antonio Water System recently placed into operation an Aquifer Storage and Recovery (ASR) wellfield that both stores excess water underground (storage mode) and pumps stored water and native groundwater (recovery mode) for use in its distribution system. The system is unique in that it must operate in both directions. In the storage mode, the wellfield is connected directly to the distribution system and must be designed to withstand the tremendous pressure associated with receiving water from a pressure zone over 350 feet in elevation above the wellfield's ground elevation. In recovery mode the wells pump to a treatment plant or ground storage tank at approximately 50 feet higher in elevation. The high pressure experienced during storage operations and the low pressure experienced during recovery operations each have their own unique transient conditions.

The 29-well wellfield will be constructed in two phases ultimately producing 64 million gallons per day (mgd), with the second phase currently in construction. The first phase of the wellfield (30 mgd capacity) was constructed with PVC C900 and C905 for the laterals and small collection mains, and AWWA C200 mortar-lined steel pipe for the mains greater than 24 inches in diameter. The surge protection system included four surge chambers located on the main line designed to keep the wellfield under positive pressure during surge events.

A surge analysis was performed prior to design of the second phase of the wellfield. The surge analysis recommended the installation of additional surge chambers, and to save costs, the allowable minimal pressure would be set at –7.0 pounds per square

inch (psi) throughout the wellfield. The cost to fully protect the wellfield exceeded $0.5 million for these options. In an effort to reduce costs further, the utility decided to harden the second phase of the system so that they could withstand pressures below –7.0 psi. The second phase piping only included laterals that would connect to the existing C905 and C200 mains. Therefore, HDPE pipe was selected for the second phase piping because it could withstand transient pressures down to full vacuum (-14.7 psi). The utility also investigated decreasing the allowable minimum pressure in the wellfield and would attempt to maintain a pressure above –10.0 psi in all piping. The cost to provide this level of protection approached $390,000.

In an effort to further reduce costs, the utility applied a risk analysis to the wellfield piping and adopted a "wait and see" policy before investing significant resources into the surge protection system. The reasons for this decision are 1) the wellfield can remain in production while damaged laterals can be taken offline for repairs, 2) the expensive components of the wellfield, i.e., the wells and the C200 mains, are well protected with surge protection devices installed during Phase 1, 3) with proper monitoring, the utility can detect and repair transient-damaged sections less expensively than to blanket the entire wellfield with surge protection, and 4) the number of operating wells is critical during recharge, not during production (which is the mode in which negative surge pressures exist).

KEYWORDS

wellfield, surge protection, pipelines

BACKGROUND

In 1997, the San Antonio Water System (SAWS) embarked upon a study to determine the feasibility of developing an aquifer storage recovery (ASR) facility to provide potable water to meet peak seasonal demands and reduce peak withdrawal rates from the Edwards aquifer. The test drilling program suggested that the Carrizo aquifer was suitable for storage of several potential source waters. Also, during the second part of the feasibility investigation, it was determined that the Carrizo aquifer in South Bexar County could provide a substantial supply of new-source groundwater for many years.

Therefore, SAWS determined that the development of a conjunctive use project, incorporating an ASR element and a groundwater production element, would be in the interest of San Antonio. This approach provides the most rapid development of the supply source. During the first phase, the ASR system was developed to provide a groundwater supply of 30 mgd. A total of 17 wells were constructed to supply raw groundwater to a new 30 mgd water treatment plant, pumping station, and transmission pipeline. A bypass around the pumping station and the water treatment plant was constructed to facilitate recharge.

Water from these facilities is transported, by way of approximately 30 miles of 60-inch steel pipe and 16 miles of 42-inch steel pipe, into San Antonio to three terminal points where it is delivered into the SAWS distribution system. Currently, these points are the Seale Pump Station, the Artesia Pump Station, and the Randolph Pump Station.

Phase 2 of the ASR Program originally anticipated expansion of the system to 60 mgd of recovery capacity. All Phase 1 facilities were designed to operate at a minimum 60-mgd rate. Enhancements necessary to achieve the 60-mgd capacity would include construction of up to 12 new ASR wells and the installation of one 20-mgd high service pump at the water treatment plant high service pump station (HSPS). The layout of the wellfield is shown in Figure 1. This layout shows all existing and projected well sites as well as existing surge chamber locations.

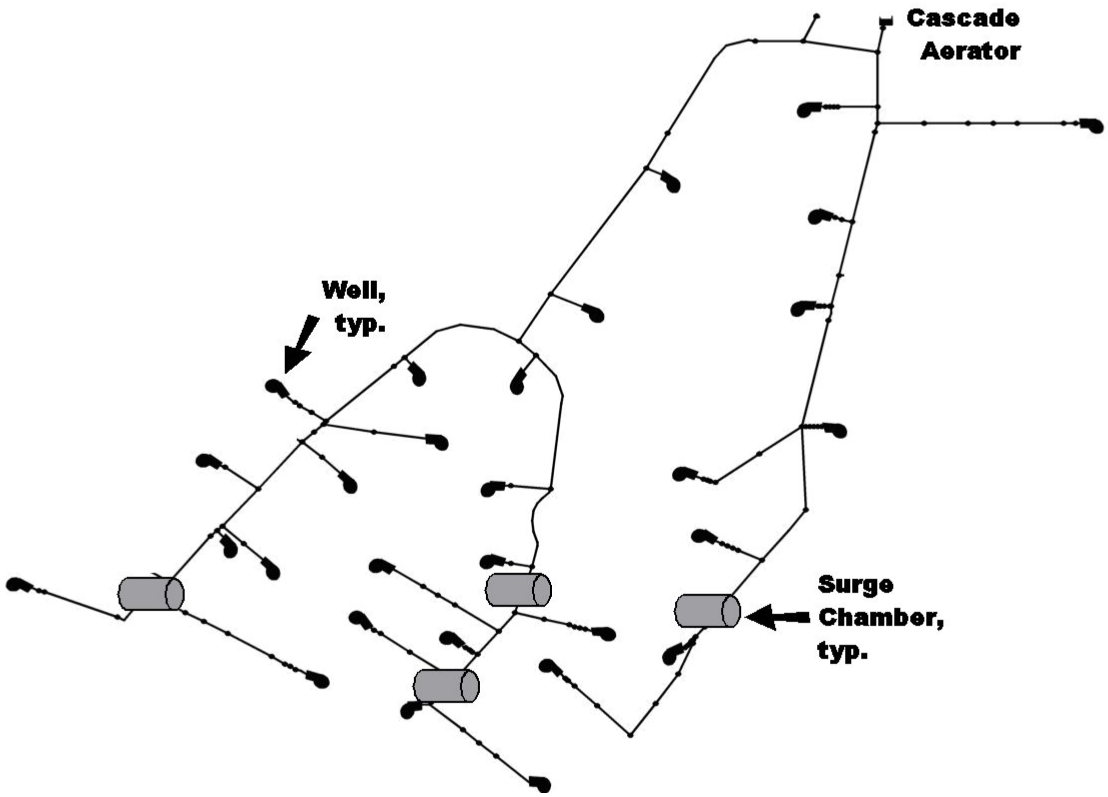

Figure 1. Layout of ASR Wellfield

The Phase 1 wellfield piping consists of C200 mortar-lined, tape coated steel pipe and C900 and C905 polyvinyl chloride (PVC) pipe. The size and characteristics of the PVC pipe is shown in Table 1 and the size and characteristics of the steel pipe is shown in Table 2. All of the main piping 24 inches in diameter and larger was constructed of steel pipe and all laterals were PVC. During Phase 1, four 300-ft^3 surge chambers were strategically located throughout the wellfield to protect the Phase 1 and Phase 2 piping from surge pressures. The initial air volume of each surge chamber was set at 50%.

Table 1. PVC Pipe Characteristics

Pipe Class	OD, in.	Type	Wall thickness, in.	DR	Long Term Strength, psi
100	12	C900	0.48	25	4,000
165	20	C905	0.80	25	4,000
165	24	C905	0.96	25	4,000

Table 2. Steel Pipe Characteristics

Pipe Class	ID, in.	OD of Steel barrel, in.	Wall thickness, in.	Specified Tensile Strength of Steel, psi	Specified Yield Stress of Steel, psi
150	30	31.5	0.25	60,000	42,000
150	36	37.5	0.25	60,000	42,000
150	42	43.5	0.25	60,000	42,000
150	54	55.54	0.27	60,000	42,000
150	60	61.62	0.31	60,000	42,000

The wellfield operates in both directions. During recovery, water is pumped from the aquifer to the cascade aerator for treatment or into a storage tank near the HSPS. During storage, the water enters the wellfield through the bypass and is injected into wells for storage in the aquifer. For the purposes of this analysis, only the recovery mode of operation was analyzed because it presented unique operating conditions for the wellfield piping. During recharge, a pressure-reducing station will control the pressure within the wellfield which will reduce the effects of positive and negative surge events.

SURGE PROTECTION OPTIONS

During recovery operations, a surge analysis revealed that the wellfield would only be subjected to very minor positive surge pressures, all within the operating range of the infrastructure. However, because of the long lateral lengths and the low operating pressure throughout the wellfield during recover, the majority of the transient problems would occur as a result of negative pressures.

Several scenarios were modeled which resulted in a negative surge pressure within the wellfield. These scenarios included loss of power, valve closure, and line breakage. Of all these scenarios, loss of power during peak production resulted in the greatest negative pressure. Significant negative pressures can result in pipe collapse or joint movement. One additional concern was the possibility of the cement mortar lining spalling and cracking because of excess stress in the steel pipe walls and because accumulated moisture between the lining and the pipe wall can push the lining out as the line pressure becomes negative.

Several options were presented to SAWS to protect the steel and PVC pipe from the effects of the negative surge. These options include 1) installing additional surge chambers, 2) installing additional air release/vacuum valves, and 3) increasing the strength of the infrastructure, or "hardening" of the system. Each of these systems have their benefits and negative attributes and a risk analysis must be performed before accepting one or more as the final solution.

Surge chambers have a well-established reputation for surge protection against both high and negative surge pressures. During Phase 1, four surge chambers were installed to protect the steel main lines. However, surge chambers require specialized control equipment, a power source, and a monitoring system in order to be dependable when they are needed. Another negative attribute of the surge chambers is their initial capital cost and constant maintenance requirements.

Air release and air vacuum valves also have a well-established reputation for protecting pipelines from the effects of surge. However, there are also several documented cases in which pipelines have been damaged beyond repair because of an undersized or under-maintained air vacuum valve. Additionally, there are several disadvantages associated with using air vacuum valves for surge protection. One disadvantage is the installation of air release valves may not significantly reduce surge pressures. For example, one 1,200-foot-long lateral was modeled with four air vacuum valves without a significant reduction in the minimum hydraulic grade line of that lateral. Effectiveness of air release valves for surge protection is often dictated by the configuration of the profile of the pipe. Air vacuum valves also must be maintained regularly to ensure their proper functionality.

A third option for protecting the wellfield from negative surge pressures is to harden the system. Hardening of the system includes installing pipelines and appurtenances that are designed to operate under negative pressure conditions (up to a complete vacuum of -14.7 psi) as well as the cavitational forces associated with column separation and the subsequent return of positive pressures. Appurtenances include isolation valves, fittings, and air vacuum valves. While hardening the system may reduce the number of installed air vacuum valves, the air vacuum valves are still required to be installed at high points in the lines and in long pipe runs for proper operation of the piping during normal operations. The air vacuum valves are suggested to be of the anti-slam configuration to reduce the shock caused by a quick-closing air vacuum valve.

One of the most expensive components of the wellfield subjected to extreme negative pressures is the piping. Therefore, it is important to consider choosing a piping material that can withstand negative pressures up to and including complete vacuum. High density polyethylene, or HDPE, pipe presented the characteristics necessary to operate under negative surge conditions. When properly installed in a trench, the pipe will not collapse under full vacuum conditions.

OPERATION AND PROTECTION OF THE WELLFIELD PIPING

In order to operate the wellfield with a factor of safety of 2.0, the recommended lowest pressure at any point in the wellfield would be approximately -7.0 psi. However, in order to maintain this pressure, several surge chambers and air release/vacuum valves would have to be installed, resulting in a surge protection cost of approximately $0.5 million. Even limiting pressures to -10.0 psi would result in a surge protection cost of approximately $390,000. The appurtenances required for this level of protection and the associated cost for these improvements are listed in Table 3. Figure 2 shows the -10.0 psi wellfield layout and the proposed arrangement of air vacuum valves and surge chambers throughout the wellfield.

Table 3. Recommended Surge Protection Devices and Cost Estimate

Minimum Surge Pressure, psi	Required number of Air/Vacuum Valves	Required number of Surge Chambers	Cost Estimate
-7.0	73	6	$500,000
-10.0	28	6	$390,000
-14.7	0	0	$0

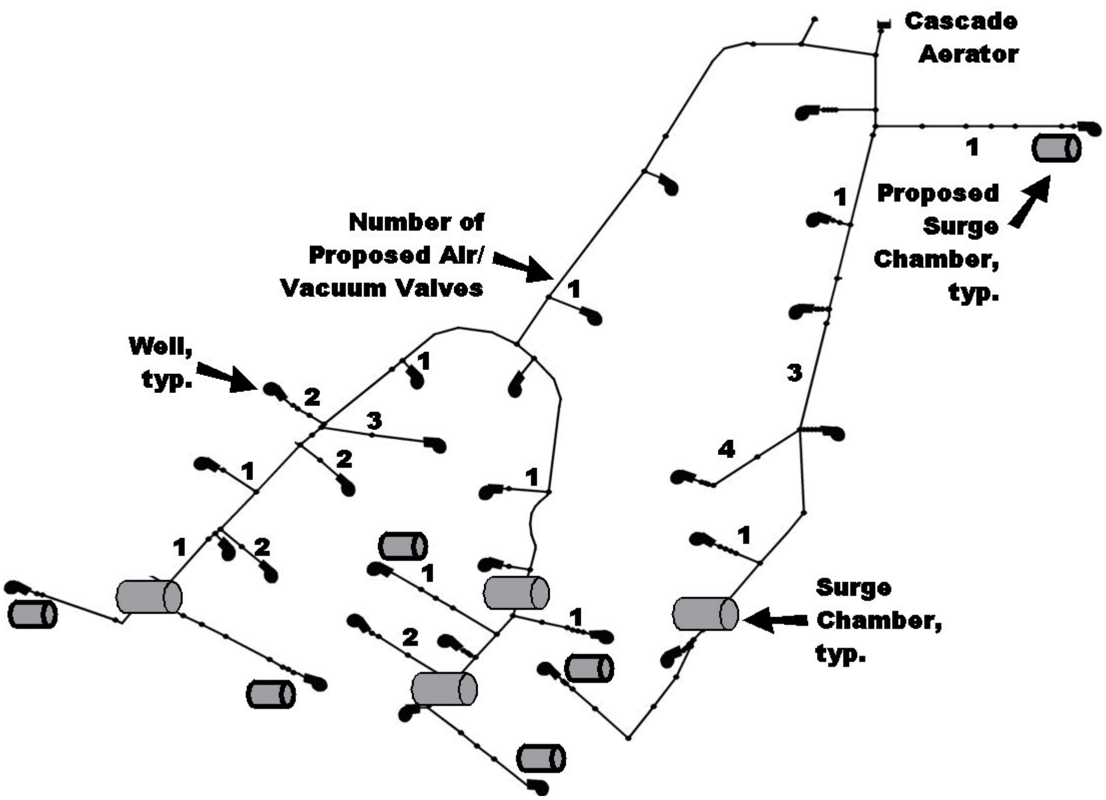

Figure 2. _Proposed Surge Protection for Minimum Pressure of -10.0 psi.

Faced with these costs, SAWS was presented with options to harden the wellfield system to reduce risk of damaging the piping during a surge event. Hardening of the system was a practical option for SAWS because if portions of the system became damaged during a surge event, the wellfield could still be operational because the damaged sections could be isolated to allow normal operation.

The use of HDPE pipe was selected as the option to protect all Phase 2 piping. However, the existing system had several miles of PVC laterals and steel main piping that required protection during a surge event. The surge analysis showed that the four existing surge chambers protected the majority of the steel piping from extreme negative pressures. Therefore, it appeared from these results that the risk remained with the PVC laterals.

SAWS had several options for protecting these existing lateral pipes. One option was to replace all of the pipes with HDPE pipe. This option was not selected because of the high cost of installing several miles of HDPE pipe and because it was deemed as wasteful. A second option was to install smaller surge chambers at each of the well sites. This option will protect the PVC laterals, however, the high costs associated with this option made it impractical.

The final option was to adopt a “wait and see” operational scenario. Based on literature of PVC pipe characteristics, it was difficult to determine if any real damage would result if the PVC pipe was subjected to a full vacuum. Laboratory tests had shown that the pipe wall could adequately withstand full vacuum pressure, but the gasket was not rated for that situation. Even though the gasket was not rated for vacuum, there was no data that showed that the gasket would fail under vacuum conditions.

Based upon this information, SAWS chose the option to leave the PVC laterals in place and closely monitor the condition of the pipe. If a power failure is experienced within the wellfield, SAWS has the option of isolating all of the PVC laterals and testing their integrity individually. This provides SAWS with the option of repairing any damaged pipe before the lateral is returned to service. The damaged section of pipe could also be replaced with HDPE pipe so as to minimize the possibility of future damage at the same location during future surge events. This repaired section would also be fitted with an anti-slam air vacuum valve to minimize the surge effect in the immediate area. The repaired section would therefore be designated as a hardened area, thus reducing the probability that this section would be damaged again in the future by surge.

While economic cost was one of the factors which SAWS considered in making their decision, another factor was water cost. The options of replacing all lateral piping, or taking all the laterals off-line to install air release valves or surge tanks, carried a cost in terms of the SAWS water budget. During construction of these options, the entire ASR system would be inactive, not allowing any water production or injection. If a drought occurred during construction of the first two options SAWS could potentially have trouble meeting the water demands of San Antonio. By waiting for surge problems to occur and correcting them then, one well could be taken off-line and the ASR System would still be able to operate as needed.

CONCLUSION

Water supply systems are constantly performing risk assessments and cost/benefit analyses to determine how much budget to spend on protecting their water supply and delivery systems. The San Antonio Water System was provided with an option of providing limited additional protection for existing piping within the aquifer storage and recovery wellfield because of several unique factors associated with the wellfield. These factors include 1) the wellfield is a critical water supply component, but individual wells and laterals can be taken offline for repairs, 2) the expensive components of the wellfield, i.e., the wells and the C200 mains, are well protected with surge protection devices installed during Phase 1, 3) with proper monitoring, the utility can detect and repair transient-damaged sections less expensively than to blanket the entire wellfield with surge protection, and 4) even with some damaged laterals, the wellfield can maintain full production because the damaged sections can be isolated.