



LESSONS LEARNED

Advanced Pressure Regulating Valve Installation,
Commissioning, and Preliminary Testing

**Energy and Water Project
EW-201715**

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ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
APRV	advanced pressure regulating valve
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
CV	control valve
DoD	Department of Defense
DPW	Department of Public Works
EO	Executive Order
ERDC	Engineering Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EXWC	Engineering and Expeditionary Warfare Center
FY	fiscal year
gpm	gallon per minute
ILA	industrial, landscaping, and agricultural
mA	milliamp
NAVFAC	Naval Facilities Engineering Systems Command
NBVC	Naval Base Ventura County
OBE	overcome by events
O&M	operation and maintenance
PRV	pressure regulating valve
psi	pound per square inch
PVC	polyvinyl chloride
ROI	return on investment
SIR	savings to investment
SNI	San Nicolas Island
UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers

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ABSTRACT

Advanced pressure regulating valves (APRVs) are designed to automatically increase downstream pressure during peak water demand or decrease pressure during non-peak hours to provide water savings. Reduced pressure in the distribution system results in reduced water loss through existing leaks, and lower stress on pipes to mitigate breaks and repairs. This report presents lessons learned from the evaluation of leak reduction and reliability of APRV operations based on two different hydraulically-actuated valve designs: the Singer 106 and Cla-Val 98-06. Additionally, a powered Cla-Val 131 APRV was evaluated. The Cla-Val Model 131 is a conversion kit that retrofits the Cla-Val 98-06 to an electronically actuated valve with two solenoids. Pressure, leak, and fire flow testing was done at the U.S. Army Engineering Research and Development Center's water distribution test-bed in Vicksburg, Mississippi.

All APRVs tested met fire flow and water loss reduction goals; however, the Singer 106 and Cla-Val 98-06 experienced harmful pressure transients during start-up and operation. Based on the test data, 10% water reduction from leaks was achieved with a high to low pressure delta of 15 psi. During the Cla-Val Model 131 testing, the team experienced minimal pressure transients when compared to the other two APRVs, and confirmed the highly programmable flow and pressure set points on the VC22-D controller. The Cla-Val 131 is not recommended for multi-feed systems, but it is applicable to tree-type water distribution systems.

EXECUTIVE SUMMARY

This project investigates the feasibility of achieving further water conservation using an advanced pressure regulating valve (APRV) technology that modulates pressure based on demand to optimize water reduction. Unlike conventional pressure regulating valves (PRVs) that have a single downstream pressure set point, the APRV design has two constant downstream pressure settings (normal and low-pressure settings) that adjust distribution system pressure in response to the flow rate through the distribution system.

The APRV saves water by operating at the lower pressure setting during low flow requirements that occur during periods of low demand (e.g., overnight, weekends). However, as water usage increases, the APRV provides higher pressure to automatically increase flow to the distribution system. The flow trigger point is set based on end user requirements and is adjustable in the field to accommodate future changes in distribution system requirements.

The Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) supported this project to assess the feasibility of achieving further water conservation using the APRV technology. This study was conducted by the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) in collaboration with the United States Army Corps of Engineers (USACE) and Battelle. The demonstration was conducted on a controlled pipeline test bed located at the U.S. Army Engineering Research and Development Center (ERDC) in Vicksburg, Mississippi to validate water savings potential, along with the overall functionality and reliability of the APRV.

Objectives:

- Reduce water loss by 10% using the APRV
- Investigate the cost savings associated with the implementation of the technology
- Test if the APRV operates as designed
- Assess any negative impact on downstream users
- Investigate if the APRV can meet normal and high water demands (i.e. fire flow)
- Analyze the impacts of failed components due to lack of maintenance

The controlled pipeline test bed was configured with simulated leaks of varying sizes to test the reliability of APRV operations through a wide range of flow and pressure regimes. Monitoring equipment measured pipeline pressure, flow, and the resulting leakage rates to validate leak reduction performance. The potential for pressure spikes and/or water hammer from APRV operations was monitored during pressure transitions.

Three APRVs were evaluated: Singer 106, Cla-Val 98-06, and Cla-Val 131. All these APRVs were able to reduce water loss up to 30% in comparison to the baseline (with the water supply at 95 pounds per square inch [psi]). Based on the test data, 10% water reduction from leakage was achieved with a high to low pressure delta of 15 psi. For all APRVs tested, the maximum APRV flow achieved was 750 gpm, exceeding the minimum UFC fire flow requirement of 500 gpm for one-story, non-sprinklered family housing over a duration of 90 minutes.

NAVFAC EXWC does not recommend implementing the Singer 106 or Cla-Val 98-06 APRVs due to transition speeds, commissioning pressure transients, and water hammer experienced during testing. The team also experienced manufacturer errors (wrong valve size shipped and a clogged strainer) and issues with temperatures below 32°F. EXWC recommends the Cla-Val 131 for use in isolated tree-type water distributions, but not multi-feed systems.

Implementation Issues and Solutions

Current DoD guidance (UFC 3-600-01) no longer allows the use of PRVs on distribution lines or service mains for future designs primarily due to lack of manpower and resources available to maintain existing critical infrastructure. The demonstration testing at ERDC was intended to validate leak reduction and reliability of APRV operations, which aligns with DoD installations' requirement to take measures to reduce water loss and to improve water use efficiency (Executive Order [EO] 13693). A follow-on full-scale demonstration at an operational environment was planned to collect data on APRV performance in the field to assess long-term maintenance issues and to develop guidance for deployment of this technology at DoD installations. This initiative was not completed due to the pressure transients observed when testing the APRVs.

For the two hydraulically actuated valves, the Singer 106 and Cla-Val 98-06 models, issues were experienced with water hammer and the valve closing speed when transitioning from high to low flow rates. This led to unwanted pressure surges and an increased potential for infrastructure damage. The team transitioned to an electronically actuated valve, the Cla-Val 131. For the Cla-Val 131, two out of 10 tests resulted in a pressure transient of 10 psi over 5 seconds, and one test with a pressure transient of 30 psi over 5 seconds. Overall, the Cla-Val 131 presented the lowest amount of pressure transients. Consequently, it is considered to be a more viable alternative than the hydraulically actuated APRVs. Therefore, the results presented within the body of the report are those obtained from Cla-Val 131. Due to the aforementioned, water hammer problems, the results obtained from Singer 106 and Cla-Val 98-06 are in Appendix B and Appendix C.

Cost Assessment

Cost savings were assessed by estimating the volume of water saved, equipment, installation, and maintenance costs. Cost savings from utilizing the APRVs were evaluated using two related metrics: Savings to Investment Ratio (SIR) and Return on Investment (ROI).

The SIR method is a pass/fail evaluation that divides the savings from avoided purchases over the lifecycle of the APRV by the capital costs of installation and maintenance. All APRVs tested have a 20-year design life as specified by the vendor. SIR greater than 1 indicates that the technology is cost effective and that the savings are at least as large as the cost. All APRVs tested have a SIR higher than 1.

ROI is a measurement of the number of years required to break even on the investment. The avoided purchase is divided by the capital costs to install and maintain the APRV. An ROI of less than 7 years was included as the cost savings performance objective. An ROI of less than 7 years indicates that the annual savings will equal the installation cost after 7 years, and then after that point the technology will result in a net savings. The ROI was determined to be 2.1 years (Singer), 2.2 years (Cla-Val 98-06), and 4.6 years (Cla-Val 131), which provides better than expected return than the 7-year ROI metric. The APRV technology readily met the cost metrics based on cost model assumptions and elements as summarized in Appendix D.

1 INTRODUCTION

This section describes the background objectives of the advanced pressure regulating valve (APRV) demonstration, and regulatory drivers for water conservation.

1.1 Background

The benefits of pressure management, as described in the American Water Works Association's (AWWA's) M36 Water Audits and Loss Control Programs, include: 1) reduced frequency of new leaks and breaks within a water distribution system, and 2) reduced flow rates of pre-existing leaks and breaks and background leakage that cannot be avoided. Conventional pressure regulating valves (PRVs) are used on Department of Defense (DoD) water distribution systems to reduce high inlet source pressures (typically above 90 pounds per square inch [psi]) to a more sustainable and constant lower downstream pressure (i.e., 65 psi).

The APRV technology modulates pressure based on demand to optimize water reduction. Unlike conventional PRVs that have a single downstream pressure set point, the APRV design has two constant downstream pressure settings (normal and low-pressure settings) that adjust distribution system pressure in response to the flow rate through the distribution system. The APRV saves water by operating at the lower pressure setting during low flow requirements that occur during periods of low demand (e.g., overnight). However, as water usage increases, the APRV provides higher pressure to automatically increase flow to the distribution system.

During off-peak demand periods for distribution systems that service military housing, the APRV would usually be at the low pressure setting because of low flow conditions typical at hours between 10 pm and 5 am. The APRV would automatically switch over to the normal pressure setting when flow reaches a trigger point (for example 250 gallons per minute [gpm]) when water demand increases in the morning. The flow trigger point is set based on end user requirements and can be adjusted in the field to accommodate future changes in distribution system requirements.

The DoD Environmental Security Technology Certification Program (ESTCP) supported this project to assess the feasibility of achieving further water conservation using the APRV technology. This study was conducted by the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) in collaboration with the United States Army Corps of Engineers (USACE) and Battelle. Appendix A includes the key points of contact for the project. The demonstration was conducted on a controlled pipeline test bed located at the U.S. Army Engineering Research and Development Center (ERDC) to validate water savings potential, along with the overall functionality and reliability of the APRV. ERDC is a research facility dedicated to addressing water-related engineering challenges in the Army, USACE, and DoD. It is a 673-acre site located in west-central Mississippi near Vicksburg within the Mississippi River watershed.

The first phase of the demonstration was intended to validate leak reduction and reliability of the APRV operations at the test bed. Upon completion of the test bed stage, a full-scale demonstration in an operational environment at a DoD installation was planned if a "go" decision was reached by the review committee to evaluate field applications and develop guidance for DoD-wide deployment of this technology. DoD has approximately 160 installations in the U.S. with extensive

water distribution systems serving industrial and residential uses with the potential to benefit from water conservation measures via the application of innovative technologies such as the APRV.

1.2 Objective of the Demonstration

The planned objectives of this study were to achieve the following:

- Reduce 10% in water loss using the APRV
- Investigate the cost savings associated with the implementation of the technology
- Test if the APRV operates as designed
- Assess any negative impact on downstream users
- Investigate if the APRV can meet normal and high water demands (i.e., fire flow)
- Analyze the impacts of failed components due to lack of maintenance

The controlled pipeline test bed was configured with simulated leaks to test the reliability of APRV operations through a wide range of flow and pressure regimes. Monitoring equipment was used to measure pipeline pressure, flow, and the resulting leakage rates to validate leak reduction performance. The potential for pressure spikes and/or water hammer from APRV operations was monitored during pressure transitions.

The test bed demonstration was designed to determine how lack of maintenance on the APRV could impact operation. The failure mode for the APRV, such as a diaphragm rupture or strainer clogging, would result in it being stuck at the pressure setting when clogging occurred. The worst-case scenario for distribution system reliability would be constant operation at the low-pressure setting regardless of water demand. To avoid unacceptable impacts of this failure scenario, the low-pressure set point must be set to ensure that fire flow demand can still be met. One of the fire flow requirements found in Unified Facilities Criteria (UFC) 3-600-01 Fire Protection Engineering for Facilities is that residential areas with one and two stories are to achieve 500 gpm and 750 gpm flow rates, respectively, for 90 minutes. Fire flow assurance testing was conducted at the test bed and a flow meter capable of reading up to 1,900 gpm was installed to verify these high flow requirements to the extent practical. In total, three different APRV models were evaluated for these performance factors in the test bed environment.

A full-scale demonstration was planned at an operational environment as a second phase if a “go” decision was reached by the review committee to collect data on APRV performance in the field and to develop guidance for deployment of this technology at DoD installations. A feasibility study was conducted on the use of the APRV technology for a full-scale Navy installation. However, several lessons learned were drawn from the installation, commissioning, and preliminary testing of the hydraulically-actuated APRV technologies, which indicated that a full-scale demonstration would not be feasible. A supplemental demonstration was then performed in the test bed to evaluate an electronically-actuated APRV as a potential alternative approach.

1.3 Regulatory Drivers

The primary regulatory requirement addressed by this research is Executive Order (EO) 13693, released in 2015, titled *Planning for Federal Sustainability in the Next Decade*, which requires DoD installations to take measures to reduce water loss and requires agencies to improve water use efficiency and management as follows:

- Reducing agency potable water consumption intensity, measured in gallons per gross square foot, by 36% by fiscal year (FY) 2025 through reductions of 2% annually relative to a baseline of the agency's water consumption in FY 2007.
- Installing water meters and collecting and utilizing building and facility water balance data to improve water conservation and management.
- Reducing agency industrial, landscaping, and agricultural (ILA) water consumption by 2% annually through FY 2025 relative to a baseline of the agency's ILA water consumption in FY 2010.
- Installing appropriate green infrastructure features on federally owned property to improve stormwater and wastewater management.

As an innovative water conservation measure, the implementation of APRV technologies on DoD water mains had the potential to support these Federal and DoD sustainability goals.

2 TECHNOLOGY DESCRIPTION

This section provides an overview of the APRV technology, a brief summary of the hydraulically actuated Singer and Cla-Val 98-06 APRVs utilized in the demonstration project, technology development, and the advantages and limitations of the technology. Section 4 contains the technology description for the Cla-Val 131, the third valve tested during this project. The Cla-Val 131 is an electronically actuated valve selected as an alternate technology for testing based on the teams experience with the first two hydraulically actuated valves.

2.1 Technology Overview

The APRV technology supplies water near the pressure of the supply source for installation operations when needed and automatically reduces pressure to the distribution system during low demand periods. This reduces water loss due to leaks and minimizes stress on pipes and fittings. There is a direct correlation between pressure and flow rate of water through a given pipe opening, such as a hole in a pipe, or a failed seal/joint (leak). Greeley's formula establishes the relationship between pressure and flow rate (summarized in the *AWWA Manual of Water Supply Practices M36: Water Audits and Loss Control Programs*¹):

$$Q = (30.394) * A * P^{0.5}$$

where: Q = flow rate
 A = area of pipe opening
 P = pressure of pipe

Conventional PRV's reduce pressure to a level compatible with fixtures and have one set point that controls the maximum pressure downstream of the device. The APRV (Figure 2-1) is innovative as it employs two pressure-setting pilot valves to control outlet pressure based on real-time flow demand downstream of the valve on single feed water distribution systems. The water operator choses set points (Table 2-1) based on site-specific conditions, which are critical for a successful installation.

Table 2-1. Typical APRV Settings

Demand	Source Pressure (psi)	Downstream Pressure Set Point (psi)	Flow Range (gpm)	Trip Flow (gpm)
Normal Operations	95	50	0-250	<250
High Demand Operations	95	65	250-750	>250

¹ American Water Works Association. 2009. Manual of Water Supply Practices M36: Water Audits and Loss Control Programs.

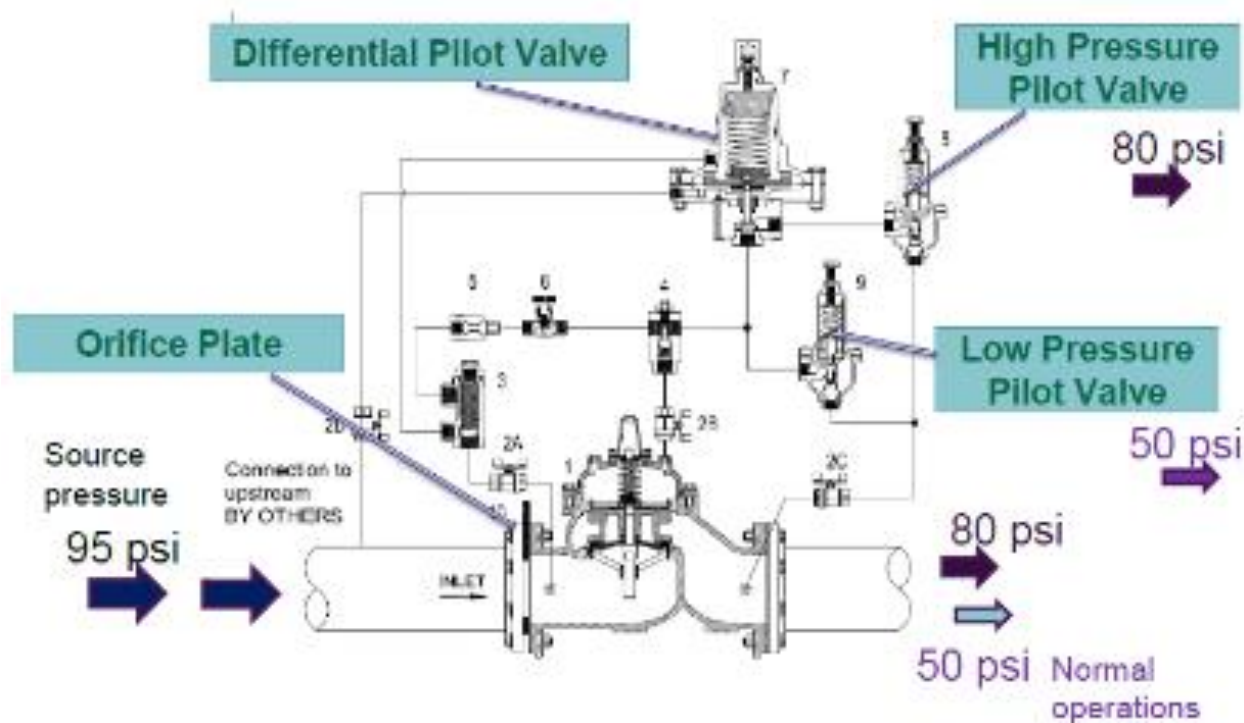


Figure 2-1. Schematic of APRV (Source: Singer)

2.2 Hydraulic APRVs Tested

2.2.1 Singer 106

The Singer APRV, Model 106/206-2PR-630, is manufactured by Singer Valve (Mueller Water Products). The APRV consists of a standard globe valve integrated with an orifice plate, differential pilot and two pressure-setting pilots (for high-pressure and low-pressure operations) to control outlet pressure based on real-time flow demand downstream of the valve. It includes flow stabilizing/opening speed control, a 40-mesh strainer, and a chloramine resistant diaphragm. The APRV model provides a fully operational back-up system in the event of diaphragm or pilot failure. The dual pressure innovation of the advanced design is made possible with the integration of an orifice plate, a second pilot valve and a differential pilot device added onto a conventional PRV design.

2.2.2 Cla-Val 98-06

The Cla-Val, Model 98-06 is an APRV consisting of adjustable high pressure and low pressure set points for high flow and low flow demand, respectively. This dual set point arrangement allows for reduction in water consumption, as well as unintentional water loss by keeping system piping from being over-pressurized during periods of low demand. The valve consists of three major components: the body with seat installed, the cover with bearings installed, and the diaphragm assembly. As flow increases from a low flow condition to a high flow condition, the outlet pressure increases from the low to high set point. The Cla-Val operates without inhibiting adequate pressure during high or fire flow demand. The Cla-Val 98-06 valve has no orifice plate or other restriction

in the main line as part of the valve control. It operates under hydraulic control without electrical controls.

2.3 Technology Development

Conventional PRVs have a single downstream pressure set point. The recent innovation that led to the APRV design is to provide two constant downstream pressure settings (normal and low-pressure settings) that automatically adjust distribution system pressure in response to the real-time flow rate through the distribution system. While the APRV valve configuration and control methodology are innovative, the components that make up the valve are not new and have a proven track record. The components are simply combined in a new way to achieve the desired outcome of changing pressure set points based on target flow rates. The technology is an emerging technology that has been commercialized, but not yet utilized on a widespread basis. The few full-scale applications identified at the time of the proposal were outside of North America (e.g., South Africa and Malaysia). The market for these valves is single source systems, which are more typical overseas where district metering areas are employed versus looped systems. More information on the technology development is available from the manufacturer's web sites linked here for the [Singer Model 106/206-2PR-630](#), [Cla-Val Model 98-06](#), and [Cla-Val Model 131-01](#) APRVs.

2.4 Advantages and Limitations of the Technology

The main advantage of the APRV technology is the ability to provide pressure near the source supply when needed, while automatically reducing pressure to the distribution system during low demand periods. This reduces water loss due to leaks and minimizes stress on pipes and fittings. The Singer and Cla-Val 98-06 models tested run completely hydraulically, giving them an advantage over solenoid valves which require electricity. A conventional PRV is used to reduce pressure to a level compatible with fixtures and has one set point that controls the maximum pressure downstream of the device. The APRV employs two pressure-setting pilot valves to control outlet pressure based on real-time flow demand downstream of the valve on single feed water distribution systems. The set points on the valves are chosen by the water operator based on site-specific conditions.

The main risks associated with installing the APRV on an operating water line are either inadequate flow during a high demand situation or disruption of the water supply. It is possible that a valve mechanism could fail mechanically, or a clogged filter might result in inadequate water flow. Excessive debris in the source water can clog strainers and cause increased friction in the valve stem (altering the pressure setting). If the filter becomes clogged, the APRV will not be able to change pressure state downstream of the valve. For maintenance, the APRV requires periodic cleaning of a strainer and an occasional diaphragm replacement (every 7 to 10 years or as required based on field conditions). Cleaning frequency is based on site-specific water quality conditions. If the diaphragm fails, it is designed to fail in the high-pressure position and not limit flow. As a further precaution, a manual bypass line is installed around the APRV so that the water supply would not be interrupted while the APRV undergoes maintenance, such as filter cleaning or diaphragm replacement.

3 PERFORMANCE OBJECTIVES AND DEMONSTRATION SUMMARY

This section describes the performance objectives and key features of the APRV demonstration including test bed design/layout, test modifications with valve installation, commissioning, and operational testing.

3.1 Performance Objectives

The planned quantitative performance objectives included water savings, cost savings, system response, and system reliability and maintenance. The planned qualitative performance objective was customer satisfaction. The performance objective metrics, data requirements, and success criteria are listed in Table 3-1.

Table 3-1. Planned Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
<i>Quantitative Performance Objectives</i>			
Water Savings	Gallons saved	Actual/estimated volume of leak based on water pressure and measured water loss	10% Reduction in water losses from leaks. Go/No-Go decision point
Cost Savings	Savings to Investment Ratio (SIR)	Cost of water, estimated gallons of water saved, APRV lifespan, cost of equipment, installation, and maintenance	SIR > 1.0
	Return on Investment (ROI)		<7 years (assuming water cost at a range between \$2-\$20 per 1000 gallons)
System Response	Reduced pressure during periods of low demand, increased pressure during periods of high demand.	Flow rates, pressure, and response time	Flow triggers pressure change 98% of time. Response time is variable. For low to high flow/pressure transition, time was initially set at 10 seconds. From high to low flow/pressure transition, less than 60 seconds. ^(a)

Table 3-1. Planned Performance Objectives (Cont.)

Performance Objective	Metric	Data Requirements	Success Criteria
<i>Quantitative Performance Objectives</i>			
System Reliability and Maintenance	Uptime	Downtime/uptime	95% system uptime
<i>Qualitative Performance Objectives</i>			
Customer Satisfaction		Feedback from Department of Public Works (DPW) operator and water program manager	No customer complaints about flow or pressure issues at both pressure set points

(a) Based on operations in the field, the safe pressure transition speed was updated to 30 seconds.

3.1.1 Purpose of Water Savings

Optimized pressure management can reduce water loss due to leaking pipes. Implementation of advanced pressure regulating technologies on DoD water mains to reduce water losses supports Federal and DoD sustainability goals. Reducing water loss at DoD installations is important to preserve potable water needed for essential functions and to limit the drawdown of available water supplies.

3.1.1.1 Water Savings Metric and Data

During the APRV test trials, water loss through leaks at various high and low pressure set points was measured in gallons. The leak measurements were used to calculate the percent reduction in losses due to leaks in comparison to the baseline.

3.1.1.2 Water Savings Success Criteria

A 10% reduction in water loss from leaks in comparison to the baseline was considered successful and used as a go/no-go decision point for the full-scale test.

3.1.2 Purpose of Cost Savings

Water costs are based on the volume consumed. Lower pressures can also extend the life of water systems and reduce the frequency of breaks and repairs. Pressure management using technologies such as APRV can significantly reduce pipe failure rates, extend infrastructure life, and reduce the magnitude of existing leaks until they can be repaired.

3.1.2.1 Cost Saving Metric and Data

Cost savings were assessed by estimating the volume of water saved, equipment, installation, and maintenance costs. Cost savings were evaluated using two related metrics: SIR and ROI. The SIR method is a pass/fail evaluation that divides the savings from avoided purchases over the lifecycle

of the APRV by the capital costs of installation and maintenance. ROI is a measurement of the number of years required to break even on the investment. The avoided purchase is divided by the capital costs to install and maintain the APRV. Typical hourly labor rates were used to calculate overall cost, as well as adding the cost of materials.

3.1.2.2 Cost Savings Success Criteria

An SIR greater than 1 indicates that the technology is cost effective. The savings is at least as large as the cost. ROI less than 7 years indicates that the annual savings equals the installation cost after 7 years, and then after that point the technology will result in a net savings.

3.1.3 Purpose of System Response

The APRV is required to provide a higher pressure when demand is high and lower pressure when conditions are static. Failure to deliver enough pressure when needed can compromise the mission in industrial areas and is a quality of life factor in the residential sector. Failure to lower the pressure is a performance factor that reduces savings and renders the technology less effective in terms of cost and water conservation.

3.1.3.1 System Response Metric and Data

In the test bed, high and low flow demand scenarios were simulated by manually opening the exit valve and letting water flow into the reservoir. The response of the APRV to the changing pressure and flow was evaluated and recorded. Data on the timing, flow, and pressure both upstream and downstream of the APRV indicated if it was responding to changing demands.

3.1.3.2 System Response Success Criteria

Response was successful if flow triggered a pressure change 98% of the time. For a low to high flow transition, the time target was initially set at 10 seconds. For a high to low flow transition, the time was set at less than 60 seconds.

3.1.4 Purpose of System Reliability and Maintenance

Uptime was the amount of time that the APRV performed its function of regulating pressure in response to demand. Periods when it was non-functioning or actively being repaired were considered downtime. The failure mode for the APRV would be constant operation at the low-pressure setting regardless of water demand. To avoid unacceptable impacts of this failure scenario, the low-pressure set point must be set to ensure that fire flow demand can still be met. One of the fire flow requirements found in UFC 3-600-01 Fire Protection Engineering for Facilities is that residential areas with one and two stories are to achieve 500 gpm and 750 gpm flow rates, respectively for 90 minutes.

3.1.4.1 System Reliability and Maintenance Metric and Data

Maintenance logs and data on system response measured the accomplishment of this objective (i.e., replacement and removal of a diaphragm and silt screen). System uptime was the amount of time the APRV was functioning properly divided by the total time period of the test.

3.1.4.2 System Reliability and Maintenance Success Criteria

The system reliability was set at 95% uptime (5% downtime) for the APRV demonstration in case any repairs were needed in association with the failure mode tests. Meeting the minimum 500 gpm UFC fire flow requirement for one story, non-sprinklered family housing was also a requirement.

3.1.5 Purpose of Customer Satisfaction

The water consumers must have adequate water pressure and flow to meet their needs. Consumer satisfaction was intended to be assessed based upon a review of the data by UFC committee members in communication with the ESTCP Water Program Manager and the ERDC DPW Director.

3.1.5.1 Customer Satisfaction Metric and Data

To determine customer satisfaction, the DPW Director was planned to be interviewed in person before APRV installation and at the end of the project. The survey was intended to determine how the APRV performed in terms of providing adequate pressure during peak water consumption periods and any maintenance or repair issues encountered during the demonstration.

3.1.5.2 Customer Satisfaction Success Criteria

No additional complaints were received about the water pressure.

3.2 Test Bed Design, Layout, and Installation

This section describes the test bed design at ERDC, test bed modifications, and APRV installation and commissioning.

3.2.1 Test Bed Design

The demonstration was conducted at ERDC, Vicksburg, Mississippi to validate water savings potential, along with the overall functionality and reliability of the APRV. ERDC is a research facility dedicated to addressing water-related engineering challenges in the Army, USACE, and DoD. This project fit the ERDC mission to demonstrate and support adoption of technologies throughout the Army and the DoD.

ERDC has an existing pipeline test bed setup located in the northeastern corner of the campus (Figure 3-1), blue line shows the existing pipeline) that was constructed as part of a previous ESTCP project that ended in 2014 and was used for this evaluation. The pipeline test bed is constructed of 6-inch diameter steel (laid approximately 3 feet below grade) and polyvinyl chloride (PVC) pipe and is located on an isolated service lateral with an inlet pressure averaging 95 psi. For testing purposes, Vicksburg has a reliable source of potable water; any water losses due to APRV testing were not expected to adversely affect the installation or the watershed.

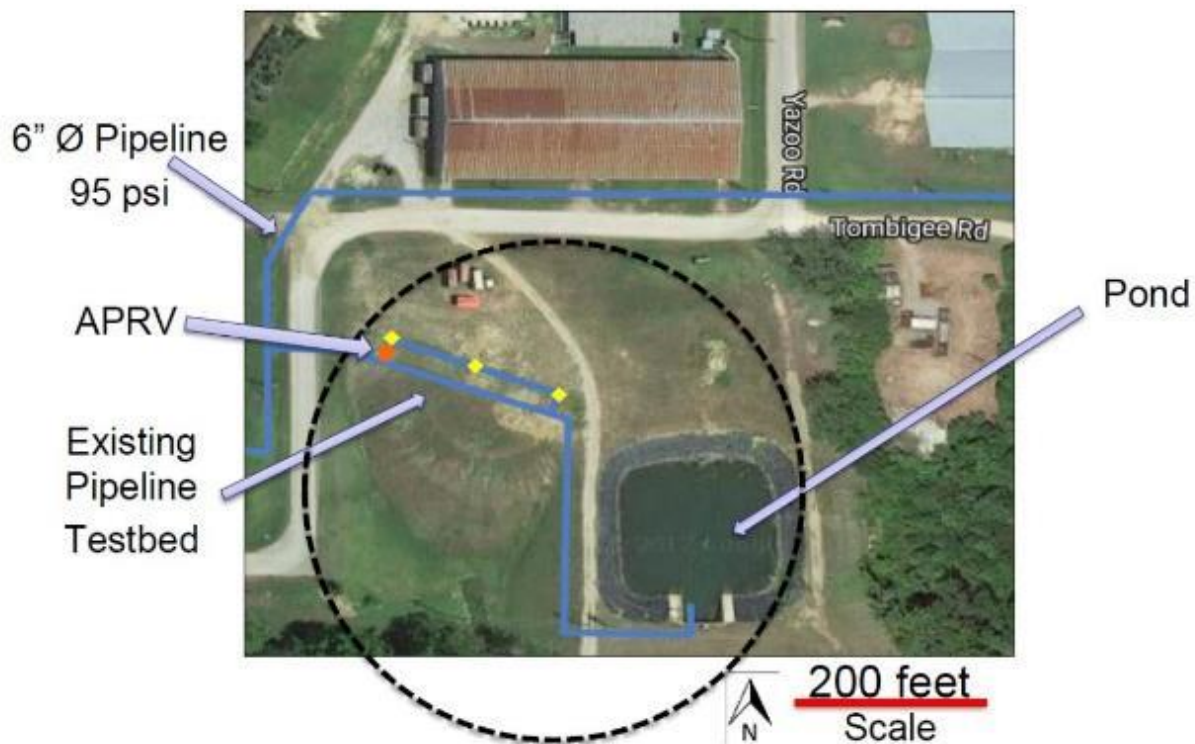


Figure 3-1. Existing Test Bed Loop at ERDC

Some of the equipment required for testing was already installed at the test bed site. The test loop had existing standpipes with pressure gauges, below grade in-line bypass isolation valves (with the controls aboveground that were manipulated by a T-handle tool), and an outlet valve that discharged to an open reservoir; however, modifications were made to the test bed for the demonstration testing as described in Section 3.2.2.

3.2.2 Test Bed Modifications

Installation of equipment and modifications to the test bed site took place in April 2019. Additionally, the test bed was modified to prepare for testing and decommission of the Singer valve. These modifications were performed by EXWC, Battelle, and ERDC staff. Modifications to the test bed consisted of the following:

- Retrofitting the existing three standpipes to simulate leaks at 1 gpm (at 95 psi) by installing orifice plugs (0.067-inch diameter orifice) as shown in Figure 3-2(a).
- Installing the digital flow meters (two Badger flow meters, Figure 3-2b) at the leak simulation setups and an Akron analog gauge (pressure and flow) with a 2-1/2-inch fire hose fitting at the reservoir outlet (Figure 3-2c).
- Installing Telog pressure transducers (Figure 3-3a), along with setting up the Telog software on the field laptop computer. Configuring the Telog pressure data loggers to transmit data. No Modbus lines or a shed to house the data logger were required as described in the Demonstration Plan as field data were manually downloaded from the Telog pressure transducers via the laptop computer (Anguiano et al., 2018).

- Installing solenoid valves with timer and 250-gallon storage tanks at the leak simulation setups (Figure 3-3b). The ground was leveled before placement of the tanks.
- Installing a manual bypass line for ease of maintenance and repair efforts (Figure 3-4).

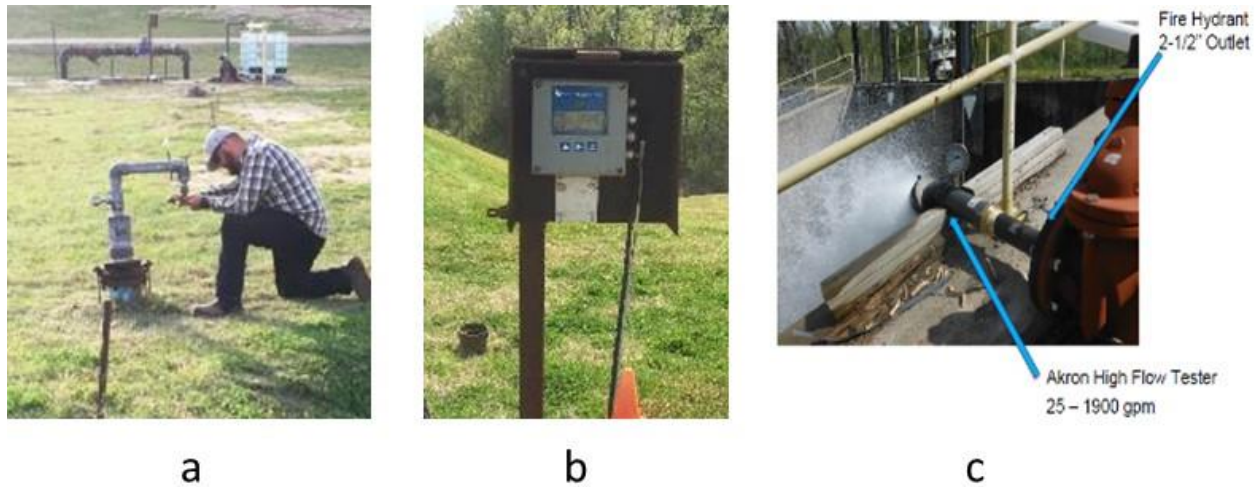


Figure 3-2. Installation of Leak Simulation and Flow Monitoring Devices: (a) Orifice Plugs on Existing Standpipe; (b) Badger Digital Flow Meter at Leak Simulation Setups; and (c) Akron High Flow Meter at Reservoir Outlet

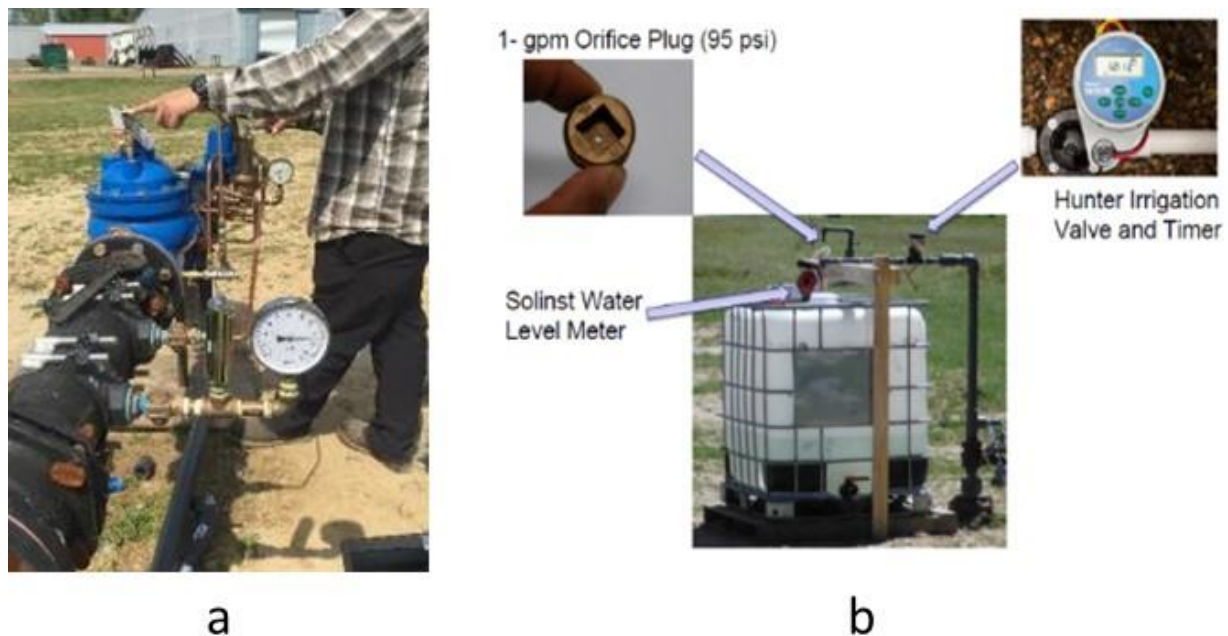


Figure 3-3. Installation of Pressure and Water Volume Monitoring Equipment: (a) Telog Pressure Transducer to Capture Pressure Data and (b) Leak Simulation Setup with Orifice Plug and Valve Timer Installed



Figure 3-4. Addition of a By-pass During Modification (Left) and After (Right)

All new equipment was calibrated and checked to ensure proper operation upon installation and remained on site at the end of the demonstration. After orifice plug installation, the orifice leak rate was checked in triplicate on the middle standpipe at distribution water supplied at 95 psi using a graduated 5-gallon bucket and stopwatch (Figure 3-5a). The orifice leak rate was calculated at 1.04 gpm based on Greeley's formula. The average orifice leak rate was 0.83 gpm. The orifice flow rates are presented in Table 3-2. In addition, the two 250-gallon tanks at the simulated leak setups were graduated at 7-liter intervals up to approximately 500 liters using the graduated 5-gallon bucket (Figure 3-5b).



a



b

Figure 3-5. Orifice Leak Measurement: (a) 5-Gallon Bucket Method and (b) Graduation of the 250-Gallon Tank

Table 3-2. Summary of Orifice Flow Rate

Orifice Size (in)	Area of Orifice (in²)	Pipeline Pressure (psi)	Theoretical Orifice Flow Rate^(a) (gpm)	Measured Orifice Flow Rate^(b) (gpm)	Relative Percent Difference (%)
0.067	0.0035	95	1.04	0.86	17%
0.067	0.0035	95	1.04	0.83	20%
0.067	0.0035	95	1.04	0.81	22%

^(a) Calculated using Greely's equation

^(b) Measured using the volume/time method

3.3 Baseline and Operational Testing on ERDC Test Bed

The planned tests, system controls, data collection procedures, and actual tests performed are included in this section.

3.3.1 Planned Tests

The test bed demonstration was initially planned for 20 weeks. The original test design involved the following:

- Comparison of the APRV technology against two baselines. Baseline 1 was the scenario with no PRV (where the APRV bypass valve was opened), and Baseline 2 was the scenario with a conventional PRV (where the APRV was adjusted with a single point pressure in lieu of the two-set point configuration). Baseline data were planned to be collected over a two-week period.
- The baseline scenario was used for comparison for follow-on APRV setting adjustments covering 10, 15, 20 and 25 psi pressure differential for both high and low flow conditions. Pressure gauges and flow meters (leakage) located on the simulated leak points were planned to be monitored weekly. Operational feasibility was to be assessed by reliability and consistency of APRV operations. The results of the test bed were planned to serve as the basis for a “go/no go” decision point on the follow-on field demonstration effort. The flow testing was planned for 6 weeks with fire assurance testing on a weekly basis.
- Evaluating the valve's ability to adjust pressure settings and APRV pressure transients were to be evaluated periodically up to 20 weeks.
- Evaluating fire flow assurance and valve maintenance after 20 weeks.
- At the end of the field demonstration, ERDC personnel planned to provide a questionnaire to the DPW operator and ESTCP Water Program Manager to capture their positive or negative feedback and any complaints associated with downstream flow or pressure.

3.3.2 System Controls

The Baseline 1 evaluation was performed by bypassing the APRV and collecting leak volume data at the distribution pressure of 95 psi. For flow scenario testing, the high- and low-pressure reducing pilot valves were independently adjusted by ERDC staff by hand turning screws to the desired downstream pressure as displayed on the upstream and downstream pressure gauges. The timers on the solenoid valves at the leak simulation setups were set at two hours to collect leak volume

data. Each trial test was run in triplicate and took approximately one day to complete. After each test, the tanks at the leak simulation setups were drained by securing flexible hosing to the discharge valve at the base of the tank. The hose was sufficiently long enough to discharge water 15 to 20 feet from the tank base. The Singer APRV (Appendix B) testing took approximately 2 weeks to complete.

3.3.3 Data Collection Protocols

During baseline and simulated flow scenario testing, pressure data were downloaded manually via a laptop computer from the Telog pressure transducers (Figure 3-6a) (with pressure data logged every second). Data were downloaded to Microsoft® Excel for subsequent processing. In addition to the pressure data, leak volume was recorded and flow rate was calculated during the test bed demonstration. The leak volume was measured from the graduated tanks at the leak simulation setups Figure 3-6b). A water level indicator (Solinst) was used to measure the ullage where 1 cm on the tank equated to 11.0 liters. The leak volume data were tabulated in Excel and the average ullage and average leak volume were calculated for each trial (data are presented in Appendix B).

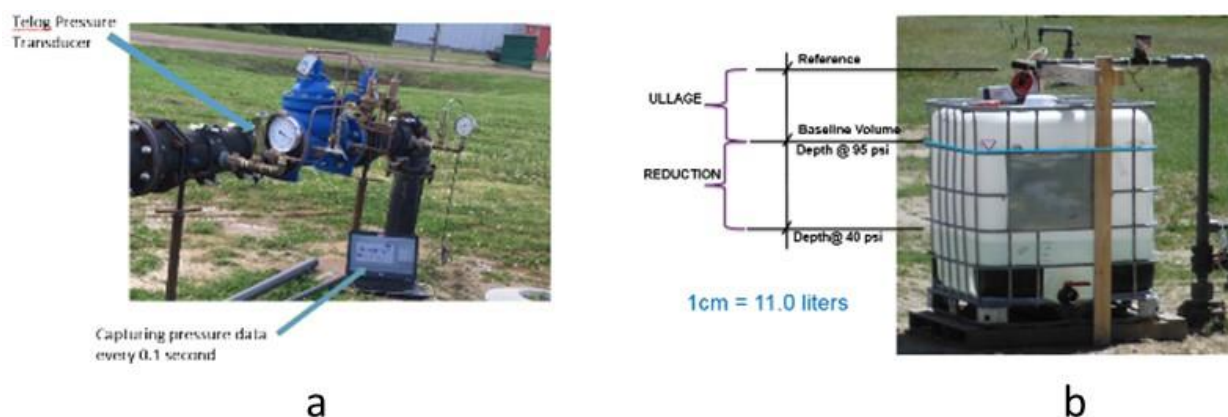


Figure 3-6. Measuring Pressure Data and Leak Volumes: (a) Downloading Pressure Data from the Telog Transducers via Laptop Computer and (b) Measuring Simulated Leak Volumes at the Leak Simulation Setups

3.3.4 Testing Protocol Implementation

The test matrix is presented in Table 3-3 and Table 3-4 of the planned and actual tests performed for the APRVs.

Table 3-3. Baseline Tests for Singer and Cla-Val APRVs

Planned APRV Testing	Test Description
Baseline 1	Determine leak (volume) with no PRV (95 psi source)
APRV Setting 1 (80 - 75 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-75 psi
APRV Setting 2 (80 -70 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-70 psi

APRV Setting 3 ^(a) (80 -65 psi) (80 - 60, 50 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-65 psi
APRV Setting 4 (70 - 60 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-60 psi
APRV Setting 5 (70 - 55 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-55 psi
APRV Setting 6 (70 - 50 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-50 psi
APRV Setting 7 (60 - 45 psi)	Preset by Cla-Val

(a) 80-60 and 80-50 testing were not evaluated.

Table 3-4. Planned Tests for Cla-Val APRV*

Planned APRV Testing	Cla-Val 131	Test Description
APRV (Fail Mode 1)	-	Performance with failed diaphragm
APRV (Fail Mode 2)	-	Performance with clogged filter screen
APRV (Fail Mode 3)	✓	Performance with power loss
APRV Fire flow (Intermittent)	✓	Determine how well APRV works with once a week low to high transition
APRV Fire flow (long-term)	OBE	Determine how well APRV works when system stays in low pressure mode for length of time
Evaluate ability to adjust pressure setting	✓	Assess ease of adjustment
APRV pressure transients	✓	Evaluate pressure transients during transitioning.
Evaluate maintenance	OBE	Assess annual maintenance requirements

*Singer and Cla-Val98-06 can be found on Appendix B and C, respectively.

In addition to the pressure testing listed in Table 3-3, the evaluators conducted pressure tests at 70-30 and 60-40 psi. Due to the short duration of the test, long-term fire flow and valve maintenance was not evaluated. The DPW operator was not formally interviewed to obtain his feedback on the valve performance as the Singer valve was not considered to be a suitable candidate for future testing due to unresolved technical issues with the valve transition speed. Lessons learned from the initial testing results are presented in Section 5.

4 CLA-VAL 131 EVALUATION

The objective of this supplemental test was to validate the performance of an electronically actuated APRV to save water, while meeting minimum flow, maintenance, and reliability system requirements. The valve configuration to be tested was specified as the Cla-Val 131. ESTCP approved the supplemental study on March 31, 2020 and EXWC procured the equipment in May 2020.

The additional equipment includes:

1. VC22-D Controller
2. Conversion Kit to 131G-DVBCSEPYKX
 - a. X14PT Transmitters
 - b. X117D Valve Position Transmitter
 - c. Electronic Control Valve
3. Tycon Solar RemotePro Remote Solar Power System
 - a. 80W Solar Panel
 - b. TC-SCPOE-1224 Solar Charger
 - c. Two 12V Batteries
 - d. System Housing
4. Associated electrical wiring and connectors

The team shipped the Cla-Val valve conversion kit to ERDC for installation. EXWC assembled the other components and verified electrical power requirements for the VC22-D controller, then shipped the system to ERDC. Cla-Val provided a custom program for the controller which was easily installed onto the controller via a USB drive that directly connects to the top of the controller. The program was loaded onto the controller and then the USB drive no longer needed to be attached to the system. ERDC Public Works retrofitted the existing valve with the provided conversion kit on September 25, 2020 (Figure 4-1). EXWC conducted field testing at ERDC from November 10-13, 2020 with on-site support from Dr. Edith Martinez and phone support from Cla-Val technicians.



Figure 4-1. Conversion Kit Installed on Cla-Val 131

4.1 Installation

The conversion kit was installed upon arrival at the ERDC test bed on September 25, 2020 by DPW. It took DPW approximately 2 hours to install the conversion kit. On November 10, 2020, EXWC mounted the solar system and controller housing next to the valve and began wiring the valve to the VC22-D controller (Figure 4-2).



Figure 4-2. Cla-Val 131 Wired Up to VC22-D Controller and Solar

4.2 Calibration

Once connected, the team worked with Cla-Val technicians to calibrate the solenoids, valve position transmitter, and adjust the hydraulic set point. The VC22-D has an override feature where users can adjust the power going to the solenoids from 0 to 100%. This override feature (denoted by blue text) is adjusted on the VC22-D on site with the push button controls on the controller panel. The valve position transmitter was manually adjusted to a ¼-inch gap (Figure 4-3) using the adjustable collar on the main transmitter stem. Once set to ¼-inch the milliamp (mA) signal going to the VC22-D was adjusted to 4 mA using the two calibration screws on the valve position transmitter body. This reflects the closed position of the valve. Once the fully closed valve position was calibrated, the team proceeded to calibrate the valve to the fully open position. The stem has a full stroke opening of 1.53 inches which would represent the valve in its fully open position. Once the full stroke of 1.53 inches was reached, calibration was performed, and the valve fully open position was set to 20 mA. Two calibration screws are located at the end of the valve position transmitter. One adjustment screw represents the fully closed position and a second screw represents the fully open valve position. Adjustment screws allow calibration while observing the mA signal on the VC22-D. The team then adjusted the pressure and flow set points on the VC22-D (Table 4-1).



Figure 4-3. Valve Position Transmitter Calibration

Table 4-1. Initial Field Programmed Set Points on VC22-D

Flow (gpm)	Pressure (psi)
0	50
150	50
350	75
1000	75

Next, the closing and opening speed of the valve was set at 50%. Both of the manual adjusting speed control needle valves on the valve covers were opened three turns (the needle valves are the hydraulic controls that determine the valve response speed). The needle valve closest to the main valve stem controls the closing speed, and the needle valve furthest away controls the main valve opening speed. Speed can be adjusted by either electronic method, in the VC22-D controller, or hydraulically by the speed control needle valves. The master valve ball valve is located adjacent to the main valve stem (Figure 4-4).



Figure 4-4. Needle Control Valves and Master Ball Valve

The hydraulic set point is used when electronic controls fail or during a power loss scenario. This set point is manually adjusted, and it is important to determine a minimum pressure set point for fire flow when power is lost. This set point must be 2 to 5 psi higher than the high pressure set point of the VC22-D. The hydraulic set point was manually adjusted to 75 psi.

The last step in commissioning was ensuring the test bed distribution system was operational. Initially the team was unable to produce consistent upstream system pressure due to a valve that was stuck partially open. After fully opening the valve, the system operated as expected and was ready to test the fully assembled and calibrated Cla-Val 131.

4.3 Testing and Results

The team conducted 10 tests on the Cla-Val 131 at the ERDC test bed on November 12, 2020. The test consisted of adjusting flow and pressure set points, increasing and decreasing the downstream flow rate, and simulating a power outage. The pressure delta for the solenoids was set at +/- 1.5 psi for all of the tests. Table 4-2 lists the VC22-D control settings for all of the tests. This prevents the solenoids from short circuiting. The pressure delta can be adjusted in the field on the VC22-D. For all tests to be successful, the valve must transition to the high or low pressure set point based

on downstream demand (flow), and the system should have minimal pressure transients. Table 4-2 shows the valve transition speed and Figure 4-5 depicts the pressures experienced during transitions. The Telog pressure transducers are the same ones used in the Singer and Cla-Val 98-06 tests.

Table 4-2. VC22-D Base Control Settings for Tests

Controller Settings	
Solenoid Speed	2 seconds
Needle Valves	3 turns open
Closing/Opening Speed	60%
Water Distribution Pressures	95 psi (static), 55 psi (dynamic)
Pressure Acceptable Delta	1.5 psi

4.3.1 Test 1

Test 1 investigates how the valve reacted once the downstream demand increased over the high flow set point. Figure 4-5 displays the VC22-D flow and pressure parameters that can be manually adjusted in the field. These are the set points for Test 1, also shown in Table 4-1. The right side of Figure 4-5 displays a graph of the set points. This graph illustrates how the valve reacts to flow rates in between the 150 to 350 gpm range. The valve will change pressure based on flow when operating in this transition zone. Outside of the transition zone, the valve will remain at a constant pressure (50 or 75 psi).



Figure 4-5. VC22-D Pressure and Flow Points for Test 1 and Test 2

The initial pressure drop (Figure 4-6) may be due to a higher demand in downstream flow causing the line pressure to drop quickly. As the valve responds to the flow demand, it automatically adjusts the pressure according to parameters programmed in the controller. The valve reached 60 psi quickly and then continued to gradually work up to 75 psi and stabilized at 75 psi. The team observed the valve gradually adjust pressure to the set point instead of a quick low to high switch.

This gradual increase in downstream pressure is displayed in Figure 4-6. Total transition time from 45 to 75 psi was 201 seconds (see Table 4-3). A pressure transient of 30 psi over 5 seconds was observed during the first 10 seconds of the test.

Table 4-3. Cla-Val 131 Test 1 Data

Test 1	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (seconds)
14:00:16	94.6	46.4	145	201
14:03:37	95.2	73.8	350+	

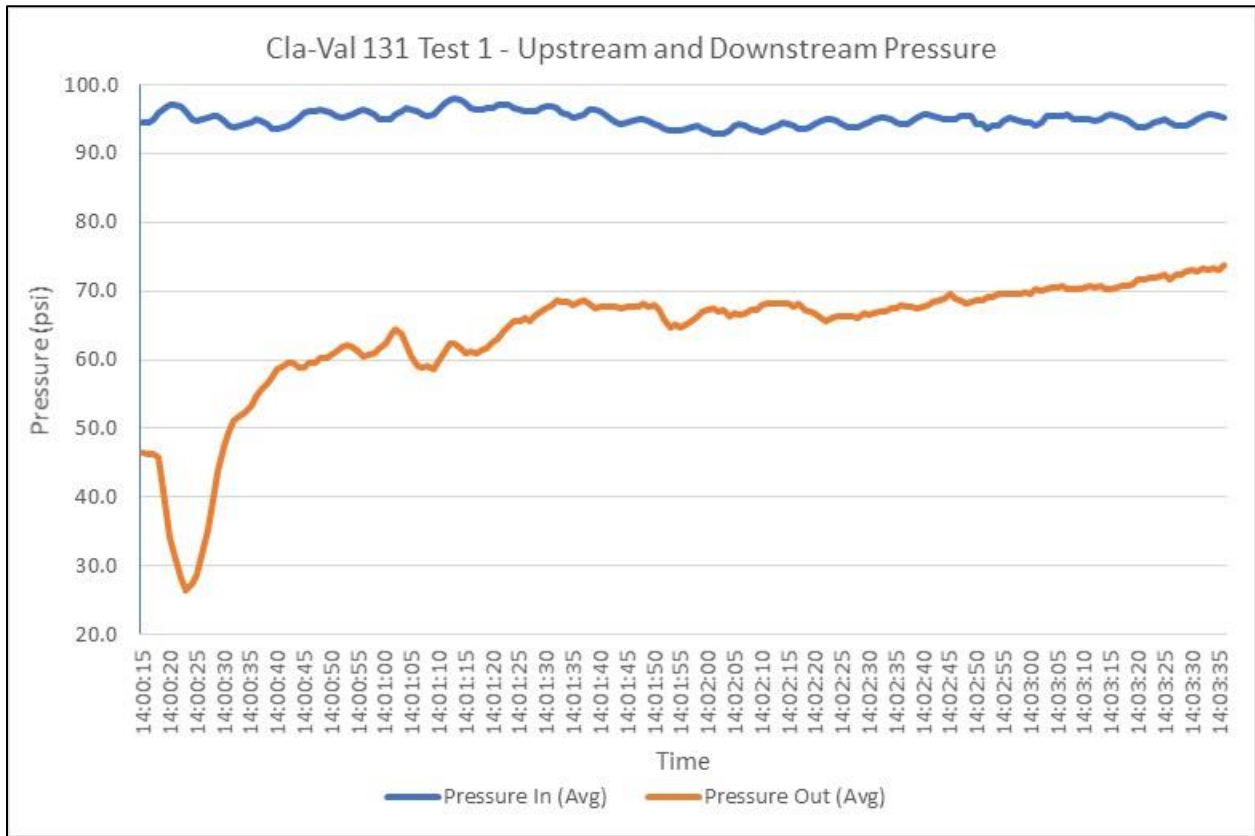


Figure 4-6. Cla-Val 131 Test 1 Pressure Graph

4.3.2 Test 2

Test 2 investigated how the valve reacts when the flow decreases from the high flow set point to below the low flow set point (see Table 4-4). The discharge valve was slowly closed to throttle the flow below 150 gpm (e.g., the low flow set point). After the controller registered less than 150 gpm, the downstream valve pressure reduced to 50 psi and the system remained stable. The transition from 75 to 50 psi took 72 seconds (see Table 4-5 and Figure 4-7). No significant pressure transients were observed.

Table 4-4. Flow and Pressure Set Points for Test 2

Flow (gpm)	Pressure (psi)
0	50
150	50
350	75
1000	75

Table 4-5. Cla-Val 131 Test 2 Data

Test 2	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
14:07:42	85.6	75.9	>350	72
14:08:54	83.8	51.1	137	

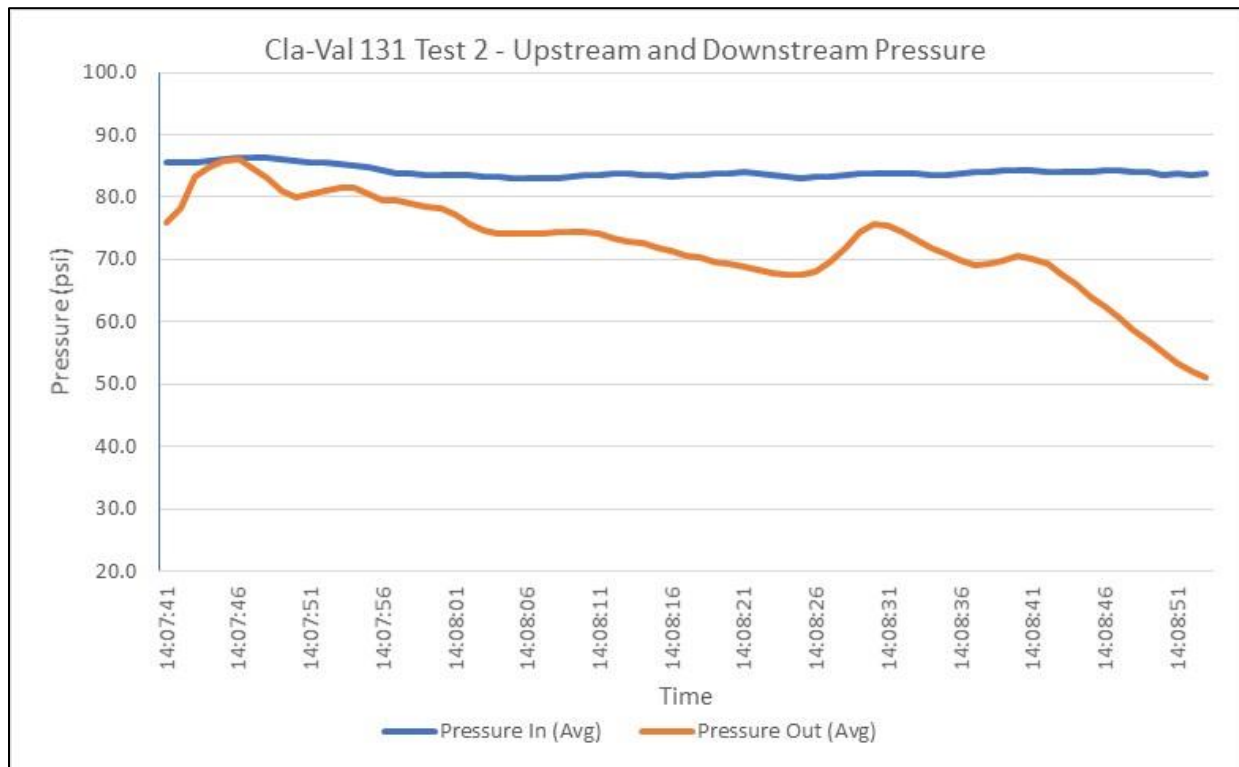


Figure 4-7. Cla-Val 131 Test 2 Pressure Graph

4.3.3 Test 3

For Test 3, the team adjusted the low flow set point from 150 to 200 gpm (Table 4-6). The pressure set points were the same as Tests 1 and 2. The goal of this test was to see how the valve reacted to field adjustments of the set points. The system was stable at 150 gpm, and the discharge valve opened up to increase flow through the system. Flow increased to over 350 gpm (high flow set point). Since the main water line dynamic pressure is lower than 75 psi, the valve downstream pressure stayed between 66 and 69 psi. The team decreased the flow closer to 350 gpm to increase

downstream pressure and the valve then quickly corrected to 75 psi (see Table 4-7). The team noted that the Cla-Val 131 valve gradually adjusts pressure as flow increases/decreases to a set point. The transition is gradual compared to the previously tested valves, which experienced sudden pressure changes while adjusting to the high and low pressure set points. Note that no upstream pressure data are available for this test (Figure 4-8). The unavailability of the upstream pressure data does not affect the valve performance. Valve changes occur based on downstream demand (flow). Upstream pressure is stable and will always remain higher than the APRV set points will were set to be 10 psi lower than upstream pressure. No significant pressure transients were observed.

Table 4-6. Flow and Pressure Set Points for Test 3

Flow (gpm)	Pressure (psi)
0	50
200	50
350	75
1000	75

Table 4-7. Cla-Val 131 Test 3 Data

Test 3	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
14:12:32	-	51.1	<150	178
14:15:30	-	73.5	481	

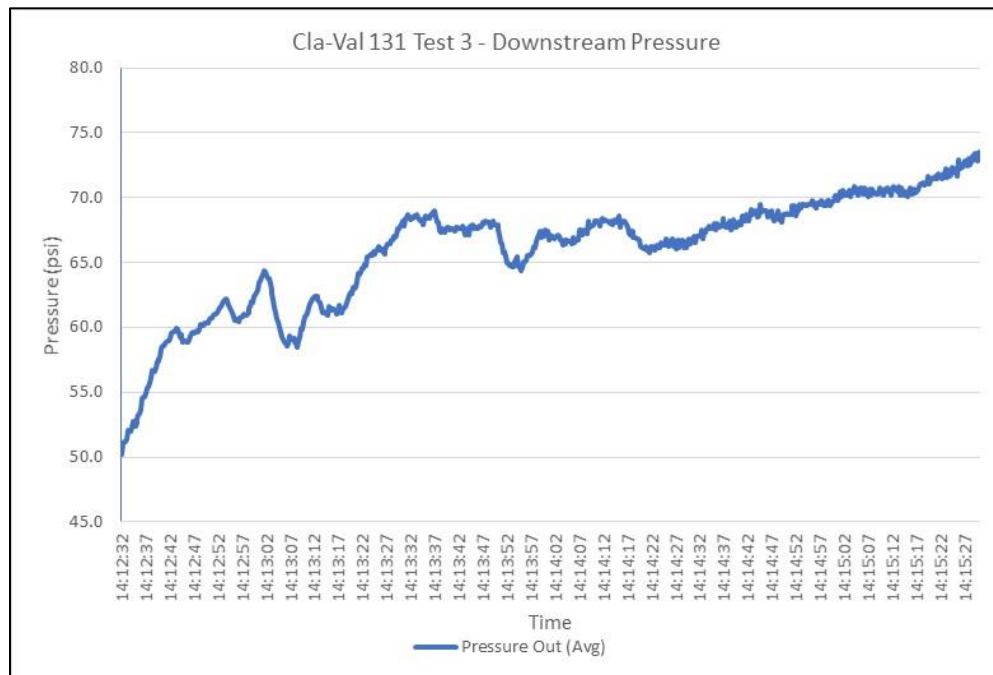


Figure 4-8. Cla-Val 131 Test 3 Pressure Graph

The peaks and valleys observed in Figure 4-8 are due to varied flow rates experienced during the discharge valves opening. In between 200 to 350 gpm the valve will change pressure based on the flow rate. After 350 gpm, the valve remains at a constant pressure of 75 psi.

4.3.4 Test 4

Test 4 replicated Test 2 but used a different low flow set point of 200 gpm (Table 4-8). The system was stable above 350 gpm and the discharge valve slowly closed to bring the flow below 200 gpm. The time the valve switches between high and low pressure set points is determined by how fast the flow increases/decreases above/below a flow set point. During transition, the valve adjusts pressure every 2 seconds (adjustable on the controller) through the solenoids. The valve transitioned to the low pressure set point in 21.5 seconds (see Table 4-9). Note that no upstream pressure data are available for this test. The unavailability of the upstream pressure data does not affect the valve performance. Valve changes occur based on downstream demand (flow). Upstream pressure is stable and will always remain higher than the APRV set points will were set to be 10 psi lower than upstream pressure. No significant pressure transients were observed (Figure 4-9).

Table 4-8. Flow and Pressure Set Points for Test 4

Flow (gpm)	Pressure (psi)
0	50
200	50
350	75
1000	75

Table 4-9. Cla-Val 131 Test 4 Data

Test 4	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
14:23:31	-	75.3	442	21.5
14:23:51	-	51.5	<200	

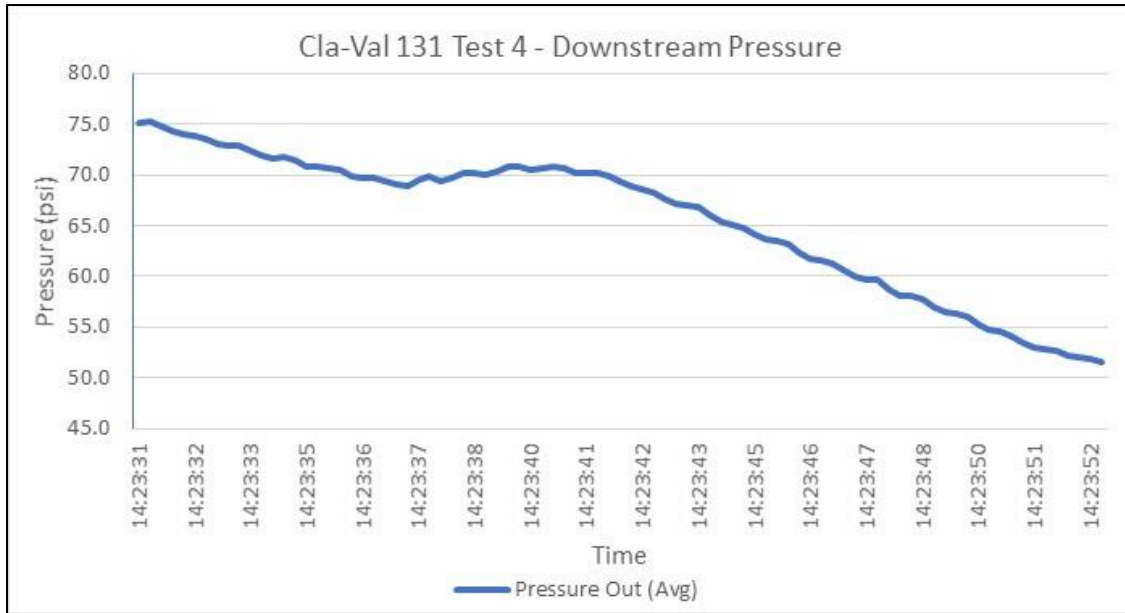


Figure 4-9. Cla-Val 131 Test 4 Pressure Graph

4.3.5 Test 5

Test 5 investigated how the valve reacts to field adjusted pressure set points. The flow set points used are the same as in Test 4. The team adjusted the low pressure set point from 50 psi to 45 psi, and the high pressure set point from 75 psi to 65 psi (Table 4-10). The upper pressure set point is now closer to the water distribution's dynamic pressure of ~55 psi. The team expected a faster transition speed since the high pressure set point was adjusted closer to the main distribution's dynamic pressure; this was confirmed by the data (see Table 4-11). No significant pressure transients were observed (Figure 4-10).

Table 4-10. Flow and Pressure Set Points for Test 5

Flow (gpm)	Pressure (psi)
0	45
200	45
350	65
1000	65

Table 4-11. Cla-Val 131 Test 5 Data

Test 5	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
15:06:38	93.8	43.5	<200	44.3
15:07:22	95.2	64.3	>350	

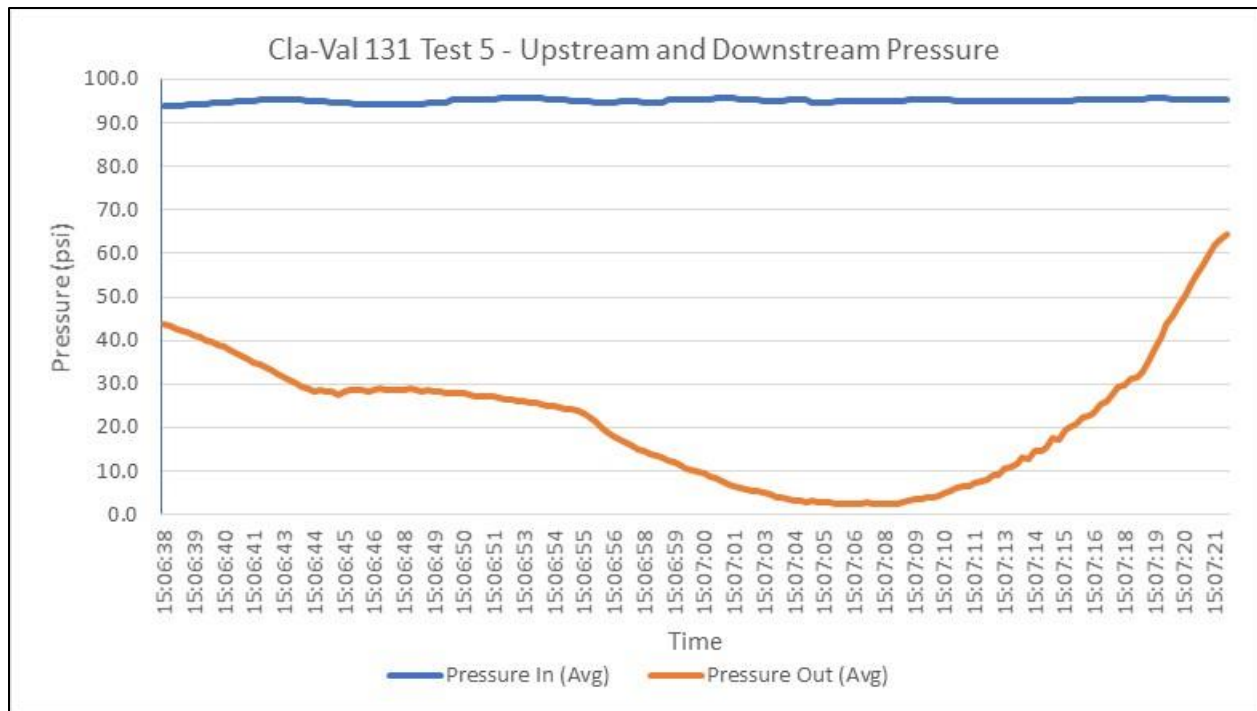


Figure 4-10. Cla-Val 131 Test 5 Pressure Graph

4.3.6 Test 6

Test 6 was performed to evaluate how the valve reacts to field-adjusted pressure set points. The flow set points used are the same as in Test 4 (Table 4-12). This test shows the valve reducing from the high pressure set point to the low pressure set point based on a reduction in flow (Figure 4-11). The valve transitioned in 110 seconds (see Table 4-13).

Table 4-12. Flow and Pressure Set Points for Test 6

Flow (gpm)	Pressure (psi)
0	45
200	45
350	65
1000	65

Table 4-13. Cla-Val 131 Test 6 Data

Test 6	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
15:07:38	94.7	65.1	>350	110
15:09:28	95.5	43.5	<200	

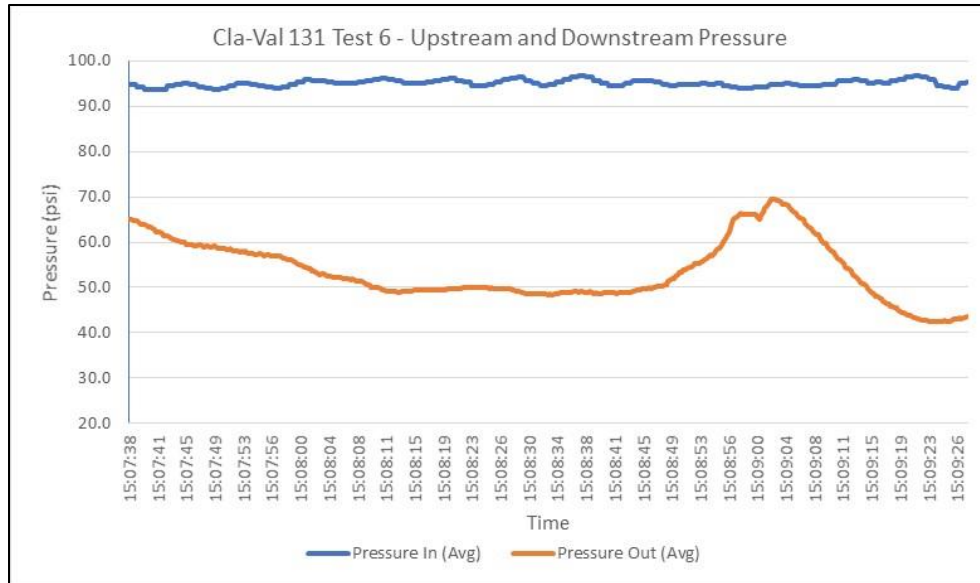


Figure 4-11. Cla-Val 131 Test 6 Pressure Graph

During the flow decrease, there was a bell curved shaped pressure movement. This does not appear problematic due to the gradual 10 psi per 5-second increases and decreases. These are not sharp pressure increases or decreases which could cause operational issues in the water distribution system. Pressure was demonstrated to be flow dependent while operating in between the high and low set points (e.g., 45 psi at 200 gpm, 65 psi at 350 gpm). The in-between pressures will adjust up or down based on the corresponding downstream flow rate.

4.3.7 Test 7

Test 7 aimed to validate the manufacturer's claims of the valve defaulting to the hydraulic set point during a loss of power situation. The set points for this test are summarized in Table 4-14. The flow was stable below 200 gpm with a pressure of 45 psi and the team disconnected one of the solenoid power cables to mimic a power outage. It took 3.3 seconds (Table 4-15) for the valve to transition to the hydraulic set point of 75 psi, which was manually set during valve calibration. The hydraulic set point should be at or above the required fire flow pressure for the specific application where the APRV is installed. The manufacturer recommends the hydraulic set point to be 2 to 5 psi higher than the electronic high pressure set point. This test validates the manufacturer's claim and shows the valve defaults to the hydraulic set point when power is lost. No significant pressure transients were observed (Figure 4-12).

Table 4-14. Flow and Pressure Set Points for Test 7

Flow (gpm)	Pressure (psi)
0	45
200	45
350	65
1000	65

Table 4-15. Cla-Val 131 Test 7 Data

Test 7	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (seconds)
15:12:14	97.0	46.4	146	3.3
15:12:17	94.8	74.5	152	

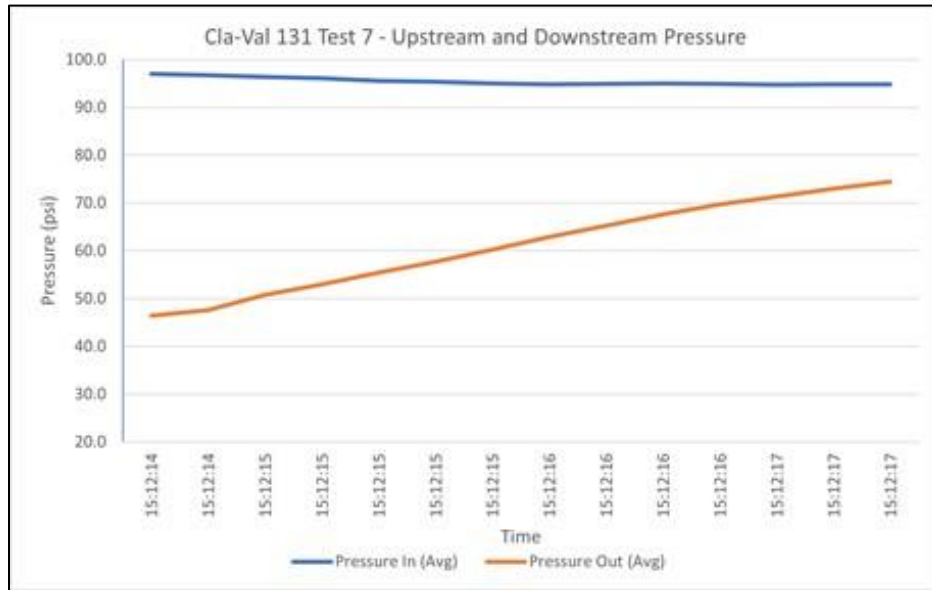


Figure 4-12. Cla-Val 131 Test 7 Pressure Graph

4.3.8 Test 8

Test 8 aimed to validate the manufacturer's claims of the valve defaulting to the open position during a loss of power situation and returning to normal operations once power is restored. The power supplied to the APRV VC22-D controller is DC power; however, an AC power controller can be requested from the vendor (Cla-Val), as an option based on power available. During the testing in Vicksburg, MS, it was decided that installing a PV panel with batteries was the most cost-efficient way. The alternative would have been to supply power from a local power pole and install a transformer/inverter, but it was determined to be costly. Backup power on the batteries provides continuous 24VDC power to the controller via a photo voltaic panel. The panel was sized to accommodate the minimal solar radiance in Vicksburg and provide backup power for a minimum of 24 hours with no sunlight, which was based on the controller's power supply/demand requirements below.

The power supply requirements are:

- Allowed power supply voltage: 12-24 VDC
- Current demand: 300 mA at 24 VDC (Steady State)
- Power demand: 36 Watts (Maximum)

During power outages the controller defaults to its hydraulic set point that is set manually and will maintain the hydraulic set point until power is restored. Power to the solenoid was disconnected for roughly two minutes, in which the VC-22D controller remained powered. The valve recognized the loss of power to the solenoid which triggered it to switch to the hydraulic set point. When the VC-22D is rebooted or power is restored, the user is prompted to go through the ValvApp and will allow the user to navigate through the ValvApp library and choose the ValvApp setting customized for users applications. Once the ValvApp program is loaded onto the controller, it will remain there indefinitely.

The set points for this test are summarized in Table 4-16. Once the solenoid cable was connected, the system took 13.5 seconds to stabilize at the low pressure set point of 45 psi (see Table 4-17). No significant pressure transients were observed (Figure 4-13).

Table 4-16. Flow and Pressure Set Points for Test 8

Flow (gpm)	Pressure (psi)
0	45
200	45
350	65
1000	65

Table 4-17. Cla-Val 131 Test 8 Data

Test 8	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
15:14:53	95.1	73.7	150	13.5
15:15:07	93.7	46.3	143	

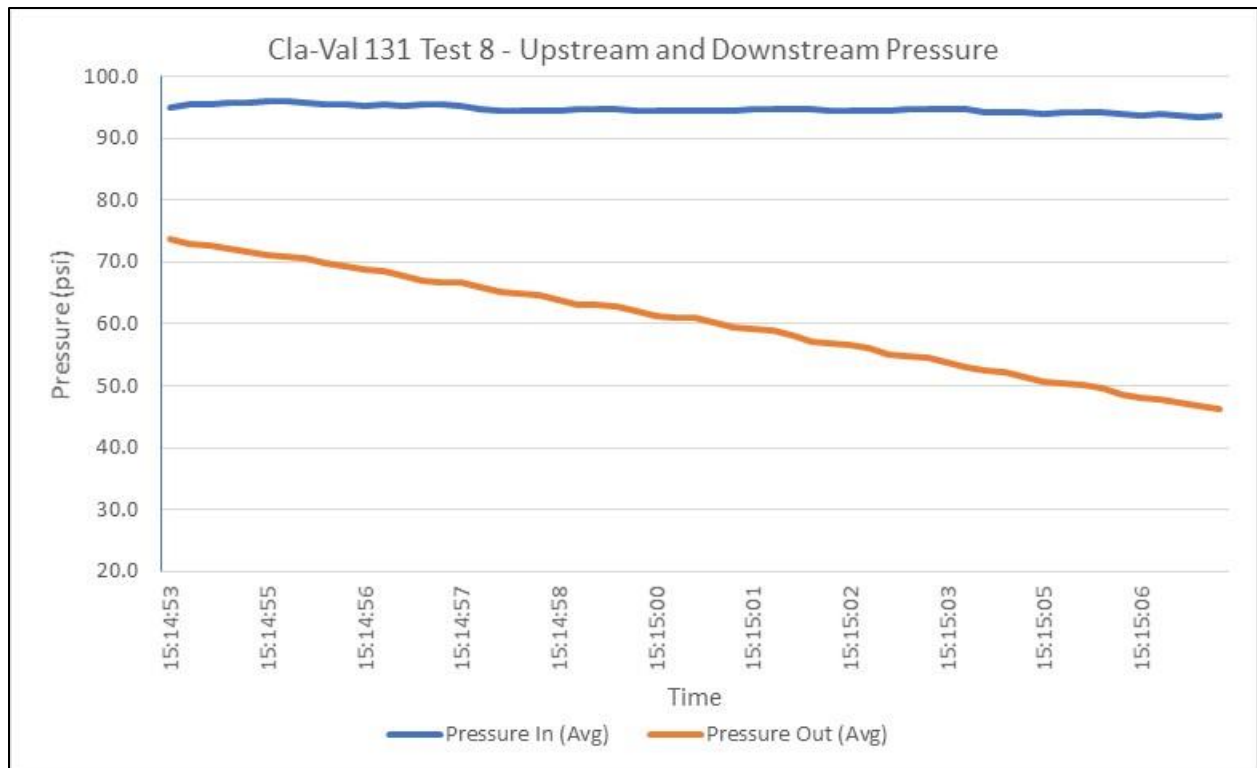


Figure 4-13. Cla-Val 131 Test 8 Pressure Graph

4.3.9 Test 9

For Test 9, the team adjusted the high pressure set point from 65 psi to 70 psi (Table 4-18) to replicate tests carried out with the Cla-Val 98-06 in December 2019. The discharge valve was opened and flow increased above 200 gpm which tripped the low pressure set point. As the flow increased, the downstream pressure increased (see Figure 4-14). The valve took 300 seconds to correct to 70 psi (see Table 4-19). No significant pressure transients were observed.

Table 4-18. Flow and Pressure Set Points for Test 9

Flow (gpm)	Pressure (psi)
0	45
200	45
350	70
1000	70

Table 4-19. Cla-Val 131 Test 9 Data

Test 9	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (Seconds)
15:22:39	92.6	43.5	172	300
15:27:39	93.5	68.5	>350	

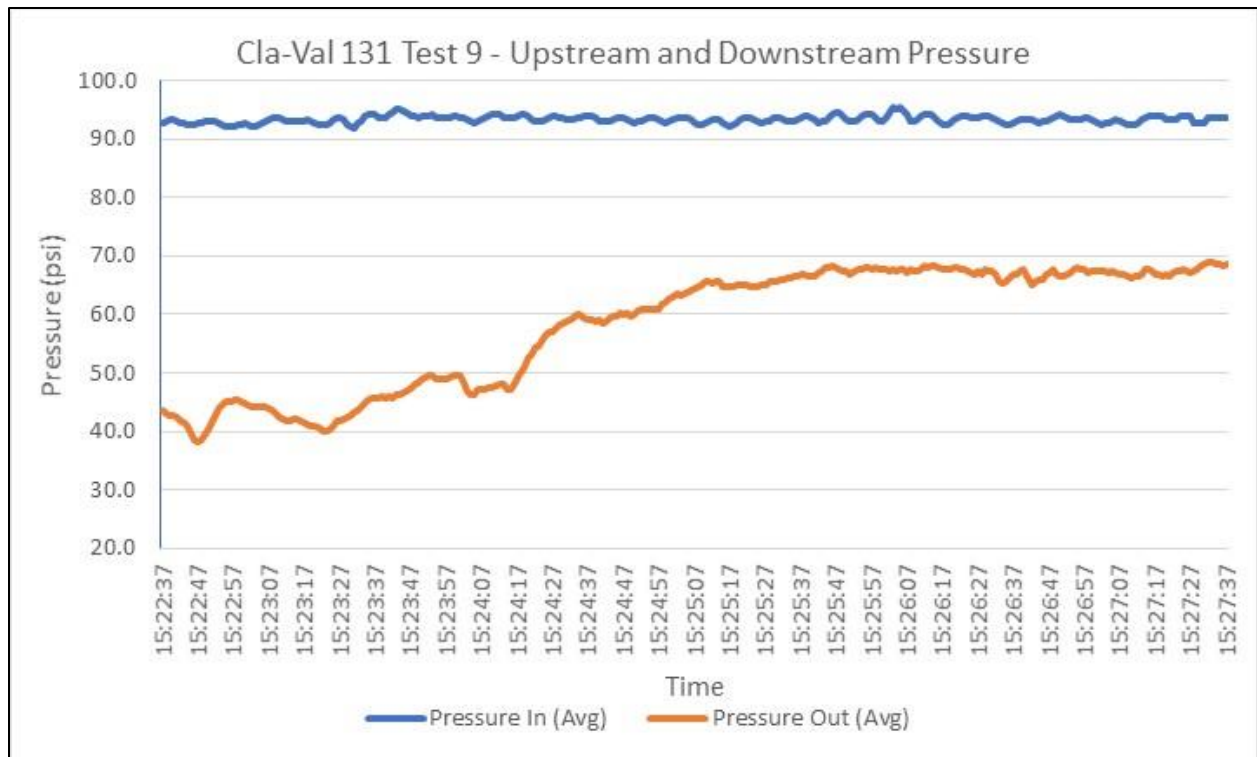


Figure 4-14. Cla-Val 131 Test 9 Pressure Graph

4.3.10 Test 10

Test 10 demonstrated reducing flow conditions with the same set points as Test 9 (see Table 4-20). Flow was reduced from 400+ gpm to below 200 gpm to observe the pressure transition. Downstream pressure increased once the discharge valve began to close, which could have caused pressure transients if the change had been abrupt. However, Figure 4-15 shows an increase of less than 10 psi over 5 seconds. The downstream pressure then reduced gradually to 45 psi as the flow decreased. The valve operating conditions stabilized at 45 psi after 79 seconds and the system remained stable as the testing concluded (see Table 4-21). Small pressure transients of 10 psi over 5 seconds were observed.

Table 4-20. Flow and Pressure Set Points for Test 10

Flow (gpm)	Pressure (psi)
0	45
200	45
350	70
1000	70

Table 4-21. Cla-Val 131 Test 10 Data

Test 10	Upstream (psi)	Downstream (psi)	Flow (gpm)	Transition Time (seconds)
15:30:45	89.6	68.4	408	79
15:32:04	87.7	45.6	<200	

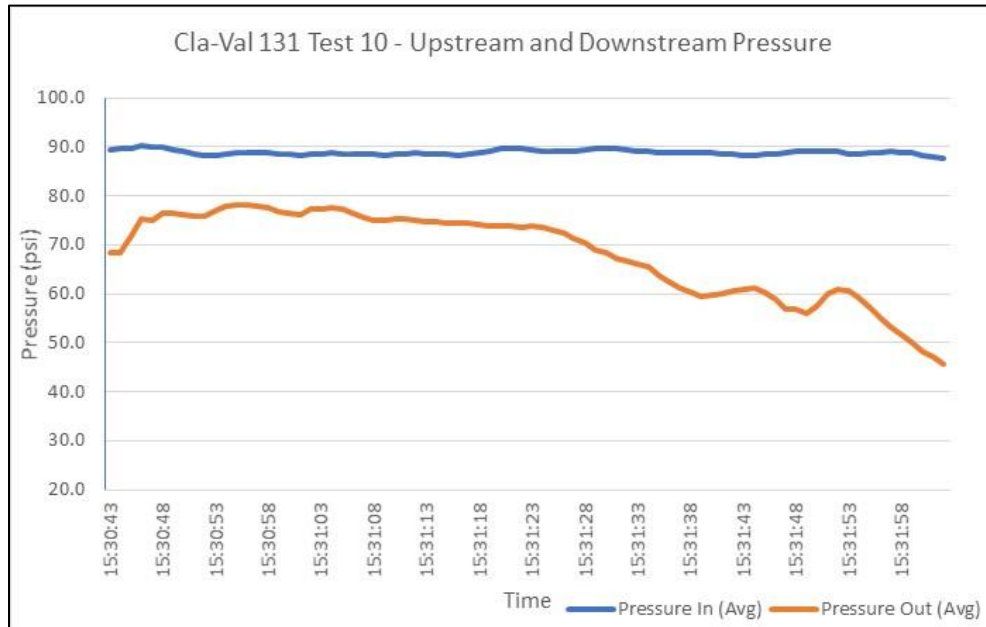


Figure 4-15. Cla-Val 131 Test 10 Pressure Graph

4.4 Cla-Val 131 Cost Data

The cost for a complete Cla-Val 131 valve is \$11,657.00 with a lead time of six weeks. The VC22-D control costs \$2,531.00. Maintenance of the APRV is consistent with the Singer and Cla-Val 98-06 valves. An additional annual cost of \$100 was added to the Cla-Val 131 to account for wiring and electrical component replacement.

A cost analysis of the Cla-Val 131 APRV calculated the SIR (based on 20 years of operation) to be 5.3, which is higher than 1, indicating a cost-effective technology. The ROI was determined to be 4.6 years, which provides better than expected return than the 7-year ROI metric. The Cla-Val 131 met the cost metrics with cost model assumptions and elements summarized in Appendix D.

4.5 Summary of Test Results for the Electronically Actuated Valve

Table 4-22 summarizes the comparison of the Cla-Val 131 test results to the performance metrics.

The Cla-Val 131 and VC22-D's gradual transition reduces the impact of pressure transients on a water distribution system. The valves transition speed is based on flow rate, not a set interval (i.e., 30 seconds transition). However, the valve has electronic and hydraulic minimum opening and closing speeds that prevent water hammer. Pressure changes are proportional after tripping the low flow set point and then pressure increases as flow increases to the high flow set point. Two tests (6 and 10) experienced pressure transients of 10 psi over 5 seconds, which is not considered significant. Test 1 did show a pressure transient of 30 psi over 5 seconds.

Commissioning the Cla-Val 131 took approximately 6 hours with an engineer and technician. It is recommended to contact the manufacturer's technical support line during commissioning, but on-site support from the manufacturer is not required. No special tools were required for installation. The VC22-D does require a custom program, created by the manufacturer, to be loaded (via USB) to the controller for the specific valve application.

The team found the controller very intuitive and easy to use. Flow and pressure set points can be adjusted in the field for specific needs or requirements. Also, the solenoids can be electronically overridden at any point to fully open or close the valve. The VC22-D has data logging capability down to 1-minute intervals, which can be quickly exported via USB drive in an Excel .csv format. The valve operated as designed when conducting testing. During the power failure mode test, the valve also performed as designed and defaulted to the hydraulic set point. The valve met the UFC fire flow requirement of 500 gpm for one-story, non-sprinklered family housing over a duration of 90 minutes.

4.6 Supplemental Testing Lessons Learned

The team concluded that adding flow rate data at a one second resolution would benefit the data analysis process. The flow data could be matched up with the Telog pressure data to validate the valve's transition when it is between set points. This would help visualize how the valve reacts.

Flow rate data are logged by the VC22-D, but the lowest resolution is every minute. The team also concluded that automating the discharge valve opening and closing would provide more linear

pressure graphs. The discharge valve opening or closing would be faster or slower at times which can be seen in the pressure data graphs for some of the tests.

Table 4-22. Comparison of Cla-Val 131 Test Results to Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Met?
Quantitative Performance Objectives				
Water Savings	Gallons saved	Actual/estimated volume of leak based on water pressure and measured water loss	10% Reduction in water losses from leaks. Go/No-Go decision point	Yes
Cost Savings	Savings to investment ratio (SIR)	Cost of water, estimated gallons of water saved, APRV lifespan, cost of equipment, installation, and maintenance	SIR > 1.0	Yes
	Return on investment (ROI)		<7 years (assuming water cost at a range between \$2-\$20 per 1000 gallons)	Yes
System Response	Reduced pressure during periods of low demand, increased pressure during periods of high demand.	Flow rates, pressure, and response time	Flow triggers pressure change 98% of time. Response time is variable. For low to high flow/pressure transition, time was initially set at 10 seconds. From high to low flow/pressure transition, less than 60 seconds. ^(a)	Yes
System Reliability and Maintenance	Uptime	Downtime/uptime	95% system uptime	Yes
Qualitative Performance Objectives				
Customer Satisfaction		Feedback from DPW operator and water program manager	No customer complaints about flow or pressure issues at both pressure set points	N/A ^b

^(a) Based on operations in the field, the safe pressure transition speed was updated to 30 seconds.

^(b) Not installed at full-scale.

5 LESSONS LEARNED

Several lessons learned were drawn from the installation, commissioning, and preliminary testing of the Singer and Cla-Val innovative valve technologies as documented below.

5.1 APRVs are Capable of Generating Significant Water Savings

The water savings success criteria for the APRV was 10% reduction in water losses (designated as a go/no-go decision point). The preliminary testing determined that the APRV was able to reduce water loss up to 30% in comparison to the baseline (with the distribution water supplied at 95 psi) as shown in Table 5-1. Based on the test data, 10% water reduction from leakage was achieved with a high to low pressure delta of 15 psi as presented in Figure 5-1.

Table 5-1. APRV Percent Leak Reduction Results for Tank 1

Tank 1	Ave. Ullage Reading	Volume	Delta	Percent Reduction
	(cm)	(Liters)		
Baseline (95 psi)	86.7	365.0	-	-
Trial 1 (80-75 psi)	90.8	315.0	50.0	13.7
Trial 2 (80-70 psi)	91.8	302.0	63.0	17.3
Trial 3 (80-65 psi)	92.7	290.0	75.0	20.5
Trial 4 (70-60 psi)	93.9	275.0	90.0	24.7
Trial 5 (70-55 psi)	95.9	263.7	101.3	27.8
Trial 6 (70-50 psi)	97.1	253.3	111.7	30.6
Trial 7 (60-40 psi)	98.4	230.0	135.0	37.0
Trial 8 (70-30 psi)	101.9	185.0	180.0	49.3

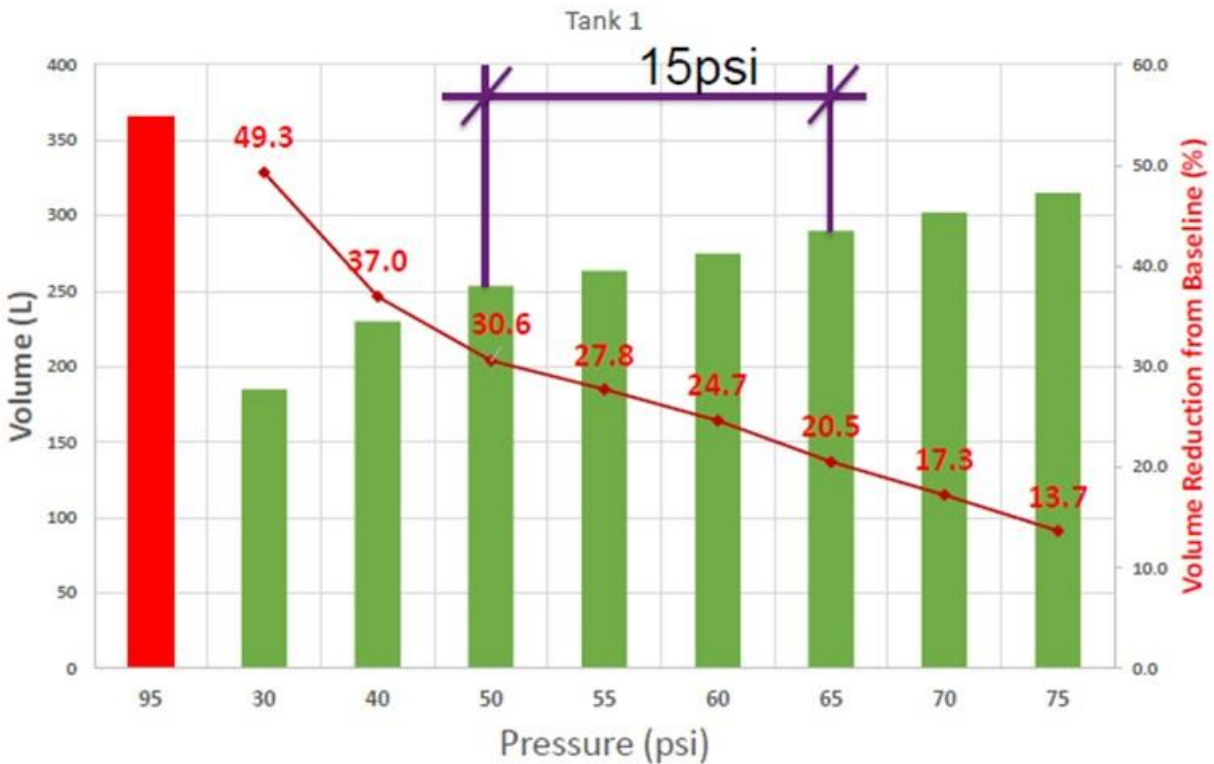


Figure 5-1. APRV Percent Leak Reduction for Tank 1

5.2 APRVs are Cost Effective

All APRVs tested have a SIR higher than 1, indicating a cost-effective technology. The ROI was determined to be 2.1 years (Singer), 2.2 years (Cla-Val 98-06), and 4.6 years (Cla-Val 131), which provides better than expected return than the 7-year ROI metric. The APRV technology readily met the cost metrics based on cost model assumptions and elements as summarized in Appendix D.

5.3 APRVs Meet the Target Fire Flow Demand

The APRVs achieved a maximum flow rate of 750 gpm, which exceeded the minimum UFC fire flow requirement of 500 gpm for one story, non-sprinklered family housing.

6 RECOMMENDATIONS

The electronically actuated Cla-Val 131 APRV was subsequently evaluated in the test bed environment as an alternate technology. The Cla-Val 131 model, operated in conjunction with a controller (VC22-D), provided for a gradual transition that reduced the impact of pressure transients on the water distribution system. The valve's transition speed is based on flow rate, not a set interval (i.e., 30 seconds transition). Pressure changes are proportional after tripping the low flow set point and then pressure increases as flow increases to the high flow set point. Two tests (6 and 10) experienced pressure transients of 10 psi over 5 seconds, which is not considered significant. Test 1 did show a pressure transient of 30 psi over 5 seconds.

The team found the controller very intuitive, highly customizable, and easy to use. Flow and pressure set points are adjustable in the field for specific needs or requirements. The valve operated as designed when conducting testing. During the power failure mode test, the valve also performed as designed and defaulted to the hydraulic set point. Overall, this valve is highly field programmable and customizable. The valve and controller do require a power source to operate, which the team used a photovoltaic panel and batteries during field testing.

NAVFAC EXWC does not recommend implementing the Singer 106 or Cla-Val 98-06 APRVs due to transition speeds, commissioning pressure transients, and water hammer experienced during testing. The team also experienced manufacturer errors (wrong valve size shipped and a clogged strainer) and issues with temperatures below 32°F. EXWC recommends the Cla-Val 131 for use in isolated tree-type water distributions, but not multi-feed systems.

7 REFERENCES

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- Cla-Val. 2019. Model 96-06, Hydraulic Pressure Management/Water Savings Valve with Dual Settings. Available at <https://www.cla-val.com/documents/pdf/E-98-06.pdf>.
- Cla-Val. Model 98-06 and 698-06 Hydraulic Water Saving Control Valve Web Site. Available at: <https://www.cla-val.com/98-06-698-06-hydraulic-water-saving-control-valve-p-62.html>
- Cla-Val. Model 131-07 and 631-01 Electronic Control Valves Web Site. Available at: <https://www.cla-val.com/131-01-631-01-brelectronic-control-valves-p-31.html>
- Singer. Pressure Reducing Valves – Constant Performance Under Pressure. Available at: <http://www.singervalue.com/water-works/pressure-reducing>
- Unified Facilities Criteria (UFC) 3-600-01 Fire Protection Engineering for Facilities, with Change 5. Department of Defense. August 8, 2016.

Appendix A: POINTS OF CONTACT

Table A-1. APRV Project Contact Information

Point of Contact	Organization	Contact Information	Role in Project
Gary Anguiano, P.E.	NAVFAC EXWC 1000 23 rd Ave., Port Hueneme, CA 93043	P: 805-982-1302 F: 805-982-4597 gary.anguiano@navy.mil	Principal Investigator and Project Manager (Ret.)
James Pilkington, P.E.	NAVFAC EXWC 1000 23 rd Ave., Port Hueneme, CA 93043	P: 805-982-1335 F: 805-982-4597 james.pilkington@navy.mil	Principal Investigator and Project Manager
Andy Vasquez	NAVFAC EXWC 1000 23 rd Ave., Port Hueneme, CA 93043	P: 805-982-5228 F: 805-982-4597 andy.vasquez@navy.mil	Project Technician
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Alejandro Duque	Singer Valve Co		Vendor Consultant
Roger Lah	Cla-Val		Vendor Consultant
Wendy Condit	Battelle 505 King Avenue Columbus, OH 43201	P: 614-424-3501 F: 614-458-3501 Conditw@battelle.org	Project Engineer & Tech Transfer

Appendix B: SINGER 106 APRV

B.1 Technology Description

The Singer APRV, Model 106/206-2PR-630 (Figure B-1), is manufactured by Singer Valve (Mueller Water Products). The APRV consists of a standard globe valve integrated with an orifice plate, differential pilot and two pressure-setting pilots (for high-pressure and low-pressure operations) to control outlet pressure based on real-time flow demand downstream of the valve. It includes flow stabilizing/opening speed control, a 40-mesh strainer, and a chloramine resistant diaphragm. The APRV model provides a fully operational back-up system in the event of diaphragm or pilot failure. The dual pressure innovation of the advanced design is made possible with the integration of an orifice plate, a second pilot valve and a differential pilot device added onto a conventional PRV design.

For maintenance, the Singer APRV requires periodic cleaning of a small filter and an occasional diaphragm replacement (every 7 to 10 years). This technology is run completely hydraulically, giving it an advantage over solenoid valves, which require electricity. The Singer APRV allows a pressure differential between the normal and low setting of 5 to 60 psi. The design life of the valve is 20 years based on vendor specifications.



Figure B-1. Singer APRV Model 106/206-2PR-630 (Source: Singer)

B.2 Singer Installation and Commissioning

As described in Section 3.2.2, the Singer valve and bypass were installed at the ERDC test bed in the Spring of 2019. Three DPW staff installed the APRV (Figure B-2). The APRV was installed on an isolated service lateral at the surface and not in a well vault as described in the Demonstration

Plan to be more accessible to troubleshooting and repair if necessary (Anguiano et al., 2018). The APRV was activated by water pressure and did not require power.

The commissioning process required field adjustments to the Singer pilot valves and flow stabilizer that were made under low and high flow conditions. During the initial adjustment of the valve, the project team observed significant pressure transients (water hammer) up and downstream of the APRV as shown in Figure B-3. The pressure transients lasted several minutes before they were eliminated by adjusting the valve's flow stabilizer. The water hammering did not create any damage to the test bed; however, the fluctuation in pressures could potentially damage aged and fragile DoD water distribution systems. After resolving the water hammer issue, the project team was able to operate the APRV with no additional problems.

Singer's response to the APRV's water hammer issue during commissioning included the following:

- There will always be a chance of oscillation during commissioning and that proper tuning of the piloted control valve greatly reduces the risk of water hammer occurring.
- Distribution lines should have pressure relief valves installed to protect the system from possible over pressurization.

The team reviewed Singer's proposed solutions and determined that the risk of creating harmful water hammer in the DoD's aged distribution system would outweigh the benefit. Subsequently, the project team performed follow-on market research to determine if there existed a technology that did not create pressure transients. Major PRV vendors researched include Cla-Val, Watts, Zurn, and Bermad. The team found that Cla-Val had recently developed a modulating valve that was designed with components to prevent water hammer, the 98-06 pressure management valve. The project team prepared to test the Cla-Val 98-06 at the ERDC test bed following approval from the ESTCP committee.



Figure B-2. Singer Valve Installation

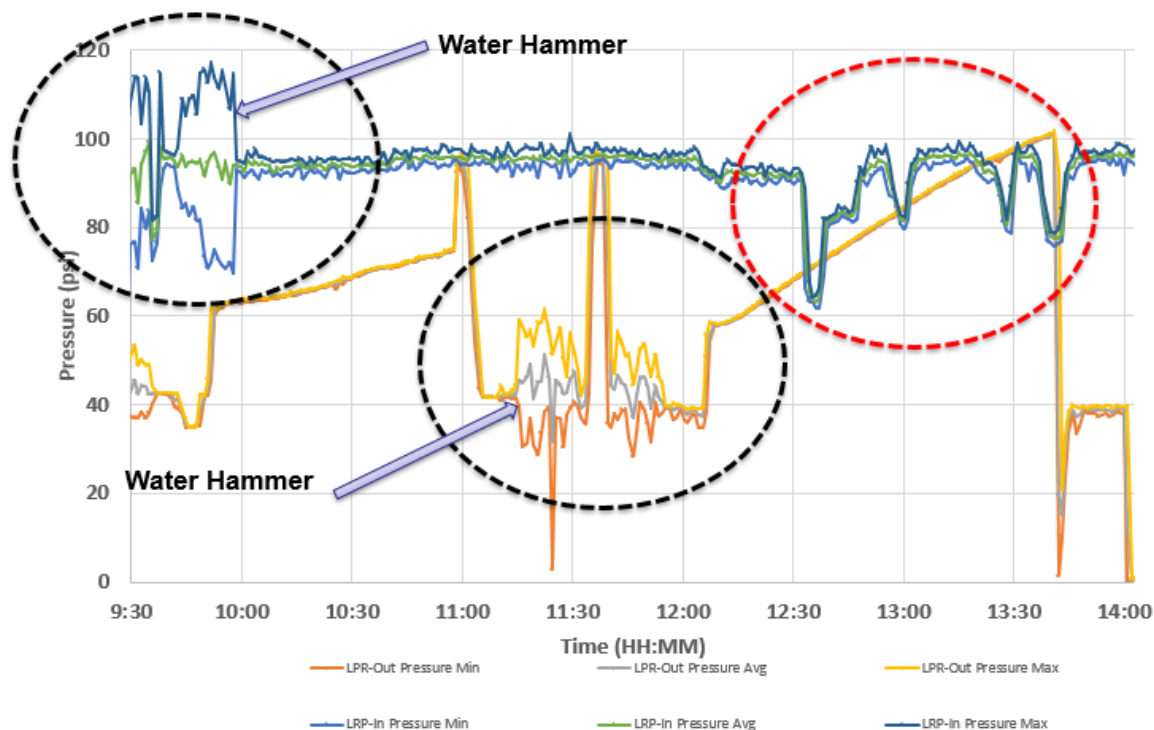


Figure B-3. Water Hammer Pressure Transients

B.3 Lessons Learned

During the Singer APRV commissioning process at the test bed, water hammer issues were observed. The team followed the commissioning guidelines provide by Singer which required adjusting the pilot set points and speed controls under flow conditions. (Note that these adjustments can only be made in the field to match site conditions [layout, flow, pressure]). Figure B-3 shows the pressure surges that occurred during commissioning. The water hammer (oscillation) continued for several minutes, while the lead technician adjusted the pilots per manufacturer instructions. The loud hammering noise (cycling every 2 to 3 seconds) and vibration were profound and continuous so after several minutes of water hammer, commissioning was suspended by shutting off the upstream valve.

The team contacted the Singer technical advisor, explained the observation, and requested on-call assistance. With Singer on the phone providing verbal instructions, the pilots and speed controls were adjusted to a point that resolved the water hammer issue. However, that process took 4 to 5 minutes, which could have damaged a compromised system. Once the pilots and speed control were adjusted, no additional surges of a harmful magnitude were experienced throughout the test cycle. The vendor's response to these commissioning technical issues indicated that pressure oscillation during commissioning was inherent to the multi-pilot valve design and that the water system should be designed with pressure relief valves to mitigate damage to distribution lines.

The team felt that the water hammer was of a magnitude that could pose real problems for fragile systems particularly if a relief valve did not respond on cue. The occurrence of the water hammer during commissioning meant the Singer Valve was a "no go" for full-scale demonstration at a DoD

installation. With that realization, the team conducted follow-up research. Subsequent research uncovered the Cla-Val 98-06 hydraulic actuated valve designed for water optimization but built with an accumulator designed to prevent water hammer during commissioning.

B.3.1 Singer Transition Speed

Another issue that was observed during the Singer demonstration was the transition time between pressure set points. The low to high pressure transition time met the performance objective but the high pressure set point to low pressure was less than 3 seconds and not adjustable as reported by the manufacturer. Although the faster transition time did not generate any water hammer issues, it did not meet the established performance objective. It is common practice to open or close valves slowly to prevent creation of pressure transients so it was felt that this rapid change could be problematic. Manual valve closures for a 6-inch plug valve can take over 2 minutes (to turn handle 24 times from fully open to fully closed).

B.3.2 Singer Orifice Sizing

The Singer design uses a fixed size orifice plate to activate tripping flow which is sized per customer specifications. During fire flow testing it also became clear how important the orifice plate design affects flows higher than fire flow. The reduction in pressure can be fairly pronounced with the addition of the orifice plate. In retrospect, this sizing of this orifice, set at 350 gpm, must be carefully considered to minimize head loss at flow higher than minimum fire flow. Although simple in concept, at high flow rates it can create enough friction loss to create a problem if not properly addressed during design. If this type of technology is deployed, it would be prudent to select the tripping flow closer to the minimum fire flow to minimize pressure losses at high flow above minimum fire flow.

B.4 Testing Protocol Implementation

The test matrix is presented in Table B-1 and Table B-2 of the planned and actual tests performed for the Singer and Cla-Val APRVs.

Table B-1. Baseline Tests for Singer and Cla-Val APRV

Planned APRV Testing	Test Description
Baseline 1	Determine leak (volume) with no PRV (95 psi source)
APRV Setting 1 (80 - 75 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-75 psi
APRV Setting 2 (80 -70 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-70 psi
APRV Setting 3 ^(a) (80 -65 psi) (80 - 60, 50 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-65 psi
APRV Setting 4 (70 - 60 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-60 psi
APRV Setting 5 (70 - 55 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-55 psi

APRV Setting 6 (70 - 50 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-50 psi
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(b) 80-60 and 80-50 testing were not evaluated.

Table B-2. Planned Tests for Singer APRV

Planned APRV Testing	Singer Valve	Test Description
APRV (Fail Mode 1)	OBE	Performance with failed diaphragm
APRV (Fail Mode 2)	OBE	Performance with clogged filter screen
APRV (Fail Mode 3)	-	Performance with power loss
APRV Fire flow (Intermittent)	✓	Determine how well APRV works with once a week low to high transition
APRV Fire flow (long-term)	OBE	Determine how well APRV works when system stays in low pressure mode for length of time
Evaluate ability to adjust pressure setting	✓	Assess ease of adjustment
APRV pressure transients	✓	Evaluate pressure transients during transitioning.
Evaluate maintenance	OBE	Assess annual maintenance requirements

B.5 Performance Objectives Results

B.5.1 Water Savings Metric and Data

During the APRV test trials, water loss through leaks at various high and low pressure set points was measured in gallons. The leak measurements were used to calculate the percent reduction in losses due to leaks in comparison to the baseline.

B.5.1.1 Water Savings Success Criteria

A 10% reduction in water loss from leaks in comparison to the baseline was considered successful and used as a go/no-go decision point for the full-scale test.

B.5.1.2 Results

The APRVs tested were able to reduce water loss up to 30% in comparison to the baseline (with distribution water supplied at 95 psi). All valves showed this by their ability to reduce pressure

from 70 to 50 psi. Based on the test data, 10% water reduction from leakage was achieved with a high to low pressure delta of 15 psi.

B.5.2 Purpose of Cost Savings

Water costs are based on the volume consumed. Lower pressures can also extend the life of water systems and reduce the frequency of breaks and repairs. Pressure management using technologies such as APRV can significantly reduce pipe failure rates, extend infrastructure life, and reduce the magnitude of existing leaks until they can be repaired.

B.5.2.1 Cost Saving Metric and Data

Cost savings were assessed by estimating the volume of water saved, equipment, installation, and maintenance costs. Cost savings were evaluated using two related metrics: SIR and ROI. The SIR method is a pass/fail evaluation that divides the savings from avoided purchases over the lifecycle of the APRV by the capital costs of installation and maintenance. ROI is a measurement of the number of years required to break even on the investment. The avoided purchase is divided by the capital costs to install and maintain the APRV. Typical hourly labor rates were used to calculate overall cost, as well as adding the cost of materials.

B.5.2.2 Cost Savings Success Criteria

An SIR greater than 1 indicates that the technology is cost effective. The savings is at least as large as the cost. ROI less than 7 years indicates that the annual savings equals the installation cost after 7 years, and then after that point the technology will result in a net savings.

B.5.2.3 Results

A cost analysis of the Singer APRV calculated the SIR (based on 20 years of operation) to be 6.3, which is higher than 1, indicating a cost-effective technology. The ROI was determined to be 2.1 years, which provides better than expected return than the 7-year ROI metric.

The Singer and Cla-Val APRV technologies met the cost metrics with cost model assumptions and elements summarized in Appendix D.

B.5.3 Purpose of System Response

The APRV is required to provide a higher pressure when demand is high and lower pressure when conditions are static. Failure to deliver enough pressure when needed can compromise the mission in industrial areas and is a quality of life factor in the residential sector. Failure to lower the pressure is a performance factor that reduces savings and renders the technology less effective in terms of cost and water conservation.

B.5.3.1 System Response Metric and Data

In the test bed, high and low flow demand scenarios were simulated by manually opening the exit valve and letting water flow into the reservoir. The response of the APRV to the changing pressure

and flow was evaluated and recorded. Data on the timing, flow, and pressure both upstream and downstream of the APRV indicated if it was responding to changing demands.

B.5.3.2 System Response Success Criteria

Response was successful if flow triggered a pressure change 98% of the time. For a low to high flow transition, the time target was initially set at 10 seconds. For a high to low flow transition, the time was set at less than 60 seconds.

B.5.3.3 Results

To avoid pressure spikes, the team changed the success criteria to greater than 30 seconds for the response time for pressure transitions. The testing found that the Singer APRV transitioned from low to high flow at 45 seconds; however, the flow transitioned from high to low flow in 3 seconds at 80-65, 80-70, and 80-75 psi set points, respectively, and did not meet the safe closure speed criteria required to avoid water hammer or other adverse impacts.

B.5.4 Purpose of System Reliability and Maintenance

Uptime was the amount of time that the APRV performed its function of regulating pressure in response to demand. Periods when it was non-functioning or actively being repaired were considered downtime. The failure mode for the APRV would be constant operation at the low-pressure setting regardless of water demand. To avoid unacceptable impacts of this failure scenario, the low-pressure set point must be set to ensure that fire flow demand can still be met. One of the fire flow requirements found in UFC 3-600-01 Fire Protection Engineering for Facilities is that residential areas with one and two stories are to achieve 500 gpm and 750 gpm flow rates, respectively for 90 minutes.

B.5.4.1 System Reliability and Maintenance Metric and Data

Maintenance logs and data on system response measured the accomplishment of this objective (i.e., replacement and removal of a diaphragm and silt screen). System uptime was the amount of time the APRV was functioning properly divided by the total time period of the test.

B.5.4.2 System Reliability and Maintenance Success Criteria

The system reliability was set at 95% uptime (5% downtime) for the APRV demonstration in case any repairs were needed in association with the failure mode tests. Meeting the minimum 500 gpm UFC fire flow requirement for one story, non-sprinklered family housing was also a requirement.

B.5.4.3 Results

The performance objectives associated with system reliability and maintenance could not be evaluated because no long-term testing was performed of the Singer APRV. At 750 gpm, the APRV exceeded the minimum UFC fire flow requirement of 500 gpm for one-story, non-sprinklered family housing.

B.5.5 Purpose of Customer Satisfaction

The water consumers must have adequate water pressure and flow to meet their needs. Consumer satisfaction was intended to be assessed based upon a review of the data by UFC committee members in communication with the ESTCP Water Program Manager and the ERDC DPW Director.

B.5.5.1 Customer Satisfaction Metric and Data

To determine customer satisfaction, the DPW Director was planned to be interviewed in person before APRV installation and at the end of the project. The survey was intended to determine how the APRV performed in terms of providing adequate pressure during peak water consumption periods and any maintenance or repair issues encountered during the demonstration.

B.5.5.2 Customer Satisfaction Success Criteria

No additional complaints were received about the water pressure.

B.5.5.3 Results

The ERDC DPW operator observed the APRV installation process but was not formally interviewed about its performance. However, the initial startup and commissioning of the valve revealed a significant risk of water hammer to be a customer concern.

B.6 Recommendations

The testing data collected to date indicate significant water and cost savings are possible from APRV operation. However, the lessons learned from the installation and startup of the APRV technology indicate that a full-scale demonstration would not be feasible due to operational issues encountered as described below.

For the Singer APRV, the project team encountered water hammer issues during commissioning. After resolving the water hammer issue, the project team was able to operate the hydraulically actuated APRV as designed. The Singer APRV demonstrated reduced water loss (10% reduction at a 15-psi delta) and met the UFC minimum fire flow testing requirement. However, during operational testing, the project team observed an unsafe valve closing speed when transitioning from high to low flow (less than 3 seconds). The vendor's response to these technical issues indicated that pressure oscillation was inherent to the valve design and that the water system should be designed with PRVs to mitigate damage to distribution lines. These solutions were a "no go" to endorse the Singer APRV to the user community (UFC committee and DoD installations). The project team recommends that the vendor resolve the water hammer issue and improve the ability to adjust valve response time in the field before continued demonstration testing can be performed.

B.7 Field Data Archive

Table B-1. Singer Percent Leak Reduction Results for Tank 1

Tank 1	Ave. Ullage Reading	Volume	Delta	Percent Reduction
	(cm)	(Liters)		

Baseline (95 psi)	86.7	365	-	-
Trial 1 (80-75 psi)	90.8	315	50	13.7
Trial 2 (80-70 psi)	91.8	302	63	17.3
Trial 3 (80-65 psi)	92.7	290	75	20.5
Trial 4 (70-60 psi)	93.9	275	90	24.7
Trial 5 (70-55 psi)	95.9	263.7	101.3	27.8
Trial 6 (70-50 psi)	97.1	253.3	111.7	30.6
Trial 7 (60-40 psi)	98.4	230	135	37
Trial 8 (70-30 psi)	101.9	185	180	49.3

Table B-2. Singer Percent Leak Reduction Results for Tank 2

Tank 2	Ave. Ullage Reading	Volume	Delta	Percent Reduction
	(cm)	(Liters)		
Baseline (95 psi)	100.8	244.3	-	-
Trial 1 (80-75 psi)	102.5	220	24.3	9.9
Trial 2 (80-70 psi)	103.2	209	35.3	14.4
Trial 3 (80-65 psi)	103.9	200	44.3	18.1
Trial 4 (70-60 psi)	104.9	190	54.3	22.2
Trial 5 (70-55 psi)	105.8	181.3	63	25.8
Trial 6 (70-50 psi)	107.1	175	69.3	28.4
Trial 7 (60-40 psi)	109.9	132.3	112	45.8
Trial 8 (70-30 psi)	110.7	120	124.3	50.9

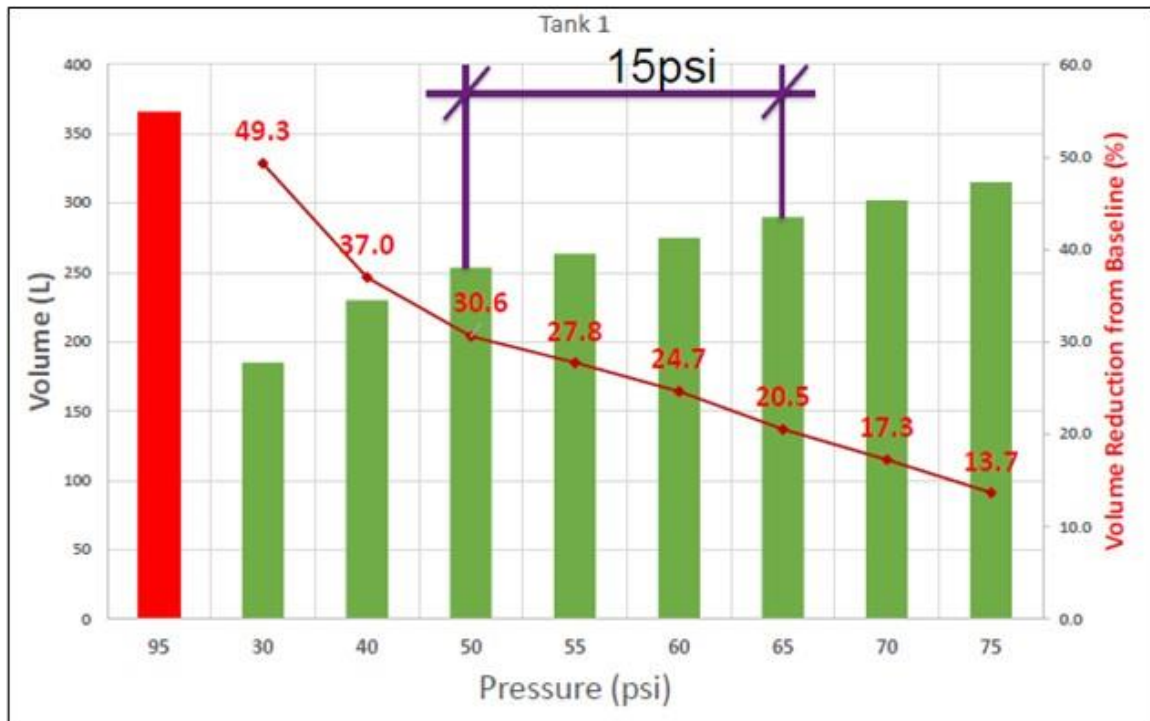


Figure B-1. Singer Percent Leak Reduction for Tank 1

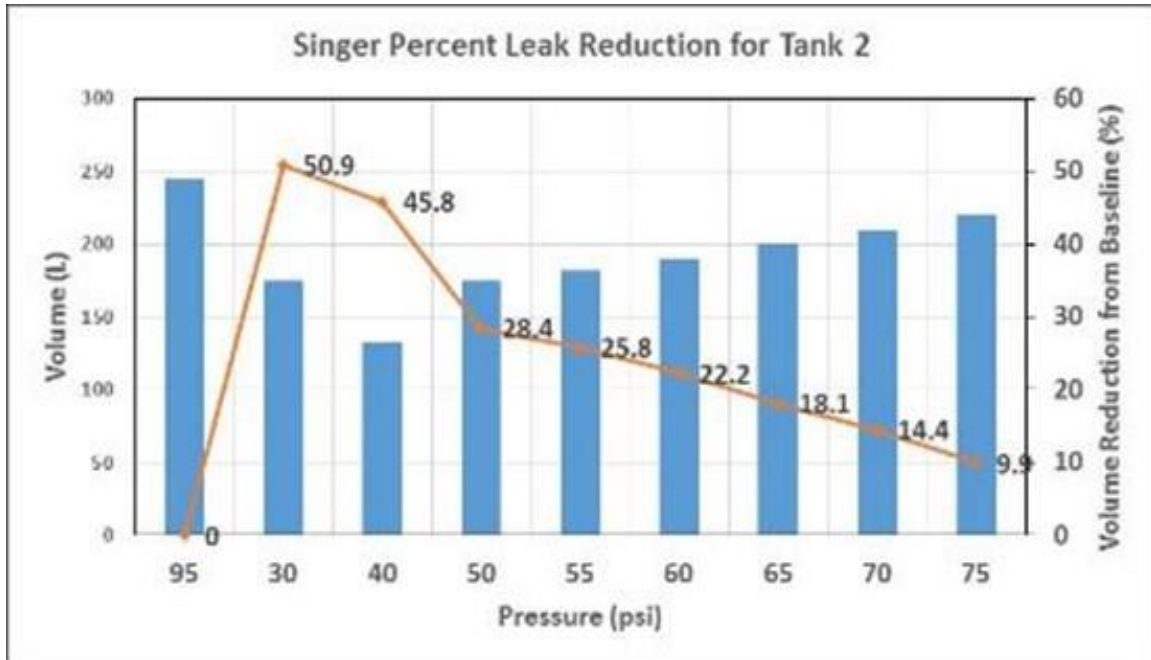


Figure B-2. Singer Percent Leak Reduction Tank 2

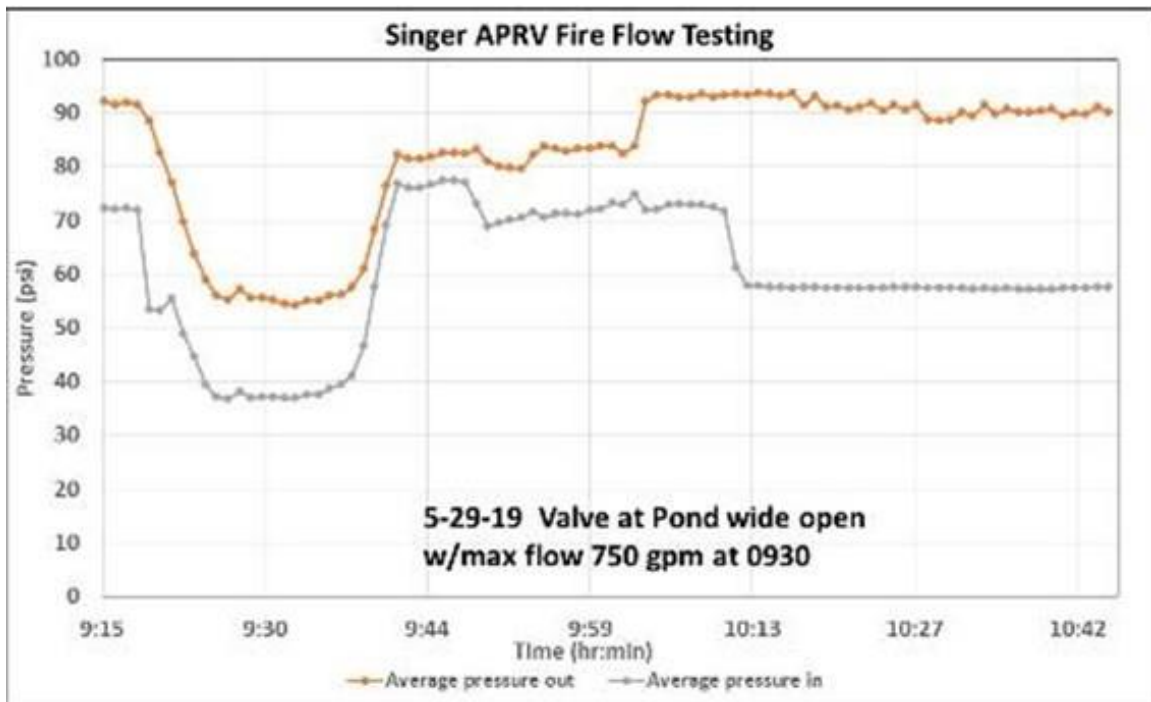


Figure B-3. Singer APRV Fire Flow Testing Pressure Plot

Table B-3. System Response Results

Setting	30 Seconds Response Time	Actual Closure Speed (Seconds)	Safe Closure Speed Met
<i>Low to High Flow</i>			
Trial 1 (80-75 psi)	>30	NA	Yes
Trial 2 (80-70 psi)	>30	45	Yes
Trial 3 (80-65 psi)	>30	NA	Yes
<i>High to Low Flow</i>			
Trial 1 (80-75 psi)	<5	NA	No
Trial 2 (80-70 psi)	<5	3	No
Trial 3 (80-65 psi)	<5	NA	No

Table B-4. Singer Test Bed Data

APRV Test Trial	Tank Ullage Level (cm)	Tank Leak Volume (gal)	Ullage Level Average (cm)	Standard Deviation (cm)	Leak Volume Average (gal)	Standard Deviation (gal)
Baseline, 95 psi (Tank 1)						
Test 1	86.7	96.4	86.7	0.1	96.4	0.0
Test 2	86.7	96.4				
Test 3	86.8	96.4				
Baseline, 95 psi (Tank 2)						
Test 1	101.3	64.2	100.8	0.4	64.6	0.6
Test 2	100.5	64.2				
Test 3	100.7	65.3				
80-75 psi (Tank 1)						
Test 1	90.9	83.2	90.8	0.1	83.2	0.0
Test 2	90.9	83.2				
Test 3	90.7	83.2				
80-75 psi (Tank 2)						
Test 1	102.5	58.1	102.5	0.1	58.1	0.0
Test 2	102.4	58.1				
Test 3	102.5	58.1				
80-70 psi (Tank 1)						
Test 1	91.8	79.8	91.8	0.1	79.8	0.0
Test 2	91.7	79.8				
Test 3	91.8	79.8				
80-70 psi (Tank 2)						
Test 1	103.4	55.2	103.2	0.2	55.2	0.0
Test 2	103.1	55.2				
Test 3	103.2	55.2				
80-65 psi (Tank 1)						
Test 1	92.6	76.6	92.7	0.1	76.6	0.0
Test 2	92.8	76.6				
Test 3	92.7	76.6				
80-65 psi (Tank 2)						
Test 1	103.8	52.8	103.9	0.1	52.8	0.0
Test 2	104	52.8				
Test 3	103.9	52.8				
70-60 psi (Tank 1)						
Test 1	93.7	72.7	93.9	0.2	72.7	0.0
Test 2	94.1	72.7				
Test 3	93.8	72.7				

Table B-4. Singer Test Bed Data, Continued

70-60 psi (Tank 2)						
Test 1	104.9	50.2	104.9	0.2	50.2	0.0
Test 2	105.1	50.2				
Test 3	104.8	50.2				
70-55 psi (Tank 1)						
Test 1	95.9	70.0	95.87	0.06	69.66	0.31
Test 2	95.9	69.5				
Test 3	95.8	69.5				
70-55 psi (Tank 2)						
Test 1	105.7	48.1	105.83	0.15	47.91	0.31
Test 2	105.8	48.1				
Test 3	106	47.6				
70-50 psi (Tank 1)						
Test 1	97.2	67.4	97.07	0.23	66.93	0.76
Test 2	97.2	67.4				
Test 3	96.8	66.1				
70-50 psi (Tank 2)						
Test 1	107.4	46.2	107.13	0.23	46.24	0.00
Test 2	107	46.2				
Test 3	107	46.2				
70-30 psi (Tank 1)						
Test 1	102	48.9	101.93	0.12	48.88	0.00
Test 2	101.8	48.9				
Test 3	102	48.9				
70-30 psi (Tank 2)						
Test 1	110.8	31.7	110.67	0.15	31.70	0.00
Test 2	110.5	31.7				
Test 3	110.7	31.7				
60-40 psi (Tank 1)						
Test 1	98.5	60.8	98.37	0.12	60.77	0.00
Test 2	98.3	60.8				
Test 3	98.3	60.8				
60-40 psi (Tank 2)						
Test 1	109.9	35.1	109.87	0.06	34.96	0.15
Test 2	109.8	34.9				
Test 3	109.9	34.9				

Appendix C: CLA-VAL 98-06 APRV

(Raw Microsoft Excel Data Available Upon Request)

C. 1 Technology Description

The Cla-Val, Model 98-06 is an APRV consisting of adjustable high pressure and low pressure set points for high flow and low flow demand, respectively. This dual set point arrangement allows for reduction in water consumption, as well as unintentional water loss by keeping system piping from being over-pressurized during periods of low demand. The valve consists of three major components: the body with seat installed, the cover with bearings installed, and the diaphragm assembly (Figure C-1). As flow increases from a low flow condition to a high flow condition, the outlet pressure increases from the low to high set point. The Cla-Val operates without inhibiting adequate pressure during high or fire flow demand. The Cla-Val 98-06 valve has no orifice plate or other restriction in the main line as part of the valve control. It operates under hydraulic control without electrical controls. The rate of change between the two set points was designed to be hydraulically dampened to gradually increase or decrease pressure to prevent downstream system surges. Existing pressure valves can be retrofitted with the Cla-Val components without removing the valve from the distribution line. More information on the technology development is available from the manufacturer's web sites linked here for the [Cla-Val Model 98-06](#).

The diaphragm assembly is the only moving part and forms a sealed chamber in the upper portion of the valve, separating operating pressure from line pressure. The pilot control system includes separate adjustments for setting the high pressure, low pressure, and flow rate at which pressure increases or decreases between set points. The pilot system incorporates a stem valve (X78-4) that either blocks or allows upstream pressure into the pressure reducing pilot control bias chamber for switching between high and low set point pressures. The pressure reducing control has a low pressure setting up to 30 psi below the high pressure set point.

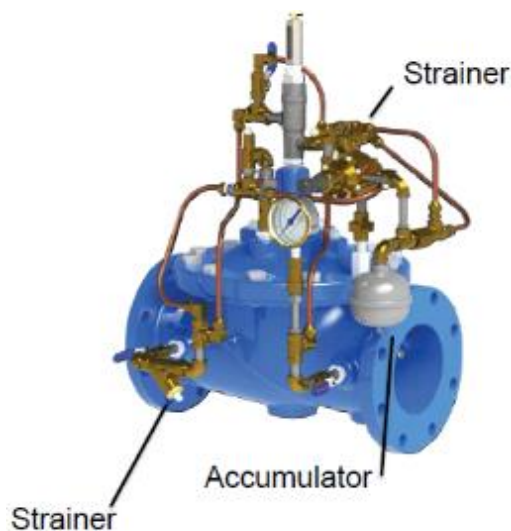


Figure C-1. Cla-Val Model 98-06 (Source: Cla-Val)

The material and operating specifications for the Cla-Val 98-06 include the following:

- Main Valve Body and Cover: ductile iron American Society for Testing and Materials (ASTM) A-536
- Main Valve Trim: stainless steel type 316

- End Detail: 150 # flanged American National Standards Institute (ANSI) B16.42
- Rubber Material: Buna-N
- Coating: internal/external heat fusion epoxy coating 6 mils thick
- Pressure Rating: 250 psi maximum working pressure
- Temperature Range: up to 180 degrees Fahrenheit

C.2 Cla-Val 98-06 Installation and Commissioning

On August 16, 2019, two ERDC DPW staff members removed the existing Singer APRV and installed the Cla-Val 98-06 at the test bed. The entire process took approximately 3 hours.

EXWC and ERDC staff attempted to commission the Cla-Val 98-06 on the week of August 19, 2019. The project team followed the 98-06 startup and adjustment instruction sheets. Commissioning involved first opening the upstream supply valve and downstream discharge valve to achieve the desired flow rate for adjusting the APRV for normal operations. All of the valves (headwork pilot tubing) were adjusted to the open position and air was purged from the upper components by loosening connector fittings. The team observed that the downstream pressure was not modulating per design as the flow rate was adjusted between 300 and 900 gpm by opening the 4-inch valve located at the pond.

Cla-Val was contacted to troubleshoot the issue and a service technician suggested to determine if the strainers were clogged. The team disconnected the strainer housing from the upstream side of the valve body. The screen cylinder was removed from the housing (Figure C-2a) and the team observed that the strainer housing was blocked by scale deposits. The outside of the strainer housing looked new; however, the deposits in the interior were inconsistent with the new assembly after just a few hours of use. The screen housing was washed with a solution of 5% nitric acid and was placed in a sonicator for 80 minutes to remove the scale material. After sonicating, the blockage was still hard as shown in Figure C-2b and had to be dislodged from the housing with a hammer and screwdriver. The scale was removed mechanically from the housing; however, residual scale was still present around the outlet of the housing after the cleaning as shown in Figure C-2c.



a



b



c

Figure C-2. Screen Cylinder Cleaning Process: (a) Screen Cylinder; (b) Strainer Housing after Sonication Cleaning Method; and (c) Strainer Housing after Mechanical Cleaning Method

The other strainer assembly was removed from the valve body to check for scale deposits. The housing and screen cylinder were disassembled. A white viscous material was observed on the plug that seats the screen cylinder and housing as shown in Figure C-3a and Figure C-3b. The white material was mechanically removed from the plug.

After removing the scale and white paste material from both strainer housings, the APRV was reassembled and pressurized following the startup instructions. The pressurized APRV produced sound associated with flow in the pilot tubing, as all check valves were in the open position. Pressure readings on the gauge upstream and downstream read 75 psi and 35 psi, respectively. The downstream discharge flow rate was adjusted between 350 and 700 gpm; however, once again, the team did not observe the downstream pressure varying with the varying flow.



Figure C-3. White Paste Material Present on Set Plug: (a) On Strainer Screen and (b) On Housing

The team contacted Cla-Val and was instructed to investigate the X78-4 (variable orifice assembly). The team disassembled the X78-4 to determine why the adjustment screw would not reach the stop point. After disassembly, the following issues were observed with the X78-4:

- It appeared that the assembly was incomplete as it only had one-half of a brass space ring that fit in the machined groove below the wider threads that hold the assembly within the valve body (Figure C-4a and Figure C-4b).
- The length of the assembly components was measured, and it was found that the fully extended adjustment threads did not allow the assembly to reach the stop point where the brass cylinder would engage the seat in the valve body (Figure C-4c).

- The team also could not get the indicator rod to pass through the adjustment assembly so that set screw could be engaged in the travel slot on the side of assembly (Figure C-4d).

The team reassembled the X78-4 to the degree possible and contacted Cla-Val. Consensus was reached amongst the project team that no further work could be accomplished with off-specification parts provided. Cla-Val investigated the issue with the valve components and informed the project team that there was a mix-up in the factory. The X78-4 was built with a 4-inch housing instead of the required 6-inch housing, which prevented the stem from reaching the stop point; therefore, the pressure could not reach its low or high set points.

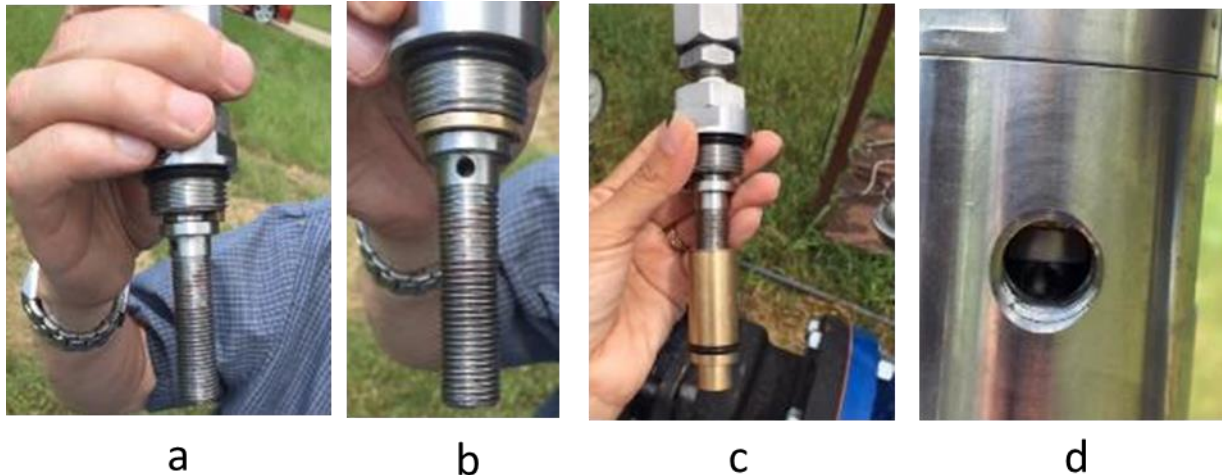


Figure C-4. Issues Noted with the Cla-Val APRV Assembly: (a) and (b) Only Half of the Brass Washer was included with the Assembly; (c) X78-4 Stem Did Not Fully Screw into the Brass Cylinder; and (d) Threaded Stem did Not Reach the Groove in the Outer Housing

To resolve the problems encountered, Cla-Val offered to build a new valve for the demonstration. The difference though was before shipping it to ERDC, they would test it at their hydraulic laboratory in Costa Mesa, California, to ensure all components were built and operating as designed. They set the tripping flow at 350 gpm and pilot pressures were set at low (40 psi) and high (60 psi) set points at the laboratory. The new valve arrived at ERDC in early October. Some delays were encountered in constructing the X78-4 as some components were not readily available.

On August 16, 2019, three ERDC DPW staff members removed the off-specification Cla-Val APRV and installed the new Cla-Val 98-06 at the test bed. The entire re-installation process took approximately 3 hours (see Figure C-5).



Figure C-5. Cla-Val 98-06

EXWC and ERDC staff commissioned this Cla-Val 98-06 on the week of December 9, 2019. The project team followed the 98-06 startup and adjustment instruction sheets provided by Cla-Val for a type I and type II startup. Step one required opening the upstream supply valve and downstream discharge valve so that the hydraulic pilot tubes and valve cover chamber could be purged of air. The following step required opening the downstream valve to achieve the normal flow rate so that pressure adjustments could be made to the pilot valve and tripping flow on the X78-4. The low and high pressure set points were readjusted from the factory settings to ensure that it could be successfully adjusted in the field.

The pressure loggers were configured to capture data every 0.1 seconds throughout the two commissioning methods to identify the presence of harmful pressure transients. The entire commissioning process was completed in 2 hours with phone assistance from Cla-Val representatives. Pressure data were captured during the entire commissioning process. No audible water hammer noises or vibration occurred as observed during the Singer APRV commissioning.

The team performed several flow cycles to determine if the flow transitioned as designed without creating pressure transients. The transition time from low to high pressure after reaching the tripping flow was about 30 seconds. The transition from high to low when the tripping flow was reached was about 50 seconds. Figure C-6 through Figure C-8 show the pressures versus time during the commissioning process.

Figure C-6 shows the pressure transients for the two adjustment methods for the CMP-A Pressure Management Control. The difference between both methods is that for Method I, isolation valve 6B is closed and isolation valve 6A is open, whereas both valves are open for Method II. According to the Cla-Val 98-06/698-06 Manual, Method I is the most accurate adjustment method and requires the ability to have a means to adjust system flow rates during the adjustment process. Method II is intended for use if an approximation of the pressure span adjustment (low pressure set point) is acceptable and there is not a practical means to vary system flow during the adjustment procedure. Both methods were not necessary to decommission the valve, but it was done for testing purposes.

Figure C-7 displays the pressure transient generated while adjusting the X78-4. An X78-4 is a stem valve (X78-4) that either blocks or allows upstream pressure into the pressure reducing pilot control bias chamber for switching between high and low set point pressures. This figure also highlights the pressure transients when the accumulator fails. The accumulator functions as a pressure transition dampening device. It allows smooth transitions between low and high pressure set points of the valve. Once the accumulator was fixed, the pressure transients in Figure C-8 were generated. This graph was generated by slowly (every one-eighth) turning the reservoir outlet valve to find the tripping point and finally reaching the desired low pressure (40 psi).

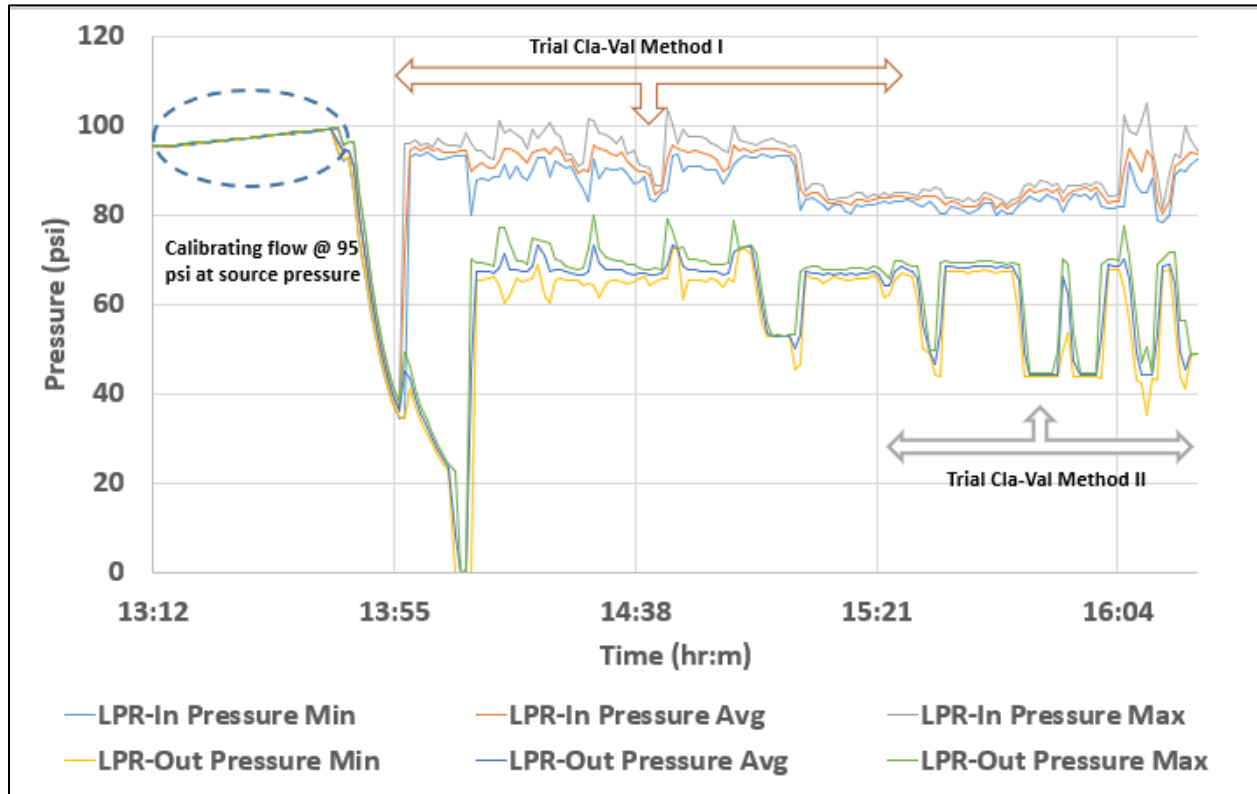


Figure C-6 Pressure Transients for Method I and Method II

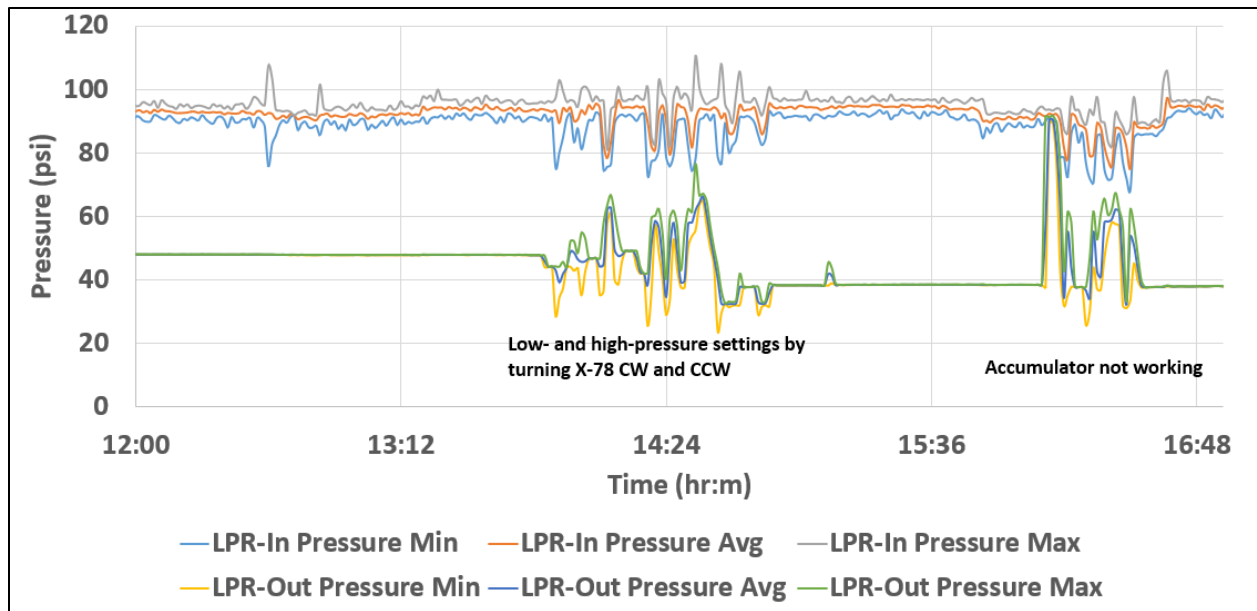


Figure C-7. Pressure Transients during the X78-4 Adjustment

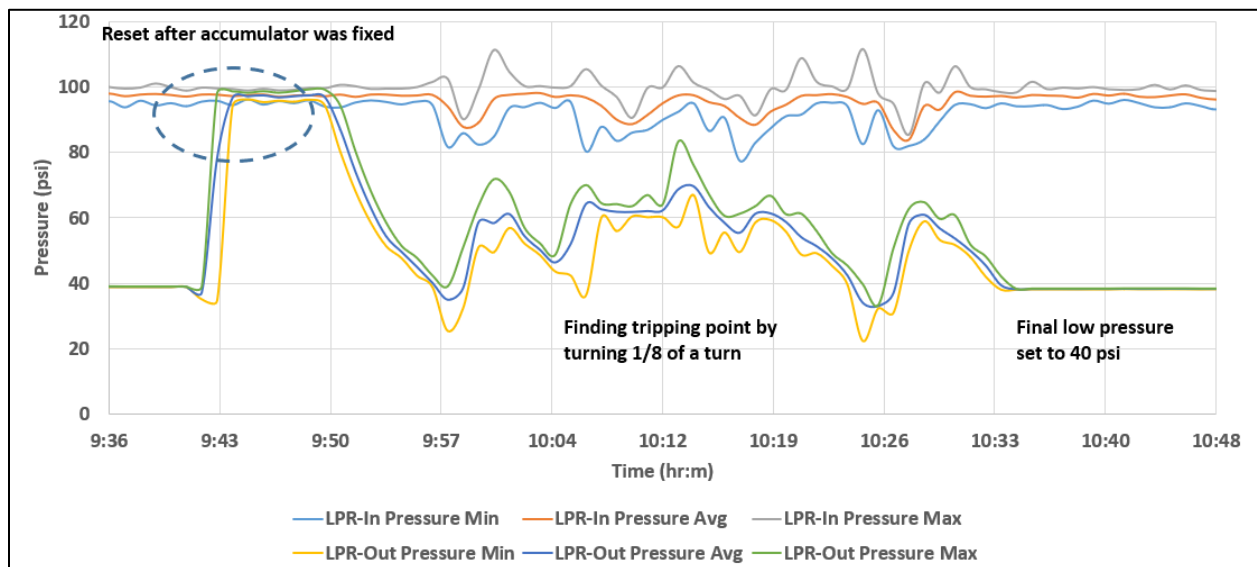


Figure C-8. Pressure Transients to Reach Tripping Point

C.3 Testing Protocol Implementation

The test matrix is presented in Table C-1 and Table C-2 of the planned and actual tests performed for the Cla-Val APRV.

Table C-1. Baseline Tests for Cla-Val APRV

Planned APRV Testing	Test Description
Baseline 1	Determine leak (volume) with no PRV (95 psi source)
APRV Setting 1 (80 - 75 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-75 psi
APRV Setting 2 (80 -70 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-70 psi
APRV Setting 3 ^(a) (80 -65 psi) (80 - 60, 50 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 80-65 psi
APRV Setting 4 (70 - 60 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-60 psi
APRV Setting 5 (70 - 55 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-55 psi
APRV Setting 6 (70 - 50 psi)	Evaluate APRV- Leaks (vol) that would occur with APRV 70-50 psi
APRV Setting 7 (60 - 45 psi)	Preset by Cla-Val

80-60 and 80-50 testing were not evaluated.

Table C-2. Planned Tests for Cla-Val APRVs

Planned APRV Testing	Cla-Val 98-06	Test Description
APRV (Fail Mode 1)	-	Performance with failed diaphragm
APRV (Fail Mode 2)	-	Performance with clogged filter screen
APRV (Fail Mode 3)	-	Performance with power loss
APRV Fire flow (Intermittent)	✓	Determine how well APRV works with once a week low to high transition
APRV Fire flow (long-term)	OBE	Determine how well APRV works when system stays in low pressure mode for length of time
Evaluate ability to adjust pressure setting	✓	Assess ease of adjustment
APRV pressure transients	✓	Evaluate pressure transients during transitioning.
Evaluate maintenance	OBE	Assess annual maintenance requirements

C.4 Lessons Learned

C.4.1 Cla-Val 98-06 Quality Assurance and Control

Cla-Val APRV specifications must be met by the manufacturer to ensure proper operation. The project team found issues with 98-06 parts during the Cla-Val commissioning effort including:

two defective strainers and the incorrect size for the X78-4 assembly (used to set the tripping flow rate) that precluded reaching the high and low set points. After discussions with Cla-Val representatives, consensus was reached amongst the project stakeholders that demonstration testing could not be accomplished with the off-specification valve. Cla-Val constructed and tested a new valve at its plant for proper operation prior to shipment back to the ERDC test bed. It would be prudent to ensure that all parts are quality control checked or tested prior to installation.

C.4.2. Cla-Val Technical Representative Support

Cla-Val technical representative should be on site or available via telephone for commissioning. The project team recommends that a knowledgeable Cla-Val technical representative be available during commissioning of the Cla-Val 98-06 to adjust these unique pilot valves and X78-4 arrangement. Unlike the conventional PRVs whereby only one adjustment is needed, the Cla-Val 98-06 has four adjustments that must be made while under flow conditions. Although the instructions are comprehensive, experience with this valve is necessary for commissioning, as the procedure is substantially different from a conventional single pilot PRV. At a minimum, a Cla-Val technical representative should be on call during the commissioning process to step through the procedure. During the time of the commissioning of the first Cla-Val APRV, the two knowledgeable (98-06) technical representative were not available due to conflicting schedules. None of Cla-Val's other technical representatives were familiar enough with the 98-06 to provide technical support when troubleshooting was required. For testing of the alternate Cla-Val 131 valve technology, the team utilized approximately 2.5 hours of time on the phone with Cla-Val for the commissioning of the Cla-Val 131. The technician walked the team through wiring diagrams, valve positioning, and calibration for this electronically-actuated valve. Overall, these technical support issues could pose implementation/operational issues for end users.

C.4.3 APRV Use on Single Feed Systems Only

In follow-up conversations, Cla-Val no longer recommends the use of the hydraulically actuated 98-06 and 131 valves in a lead/lag configuration on multi-feed water distribution systems. Two 98-06 valves or 131 valves in the same water distribution loop will create a pressure conflict that has no resolve without complete isolation of one of the valves. Isolating valves would be problematic, as it would require additional maintenance to exercise the valves that are isolated, which effectively adds maintenance that is counter to UFC requirements.

C.4.4 Accumulator Pressure Checks and Maintenance

The Cla-Val 98-06 uses an accumulator to prevent surges during commissioning and throughout lifecycle operations. It consists of a stainless-steel sphere with an air-filled bladder that absorbs pressure transients that may occur in the system. The internal rubber bladder is filled with air pressurized to 50 psi that absorbs hydraulic shock. To confirm the actual pressure during the demonstration, a standard tire gauge (Schrader valve) was used. However, the team learned that it is not as simple as measuring air from a tire. Once the air gauge was installed, it released a small amount of air, resulting in the cavity being filled with water. Once filled with water, the accumulator could not be filled with air until the water was removed. The immediate solution was to shut off valves to the headworks, bleed air, remove the accumulator and purge with pressurized

air. The long-term solution would be to add a shut-off valve just prior to the accumulator to isolate it prior to testing or filling.

C.4.5 Cla-Val 98-06 Freeze Protection

The Cla-Val 98-06 uses a sight glass that allows the operator to assess the relative movement of the diaphragm stem which correlates to flow. It is used during the commissioning process to adjust tripping flow rate. Two weeks after commissioning the APRV, the Vicksburg site experienced freezing temperatures for several hours of the early morning. The sight glass situated above the X78-4 ruptured (Figure C-9) due to the cold temperatures, creating a significant leakage until it was spotted hours later. The solution for this problem in freeze prone areas is to simply remove after commissioning and replace with a stainless-steel nipple and cap.



Figure C-9. Ruptured Sight Glass on Cla-Val 98-06

C.5 Performance Objectives Results

C.5.1 Water Savings Metric and Data

During the APRV test trials, water loss through leaks at various high and low pressure set points was measured in gallons. The leak measurements were used to calculate the percent reduction in losses due to leaks in comparison to the baseline.

C.5.1.1 Water Savings Success Criteria

A 10% reduction in water loss from leaks in comparison to the baseline was considered successful and used as a go/no-go decision point for the full-scale test.

C.5.1.2 Results

The APRVs tested were able to reduce water loss up to 30% in comparison to the baseline (with distribution water supplied at 95 psi). All valves showed this by their ability to reduce pressure from 70 to 50 psi. Based on the test data, 10% water reduction from leakage was achieved with a high to low pressure delta of 15 psi.

C.5.2 Purpose of Cost Savings

Water costs are based on the volume consumed. Lower pressures can also extend the life of water systems and reduce the frequency of breaks and repairs. Pressure management using technologies such as APRV can significantly reduce pipe failure rates, extend infrastructure life, and reduce the magnitude of existing leaks until they can be repaired.

C.5.2.1 Cost Saving Metric and Data

Cost savings were assessed by estimating the volume of water saved, equipment, installation, and maintenance costs. Cost savings were evaluated using two related metrics: SIR and ROI. The SIR method is a pass/fail evaluation that divides the savings from avoided purchases over the lifecycle of the APRV by the capital costs of installation and maintenance. ROI is a measurement of the number of years required to break even on the investment. The avoided purchase is divided by the capital costs to install and maintain the APRV. Typical hourly labor rates were used to calculate overall cost, as well as adding the cost of materials.

C.5.2.2 Cost Savings Success Criteria

An SIR greater than 1 indicates that the technology is cost effective. The savings is at least as large as the cost. ROI less than 7 years indicates that the annual savings equals the installation cost after 7 years, and then after that point the technology will result in a net savings.

C.5.2.3 Results

A cost analysis of the Cla-Val 98-06 APRV calculated the SIR (based on 20 years of operation) to be 6.3, which is higher than 1, indicating a cost-effective technology. The ROI was determined to be 2.2 years, which provides better than expected return than the 7-year ROI metric. The Cla-Val APRV technology met the cost metrics with cost model assumptions and elements summarized in Appendix D.

C.5.3 Purpose of System Response

The APRV is required to provide a higher pressure when demand is high and lower pressure when conditions are static. Failure to deliver enough pressure when needed can compromise the mission in industrial areas and is a quality of life factor in the residential sector. Failure to lower the pressure is a performance factor that reduces savings and renders the technology less effective in terms of cost and water conservation.

C.5.3.1 System Response Metric and Data

In the test bed, high and low flow demand scenarios were simulated by manually opening the exit valve and letting water flow into the reservoir. The response of the APRV to the changing pressure and flow was evaluated and recorded. Data on the timing, flow, and pressure both upstream and downstream of the APRV indicated if it was responding to changing demands.

C.5.3.2 System Response Success Criteria

Response was successful if flow triggered a pressure change 98% of the time. For a low to high flow transition, the time target was initially set at 10 seconds. For a high to low flow transition, the time was set at less than 60 seconds.

C.5.3.3 Results

To avoid pressure spikes, the team changed the success criteria to greater than 30 seconds for the response time for pressure transitions. The testing found that the Cla-Val APRV transitioned low to high pressure after reaching the tripping flow in about 30 seconds. The transition from high to low pressure when the tripping flow was reached was about 50 seconds. The valve did meet the safe closure speed criteria required to avoid water hammer or other adverse impacts.

C.5.4 Purpose of System Reliability and Maintenance

Uptime was the amount of time that the APRV performed its function of regulating pressure in response to demand. Periods when it was non-functioning or actively being repaired were considered downtime. The failure mode for the APRV would be constant operation at the low-pressure setting regardless of water demand. To avoid unacceptable impacts of this failure scenario, the low-pressure set point must be set to ensure that fire flow demand can still be met. One of the fire flow requirements found in UFC 3-600-01 Fire Protection Engineering for Facilities is that residential areas with one and two stories are to achieve 500 gpm and 750 gpm flow rates, respectively for 90 minutes.

C.5.4.1 System Reliability and Maintenance Metric and Data

Maintenance logs and data on system response measured the accomplishment of this objective (i.e., replacement and removal of a diaphragm and silt screen). System uptime was the amount of time the APRV was functioning properly divided by the total time period of the test.

C.5.4.2 System Reliability and Maintenance Success Criteria

The system reliability was set at 95% uptime (5% downtime) for the APRV demonstration in case any repairs were needed in association with the failure mode tests. Meeting the minimum 500 gpm UFC fire flow requirement for one story, non-sprinklered family housing was also a requirement.

C.5.4.3 Results

The performance objectives associated with system reliability and maintenance could not be evaluated because no long-term testing was performed of the Cla-Val APRV. At 750 gpm, the APRV exceeded the minimum UFC fire flow requirement of 500 gpm for one-story, non-sprinklered family housing.

C.5.5 Purpose of Customer Satisfaction

The water consumers must have adequate water pressure and flow to meet their needs. Consumer satisfaction was intended to be assessed based upon a review of the data by UFC committee

members in communication with the ESTCP Water Program Manager and the ERDC DPW Director.

C.5.5.1 Customer Satisfaction Metric and Data

To determine customer satisfaction, the DPW Director was planned to be interviewed in person before APRV installation and at the end of the project. The survey was intended to determine how the APRV performed in terms of providing adequate pressure during peak water consumption periods and any maintenance or repair issues encountered during the demonstration.

C.5.5.2 Customer Satisfaction Success Criteria

No additional complaints were received about the water pressure.

C.5.5.3 Results

The ERDC DPW operator observed the APRV installation process but was not formally interviewed about its performance. However, the initial startup and commissioning of the valve revealed a significant risk of water hammer to be a customer concern.

C.6 Recommendations

The testing data collected to date indicate significant water and cost savings are possible from APRV operation. However, the lessons learned from the installation and startup of the APRV technology indicate that a full-scale demonstration would not be feasible due to operational issues encountered as described below.

During the Cla-Val 98-06 commissioning, the project team found significant issues with the valve parts and assembly as provided by the manufacturer. After discussions with Cla-Val representatives and project stakeholders, a consensus was reached that demonstration of the Cla-Val 98-06 APRV technology could not be accomplished with the off-specification valve as provided. Issues included APRV components in poor condition or missing and the supply of a 4-inch housing instead of the required 6-inch housing, which prevented the valve from properly reaching the low or high set points. Subsequently, a new Cla-Val 98-06 APRV unit was provided by the manufacturer for re-installation. When the working valve was tested, the team still saw pressure transients that the accumulator did not fully protect against.

C.7 Field Data Archive

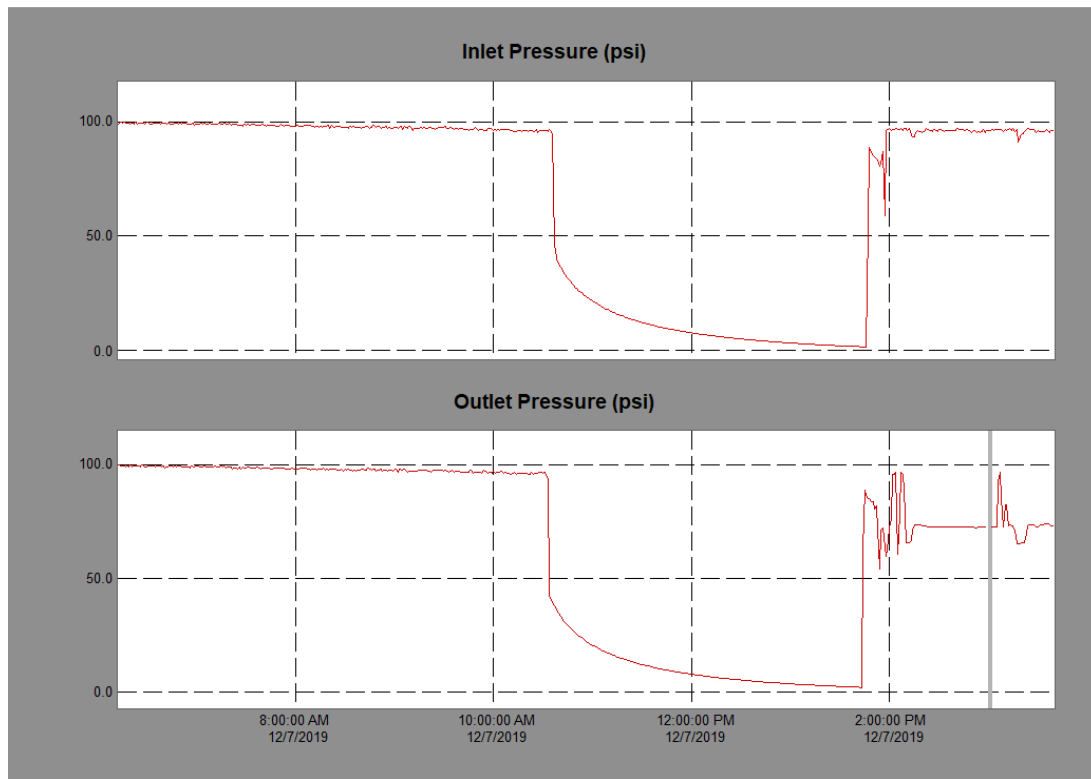


Figure C-10. December 7, 2019 Inlet and Outlet Pressures

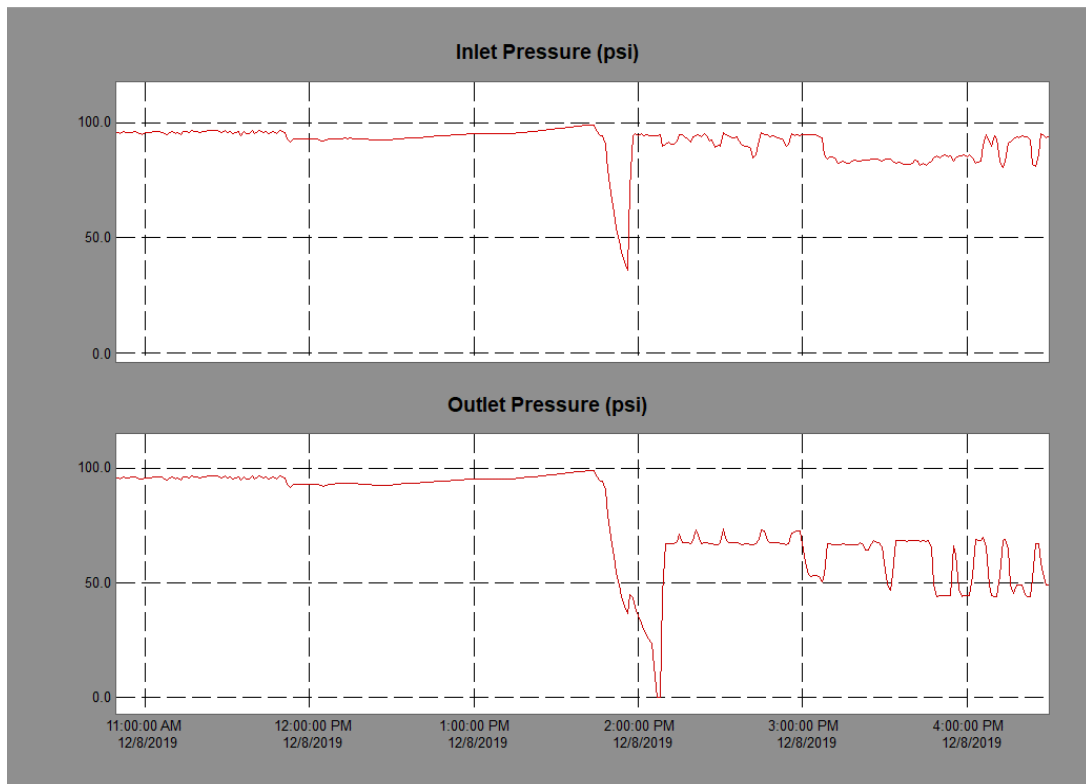


Figure C-11. December 8, 2019 Inlet and Outlet Pressures

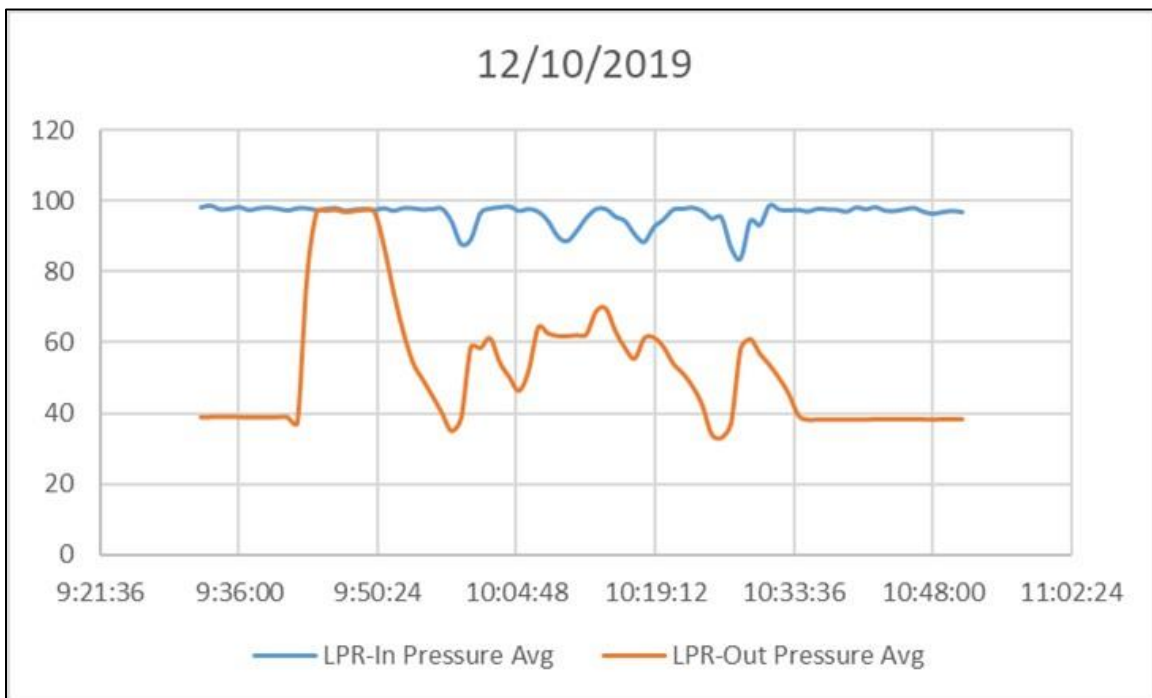


Figure C-12. December 10, 2019 Graph

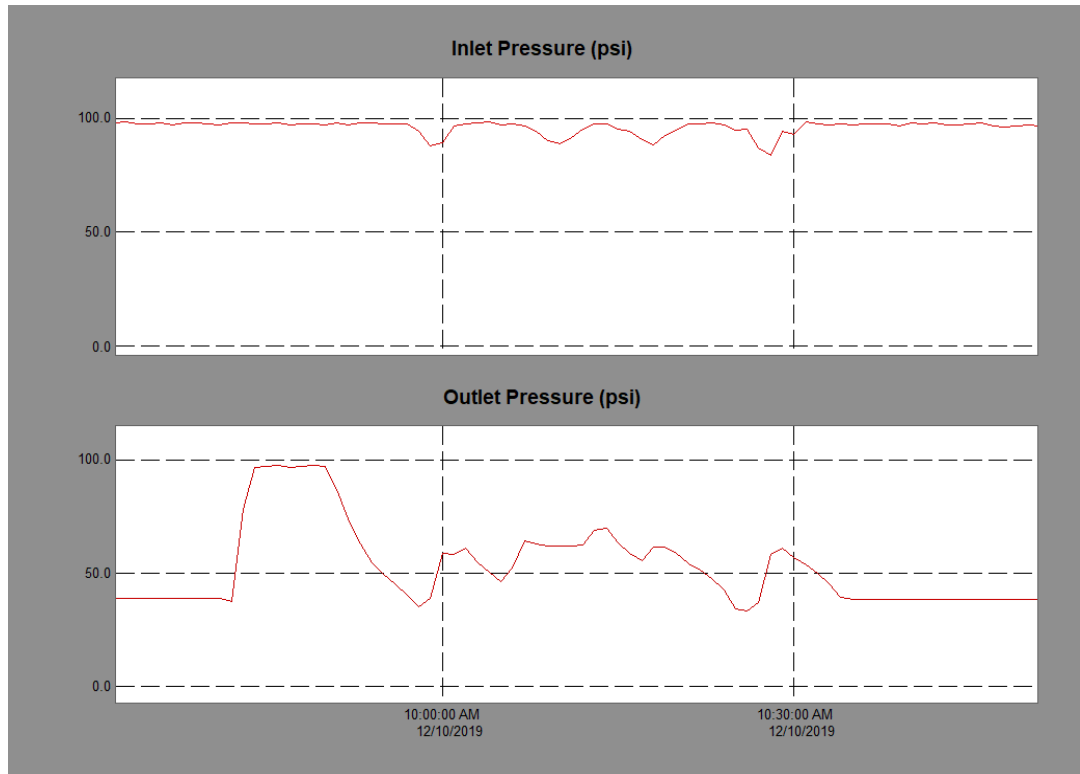


Figure C-13. December 10, 2019 Inlet and Outlet Pressures (Morning)

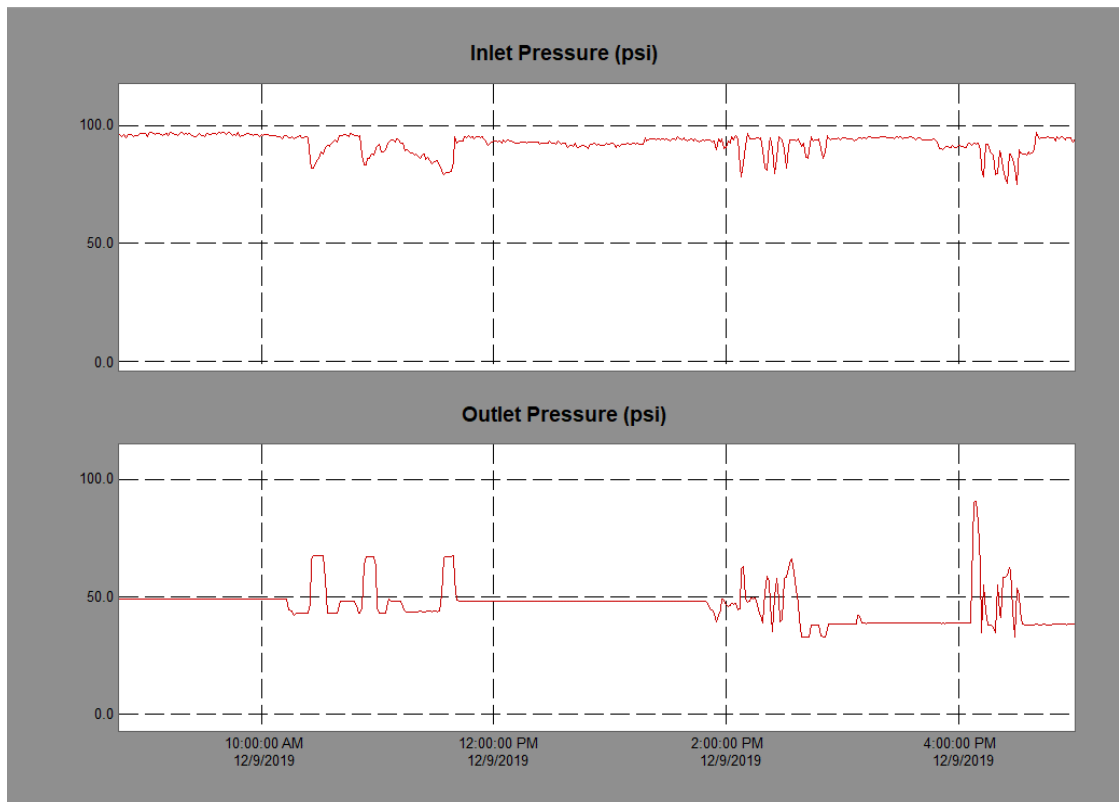


Figure C-14. December 9, 2019 Inlet and Outlet Pressures (Afternoon)

Appendix D: COST DATA ARCHIVE

COST ASSESSMENT

Cost savings were assessed by estimating the volume of water saved, equipment cost, installation, and maintenance. The cost elements are listed in Table D-1. Cost savings from utilizing the APRVs were evaluated using two related metrics: SIR and ROI. The SIR method is a pass/fail evaluation that divides the savings from avoided purchases over the lifecycle of the APRV by the capital costs of installation and maintenance (Equation 1). The APRVs have a 20-year design life as specified by the vendor. SIR greater than 1 indicates that the technology is cost effective. The savings is at least as large as the cost.

$$SIR = \frac{\text{Total Savings of Operating the APRV}}{\text{Total Costs of Operating the APRV}} \quad (\text{Equation 1})$$

ROI is a measurement of the number of years required to break even on the investment (Equation 2). The avoided purchase is divided by the capital costs to install and maintain the APRV. An ROI of less than 7 years was included as a cost savings performance objective. An ROI of less than 7 years indicates that the annual savings will equal the installation cost after 7 years, and then after that point the technology will result in a net savings.

$$ROI = \frac{\text{APRV Capital Cost}}{\text{Annualized Cost Savings}} \quad (\text{Equation 2})$$

Table D-1. Cost Elements for Singer Model 106 2PR-630

Cost Element	Data Tracked During the Demonstration
Hardware Capital Costs	APRV, Flange Kit, Saddle for Pipe Penetration, Spool Orifice Plate, and Shipping
Installation Costs	Labor and equipment required to install the APRV
Consumables	Diaphragm replacement cost Note: Replacement is recommended every 7 to 10 years. One replacement is assumed over the valve lifetime as defined below.
Operation and Maintenance	Labor hours, material costs, and frequency for O&M activities
Hardware Lifetime	Design life for the valve is 20 years based on vendor specifications.

A breakdown of the assumptions used to estimate the water loss and cost savings are included in Table D-2. For annual O&M labor (monitoring and maintenance of the APRV [checking pressures, cleaning strainers, and consumable replacement]), an estimated labor rate of \$50 per hour was utilized.

Water savings from reduced leaks was calculated based on the Singer test bed data (up to 15% water loss reduction). The water rate of \$5.99 per thousand gallons was sourced from the Port Hueneme Water Authority utilities website ([PHWA Utility Rates](#)). To extrapolate the savings to a full-scale system, residential data from Naval Base Ventura County (NBVC) Pt Mugu (number of households, persons per household, occupancy percentage, and water usage per capita, and

estimated water saved per capita with pressure management) were used to estimate the water saved per capita. The reduced annual pipe repair as a result of using the APRV at ERDC was estimated by assuming 0.25 leaks per mile of pipe per year, 5 miles of pipe, and an annual cost of pipe repair.

Table D-2. Estimated Water Loss and Savings

Water Loss Estimate Assumptions	Data
ERDC Water Cost (per 1,000 Gallon)	\$5.99
Water Savings (percent reduction based on test bed data)	15%
Leak Frequency (leaks per mile per year)	0.25
Miles of Pipe	5
Assumed Leak Rate (gpm)	2
APRV Service Life (years)	20
Diaphragm Replacement Frequency (years)	7
Labor	\$50/hr
Estimated Cost of Pipe Repair	\$7,500
Residential Data (NBVC PT. Mugu)	Data
Number of Houses	200
Number of Persons per Household	2
Occupancy %	75%
Water Loss Volumes and Cost Savings Estimates	Results
Estimated Annual Water Loss Through Leakage (gal)	1,314,000
Estimated Annual Water Conservation (gal)	197,100
Estimated Annual Water Conservation Per capita Operating at a Lower Distribution Pressure (using NBVC Pt. Mugu residential data) (gal)	82,125
Estimated Annual Water Savings	\$1,180.63
Estimated Annual Water Savings Per capita Operating at a Lower Distribution Pressure (using NBVC Pt. Mugu residential data)	\$491.93
Estimated Annual Savings from Reduced Pipe Repair	\$1,406.25

Table D-3. Operations and Maintenance Costs for Singer and Cla-Val 98-06 APRVs

Operations and Maintenance			
Monitor (Once per Quarter)	# of Technicians	Hours/Year	Subtotal
Check pressures	1	4	\$200.00
Maintain (Annual)	# of Technicians	Hours/Year	Subtotal
Labor	1	4	\$200.00
Maintain (7 Year Diaphragm Replacement)	# of Technicians	Hours/Year	Subtotal
Labor	2	3/7	\$42.86
Material (7 Year Diaphragm Replacement)	Unit Cost	Quantity	Subtotal
Diaphragm Kit	250.00	1/7	\$35.71
Strainer	50.00	1/7	\$7.14
GRAND TOTAL			\$485.71

Table D-4. Operations and Maintenance Costs for Cla-Val 131 APRV

Operations and Maintenance			
Monitor (Once per Quarter)	# of Technicians	Hours/Year	Subtotal
Check pressures	1	4	\$200.00
Maintain (Annual)	# of Technicians	Hours/Year	Subtotal
Labor	1	4	\$200.00
Material (Electrical Components)	Unit Cost	Quantity	Subtotal
Miscellaneous	100.00	1.00	\$100.00
Maintain (7 Year Diaphragm Replacement)	# of Technicians	Hours/Year	Subtotal
Labor	2	3/7	\$42.86
Material (7 Year Diaphragm Replacement)	Unit Cost	Quantity	Subtotal
Diaphragm Kit	250.00	1/7	\$35.71
Strainer	50.00	1/7	\$7.14
GRAND TOTAL			\$585.71

Table D-5. SIR and ROI Calculations for All APRVs Tested

Valve Savings	Singer	Cla-Val 98-06	Cla-Val 131
Valve Capital Cost	\$6,465.00	\$6,625.00	\$14,188.00
Installation Cost	\$450.00	\$450.00	\$450.00
Estimated Costs for the Valve over the Service Life	\$9,714.29	\$9,714.29	\$11,714.29
Estimated Water Savings for the Valve over the Service Life	\$61,576.16	\$61,576.16	\$61,576.16
SIR	6.3	6.3	5.3
ROI	2.1	2.2	4.6

Appendix E: SAN NICOLAS ISLAND FEASIBILITY STUDY

E.0 SAN NICOLAS ISLAND FEASIBILITY STUDY

E.1 Introduction

The APRV is most appropriate for single feed water distribution system configurations. Naval Base Ventura County (NBVC) Public Works Office manages the water distribution systems at NBVC San Nicolas Island (SNI). This feasibility study addresses possible use of the APRV in lieu of single pressure setting PRVs currently used to control pressure at “Nictown”, one of the water distribution service areas at SNI. The objectives of this portion of the demonstration project were to evaluate cost effectiveness and reliability and to address any operation and maintenance issues that would be a barrier to a successful implementation at Nictown.

E.2 General Description of Water System at San Nicolas Island

Due to its remote location, water desalination through reverse osmosis is used to provide potable water to the entire island. Processed water from the desalination plant is pumped to two large holding tanks located several hundred feet above Nictown for gravity flow through 8-inch diameter pipelines. Consequently, the water is significantly more expensive than other locations at approximately \$250/1,000 gallons (as compared to approximately \$15/1,000 gallons at NBVC Point Mugu), meaning water losses from this distribution system are much more costly. Water production through the desalination plant serves a population of approximately 150 personnel during the business week and 50 personnel during the weekend. The tanks and water distribution systems serve three pressure zones locations at SNI: Nictown, Monroe, and the Fuel Station. This feasibility study addresses the distribution system component located at Nictown, which is comprised of the main housing and administrative facilities. The distance from the water tank located at the top of the hill down to Nictown is approximately 2.25 miles (estimated via the SNI water system atlas). The exiting PRV reduces the pressure from 92 psi to 52 psi $\pm$ 3 psi.

Figure E-1 and Figure E-2 provide a general schematic of the Nictown water sub-system, as well as an image of the existing PRV bank. The PRV in the foreground is a 4-inch Hytrol followed by a Sensus flow meter. This PRV handles normal flow to Nictown, while the 6-inch Hytrol handles the flow demand during a high load requirement such as a fire flow. The flow meter provides data support for regulating the flow output of the desalination plant. The 6-inch PRV is not equipped with a flow sensor and is operational only when there is a high flow demand characterized by a substantial drop in pressure downstream of the 4-inch PRV. When the pressure drops approximately 7 psi, this triggers the 6-inch Hytrol to open.

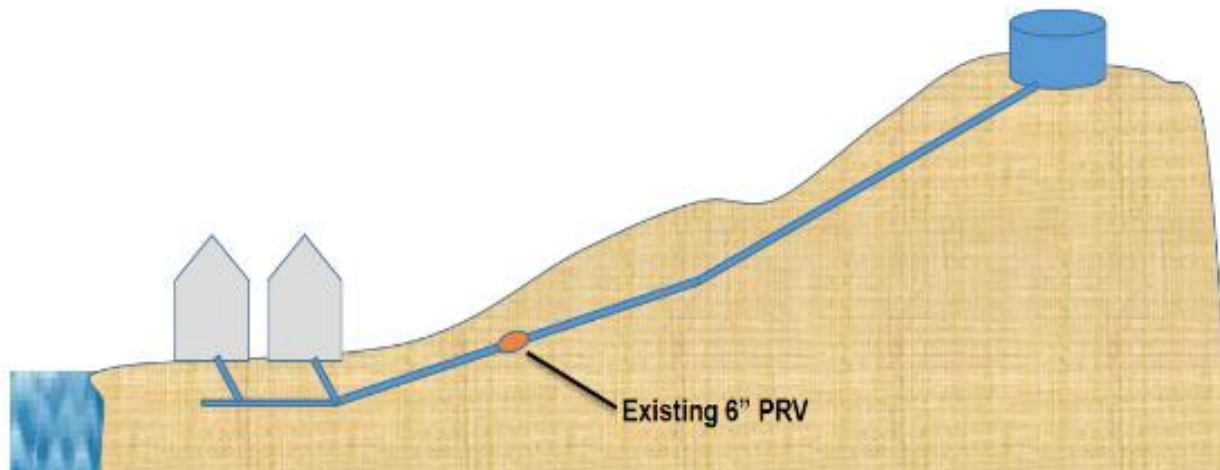


Figure E-1. Schematic Diagram of Water System and PRV Layout at Nictown



Figure E-2. Image of 6-inch PRV Currently Installed at Nictown

E.3 Technology Overview

The feasibility study considered the installation of an APRV specified as the Cla-Val Pressure Management Valve 98-06 (Figure E-3 and Figure E-4). The Cla-Val 98-06 uses the same PRV globe valve (100-01 Hytrol Valve) component currently deployed at SNI but with a different hydraulic headwork (pilot valve pressure and flow assembly). The primary headwork components include:

- 1) Accumulator to protect against surges or water hammer;
- 2) Adjustable flow mechanism (X78-4) that gradually transitions from high to low pressures; and
- 3) Dual set pilot control valve that is used to adjust the high and low pressure settings.

The 98-06 has the same flange-to-flange face as the existing Cla-Val PRVs, enabling a simple replacement. Alternatively, the pilot control headworks can be simply retrofitted onto an existing Cla-Val PRV if desired.

The accumulator featured in the Cla-Val system is air charged by the factory to approximately 51 psi and acts as a pressure transition dampening device which allows for a smooth switch between the low and high pressure set points without pressure oscillations and water hammer. The factory air charge should be sufficient for most uses and no additional field charging is required. However, there is a stem valve that allows for the pressure to be changed if required (e.g., the low pressure set point is greater than 80 psi). A simple hand pump such as that used to inflate a bicycle tire may be used to adjust the pressure.

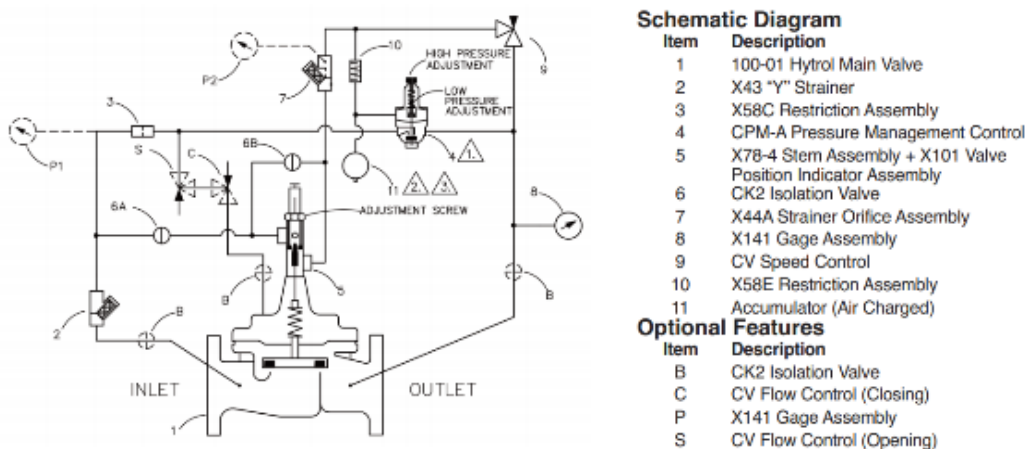


Figure E-3. Schematic of Cla-Val 98-06 APRV



Figure E-4. Cla-Val 98-06 APRV System

E.4 Configuration

The 98-06 can be configured similar to the parallel configuration shown in Figure E-5 with exception that only one 6-inch APRV would be needed in lieu of two conventional PRVs. Isolation valves (manually operated) and a bypass valve would be required for maintenance as illustrated below.

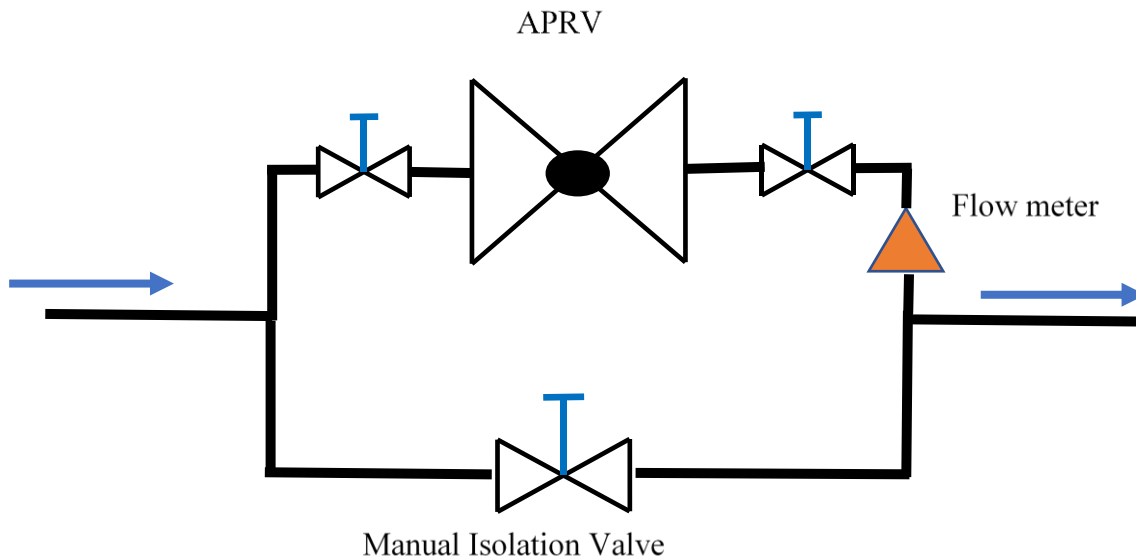


Figure E-5. Parallel Valve Configuration

E.5 Installation

The Cla-Val 98-06 has very similar requirements to installing as a standard PRV if a complete replacement is being performed. Installation requires isolating the valve to be replaced and can be accomplished with a crew of three technicians in less than 3 hours using the same equipment required for a conventional PRV install. Heavy material handling equipment such as a backhoe with rigging straps is required, as the valve weighs close to 300 lbs. A typical crew might consist of a heavy equipment operator, a pipe fitter, and a field technician.

The 6-inch standard PRV at Nictown is in fairly good condition, having only been installed within the last 5 years. As such, the conventional PRV can simply be kept in place and the headworks replaced. This could be easily accomplished with one technician and a Cla-Val field or phone representative. It is recommended that a representative from Cla-Val be available during installation and commissioning which can be performed on the same day.

E.6 Commissioning

Commissioning of the Cla-Val 98-06 APRV requires adjusting the low and high pressure set points, as well as the flow requirement for when to transition. This is accomplished with water flowing at normal conditions and should take less than 30 minutes to complete. The pressure management control (CPM-A) is tuned to set the desired low and high set points for the

downstream pressure. After adjusting the set points, the X78-4 Adjustable Orifice Assembly is tuned to set the flow at which the pressure will transition between the low and high set points. The CPM-A adjustment screw can be adjusted with a screwdriver and the X78-4 is tuned via set screws, which can be adjusted either by hand or with an open-end wrench.

There is a speed control valve (CV) present which can quickly adjust the pressure in and out of the CPM-A sensing chamber. For regular operation, the CV speed control is adjusted to two turns open. Closing the CV will cause the APRV to regulate at only the high pressure set point and opening past five turns will operate at only the low pressure set point. Appendix C describes and shows the data acquired during installation and commissioning of the Cla-Val 98-06 at ERDC.

E.7 Water Hammer

Water program managers have concerns with the occurrence of water hammer within pipe distribution systems as it risks major pipe ruptures requiring shutdown of water supply for extended time periods. Accordingly, NBVC's water program manager questioned the application of the APRV and its potential for water hammer during transitioning from one pressure set point to the other. Based on his concern, the team configured the test bed at the Army ERDC in Vicksburg, Mississippi to evaluate the possibility. As it turned out, there is a risk of water hammer as it was discovered on the ERDC pipeline test bed at the commissioning of another APRV (Singer) that was evaluated during this study. The team conducted some follow-up research and found Cla-Val developed a comparable technology (Cla-Val 98-06) along with a means to control the water hammer with the addition of an accumulator.

A follow-on field study with the Cla Val 98-06 demonstrated that the water hammer issue during commission could be resolved with the accumulator design integrated with the pilot valves. No pressure transients were observed throughout the test bed study on the ERDC single feed system. However, it should be noted that good design practice would include the installation of a nearby pressure relief valve to protect against water hammer due to other unforeseen problems (i.e., pump and power failures, closing the valve too fast, or line breaks).

E.8 Operations and Maintenance

The APRV was designed to operate just like a standard PRV except it will modulate with flow demand. Cla-Val recommends recording pressure and flow data as a means to evaluating daily or periodic pressure and flow trends in order to make additional adjustments to the APRV as required to achieve desired performance. Automatic data logging sensors and products are available if desired.

Regular maintenance and inspection of the APRV system is expected to be 4 hours per year for one technician (approximately \$400/year). Routine checks of line pressures, along with cleaning strainers and verifying pressure in the accumulator should be accomplished at least twice a year. Spare parts for system maintenance or repair include a \$50 strainer and \$250 XP 75 diaphragm kit. Every 7 years, the XP 75 diaphragm and strainer must be replaced with an estimated labor requirement of 3 hours for two technicians (total cost of approximately \$900 every 7 years for materials and labor).

E.9 Fire Flow

If a conventional PRV already exists in a water distribution system, then it is highly likely that the supply and inflow pressure are more than adequate to warrant regulated pressure reduction and still meet downstream demand (fire flow) requirements. The existing PRV bank installation at SNI is designed to use the 4-inch PRV for normal operations, while the 6-inch PRV only operates with high flow demand (fire flow). It should be noted that these two valves are Cla-Val globe valves which are also used in the proposed APRV except with different controller configurations for modulating flow in response to system demand. The APRV pressure set points can be adjusted similar to the conventional PRVs to meet site-specific pressure requirements. The APRV should not affect any downstream sprinkler system performance as long as the set points on the APRV are adjusted to meet the sprinkler flow requirements. Once the APRV senses a requirement to increase pressure on the downstream side of the system, the valve would adjust automatically to meet the required demand.

The ability of the Cla-Val 98-06 to meet fire flow requirements greater than 750 gpm was demonstrated at the test bed at ERDC. The worst-case scenario for the APRV would be a failure to transition to a higher pressure set point when higher flows are required for firefighting. Accordingly, the low-pressure point should not be set too low to ensure adequate flow during periods of low demand. This can be field tested on site.

It can be argued that without proper testing/exercising of the 6-inch PRV, there is a chance that it may not operate when needed because of lack of use. With the dual use of the 6-inch APRV, its diaphragm and associated mechanical components could be exercised daily to increase the likelihood it will operate under a high flow need.

E.10 Training

Training on installation, operation and maintenance is available from Cla-Val at its Costa Mesa, California site.

E.11 Troubleshooting

The technical manual provided by Cla-Val offers a detailed description for troubleshooting, focusing primarily on the Model 100-01 Hytrol Valve assembly. All troubleshooting can be performed on the valve without removing the valve or its cover. The following troubleshooting table is from the technical manual (see Table E-1).

The only moving part in the 100-01 Hytrol Valve is the diaphragm and disc assembly. As a result, only three major issues are likely to occur with improper maintenance. After checking the probable causes and remedies from Table E-1, the following three checks should be performed in the order shown to diagnose the nature of the issue prior to performing maintenance.

- 1) Diaphragm Check
- 2) Freedom of Movement Check
- 3) Tight Sealing Check

The APRV cannot be serviced under pressure. To resolve this, a bypass and isolation valve should be installed to allow for redirecting flow and pressure away from the APRV for troubleshooting and service.

Table E-1. Troubleshooting Chart for 100-01 Hytrol Valve
(Source: Cla-Val 98-06 Technical Manual)

Symptom	Probable Cause	Remedy
Fails to close	Closed isolation valves in control system, or in main line	Open isolation valves
	Lack of cover chamber pressure	Check upstream pressure, pilot system, strainer, tubing, valves, or needle valves for obstruction
	Diaphragm damaged (see diaphragm check)	Replace diaphragm
	Diaphragm assembly inoperative. Corrosion or excessive buildup on valve stem (see freedom of movement check)	Clean and polish stem. Inspect and replace any damaged or badly eroded part
	Mechanical obstruction. Object lodged in valve (see freedom of movement check)	Remove obstruction
	Worn disc (See tight sealing check)	Replace disc
	Badly scored seat (see tight sealing check)	Replace seat
Fails to open	Closed upstream and/or downstream isolation valves in main line	Open isolation valves
	Insufficient line pressure	Check upstream pressure (minimum 5 psi flowing line pressure differential)
	Diaphragm assembly inoperative. Corrosion or excessive buildup on valve stem (see freedom of movement check)	Clean and polish stem. Inspect and replace any damaged or badly eroded part
	Diaphragm damaged (for valves in “reverse flow” only)	Replace diaphragm

E.12 Cla-Val Technical Support

The Cla-Val company has technical support staff available during normal working hours for questions related to installation, commissioning, operation and maintenance of its valves. Cla-Val representatives supported the ESTCP team when problems were encountered during the 98-06 APRV commissioning and for troubleshooting. However, the 98-06 is a system that is primarily used overseas and many of the technical representatives contacted were not familiar with 98-06 to provide guidance. Although conceptually the operational benefits of the Cla-Val 98-06 APRV are easy to understand, it is not straight forward mechanically as it has two components that are unique to this system only. Only two individuals at Cla-Val were knowledgeable enough to provide guidance during the installation and test bed trials but they were not always available for technical consultation as needed. This limited availability of technical support may be a problem if issues arise in the field. Since the valve is intended for single feed systems only, the growth of the market for the Cla-Val 98-06 APRV remains limited primarily to out-of-country users who have predominantly single feed systems. The multi-feed system design approach primarily used in the US will limit future application of the APRV technology. Although SNI represents a single feed system, its remote location could create challenges for implementation with limited accessibility to long-term technical support.

E.13 Potential Operational Concerns

Follow-up conversations with Cla-Val representatives have brought out additional concerns with the 98-06 pressure management valve for DoD-wide usage. Cla-Val recanted and no longer supports using the valves in a lead/lag configuration on multi-feed water distributions system claiming that two 98-06 APRVs in the same loop will create a pressure conflict that has no resolve without complete isolation of one of the valves. Their stance is that pressure management on multi-feed distribution systems can only be safely accomplished with the use of electrically powered solenoid/pilot valves. They have recently installed a limited number of this electrically powered system at operational sites in Southern California and have discussed how they can be used for water conservation at SNI. See Section 4 for analysis of the Cla-Val 131 electronically-actuated valve as conducted under this ESTCP demonstration project.

E.14 Cost Analysis for Cla-Val 98-06 APRV

The proposed Cla-Val 98-06 when operating near 45 psi is expected to provide a 15% reduction in water loss from leaks based on the test-bed results as well as an estimated 1% water savings per capita in general use as a result of the lower pressures during off-hours. With the approximate 2.25 miles of piping, leaks are expected to lose 590,000 gallons of water a year, which is valued at an annual loss of \$148,000. Implementation of the APRV should reduce the amount lost by 15%, saving SNI more than \$22,000 per year. The expected water usage of Nictown is 4,730,000 gallons per year with an estimated savings of 47,300 gallons per year for simply operating at lower pressures during off peak hours. This is valued at an \$11,800 of annual savings. An additional \$600 of savings is also anticipated from the reduced pipe repair necessary as a result of using lower pressures during off-hours.

The Cla-Val 98-06 valve costs approximately \$6,575. Also required is a \$50 flange kit which allows for a simple swap out with the existing PRVs as the face-to-face flange fitting will be identical to the current system. The total expected capital cost is approximately \$8,580 for the device, estimated shipping (factor of 3 times NBVC Point Mugu quote), and installation costs at

NBVC SNI (see Appendix D). Once installed, the annual operation and maintenance (O&M) cost of the valve is estimated to be \$1,150.

Over the 20-year expected service life, the Cla-Val 98-06 APRV will cost approximately \$27,500 and produce a net savings of \$580,000. The ROI for implementation of this system at SNI is therefore 21.0 (2100%) with a payback period of about 4 months.

E.15 Cost Analysis Tables

The cost elements and assumptions for use of this technology at SNI are summarized in Table E-2 through Table E-4.

Table E-2. Economic Factors for SNI Used in Economic Analysis

Factor	Value	Notes
Cost of Water	\$250.00	Cost per 1,000 gallons
Water Savings	15%	Percent reduction in water loss (Based on Testbed)
Labor Cost	\$100.00	SNI 2016 Rate
Service Life of Valve	20	years
Diaphragm Replacement Frequency	7	years
Leaks per Mile per Year	0.25	
Leak Rate (unknown year round)	2	gpm per leak
Water Usage per Capita	75	gallon per day
Water Saved per Capita with Pressure Management (estimated)	1%	
Operation at Low Pressure	75%	Portion of Day
Cost of Pipe Repair (\$5 -10K)	\$7,500.00	Estimated
Miles of Pipe	2.25	Miles
Shipping Factor	3	Estimated increase for SNI

Table E-3. Capital Cost for Cla-Val 98-06

Material	Unit Cost	Quantity	Subtotal
PRV	6575	1	\$6,575.00
Flange Kit	50	1	\$50.00
Shipping	555	1	\$555.00
Installation	# of Technician	Hours	Subtotal
Remove Old PRV	3	1	\$300.00
Install New APRV	3	2	\$600.00
Equipment	Rental Cost/Day	Days	Subtotal
Backhoe	\$500.00	1	\$500.00
GRAND TOTAL			\$8,580.00

Table E-4. Operational Costs

Monitor (Once per Quarter)	# of Technicians	# of Hours/Year	Subtotal
Check pressures	1	4	\$400
Maintain (Annual)	# of Technicians	# of Hours/Year	Subtotal
Labor	1	4	\$400
Maintain (7-year diaphragm replace)	# of Technicians	# of Hours/Year	Subtotal
Labor	2	3	\$600
Material	Unit Cost	Quantity	Subtotal
Strainer	\$50	1	\$50
Diaphragm Kit	\$250	1	\$250
TOTAL ANNUAL COST			\$928.57

E.16 Conclusions and Recommendations

The proposed APRV installation for Nictown at NBVC SNI is economically feasible. The relatively low cost and large projected savings of the technology result in a large ROI of 21.0 and short payback period of 4 months. This technology has the potential of reducing maintenance requirements and put less strain on the water system when compared to the current PRVs being used at SNI. From an economic standpoint this project should be a low-risk and worthwhile investment.

However, the remoteness of SNI warrants the use of simple technologies that are well understood by the public works staff on island. The uniqueness of the 98-06 APRV and the limited availability of personnel with expertise even within Cla-Val company, could present logistical challenges that cannot be overlooked.

Therefore, the team does not recommend the installation of the hydraulically-actuated APRV at this time, but the electronically-actuated system with hydraulic backup discussed in Section 4 of this report should be considered, particularly for installations that are not as remote and where personnel with more familiarity with advanced systems would be available to troubleshoot and maintain APRVs.