Appendix D4. Bethany Reservoir Aqueduct Surge Protection (Final Draft)

1. Introduction and Purpose

The purpose of this technical memorandum (TM) is to conduct an evaluation of candidate surge mitigation facilities for the Delta Conveyance Project's (Project) pressurized aqueduct system between the Bethany Reservoir Pumping Plant (BRPP) and the Bethany Reservoir for the Project. The candidate surge mitigation facilities considered in this evaluation were sized for the maximum transient-surge conditions associated with the pressurized aqueduct systems at the maximum Project design flow capacity of 6,000 cfs for the configurations of the BRPP facilities and Bethany Reservoir Aqueduct (Aqueduct) pipelines as described in the Concept Engineering Report (CER) Appendix D3 *Bethany Reservoir Pumping Plant Facilities and Site Configuration* and as shown in the engineering concept drawings.

Results of this evaluation were used to:

- Develop the maximum and minimum hydraulic gradeline (HGL) envelop for each Aqueduct pipeline between the BRPP and the Bethany Reservoir outlet structure for each surge mitigation facility considered and compare the HGL results against the conceptual design parameters of the BRPP yard piping and connecting Aqueduct pipelines.
- Perform a screening analysis of each surge mitigation alternative considered with the DCO and recommend the type and configuration of the surge mitigation strategy and corresponding facilities
- Results of this analysis will be used to develop the selected surge mitigation facilities layout configuration and footprint for incorporation into the Bethany Reservoir Alignment's conceptual engineering drawings.

1.1 Organization

This TM is organized as follows:

- Introduction and Purpose
- Surge Analyses
- Conclusions
- References

2. Surge Analyses

2.1 Analyses Description

In accordance with the methodology and criteria established for the Project as described in Appendix A2 *Hydraulic Analysis of Delta Conveyance Options*, hydraulic transient-surge analyses were performed for the BRPP's welded steel discharge pipelines (Bethany Reservoir Aqueduct) located between the Bethany Reservoir Pumping Plant (BRPP) and the Bethany Reservoir Discharge Structure. The analyses were conducted to establish the maximum and minimum HGLs along each Aqueduct pipeline and to evaluate potential candidate surge mitigation facilities that would maintain transient-surge pressures to within the conceptual internal pressure design limits of the Aqueduct pipelines. The wave speed for each Aqueduct pipeline used in each transient-surge analysis was 3,000 feet per second (fps). The maximum allowable pressure limit associated with surge conditions in this analysis was limited to 263 psi which is based on a maximum allowable stress within the pipeline of 31,500 psi (75 percent of the assumed yield stress of steel of 42,000 psi) and an assumed pipeline steel wall thickness of 0.75 inches. The minimum allowable pressure was limited to -7.0 psi (50 percent of full vacuum pressure). In this analysis, internal pipeline pressure limits during the transient-surge conditions must be maintained within the maximum and minimum allowable pressure limits at all locations along the pipelines.

Transient-surge events in the BRPP’s discharge pipelines were simulated for analysis of each candidate surge mitigation facility by simultaneously stopping all BRPP’s main pumps and closing their connecting pump control valves, located at the discharge of each pump, within 15 seconds (from fully open to fully closed). The 15 second simulated closure rate for the pump control valves prevented reverse flow through the pumps for all transient-surge events evaluated. The steady-state water surface elevation within the Bethany Reservoir prior to the transient-surge condition was 245 feet for each analysis conducted. Each transient-surge event simulated a maximum flow of 1,500 cubic feet per second (cfs) in each pipeline. Four 15-foot-diameter pipelines would convey up to 6,000 cfs (1,500 cfs per pipeline) to the Bethany Reservoir.

2.1.1 Tools

Bentley’s HAMMER software was used to perform the transient-surge analysis. In addition to the steady-state pipe and hydraulic parameters, the HAMMER program uses the method of characteristics described by Wylie and Streeter (1993) to solve the pressure transients in the system. This method consists of deriving basic equations from physical principles (the continuity equation and conservation of energy and momentum). The equations are then solved along characteristic lines whose slope is dependent upon the acoustic wave speed.

2.2 Candidate Surge Mitigation Facilities Considered

The candidate surge mitigation facilities alternatives evaluated in this analysis were:

- Surge Mitigation Alternative 1 - No surge mitigation facilities incorporated into the Aqueduct systems
- Surge Mitigation Alternative 2 - Fast opening surge blow-off valves discharging to the Surge Basin and connected to each 108-inch buried pump discharge headers including combination air release and vacuum valves located along the alignment of each Aqueduct pipeline
- Surge Mitigation Alternative 3 – Hydro-pneumatic surge tanks connected to each buried pump discharge header. No air vacuum valves along the Aqueduct pipelines were include in this surge mitigation alternative
- Surge Mitigation Alternative 4 - One-way surge tanks connected to each 108-inch buried pump discharge header including air release and vacuum valves located along each Aqueduct pipeline alignment.

2.2.1 Surge Mitigation Alternative 1 – No Surge Mitigation Facilities

An initial hydraulic transient-surge analysis was performed for the Aqueduct pipelines with no surge protection facilities or vacuum relief valves included along the alignment of the Aqueduct pipelines. This analysis was conducted to establish the maximum and minimum HGL envelop along the Bethany Reservoir Aqueduct pipelines and determine if surge protection would be required to maintain pipeline internal pressures within their conceptual design limits.

Results for the transient analysis with no surge protection for the Aqueduct to the Bethany Reservoir are presented on Figures 1 and 2. Since each aqueduct pipeline would operate in parallel with one another and diameters would be identical and sized for a maximum flow capacity of 1,500 cfs, Figures 1 and 2 results are applicable for all four pipelines to the Bethany Reservoir for the maximum combined capacity of 6,000 cfs.

Figure 1 shows the envelop of the maximum and minimum HGLs developed during the transient-surge event plotted across the Aqueduct alignment between the BRPP and the Bethany Reservoir Discharge Structure. Figure 1 also includes the initial HGL at the steady-state conditions at the maximum capacity of 1,500 cfs per pipeline. The maximum and minimum HGLs are plotted with red and blue lines, respectively, and the initial steady-state HGL profile (prior to the transient-surge condition) is plotted with a black line. For reference, the pipeline profile is plotted with a green line.

Figure 2 shows the envelop of the maximum and minimum pressures during the transient-surge event plotted across the Aqueduct profile between the BRPP pump discharge and the Bethany Reservoir Discharge Structure. Figure 2 also includes the initial steady-state pressure profile at the maximum capacity of 1,500 cfs per pipeline. The maximum and minimum pressures are plotted with red and blue lines, respectively, and the initial steady state pressure profile (prior to the transient-surge condition) is plotted with a green line. For reference, vapor pressure (full vacuum inside the pipeline) is plotted with a dashed yellow line.

As shown in Figures 1 and 2, the results of the transient-surge analysis indicate HGLs above 700 feet (about 325 psi at the maximum HGL) would occur downstream of the BRPP within the first 5,000 linear feet of the Aqueduct. The upper HGL envelop within this section of the Aqueduct pipelines exceeds the pipeline's established maximum internal pressure design limit of 263 psi. The upper HGL envelop within the Aqueduct for the pipeline sections beyond the first 5,000 linear feet and up to the Bethany Reservoir Discharge Structure would generally range between 575 to 640 feet. The maximum pressures within this section of the Aqueduct pipelines (beyond the first 5,000 linear feet) would be below 250 psi, as shown in Figure 2, and would be below the internal pressure design limit of the pipeline. Figures 1 and 2 further indicate that a full vacuum (along the entire pipeline profile) would be developed under the minimum surge HGL conditions, which would result in column separation along the entire length of each pipeline.

Based on the results of this analysis, mitigation facilities would be required for the Aqueduct pipelines to maintain their internal pressures to within the conceptual design limits during transient-surge events. Therefore, Surge Mitigation Alternatives 2, 3, and 4 were developed as described in the following sections.

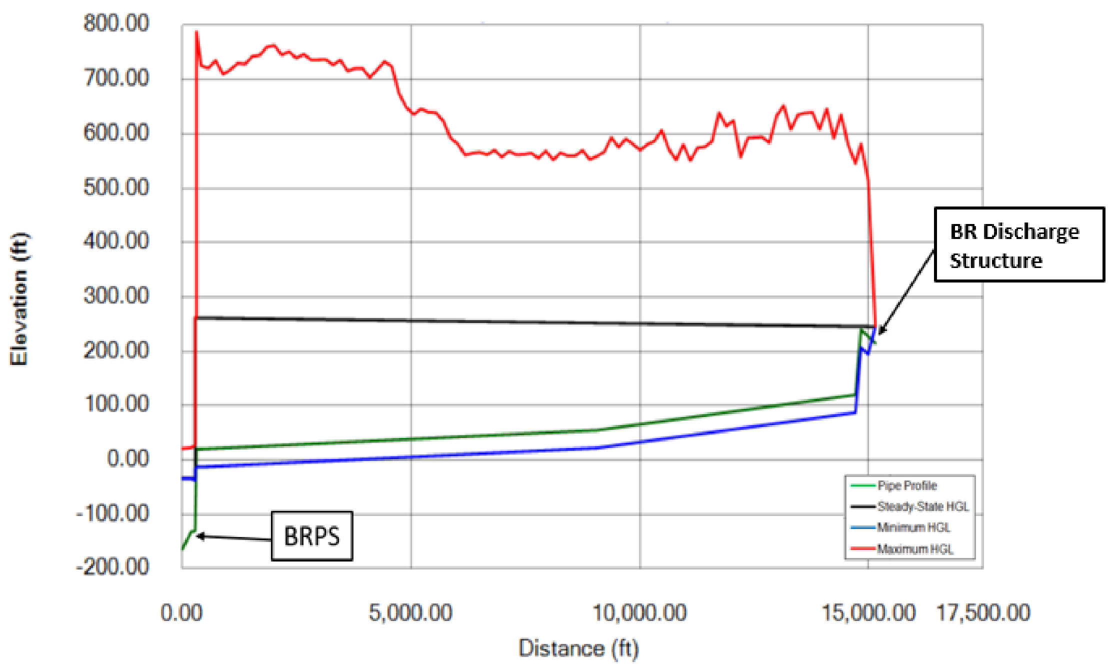

Figure 1. Surge Mitigation Alternative 1 - No Surge Mitigation Facilities for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Hydraulic Gradeline Profiles

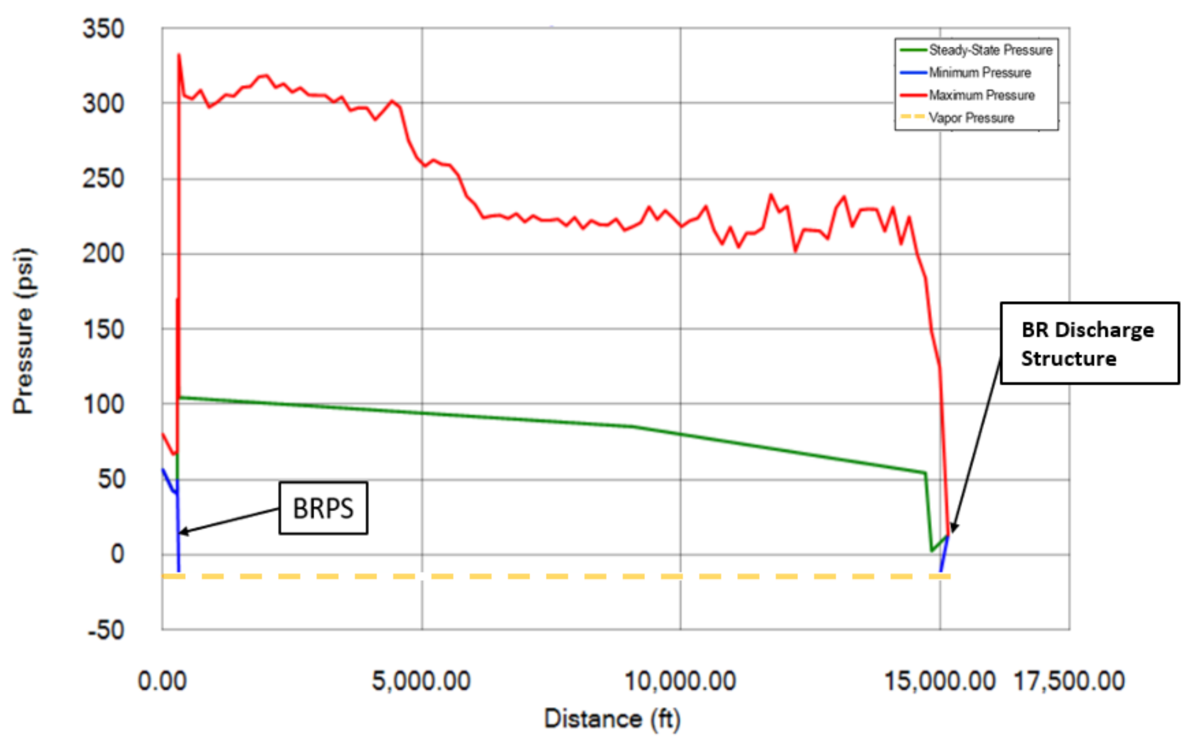

Figure 2. Surge Mitigation Alternative 1 – No Surge Mitigation Facilities for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Pressure Profiles

2.2.2 Surge Mitigation Alternative 2 – Surge Blow-off Valves

For this surge mitigation alternative, cone valves acting as surge blow-off valves and combination air release and vacuum release valves along each Aqueduct pipeline's alignment were simulated in the transient-surge analysis for the Aqueduct pipelines. In this analysis, 30-inch cone valves were simulated since the flow characteristics for this valve were already contained in the surge analysis application software data base. Larger diameter cone valves could be used resulting in few valves being required in the installation and would provide nearly identical results since the large valves would be sized to provide the identical range of flow capacities as the combination of smaller valves in this analysis. In this evaluation, each pump discharge header (located within the BRPP's yard piping) would be connected to fourteen, 30-inch cone valves arranged in parallel (a total of 56 cone valves for all four Aqueduct pipelines). The cone valves would be installed in separate above or below ground structures adjacent to the Surge Basin structure. Buried pipelines would connect the cone valves to the BRPP discharge headers and would convey water discharged by each cone valve directly into the Surge Basin structure.

Each cone valve would be equipped with a hydraulic fluid cylinder actuator and would be connected to centralized hydraulic power units. The centralized hydraulic power units would be located either within the below ground pumping plant structure or within the cone valve structures. The centralized hydraulic power units would be sized to provide stored pressurized hydraulic fluid to open and close all blow-off valves without the use of electrical power. Hydraulic fluid supply and return piping would connect the cone valves cylinder operators to the centralized hydraulic power units.

Under normal system steady-state operating conditions, all cone valves would be in the fully closed position. When a hydraulic transient-surge event occurs within any connected aqueduct pipeline and the internal pressure threshold of 20 psi is met in any pumping plant discharge header, the blow-off cone valves would be simultaneously opened from their fully closed positions to their fully open positions within 30 seconds. Water would flow from the aqueduct pipelines and enter the Surge Basin structure. The valves would be maintained wide open for up to 30 seconds and then slowly closed at a linear rate over 7 minutes.

Since each Aqueduct pipeline would operate in parallel with one another and diameters would be identical and sized for a maximum flow capacity of 1,500 cfs, Figures 3 and 4 results are applicable for all four pipelines to the Bethany Reservoir for the maximum combined capacity of 6,000 cfs.

Figures 3 and 4 show the envelop of the maximum and minimum HGLs and pressures plotted across the Aqueduct profile between the BRPP pump discharge and the Bethany Reservoir Discharge Structure during the transient-surge event. Figures 3 and 4 also show the initial steady-state HGL and steady-state pressure conditions at the maximum capacity of 1,500 cfs per aqueduct.

As shown in Figures 3 and 4, the results of the transient-surge analysis indicate the maximum pressure of 147 psi would occur at the BRPP's pump discharge control valves (at the outlet side of the valve after closure) and the minimum pressure of -6.9 psi would occur within the Aqueduct pipelines about 420 linear feet downstream of the pump discharge control valves. No column separation would occur in any section of the Aqueduct pipelines. The upper and lower HGL envelop along the entire alignment of the Aqueduct would be maintained within the pipelines' established maximum and minimum internal pressure limits of the conceptual design. Therefore, at face value, this surge mitigation alternative would meet the basic surge control criteria.

The calculated total volume of water discharged into the Surge Basin structure from all four Aqueduct pipelines during the transient-surge event would be 7,444,920 cubic feet (55,688,000 gallons) which would require the Surge Basin structure to accommodate both the tunnel overflow volume and the surge blow-off volume from the Aqueduct pipelines. Accommodation of both volumes would be required because both the tunnel and Aqueduct surge events would simultaneously occur during any transient-surge event involving the rapid shutdown of the BRPP. The surge basin has been sized to tunnel surge overflow volumes of 4.8 million cubic feet associated with the tunnels sized for the Project design capacity of 6,000 cfs, as shown in the engineering concept drawings. As such with this surge mitigation alternative, the surge basin storage capacity requirement would more than double resulting in a substantially larger and more costly structure.

A screening analysis of this surge mitigation alternative was conducted with the DCO. On the basis of the review of this surge mitigation alternative it was determined that Surge Mitigation Alternative 2 would be overly complicated and would have potentially low reliability. This conclusion was developed since the proposed system would rely upon numerous fast acting surge blow-off valves, connecting hydraulic power systems, and pipeline monitoring instrumentation. The panel suggested that a more passive surge protection system could function effectively and deliver a more reliable solution.

Also considered as part of the screening analysis was the additional cost and impacts associated with facilities that would include the large number of valves with appurtenant equipment and the larger footprint of the required Surge Basin.

This surge mitigation alternative was compared to more passive systems (Surge Mitigation Alternatives 3 and 4) and eliminated from further consideration because those alternatives would also provide effective surge control using a more reliable combination of features.

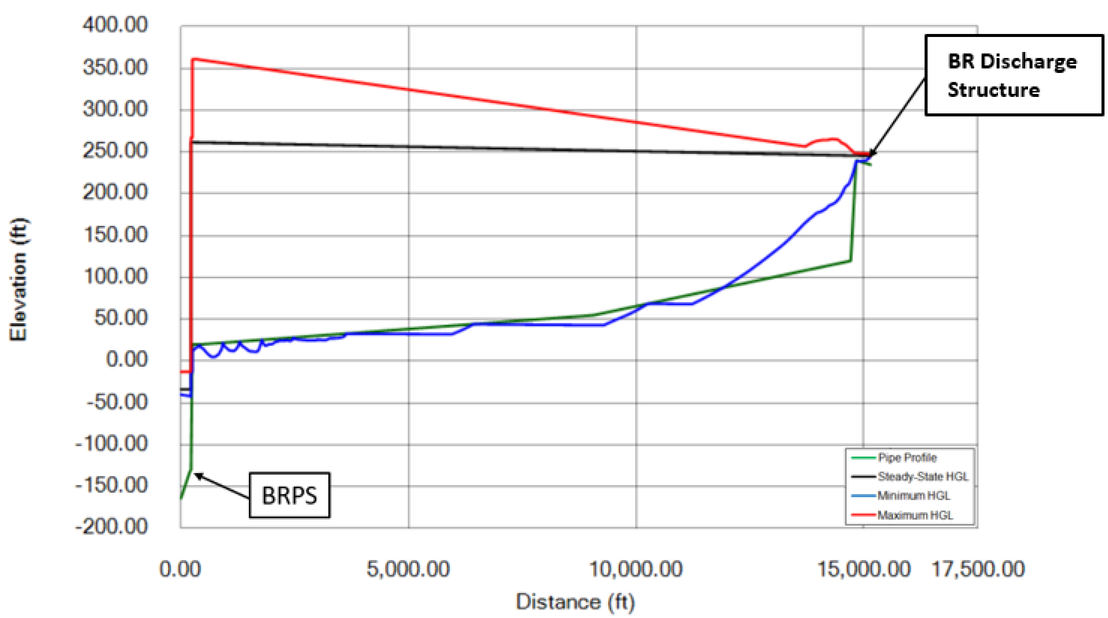

Figure 3. Surge Mitigation Alternative 2 – Surge Blow Off Valves for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Hydraulic Gradeline Profiles

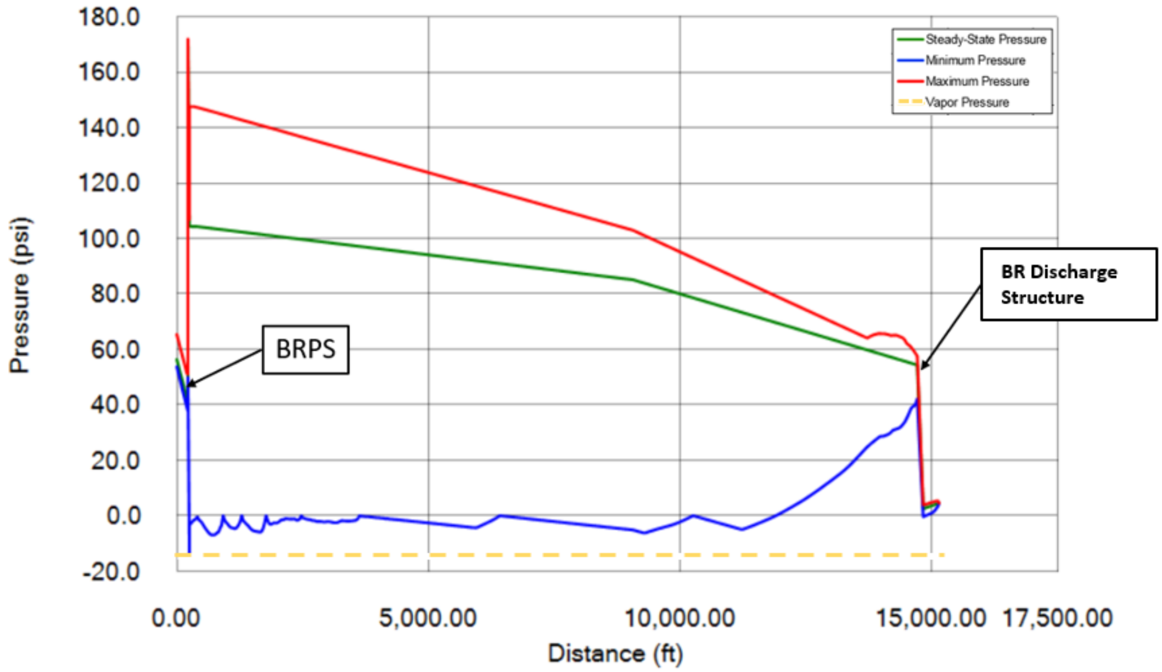

Figure 4. Surge Mitigation Alternative 2 – Surge Blow Off Valves for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Pressure Profiles

2.2.3 Surge Mitigation Alternative 3 – Hydro-pneumatic Surge Tanks

In this surge mitigation alternative, pressurized hydro-pneumatic surge tanks were simulated in the transient-surge analysis for the Aqueduct pipelines routed to the Bethany Reservoir. Each pump discharge header (located within the BRPP's yard piping) would be directly connected to nine, hydro-pneumatic surge tanks arranged in parallel (a total of 36 surge tanks for all four Aqueduct pipelines). The surge tanks would be located within the BRPP's yard piping area adjacent to each pump discharge header. Each cylindrical surge tank would be identically sized to a 15-foot inside diameter with an overall length of 50-feet. Air compressor systems would be located within the pumping plant's below ground structure and would be connected to each surge tank with buried compressed air piping. At steady-state conditions the initial pressurized air volume contained in each tank of 3,420 cubic feet would be maintained. Combination air release and vacuum release valves along each Aqueduct pipeline's alignment were not included with this surge mitigation alternative.

When a hydraulic transient-surge event occurred within any connected aqueduct pipeline and the internal pressure within the pipeline (at the tank location) falls below the internal pressure of the surge tank, the compressed air would expand within the tank would force water from the tank into the pipeline. When the internal pressure within the pipeline (at the tank location) rises above the internal pressure of the surge tank, water from the pipeline would enter the tank and the air within the tank would compress. This management of water into and out of the pipeline using the surge tank system would help dampen the magnitude of the pressure surges. The surge tanks in this evaluation were sized with sufficient pressurized water and air volumes such that the maximum and minimum internal pressures within each Aqueduct pipeline would be maintained within the pipeline's conceptual design limits and resulted in all minimum pressures above -7 psi along the entire alignment of Aqueduct pipelines during the transient-surge event.

Since each Aqueduct pipeline operates in parallel with one another and diameters are identical and sized for a maximum flow capacity of 1,500 cfs, Figures 5 and 6 results are applicable for all four Aqueduct pipelines to the Bethany Reservoir for the maximum combined flow capacity of 6,000 cfs.

Figures 5 and 6 show the envelop of the maximum and minimum HGLs and pressures plotted across the Aqueduct profile between the BRPP and the Bethany Reservoir Discharge Structure during the transient-surge event. Figures 5 and 6 also show the initial steady-state HGL and steady-state pressure conditions at the maximum capacity of 1,500 cfs per Aqueduct pipeline.

As shown in Figures 5 and 6, the results of the transient-surge analysis indicate the maximum pressure of 259 psi would occur at the BRPP's pump discharge control valves (at the outlet side of the valve after closure) and the minimum pressure of 22 psi occurs within the Aqueduct pipelines about 10,350 linear feet downstream of the pump discharge control valves. The upper and lower HGL envelop along the entire alignment of the Aqueduct would be maintained within the pipelines' established maximum and minimum internal pressure limits of the conceptual design.

A screening analysis of this surge mitigation alternative was conducted with the DCO. On the basis of their review of this surge mitigation alternative, the Surge Mitigation Alternative 3 would involve extensive operation and maintenance (O&M) activities for up to thirty six large steel pressure vessels, connected instrument devices, and extensive compressed air systems, including all required equipment and instrument redundancies. Additionally, the cost of the facilities required for this surge mitigation approach would be expected to be higher than Surge Mitigation Alternative 4 which is also a passive surge protection system, but far less complex to operate and maintain. Therefore, this surge mitigation alternative was eliminated from further consideration.

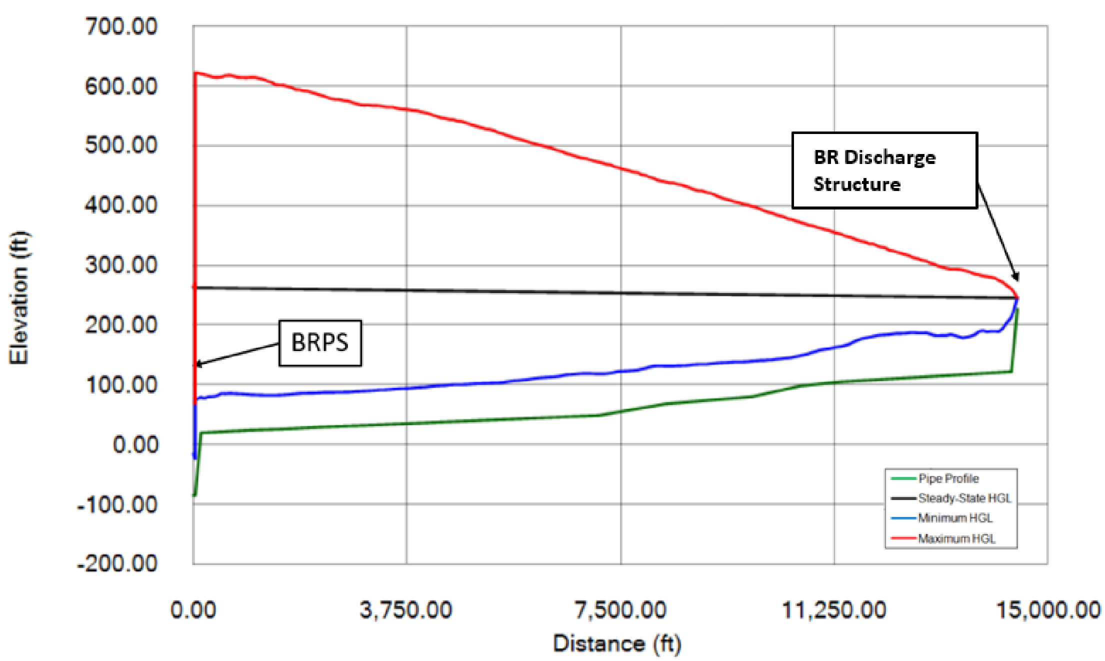

Figure 5. Surge Mitigation Alternative 3 – Hydro-pneumatic Surge Tanks for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Hydraulic Gradeline Profiles

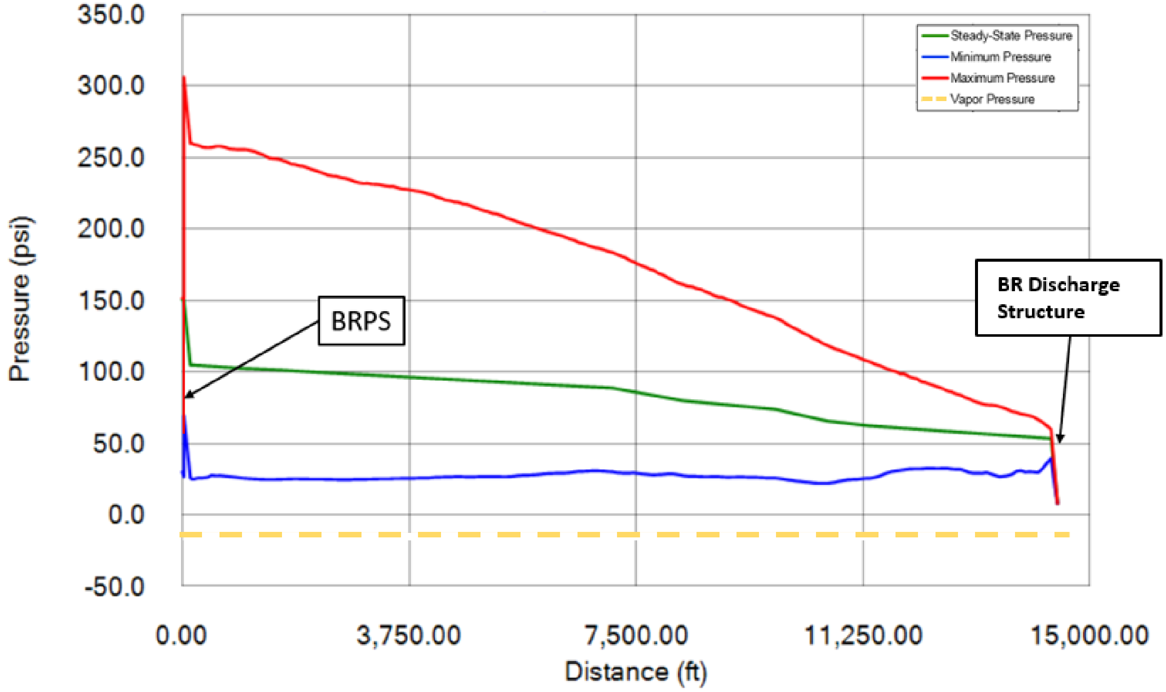

Figure 6. Surge Mitigation Alternative 3 – Hydro-pneumatic Surge Tanks for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Pressure Profiles

2.2.4 Surge Mitigation Alternative 4 – One-way Surge Tanks

For this surge mitigation alternative, each pump discharge header (located within the BRPP's yard piping) would be directly connected to a dedicated surge tank by a welded steel pipe, and a below ground vault containing up to four swing check valves arranged in parallel. Each tank would be sized to an inside diameter of 75 feet with a side wall height of up to 20 feet. Tanks would be open to the atmosphere and provide the required depth for required storage volume and freeboard including internal vertical clearance needed in the event of a tank overflow condition. When a hydraulic transient-surge event would occur within any given BRPP discharge Aqueduct pipeline and the internal pressure within that pipeline (at the tank location) would drop below the free-water surface elevation within the connecting tank, the surge tank's check valves would open and allow stored water from the tank to enter the pipeline. When the pressure within that pipeline (at the tank location) would rise above the free-water surface elevation within the connecting tank, the surge tank's check valves would close, and pressure would build within the pipeline. Combination air release and vacuum release valves along each Aqueduct pipeline's alignment were included with this surge mitigation alternative.

Each surge tank would be sized to provide sufficient stored water volume to maintain the internal pressure of each pipeline to within the Aqueduct pipelines' conceptual design limits. Whenever the water level in the tank would drop below the designated set-point level, a separate control valve would be included in each valve vault and would use the head from the connecting pipeline to automatically fill and maintain the free-water surface within any surge tank at the predetermined set-point level.

Since each Aqueduct pipeline would operate in parallel with one another and diameters would be identical and sized for a maximum flow capacity of 1,500 cfs, Figures 7 and 8 results are applicable for all four pipelines to the Bethany Reservoir for the maximum combined capacity of 6,000 cfs.

Figures 7 and 8 show the envelop of the maximum and minimum HGLs and pressures plotted across the Aqueduct profile between the BRPP pump discharge and the Bethany Reservoir Discharge Structure during the transient-surge event. Figures 7 and 8 also show the initial steady-state HGL and steady-state pressure conditions at the maximum capacity of 1,500 cfs per aqueduct.

As shown in Figures 7 and 8, the results of the transient-surge analysis indicate the maximum pressure of 217 psi would occur at the BRPP's pump discharge control valves (at the outlet side of the valve after closure) and the minimum pressure of -4.5 psi would occur within the aqueduct pipelines about 10,500 feet downstream of the pump discharge control valves. The upper and lower HGL envelop along the entire alignment of the Aqueduct would be maintained within the pipelines' established maximum and minimum internal pressure limits of the conceptual design. No column separation would be expected in any section of the aqueduct pipelines or within the connecting pumping plant yard piping system.

A screening analysis of this surge mitigation alternative was conducted with the DCO. On the basis of the review of this alternative, DCO indicated that the surge protection system described for Surge Mitigation Alternative 4 would meet Project requirements and would represent an effective passive system that would requiring less O&M and system redundancy for reliability. This alternative required the least facilities which would be reasonably sized and easily fit on the site. Therefore, this surge mitigation alternative was selected for inclusion in the conceptual engineering documents.

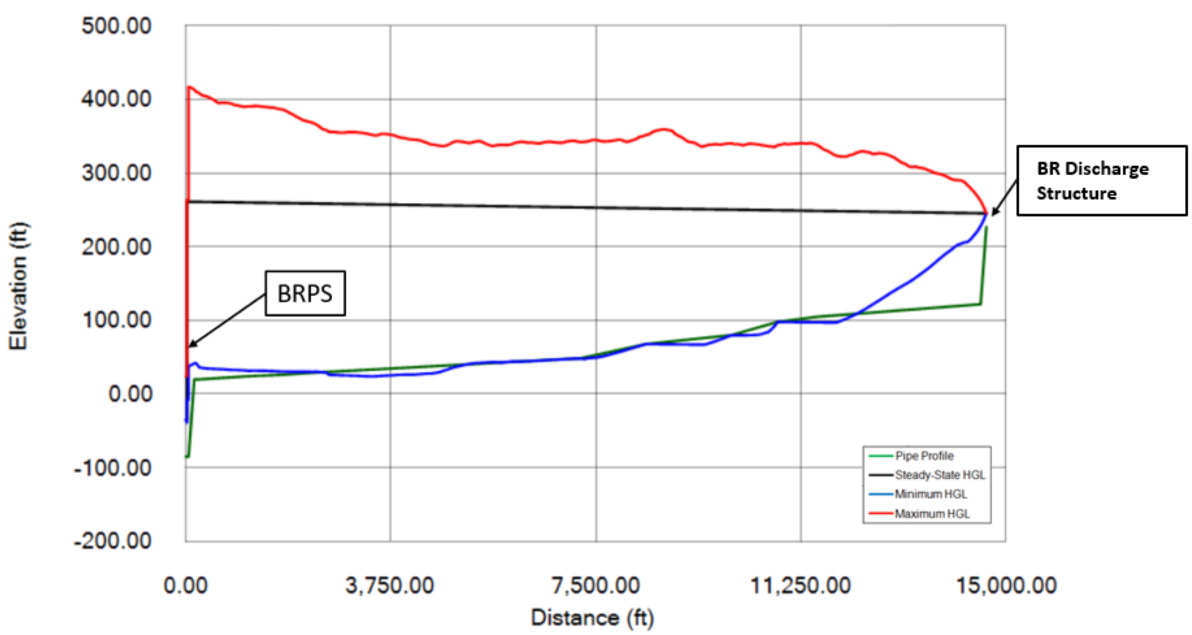

Figure 7. Surge Mitigation Alternative 4 – One-way Surge Tanks for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Hydraulic Gradeline Profiles

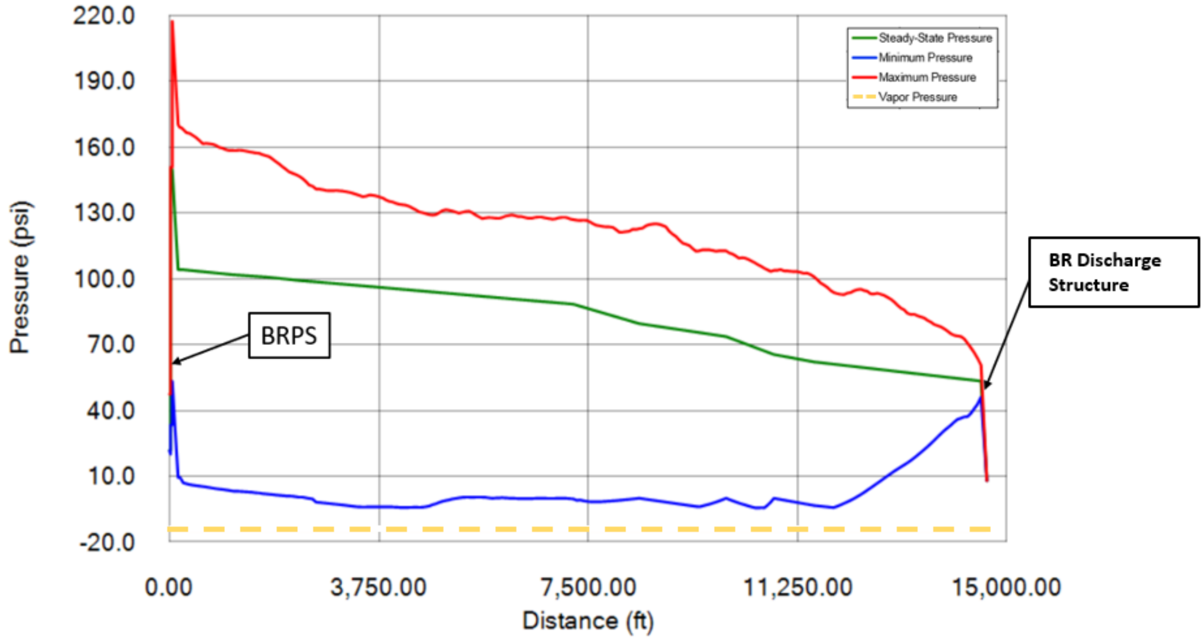

Figure 8. Surge Mitigation Alternative 4 – Hydro-pneumatic Surge Tanks for Bethany Reservoir Aqueduct Pipelines: Maximum and Minimum Pressure Profiles

3. Conclusions

This TM presents a comparison of the Bethany Reservoir Aqueduct pipeline surge mitigation facility alternatives and their associated hydraulic transient mitigation performance. The analysis of Surge Mitigation Alternative 1 indicated that mitigation facilities would be required for the Aqueduct pipelines to maintain their internal pressures to within the conceptual design limits during transient-surge events. The analyses of Surge Mitigation Alternatives 2, 3 and 4 indicated that internal pressures would be maintained in the Aqueduct pipelines to within the conceptual design limits during the simulated transient-surge conditions for the maximum combined flow capacity of 6,000 cfs. Surge Mitigation Alternative 4 with one-way surge tanks was selected for inclusion in the conceptual engineering documents because it included an effective passive system with reasonable O&M requirements and would provide reliable long-term operation over the service life of the Project.

4. References

Wylie, Benjamin E., and Victor L. Streeter. 1993. *Fluid Transients in Systems.* Englewood Cliffs, NJ: Prentice Hall.