Hydraulic Laboratory Technical Memorandum, PAP-1190

Palisades Dam Hollow-Jet Valve Replacement – Hydraulic Considerations for Jet-Flow Gates

Palisades Project, Idaho
Pacific Northwest Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services
Denver, Colorado

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Introduction and Background

Palisades Dam was constructed in the early 1950's on the South Fork of the Snake River in eastern Idaho near the Wyoming state boundary. It consists of an earthen dam (hydraulic height of 250 ft), powerplant, spillway, and outlet works [1]. The outlet works include a 26-ft diameter tunnel that feeds four 7.5-by-9-ft slide gates and two 96-inch hollow-jet valves (Figures 1 and 2). The hollow-jet valves are used to regulate normal outlet flows and discharges in excess of their capacity are routed through fully open slide gates [2]. The hollow-jet valves are reaching the end of their service life and need to be replaced.

As part of the market research to replace the two 96-inch hollow-jet valves, TSC's Hydraulic Investigation and Laboratory Services group (86-68560) was tasked with evaluating jet-flow gates as a viable replacement option from a hydraulic perspective (Figure 3). This Memorandum presents results from this preliminary evaluation which includes the size and discharge capacity of the jet-flow gates, potential hydraulic impacts to the existing stilling basin, and the possibility of adverse impacts from submerged operation. Conclusions and recommendations for jet-flow gates as an option at Palisades Dam are provided.

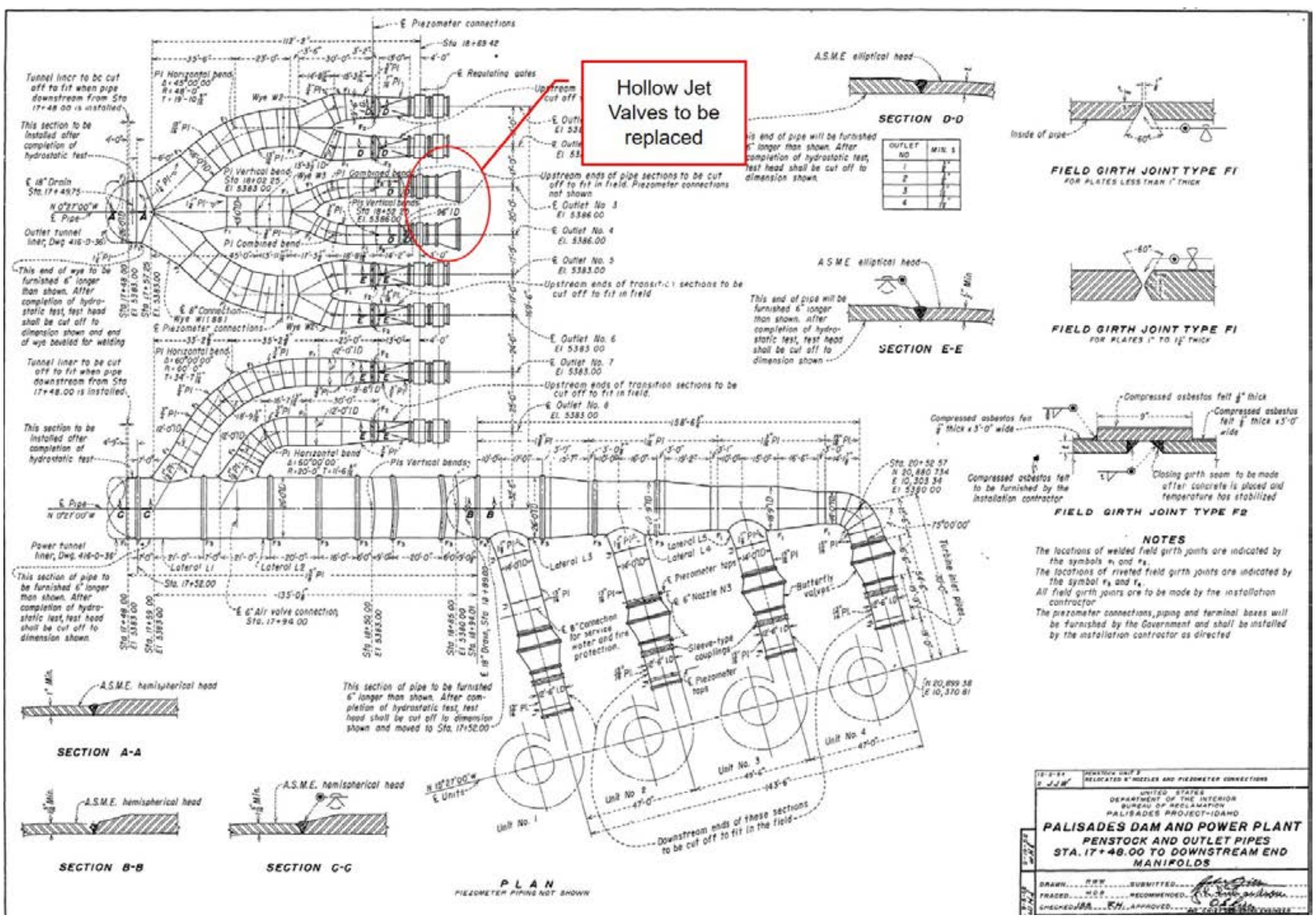


Figure 1 Drawing of penstocks and outlet pipes, identifying existing 96-inch hollow-jet valves to be replaced.

Figure 2 Aerial view of outlet works discharging into stilling basin (approximately 20,700 ft³/s total discharge), showing jets from hollow-jet valves to be replaced.

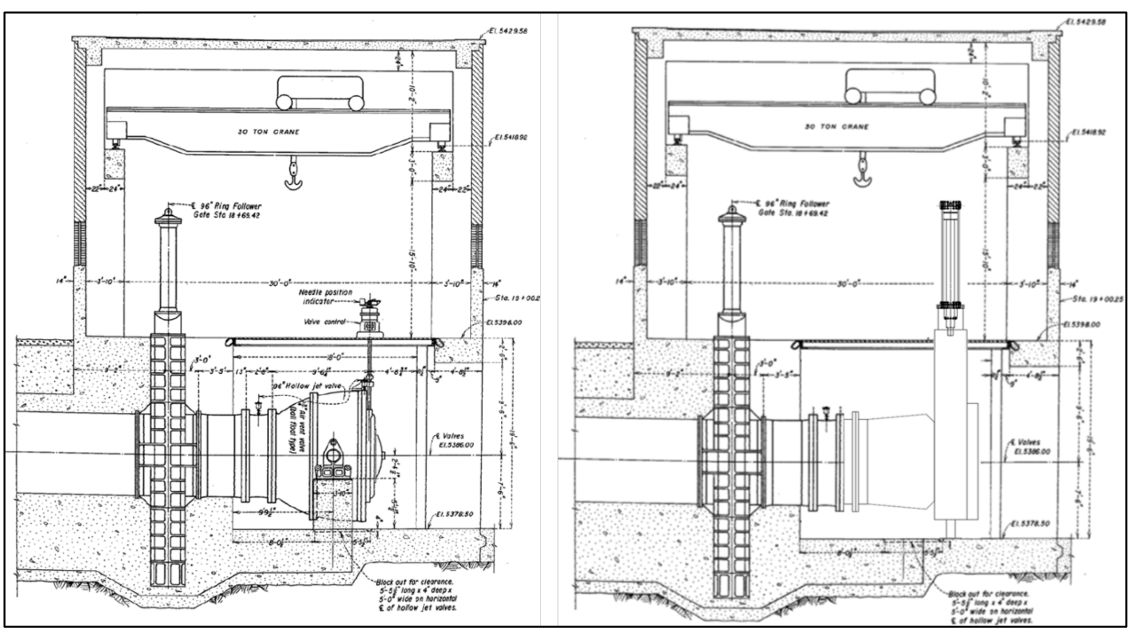


Figure 3 Drawing profile of existing 96-inch hollow-jet valve (left) and proposed jet-flow gate installation (right).

Discharge Capacity

A physical hydraulic model study of the outlet works and stilling basin was performed in Reclamation's Hydraulics Lab in 1956 at a model to prototype Froude scale of 1:61.82 [2]. The model was used to develop a discharge rating curve for the hollow-jet valves (1.55-in diameter, model scale) and determine energy losses associated with the 26-ft diameter outlet tunnel and bifurcations. For all outlet gates and valves fully open, model results showed that 22.6% of the total outlet flow was discharged through the hollow-jet valves and 77.4% through the slide gates. It is unknown if any field tests were performed to compare the rating curve of the prototype hollow-jet valves to results from the model study.

Results from the physical model study were used to compare the discharge capacity of a single 90-inch jet-flow gate to the existing 96-inch hollow-jet valve for total outlet flows of 23,000 and 33,000 ft^3/s (Table 1). The total head immediately upstream of the hollow-jet valves was approximated by back-calculation of the flow equation (Eq. 1), assuming 22.6% of the total outlet flow. For both flow conditions the jet-flow gate discharge compared very well to the hollow-jet (within 1%). This comparison suggests that 90-inch jet-flow gates will have sufficient discharge capacity to replace the hollow-jet valves.

$$Q = C_d A_o \sqrt{2gH} \qquad \text{(Eq. 1)}$$

Q = discharge (ft^3/s)
C_d = discharge coefficient (0.70 for full open hollow-jet [1] and 0.79 for full open jet-flow gate [3])
A_o = nominal area of valve or gate at full open (ft^2)
g = acceleration due to gravity (32.2 ft/s^2)
H = total dynamic head (ft)

Table 1 Comparison of Discharge Calculations for 96-inch Hollow-jet Valve and proposed 90-inch Jet-flow Gate.

	Outlet Works Flow Condition			**Notes**
	Flood Control Release	***Max Release***		HJV = Hollow-jet Valve (existing) JFG = Jet-flow Gate (proposed)
Q_{total}	23,000	33,000	*cfs*	Total outlet discharge [1]
H	84.7	174.4	*ft*	Total Head immediately upstream of HJV/JFG, estimated from flow equation assuming single HJV flow
D_{HJV}	96	96	*ft*	HJV diameter
D_{JFG}	90	90	*ft*	JFG diameter
Cd_{HJV}	0.70	0.70	-	HJV discharge coefficient, [1] and [4]
Cd_{JFG}	0.79	0.79	-	JFG discharge coefficient [3]
Q_{HJV}	2,599	3,729	*cfs*	Discharge for single HJV, 22.6% of total outlet flow, [1] and [2]
$\mathbf{Q_{JFG}}$	**2,578**	**3,699**	*cfs*	discharge for single JFG, flow equation with same *H*
Difference	**-21.0**	**-30.2**	*cfs*	discharge difference from HJV
	-0.8%	**-0.8%**	*%*	percentage difference from HJV discharge

Impacts to Outlet Works Stilling Basin

The Palisades outlet works stilling basin is similar to a Type III stilling basin [5] with modifications that were made during the 1956 physical model study [2]. The stilling basin includes a sloped upstream invert designed with a more shallow curvature than that of the estimated jet trajectory [1], chute blocks, baffle piers, end sill, and three dividing walls to allow for asymmetric flow from the slide gates and hollow-jet valves (see drawing 456-D-126 [2]).

Figure 4 shows a comparison of the estimated jet trajectory of the proposed jet-flow gate to the hollow-jet valve at a maximum outlet discharge of 33,000 ft^3/s (individual flow of 3,700 ft^3/s). Trajectories were estimated using Eq. 2 [6]. At this condition the jet from the jet-flow gate extended approximately ten feet further than the hollow-jet. Jet impact was still near the upstream end of the sloped invert and well upstream of the chute blocks, suggesting that the upstream flow depths (and resulting Froude number) approaching the chute blocks would not be significantly different from those of a hollow-jet valve and would not negatively affect the performance of the stilling basing. Hydraulics downstream of the stilling basin as the flow enters the river will also be unaffected.

$$y = -\frac{x^2}{4h_v} \qquad \text{(Eq. 2)}$$

y = elevation of bottom edge of the jet (ft)
x = horizontal distance of the bottom edge of the jet (ft)
h_v = velocity head at the exit of the valve or gate (ft, $V^2/2g$)

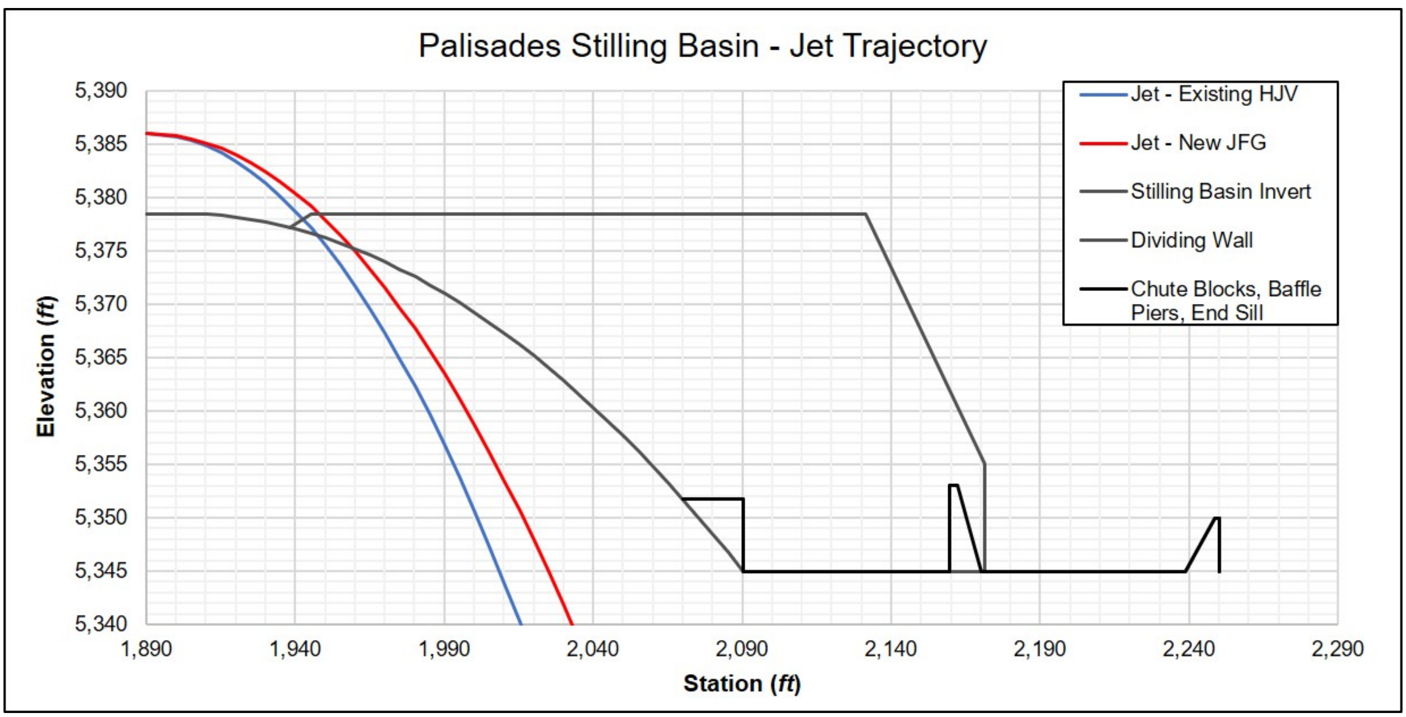


Figure 4 Comparison of jet trajectories of fully open 96-inch hollow-jet valve and 90-inch jet-flow gate in the Palisades stilling basin at a maximum outlet discharge of 33,000 ft^3/s.

Submerged Discharge

A review was made of the tailwater elevation in the stilling basin to determine if there is a need to consider submerged discharge operating conditions of the proposed jet-flow gates.

Tailwater Elevation

Assuming the same center line elevation of the hollow-jet valves (5,386 ft), the invert of the proposed 90-inch jet-flow gates is 5,382.25 ft. Tailwater elevations were compared to the jet-flow gate invert to help gage the potential for submerged operation. The plot in Figure 5 shows the relationship between tailwater elevation and total discharge (total of spillway, outlet works, and powerplant bypass) for flows up to 65,000 ft^3/s. The physical model study reported a tailwater elevation of 5,386 ft at the maximum total discharge of 94,000 ft^3/s [2].

Historic tailwater data (1955 – 2017) were estimated using the correlation from Figure 5 and discharge readings from a stream gaging station downstream of Palisades Dam. These estimates are shown in Figure 6 and suggest that tailwater levels reach the invert of the jet-flow gates less than 0.03% of the time. Also, tailwater readings from a stilling well in the tail bay of the powerplant are presented in Figure 7. These measurements also suggest that the likelihood of submerged operation is low.

Historic photographs of the outlet works in operation show that a tailwater elevation near the invert of the valves or gates does not necessarily mean there will be submergence. Figure 8 shows two examples. The photograph on the left shows the outlet works discharging approximately 14,400 ft^3/s, resulting in an estimated tailwater elevation of 5,378 ft as shown by the water surface in the powerplant bypass bay near the diversion wall. However, the water level is much lower on the other side of the diversion wall where the gates and valves are discharging in a free discharge condition into the outlet stilling basin. The physical model produced a similar result at a discharge of 31,600 ft^3/s and measured tailwater elevation of 5,382 ft with no apparent submergence (Figure 8, right photograph). Due to the high velocity head immediately downstream of the gates and valves, a tailwater elevation greater than the jet-flow gate invert would likely be required to induce a submerged discharge condition.

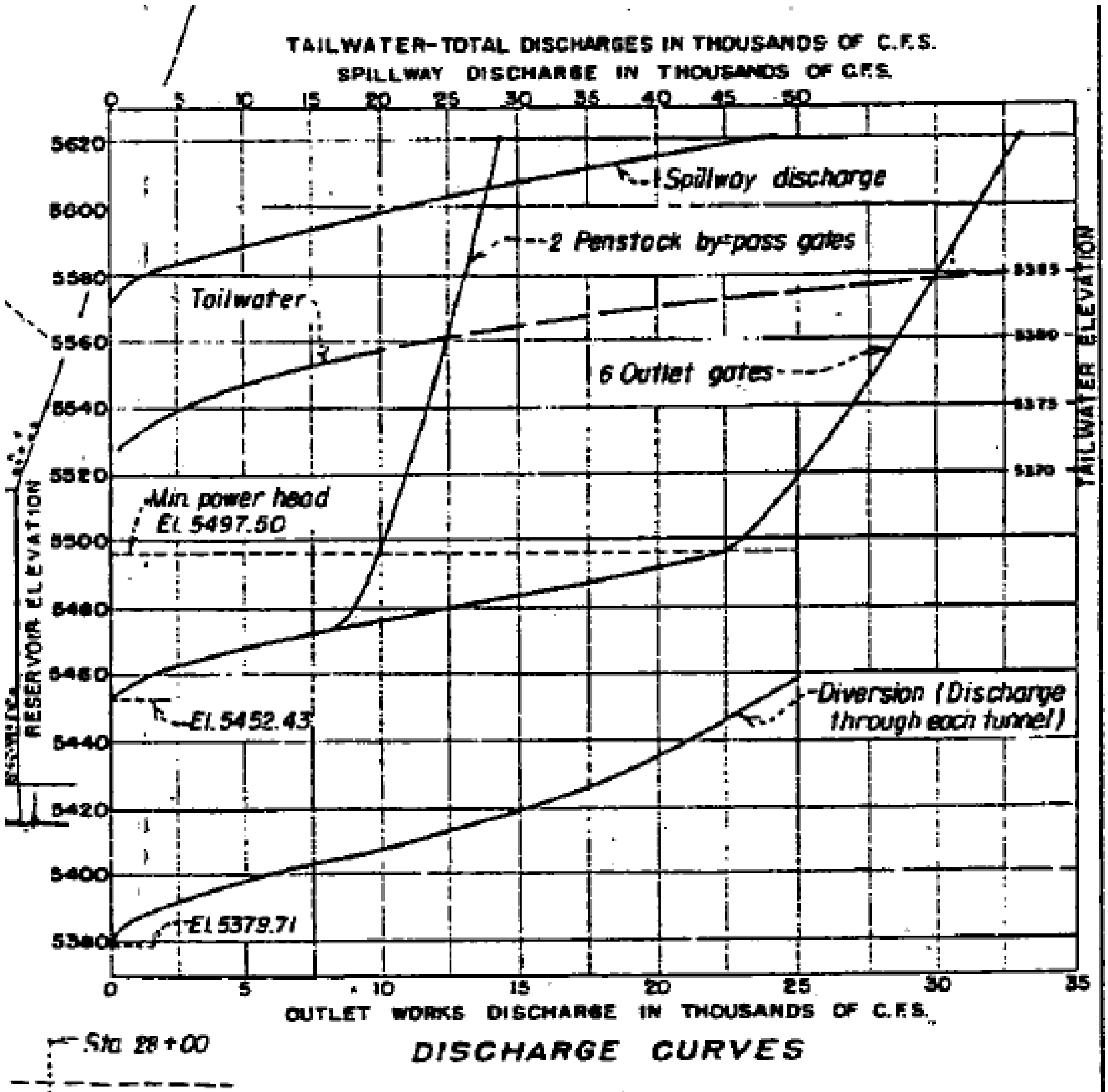


Figure 5 Tailwater curve vs. total discharge from drawing 456-D-120.

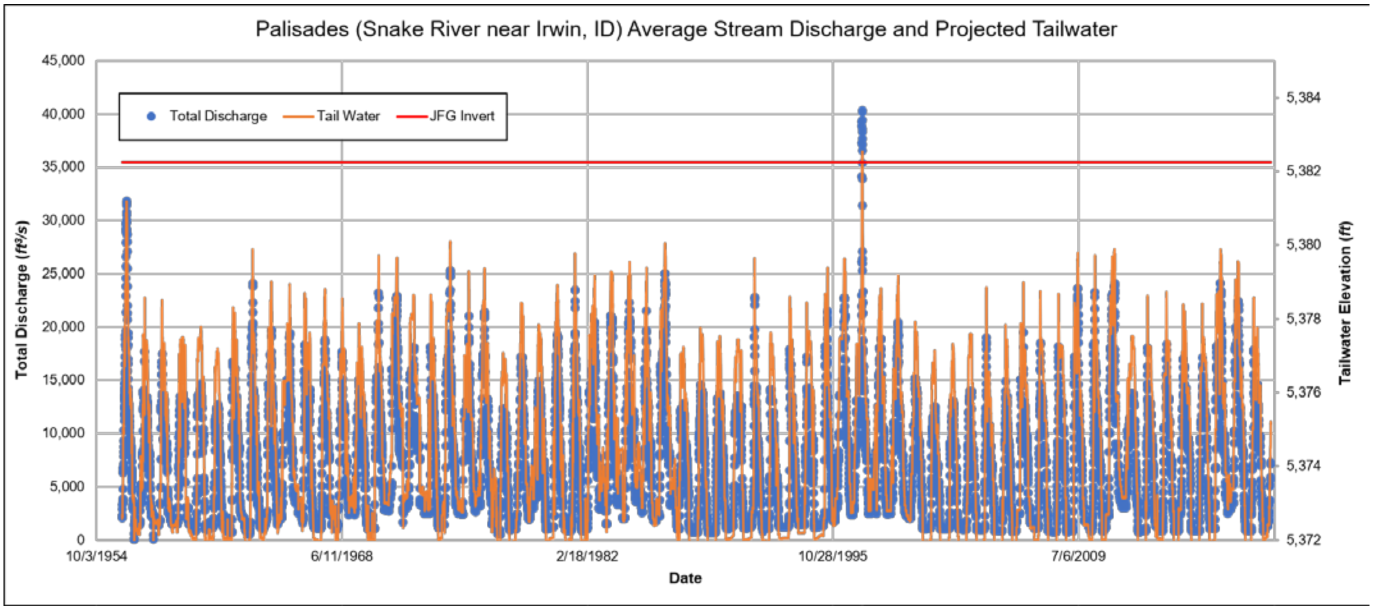


Figure 6 Time series of total discharge measurements and projected tailwater elevations from 1955 – 2017.

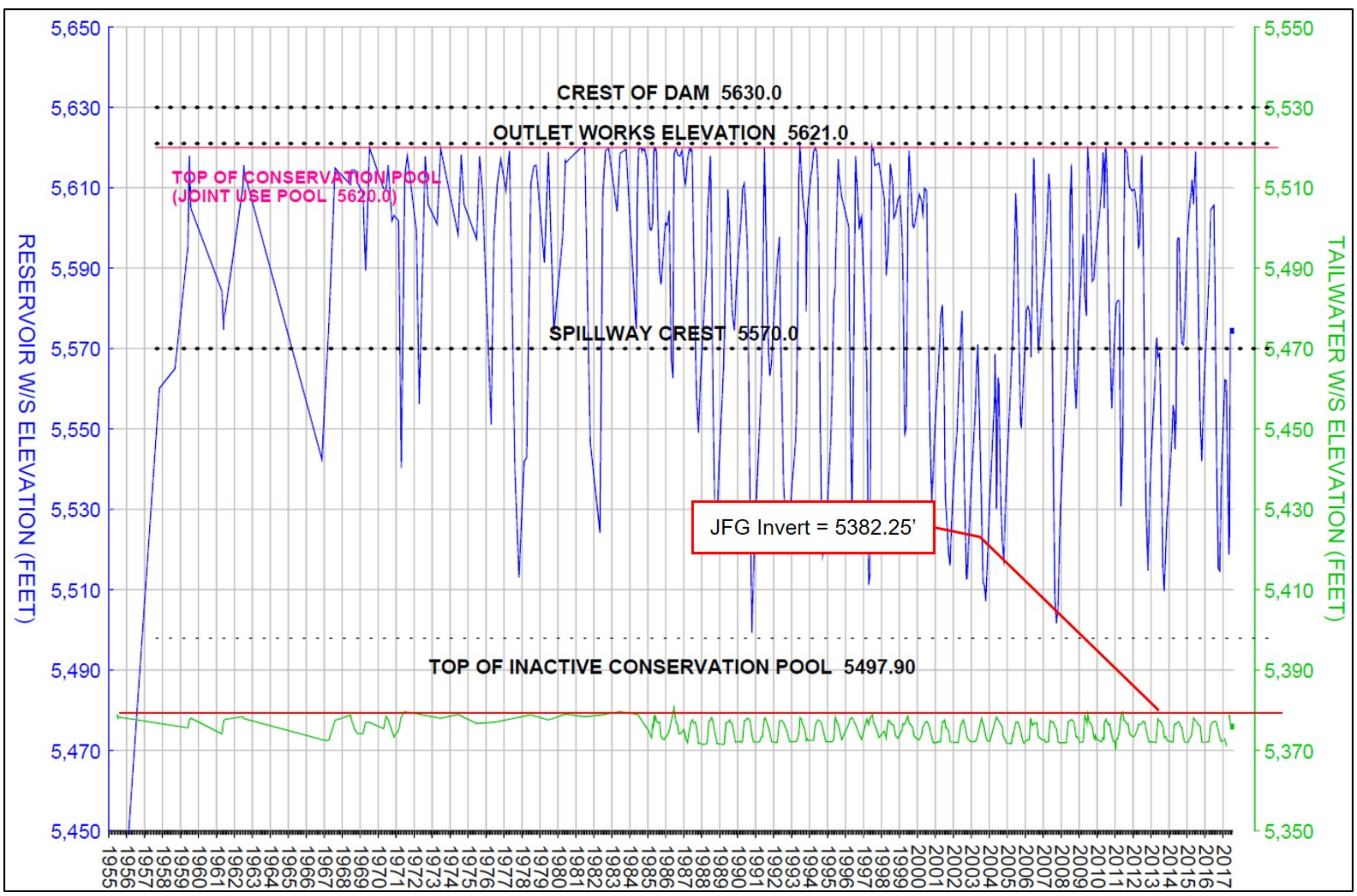
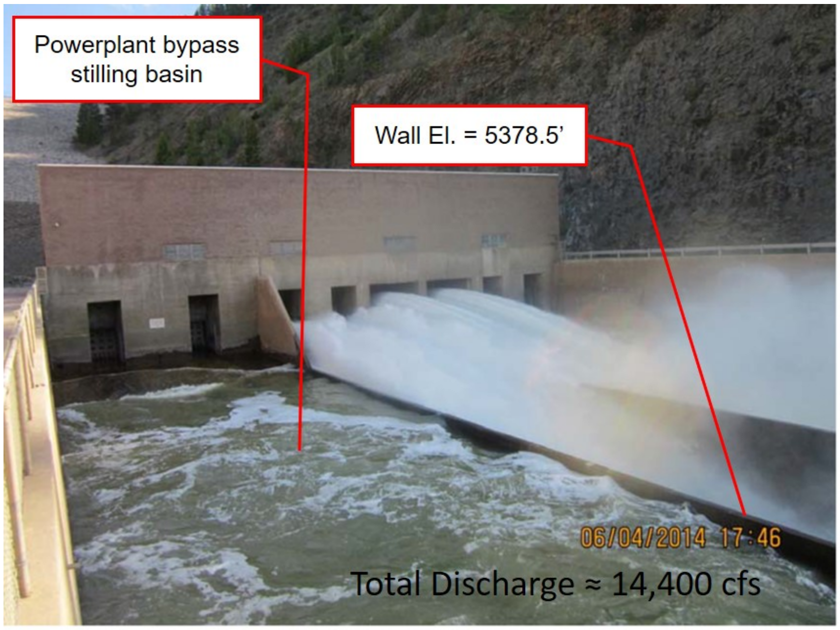
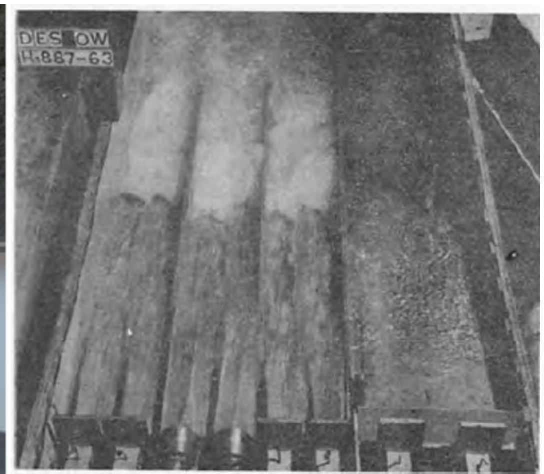


Figure 7 Time series of powerplant tail bay measurements (green) from 1955 – 2017.





F. Two valves and four gates discharging 31,600 cfs - Tailwater elevation 5382

Figure 8 Photograph of outlet discharge into spilling basin with tailwater elevation near 5378 ft (left, looking upstream), and photograph of outlet discharge into spilling basin at tailwater elevation 5382 ft in scaled physical model (right, looking downstream).

Implications for Submerged Operation of Jet-Flow Gates

If the jet-flow gates were to become submerged during operation, many operational issues would likely occur. These include damaging cavitation in the gate slots, excessive vibration and turbulence in the gate housing, and significantly increased levels of down pull and hydrodynamic forces on the gate leaf [7]. Physical model studies have been used to modify jet-flow gate designs for successful submerged operation [8]. This has typically been done by utilizing air vents and a gate body expansion downstream. These typically extend no more than 1 gate diameter (D) in length and 2.5 to over 3D in diameter. For the outlet works at Palisades, the diameter of the gate body expansion would be restricted to less than 2-D due to vertical space dimensions. Fortunately for Palisades, submergence is unlikely and would only occur at extreme flow conditions where the jet-flow gates are fully open which would help mitigate many of these operational issues with partial gate openings [4].

Conclusions & Recommendations

A preliminary hydraulic evaluation was made to determine if jet-flow gates are an appropriate option to replace the existing 96-inch hollow-jet valves and if further investigation is warranted before proceeding to the next phase of design. Conclusions and recommendations from this evaluation include:

1) The 90-inch jet-flow gates have sufficient discharge capacity to replace the hollow-jet valves without reducing the overall capacity of the outlet works.
2) It is strongly recommended that a field test be conducted following the installation of the jet-flow gates (or whichever option is chosen). Measurements should include pressure immediately upstream of the gates and upstream of the bifurcation, and vibration on the gate body throughout the full range of gate openings. Test results will help confirm the discharge rating of the new gates, demonstrate appropriate operation throughout the full range of gate openings, and establish an operational baseline for comparison of potential operational issues in the future.
3) While the estimated jet trajectory of the jet-flow gates does exceed that of the hollow-jet valves it is not expected to significantly alter the performance of the stilling basin.
4) Tailwater levels are not expected to cause submerged operating conditions of the jet-flow gates. Submerged discharge is only expected for extreme flow conditions when the gates are fully open and operational issues are reduced, however damage to the gates would still be a concern if extended operation were expected.

References

[1] Bureau of Reclamation, "Palisades Dam and Powerplant - Technical Record of Design and Construction," U.S. Department of the Interior, Denver, CO, 1960.

[2] J. Schuster, "Hydraulic Model Studies of the Palisades Dam Outlet Works and Spillway Palisades Project - Idaho, Hydraulic Laboratory Report No. HYD-350," U.S. Department of the Interior, Denver, CO, 1956.

[3] D. Colgate, "Calibration of a 10-inch Jet Flow Gate," U.S. Department of the Interior, Denver, CO, 1969.

[4] C. V. Davis and K. E. Sorensen, Handbook of Applied Hydraulics, McGraw-Hill, 1984.

[5] A. Peterka, "Hydraulic Design of Stilling Basins and Energy Dissipators, Engineering Monograph No. 25," U.S. Department of the Interior, Denver, CO, Eighth Printing, 1984.

[6] T. L. Wahl, K. H. Frizell and E. A. Cohen, "Computing the Trajectory of Free Jets," *Journal of Hydraulic Engineering @ ASCE,* pp. 256-260, 2008.

[7] T. J. Isbester, "Cavitation in Submerged Jet Flow Gates, PAP-335," U.S. Bureau of Reclamation, Denver, CO, 1975.

[8] B. Mefford, "Hydraulic Model Study of Submerged Jet Flow Gates for Arrowrock Dam Outlet Works Modification, PAP-511," U.S. Bureau of Reclamation, Denver, CO, 1987.