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Hydraulic Laboratory Technical Memorandum, PAP-1198

Field Test of Green Springs Turbine Bypass Operation

Rogue River Basin Project, Oregon
Interior Region 9: Columbia Pacific Northwest (CPN)

U.S. Department of the Interior
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Introduction

In the Fall of 2020 an assessment was made of the operation of the Green Springs Powerplant and penstock system to investigate and develop an emergency procedure to bypass the Pelton turbine in order to continue water delivery into the river in the unlikely event of a generator failure [1]. This procedure deviates from the Standard Operating Procedure and requires the flow to be controlled by the upstream slide gate to reduce pressure at the turbine needle valves. These needle valves discharge a water jet against deflector plates which are engaged (closed) to block the water jet from impinging on the Pelton runner buckets and rotating the turbine. The assessment concluded that a field investigation was necessary to help address concerns and confirm hydraulic calculations to ensure safe performance of the slide gate, penstock, and air valves during emergency bypass operations. This field investigation was performed during the week of April 5th, 2021.

The main objective of this memorandum is to present the findings, conclusions, and recommendations from the field investigation regarding the emergency bypass procedure. Test measurements were focused on the performance of the slide gate, operation of the air valves, resulting hydrodynamics within the penstock, and discharge estimation through the turbine needle valves which control flow through the downstream section of the system.

Approach

Test equipment was installed on key components of the system and measurements were recorded for several bypass discharge conditions throughout April 6 – 8 (Table 1). Measurements included vibration and position of the 60-inch slide gate (Figure 1), penstock pressure immediately downstream of the slide gate at the 4-inch air valve (Figure 2), penstock pressure downstream of a saddle in the penstock at the 2-inch air valve (Figure 3), discharge and penstock pressure immediately upstream of the turbine guard valve inside the powerplant (Figure 4), and turbine needle valve position (Figure 5). A complete description of the water conveyance system from Keene Creek Reservoir to Green Springs Powerplant is provided in the assessment report [1].

Table 1 Summary of bypass operating conditions tested during the week of April 5-9, 2021.

Date	Start Time	End Time	Slide Gate Position	Penstock Pressure	Needle Position	Discharge
MM/DD/YYYY	*HH:MM-*	*HH:MM-*	*inch*	*psig*	*% open*	*cfs*
4/6/2021	15:15	15:25	6.0	100.0	100.0	54.7
	16:18	16:28	5.0	102.9	68.8	45.9
	17:08	17:18	4.0	100.1	47.4	35.0
	18:11	18:21	4.5	99.0	53.7	38.3
	19:20	19:30	5.5	99.9	79.2	49.0
4/7/2021	12:26	12:36	6.5	224.7	54.4	57.9
	13:45	13:55	7.0	229.3	59.1	61.9
	15:13	15:23	7.5	222.8	67.0	66.2
	16:28	16:38	8.0	222.7	74.5	70.1
	19:37	19:47	9.0	224.2	91.7	78.2

Date	Start Time	End Time	Slide Gate Position	Penstock Pressure	Needle Position	Discharge
MM/DD/YYYY	*HH:MM-*	*HH:MM-*	*inch*	*psig*	*% open*	*cfs*
4/8/2021	8:53	9:03	3.0	100.9	24.1	19.8

Figure 1 Measuring tape used for gate position and accelerometers mounted on the 60-inch slide gate shaft to measure horizontal (in direction of flow) and vertical vibrations.

Figure 2 Pressure sensor mounted on the downstream side of the 4-inch air valve to measure pipe pressures directly downstream of the slide gate.

Figure 3 Manhole access for the 2-inch air valve and remote data logger (left) and pressure sensor mounted on the downstream side of the 2-inch air valve to measure penstock pressures at a high point downstream of the last saddle in the piping system.

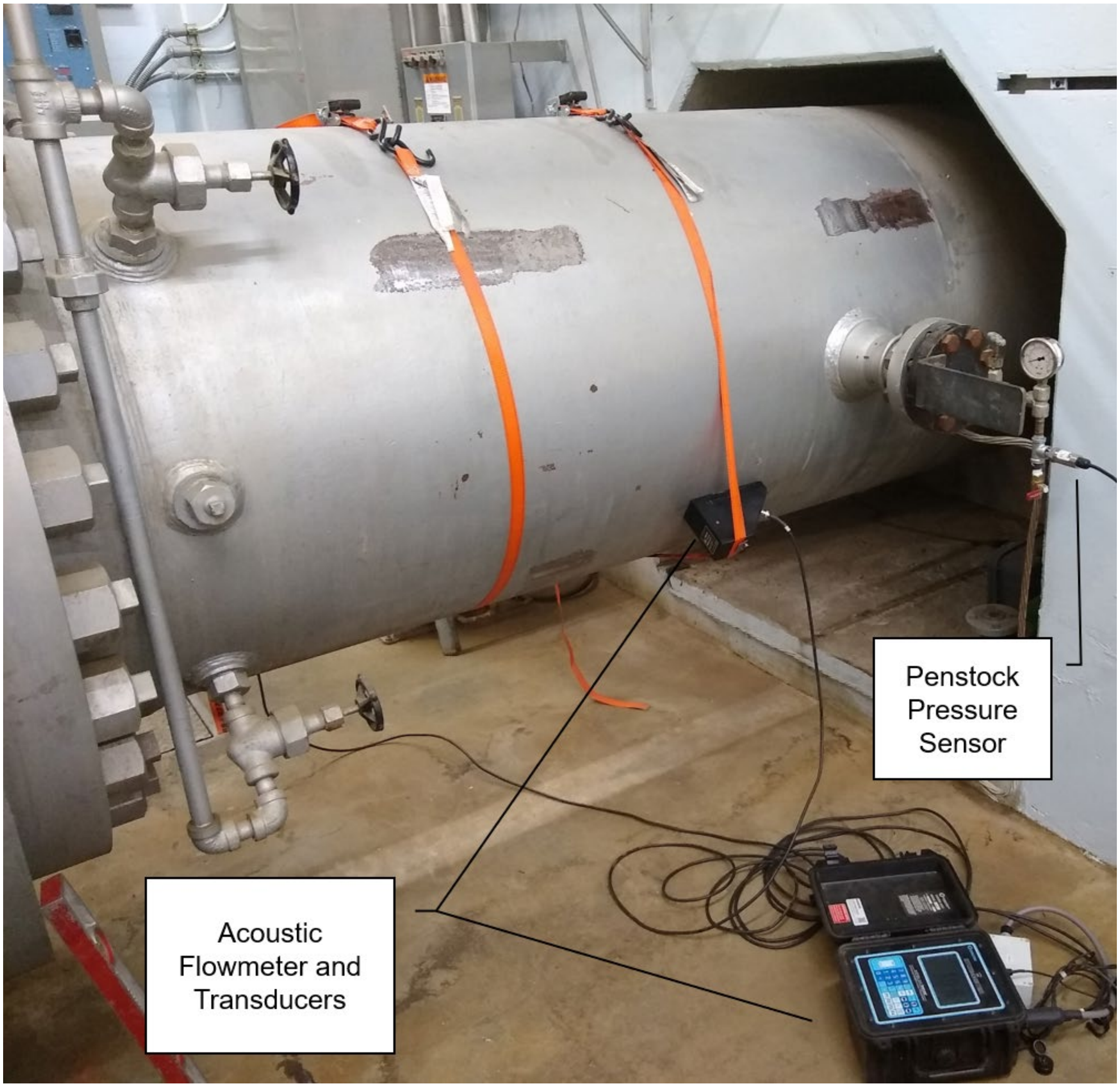

Figure 4 Acoustic flow meter and pressure sensor mounted on the exposed penstock in the powerplant immediately upstream of the turbine guard valve and scroll case. Flow is from right to left in photo.

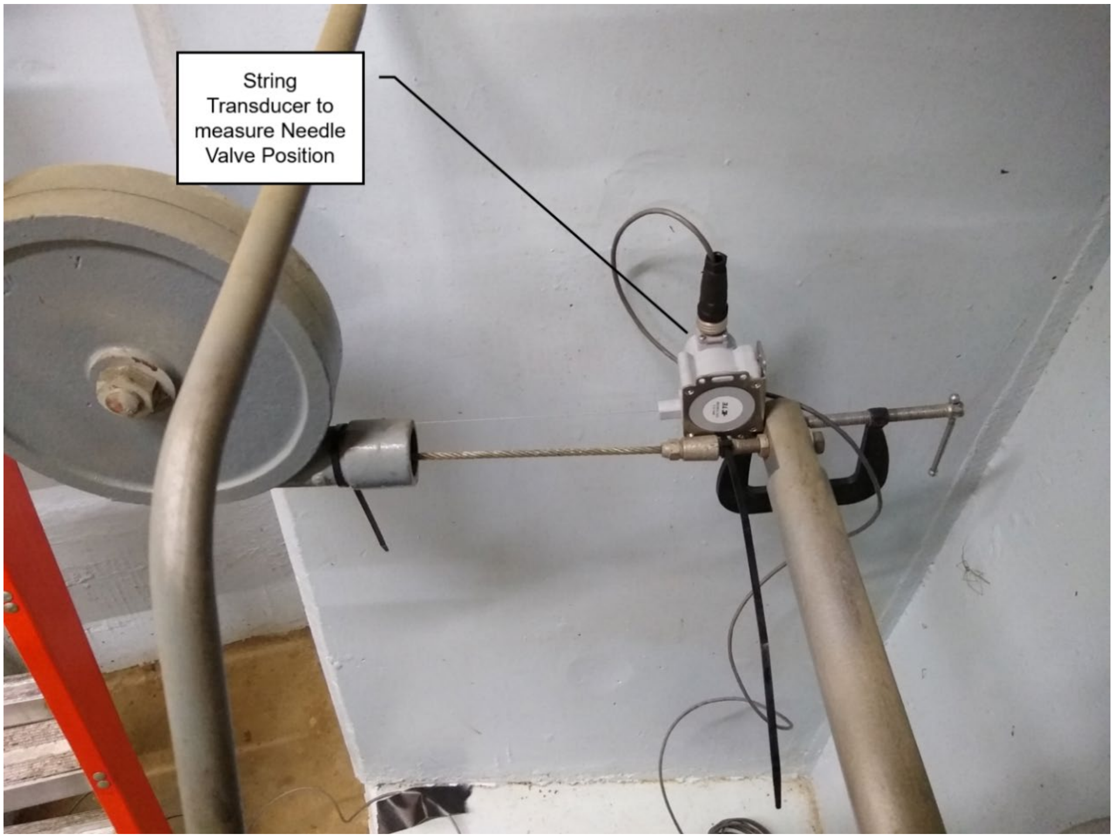

Figure 5 String transducer used to measure the position of the Turbine Needle Valve 4.

Testing was conducted in bypass operating mode by setting the upstream slide gate partially open and adjusting the turbine needle valves to balance the discharge at the powerplant with that of the slide gate at a constant upstream pressure (either 100 psi or 225 psi). Once pressure and flow readings stabilized (typically about 60 – 90 minutes) no changes were made for a minimum of 10 minutes to ensure the measured condition was steady and to observe any hydrodynamic activity within the penstock at each condition. Measurements were observed live during the test except for the 2-inch air valve pressure measurement which was recorded with a battery powered data acquisition system due to its remote location. All measurements were recorded at an interval of 1 sample-per-second with exception to slide gate vibration which was recorded at 1,000 samples-per-second.

Results and Discussion

60-inch Slide Gate and 4-inch Air Valve

For bypass operations, the slide gate was partially opened to control the flow into the pipeline. Observations and vibration measurements suggested that, for most gate positions, the gate performed well with no observed erratic operation (i.e. gate chatter, flutter, etc.) or damage to the gate or structure. For gate positions of 6.5- to 7-inches open (58 – 62 cfs in this case) pinging and crackling noises were heard coming from the gate structure which may be indicative of cavitation. These observations are not alarming and agree with higher vibration levels measured for the same conditions (Figure 6). The magnitude of vibration recorded is less than 0.1g and is not an area of concern for excessive wear or fatigue of the slide gate over the lifespan of the gate given the limited occurrence of bypass operations.

Pressure measurements (Figure 6) as well as observations showed that air flow through the 4-inch air valve immediately downstream of the slide gate was almost imperceptible. The lack of air flow though the valve suggests that the piping between the slide gate and surge tank was only partially filled which maintained atmospheric pressure within this reach of pipe. While the slide gate opening should be limited to 6-inches if possible to avoid cavitation potential, an unrestricted air supply from both the 4-inch air valve and surge tank will help alleviate operational issues at the gate if openings greater than 6-inches were required for larger discharges.

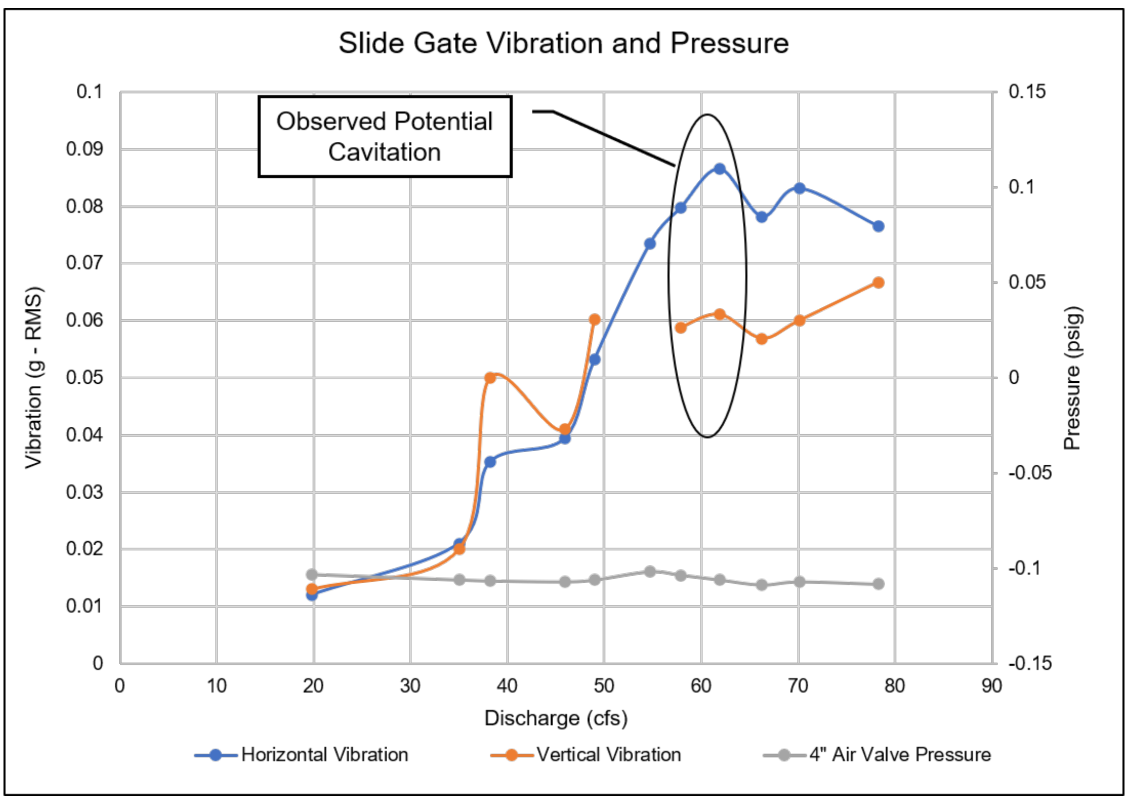

Figure 6 Slide Gate vibration (root-mean-square) and 4-inch air valve pressure (average) measured for each discharge test condition.

During gate position changes it was recognized that the slide gate is not designed to be operated under unbalanced pressure conditions (i.e. atmospheric downstream pressure). The motorized actuator is not sized to overcome the unbalanced force of the gate leaf and seat friction and reaches the torque limit when attempting to open or close the gate. All gate position changes were made using a portable electric-drive wrench. When operated with the portable electric wrench under unbalanced head conditions, the gate repeatedly became bound and then broke free. This sequence was repeated approximately every 0.25-inch of gate travel and confirms that the gate was not designed to be operated under unbalanced head conditions. Gate operation under unbalanced head conditions should be limited to emergency bypass only. Frequent gate adjustments under unbalanced head conditions may lead to increased wear on the gate seats, operator, and operator pedestal concrete anchor system.

Test results were helpful in developing a discharge rating for the 60-inch slide gate. Discharge controlled by the slide gate depends on both slide gate position and the reservoir elevation at Keene Creek. These data were recorded along with discharge during the field test to produce Table 2 and Figure 7 for use in estimating the flow rate and slide gate opening for bypass operation.

Table 2 Tabular discharge data for the 60-inch slide gate when used for flow control during emergency bypass operations, based on reservoir elevation at Keene Creek and slide gate position.

	G_o = Slide Gate Opening (*inches open*)						
Reservoir Elev. (*ft*)	**3"**	**4"**	**5"**	**6"**	**7"**	**8"**	**9"**
4,377	11.9	17.8	23.6	29.3	34.7	39.9	45.0
4,378	12.4	18.7	24.8	30.7	36.4	41.9	47.2
4,379	13.0	19.6	25.9	32.1	38.1	43.8	49.4
4,380	13.5	20.4	27.0	33.4	39.6	45.6	51.4
4,381	14.1	21.1	28.0	34.7	41.1	47.4	53.4
4,382	14.6	21.9	29.0	35.9	42.6	49.0	55.3
4,383	15.0	22.6	30.0	37.1	44.0	50.7	57.1
4,384	15.5	23.3	30.9	38.3	45.4	52.3	58.9
4,385	16.0	24.0	31.8	39.4	46.7	53.8	60.6
4,386	16.4	24.7	32.7	40.5	48.0	55.3	62.3
4,387	16.8	25.3	33.6	41.5	49.3	56.7	63.9
4,388	17.3	26.0	34.4	42.6	50.5	58.1	65.5
4,389	17.7	26.6	35.2	43.6	51.7	59.5	67.0
4,390	18.1	27.2	36.0	44.6	52.9	60.9	68.5
4,391	18.5	27.8	36.8	45.5	54.0	62.2	70.0
4,392	18.8	28.3	37.6	46.5	55.1	63.5	71.5
4,393	19.2	28.9	38.3	47.4	56.2	64.7	72.9
4,394	19.6	29.5	39.0	48.3	57.3	66.0	74.3
4,395	19.9	30.0	39.8	49.2	58.4	67.2	75.7
4,396	20.3	30.5	40.5	50.1	59.4	68.4	77.0
4,397	20.6	31.1	41.2	51.0	60.4	69.6	78.4
4,398	21.0	31.6	41.8	51.8	61.4	70.7	79.7
4,399	21.3	32.1	42.5	52.6	62.4	71.9	80.9
4,400	21.7	32.6	43.2	53.5	63.4	73.0	82.2
4,401	22.0	33.1	43.8	54.3	64.3	74.1	83.4

	G_o = Slide Gate Opening (*inches open*)						
Reservoir Elev. (*ft*)	**3"**	**4"**	**5"**	**6"**	**7"**	**8"**	**9"**
4,402	22.3	33.6	44.5	55.1	65.3	75.2	84.7
4,403	22.6	34.0	45.1	55.8	66.2	76.2	85.9
4,404	22.9	34.5	45.7	56.6	67.1	77.3	87.1

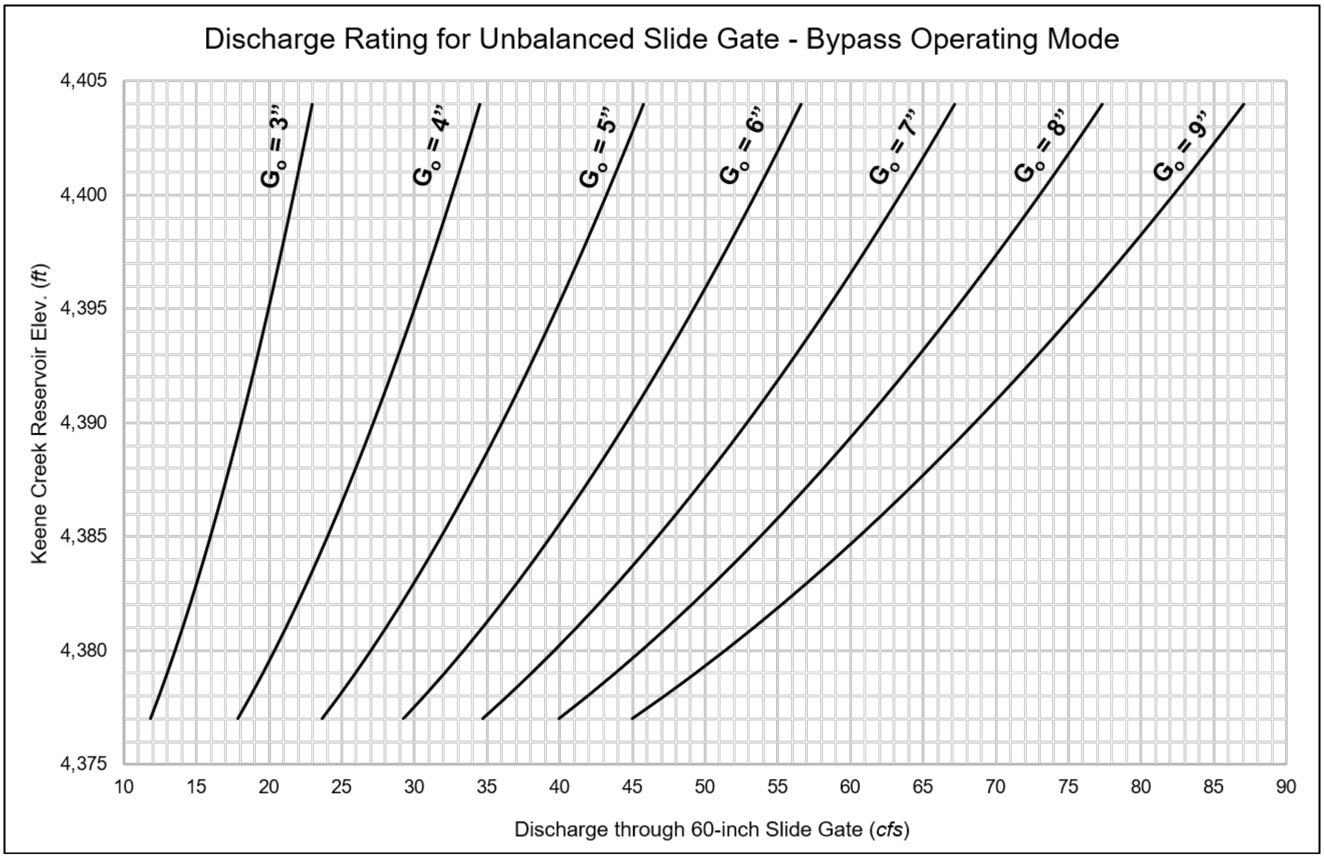

Figure 7 Discharge rating curve for the 60-inch slide gate when used for flow control during emergency bypass operations. Rating curve was developed from data in Table 2.

2-inch Air Valve and Pressure Surging in the Penstock

During bypass operations the penstock downstream of the 2-inch air valve flowed partially full until forced into pressurized pipe flow by the back pressure from the turbine needle valves. This change from partial to pressurized flow is a result of a hydraulic jump which is characterized by turbulent air entrainment and potential surging [2]. A key component of this field test was to determine whether the 2-inch air valve could admit sufficient airflow to prevent excessively low pressures in the penstock. Testing also helped determine if "blow-back", rapid upstream travel of entrapped air pockets in the flow, would be a concern during emergency bypass operations.

Pressure measurements at the 2-inch air valve and within the powerplant showed that airflow and internal pipe pressures were well within the design limitations of both the air valve and penstock for all discharge conditions tested (Figures 8 through 10). For discharges up to approximately 80 cfs, the minimum penstock pressure at the 2-inch air valve was negative 2 psi gage (Figure 9). The noise observed at the valve at this condition, although quite loud, was constant suggesting a constant air flow. The greatest penstock pressure fluctuation was 25 psi at the powerplant and less than 1 psi at the 2-inch air valve.

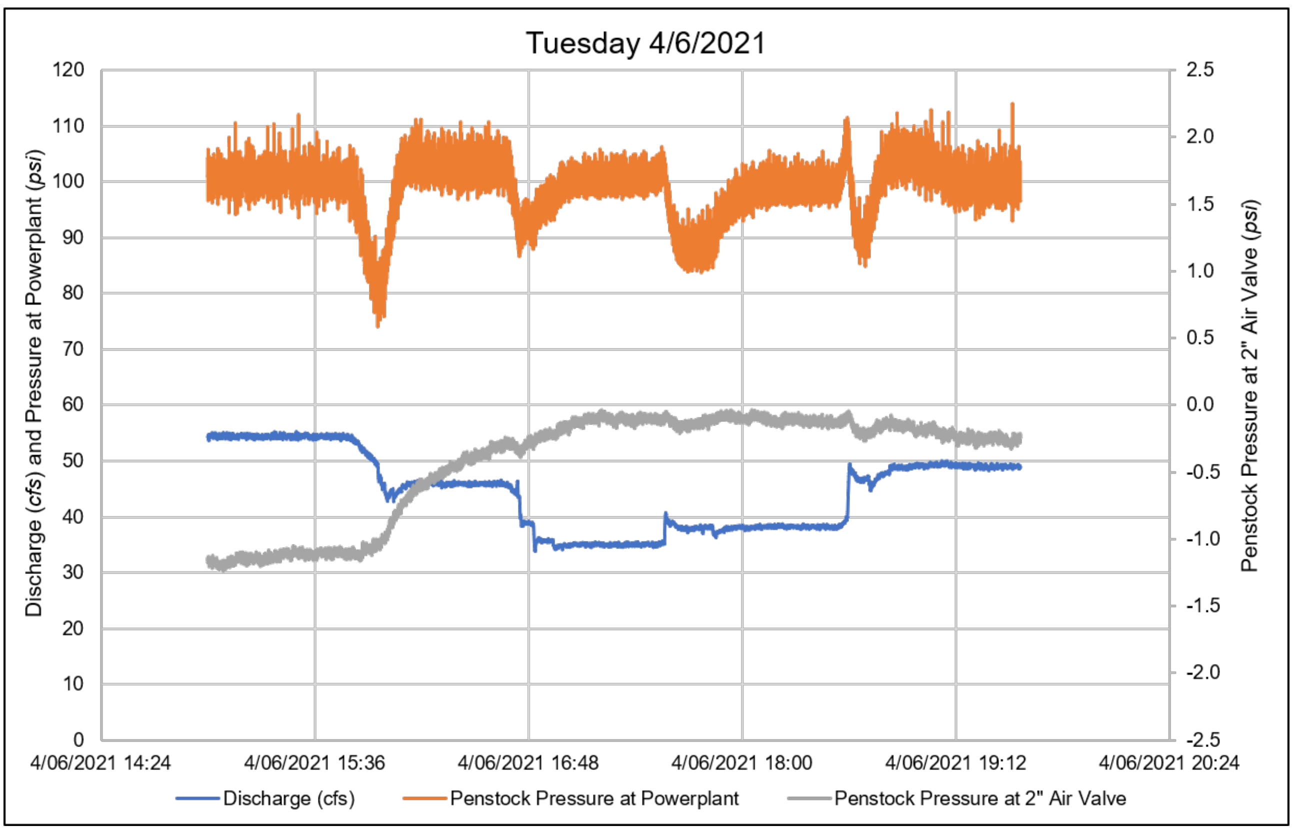

Figure 8 Time series for turbine needle discharge and penstock pressure at the powerplant and 2-inch air valve measured on Tuesday 4/6/2021.

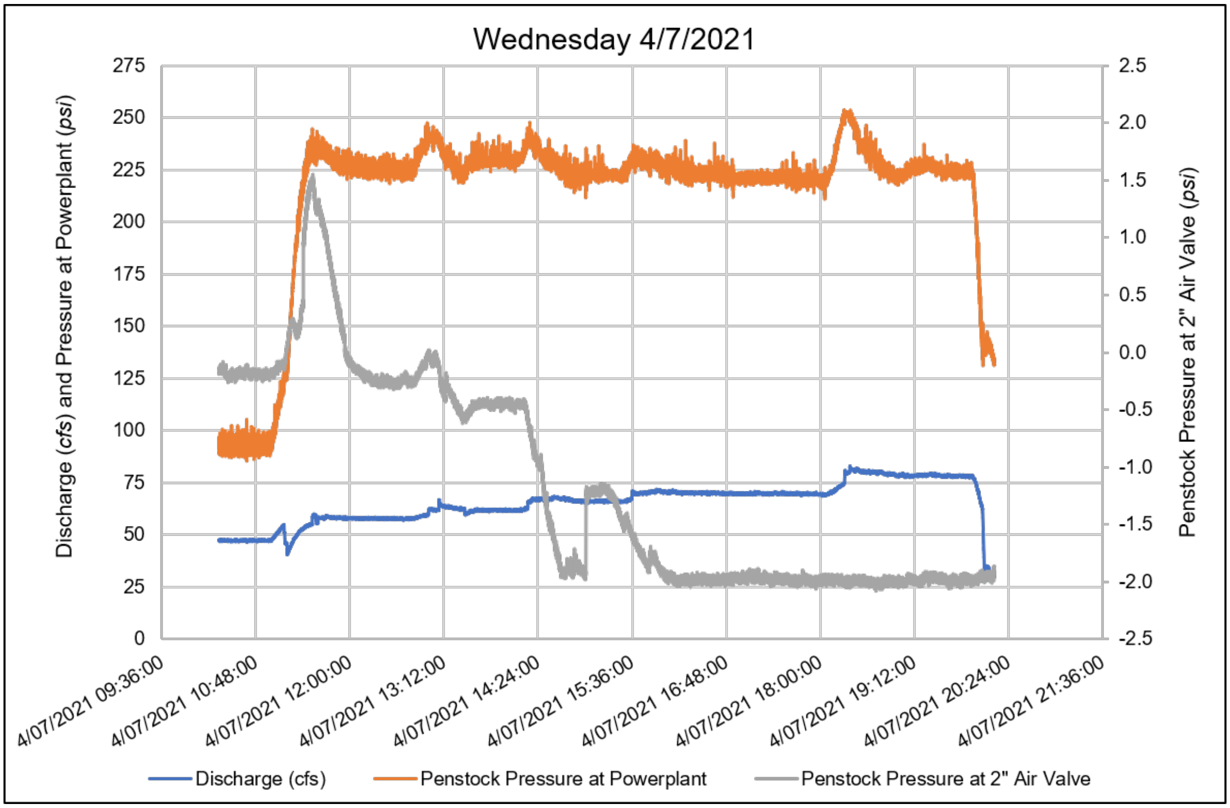

Figure 9 Time series for turbine needle discharge and penstock pressure at the powerplant and 2-inch air valve measured on Wednesday 4/7/2021.

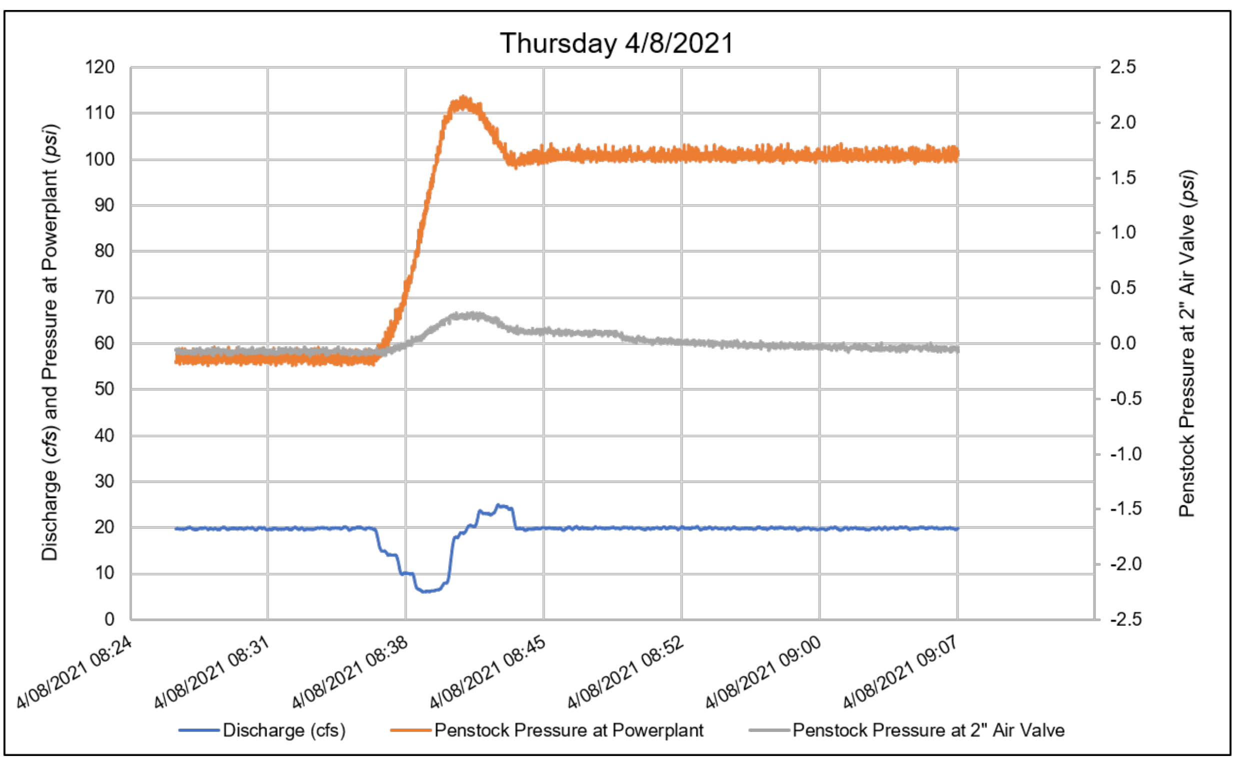

Figure 10 Time series for turbine needle discharge and penstock pressure at the powerplant and 2-inch air valve measured on Thursday 4/8/2021.

Test measurements and observations suggest that there is low potential for extreme pressure surging or "blow-back" to occur with sufficient force to damage the penstock for the range of conditions tested. Figure 11 shows operating points for 40 cfs (at 100 psi – results in hydraulic jump at a location with a pipe slope of 0.410) and 70 cfs (at 225 psi – results in hydraulic jump at a location with a pipe slope of 0.097). These points are outside the area of concern (shown in purple), where air bubbles may accumulate downstream and then surge back upstream with sufficient force to cause damage.

Several factors help provide confidence that pressure surging will not be a concern for bypass operations. Pressure measurements and observations at the 2-inch air valve indicate that air flow was minimal but fluctuated to some degree at discharges of 40 cfs and lower which support the finding on Figure 11 where air does not flow downstream. For 70 cfs, the air flow was constant and much greater according to both observations and measurements at the 2-inch air valve suggesting that all air entrained into the pipe was passed downstream with the water flow in agreement with Figure 11. This test condition was held steady for approximately 4 hours with no observed adverse conditions. Finally, the reach of penstock with turbulent air mixing and surging in question is also the most robust of the system with thick pipe walls designed for pressures above 300 psi at the weakest section (near the 2-inch air valve), well above pressures and surges measured during the bypass test.

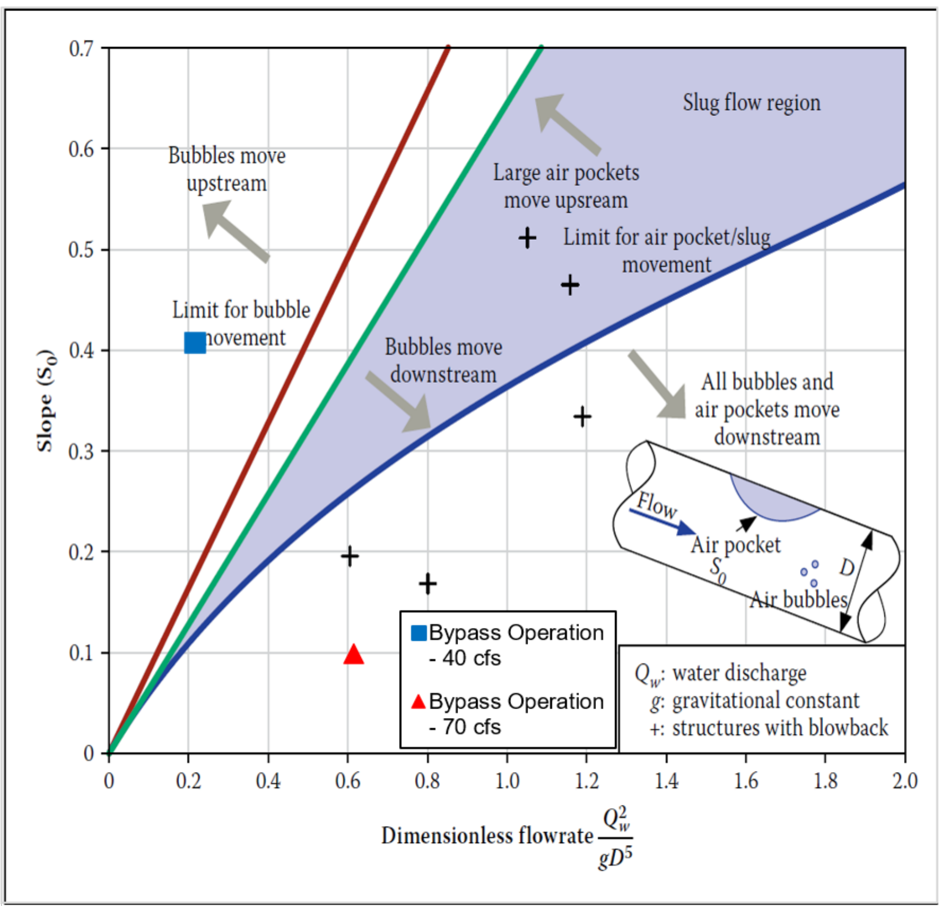

Figure 11 Plot used to indicate air bubble movement within pipes with mixed air/water flows as a function of pipe slope and dimensionless discharge [2]. Points are shown for Green Springs bypass operations at 40 and 70 cfs.

Turbine Needle Valve Discharge Rating

Test results were also used to develop discharge rating curves for the turbine needle valves. Within the powerplant discharge controlled by the needle valves depends on both needle position and the penstock pressure immediately upstream. Discharge ratings curves were developed for penstock pressures at both 100 psi (Figure 12) and 225 psi (Figure 13). A pressure of 225 psi was necessary to pass higher discharges for needle valve positions where reasonable flow control could be maintained.

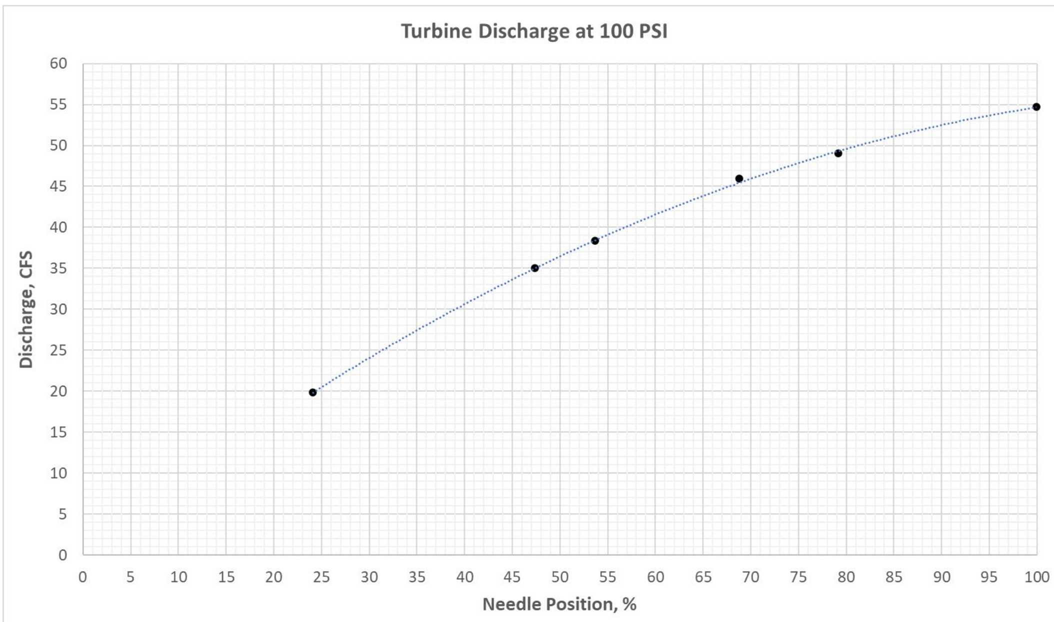

Figure 12 Turbine needle discharge at 100 psi.

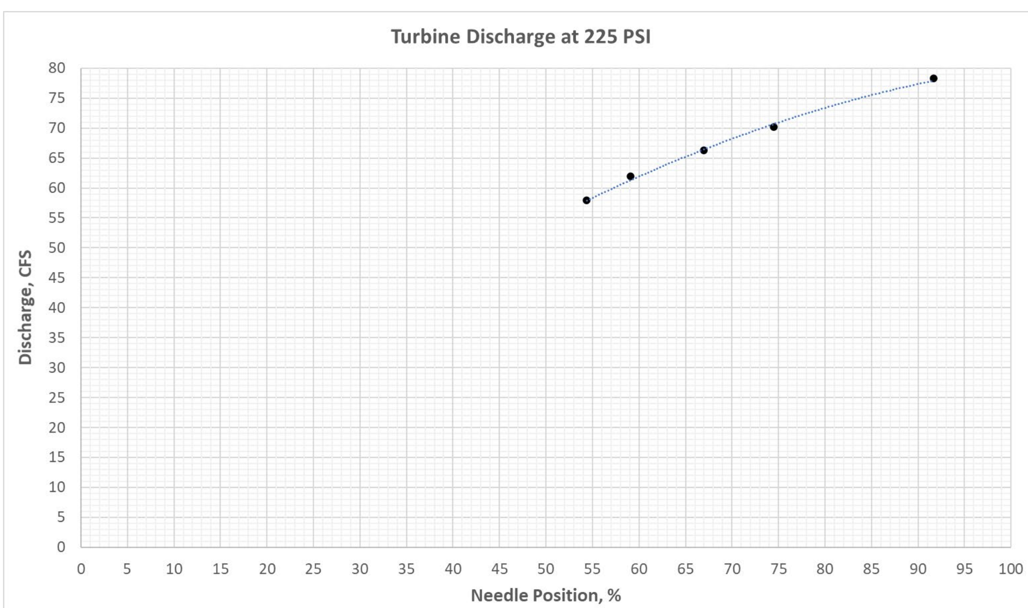

Figure 13 Turbine needle discharge at 225 psi.

Tailrace Conditions

Water levels in the tailrace were measured and observed for all test conditions with the original intent to correlate discharge with tail water levels that could be estimated with a staff gage during normal operation. Test results and observations showed this is not possible because of the different exit conditions of the flow for bypass and normal operations in the tailrace chute (Figure 14) as well as the potential for different back-water conditions from the irrigation weir and diversion downstream which may result in incorrect discharge estimates. The location of the open channel hydraulic jump and energy dissipation remained within the concrete chute for all bypass conditions tested, eliminating any concern for scour and erosion of the downstream channel.

Figure 14 Flow conditions in the powerplant tailrace (looking downstream) for approximately 70 cfs in both bypass mode (left) and normal power generation mode, post-test (right).

Conclusions and Recommendations

1. No adverse conditions were observed with unbalanced flow control at the 60-inch slide gate that would prohibit bypass operations for the range of operating conditions tested. However, observations indicated that cavitation is possible for slide gate openings greater than 6-inches, and operation under unbalanced head may result in additional wear and tear on the slide gate seats and actuator. Gate operation under unbalanced head conditions should be limited to emergency bypass only. A discharge rating was developed to estimate flows through the slide gate for various gate openings and reservoir elevations to be used as part of the turbine bypass procedure. The gate leaf and seats, and actuator should be inspected regularly to monitor condition changes.

2. Performance of the 2-inch air valve was satisfactory at all flow conditions tested and did not produce excessively low internal pressures or adverse transient conditions within the penstock that would limit bypass operation. The wire mess screen on the 2-inch air valve inlet should be repaired immediately.

3. A discharge rating was developed for the turbine needle valves for an upstream pressure of 100 psi (discharge range of 20 – 55 cfs) and 225 psi (discharge range of 55 – 80 cfs) to be used as part of the turbine bypass procedure.

4. Tailrace water levels should not be used to estimate discharge due to the potential to provide incorrect discharge readings caused by different exit flow and back-water conditions from the irrigation diversion downstream.

5. While bypass operation up to 70 cfs is acceptable, it is recommended that discharges be limited to no greater than 40 cfs whenever possible. This will reduce the potential for any cavitation at the slide gate observed at gate openings greater than 6-inches and will minimize wear on the deflector plates caused by the high velocity water jets coming out of the needle valves. The deflector plate assembly should be inspected regularly after bypass operations and/or regular use due to potential for sediment laden flows.

References

[1] R. Stephen and N. N. Myers, "Green Springs Powerplant Turbine Bypass Assessment (Unofficial)," U.S. Department of the Interior, Denver, CO, 2020.

[2] H. T. Falvey, "Engineering Monograph No. 41 - Air-Water Flow in Hydraulic Structures," U.S. Department of the Interior, Denver, CO, 1980.