Study No. 6

Hydrologic Characterization of the West Rosebud Creek Bypass Reach Between Mystic Lake Dam and the Powerhouse – April 2006 Final Report

Mystic Lake Hydroelectric Project FERC No. 2301

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Table of Contents

1.0 Executive Summary

The purpose of this study was to determine the proportion of water released by the fish valve relative to the amount of water that is measured at the upper weir. The upper weir has traditionally been the location where bypass channel flows have been measured to maintain minimum flows for compliance purposes. The question has been raised as to whether or not the flows measured at the lowermost reach of the bypass channel are reflective of the actual flows at the upstream end of the bypass reach. The study presented in this document presents data analysis from two summer seasons and one winter season in the bypass reach. The goal of this analysis was to differentiate between the flow emitted by the fish valve vs. flow originating from other sources.

Whenever the project is spilling over the dam, there is no need to operate the fish valve since the flows throughout the entire bypass reach are well above the 10 cfs minimum required flow. Based on the analysis, it is evident that fish valve releases in summer months are sometimes low relative to flow from other sources such as leakage, tributary inflows, and other sources. Our evidence for this conclusion is based on the observation that changes in the fish valve position result in highly correlated changes in the observed flow at the upper weir. In many cases, the fish valve is closed for extended periods during summer months when no intentional spill is coming from the dam, but when the lake elevation is above crest. In this case, significant leakage from the flashboards could be responsible for the reduced need for additional fish valve release flows. The data clearly indicate that during the summer, significant portions of the required 10 cfs minimum flows are from origins other than the fish valve. If bypass flows become low enough, as SCADA data has shown, operators will adjust the fish valve to compensate and increase flows to make certain that the 10 cfs minimum flow is sustained, but for most of the summer, the fish valve is often completely closed, and all bypass flow is provided by leakage, tributary inflows and sources other than the fish valve.

Flow data from the fish valve and the upper weir were gathered through the winter of 2005 and into the spring of 2006. Additional analyses were performed to gauge the proportion of fish valve flows to bypass flows under low flow, low runoff, and low lake elevation conditions. Although, the analysis for winter conditions was slightly complicated by icing events at the upper weir, which seriously impaired accurate measurement of the flow in several cases, an evident change in stage corresponding to the two changes in fish valve position was observed in the data set. Less head at lower lake elevations result in a decreased amount of flow being released from the fish valve in comparison to the amount of flow that is released at comparable valve settings at higher pool elevations. However, releases from the fish valve were adequate, even at low pool, to maintain the 3 cfs minimum instream flow in the bypass during the winter of 2005 – 2006, as measured at the upper weir.

In summary, there are often water sources other than the fish valve that are providing flow to the bypass reach during the summer and winter months. However, when measured flows at the upper weir indicate minimum requirements are not being met, the fish valve can be opened to augment flows in the bypass reach to obtain minimum flows whether these flows are 10 cfs in the summer or 3 cfs the rest of the year. The main limitation to measuring flow accurately in the winter at the upper weir occurs when extreme cold air freezes the upper weir.

2.0 Bypass Channel Flow Augmentation Facilities

Introduction

The purpose of this study was to determine the proportion of water released by the fish valve relative to the amount of water that is measured at the upper weir. The upper weir has traditionally been the location where bypass channel flows have been measured to maintain minimum flows for compliance purposes. The question has been raised as to whether or not the flows measured at the lowermost reach of the bypass channel are reflective of the actual flows at the upstream end of the bypass reach. The study presented in this document presents analysis is of flows for two summer seasons and one winter season in the bypass reach. The goal of this analysis was to differentiate between the flow emitted by the fish valve vs. flow originating from other sources.

Description of Project Facilities

The Mystic Lake Hydroelectric Project consists of a high mountain reservoir, a five-foot diameter steel flow line, a steep penstock and a powerhouse. Water is diverted from the reservoir to the powerhouse via a flow line and penstock. Minimum bypass channel flows of 10 cfs in the summer (June 1 – August 31) and 3 cfs in the winter (September 1 – May 31) are required to maintain compliance. In order to sustain flows in the upper bypass channel, a small valve (called a fish valve) is used to bypass water at the uppermost point of the steel flow line to maintain adequate flows throughout the year.

Figure 1 shows an aerial view of the location where this valve is located. Figure 2 shows a view of the fish valve in operation. This photograph was taken in the afternoon on August 31, 2005. At the time this photograph was taken, the valve was discharging an estimated five cfs of flow. The discharge pipe is 12 inches in diameter. In the background, some flow from the waterfall (also visible in Figure 1) can be seen flowing, although the lake level was below crest elevation when this photograph (Figure 2) was taken. Therefore, all of the flow coming from the waterfall in the background is due to seepage through and under the dam and not to intentional spill.

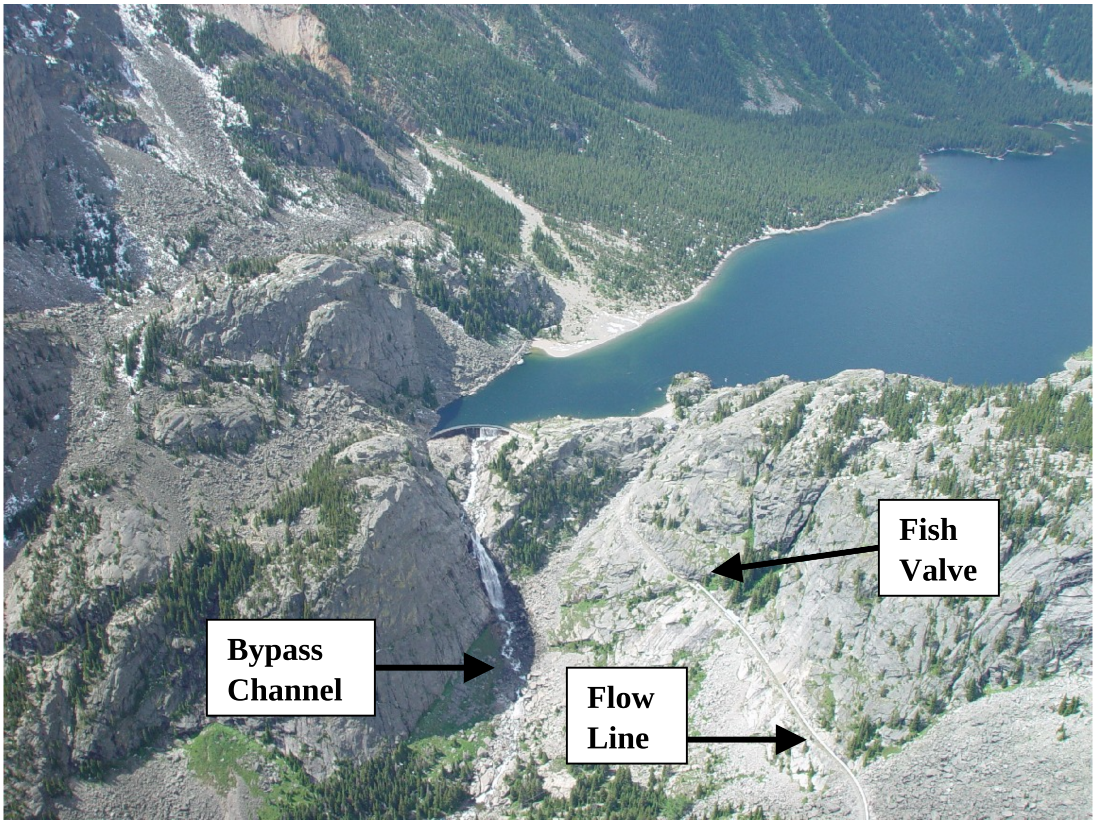

Figure 1

Figure 2

A short distance downstream of the fish valve is Maxie Creek (Figure 3); the largest tributary in the bypass reach. This photograph was taken (August 31, 2005). Numerous other small rivulets supply flow to the upper bypass channel in small amounts. At the bottom end of the bypass channel, a small weir is positioned across the creek and is fitted with a stilling well that contains a vented pressure transducer that allows the differential pressure between the pool depth and atmospheric pressure to be measured. This sensor is regularly polled by the plant PLC and data from these sensor measurements are stored in a database at the plant and on an Internet based database. Determination of the pressure differential allows for depth upstream of the weir to be accurately measured. Using the upstream depth in conjunction with a weir formula allows for the flow aross the weir to be calculated. These calculations are stored by both plant and remote databases for archiving and future analysis.

Figure 4 shows a view of the upper weir at the lowermost reach of the bypass channel. This weir provides measurements of flows at low discharge levels. The PLC records measurements taken at this weir at approximately 10-minute intervals around the clock. These data were collected in the summer of 2004 and from June 2005 to present. All available data were assembled and the relative percent opening of the fish valve was noted. For each data point, the pool elevations at Mystic Lake, and the rate of upper weir flow for each 15-minute interval were noted. A total of 19021 data points were evaluated. In situations where the fish valve flows were adjusted, the changes in flow at the lower weir were observed. It was assumed that the rapid flow changes observed at the upper weir that exactly corresponded to changes in the percent opening of the fish valve were entirely attributable to the fish valve adjustment. Hence a means of noting the amount of the position change in the fish valve resulted in a corresponding change in flow at the upper weir.

Figure 3. Maxie Creek

Several independent examples of this were observed, and in each case, identical results were obtained. From this evaluation, given the available data, it was possible to definitively estimate the amount of flow released by the fish valve as a function of the pool elevation (at values close to crest), the fish valve percent opening, and the observed flow at the upper weir.

Figure 4. Upper weir on West Rosebud Creek.

3.0 Results

Based on the analysis, it is evident that fish valve releases in summer months are sometimes low relative to flow from other sources such as leakage, tributary inflows, and other sources. Our evidence for this conclusion is based on the observation that changes in the fish valve position result in highly correlated changes in the observed flow at the upper weir. In many cases, the fish valve is closed for extended periods during summer months when no intentional spill is coming from the dam, but when the lake elevation is above crest (Figure 5). In this case, significant leakage from the flashboards could be responsible for the reduced need for additional fish valve release flows. The data clearly indicate that during the summer, significant portions of the required 10 cfs minimum flows are from origins other than the fish valve. If bypass flows become low enough, as SCADA data has shown, operators will adjust the fish valve to compensate and increase flows to make certain that the 10 cfs minimum flow is sustained, but for most of the summer, the fish valve is often completely closed, and all bypass flow is provided by leakage, tributary inflows and sources other than the fish valve.

A series of responses to fish valve adjustments were analyzed to estimate the amount of change in flow that was experienced due to a change in fish valve position. It is notable that

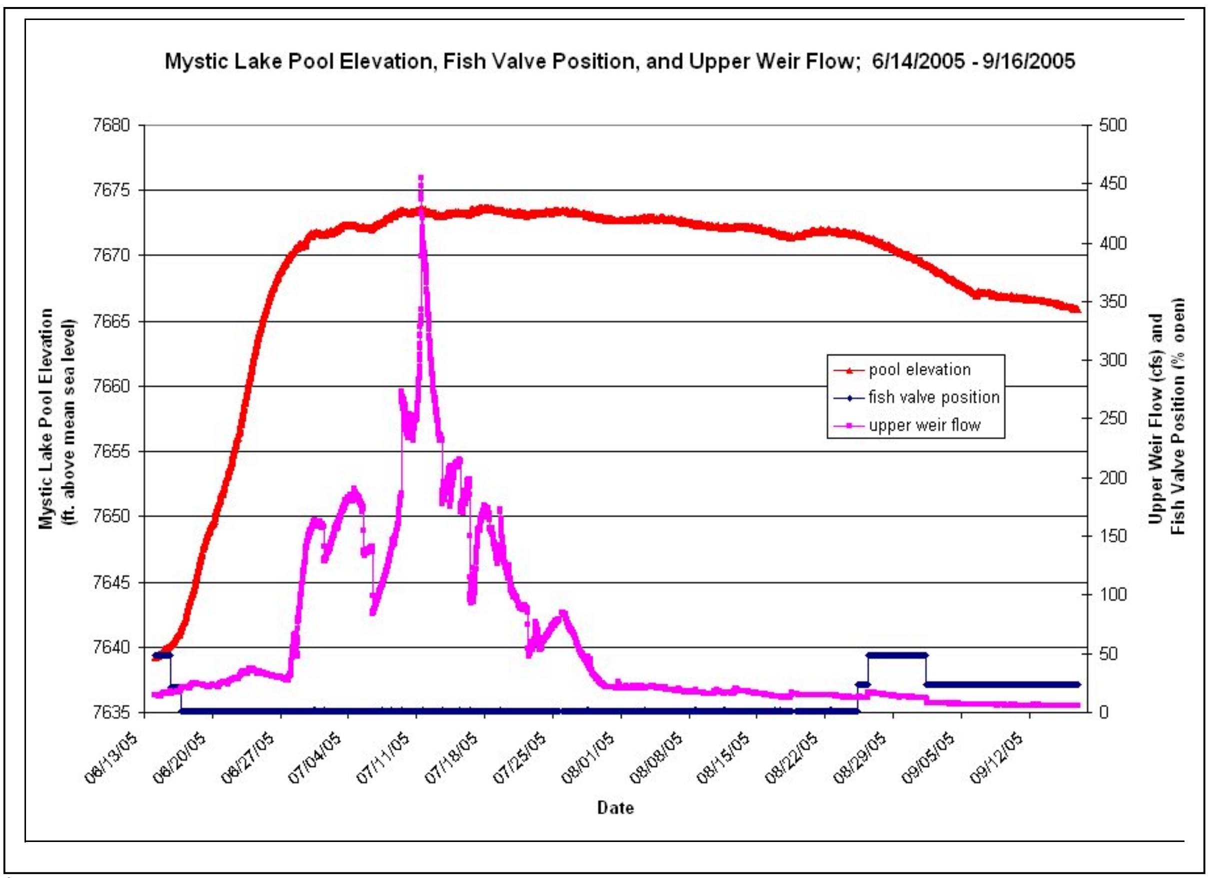

Figure 5

in many cases, the fish valve would be completely closed, so that all flow in the upper bypass channel was due to tributary influx, or subduction of flows under or through the dam. Cases where the dam was spilling are automatically excluded from the observation set because the fish valve is never open during spill events. Figure 5 shows the data set for the summer of 2005. Figure 6 shows a close-up view of the area in the lower right side of Figure 5 at the point where the fish valve was opened. This is one of two examples where the positions of the fish valve were changed from zero to 25% and then from 25% to 50% open and then back down from 50% to 25%. Flows at the lower weir were measured and the changes in flow were calculated.

At the point where the fish valve is opened from fully closed to 25% open, the change noted at the lower weir was 0.83 cfs. The valve was opened from 25% to 50% a short time later, with a resulting change in flow at the lower weir of 4.11 cfs. When the valve was later closed back down to 25% from the original 50%, the corresponding decrease in flow at the lower weir was 4.2 cfs; almost exactly the same amount of decrease as was yielded by the increase when the valve was opened by that amount earlier on. Based on these resultant changes in flow, it can be concluded that when the fish valve was first opened from 0% to 25,

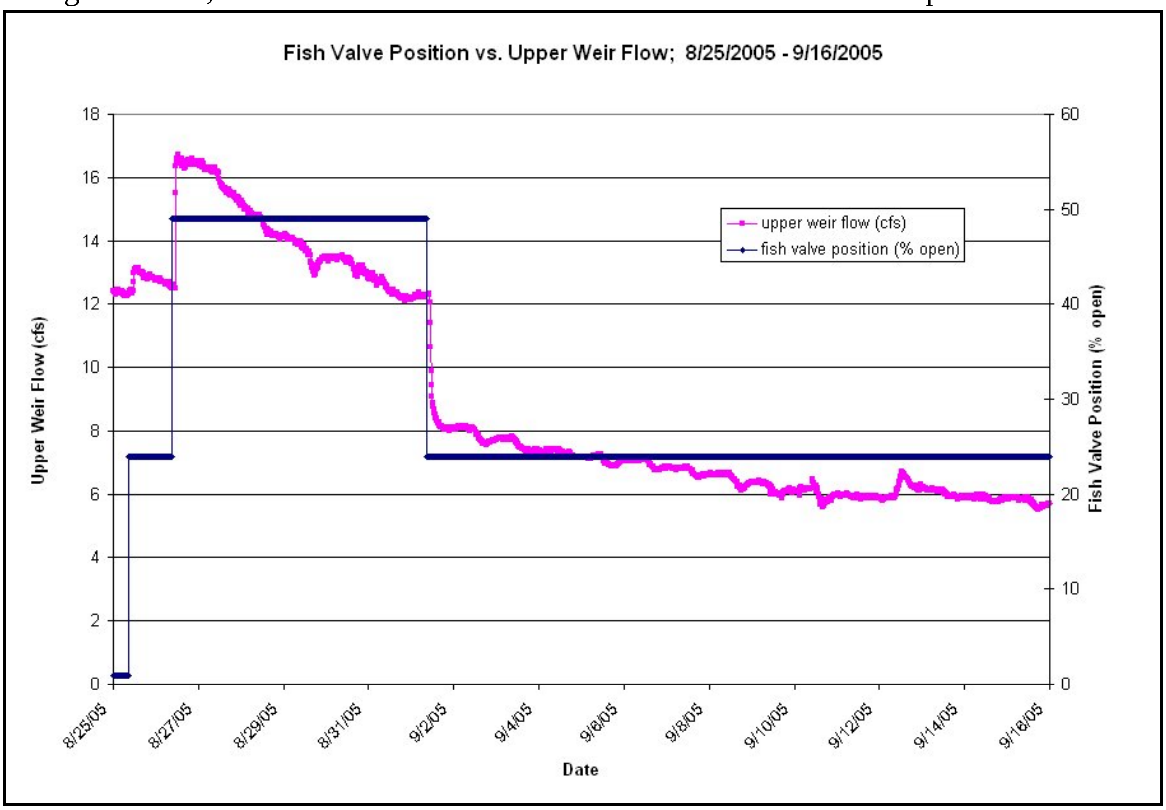

Figure 6

the contribution to flow in the bypass channel was initially zero. The increase in flow that occurred was about 0.83 cfs, because the river flow rate at the upper weir changed from 12.3 to 13.13 cfs. This represents 0.49% of the total flow at the upper weir. When the fish valve was soon opened further to 50% open, the change in flow at the upper weir went from 12.59

to 16.7 cfs. This represents a change in flow of 4.11 cfs when changing the valve from 25% open to 50% open. Adding the 0.83 cfs for the 0 to 25% portion brings the total flow through the valve to 4.94 cfs. Since the total flow at the upper weir was measured at 16.7 cfs, the percentage at that point coming through the fish valve was 29.6% of the total bypass channel flow. The effect was nearly identical later on when the valve was closed back down from 50% open to 25% open. In that case, the flow rate decreased from 12.3 to 8.1 cfs, which totals a drop of 4.2 cfs, nearly identical to the 4.11. cfs increase observed during the opening from 25% to 50%.

Figure 7 shows the responses when during fish valve position changes made in 2004. In this case, the valve was adjusted between fully closed and openings up to 65%. This time, the change from 0% open to 25% open resulted in a flow increase from 12.09 to 12.87 (0.78 cfs). When the valve was opened from 25% to 50%, the flow increase changed from 12.46 to 16.56 cfs (4.1 cfs). These are practically identical to the results obtained in 2005. Increasing the valve opening from 50% to 65% caused flow to increase from 11.75 to 14.3 cfs (2.55 cfs) for a total flow through the fish valve of 7.43 cfs; or approximately 52% of the total bypass channel flow when the fish valve is 65% open.

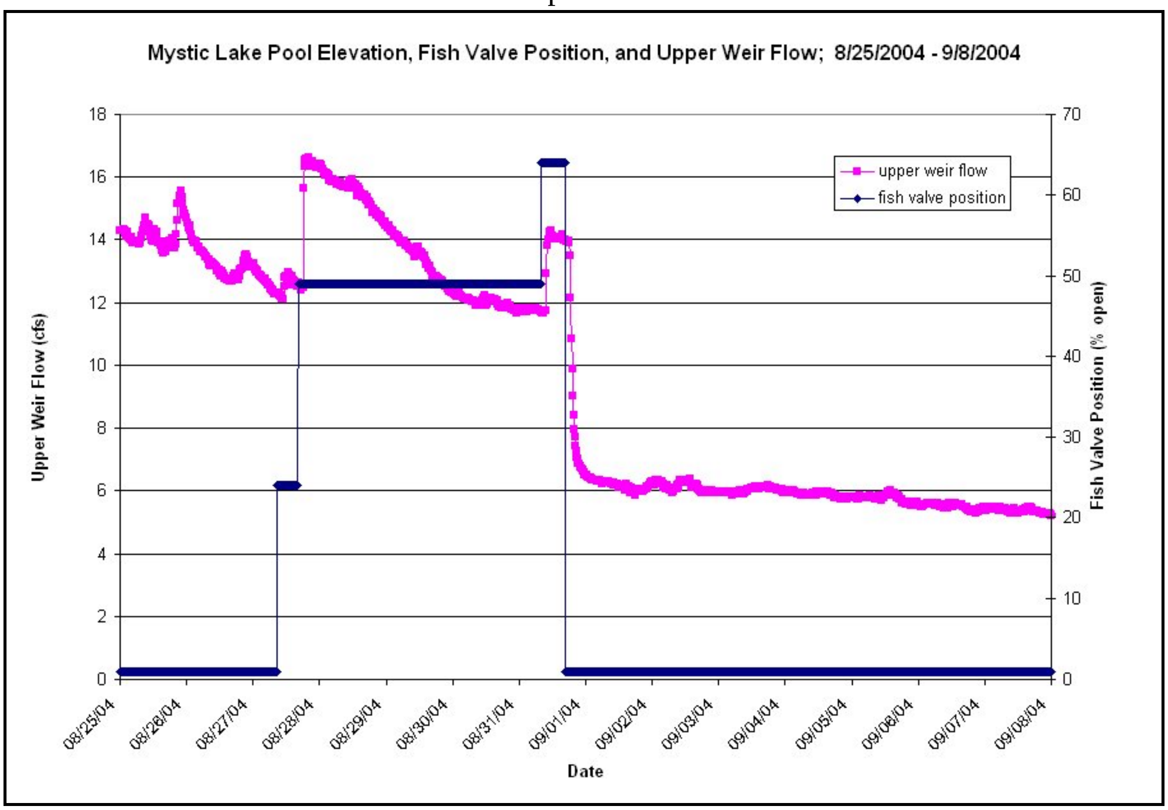

Figure 7

Based on these results, a chart was constructed to display the observed relationship between the valve setting and the resulting discharge at near full pool lake elevations. This chart appears in Figure 8.

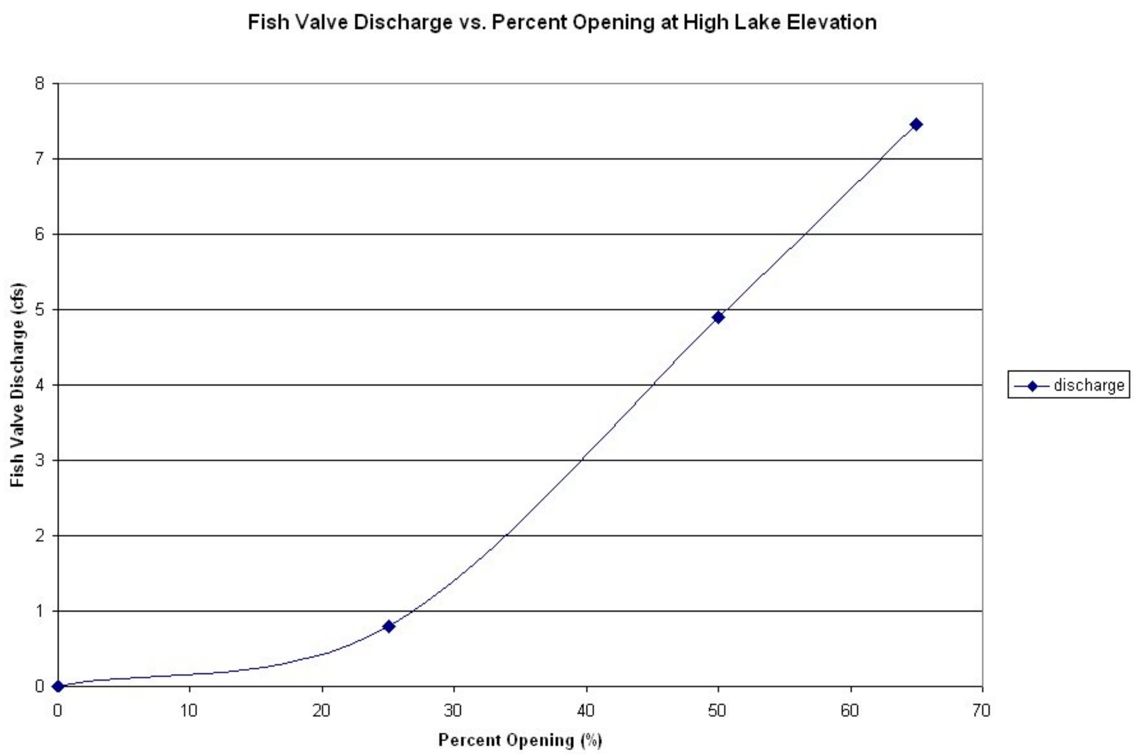

Figure 8

Additional data representative of wintertime conditions were collected from December 9, 2005 to March 8, 2006. A second analysis was performed to gauge the proportion of fish valve flows to bypass flows under low flow, low runoff, and at lower lake elevations. These measurements have yielded a small amount of additional data for the fish valve when operating at reduced pool elevations.

A comparison of the Mystic Lake reservoir elevation vs. flow in the upper weir and the fish valve position for the period from 12/9/2005 to 3/8/2006 is presented in Figure 9. During this period, the fish valve percent opening was increased twice; once from 34% to 54% (December 22, 2005) when Mystic Lake reservoir was at an elevation of 7644.84 ft, and a second time where the valve opening was increased from 54% to 74% (February 27, 2006) when the reservoir pool was at an elevation of 7625.02 ft. During the winter period, operators reported substantial icing, which seriously impaired accurate measurement of the flow in many cases. However, an observable change in stage corresponding to the two changes in fish valve position was seen in the data set. It should be noted that for this analysis we used the operators log records at the time the fish valve was opened, which varied from the SCADA data by a few hours.

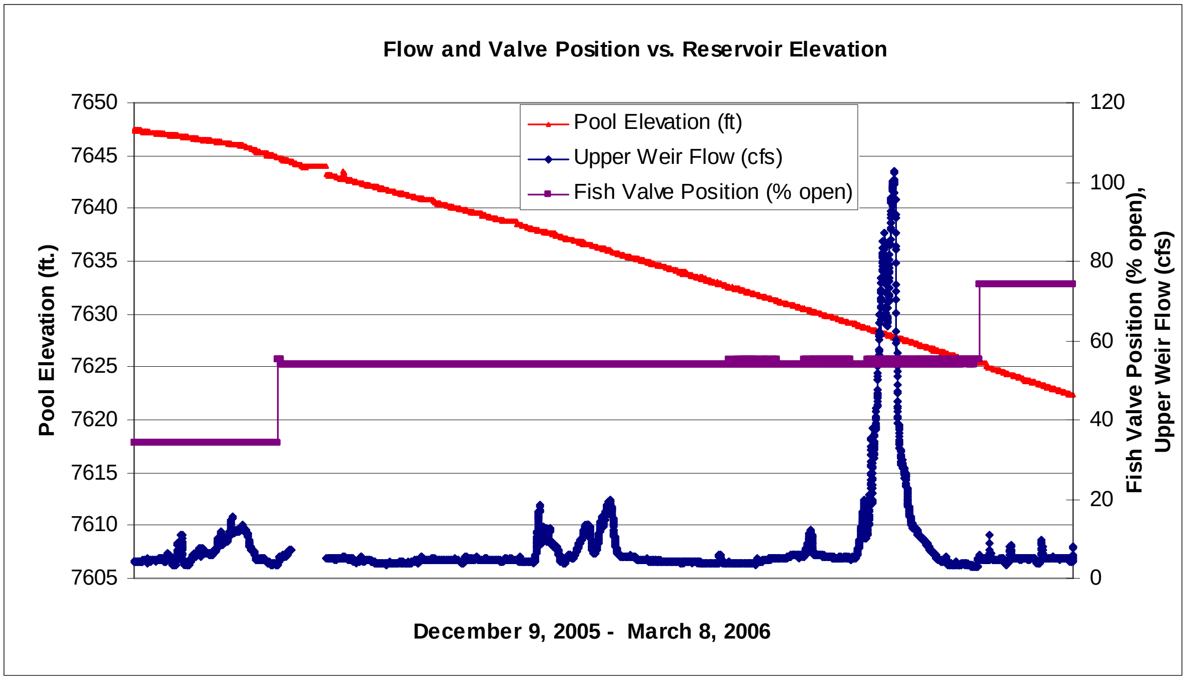

Figure 9

The spike in flow measure in mid-February is attributed to extreme cold temperatures and ice conditions over the upper weir, which impaired the ability of the sensor to accurately measure flow (Figure 10). The high and low temperatures at the powerhouse on February 17, 2006 were -6 ˚F and -25 ˚F, respectively. The extreme cold temperatures continued until February 25, 2006. The high flow measurements (up to 100 cfs) are a result of ice and are not accurate estimates of actual flow. Prior to the spike in flow as shown in Figure 10, the stream at the upper weir was flowing 5 cfs (D. Robinson, PPL Montana, personal comm., 3/27/06).

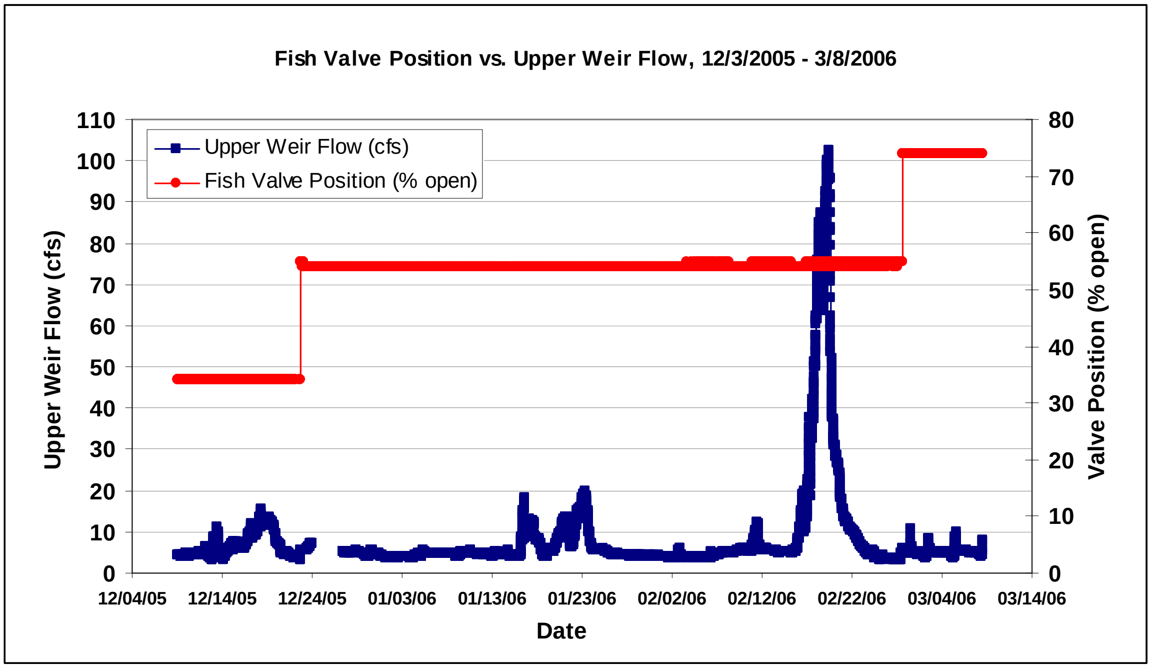

Figure 10

Other flow fluctuations observed over the winter, such as the mid-December (12-18-05) and mid-January (2-22-06) when flows increase to about 15 cfs from 3-5 cfs, could have been due to a icing at the upper weir or thaw causing issues with the sensor. These flow fluctuations were not a result of changes in the fish valve position. A review of the National Weather Service daily air temperature data from Billings indicate high and low temperatures ranged from -3˚F to 16˚F in mid-December and were a bit warmer in January with lows in the mid-20s ˚F and the highs in the low 40s ˚F (Available: http://www.weather.gov/climate/index.php?wfo=byz). Therefore, these higher flow periods may represent icing events (e.g. December) or daily thawing and nightly freezing (January).

Figure 11 shows the response at the lower weir for a valve opening increase from 34% to 54%. The flow rate increased to 5.53 cfs from an initial flow rate of about 3.34 cfs. This represents a change of about 2.2 cfs. At the higher head seen in the summer data, an equivalent valve opening resulted in about a 3.5 cfs increase in the flow for an equivalent change in percentage opening from 35 to 55%. Hence, the approximately 25 foot reduction in reservoir elevation head reduced the valve output by about 1.3 cfs over what it was capable of releasing at full reservoir elevation.

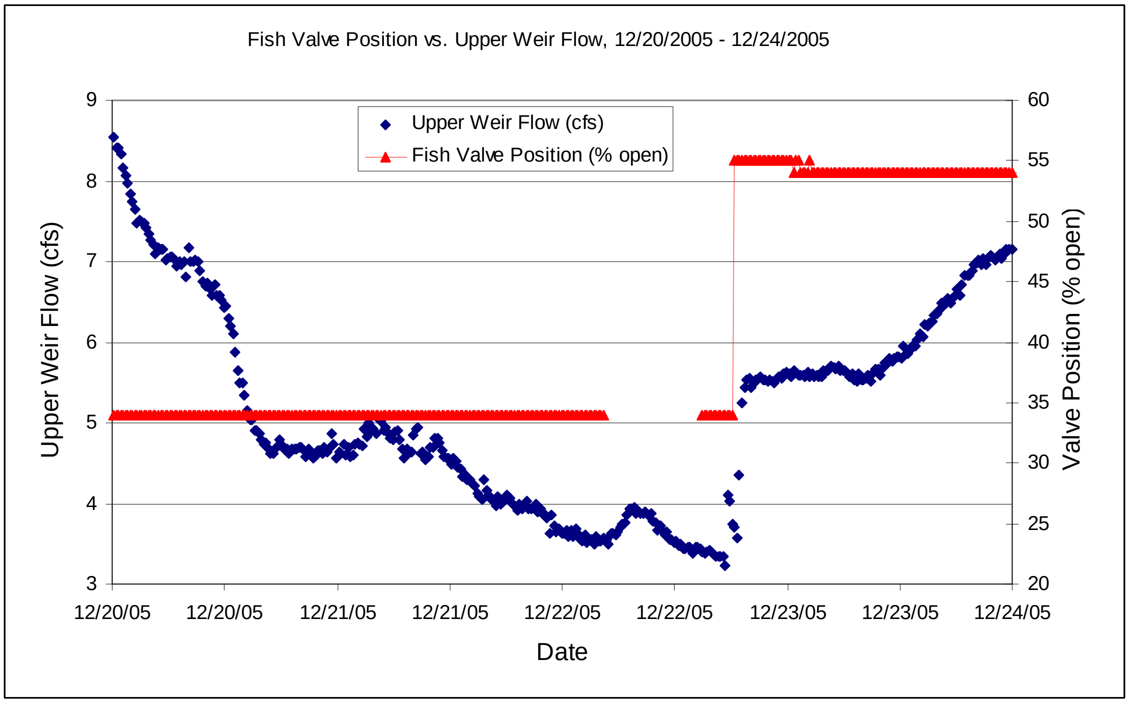

Figure 11

Figure 12 shows the response at the lower weir for a valve percent opening increase from 54% to 74%. The flow rate increased to about 4.8 cfs from an initial flow rate of about 3 cfs. This represents a change in flow of about 1.8 cfs vs. about 3 cfs for the same valve setting with a near full reservoir. In this case, the effect of the pool elevation reduction from 7670 ft to 7625 ft (a difference of roughly 45 ft) reduced the output of the valve by about 1.2 cfs.

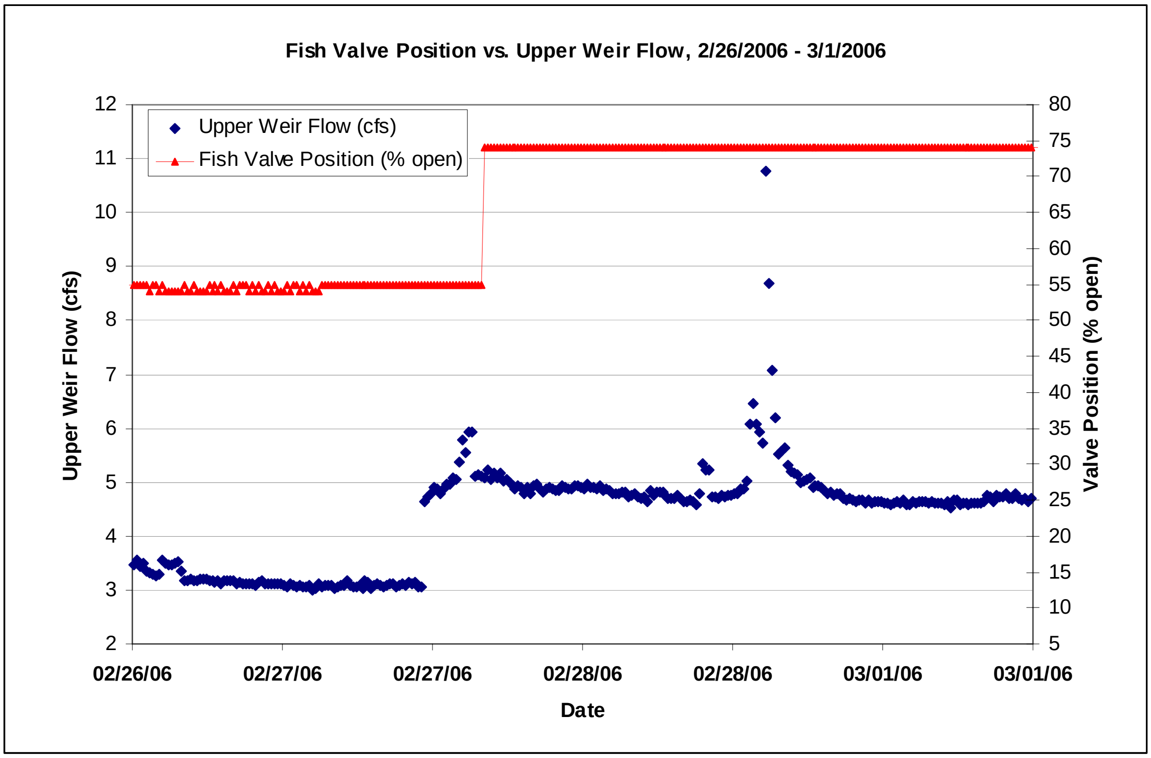

Figure 12

In every case, the performance of the valve is diminished by the reduction in pressure head due to lower reservoir pool elevations. It can be assumed that the output of the valve at reduced head will always be less than the same valve with the same setting but at higher heads. Therefore, it can be assumed that the valve, when operating at 35% open will deliver no more than 2 cfs (see figure 8) and likely less than this value. Hence, at least 1.34 cfs (at least 40%, or more) must have come from sources other than the fish valve to account for the observed flow rate of about 3.34 cfs while the valve was operating at 35% open at a pool elevation of 7644.84 ft.

4.0 Conclusion

In summary, this study analyzed summer and winter flows in the bypass reach. The goal of this analysis was to differentiate between the flow emitted by the fish valve vs. flow originating from other sources and determine how much flow the fish valve emits to the upper bypass channel versus the amount flow measured at the upper weir under summer and winter conditions.

During the summer (June-August), the data clearly indicate that significant portions of the required 10 cfs minimum flows are from origins other than the fish valve. The fish valve is often completely closed and all bypass flow is provided by leakage, tributary inflows and sources other than the fish valve. If bypass flows become low enough, as SCADA data has shown, operators can and will adjust the fish valve to compensate and increase flows to make certain that the 10 cfs minimum flow is sustained.

Winter flows evaluated from December through March are defined by: low flow, low runoff, and lower lake elevations. During this time period the required minimum flow in the bypass reach is 3 cfs. Although, the analysis for winter conditions was slightly complicated by icing events at the upper weir, which seriously impaired accurate measurement of the flow in several cases, an evident change in stage corresponding to the two changes in fish valve position was observed in the data set. When the valve position increased from 34 to 54% open, the flow rate increased 2.2 cfs, from 3.34 cfs to 5.53 cfs. When the valve position increased from 54 to 74%, the flow rate increased 1.8 cfs, from 3 cfs to 4.8 cfs. The analysis also found that the overall performance of the fish valve is diminished by the reduction in pressure head due to lower reservoir pool elevations. The winter analysis concluded that the fish valve could deliver no more than 2 cfs when operating at 35% open (see figure 8). The data also suggest that at least 1.34 cfs (at least 40%, or more) must have come from sources other than the fish valve to account for the observed flow rate of about 3.34 cfs at the upper weir while the valve was operating at 35% open at a pool elevation of 7644.84 ft.

In summary, there are often other sources than the fish valve are providing flow to the bypass reach during the summer and winter months. However, when measured flows at the upper weir indicate minimum requirements are not being met, the fish valve can be opened to augment flows in the bypass reach to obtain minimum flows whether these flows are 10 cfs in the summer or 3 cfs the rest of the year. The main limitation to measuring flow accurately in the winter at the upper weir occurs when extreme cold air freezes the upper weir.