UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

PROJECT REPORT 462

The Physical Model Study of the Fish Bypass Louver System of the School Street Hydroelectric Project

By

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Abstract

To determine the head losses associated with a 20-degree fish bypass louver system proposed for the School St. Hydroelectric Project in Cohoes, NY, a physical model study of a section of the channel leading to the power house and the louver structure was conducted at St. Anthony Falls Laboratory. The model scale was 1:14. The tests were conducted under 3,100, 5,100 and 7,100 cfs flow conditions, and three louver configurations: 1) 2-inch bar spacing, 2) 4 3/8-inch bar spacing and 6 3/4 & 4 3/8 & 2-inch bar spacing. In addition to head loss, other parameters such as water surface drop across the louver, and flow velocities along the louver as well as upstream of the louver were measured.

The results of the model study show that the louver with 4 3/8-inch bar spacing configuration creates the smallest head loss among the three configurations, i.e. about 0.8 ft under 7,100 cfs flow condition; the highest normal velocity at a 0.9 ft distance of the louver surface occurs near the fish bypass but does not exceed 4 fps. The sweeping velocities along the 4 3/8-inch bar spacing louver increase along the louver reaching a maximum of 6.5 fps near the fish bypass and are similar to those along the 2-inch bar spacing louver.

Acknowledgements

The work reported herein was supported by Reliant Energy/Kleinschmidt Associates, and Mr. Tom Kahl from Kleinschmidt Associates was the project manager. We would like to thank Richard Christopher, Mike Plante, Diana Smith, Brett Otteson, Ben Erickson, Matthew Leuker, Ryan Fleming, Andrew Fyten, Alex Ding and Luke Carlson of St. Anthony Falls Laboratory for their contribution to the model construction, instrumentation and data collection.

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1. Introduction

Reliant Energy requested a model study of the hydraulic impacts resulting from the construction of a fish bypass louver system in the water conveying channel to the School St. hydroelectric Power Plant at Cohoes, NY. The hydroelectric power plant is located about one mile downstream of a gate house at the south end of the School St. Dam on the Mohawk River (Figure 1). The proposed louver is expected to be built about 500 feet downstream of the gate house. In addition and in order to increase the capacity of the channel leading to the powerhouse, excavation from the channel bed has been proposed.

The scope of this study was to build a physical model of a 20-degree louver fish bypass (the longitudinal axis of the louver redirects the flow direction by 20 degrees) with several bar spacing configurations and for future channel condition, i.e. after the proposed excavation, and to determine the additional energy loss associated with the louver structure. Additional tasks were to measure the normal and sweeping velocities along the louver under 3,100, 5,100, and 7,100 cfs flow conditions. A critical requirement for Reliant Energy was that the maximum energy loss should not exceed 1 ft under 7,100 cfs flow condition. In addition, it was desired that the cross-vane velocities approaching the fish bypass would not exceed 5 fps.

2. Project Approach

To minimize cost and increase effectiveness, the model study included a deliberate incremental approach where the number of tests, procedures, and measurement techniques were determined and finalized as the testing progressed. Following are the project steps in chronological order.

- The project started on October 6, 2003.
- The model construction, calibration and initial testing ended on January 15, 2004 within the original schedule.
- On January 15, representatives from Reliant Energy, US Fish and Wildlife Service (USFWS), and Kleinschmidt Associates visited SAFL and viewed the constructed model. During the on-site visit, the model geometry, calibration, and testing procedures were confirmed in collaboration with SAFL.
- Following the site visit, the model review and testing details were summarized, and then reviewed and approved by Reliant Energy and the USFWS. SAFL received authorization on 2/9/04 to proceed with minor corrections of the physical model and with testing the 2-inch bar spacing louver under both clear and 30% blocked conditions.
- The model modifications were completed in February and SAFL performed the testing in March which they reported via email on 3/29/04.
- These results were discussed at the 3/30/04 School St. meeting at Reliant Energy's office, and direction for the final testing scenarios was conveyed to SAFL on 3/31/04. The final testing was completed providing interim results on 5/3/04.
- The comprehensive draft report was provided and submitted on 5/13/04.

3. Model Construction

To determine the louver head loss, it was necessary to accurately simulate the approach flow to and through the louver structure. As is evident from Figure 1, the gate house structure has a non-symmetrical position with respect to the canal leading to the powerhouse with small sluice gates on the east side of the gate house and large taintor gates on the west side of the gate house. This configuration causes a non-uniform approach flow condition in the channel upstream of the proposed louver. To correctly model the flow patterns, it was decided to build the physical model from the gate house to some point downstream of the louver structure.

The model was built at St. Anthony Falls Laboratory at a scale of 1:14. With a 1:14 scale Froude similarity, the flow patterns can be correctly reproduced while the flow regime stays turbulent. Using a 1:14 scale Froude similarity, flow parameters were scaled as follows:

Length	1:14
Area	1:196
Volume	1:2744
Flow rate	1:733.4
Velocity	1:3.74
Time	1:3.74

3.1. General Features of the Physical Model

The physical model consisted of a head tank upstream of the gate house representing the reservoir, the gate house and 1120 ft of the channel. In the model, the Mississippi River water was discharged into the head tank using a multi-port diffuser. Figure 2 shows the layout (plan view) of the constructed model. In the head tank, water, after being discharged through the ports of the diffuser, flowed over a weir into a stilling basin with a second overflow weir. By utilizing a short sill, chicken wire screens, and a floating board, surface turbulence of the flow approaching the gate house was minimized (Figure 3). The gate house was the downstream end of the head tank; it had no gates and was operated at fully open conditions. Gate no. 9 is not currently in operation; therefore, initially the model was built with no opening for gate no. 9 (Figure 4). Since Reliant Energy is planning to repair this gate in the future and to bring it back into operation, the gate no. 9 opening was later added in the physical model.

To accurately simulate water surface elevations at the downstream end of the conveyance channel, a tilting gate was built and mounted at the downstream end of the model. A belt control crank was used to adjust the gate (Figure 5). The geometry of the gatehouse structure and the conveyance channel was taken from drawings supplied by Kleinschmidt Associates. The model was built of plywood, sealed and painted to minimize leakage.

The water supply into the 12-inch multi-port diffuser at the upstream end of the head tank was controlled by two valves in a 12-inch and an 8-inch water supply lines connected to the laboratory Supply Channel. Model flow rates varied from 4.63 cfs to 11.32 cfs to represent the prototype flows for the model calibration and model testing.

3.2. Louver Structure

The proposed prototype louver structure consists of fixed 2½″ × 3/8″ bars with 2-inch spacing. For structural purposes, a W6×20 column will be built at every 5 ft (Figure 6). The upper and lower beams of the model louver structure were built from aluminum and the bars were built from stainless steel to withstand the forces due to change of momentum in the flow approaching the louver bars. The model bar dimensions were 0.18″ × 0.027″. The initial model bar spacing was 0.143″ to simulate the 2-inch spacing of the prototype. A sample of the louver with a horizontal bar in the middle was tested in a 6-inch flume under the maximum expected flow velocity. The sample did not exhibit any significant deflection, i.e. deflections were smaller than 0.03″, and no visible vibration. To simulate the hydraulic effects of the W6×20 columns, rectangular bars with 0.142″ × 0.145″ dimensions were built from aluminum. To simulate an eel passage, the channel floor upstream of the louver structure was sloped by 1(V):4(H) (Figure 7).

3.3. Fish Bypass

A fish bypass was constructed at the downstream end of the louver structure. The flow through the fish bypass was controlled using a sluice gate. The sluice gate was graduated to measure the gate opening. The water surface difference between upstream and downstream of the sluice gate was measured by connecting an inverse U-tube manometer to two pressure taps mounted next to the channel bed upstream and downstream of the gate (Figure 8). The difference in water elevations in the two stems of the manometer would give the water elevation difference. The accuracy of measuring flow through the fish bypass was ±5%.

3.4. Instrumentation

To measure water surface elevations, six wet wells were provided (see Figure 2). The wells were connected to the bottom of the channel, close to the middle of each cross-section via pressure taps and ¼-inch plastic tubes. The pressure taps were located upstream of the gate house (Point 2), 110 ft downstream of the gate house at cross-section 15.75[1] (Point 3), at the bend downstream of the gate house (Point 6), at a point upstream of the louver (Point 7), at cross-section 14 (Point 4) and at cross-section 13.888 (Point 5). Points 6 and 7 were added later to measure the head loss due to flow separation downstream of the bend. Water levels in the wet wells were measured using point gages with a precision of 0.001 ft. The zero points of all gages were determined from a single datum when the entire model was filled with standing water. Figure 9 shows the wet wells used to measure the water surface elevations at cross-sections 14 and 13.888. Five readings were made on each point gage during each test, and averaged.

To measure water velocity, a carriage was built and installed on the model, which could travel from 4 ft upstream of the louver structure to 4 ft downstream of the louver structure. A two-dimensional Sontek FlowTracker Acoustic Doppler Velocimeter (ADV) was mounted on the carriage, which could measure velocity of a cylindrical sampling volume (0.24″ diameter, 0.35″ height) located 4 inches away from the probe with an accuracy of +/-1.0% (Figure 10). The ADV was tested on the diagnostic mode and showed that it could measure velocity 0.7″ away from the louver without influence, i.e. 0.9 ft away from the prototype louver. All velocity measurements were taken at 20% and 80% of the total water depth.

To measure water surface drop across the louver, two MassaSonic M-5000/220 Smart Ultrasonic Sensors were mounted on the carriage and connected to a PC. The MassaSonic Emits a pulse of high-frequency (220 kHz) sound and measures the time taken for the signal to return. Sensing ranges from 4 to 40 inches. Sound is emitted in a narrow (8°) conical beam. In our case, probes were held about 6" (7 ft in the prototype) above the water to reduce the effect of temperature

[1] Cross-section 15.75 was an interpolated cross-section in the HEC-RAS model of the channel and corresponded to the location where water surface elevations were measured at the site.

gradients in the air. Listed accuracy is +/-0.25% of the maximum distance. Using a 6″ distance, accuracy works out to be about 0.0012 ft, which is close to the observed repeatability of 0.001 ft. Accuracy was significantly improved through averaging of roughly 400 individual measurements.

To measure total flow through the model, a pressure tap was mounted at the end of the diffuser in the head tank. The pressure tap was connected to a graduated wet well. The wet well readings were calibrated using the SAFL weigh tanks. Figure 11 shows the results of the calibration.

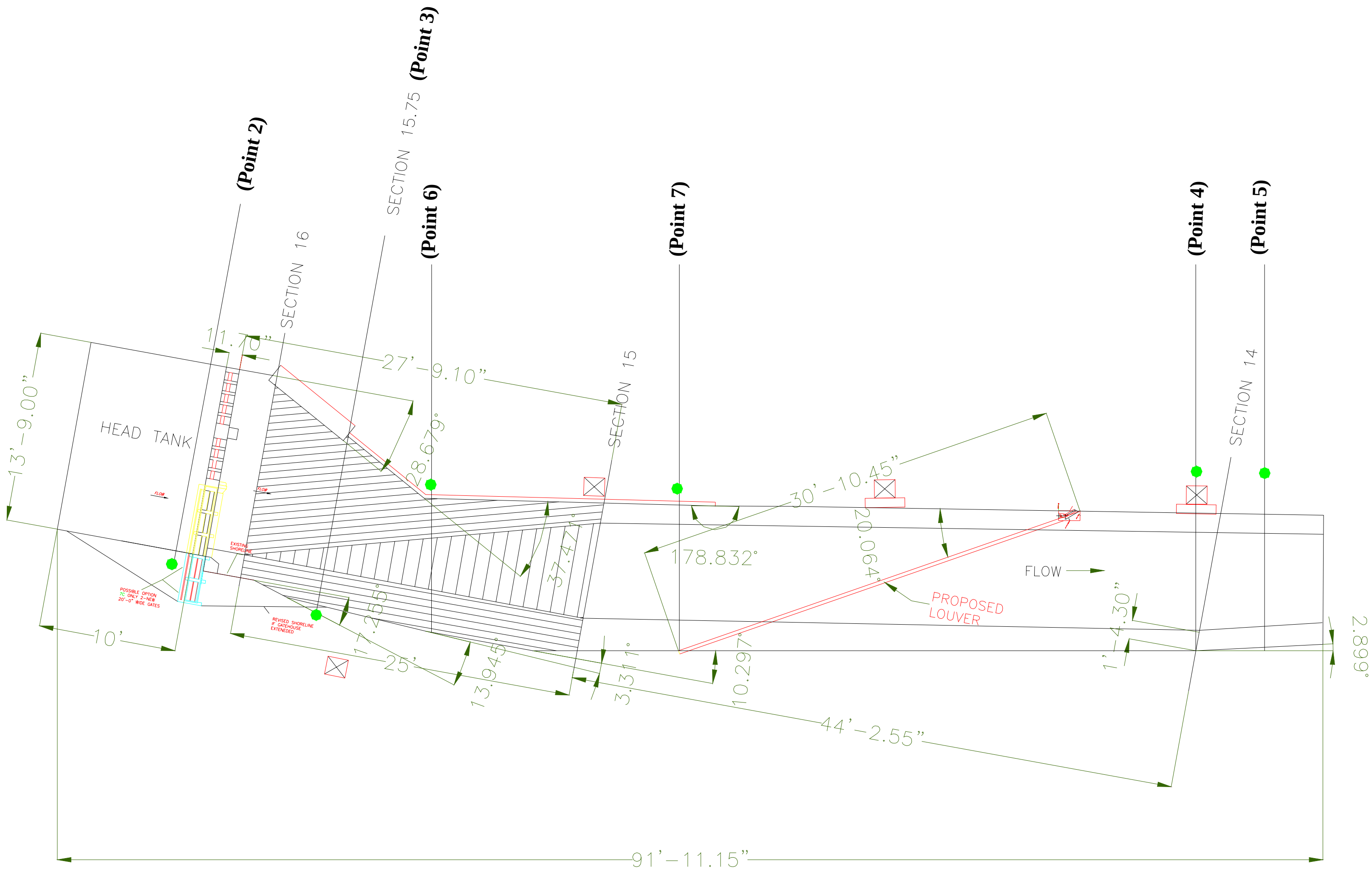

Figure 2. Layout of the model constructed in St. Anthony Falls Laboratory. Points 2 to 7 show the cross-sections where water levels were measured.

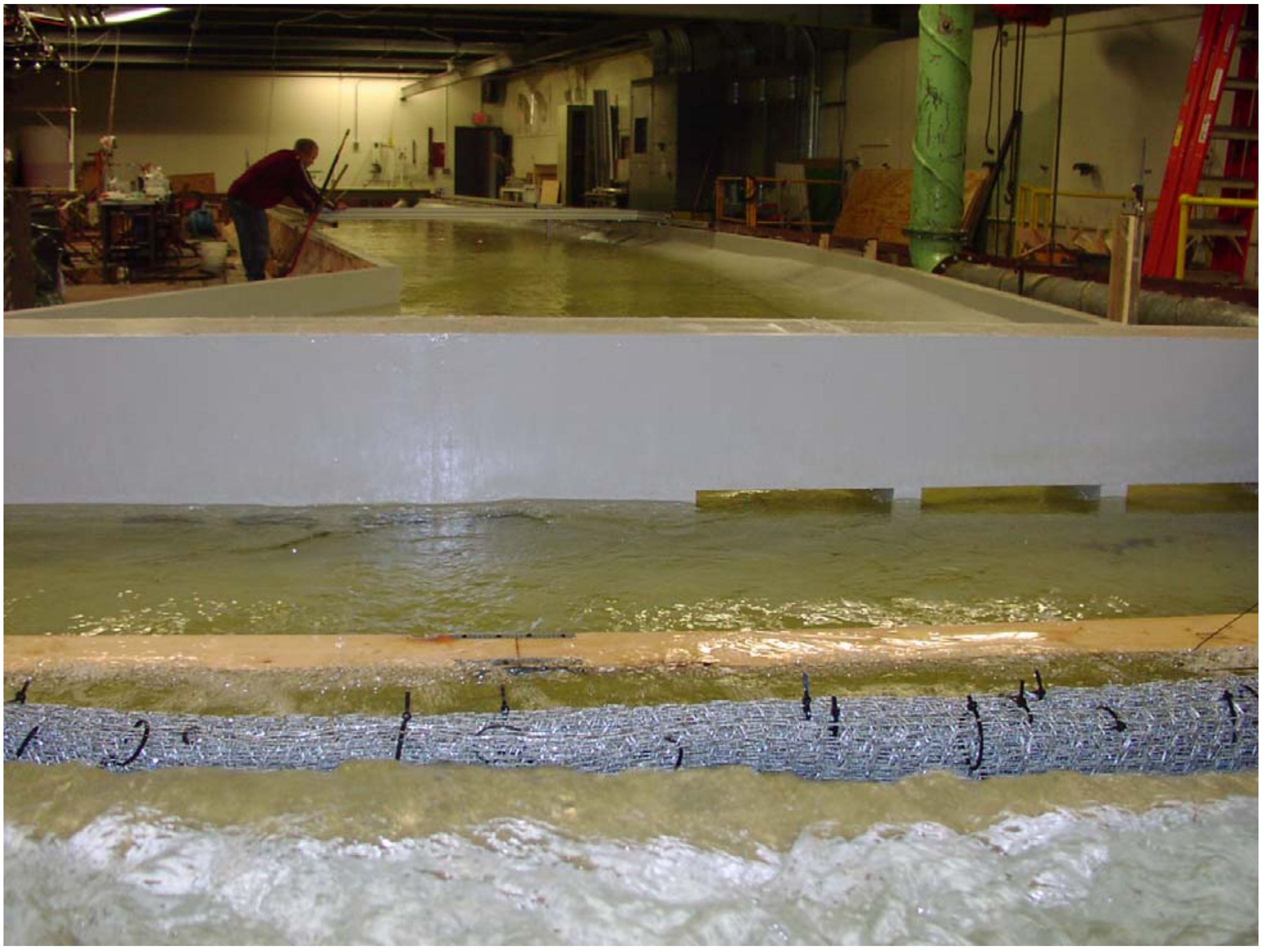

Figure 3. Views of water in the head tank and flow into the gatehouse and canal in the background. A sill, wire screen and a floating board reduced the surface turbulence from the approach flow upstream of the gate house.

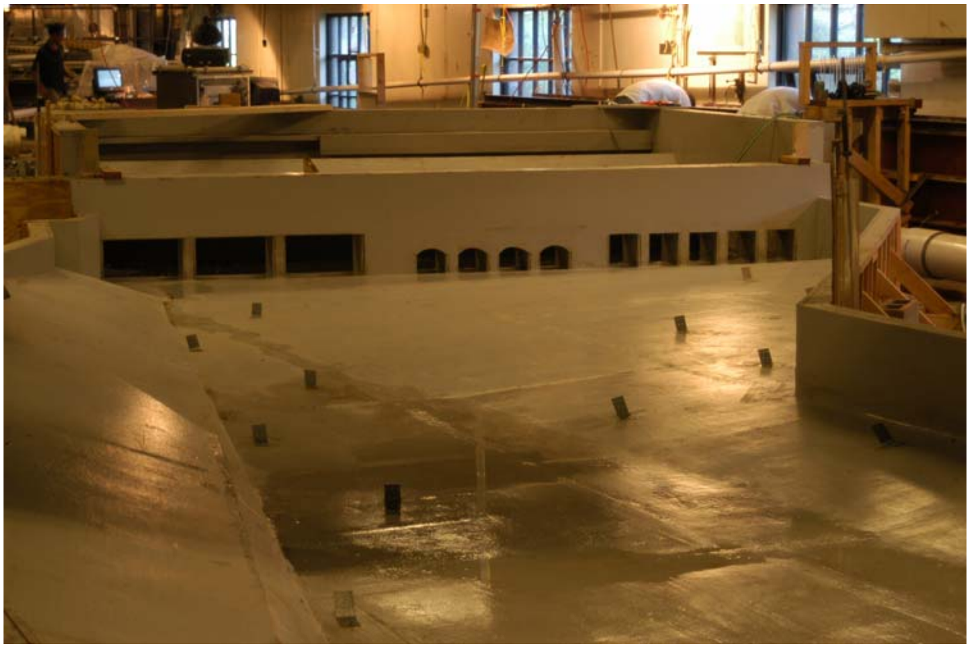

Figure 4. View of the model gate house from downstream.

Figure 5. The tilting gate at the end of the model to control the downstream water level boundary conditions.

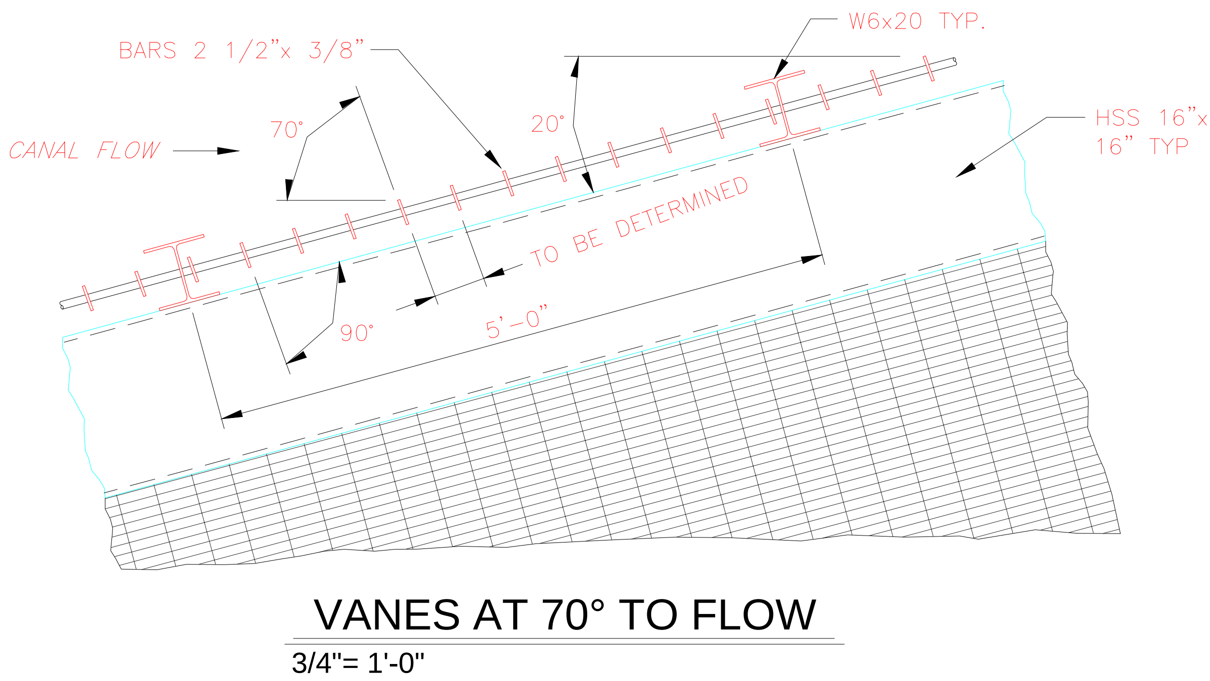

Figure 6. Plan view of the prototype louver structure.

Figure 7. View of the model louver structure from upstream. The sloped board at the bottom is the eel passage.

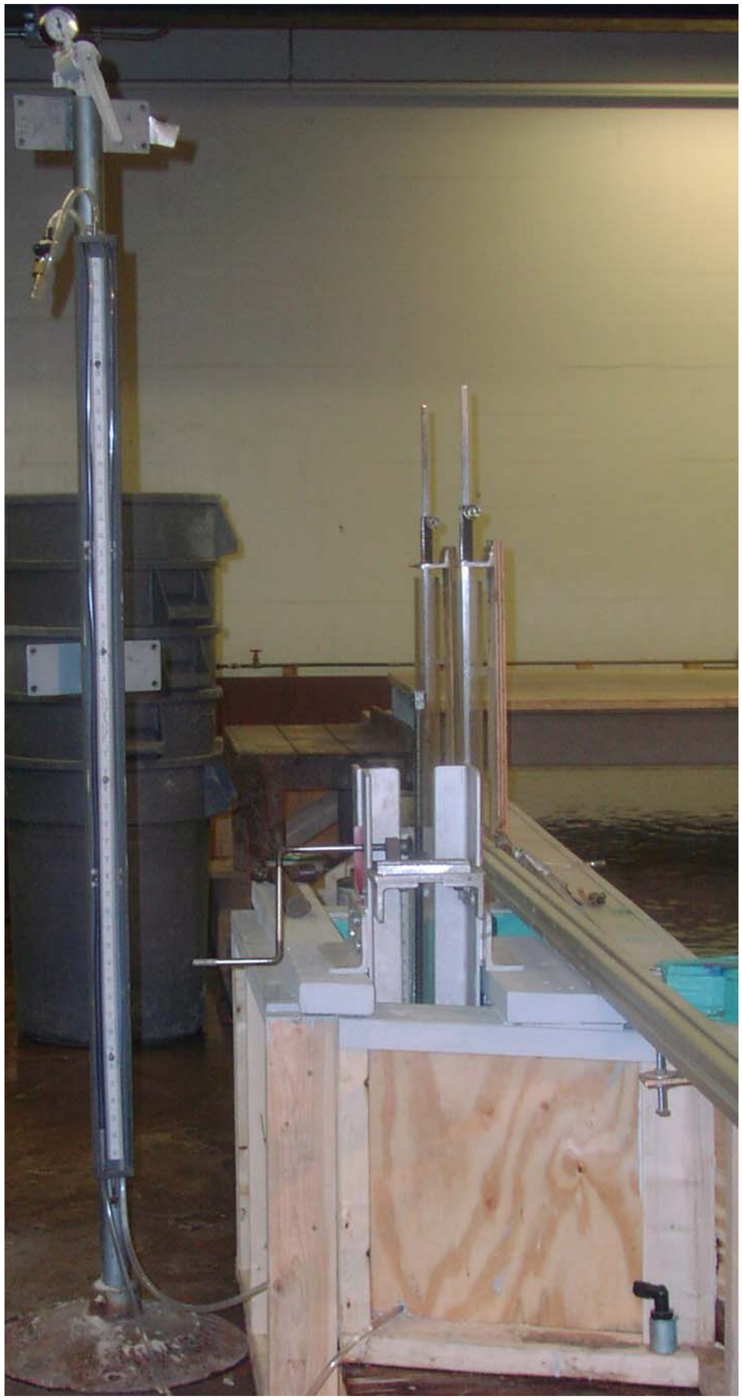

Figure 8. The fish bypass sluice gate and the inverse U-tube manometer to measure the water surface difference upstream and downstream of the gate.

Figure 9. The wet wells for reading water surface elevations at cross-sections 14 and 13.88.

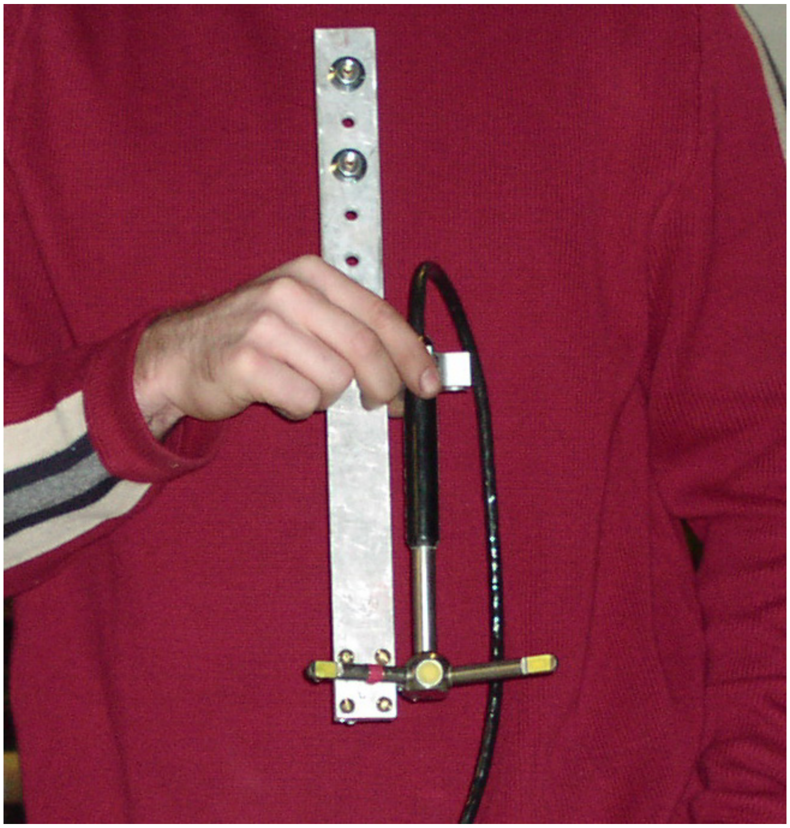

Figure 10. The Acoustic Doppler Velocimeter used to measure flow velocities.

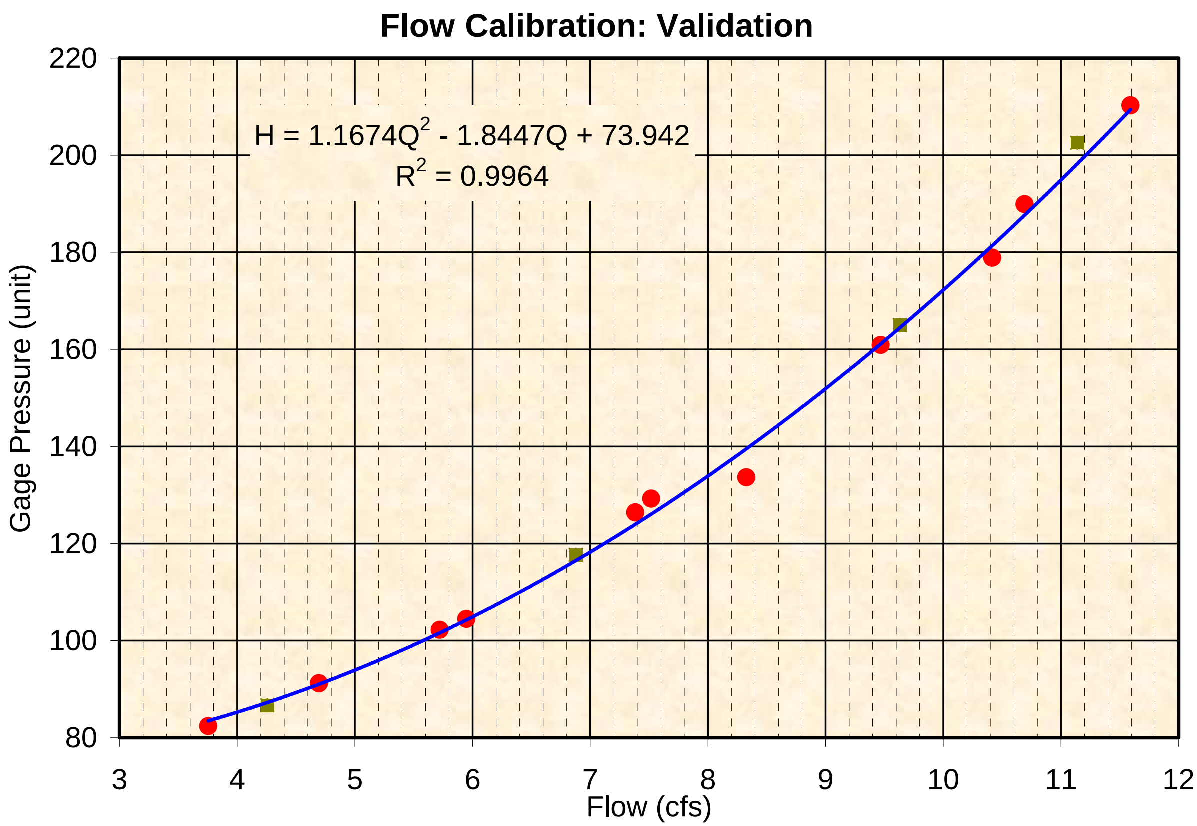

Figure 11. To calibrate the graduated wet well for flow measurements, the wet well reading (gage pressure) was plotted versus the measured flows using the SAFL weigh tanks. The circles are the original data to which the quadratic function shown on the graph was fitted. The square markers were flow measurements taken subsequently to validate the quadratic function.

4. Model Runs and Results

Five series of tests were conducted. The first series of tests were with no louver in the channel, and the other 4 series were with the louver installed in the channel. The results of these tests are summarized in the following sections.

4.1. No Louver Condition / Model Calibration

Before installing the louver structure and constructing the fish bypass, the channel flow regime needed to be tested and calibrated against water surface elevations observed in the prototype. Since the physical model was built to test the impact of the proposed louver on the water surface elevation in the channel reach under future conditions, i.e. a channel approximately 5 feet deeper than the existing channel, the prototype observations could not be directly compared to measurements in the model, because the existing channel is not geometrically similar to the model. It was also expected that the channel bed roughness would change after excavation, from its existing condition; therefore, the following procedure for the physical model calibration was proposed by SAFL and approved by Kleinschmidt and Reliant Energy.

Using the water surface elevations observed in the existing prototype channel, the existing HEC-RAS model of the reach (which was provided by Reliant Energy), was calibrated for Manning's *n*. Using the calibrated Manning's *n* under existing conditions and the pictures provided by Kleinschmidt, SAFL proposed the best estimate of the future Manning's *n* of the reach after excavation. The physical model was then calibrated against simulations with the HEC-RAS model for projected future conditions. The HEC-RAS model therefore served as an intermediary to connect observations made in the existing prototype channel and the model representing the geometry of the future channel.

Even though the model calibration, as explained above, seems to be not a true calibration, the procedure provides flow patterns and flow velocities in the channel which are expected to be close to those under future conditions. In addition, the head loss determined for the louver will be calculated from the relative difference between the model with and without the louver. Therefore, the effect of the louver is accurately determined, because the only variable changed in the louver head loss estimation is addition of the louver.

4.1.1. HEC-RAS Model Calibration

For calibration, the default contraction/expansion coefficients were set equal to zero for all cross-sections except upstream and downstream of the gate house, where there was a significant change in the flow velocities and along the transition reach downstream of the gate house. In the HEC-RAS model, the gate house was modeled as a bridge.

The channel roughness was calibrated by comparing the simulated water surface elevations with the water surface elevations observed on 10/08/2003. The final *n*-values became 0.026 for the reach downstream of cross-section 14 (third transmission tower) and 0.039 for the reach upstream of cross-section 14 up to the gate house. The low *n*-value downstream of cross-section 14 is associated with one foot of head loss from cross-section 14 to the power house. There is also one foot of head loss from the gate house to cross-section 14 under the 10/08/03 flow conditions. In order to check the validity of two different *n*-values along the channel, the *n*-value of 0.039 was replaced with 0.026 for the upper reach (between the gate house and cross-section 14) and large contraction coefficients were assigned for the transition channel (between cross-sections 16 and 15). With a contraction coefficient of 0.5, the model could not simulate the observed water surface elevations. The photos of the bed also showed that the upstream reach of the channel has a higher roughness. The calibrated water surface elevations were within 0.1 feet of the observed water surface elevations (Figures 12a and 12b). In Figure 12a and the following figures, X= 0 is at the power plant intake; X is positive going upstream and reaches X = 4600 ft at the gatehouse.

For validation, the observed data collected on 4/16/2002 were used. There were some operational and observation differences, however, between the data set collected on 4/16/2002 and the data set collected on 10/08/2003. On 4/16/2002, 2.75 taintor gates were closed while on 10/08/03 all gates were fully open. In addition, the locations of the observation points were different on the two dates. For validation, the HEC-RAS geometry file was adjusted to simulate 2.75 closed taintor gates. The simulated water surface elevations were within about 0.1 feet of the data observed on 4/16/2002 (Figure 13). It was concluded that an *n*-value of 0.039 was a good estimate of the surface roughness for the reach upstream of cross-section 14.

Since the future excavation will most likely reduce the roughness, an *n*-value of 0.030 was used for the areas to be excavated upstream of cross-section 14, and 0.025 downstream of cross-section 14. Figure 13 shows simulated water surface elevations of 1,200 ft of the channel downstream of the gate house after the proposed excavation under several flow conditions.

4.1.2. Physical Model Calibration

In order to measure the head loss associated with the louver in the physical model, it was necessary to first correctly reproduce the friction head loss in the laboratory made channel, i.e. to match the friction head loss projected by the HEC-RAS model. Therefore, the roughness of the physical model channel was adjusted such that the measured water surface drops along the model channel matched the HEC-RAS model projected water surface drops for future conditions. Initially, the physical model channel was not quite as rough as its prototype. To simulate the HEC-RAS model channel roughness, metal bars were attached to the bed of the physical model channel (see Figure 7) by trial and error until the water surface drops and water depths of the physical model matched those of the HEC-RAS model as nearly as possible. Table 1 gives the final water surface drops and depths from cross-section 15.75 to 14 and 15.75 to 13.888. Since, cross-section 14 was used as the downstream boundary condition, the water depths observed in the model channel and the water depths simulated by the HEC-RAS model were equal.

The calibration results showed that the difference between the physical model water surface drops and the HEC-RAS model water surface drops were less than 0.05 feet for all flows less than or equal to 7,100 cfs, except for the water surface drop from cross-section 15.75 to 13.888 under 7,100 cfs flow which was about 0.2 feet. Using the HEC-RAS model of the channel, the upstream and downstream boundary conditions of the observed flow on 10/08/2003 under the projected future condition, i.e. the excavated channel, it is estimated that 8,300 cfs will flow through the channel. For the projected 8,300 cfs flow, the difference between the physical model water surface drops and the HEC-RAS model water surface drops was about 0.2 ft. The results were considered to be within an acceptable range.

Table 1. Physical Model Calibration Results

Cross-sections	15.75		14			13.888*			
Prototype Flows	HEC-RAS Depth	Physical Model Depth	HEC-RAS WSE Drop from 15.75 to 14	Physical Model WSE Drop from 15.75 to 14	HEC-RAS & Physical Model Depth	HEC-RAS WSE Drop from 15.75 to 13.888	Physical Model WSE Drop from 15.75 to 13.888	HEC-RAS Depth	Physical Model Depth
3100	12.02	11.93	0.05	0.03	13.94	0.05	0.08	13.94	13.89
5100	11.90	11.79	0.14	0.10	13.73	0.15	0.18	13.72	13.65
7100	11.65	11.52	0.31	0.26	13.31	0.33	0.56	13.29	13.01
8300	11.45	11.19	0.56	0.37	12.86	0.58	0.45	12.84	12.78

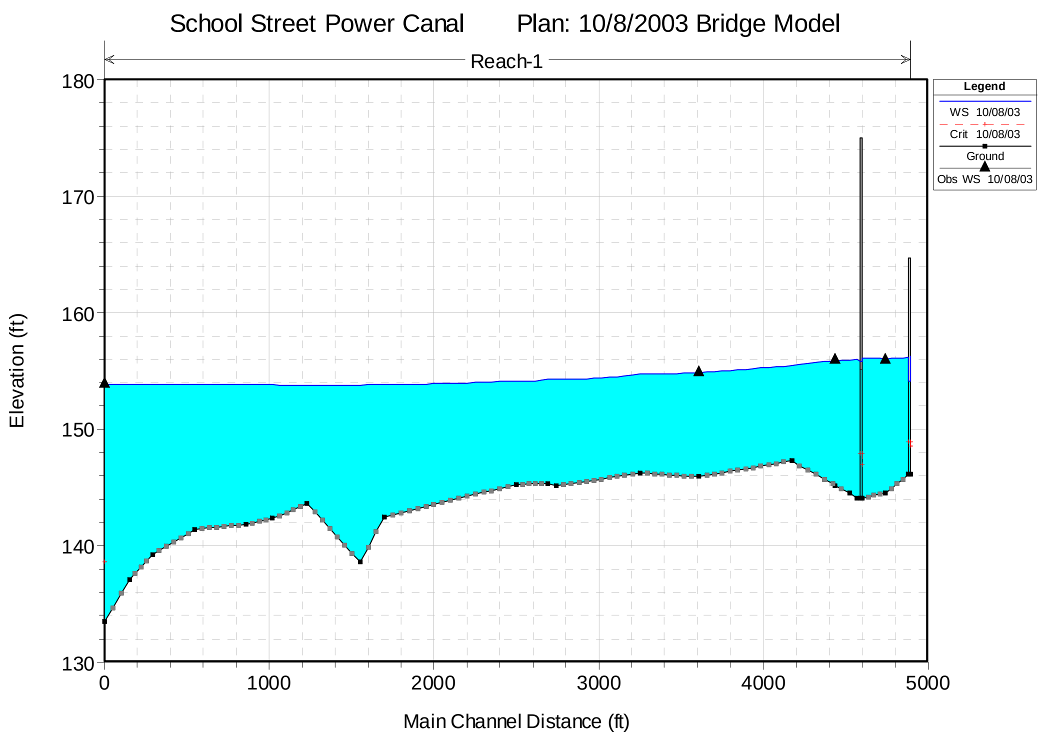

Figure 12a. The calibration results of the HEC-RAS model for the entire channel.

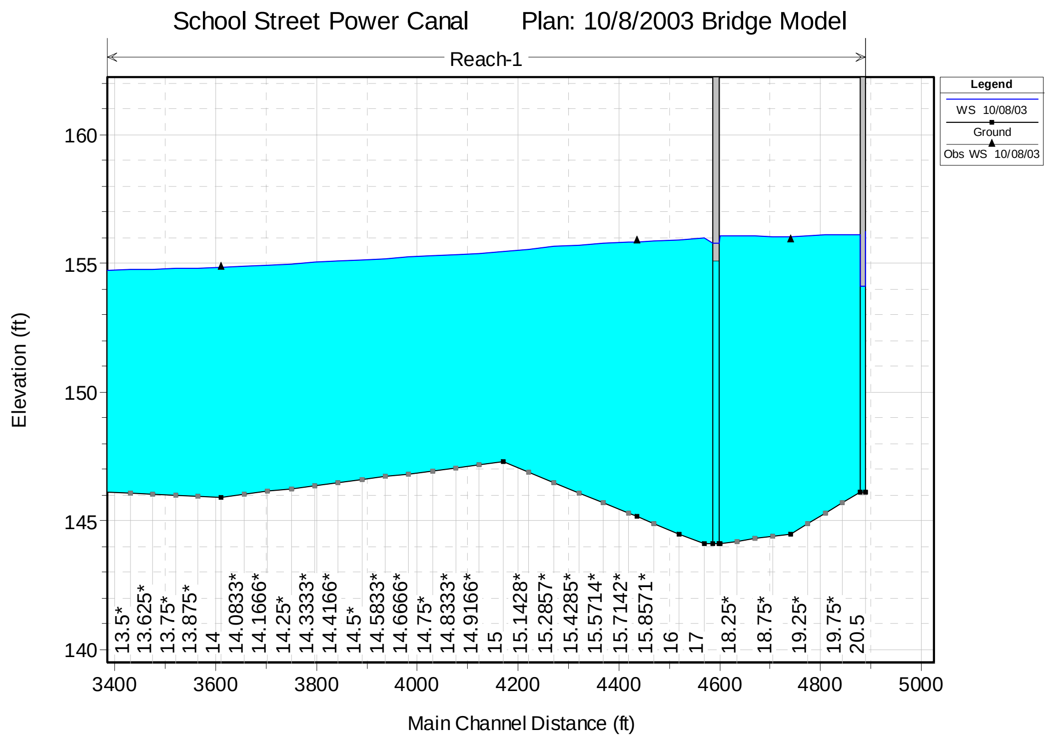

Figure 12b. The calibration results of the HEC-RAS model for the upstream part of the channel.

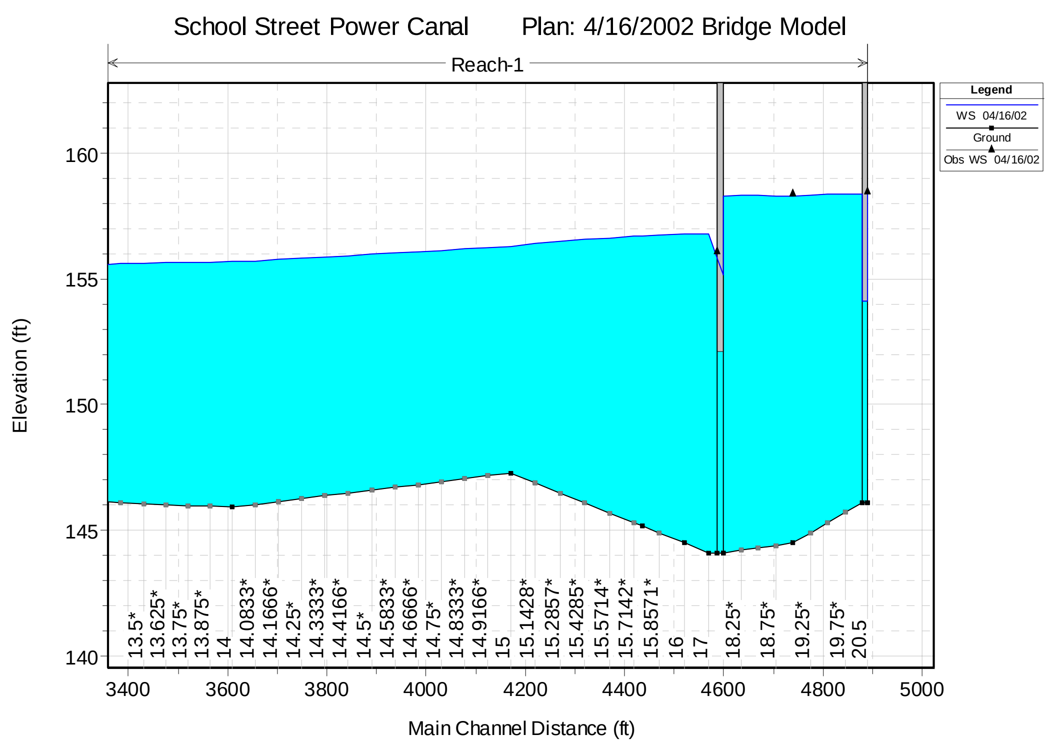

Figure 13. The validation results of the HEC-RAS model for the upstream part of the channel.

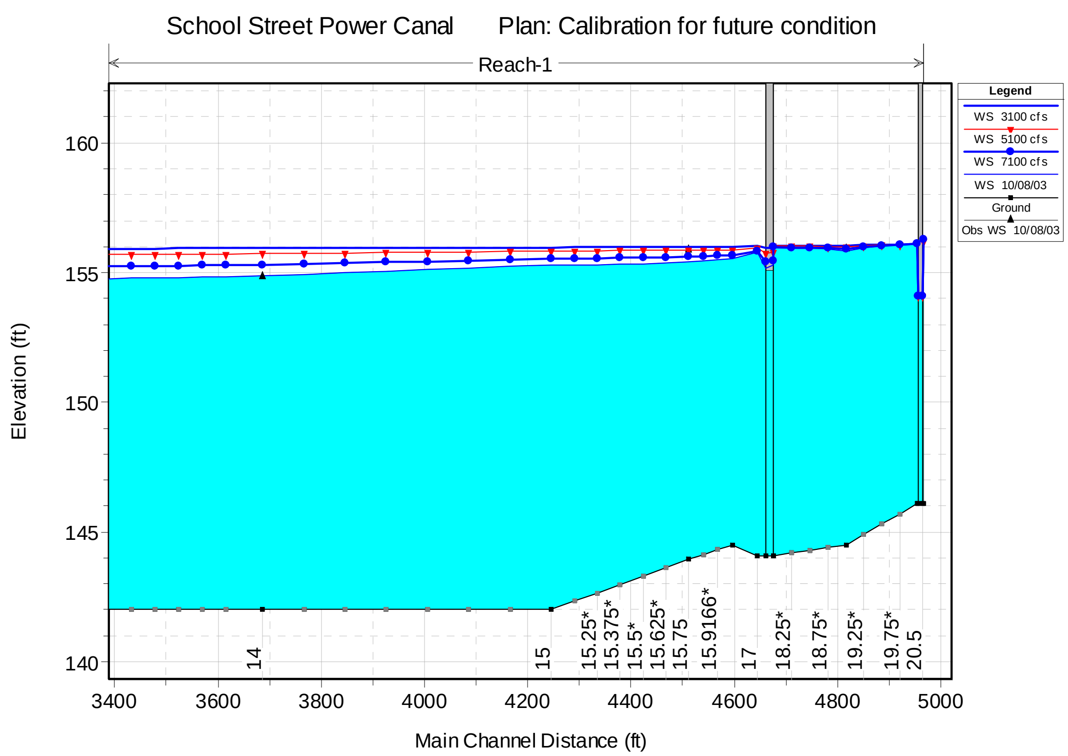

Figure 14. The HEC-RAS model projection of the water surface profiles after excavation under different flow conditions.

4.2. Different Louver Configurations

After model calibration, the louver was installed in the channel (Figure 7). Gate no. 9 was opened and water surface elevations, flow velocities and water surface drops across the louver were measured under three flow conditions. All measurements were made for three louver configurations:

1) 2-inch bar spacing throughout the louver,

2) 4 3/8-inch bar spacing throughout the louver, and

3) 6 3/4-inch bar spacing for the upstream one third, 4 3/8-inch bar spacing for the middle one third and 2-inch bar spacing for the downstream one third of the louver (6 3/4 & 4 3/8 & 2-inch).

In addition, the same measurements were taken with for the 2-inch bar spacing louver while 30% of the louver surface area was blocked by debris. The blockage was simulated using a triangular board covering most of the louver surface area near the fish bypass as shown in Figure 15.

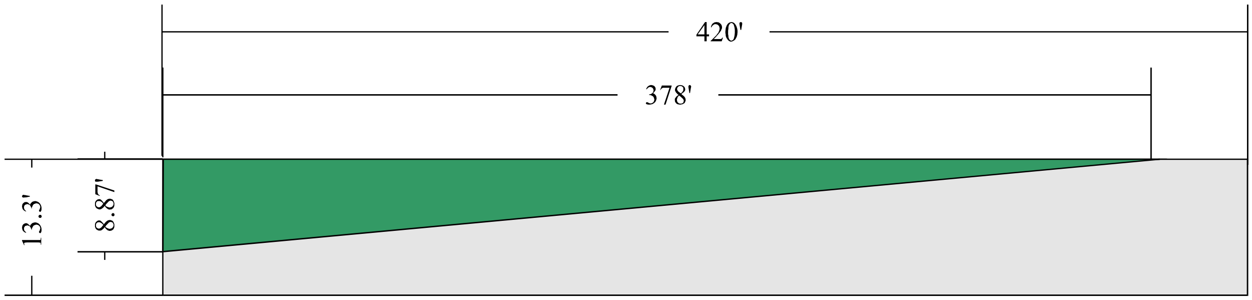

Figure 15. The prototype dimensions simulating a 30% blocked louver by debris. Blockage is by accumulation of floating debris in the prototype and by a board in the model.

4.2.1. Upstream Approach Velocities

To determine the flow distribution in the channel, velocities were measured 50 ft upstream of the louver structure at approximately six equally spaced locations across the width of the channel (see Figure A-1) under two conditions: 1) clear louver with 2-inch bar spacing, and 2) 30% blocked louver with 2-inch bar spacing. The velocity profiles are displayed in Figures 16 to 18 and a summary of the results is shown in Table 2.

The non-uniformity in the velocity distribution is attributed to the presence of the bend in the channel about 250 ft downstream of the gatehouse. There is a flow separation at the bend, and the negative velocity measurements are obvious indicators of the separation zone. According to Figures 16 to 18, the separation zone grows in size as the flow rate decreases.

With a 30% blocked louver, a backwater profile is created (see Table 2) which is more pronounced under high flow conditions, i.e. 7,100 cfs. Despite the backwater, the average approach velocities with a 30% blocked louver are not significantly different from a clear louver due to a shift in effective flow areas. Effective flow areas will be further discussed in section 4.2.3.

Table 2. Summary of the velocity and depth measurements 50 ft upstream of the louver

	7100 cfs		5100 cfs		3100 cfs	
	Hi Flow		Medium Flow		Low Flow	
	Clear	30% Blocked	Clear	30% Blocked	Clear	30% Blocked
Flow Gage Reading (cfs)	7097	7085	5082	5076	3074	3074
Water Depth (ft)	14.28	14.83	14.16	14.56	13.97	14.07
Total Area (ft^2)	2051	2135	2032	2093	2002	2019
Effective Flow Area (ft^2)	1856	1797	1589	1580	1486	1642
Mean Velocity (fps)	***3.89***	***3.92***	***3.33***	***3.29***	***2.17***	***1.98***
Theoretical Flow (cfs)	7222	7040	5291	5202	3224	3257
Error in Flow	1.8%	-0.6%	4.1%	2.5%	4.9%	6.0%

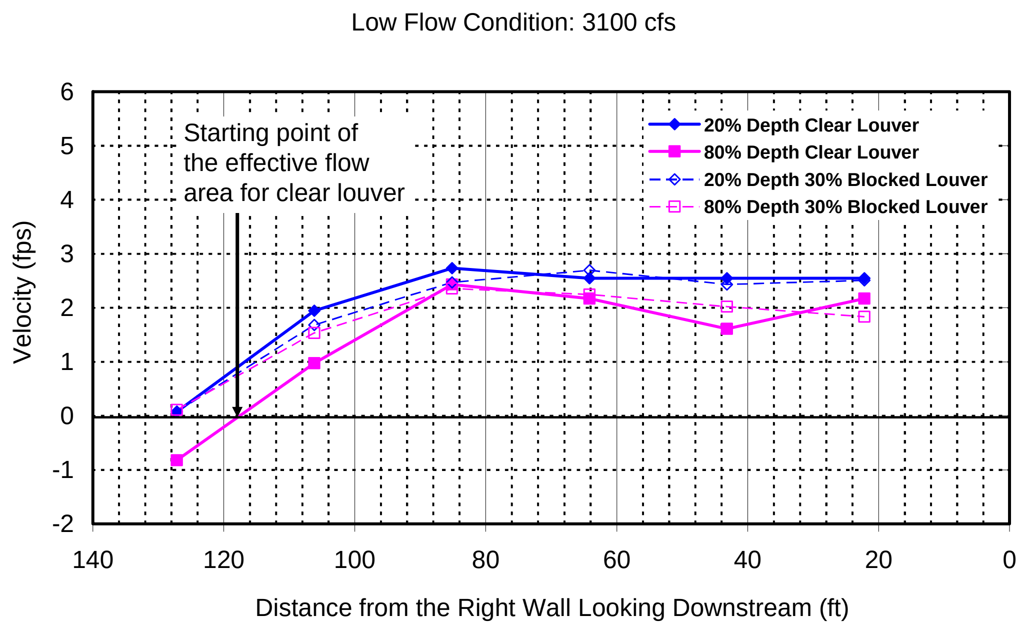

Figure 16. Cross-sectional velocity distribution 50 ft upstream of the louver for 3,100 cfs.

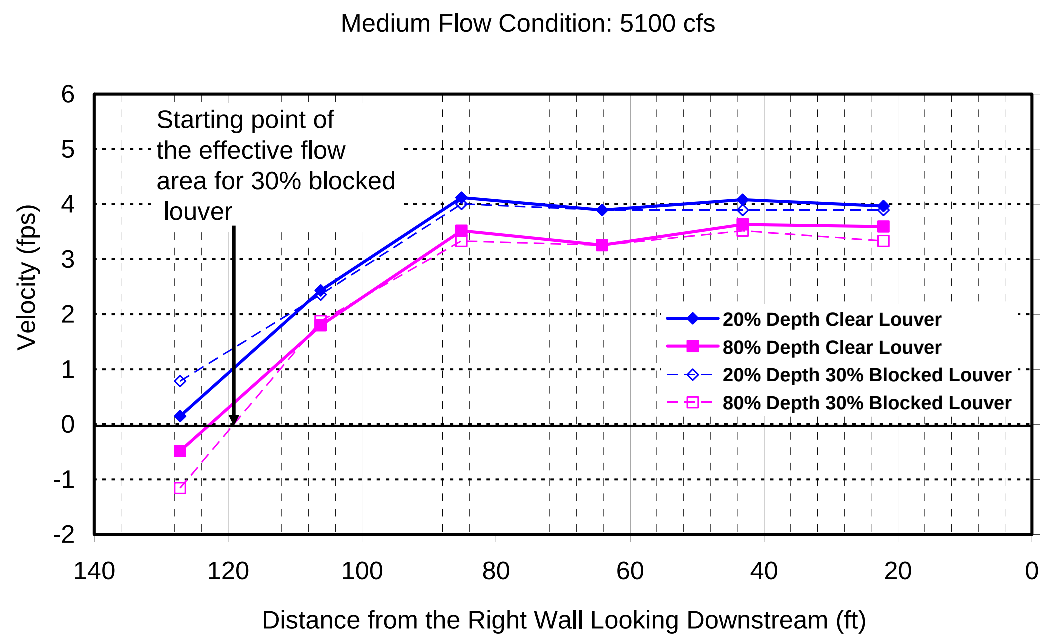

Figure 17. Cross-sectional velocity distribution 50 ft upstream of the louver for 5,100 cfs.

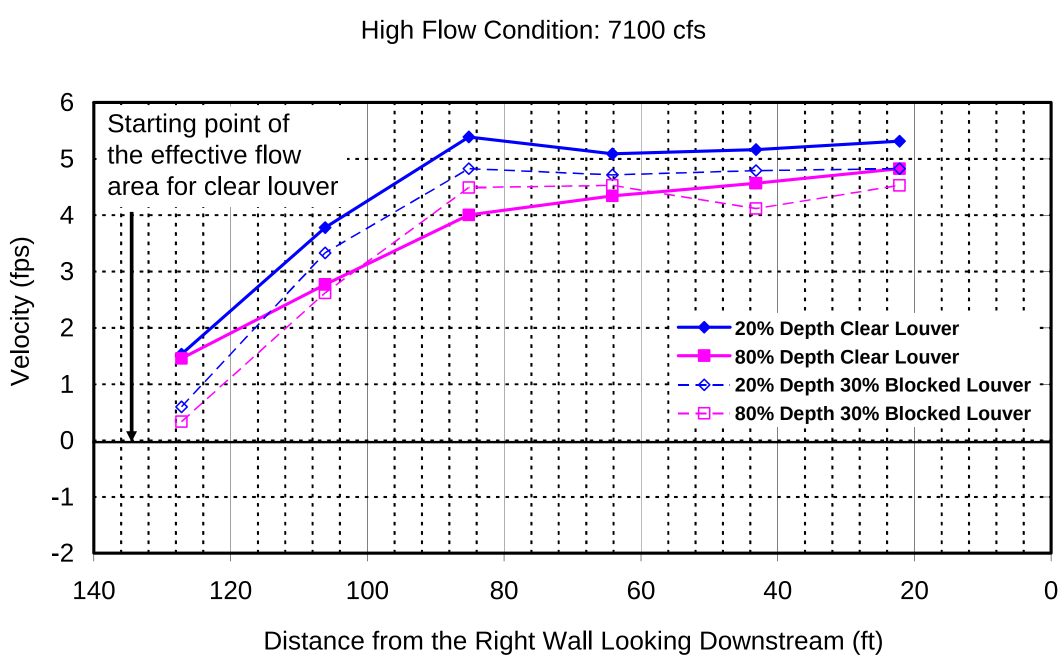

Figure 18. Cross-sectional velocity distribution 50 ft upstream of the louver for 7,100 cfs.

4.2.2. Head Loss Caused by the Louver

To determine the incremental energy (head) loss caused by the louver, the energy equation between cross-sections 15.75 upstream of the bend and cross-section 13.888 downstream of the louver was utilized as follows:

$$y_{15.75} + z_{15.75} + \frac{V_{15.75}^2}{2g} = y_{13.888} + z_{13.888} + \frac{V_{13.888}^2}{2g} + h_f + h_{louver} \quad (1)$$

In equation 1, y is the water depth, z is the bed elevation, V is the cross-sectional average velocity, h_f is the head loss due to friction which was estimated during the "no louver" condition, and h_{louver} is the head loss due to the louver structure and the separation downstream of the fish bypass structure. By rearranging equation 1, the incremental energy loss due to the louver becomes

$$h_{louver} = WSD_{15.75-13.888} + \frac{V_{15.75}^2}{2g} - \frac{V_{13.888}^2}{2g} - h_f \quad (2)$$

In equation 2, WSD is the water surface elevation drop from cross-section 15.75 to cross-section 13.888. By measuring the flow depth and using the geometry of the two cross-sections (see Figure A-2) the average velocities were obtained for each test. In order to avoid the impacts of separation zone on the effective flow area, i.e. using the entire cross-section for estimating average velocity, cross-section 13.888 instead of cross-section 14 was used in equation 2.

The louver head loss was estimated under five conditions and three flows. The conditions are as follows:

1. Clear louver with 2-inch bar spacing and fully open fish bypass,
2. Clear louver with 2-inch bar spacing and 140 cfs flow through the fish bypass,
3. Clear louver with 4 3/8-inch bar spacing and 140 cfs flow through the fish bypass,
4. Clear louver with 6 3/4 & 4 3/8 & 2-inch bar spacing and 140 cfs flow through the fish bypass,
5. 30% blocked louver with 2-inch bar spacing and 140 cfs flow through the fish bypass,

The test results for all five conditions are given in Appendix B (Tables B-1 to B-5). The overall flow through the fully open fish bypass was significantly smaller than the flow through the louver. Therefore the energy loss difference between conditions 1 and 2 is not significant. The results of conditions 2 to 5 are summarized in Table 3. The values shown in Table 3 are the averages of 5 measurements taken in each test. Before averaging, the outliers were removed from the tests. The following criteria were used to identify the outliers:

$$\text{If} \qquad X \leq \overline{X} - 5S_x \;\; or \; X \geq \overline{X} + 5S_x \qquad \text{then } X \text{ is an outlier} \qquad (3)$$

In equation 3, X is a measurement of either a flow rate, a water surface elevation or an estimated head loss. $\overline{X}$ and S_x are the average and standard deviation of the remaining four measurements or estimates, respectively. The outliers are identified in Appendix B.

Table 3 shows that the system will exhibit a maximum louver head loss of about 1.2 ft with the 2-inch bar spacing louver at maximum flow, i.e. 7,100 cfs. However, for a 30% blocked louver the louver head loss does not change significantly.

With a 4 3/8-inch bar spacing configuration, the louver head loss decreases by 30%; while with a 6 3/4 & 4 3/8 & 2-inch bar spacing, the louver head loss decreases by 15%.

Table 3. Summary of louver head losses for different louver configurations

Louver Head Loss (ft)				
Flows (cfs)	**Clear, 2-inch Spacing**	**Clear, 4 3/8-inch Spacing**	**Clear, 6 3/4 & 4 3/8 & 2-inch Spacing**	**30% Blocked, 2-inch Spacing**
3100	0.31	0.19	0.25	0.27
5100	0.61	0.44	0.56	0.63
7100	1.18	0.82	0.99	1.20

The total louver head loss (Table 3) is not linearly related to average approach velocity upstream of the louver (see Figures 16-18). The head loss was plotted versus average approach velocities obtained 50 ft upstream of the louver (Figure 19). Using a power function for the regression analysis, the louver head loss is approximately proportional to the approach velocity squared, which is in general agreement with classical definition of head loss. Unfortunately, only three points were available to derive the power function. In the same figure, head loss has also been plotted versus total flow rate in the channel, and not surprisingly, a strong relationship (R^2 = 0.99) between the louver head loss and flow is evident. If the future excavations are different from the channel geometry tested in this model study, such that approach velocities remain close to the model velocities, then Figure 19 can be used to estimate the louver head loss for other excavations within the limits of the tested flows.

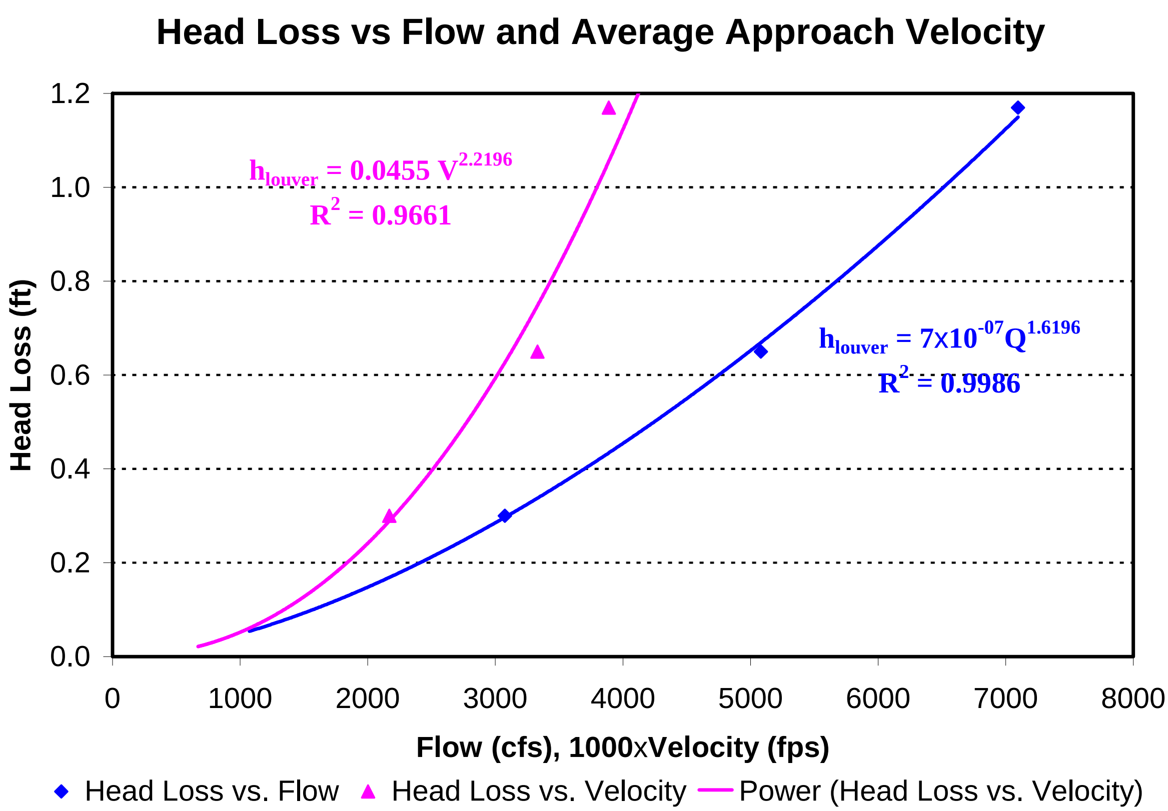

Figure 19. Head loss of the clear 2-inch bar spacing louver versus average approach velocity and flow.

4.2.3 Water Surface Drop across the Louver

Figures 20 through 23 show the water surface drop across the louver for the conditions in Table 3. For 2-inch bar spacing and 7,100 cfs flow, the water surface drop is on the order of 0.12 ft or less along 90% of the louver. It sharply rises to 0.7 ft in the last 30 ft of the louver, associated with very high flow velocities through the very last section of the louver. With 4 3/8-inch bar spacing and 7,100 cfs flow, water surface drop is less than 0.1 ft for the first 250 ft and exceeds 0.25 ft for the last 150 ft, indicating more water flows through the last 150 ft of the louver than in the 2-inch bar spacing louver. With 6 3/4 & 4 3/8 & 2-inch bar spacing and 7,100 cfs flow, the water surface drop along the first 250 ft is relatively similar to the other two configurations. Water surface drop exceeds 0.5 ft in the last 150 ft, indicating a flow distribution similar to the one through the 4 3/8-inch bar spacing louver, only with higher velocities through the last 150 ft due to smaller spacing (2-inch spacing versus 4 3/8-inch spacing). With the 30% blocked condition, water surface drop is substantially higher for the last 200 ft due to smaller opening under the blockage. The total louver head loss (Table 3) for the 30% blocked condition and the clear 2-inch bar spacing louver were shown to be virtually identical, indicating that in such setting and configuration, the 30% blocked louver is a more efficient structure than the clear louver.

4.2.4. Flow Distribution along the Louver

To determine whether the water surface drops were true indicators of flow distribution along the louver, cross sectional velocities were measured at two additional cross sections for conditions 3 and 4 (Figure A-3), and at nine additional cross-sections for condition 2 (Figure A-4). The results of the cross-sectional velocity measurements show that only a small fraction of the total flow passes through the upper one third of the louver regardless of the louver configuration, e.g. about 1,000 cfs for 7,100 cfs total flow (Figures 24 to 26).

The flow distributions through the 2-inch and 4 3/8-inch bar spacing louvers are relatively similar (Figures 24 and 25). Therefore, a smaller head loss exhibited in the case of the 4 3/8-inch bar spacing louver was associated with smaller cross-vane velocities through the louver. For the 6 3/4 & 4 3/8 & 2-inch bar spacing, however, flow is more or less uniformly distributed through the middle and last one thirds of the louver (Figure 26). Therefore, the additional head loss for the 6 3/4 & 4 3/8 & 2-inch bar spacing louver is associated with higher velocities in the lower one third of the louver with 2-inch spacing.

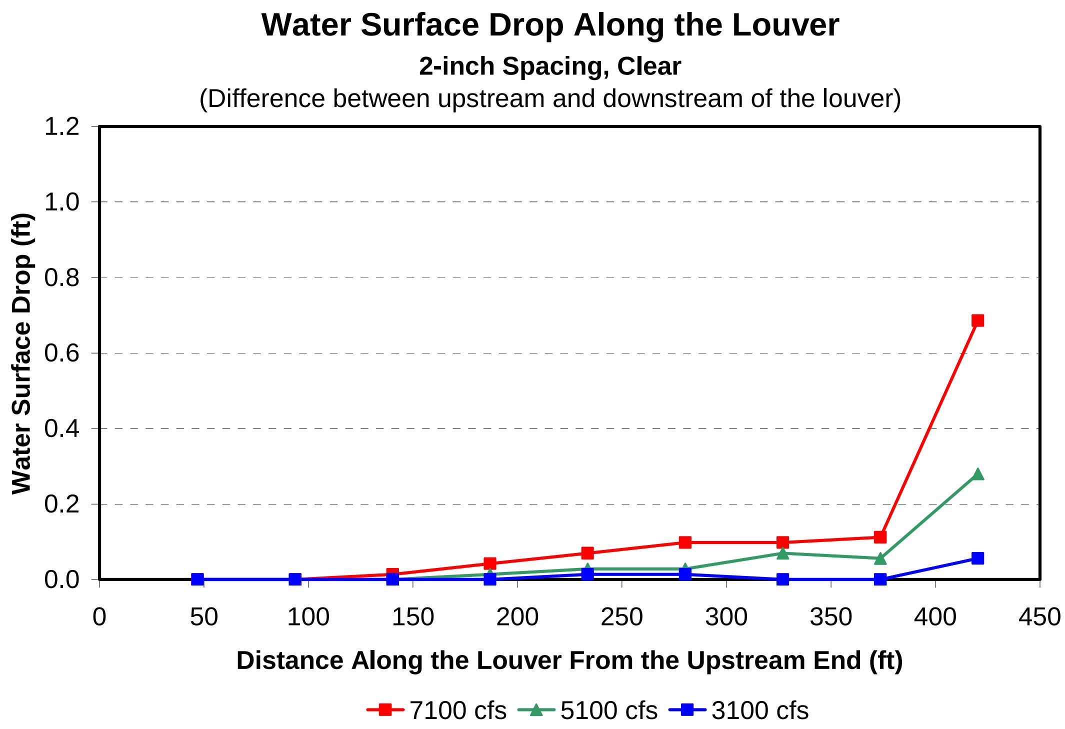

Figure 20. Water surface drop along the louver for the 2-inch bar spacing louver.

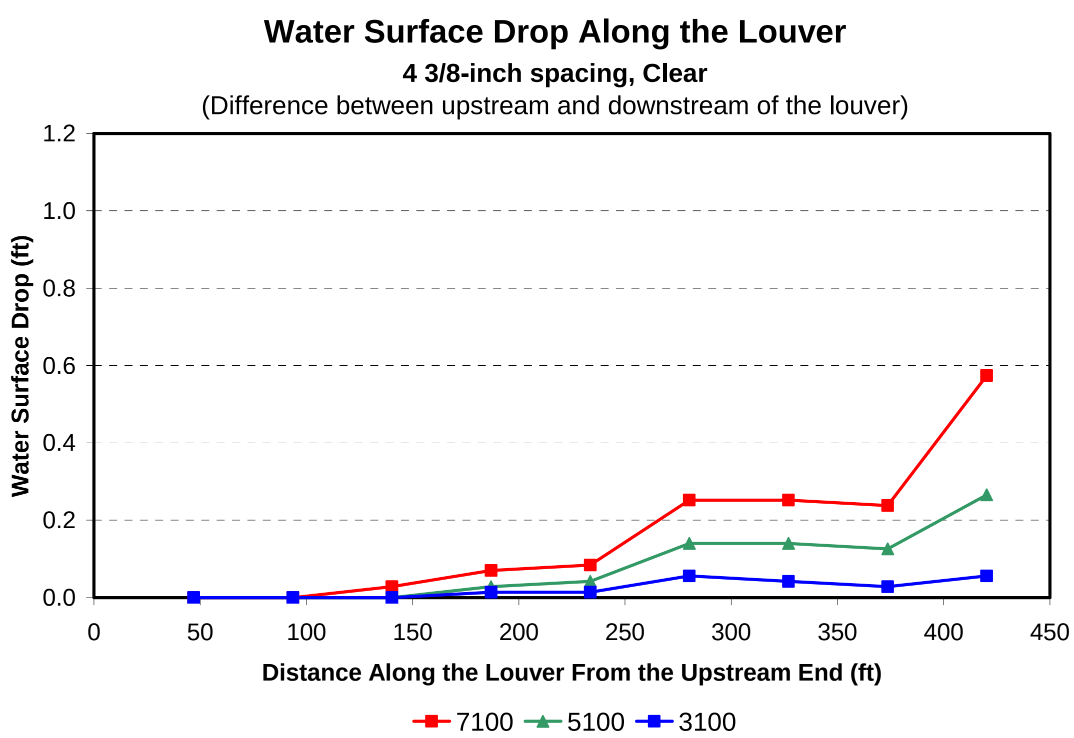

Figure 21. Water surface drop along the louver for the 4 3/8-inch bar spacing louver.

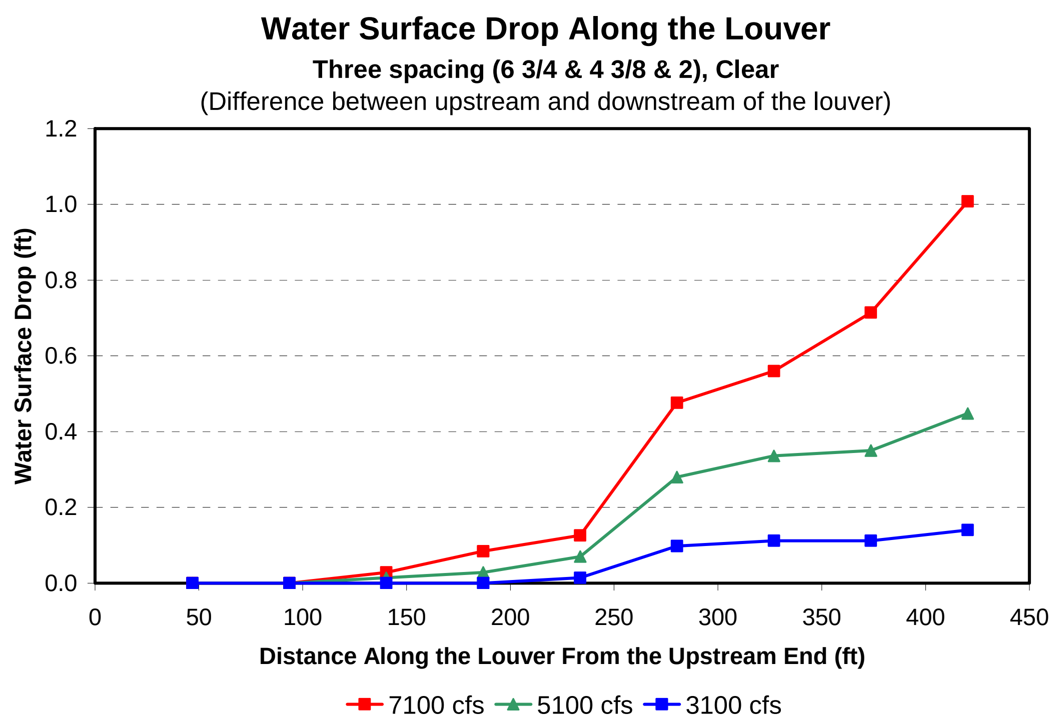

Figure 22. Water surface drop along the louver for the 6 ¾ & 4 3/8 & 2-inch bar spacing louver.

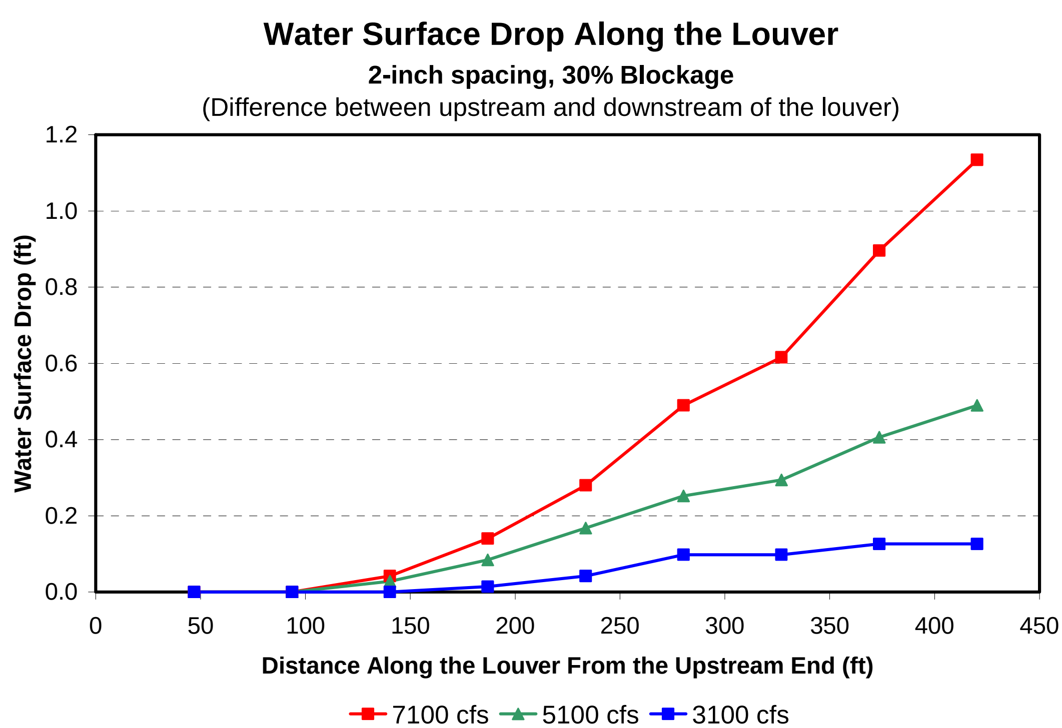

Figure 23. Water surface drop along the louver for the 2-inch bar spacing louver with 30% blocked condition.

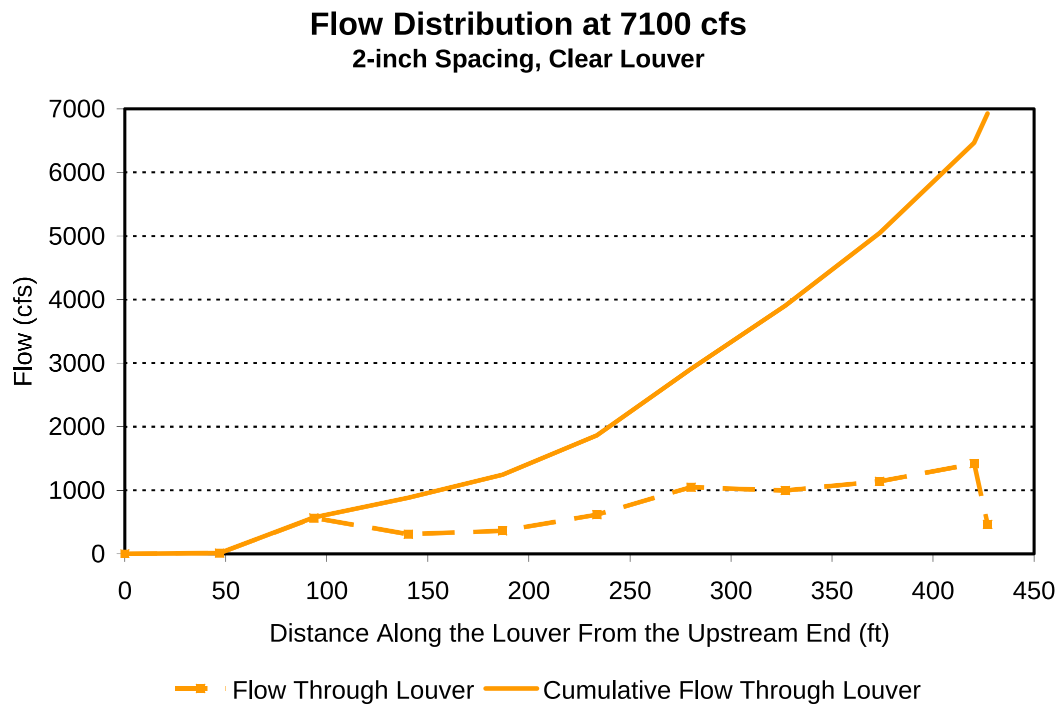

Figure 24. Flow distribution through the clear 2-inch bar spacing louver for 7,100 cfs flow condition.

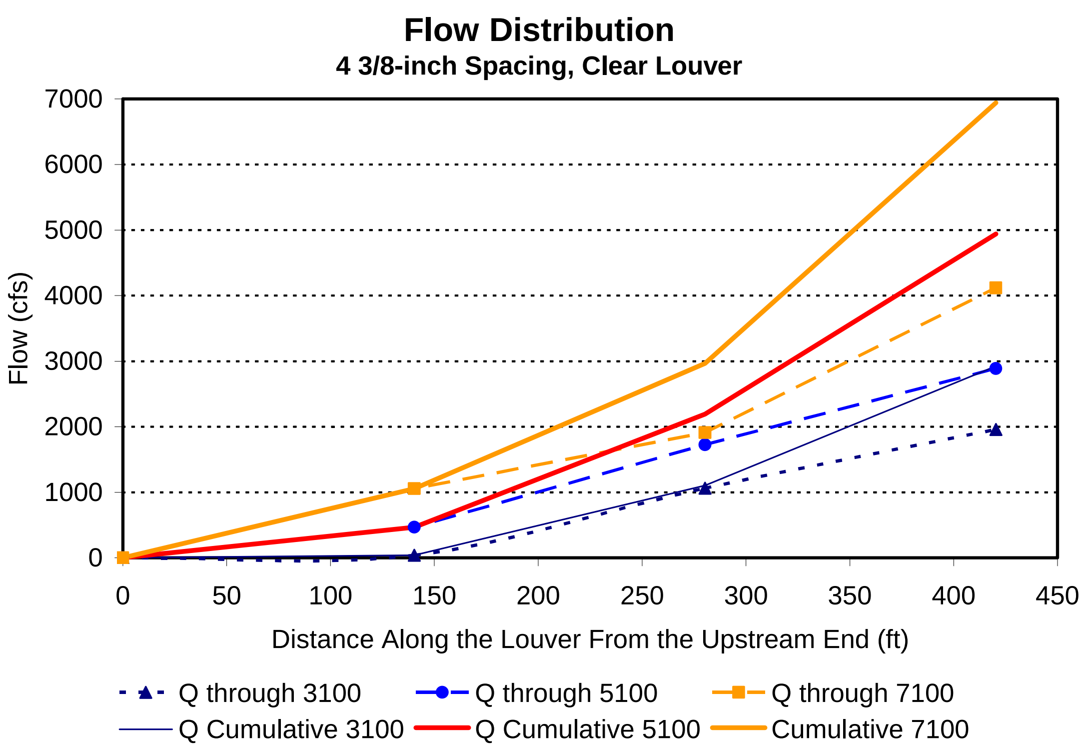

Figure 25. Flow distribution through the clear 4 3/8-inch bar spacing louver for all flow conditions.

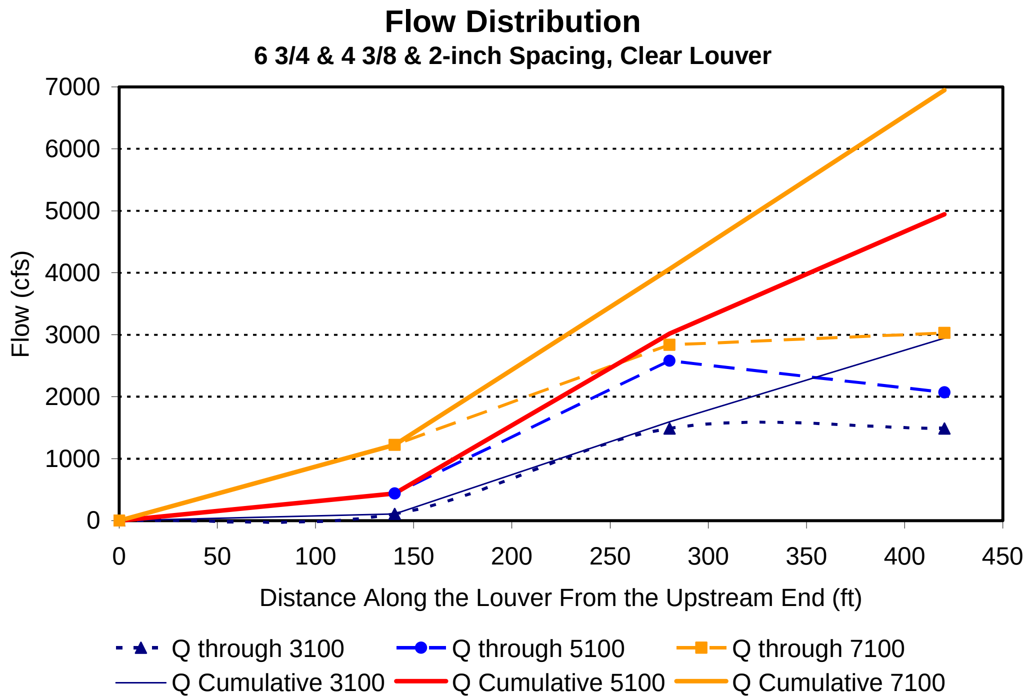

Figure 26. Flow distribution through the clear 6 ¾ & 4 3/8 & 2-inch bar spacing louver under all flow conditions.

4.2.5. Normal and Sweeping Velocities

Normal and sweeping velocities are the velocity components perpendicular and parallel to the longitudinal axis of the louver structure measured near the louver (Figure 27). Fish will be affected by these velocities. Using the ADV, velocities were measured 0.9 ft (0.73 inches at the model scale) away from the louver in two directions. Subsequently, normal and sweeping velocities were estimated using the angle between the probe direction and the longitudinal axis of the louver. Figures 28 to 36 show velocities for conditions 2 to 5 (section 3.2.2). In all figures average sweeping and normal velocities through the 2-inch bar spacing louver have been shown for comparison.

For the 2-inch bar spacing louver and 7,100 cfs flow, sweeping velocity varies from 3.8 fps near the upstream end to 7.4 fps 50 ft away from the fish bypass (Figure 30). The average sweeping velocity near the fish bypass is slightly lower (6.5 fps) for the 4 3/8-inch bar spacing louver (Figure 33) and significantly drops (2.3 fps) for the 6 3/4 & 4 3/8 & 2-inch bar spacing louver

(Figure 36). The sudden velocity drop for the 6 3/4 & 4 3/8 & 2-inch bar spacing louver occurs where bar spacing changes from 4 3/8 inches to 2 inches.

When 30% of the louver surface is blocked (Figure 30), the sweeping velocity near the fish bypass drops to 6 fps. The sweeping velocity profile also indicates a flow redistribution through the louver structure at the 30% blocked condition.

The average normal velocity near the fish bypass is about 5 fps for 2-inch louver spacing, drops to 4 and 2.3 fps for the 4 3/8-inch bar spacing and 6 3/4 & 4 3/8 & 2-inch bar spacing louvers, respectively.

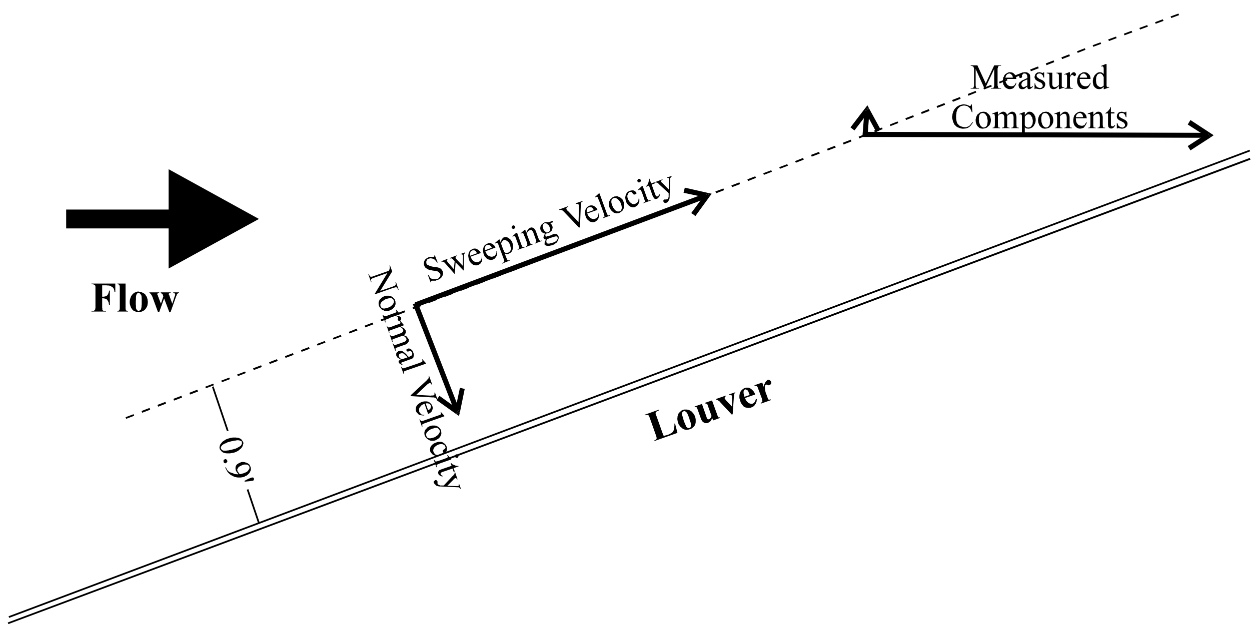

Figure 27. Schematic of normal and sweeping velocities, and the measured components of velocity.

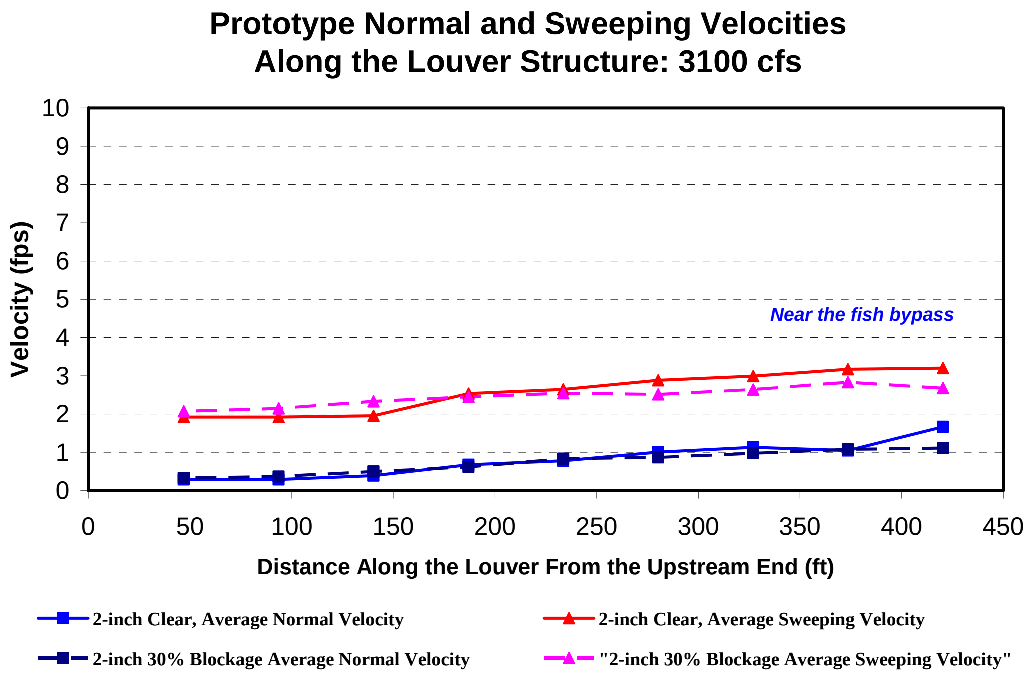

Figure 28. Average normal and sweeping velocities measured 0.9 ft away from the louver for 2-inch bar spacing under clear and 30% blocked conditions and 3,100 cfs flow.

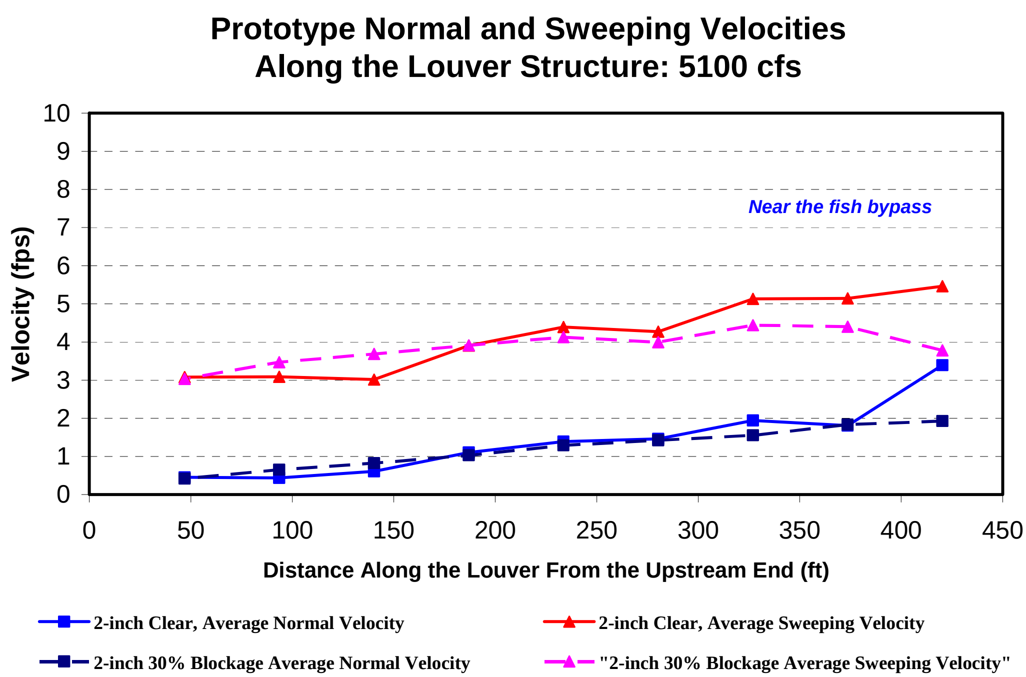

Figure 29. Average normal and sweeping velocities measured 0.9 ft away from the louver for 2-inch bar spacing under clear and 30% blocked conditions and 5,100 cfs flow.

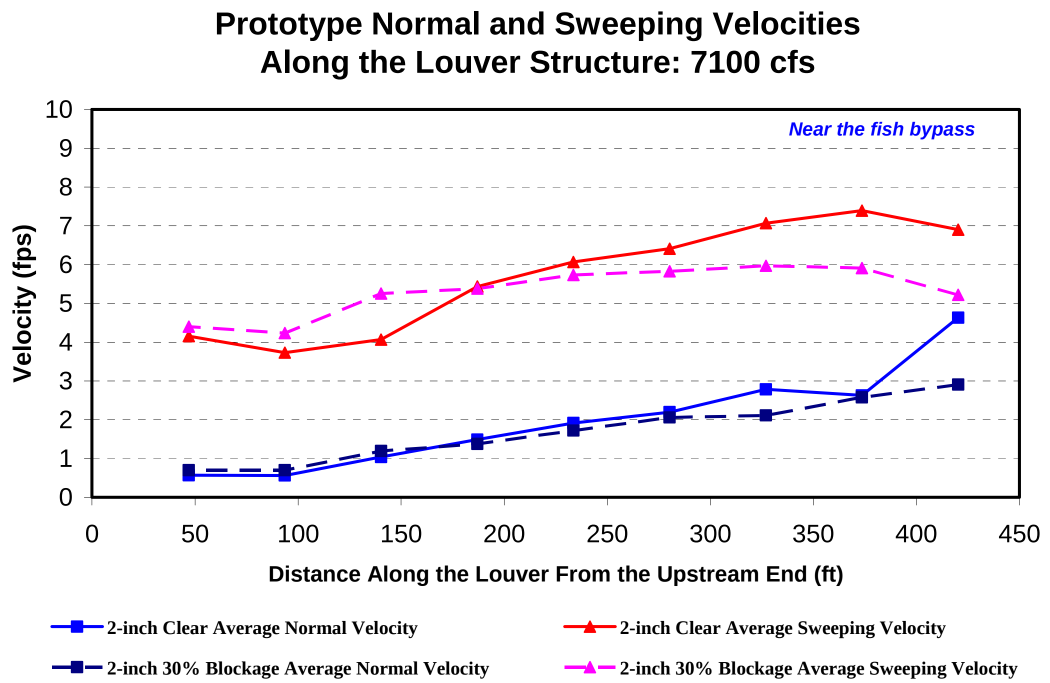

Figure 30. Average normal and sweeping velocities measured 0.9 ft away from the louver for 2-inch bar spacing louver under clear and 30% blocked conditions and 7,100 cfs flow.

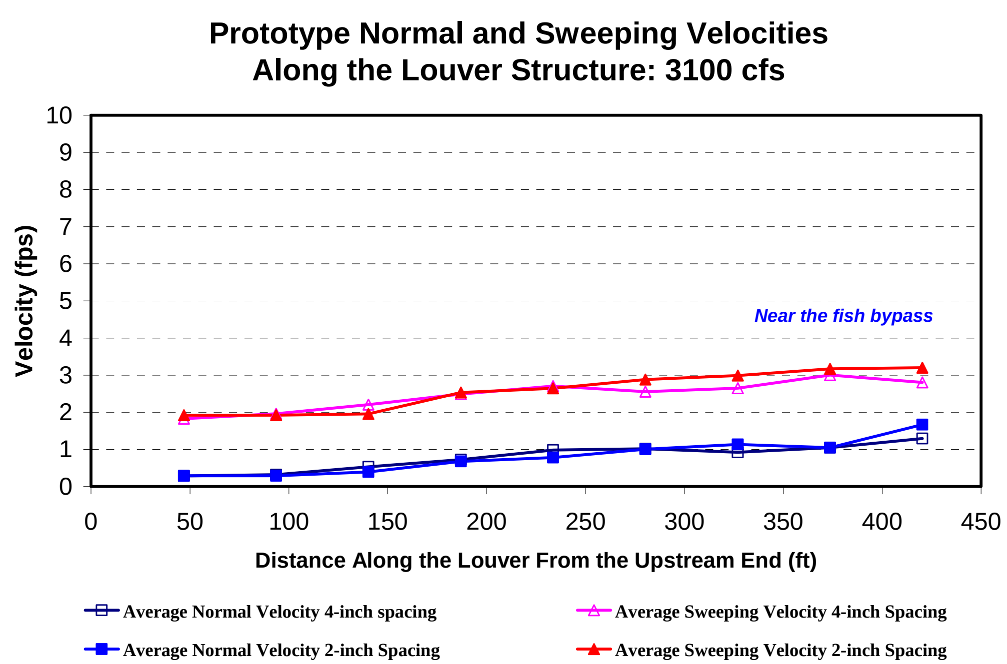

Figure 31. Average normal and sweeping velocities measured 0.9 ft away from the louver for the 4 3/8-inch bar spacing and the 2-inch spacing (for comparison) under 3,100 cfs flow condition.

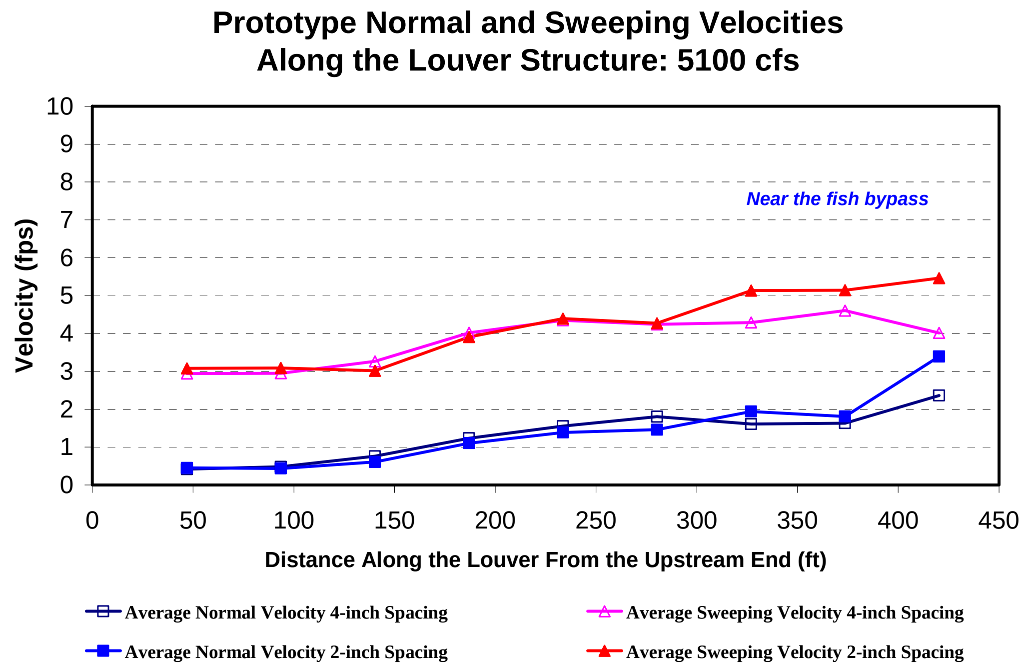

Figure 32. Average normal and sweeping velocities measured 0.9 ft away from the louver for the 4 3/8-inch bar spacing and the 2-inch spacing (for comparison)under 5,100 cfs flow condition.

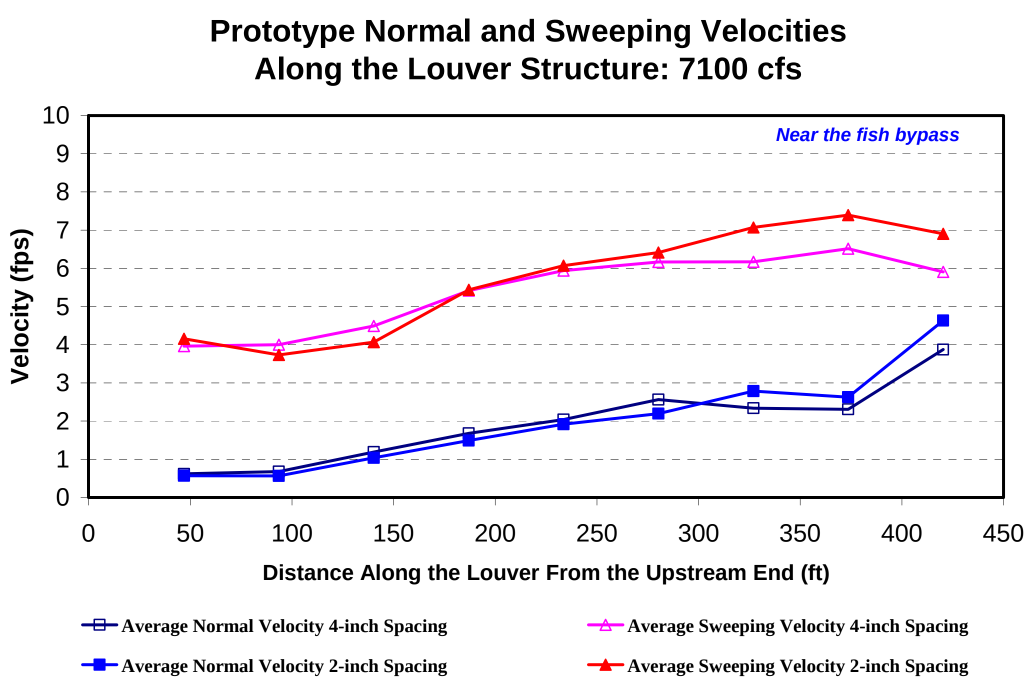

Figure 33. Average normal and sweeping velocities measured 0.9 ft away from the louver for the 4 3/8-inch bar spacing and the 2-inch spacing (for comparison) under 7,100 cfs flow condition.

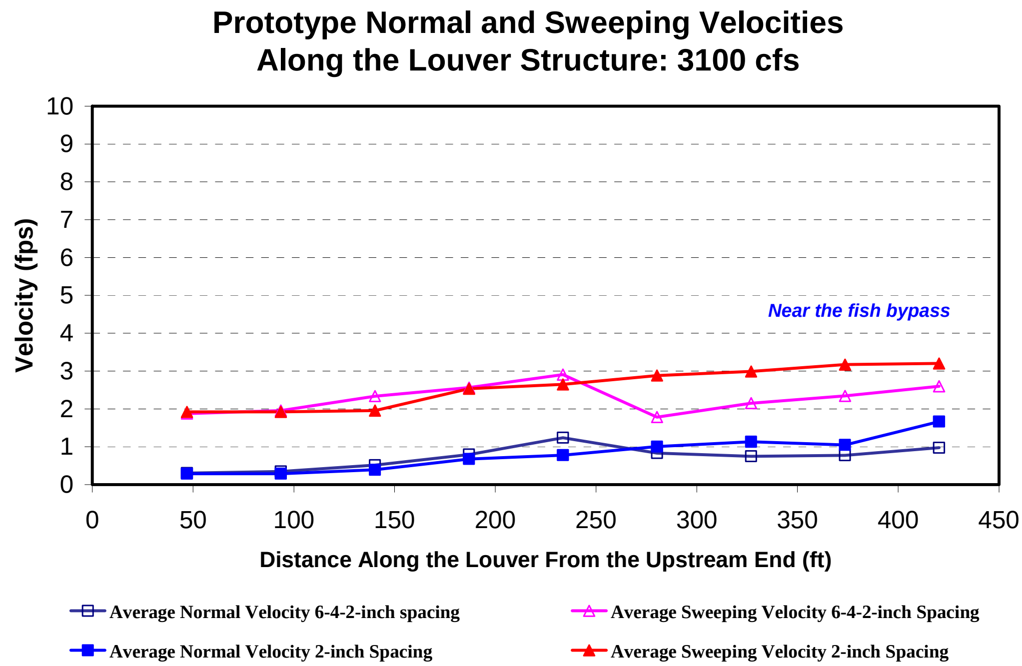

Figure 34. Average normal and sweeping velocities measured 0.9 ft away from the louver for the 6 ¾ & 4 3/8 & 2-inch bar spacing and the 2-inch spacing under 3,100 cfs flow condition.

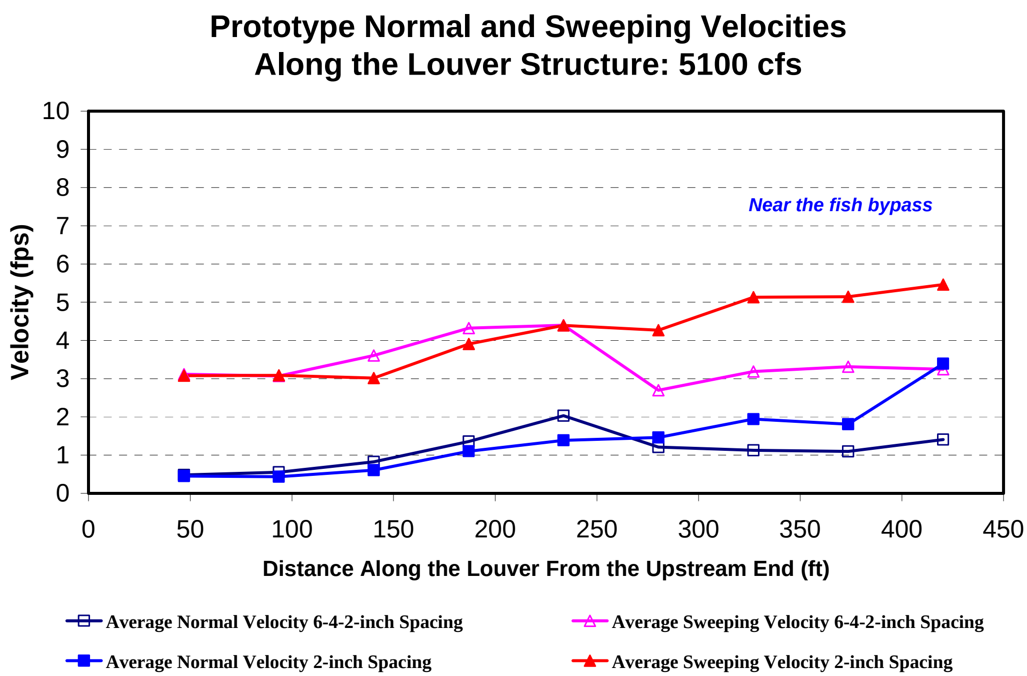

Figure 35. Average normal and sweeping velocities measured 0.9 ft away from the louver for the 6 ¾ & 4 3/8 & 2-inch bar spacing and the 2-inch spacing under 5,100 cfs flow condition.

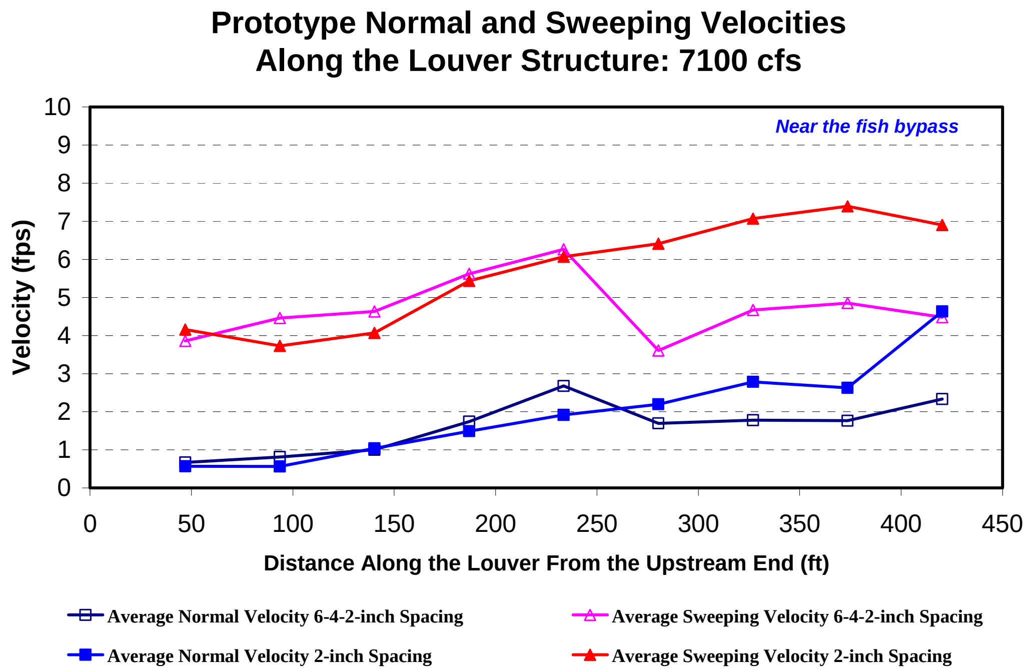

Figure 36. Average normal and sweeping velocities measured 0.9 ft away from the louver for the 6 ¾ & 4 3/8 & 2-inch bar spacing and the 2-inch spacing under 7,100 cfs flow condition.

5. Other Potential Modifications to the Water Conveying Channel

Reliant Energy and Kleinschmidt Associates inquired about (a) the head loss associated with the channel bend 168 feet downstream of the gatehouse and (b) the feasibility of reducing the louver head loss by deepening the section of the channel, where the louver is located, by 8 feet (an additional 3 feet) which is the location of the bedrock.

For the head loss associated with the channel bend, several water surface level measurements were taken at points 6 and 7 (Figure 2). The results are shown in Table 4. Since the velocity in the downstream end of the bend was not uniformly distributed (see Figures 16-18), it was difficult to accurately quantify the velocity head. The kinetic energy correction factors, α, were estimated using Figures 16-18. However, the estimate of energy loss along the bend for low flows was significantly sensitive to the velocity distribution. Therefore, by using the test results of the flows larger than 5,100 cfs, it is evident that the energy loss along the bend is about 70% of the total head loss in the channel reach from cross-section 15.75 to 13.888, while the friction loss along the bend is about 25% of the friction loss over this reach.

Table 4. Head loss along the modeled channel and attributed to the bend under 3 flow conditions

Flow (cfs)	Upstream of the Bend		Downstream of the Bend			Δhl_{Bend} (ft)	Flow and Head Loss Along the Channel	
	Velocity Head (ft)	Depth (ft)	α	Corrected Velocity Head (ft)	Depth (ft)		Flow (cfs)	$\Delta hl_{15.75-13.888}$ (ft)
3069	0.07	12.96	1.68	0.15	13.52	0.05	3060	0.05
5084	0.18	13.22	1.56	0.32	13.72	0.04	5085	0.06
7088	0.34	13.36	1.31	0.39	13.93	0.06	7079	0.08

The deepening of the water conveying channel by another 3 feet will require approximately an additional 7000 cubic yards of earth work plus a taller louver structure. In the deepened reach the water depth along the louver will increase by slightly over 3 ft. Under 7,100 cfs flow condition, the resulting average velocity will become about 3.5 fps. Assuming Figure 19 can be applied to the new channel geometry, the louver head loss with 2-inch bar spacing will decrease by 25%. Since the bottom of the channel is only reduced by 3 ft where the louver is located, it will be subject to extensive silting. Over time, the head loss reduction due to deepening of the channel will be lost due to change in bed elevation. Therefore, it will be necessary to regularly dredge that section of the channel.

6. Summary

The results of the physical model study show that the head loss through the three investigated louver configurations varies from 1.2 ft to 0.8 ft when flow in the channel is 7,100 cfs. The 4 3/8-inch bar spacing louver exhibits the lowest head loss among the three configurations and the 2-inch bar spacing the highest. The normal velocity measured 0.9 ft away from the louver occurs near the fish bypass and ranges from 2.3 fps to 4.8 fps for all configurations with the lowest for the 6 3/4 & 4 3/8 & 2-inch bar spacing louver. The sweeping velocity along the louver for the 2-inch bar spacing and 4 3/8-inch bar spacing varies from 4 fps to 7.4 fps. The 4 3/8-inch bar spacing exhibits slightly lower sweeping velocity near the louver. The louver with 6 3/4 & 4 3/8 & 2-inch bar spacing configuration exhibits a sharp drop when the bar spacing changes from 4 3/8 inches to 2 inches and remains at about 5 fps near the fish bypass.

For all louver configurations, less than 15% of the total flow passes through the upper one third of the louver. When the louver is 30% blocked, mostly on its downstream portion, the louver functions more efficiently, i.e. more flow passes through the middle portion of the louver.

Appendix A. Gage reading cross-sections and velocity measurement locations

In this appendix, the geometry of cross-sections and the locations where velocity was measured are presented. All data presented in this appendix are at the model scale.

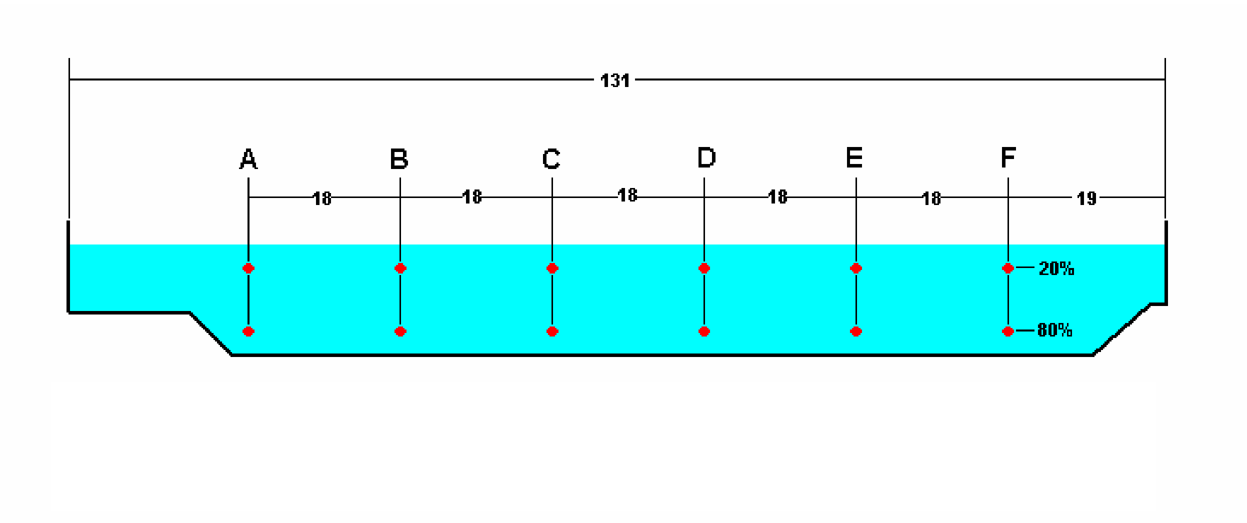

Figure A-1. Locations of point velocity measurements in a cross-section located 42” (about 50 ft prototype) upstream of the louver leading edge. All dimensions are in inches and view is looking downstream.

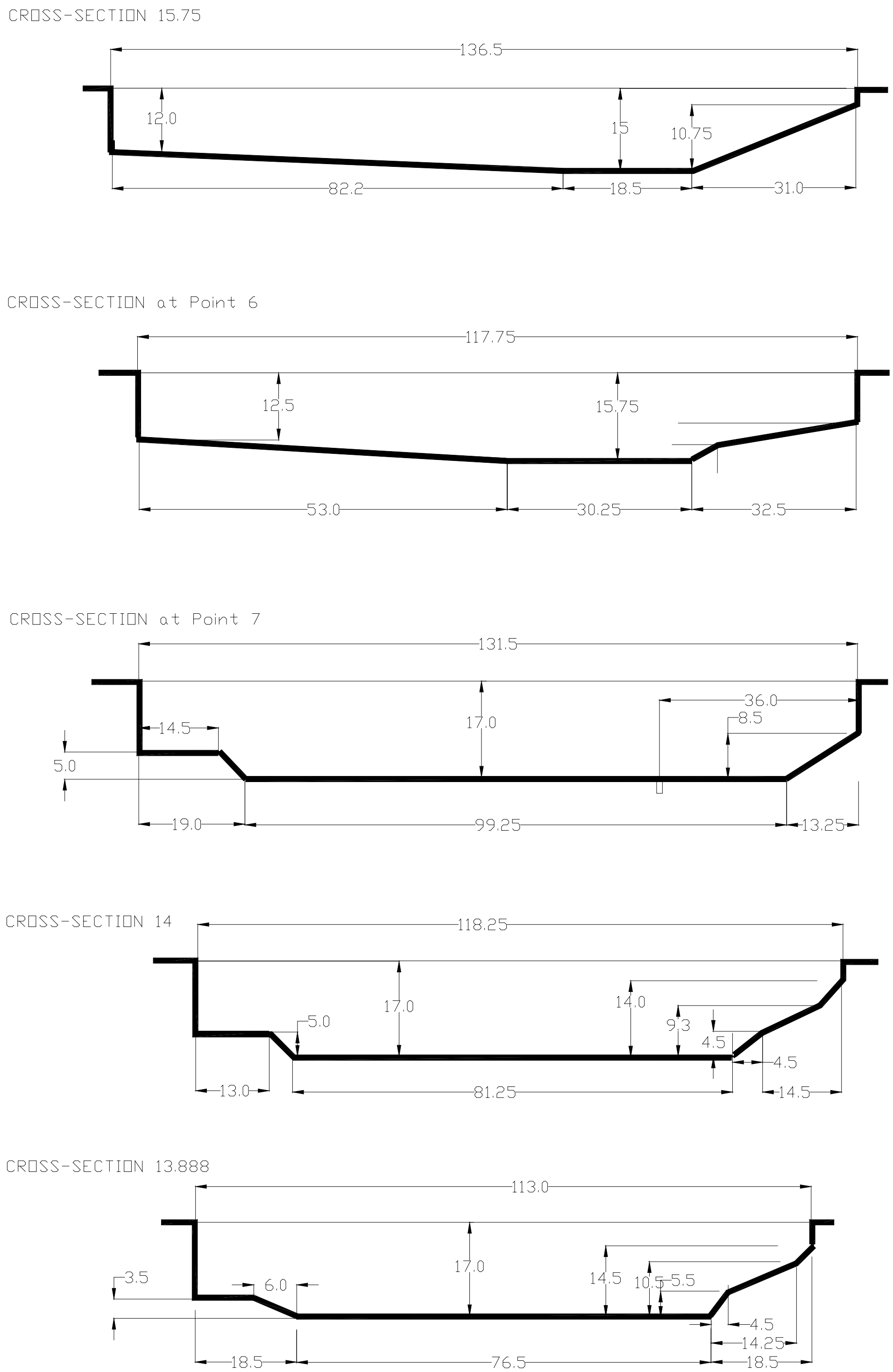

Figure A.2. Geometry of the model cross-sections where either velocity or water surface elevations were measured. All dimensions are in inches and view is looking downstream

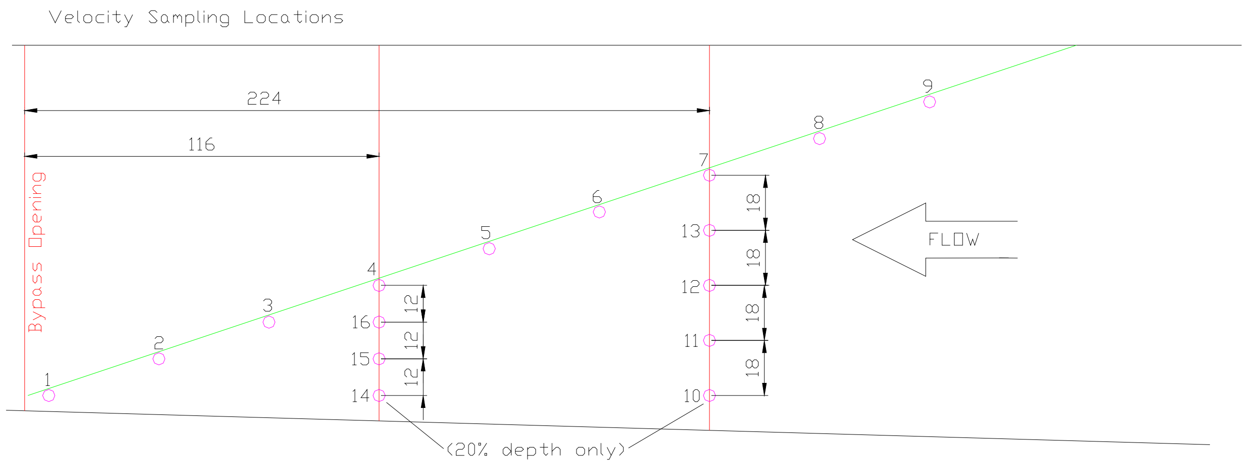

Figure A-3.Model locations where velocity was measured to determine the flow distributions through the louver with 4 3/8-inch bar spacing and 6 ¾ & 4 3/8 & 2-inch spacing. All dimensions are in inches.

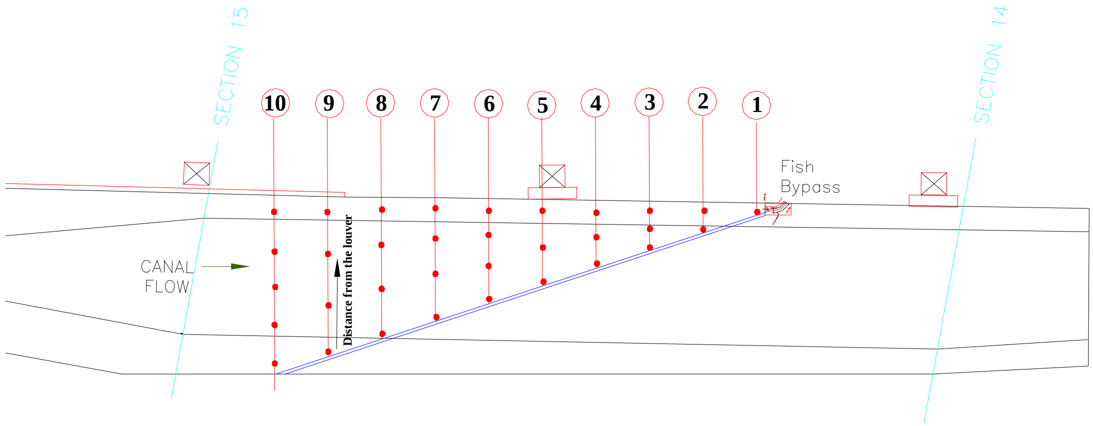

Figure A-4. Model locations where velocity was measured to determine the flow distribution through the louver for 2-inch bar spacing louver.

Appendix B. Model Data

All tables and data presented in this appendix are in ft and at the model scale.

Table B-1. Model head loss estimation for 2-inch spacing clear louver with fully open fish-bypass. The green shaded cells are considered as outliers.

Headloss for fully open fish bypass

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
3100	4.16	100.829	100.821	0.0018	100.819	0.002	100.815	0.004	0.006	0.0036
	4.15	100.832	100.825	0.0017	100.819	0.006	100.818	0.004	0.007	0.0046
	4.17	100.831	100.830	0.0017	100.819	0.011	100.819	0.004	0.011	0.0086
	4.23	100.830	100.824	0.0018	100.819	0.005	100.819	0.004	0.005	0.0025
	4.15	100.831	100.824	0.0017	100.819	0.005	100.818	0.004	0.006	0.0036
Average	**4.17**	**100.831**	**100.825**	**0.0018**	**100.819**	**0.006**	**100.818**	**0.004**	**0.007**	**0.004**
Stdev	**0.036**	**0.0011**	**0.0033**	**0.0000**	**0.0000**	**0.0033**	**0.0016**	**0.0001**	**0.0023**	**0.0009**

	Louver								
Flow		15.75		14		13.888			Headloss from
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
87.000	4.185	100.843	0.002	100.819	0.024	100.818	0.004	0.025	0.0224
87.050	4.191	100.843	0.002	100.819	0.024	100.819	0.004	0.024	0.0214
87.000	4.185	100.843	0.002	100.819	0.024	100.819	0.004	0.024	0.0215
86.950	4.178	100.844	0.002	100.819	0.025	100.819	0.004	0.025	0.0225
87.000	4.185	100.843	0.002	100.819	0.024	100.819	0.004	0.024	0.0215
Average	**4.185**	**100.843**	**0.002**	**100.819**	**0.024**	**100.819**	**0.004**	**0.024**	**0.022**
Stdev	**0.0045**	**0.0004**	**0.0000**		**0.0004**	**0.0004**	**0.0000**	**0.0005**	**0.0005**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
5100	6.88	100.831	100.811	0.0051	100.804	0.007	100.798	0.012	0.013	0.0062
	6.96	100.837	100.817	0.0051	100.804	0.013	100.803	0.012	0.014	0.0071
	6.97	100.831	100.809	0.0053	100.804	0.005	100.800	0.012	0.009	0.0022
	6.90	100.831	100.811	0.0051	100.804	0.007	100.800	0.012	0.011	0.0043
	6.96	100.836	100.813	0.0051	100.804	0.009	100.803	0.012	0.010	0.0032
Average	**6.93**	**100.833**	**100.812**	**0.0051**	**100.804**	**0.008**	**100.801**	**0.012**	**0.011**	**0.005**
Stdev	**0.041**	**0.0030**	**0.0030**	**0.0001**	**0.0000**	**0.0030**	**0.0022**	**0.0001**	**0.0021**	**0.0021**

	Louver								
Flow		15.75		14		13.888			Headloss from
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
117.550	6.930	100.864	0.004	100.804	0.060	100.804	0.012	0.060	0.0522
117.550	6.930	100.859	0.004	100.804	0.055	100.803	0.012	0.056	0.0483
117.550	6.930	100.861	0.004	100.804	0.057	100.804	0.012	0.057	0.0493
117.650	6.937	100.862	0.004	100.804	0.058	100.804	0.012	0.058	0.0503
117.650	6.937	100.861	0.004	100.804	0.057	100.803	0.012	0.058	0.0502
Average	**6.932**	**100.861**	**0.004**	**100.804**	**0.058**	**100.804**	**0.012**	**0.058**	**0.050**
Stdev	**0.0038**	**0.0018**	**0.0000**		**0.0018**	**0.0005**	**0.0000**	**0.0015**	**0.0015**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
7100	9.63	100.834	100.792	0.0108	100.774	0.018	100.752	0.026	0.040	0.0249
	9.66	100.835	100.791	0.0110	100.774	0.017	100.771	0.025	0.020	0.0061
	9.64	100.839	100.795	0.0107	100.774	0.021	100.773	0.025	0.022	0.0080
	9.67	100.831	100.787	0.0112	100.774	0.013	100.770	0.025	0.017	0.0032
	9.67	100.833	100.790	0.0110	100.774	0.016	100.769	0.025	0.021	0.0070
Average	**9.65**	**100.834**	**100.791**	**0.0109**	**100.774**	**0.017**	**100.767**	**0.025**	**0.024**	**0.006**
Stdev	**0.016**	**0.0030**	**0.0029**	**0.0002**	**0.0000**	**0.0029**	**0.0085**	**0.0005**	**0.0091**	**0.0021**

	Louver								
Flow		15.75		14		13.888			Headloss from
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
165.350	9.658	100.894	0.007	100.774	0.120	100.783	0.024	0.111	0.0938
165.650	9.672	100.884	0.007	100.774	0.110	100.778	0.025	0.106	0.0888
165.450	9.663	100.879	0.007	100.774	0.105	100.776	0.025	0.103	0.0858
165.550	9.668	100.882	0.007	100.774	0.108	100.777	0.025	0.105	0.0878
165.550	9.668	100.881	0.007	100.774	0.107	100.776	0.025	0.105	0.0878
Average	**9.666**	**100.884**	**0.007**	**100.774**	**0.110**	**100.778**	**0.025**	**0.106**	**0.089**
Stdev	**0.0055**	**0.0059**	**0.0002**		**0.0059**	**0.0029**	**0.0002**	**0.0030**	**0.0030**

Table B-2. Model head loss estimation for 2-inch spacing clear louver with 140 cfs flow through the fish-bypass. The green shaded cells are considered as outliers.

Headloss for 140 cfs through fish bypass with 2-inch Spacing, Clear

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
3100	4.16	100.829	100.821	0.0018	100.819	0.002	100.815	0.004	0.006	0.0036
	4.15	100.832	100.825	0.0017	100.819	0.006	100.818	0.004	0.007	0.0046
	4.17	100.831	100.830	0.0017	100.819	0.011	100.819	0.004	0.011	0.0086
	4.23	100.830	100.824	0.0018	100.819	0.005	100.819	0.004	0.005	0.0025
	4.15	100.831	100.824	0.0017	100.819	0.005	100.818	0.004	0.006	0.0036
Average	**4.17**	**100.831**	**100.825**	**0.0018**	**100.819**	**0.006**	**100.818**	**0.004**	**0.007**	**0.004**
Stdev	**0.036**	**0.0011**	**0.0033**	**0.0000**	**0.0000**	**0.0033**	**0.0016**	**0.0001**	**0.0023**	**0.0009**

Flow		Louver							
		15.75		14		13.888			Headloss from
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
87.000	4.185	100.852	0.002	100.819	0.033	100.818	0.004	0.034	0.0314
86.900	4.172	100.848	0.002	100.819	0.029	100.818	0.004	0.030	0.0274
87.100	4.197	100.846	0.002	100.820	0.026	100.821	0.004	0.025	0.0224
87.350	4.229	100.844	0.002	100.819	0.025	100.818	0.004	0.026	0.0234
87.050	4.191	100.848	0.002	100.821	0.027	100.821	0.004	0.027	0.0244
Average	**4.186**	**100.849**	**0.002**	**100.819**	**0.028**	**100.820**	**0.004**	**0.029**	**0.026**
Stdev	**0.0211**	**0.0030**	**0.0000**		**0.0032**	**0.0016**	**0.0000**	**0.0036**	**0.0036**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
5100	6.88	100.831	100.811	0.0051	100.804	0.007	100.798	0.012	0.013	0.0062
	6.96	100.837	100.817	0.0051	100.804	0.013	100.803	0.012	0.014	0.0071
	6.97	100.831	100.809	0.0053	100.804	0.005	100.800	0.012	0.009	0.0022
	6.90	100.831	100.811	0.0051	100.804	0.007	100.800	0.012	0.011	0.0043
	6.96	100.836	100.813	0.0051	100.804	0.009	100.803	0.012	0.010	0.0032
Average	**6.93**	**100.833**	**100.812**	**0.0051**	**100.804**	**0.008**	**100.801**	**0.012**	**0.011**	**0.005**
Stdev	**0.041**	**0.0030**	**0.0030**	**0.0001**	**0.0000**	**0.0030**	**0.0022**	**0.0001**	**0.0021**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
117.600	6.933	100.863	0.004	100.804	0.059	100.802	0.012	0.061	0.0532
117.650	6.937	100.865	0.004	100.803	0.062	100.805	0.012	0.060	0.0522
117.700	6.940	100.861	0.004	100.804	0.057	100.817	0.012	0.044	0.0366
117.650	6.937	100.860	0.004	100.803	0.058	100.802	0.012	0.058	0.0502
117.600	6.933	100.859	0.004	100.804	0.055	100.803	0.012	0.056	0.0483
Average	**6.935**	**100.862**	**0.004**	**100.803**	**0.058**	**100.803**	**0.012**	**0.059**	**0.048**
Stdev	**0.0029**	**0.0024**	**0.0000**		**0.0025**	**0.0064**	**0.0002**	**0.0022**	**0.0067**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
7100	9.63	100.834	100.792	0.0108	100.774	0.018	100.752	0.026	0.040	0.0249
	9.66	100.835	100.791	0.0110	100.774	0.017	100.771	0.025	0.020	0.0061
	9.64	100.839	100.795	0.0107	100.774	0.021	100.773	0.025	0.022	0.0080
	9.67	100.831	100.787	0.0112	100.774	0.013	100.770	0.025	0.017	0.0032
	9.67	100.833	100.790	0.0110	100.774	0.016	100.769	0.025	0.021	0.0070
Average	**9.65**	**100.834**	**100.791**	**0.0109**	**100.774**	**0.017**	**100.767**	**0.025**	**0.024**	**0.006**
Stdev	**0.016**	**0.0030**	**0.0029**	**0.0002**	**0.0000**	**0.0029**	**0.0085**	**0.0005**	**0.0091**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
165.850	9.682	100.887	0.007	100.774	0.113	100.776	0.025	0.111	0.0935
164.400	9.612	100.886	0.007	100.774	0.112	100.778	0.024	0.108	0.0909
165.650	9.672	100.883	0.007	100.774	0.109	100.776	0.025	0.107	0.0897
165.300	9.656	100.882	0.007	100.774	0.108	100.775	0.025	0.107	0.0897
165.650	9.672	100.879	0.007	100.771	0.108	100.772	0.025	0.107	0.0896
Average	**9.653**	**100.883**	**0.007**	**100.773**	**0.110**	**100.775**	**0.025**	**0.107**	**0.091**
Stdev	**0.0279**	**0.0032**	**0.0001**		**0.0024**	**0.0022**	**0.0002**	**0.0017**	**0.0017**

Table B-3. Model head loss estimation for 2-inch spacing louver, 30% blocked with 140 cfs flow through the fish-bypass. The green shaded cells are considered as outliers.

Headloss for 140 cfs through fish bypass with 2-inch Spacing and 30 % blockage

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
3100	4.16	100.829	100.821	0.0018	100.819	0.002	100.815	0.004	0.006	0.0036
	4.15	100.832	100.825	0.0017	100.819	0.006	100.818	0.004	0.007	0.0046
	4.17	100.831	100.830	0.0017	100.819	0.011	100.819	0.004	0.011	0.0086
	4.23	100.830	100.824	0.0018	100.819	0.005	100.819	0.004	0.005	0.0025
	4.15	100.831	100.824	0.0017	100.819	0.005	100.818	0.004	0.006	0.0036
Average	**4.17**	**100.831**	**100.825**	**0.0018**	**100.819**	**0.006**	**100.818**	**0.004**	**0.007**	**0.004**
Stdev	**0.036**	**0.0011**	**0.0033**	**0.0000**	[redacted]	**0.0033**	**0.0016**	**0.0001**	**0.0023**	**0.0009**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	to 13.888
87.100	4.197	100.843	0.002	100.818	0.025	100.818	0.004	0.025	0.0224
87.200	4.210	100.845	0.002	100.819	0.026	100.818	0.004	0.027	0.0244
87.050	4.191	100.844	0.002	100.819	0.025	100.820	0.004	0.024	0.0215
87.200	4.210	100.839	0.002	100.819	0.020	100.820	0.004	0.019	0.0165
87.100	4.197	100.845	0.002	100.819	0.026	100.820	0.004	0.025	0.0224
Average	**4.199**	**100.844**	**0.002**	**100.819**	**0.025**	**100.819**	**0.004**	**0.025**	**0.023**
Stdev	**0.0084**	**0.0025**	**0.0000**	[redacted]	**0.0025**	**0.0011**	**0.0000**	**0.0030**	**0.0012**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
5100	6.88	100.831	100.811	0.0051	100.804	0.007	100.798	0.012	0.013	0.0062
	6.96	100.837	100.817	0.0051	100.804	0.013	100.803	0.012	0.014	0.0071
	6.97	100.831	100.809	0.0053	100.804	0.005	100.800	0.012	0.009	0.0022
	6.90	100.831	100.811	0.0051	100.804	0.007	100.800	0.012	0.011	0.0043
	6.96	100.836	100.813	0.0051	100.804	0.009	100.803	0.012	0.010	0.0032
Average	**6.93**	**100.833**	**100.812**	**0.0051**	**100.804**	**0.008**	**100.801**	**0.012**	**0.011**	**0.005**
Stdev	**0.041**	**0.0030**	**0.0030**	**0.0001**	[redacted]	**0.0030**	**0.0022**	**0.0001**	**0.0021**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	to 13.888
117.600	6.933	100.862	0.004	100.804	0.058	100.804	0.012	0.058	0.0503
117.400	6.919	100.862	0.004	100.804	0.058	100.802	0.012	0.060	0.0522
117.450	6.923	100.864	0.004	100.805	0.059	100.807	0.012	0.057	0.0493
117.600	6.933	100.861	0.004	100.804	0.057	100.804	0.012	0.057	0.0493
117.700	6.940	100.862	0.004	100.804	0.058	100.806	0.012	0.056	0.0483
Average	**6.930**	**100.862**	**0.004**	**100.804**	**0.058**	**100.805**	**0.012**	**0.058**	**0.050**
Stdev	**0.0085**	**0.0011**	**0.0000**	[redacted]	**0.0006**	**0.0019**	**0.0001**	**0.0015**	**0.0015**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	15.75 to 13.888
7100	9.63	100.834	100.792	0.0108	100.774	0.018	100.752	0.026	0.040	0.0249
	9.66	100.835	100.791	0.0110	100.774	0.017	100.771	0.025	0.020	0.0061
	9.64	100.839	100.795	0.0107	100.774	0.021	100.773	0.025	0.022	0.0080
	9.67	100.831	100.787	0.0112	100.774	0.013	100.770	0.025	0.017	0.0032
	9.67	100.833	100.790	0.0110	100.774	0.016	100.769	0.025	0.021	0.0070
Average	**9.65**	**100.834**	**100.791**	**0.0109**	**100.774**	**0.017**	**100.767**	**0.025**	**0.024**	**0.006**
Stdev	**0.016**	**0.0030**	**0.0029**	**0.0002**	[redacted]	**0.0029**	**0.0085**	**0.0005**	**0.0091**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	to 13.888
165.650	9.672	100.882	0.007	100.774	0.108	100.774	0.025	0.108	0.0906
165.650	9.672	100.881	0.007	100.774	0.107	100.771	0.025	0.110	0.0925
165.400	9.660	100.880	0.007	100.774	0.106	100.771	0.025	0.109	0.0915
165.600	9.670	100.878	0.008	100.773	0.105	100.769	0.025	0.109	0.0914
165.500	9.665	100.881	0.007	100.774	0.107	100.771	0.025	0.110	0.0925
Average	**9.668**	**100.880**	**0.007**	**100.774**	**0.107**	**100.771**	**0.025**	**0.109**	**0.092**
Stdev	**0.0052**	**0.0015**	**0.0000**	[redacted]	**0.0012**	**0.0018**	**0.0001**	**0.0008**	**0.0008**

Table B-4. Model head loss estimation for clear 4 3/8-inch spacing louver with 140 cfs flow through the fish-bypass. The green shaded cells are considered as outliers.

Headloss for 140 cfs through fish bypass with 4-inch spacing, Clear

Flows		No Louver								
		18	15.75		14		13.888			Headloss from 15.75 to 13.888
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
3100	4.16	100.829	100.821	0.0018	100.819	0.002	100.815	0.004	0.006	0.0036
	4.15	100.832	100.825	0.0017	100.819	0.006	100.818	0.004	0.007	0.0046
	4.17	100.831	100.830	0.0017	100.819	0.011	100.819	0.004	0.011	0.0086
	4.23	100.830	100.824	0.0018	100.819	0.005	100.819	0.004	0.005	0.0025
	4.15	100.831	100.824	0.0017	100.819	0.005	100.818	0.004	0.006	0.0036
Average	**4.17**	**100.831**	**100.825**	**0.0018**	**100.819**	**0.006**	**100.818**	**0.004**	**0.007**	**0.004**
Stdev	**0.036**	**0.0011**	**0.0033**	**0.0000**	**0.0000**	**0.0033**	**0.0016**	**0.0001**	**0.0023**	**0.0009**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75 to 13.888
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
87.250	4.216	100.840	0.002	100.819	0.021	100.822	0.004	0.018	0.0155
87.100	4.197	100.841	0.002	100.819	0.022	100.820	0.004	0.021	0.0185
87.050	4.191	100.841	0.002	100.819	0.022	100.821	0.004	0.020	0.0175
86.950	4.178	100.840	0.002	100.818	0.022	100.821	0.004	0.019	0.0165
87.100	4.197	100.842	0.002	100.820	0.022	100.822	0.004	0.020	0.0175
Average	**4.201**	**100.841**	**0.002**	**100.819**	**0.022**	**100.821**	**0.004**	**0.020**	**0.017**
Stdev	**0.0136**	**0.0008**	**0.0000**		**0.0005**	**0.0008**	**0.0000**	**0.0011**	**0.0011**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from 15.75 to 13.888
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
5100	6.88	100.831	100.811	0.0051	100.804	0.007	100.798	0.012	0.013	0.0062
	6.96	100.837	100.817	0.0051	100.804	0.013	100.803	0.012	0.014	0.0071
	6.97	100.831	100.809	0.0053	100.804	0.005	100.800	0.012	0.009	0.0022
	6.90	100.831	100.811	0.0051	100.804	0.007	100.800	0.012	0.011	0.0043
	6.96	100.836	100.813	0.0051	100.804	0.009	100.803	0.012	0.010	0.0032
Average	**6.93**	**100.833**	**100.812**	**0.0051**	**100.804**	**0.008**	**100.801**	**0.012**	**0.011**	**0.005**
Stdev	**0.041**	**0.0030**	**0.0030**	**0.0001**	**0.0000**	**0.0030**	**0.0022**	**0.0001**	**0.0021**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75 to 13.888
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
117.600	6.933	100.855	0.004	100.805	0.050	100.810	0.012	0.045	0.0376
117.400	6.919	100.851	0.004	100.803	0.048	100.808	0.012	0.043	0.0356
117.450	6.923	100.852	0.004	100.806	0.046	100.809	0.012	0.043	0.0356
117.600	6.933	100.853	0.004	100.805	0.048	100.810	0.012	0.043	0.0356
117.700	6.940	100.851	0.004	100.803	0.048	100.807	0.012	0.044	0.0365
Average	**6.930**	**100.852**	**0.004**	**100.804**	**0.048**	**100.809**	**0.012**	**0.044**	**0.036**
Stdev	**0.0085**	**0.0017**	**0.0000**		**0.0014**	**0.0013**	**0.0000**	**0.0009**	**0.0009**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from 15.75 to 13.888
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
7100	9.63	100.834	100.792	0.0108	100.774	0.018	100.752	0.026	0.040	0.0249
	9.66	100.835	100.791	0.0110	100.774	0.017	100.771	0.025	0.020	0.0061
	9.64	100.839	100.795	0.0107	100.774	0.021	100.773	0.025	0.022	0.0080
	9.67	100.831	100.787	0.0112	100.774	0.013	100.770	0.025	0.017	0.0032
	9.67	100.833	100.790	0.0110	100.774	0.016	100.769	0.025	0.021	0.0070
Average	**9.65**	**100.834**	**100.791**	**0.0109**	**100.774**	**0.017**	**100.767**	**0.025**	**0.024**	**0.006**
Stdev	**0.016**	**0.0030**	**0.0029**	**0.0002**	**0.0000**	**0.0029**	**0.0085**	**0.0005**	**0.0091**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75 to 13.888
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
165.550	9.668	100.861	0.008	100.773	0.088	100.781	0.024	0.080	0.0637
165.500	9.665	100.864	0.008	100.774	0.090	100.785	0.024	0.079	0.0628
165.550	9.668	100.862	0.008	100.773	0.089	100.781	0.024	0.081	0.0647
165.450	9.663	100.864	0.008	100.773	0.091	100.782	0.024	0.082	0.0657
165.600	9.670	100.863	0.008	100.773	0.090	100.781	0.024	0.082	0.0656
Average	**9.667**	**100.863**	**0.008**	**100.773**	**0.090**	**100.782**	**0.024**	**0.081**	**0.065**
Stdev	**0.0028**	**0.0013**	**0.0000**		**0.0012**	**0.0017**	**0.0001**	**0.0013**	**0.0012**

Table B-5. Model head loss estimation for clear 6 3/4 & 4 3/8 & 2-inch spacing louver with 140 cfs flow through the fish-bypass. The green shaded cells are considered as outliers.

Headloss for 140 cfs through fish bypass with 6-4-2-inch spacing, Clear

Flows		No Louver								
		18	15.75		14		13.888			Headloss from 15.75 to 13.888
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
3100	4.16	100.829	100.821	0.0018	100.819	0.002	100.815	0.004	0.006	0.0036
	4.15	100.832	100.825	0.0017	100.819	0.006	100.818	0.004	0.007	0.0046
	4.17	100.831	100.830	0.0017	100.819	0.011	100.819	0.004	0.011	0.0086
	4.23	100.830	100.824	0.0018	100.819	0.005	100.819	0.004	0.005	0.0025
	4.15	100.831	100.824	0.0017	100.819	0.005	100.818	0.004	0.006	0.0036
Average	**4.17**	**100.831**	**100.825**	**0.0018**	**100.819**	**0.006**	**100.818**	**0.004**	**0.007**	**0.004**
Stdev	**0.036**	**0.0011**	**0.0033**	**0.0000**	**0.0000**	**0.0033**	**0.0016**	**0.0001**	**0.0023**	**0.0009**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75 to 13.888
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
86.900	4.172	100.845	0.002	100.819	0.026	100.821	0.004	0.024	0.0215
87.000	4.185	100.845	0.002	100.819	0.026	100.823	0.004	0.022	0.0195
87.000	4.185	100.844	0.002	100.819	0.025	100.819	0.004	0.025	0.0224
87.000	4.185	100.846	0.002	100.820	0.026	100.822	0.004	0.024	0.0215
87.100	4.197	100.846	0.002	100.820	0.026	100.822	0.004	0.024	0.0214
Average	**4.185**	**100.845**	**0.002**	**100.819**	**0.026**	**100.821**	**0.004**	**0.024**	**0.021**
Stdev	**0.0089**	**0.0008**	**0.0000**	[redacted]	**0.0004**	**0.0015**	**0.0000**	**0.0011**	**0.0011**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from 15.75 to 13.888
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
5100	6.88	100.831	100.811	0.0051	100.804	0.007	100.798	0.012	0.013	0.0062
	6.96	100.837	100.817	0.0051	100.804	0.013	100.803	0.012	0.014	0.0071
	6.97	100.831	100.809	0.0053	100.804	0.005	100.800	0.012	0.009	0.0022
	6.90	100.831	100.811	0.0051	100.804	0.007	100.800	0.012	0.011	0.0043
	6.96	100.836	100.813	0.0051	100.804	0.009	100.803	0.012	0.010	0.0032
Average	**6.93**	**100.833**	**100.812**	**0.0051**	**100.804**	**0.008**	**100.801**	**0.012**	**0.011**	**0.005**
Stdev	**0.041**	**0.0030**	**0.0030**	**0.0001**	**0.0000**	**0.0030**	**0.0022**	**0.0001**	**0.0021**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75 to 13.888
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
117.550	6.930	100.858	0.004	100.804	0.054	100.806	0.012	0.052	0.0444
117.700	6.940	100.861	0.004	100.805	0.056	100.808	0.012	0.053	0.0454
117.600	6.933	100.858	0.004	100.805	0.053	100.807	0.012	0.051	0.0434
117.450	6.923	100.860	0.004	100.805	0.055	100.808	0.012	0.052	0.0444
117.600	6.933	100.860	0.004	100.803	0.057	100.808	0.012	0.052	0.0444
Average	**6.932**	**100.859**	**0.004**	**100.804**	**0.055**	**100.807**	**0.012**	**0.052**	**0.044**
Stdev	**0.0063**	**0.0013**	**0.0000**	[redacted]	**0.0017**	**0.0009**	**0.0000**	**0.0007**	**0.0007**

Flows		No Louver								
		18	15.75		14		13.888			Headloss from 15.75 to 13.888
Prototype	Model	WSE	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
7100	9.63	100.834	100.792	0.0108	100.774	0.018	100.752	0.026	0.040	0.0249
	9.66	100.835	100.791	0.0110	100.774	0.017	100.771	0.025	0.020	0.0061
	9.64	100.839	100.795	0.0107	100.774	0.021	100.773	0.025	0.022	0.0080
	9.67	100.831	100.787	0.0112	100.774	0.013	100.770	0.025	0.017	0.0032
	9.67	100.833	100.790	0.0110	100.774	0.016	100.769	0.025	0.021	0.0070
Average	**9.65**	**100.834**	**100.791**	**0.0109**	**100.774**	**0.017**	**100.767**	**0.025**	**0.024**	**0.006**
Stdev	**0.016**	**0.0030**	**0.0029**	**0.0002**	**0.0000**	**0.0029**	**0.0085**	**0.0005**	**0.0091**	**0.0021**

Flow		Louver							
		15.75		14		13.888			Headloss from 15.75 to 13.888
Gage	Flow	WSE	V2/2g	WSE	WS Drop	WSE	V2/2g	WS Drop	
165.750	9.677	100.877	0.008	100.775	0.102	100.782	0.024	0.095	0.0782
165.350	9.658	100.871	0.008	100.775	0.096	100.778	0.024	0.093	0.0762
165.550	9.668	100.874	0.008	100.776	0.098	100.783	0.024	0.091	0.0744
165.550	9.668	100.873	0.008	100.775	0.098	100.779	0.024	0.094	0.0772
165.700	9.675	100.873	0.008	100.775	0.098	100.778	0.025	0.095	0.0781
Average	**9.669**	**100.874**	**0.008**	**100.775**	**0.099**	**100.780**	**0.024**	**0.094**	**0.077**
Stdev	**0.0076**	**0.0022**	**0.0001**	[redacted]	**0.0022**	**0.0023**	**0.0001**	**0.0017**	**0.0016**

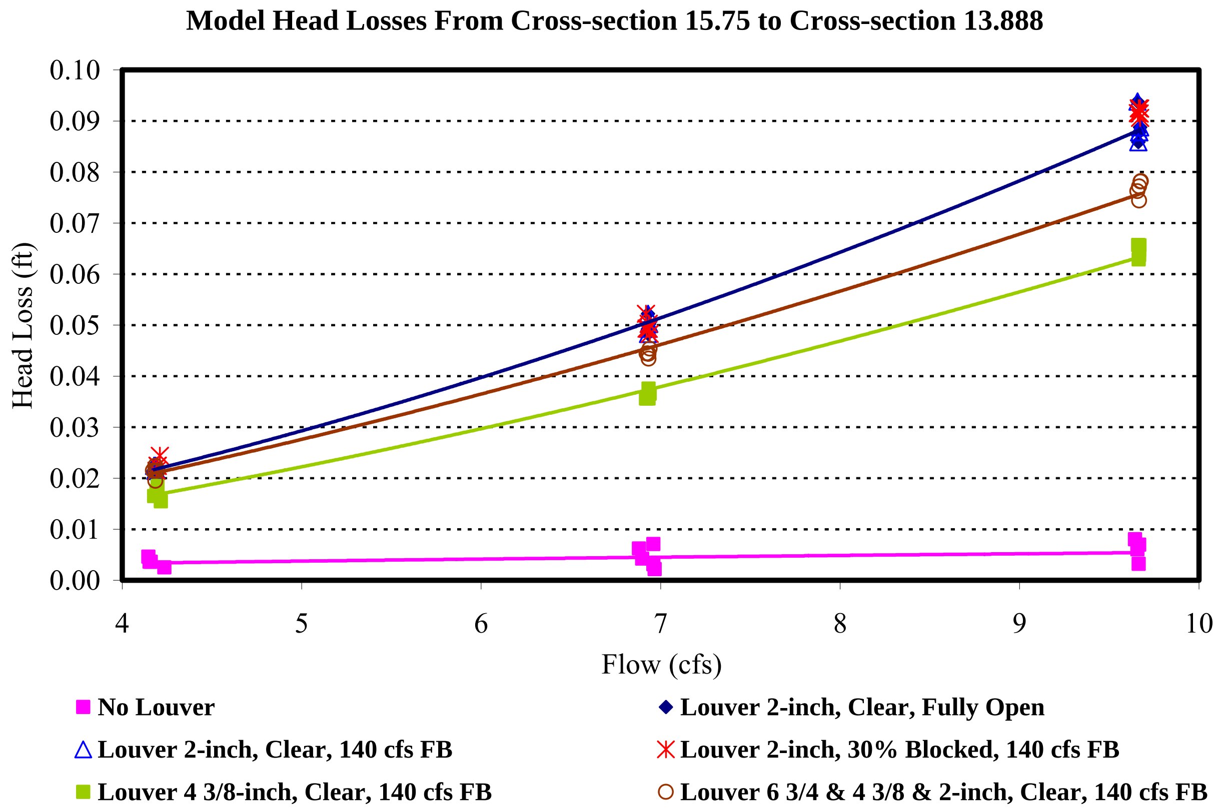

Figure B-1. Total model head loss (friction loss plus the louver head loss) versus flows under the no louver condition and the 5 louver conditions described in section 3.2.2.