PAP-1015

Hydraulic Model Study Results for the Nimbus Fish Hatchery Replacement Weir – In-River Barrier with Bladder-Controlled Gates

By
Kathleen H. Frizell
US Department of Interior, Bureau of Reclamation
Technical Services Center, Hydraulic Investigations and Laboratory Services
Denver, CO 80225

May 2010

Hydraulic Model Study Results for the Nimbus Fish Hatchery Replacement Weir – In-River Barrier with Bladder-Controlled Gates

Initial Draft - September 2002
Final Draft - May 2010

By
Kathleen H. Frizell
US Department of Interior, Bureau of Reclamation
Technical Services Center, Hydraulic Investigations and Laboratory Services
Denver, CO 80005

Background

Over the lifetime of the structure significant maintenance and repair issues have been encountered. When pickets are in place, it is necessary to manually remove debris twice weekly. At high discharges, it is necessary to raise or remove components of the barrier to prevent components from being damaged or destroyed. When flows exceed about 5000 ft^3/s, pickets are raised, at a 10,000 ft^3/s, the pickets are removed and at a threshold of 15,000 ft^3/s, the walkway/support-racks are removed. Removal of the support frames and pickets is approximately a three day task.

The need to replace this barrier with a new structure began a series of planning efforts. This report follows the previous effort in modeling a floating bar rack barrier with draft report titled "DRAFT: Nimbus Hatchery Fish Barrier Physical Model Study – Floating Bar Rack Tom Gill, Water Resources Research Laboratory, US Bureau of Reclamation, 2002".

Barrier Geometry and Operation Description

The modeled fish barrier includes a 180-ft-wide sill crest at EL. 79.5 with 8.5-ft-high picketed gates for a fish barrier. The sill was set at this elevation to pass 2,500 ft^3/s through four 15 ft-wide bypass channel bays at elevation 73 without flow over the top of the sill crest. This would allow access to the sill across a bridge over the bypass to perform maintenance and minimize the upstream power impacts caused by raising the upstream head. The 13-ft-high picketed gates in the bypass section have a 6.5-ft-high solid panel at the base with pickets above to force flow evenly across the entire structure while the barrier is up or the gates are in the closed position. Bulkheads are required in the bypass section to perform maintenance in these 4 bays. The ladder entrance is located adjacent to the bypass structure on the south bank.

This alternative was chosen because:

- Raising the barrier would not require the flow in the river to be lowered
- Maintenance should be very infrequent

Flow in the ladder is 30 ft^3/s. It is realized that this flow is smaller than would generally be acceptable, however, this ladder flow has been adequate over the history of the project to attract the necessary fish into the ladder and was not changed for the new design.

Adult salmon and steelhead were to use the ladder from approximately Nov. 1 to April 1 of each spawning season. The picketed gates would be up forming the barrier from early Sept. until mid Dec., and the steelhead would be attracted to the ladder with the barrier down. The drop through each weir section of the ladder would be 1 ft for adult travel.

Model Descriptions

Two models were used to evaluate the performance of the proposed new structure for the Nimbus fish hatchery barrier. The first was a 1:30 scale three dimensional model to including the entire new barrier with the 180-ft-long fixed sill at elevation 79.5, the 60-ft-wide bypass at elevation 73 ft and the new joint adult and juvenile fish ladder entrance, figure 1. The model also included long portions of the river upstream and downstream from the structure. Simulated picketed gates were installed in this model.

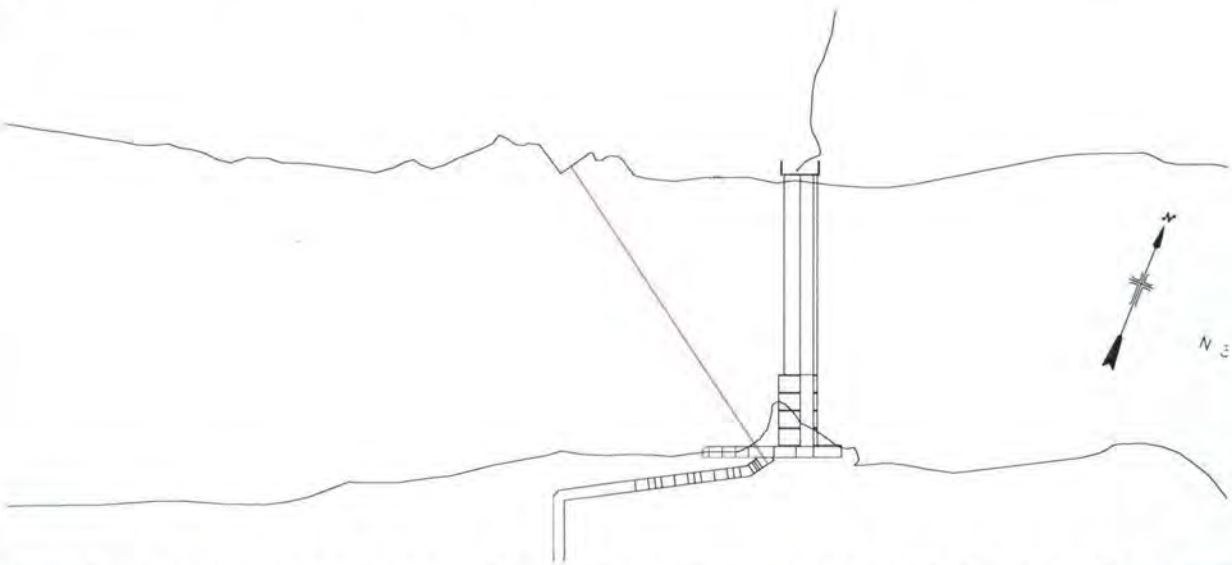

Figure 1. - Overall view of the new fish hatchery barrier dam as modeled in the 1:30 scale model. The angled lined downstream from the new dam shows the alignment of the existing structure. The new ladder entrance is along the south bank and connects into the existing ladder going up the hill to the hatchery.

The second model was a 1:4 scale sectional model of the fixed sill with the downstream apron and an Obermeyer bladder-controlled picket gate constructed and installed, as the prototype gate would be, figure 2. The sectional model was constructed in the Water Resources Research Laboratory's permanent 4-ft-wide flume facility. This scale was necessary to ensure that the gate would perform as an effective barrier. Tailwater levels were controlled by a hinged gate downstream according to the Fair Oaks gage data for each of the flow rates tested.

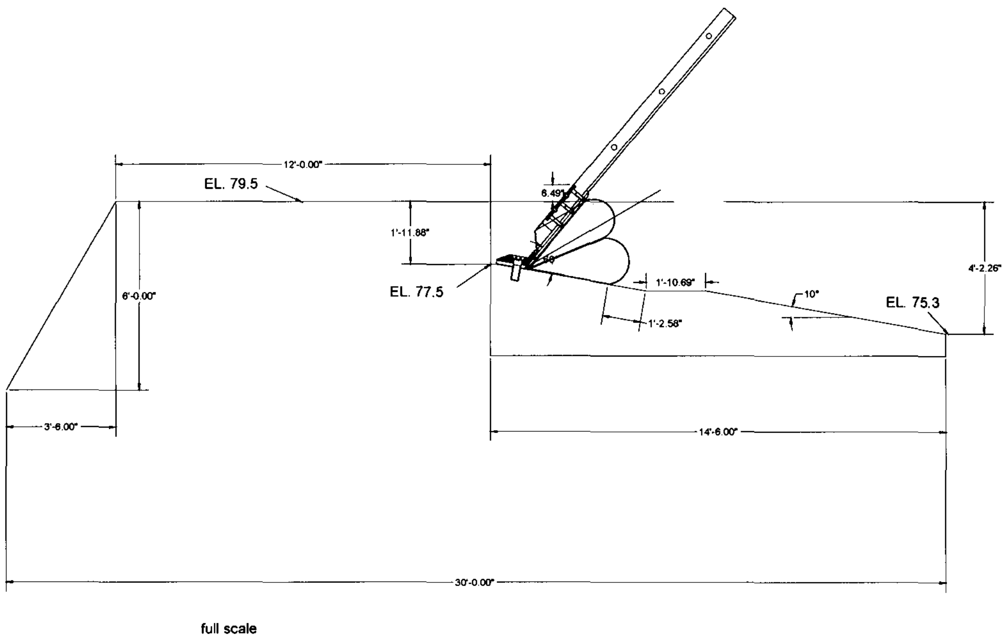

Figure 2. - 1:4 scale sectional model of the fixed sill with the downstream apron and an Obermeyer bladder-controlled picket gate.

Objectives

The 1:4 scale sectional model was used to investigate the hydraulics through the gate and across the sill for flow rates up to 7000 ft^3/s with a tailwater of 80.24 ft. The gate seating elevation relative to the sill elevation and the head loss through the gate were determined. The length and geometry of the apron necessary to accommodate the gate and support the pickets were also determined. The flow depths on the sill and the locations of the hydraulic jumps were noted and used to determine expected fish jumping behavior.

The 1:30 scale model was used to investigate the overall flow conditions across the structure and near the new ladder entrance. Flow conditions in front of the new ladder entrance and across the width of the river associated with the gate barrier up and the bypass only were documented. In addition, the elevation of the bypass bridge was determined for maintenance access. The location of flow from the ladder and juvenile passage channel was also documented and judgment made as to the adequacy of the location of the attraction flow.

Test Conditions

Data were recorded for the following test conditions:

Discharge (ft^3/s)	Tailwater (ft) from Fair Oaks gage
1500	76.48
2500	77.4
5000	79.03
7000	80.02
Additional high flows in 3D model	

Obermeyer Gate Fish Barrier Evaluation

Fish jumping abilities were evaluated based upon a chart relating jump height and distance to the condition of the particular fish species. The species evaluated in the chart were Chinook, Coho, Sockeye salmon and Steelhead trout. The jumping ability of fish depends upon the hydraulics of the situation, depth, velocity, turbulence level, etc. A 1:4 model of a section of the Obermeyer bladder gate with pickets was installed in the WRRL 4-ft-wide flume. The gate was installed in the model with the solid gate leaf located below the sill or crest elevation with the gate at a 60-degree angle. The river flow rates and tailwater elevations were set and observations made of the hydraulics to determine the effectiveness of the gates to act as a barrier.

The fish jumping point was determined from the hydraulics of the flow condition through the gate and over the sill. Figures 3-6 show the flow conditions for discharges of 1500, 2500, 5000, and 7000 ft^3/s through the picket gate. The fish will jump from the hydraulic jump that is located on the sill or just off the end of the 30-ft-long sill. Fish will actually use the hydraulics of the roller to help propel them upwards. The following schematics were developed from the model observations. The sweeping flow over the concrete sill is not conducive to fish jumping both from a velocity and depth standpoint.

The jumping points for discharges of 1500, 2500, 5000, and 7000 ft^3/s are located on figures 7-10 with the assumed fish jumping trajectories drawn. The trajectories are for steep short jumps of 80 degrees or for flatter long jumps of 40 degrees. When there appeared to be a need the intermediate trajectory of 60 degrees was also plotted to ensure that this situation was not critical. The fish health at 1 is a very strong specimen that has not endured a long migration. The fish health of 0.75 is a fish that has used a significant amount of energy in its travels. The figures are for both fish conditions and for Chinook, Coho, and Sockeye and for Steelhead, that are the stronger performers.

The depth of flow required for sounding and effective jumping is also a variable that needs consideration. A general rule-of-thumb is that a fish needs at least 1½ to 2 times its body length in depth to jump effectively. The flow depth in the hydraulic jump over the sill at the jump point was also recorded. The conditions at the jump point varied. With smaller discharges the jump was more fully formed without a high velocity sweeping jet of flow underneath the jumping point. As the discharged increased the depth increased, but beneath the turbulent surface of the jump was a coherent sweeping jet of high velocity underneath the jump surface over the sill surface. It is assumed that this would limit effective sounding for maximum jumping.

In summary, the gate should act as an effective fish barrier. Only the strongest swimming steelhead trout have any chance of passing over the barrier.

(After completion of these tests the gate was raised upon realizing that the gate bolts would be below the tw at 2500 ft^3/s through the bypass. Therefore, the gate seat elevation was raised to 77.5, 2 ft below the crest. This however causes the solid gate panel to be above the sill at the 60-degree angle. Still need to look at this.)

Figure 3 - Flow conditions for Q=1500 ft^3/s, TW=El. 76.5 ft through the sectional model of the picketed gate. Note the flow depth and location of the jump relative to the gate and the sill.

Figure 4. - Flow conditions for Q=2500 ft^3/s, TW=El. 77.4 ft through the sectional model of the picketed gate. Note the flow depth and location of the jump relative to the gate and the sill.

Figure 5. - Flow conditions for Q=5000 ft^3/s, TW=El. 79.03 ft through the sectional model of the picketed gate. Note the flow depth and location of the jump relative to the gate and the sill.

Figure 6. - Flow conditions for Q=7000 ft^3/s, TW=El. 80.02 ft through the sectional model of the picketed gate. Note the flow depth and location of the jump relative to the gate and the sill.

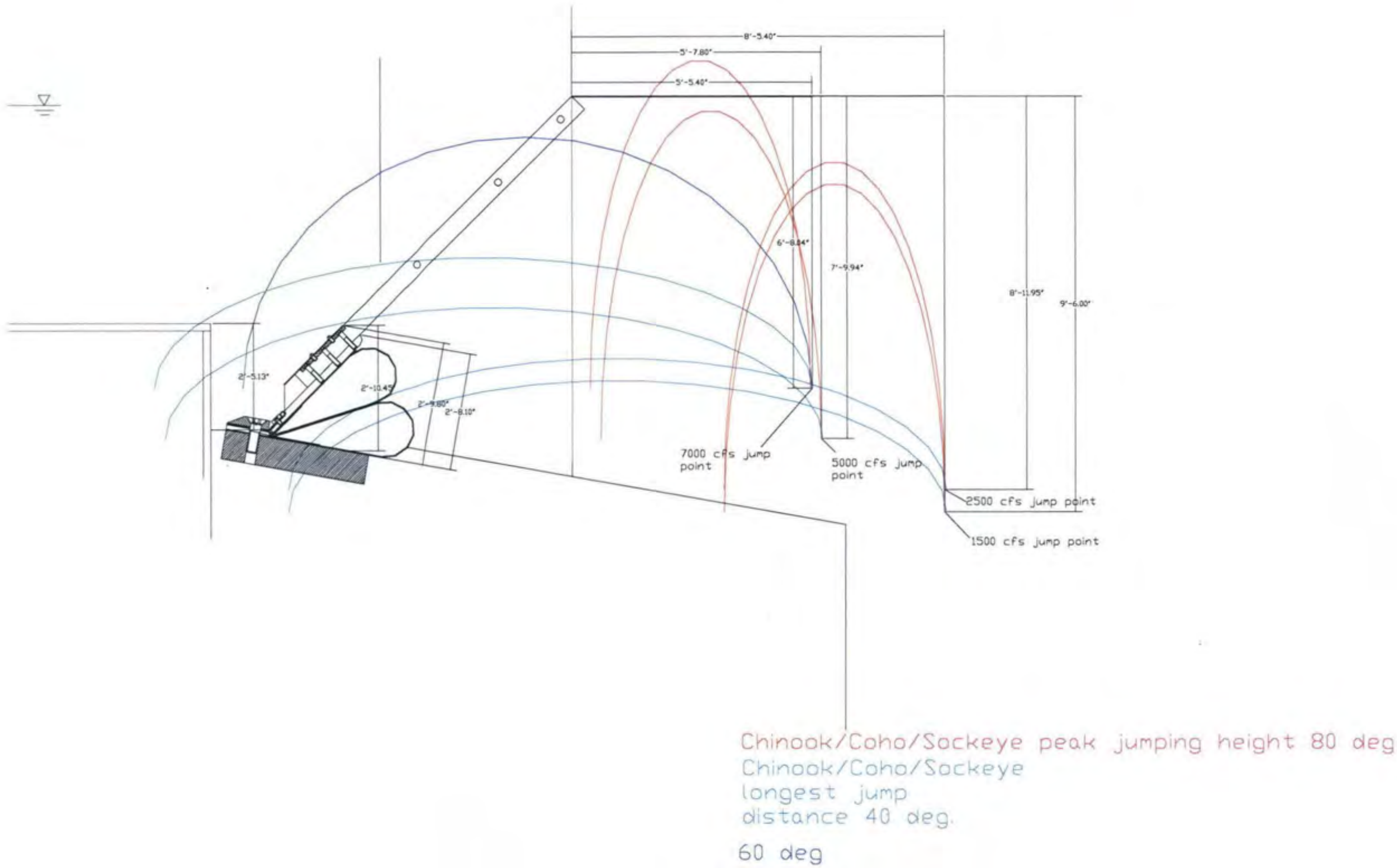

Figure 7. Gate fish barrier for the sill at El. 79.5 ft with the jump points shown for various flow rates up to 7000 ft^3/s. Jumping trajectories are for the best salmonid fish condition and the barrier should be entirely effective.

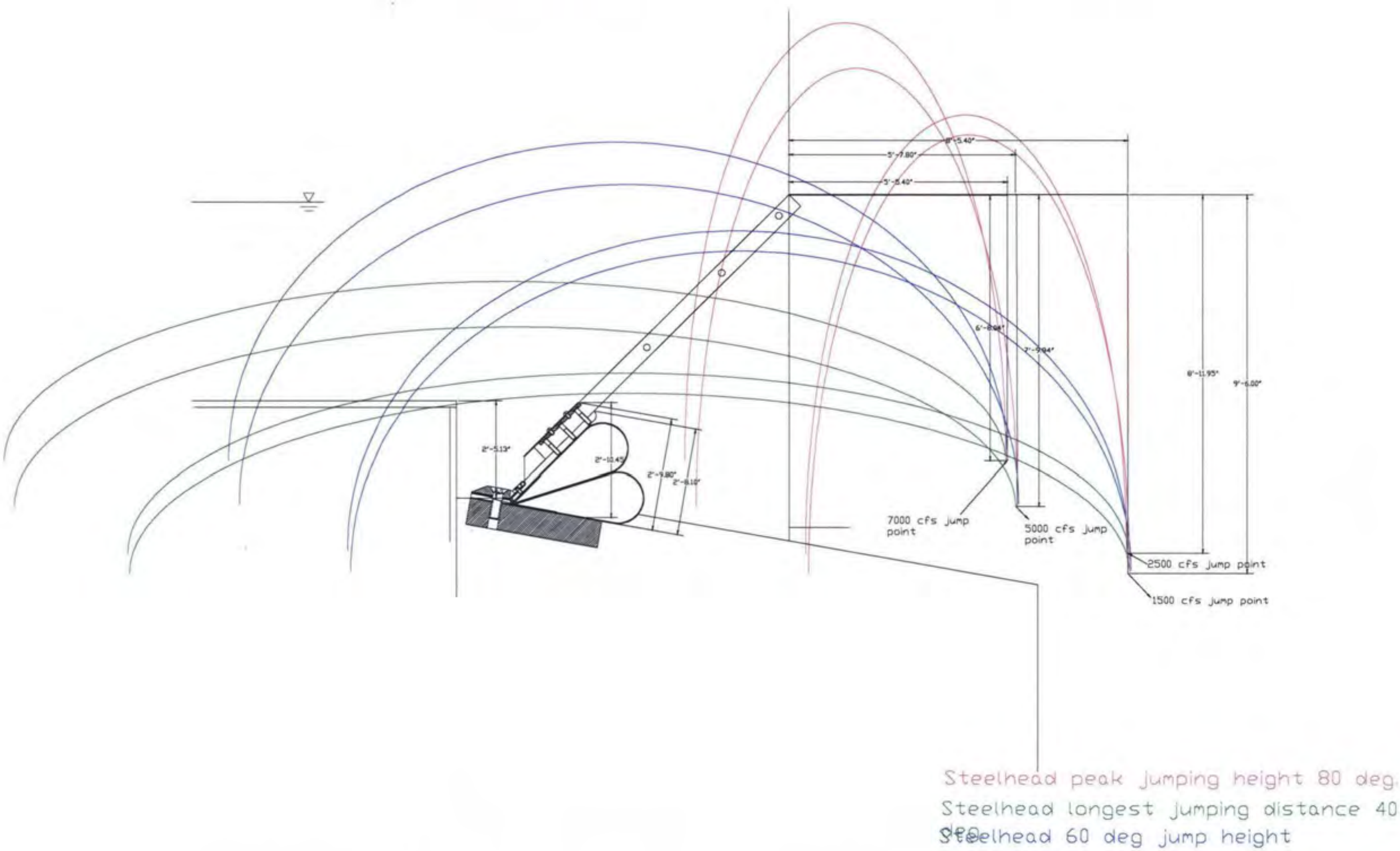

Figure 8. Gate fish barrier for the sill at El. 79.5 with the jump points shown for various flow rates up to 7000 ft^3/s. Jumping trajectories for the best steelhead trout condition and the barrier should be only partially effective at 5000 and 7000 ft^3/s. The strongest trout could conceivably jump the barrier if the flow depth of about 3.5 ft over the sill is adequate for staging and sounding.

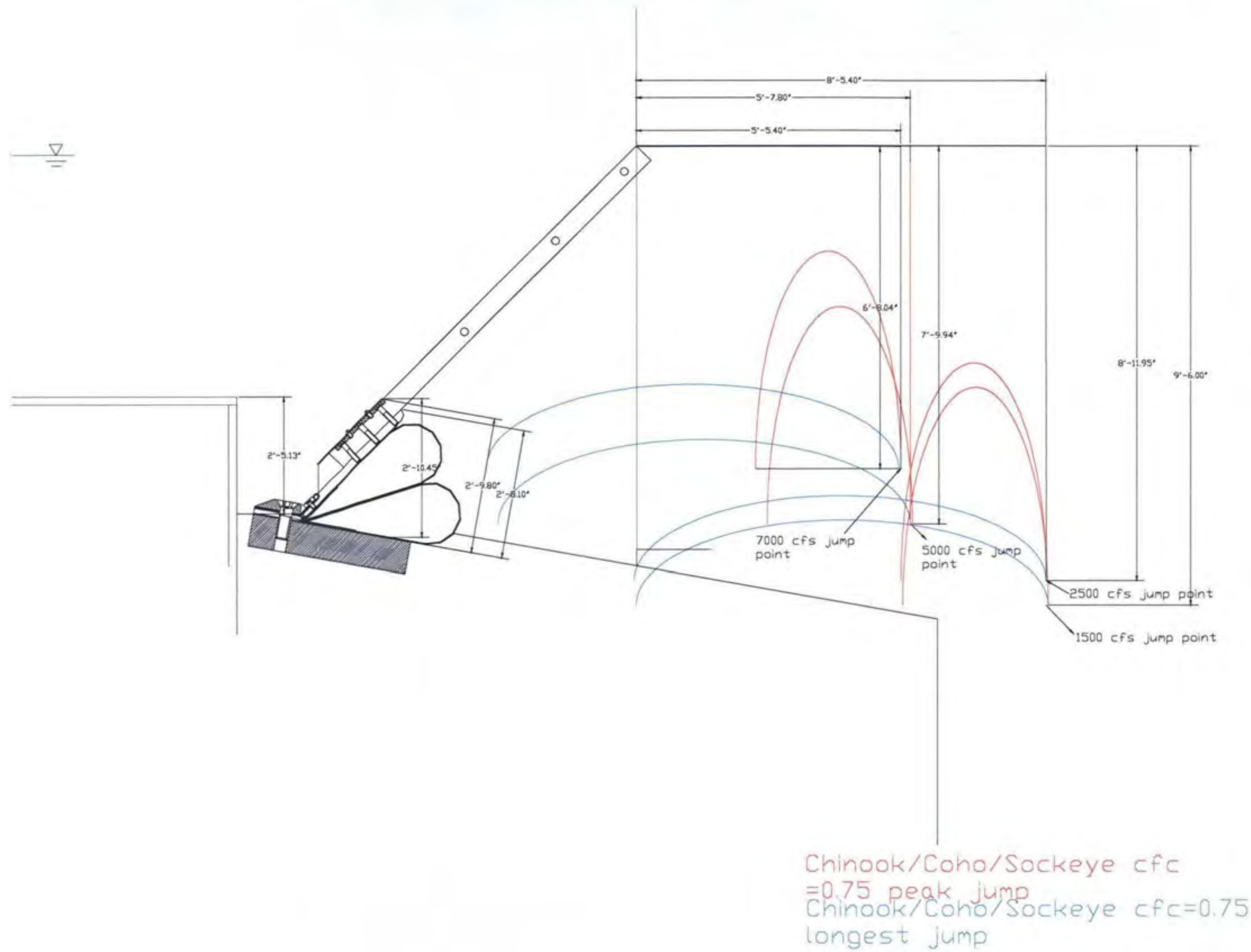

Figure 9. Gate fish barrier for the sill at El. 79.5 with the jump points shown for various flow rates up to 7000 ft^3/s. Jumping trajectories for the weakened salmonid fish condition and the barrier should be entirely effective.

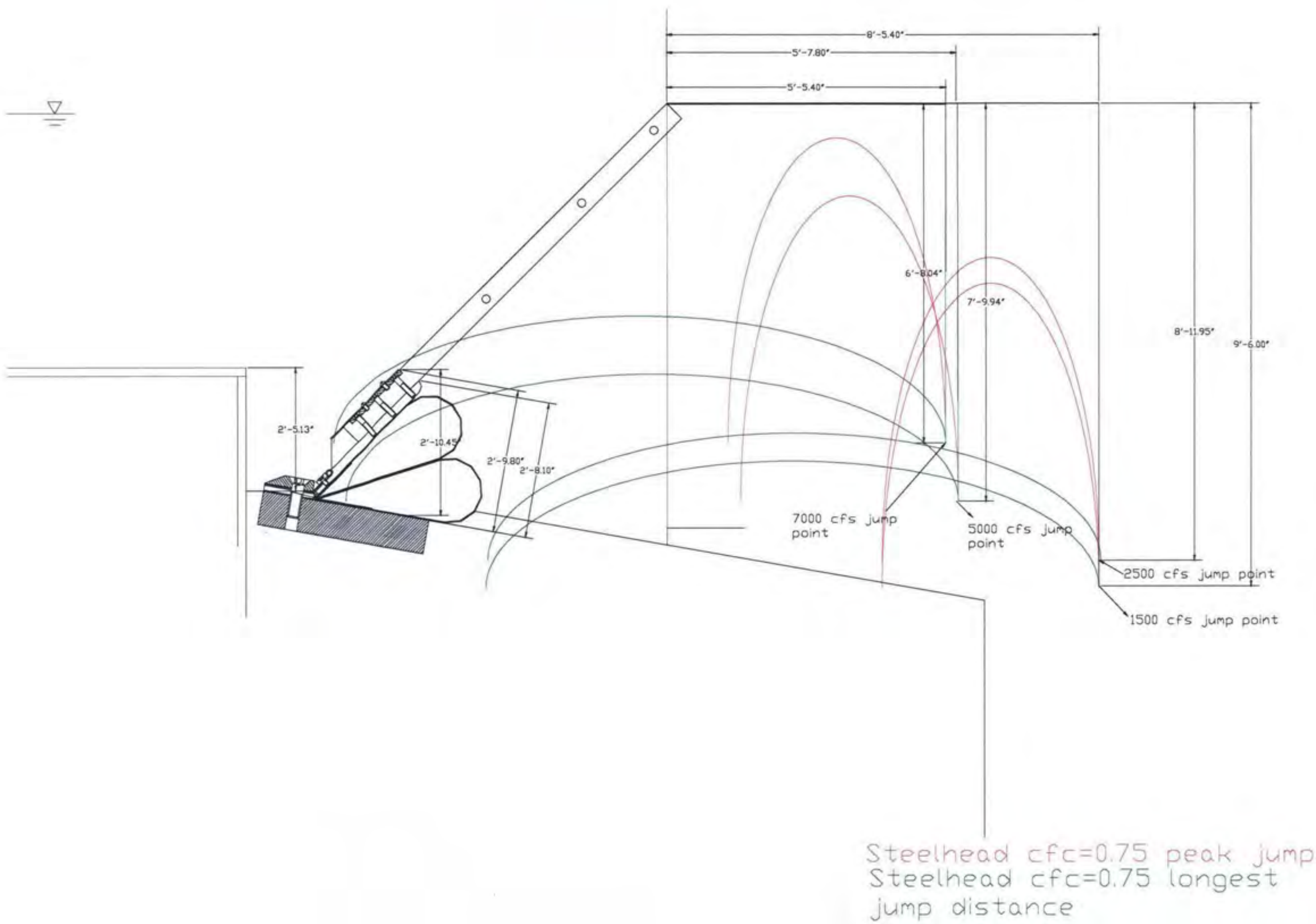

Figure 10. Gate fish barrier for the sill at El. 79.5 with the jump points shown for various flow rates up to 7000 ft^3/s. Jumping trajectories for the weakened steelhead trout condition and the barrier should be entirely effective.

The picket gate locally affected flow conditions across the sill. The 12 ft width of the sill was determined by the width needed to driver vehicles across the sill for maintenance. This width alone causes undulating flow over the crest due to shallow flow depths. The picket gate also affects the location of critical depth on the sill, but the pickets do not create enough loss to affect the reservoir level. Only the sill portion of the barrier was modeled. This portion is 180 ft long. The rating curve, figure 11, for the sill only and with the picket gate up shows the influence of the pickets on the head loss. The discharge coefficient without the picket gate up matches that of a typical broad crested weir. With the picket gate up, there is a slight localized increase in head or loss through the gate, but it does not significantly affect the upstream reservoir elevation.

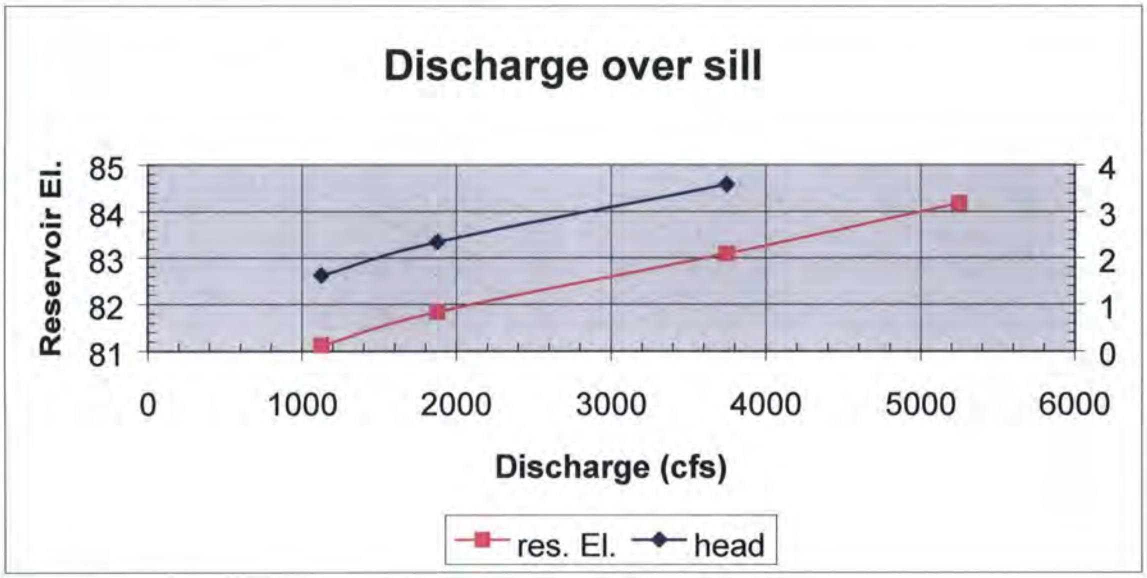

Figure 11. Rating curve for the 180-ft-long sill at El. 79.5 ft.

Overall Flow Conditions with 4-bay Bypass, Sill, and Juvenile Channel

The 1:30 scale three-dimensional model was used to evaluate the flow field of the entire structure including with the gates down, gates up and the attraction flow from the new ladder entrance. The gate tested for the sill will have a 6.5-ft-high solid panel below the picketed portion of the 12.5-ft total height of the gate in the bypass. This section will discuss:

- The new ladder requirements and design
- Flow conditions with the barrier gates down
- Flow conditions with the barrier gates up

<u>New Hatchery Ladder Entrances</u>

The new hatchery ladder entrance was designed using the same philosophy and geometry as presently used for passage of adult salmon and steelhead. The new entrance however will not be an overflow weir that extends across the barrier into the flow. It will be an extension of the 9-ft-wide weir and pool ladder along the south riverbank with a series of orifice openings and an angled downstream weir opening. Any or all of the openings may be used as necessary based upon the flow conditions and tendencies of the fish as they travel up to the barrier. The design features of the new ladder entrance are:

- Join the new ladder entrance where it can be feasibly attached to the existing ladder. At the joint location add bulkhead slots for closing off the existing ladder portion from the new ladder entrance.
- Maintain the 12:1 sloping floor beginning at El. 74ft at the attachment point and ending at El. 70.5 ft. Maintain the 1 ft drop between adjustable weirs beginning with El. 78 ft and dropping down to El. 75 with each weir forming a 4.5-ft-high pool.
- Four orifice openings 2.5-ft-wide by 1.5-ft-high located on center between weirs at various elevations down the 12:1 slope. The openings will be at various elevations and distances from the end of the bypass which will offer flexibility during ladder operation.
- The ladder entrance will be 71.5 ft long along the south bank from where it connects to the existing ladder. At the downstream end of the entrance is an overflow weir at El. 74ft and angled at 45 degrees out into the river channel. This weir is 7 ft wide.
- Each orifice and the end weir will all be gated for operation either open or closed.
- A fillet should be constructed in the wall adjacent to the end weir or the actual ladder wall adjacent to the end weir should be beveled inward to prevent a Recirculation zone at the downstream end of the ladder entrance.
- The elevation of the top of the wall of the new ladder entrance is 88.5 ft to be consistent with the wall height of the existing ladder.

The new ladder entrance must also meet criteria for upstream passage of juvenile steelhead. Therefore, the structure will split with one end leading to the existing ladder and one end leading to the river upstream from the barrier. The weir heights will be adjustable and the downstream end weir will be the primary entrance along the south bank where the entrance is offset from the sweeping flow from the bypass channel.

Upstream Juvenile Fish Passage

Currently, the existing barrier is low enough and has enough "holes" in the dumped rock structure that juveniles are capable of passing upstream. Upstream passage of juvenile steelhead must be provided for at the new hatchery barrier based upon discussions with NMFS. As a result, juvenile passage must be designed for usage when the barrier gates are down, adult fish are not being collected and the flow in the river is being bypassed. Since, juvenile passage is not required when adult fish are being collected, it was decided to use a common downstream portion of the new ladder for both collecting of adults and passage of juveniles. The exception to this is when adult steelhead are needed in the hatchery. Steal head are currently collected occasionally through April without the barrier installed. Therefore, it is possible that the adult ladder and the juvenile channel would be operating at the same time. The adults could go either direction and may choose the hatchery ladder or not. Whether the juvenile ladder will need to be briefly closed or not will need to be determined by field operation.

Juvenile steelhead about 100 mm in length can only swim with sustainable speed of up to 2.9 ft/s. This is much less than adult fish and therefore requires special accommodations.

Assumed criteria for juvenile fish passage in a weir and pool ladder are:

Head differential = 0.7 ft
Minimum water depth over weir = 0.33 ft
Velocity in pool = 1 to 2 ft/s
Minimum depth in pool = 3 to 4 ft

Entrance should be located near the bank and where the fish encounter a flow velocity less than 3 ft/s. Exit should be located along the bank far enough upstream to avoid being sucked right back downstream by the bypass flow approach velocity or a groin or low safe area should be provided.

The new entrance design will include the following features for upstream juvenile passage while the barrier gates are down:

- A common ladder entrance chamber will be utilized with.
- Extension of the 9-ft-wide entrance parallel to and upstream of the bypass channel by 15 ft. The wall heights of the upstream portion of the entrance from the joint lower portion to the reservoir are limited by the elevation of the access road across the top of the bypass and crest structure to elevation 81. This will limit operation of the juvenile bypass to flows of about 3500 ft^3/s without accounting for drawdown at the structure. With drawdown at the structure the discharge before inundation of the juvenile passage channel occurs at about 5,000 ft^3/s.
- Addition of a control weir at the upstream junction with the existing ladder connection. This weir must control the flow into the juvenile passage channel keeping the head differential at or below 0.7 ft for <u>all</u> operating conditions. In addition, this weir must have adequate height and strength to withstand upstream water level loading when closed due to use of the existing ladder when taking adult fish.
- Lower the elevation of the juvenile channel upstream from the existing ladder entrance floor elevation of 74 ft to El. 72 ft.

The juvenile passage must have enough flow to provide attraction and a velocity through the pools but not exceed the head differential criteria. The juvenile fish do like to jump as opposed to swim in stream flow so the weir and pool geometry should be acceptable. The floor of the channel was lowered to El. 72 ft to produce an offset below the bypass channel elevation of 73 ft, thus providing a zone near the bottom for the juveniles to use and avoid the bypass velocities. At 2500 ft^3/s, the velocities in front of the bypass channel adjacent to the juvenile channel are 6 ft/s and 3 ft/s at 15 and 30 ft upstream, respectively. Every attempt should be made to provide rock cover near the channel exit for the juveniles as they move up the bank away from the bypass entrance.

The height of the control weir and the height of the subsequent weirs forming pools downstream should be set on site. There is a total of 1.9 ft of head differential under the 2500 ft^3/s discharge so only three weirs should need to be used.

The downstream end weir will be the most useful for juvenile passage. Fish will sense the attraction flow along the south bank and be able to enter the ladder without being exposed to the sometimes high velocities sweeping by the orifice openings produced by the bypass flow.

Barrier Gates Down

Discharges were set and the reservoir head and local upstream and downstream head readings were recorded through bay 3 of the bypass structure. The bypass bays are numbered 1 through 4 from left to right looking downstream. Velocities were measured downstream of the bypass adjacent to the fish ladder entrance for a distance of 60 ft off the centerline of each bay. Ladder attraction flow was then added and released from the various ladder entrance locations and the flow patterns observed with dye tracing.

A rating curve was developed for flow over the barrier with the gates down in the bypass and over the sill crest. Flows up to 2500 ft^3/s would pass through the bypass with progressively larger flows passing over the sill crest then finally inundating the bridge deck over the bypass and the fish ladder. Unlike the existing structure as flows increase the additional height of the crest sill prevents submergence of the structure by the downstream tailwater. The rating curve is shown on figure 12 with the bypass gates down and the head referenced to El. 79.5 ft of the sill crest.

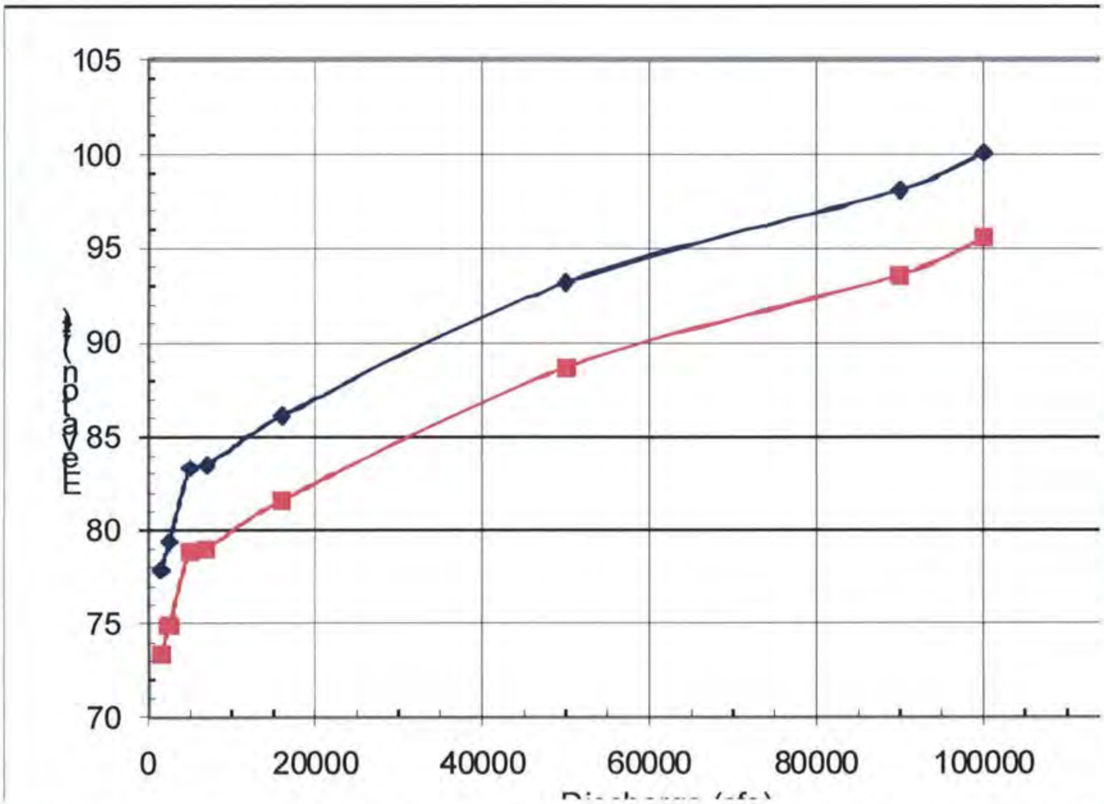

Figure 12. - Discharge rating curve for the barrier structure with the gates down. Note: 100,000 ft^3/s was the maximum flow that could be obtained with the model.

During the time of bypass flow juvenile steelhead must be able to pass upstream and adult steelhead will need to be able to use the hatchery ladder. Therefore, the velocities and flow conditions adjacent to the ladder entrance are important. Table 1 gives the velocities measured downstream of the bypass for the various flow rates tested.

Table 1. - Velocities measured below the bypass structure with the bypass gates down.

Q=1500 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	4.55	7.34	6.41	7.45
15	6.35	4.82	6.46	4.60
30	6.30	6.08	6.19	0.49
45	5.64	5.09	7.07	0.00
60	6.74	4.87	4.33	0.00
Q=2500 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	10.35	12.54	10.84	9.97
15	9.48	12.32	9.69	5.81
30	7.89	11.01	9.42	0.00
45	6.30	8.54	4.44	0.00
60	5.86	8.93	3.12	0.00
Q=5000 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	12.65	14.19	13.58	11.34
15	11.17	14.02	13.31	11.23
30	11.56	12.05	12.10	2.14
45	10.46	10.02	11.06	0.49
60	10.41	10.19	8.27	0.11
Q=7000 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	15.39	15.66	15.23	14.24
15	14.79	15.23	14.51	12.76
30	13.75	12.93	13.58	7.01
45	12.21	12.49	12.71	2.46
60	12.43	11.72	12.00	2.08

The velocities increase with flow rate, as expected. The velocities are fairly constant across the width of the three bays closest to the ladder entrance. The velocities in bay 4 adjacent to the sill drop off significantly caused by the shear zone between the higher velocity flow through the bypass and the calmer, tailwater pool near the sill.

These velocities indicate that the fish will be able to swim upstream with the barrier gates down, but the sweeping velocity in front of the orifice entrances of the ladder are quite high. Usage of these openings will need to be determined based upon the fish behavior in the field and will depend on the strength of the fish and the total flow in the river. Dye tracings showed that with the gates down the attraction flow from the ladder orifices travels only a very short distance out from the face of the opening prior to being sweep downstream along the south bank. After traveling about 200 ft downstream the attraction flow travels towards the center of the river. As the river discharge increases in the attraction flow is swept more tightly against the bank. Flow from the downstream end weir entrance is also swept along the bank, but the velocities downstream from that entrance are greatly reduced and should be adequate for both adults and juveniles to enter the ladder.

The flow conditions with all the gates down under the various test discharges are shown on figures 13-18.

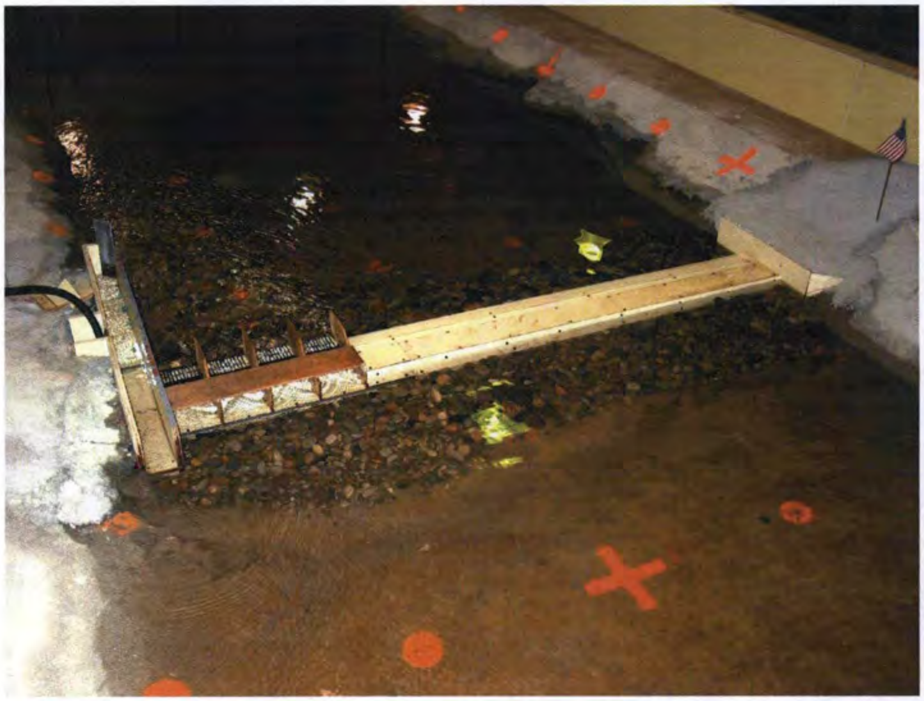

Figure 13. Overall view of the barrier with Q=1500 ft^3 /s and the gates down. Flow is only going through the bypass.

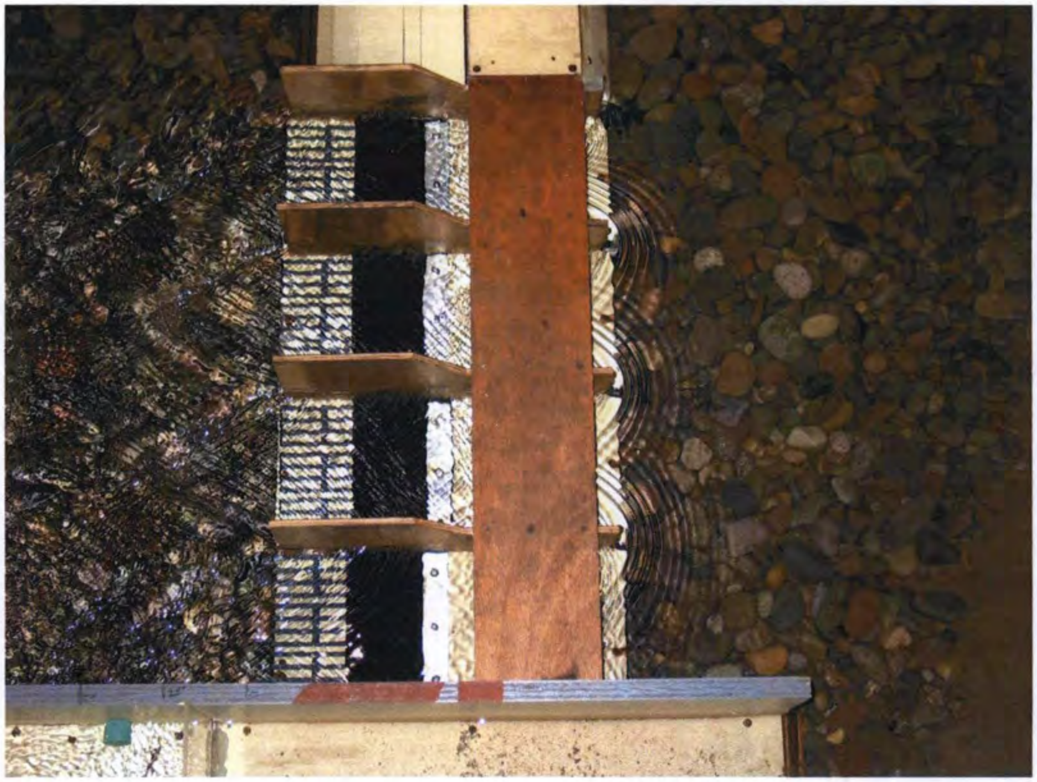

Figure 14. – View looking down on the bypass structure with Q=1500 ft^3/s. With this discharge there is no flow over the sill. (Flow is from right to left.)

Figure 15. - Overall view of the barrier with Q=5000 ft^3/s and the bypass gates down. Flow is over the sill and fairly uniformly distributed across the river.

Figure 16. - Looking upstream at the bypass and ladder entrance area with Q=5000 ft^3/s. Flow is from the top to the bottom in the photo.

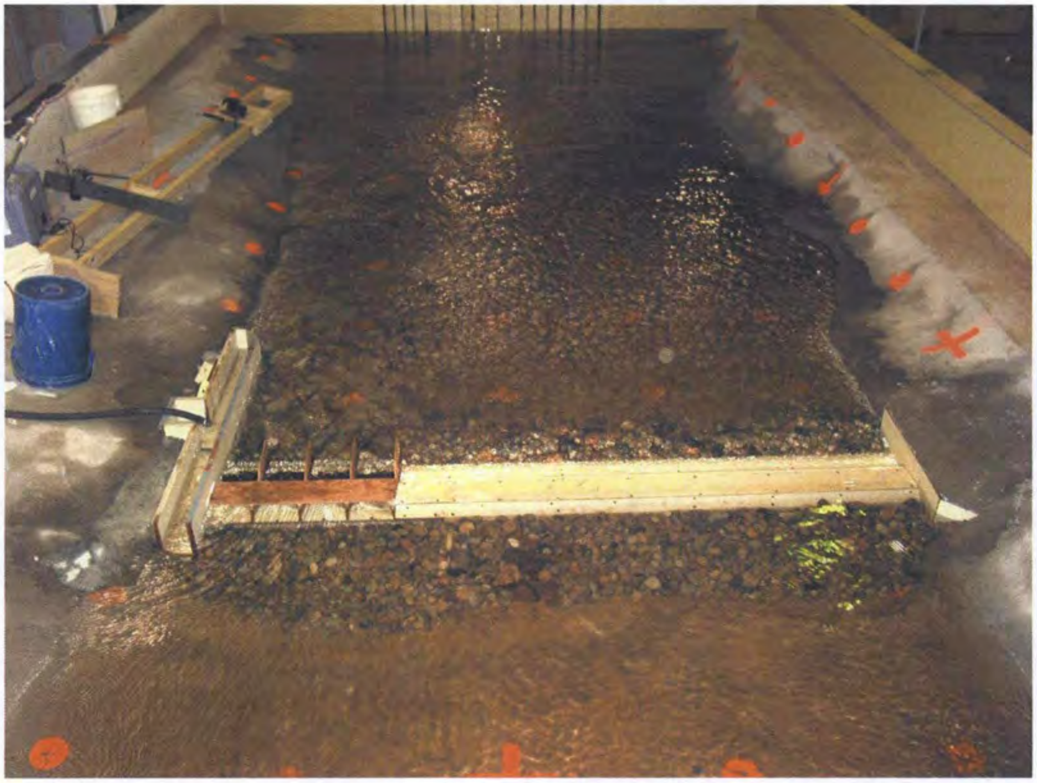

Figure 17. - Overall view of flow over the entire structure with Q=7000 ft3/s and the barrier gates down.

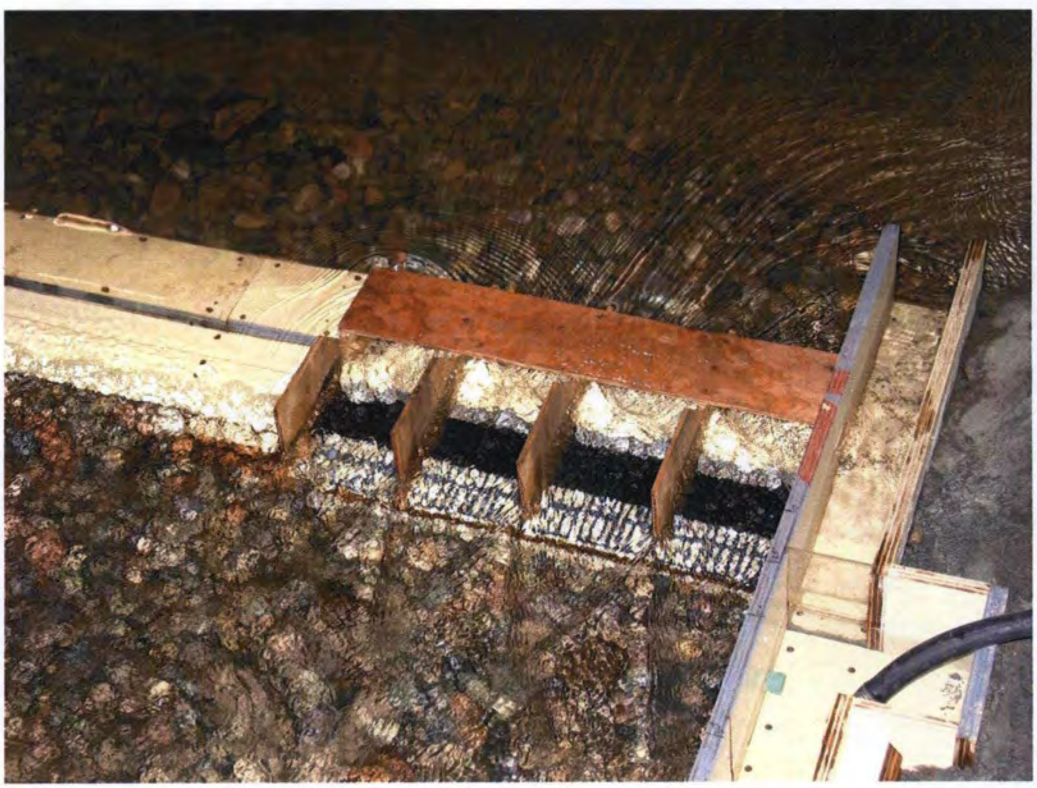

Figure 18. - View of the bypass and entrance area with Q=7000 ft3/s and the gates down. Flow is from top to bottom.

Bridge Elevation over Bypass

The bridge over the bypass structure should be dry while passing 2500 ft^3/s through the bypass. The water surface draws down as the flow accelerates and passes through the bypass producing a water surface elevation of 79.5+ ft. This means that the bottom of the bridge can be at El. 80 ft and still be out of the flow during bypass season. With one of the 4 bypass bays bulkheaded off for maintenance the water surface will be at El. 79.72 ft, still below the bridge but above the sill elevation by about 0.2 ft.

During construction, 2500 ft^3/s must pass over the 180-ft-long sill. This occurs with the upstream water level at El. 82.32. The pier wall between the sill and the bypass must be high enough, either by some temporary means or permanently, to keep the bypass area dry during construction. The bridge at El. 82.5 ft with a permanent 10 percent grade ramp over the sill was installed initially in the model. This large ramp produced a recirculation zone between the sill and the bypass that was unacceptable. Therefore, a more temporary means of accessing the sill from the bridge will be developed.

Barrier Gates Up – Fish Collection Season

The gates in the bypass will also function as an effective barrier in the bypass region of the structure because there is adequate picket height, shallow depths of flow over the bypass apron near the gate and too much distance away from the gate where other sounding and staging would be possible. The flow conditions varied significantly with the gates up. A discharge of 1,500 ft^3/s was contained within the bypass bays; however, water flowed over the bridge with a discharge of 2,500 ft^3/s. Velocities measured below the bypass in front of the ladder entrance are much lower because the same flow volume is now spread over the entire structure. Table 2 shows the velocities measured below the bypass structure with the bypass gates up.

Table 2. - Velocities measured below the bypass structure with the bypass gates up.

Q=1500 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	1.26	2.68	2.14	1.81
15	1.70	1.53	1.37	0.88
30	1.75	0.33	0.44	0.00
45	1.81	0.00	0.00	0.00
60	1.59	0.00	0.00	0.00
Q=2500 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	5.64	4.49	4.49	4.77
15	4.77	4.49	4.11	2.14
30	2.41	2.90	3.07	0.00
45	2.08	2.85	1.26	0.00
60	1.81	2.41	0.00	0.00
Q=5000 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4

7.5	6.19	7.07	7.39	6.13
15	5.59	6.74	7.01	3.56
30	2.85	3.78	4.77	0.88
45	1.75	2.90	3.29	0.44
60	1.10	0.88	1.92	1.42
Q=7000 ft^3/s	Velocities (ft/s)			
Distance Downstream (ft)	1	2	3	4
7.5	15.39	15.66	15.23	14.24
15	14.79	15.23	14.51	12.76
30	13.75	12.93	13.58	7.01
45	12.21	12.49	12.71	2.46
60	12.43	11.72	12.00	2.08

These velocities indicate that the fish will be able to swim upstream with the barrier gates up. Therefore, the adult fish depending upon the total discharge and the tailwater may use the orifice openings in the ladder. Flow patterns with the barrier gates up are shown on figures 19-22.

Dye tracings showed that with the gates up the attraction flow from the ladder orifices travels quite a distance across the channel in front of the barrier. Flow from the most upstream orifice travels the least distance across the barrier than flow from the downstream orifice before being swept downstream. As the river discharge increases the attraction flow spreads even farther across the river with a lesser percentage of the flow going over the bypass gates due to the bridge interference. For attraction flow release from the downstream end the flow travels out toward the center of the channel and is fairly stagnant, even moving upstream toward the structure. This flow then eventually sweeps downstream. Additional information about the attraction flow characteristics associated with releases from various places in the ladder entrances is given in the appendix at the end of this report.

Figure 19. – Overall view of the barrier dam with the gates up and Q=1500 ft^3/s. There is a small flow depth across the entire sill with low velocities adjacent to the ladder entrances.

Figure 20. – Looking upstream at the bypass and ladder entrance area with Q = 1500 ft^3/s. Flow is from the top to the bottom in the photo.

Figure 21. - Overall view of flow over the barrier with Q=5000 ft^3/s and the gates up.

Figure 22. - View of the area adjacent to the ladder with Q=5000 ft^3/s over the entire structure and the gates up.

Conclusion

Adult salmon and steelhead were to use the ladder from approximately Nov. 1 to April 1 of each spawning season. The picketed gates would be up forming the barrier from early Sept. until mid Dec., and the steelhead would be attracted to the ladder with the barrier down. The drop through each weir section of the ladder would be 1 ft for adult travel. The juvenile passage was to take place outside of the time that the adults would be using the ladder. This decision was based upon information obtained from John Hannon about the size of fish in the river and when they would be looking to move to other rearing habitat in the river, potentially upstream from the structure. The assumed drop for the juveniles was 0.7' (8.4") (Ken Bates, WSFWS). The weirs would be lowered with the upstream weir providing connection to the water level upstream from the structure. The following head values were used to design the drop through the ladder that was needed for upstream passage and could be accomplished using a 6" head drop per weir.

Table 3 shows head values measured in the model corresponding to a location about 100 ft upstream from the weir. The juvenile passage channel exits 1 ft below the invert of the bypass and extends upstream of the bypass structure by 15 ft to allow the juveniles to avoid being entrained back downstream immediately upon leaving the channel. The velocities measured in front of the bypass channel along the wall with the juvenile channel were 6 ft/s and 3 ft/s at 15 and 30 ft upstream, respectively. The bank of the river will be covered with riprap to provide bank erosion protection and also should provide hiding or cover for the juveniles.

Table 3. - Water surface elevations measured 100 ft upstream from the barrier and compared to the tailwater levels for use in upstream juvenile fish passage decision.

Discharge (ft^3/s)	Tailwater (ft) tw Fair Oaks gauge	Upstream El. (ft) Gates up or closed	Head differential (ft) Hup-tw	Upstream El. (ft) Gates down or open	Head differential (ft) Hdown-tw	Max head diff. Head@Q5000-tw@Q500	
1,500	76.5	81.12	4.62	77.85	1.35	Bypass open	Bypass closed
2,500	77.4	80.8	3.40	79.38	1.98		
5,000	79.03	83.46	4.43	81.33	2.13	6.23	8.36

Table 4 is an attempt to summarize the capability of the ladder and barrier as currently designed or as could be designed with changes within the existing ladder geometry. These dates should correspond to the construction timeframe restrictions that we are currently using for operation and construction. The u/s (upstream) passage issue depends upon size of fish needing to pass upstream. Perhaps the size and life cycle needs to be addressed as to when fish of what size need to pass. The current design assumed that very small juveniles would not need to pass upstream while the existing ladder was operating because they were not in the river or not big enough to move from September 1st – April 1st. *The information on fish size and "inclination" I assumed from the information that Shirley had sent and certainly needs to be addressed by John, Bruce, Shirley, DGF biologists.* The current design, I believe could allow passage from about 1,500 ft^3/s up to about 3,400 ft^3/s with 4" drops by adding gates and/or lowering the floor for passage from 1500 ft^3/s to 5000 ft^3/s with 1 ft drops.

Table 4. - Conditions for upstream passage with juvenile bypass channel and 4-bay bypass barrier.

Dates	Barrier Position	Ladder	U/s Passage	Salmon Size	Steelhead Size	Construction
Sept.1-Oct. 31	Up	Closed	Yes*	Adults coming u/s		In river or cofferdam as long as WQ stds met
Nov.1-Dec.15	Up	Open for Chinook	Not possible**	Spawning	Adults coming u/s	High flood flows would probably prevent construction
Dec.15-April 1	Down	Open for steelhead	Not possible** yearlings?	Incubation of newly laid eggs	Spawning adults/year-lings rearing	High flood flows would probably prevent construction
April 2 – May 31	Down	Closed	Yes*	Coming out of gravels	Incubation/coming out of gravels/year-lings rearing	No construction in river w/o further consultation and decision on nearby spawning habitat
June 1-Sept. 1	Down	Closed	Yes*	Rearing/out migrating	Rearing of juveniles or immature fish	Work in river or cofferdam allowed

*Upstream passage possible for "juveniles" and small adults if a pipe rack installed to prevent passage of adult spawning fish, but limited to normal flow range under current design because of upstream water level fluctuations outside of normal discharge range.
**Upstream passage would be possible if fish size large enough for 1' head drop and a pipe rack installed to prevent passage of adult spawning fish.

This configuration with 4 bypass bays and a juvenile bypass channel was issued in the specifications and drawings in 2002. There is **NO** upstream juvenile passage when the barrier is up. At this time, it was determined by the Resource Agencies and the Reclamation Central California Area Office and Regional Office staffs that upstream passage of juvenile steelhead was required while the barrier was up and that the velocities in the 4-bay bypass were too high for upstream passage during the time the barrier was down. Therefore, the model was used to investigate a 6-bay bypass structure with addition of a denil fishway for upstream passage with the barrier up designed separately.

Model Results with 6-bay Bypass and Upstream Juvenile Ladder

The 1:30 scale model was modified to make 6 bypass bays and reduce the raised sill. The denil ladder for upstream fish passage with the barrier up was designed using the water surface information from the model. Even though the specification had been completed, the discussions continued about upstream juvenile fish passage with the barrier up. Figure XX shows the final rating curve for the 4 and 6 bypass bay options with the barrier up or down.

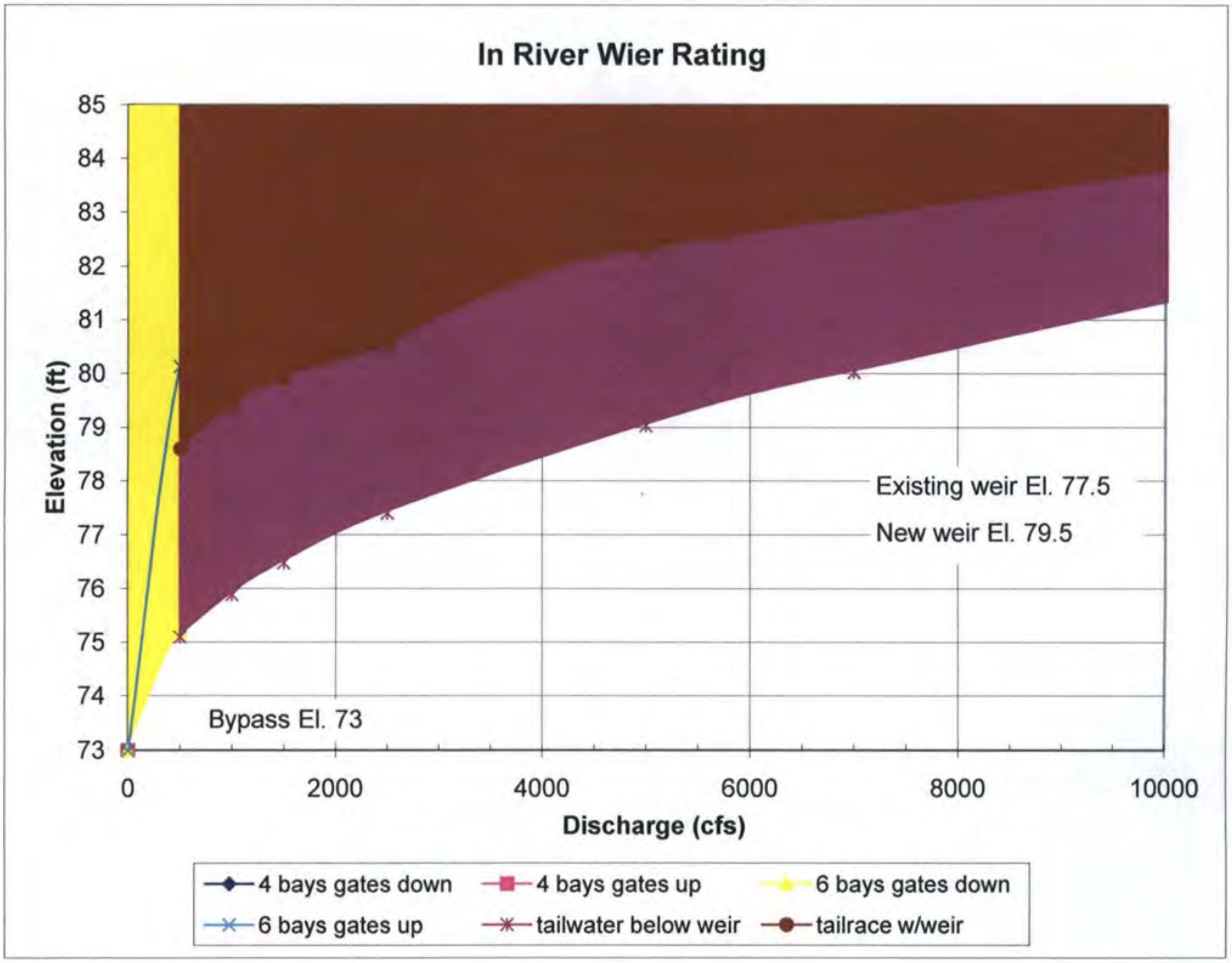

Figure 23. - Summary of rating curves developed from the model testing of the 4 and 6 bypass bay options for the fish hatchery barrier.

Tables 5 and 6 provide the new values for water surface elevations from the hydraulic model modified to include the 6 bypass bays. The model was used to measure the upstream water level with set tailwater elevations for flow rates of 1500 ft^3/s and above. The heads were estimated for the lower discharges by extrapolating the model rating curve. Velocities through the 6 bay bypass with the barrier down were then computed based upon the head differentials and assuming no other losses, table 5.

Table 5. - Prototype water surface elevations measured in the model for the 6-bay bypass with the barrier down.

Discharge (ft^3/s)	Tailwater El. (ft)	El. (ft)	Head diff. (ft)	Bypass velocity (ft/s)
500	75.10	75.2*	0.2*	2.58*
1000	75.89	76.15*	0.26*	4.09*

1500	76.48	76.77	0.29	4.31
2500	77.4	77.94	0.54	5.91
3000	77.78	78.75	0.97	7.91
5000	79.03	80.4	1.37	9.40
7000	80.02	81.66	1.64	10.28
16000	83.2	85.17	1.97	11.26
50000	90.04	92.82	2.78	13.38
100000	96.26	99.87	3.61	15.25

*Estimated values

Passage should easily occur through the bypass with the barrier down, particularly for the very low flow rates where the velocities in the bypass channel are estimated to be 2.6 and 4 ft/s for river flows of 500 and 1000 ft^3/s, respectively. Velocities are still very low for 1500 ft^3/s and 2500 ft^3/s at 4.3 and 5.9 ft/s, respectively. These are average velocities and turbulence near the boundary should aid in passage. With this information, it is hoped that a reasonable river flow rate and expected passage velocity through the 6-bay bypass may be decided upon.

Obviously, no passage occurs during the time the barrier is up. Therefore, the passageway was designed to provide passage during that time. Table 6 shows the head differentials and elevations for water surfaces while the barrier is up. The upstream water levels were used for passage design.

Table 6. - Prototype water surface elevations measured in the model for the 6-bay bypass with the barrier up.

Discharge (ft^3/s)	Head above El. 79.5 ft	El. (ft)	Head-tw (ft)
500	0.63*	80.13	5.03
1000	1.07*	80.57	4.68
1500	1.38	80.88	4.40
2500	2.1	81.6	4.21
5000	3.87	83.37	4.34
7000	4.59	84.09	4.07

*Estimated values

Table 7 shows the head differentials for the barrier up and down for 500 or 1000 tailwater levels and 500-5000 ft/s flows. This shows that requiring separate passage with the barrier up or down greatly complicates the requirements for the passage design.

Table 7. – Computations for the denil ladder entrance and exit across the barrier for a range of flows and tailwaters.

Discharge range (ft^3/s)	(ft)	Design head differentials (ft)		Ladder entrance El. (ft)	Ladder exit El. (ft)	Ladder exit El. (ft)
tw - u/s	TW@ 500	Bypass gates down	Barrier up	2' below tw depth @ 500	2' below u/s depth	2' below u/s depth
					Barrier up	Barrier down
500-5000	75.10	5.30	8.27	73.00	81.37	78.4
500-2500		2.84	6.50	73.00	79.6	75.94
500-1500		1.67	5.78	73.00	78.88	74.77
500-1000		0.81	5.47	73.00	78.57	73.91
500-500		0.10	5.03	73.00	78.13	72.91*
	TW@ 1000			2' below tw depth @ 1000		*same elevation as bypass
1000-5000	75.89	4.51	7.48	73.89	81.37	78.4
1000-2500		2.05	5.71	73.89	79.6	75.94
1000-1500		0.88	4.99	73.89	78.88	74.77
1000-1000		0.26	4.68	73.89	78.57	73.91

Entrance and exit elevations are given for the tailwaters of 500 and 1000 ft^3/s, because a flow of 500 ft^3/s was selected as a minimum flow for passage. The minimum tailwater level will set the required elevation of the passage entrance. The flow rate and corresponding tailwater for 1000 ft^3/s was used in the current design with the entrance set at El. 74 ft. The exit must then have various opportunities for the fish to exit depending upon the upstream head at various flow rates up to the selected maximum flow and barrier or non-barrier operating condition. There is a large difference in upstream water level depending upon whether or not the barrier is up or down. The point of the barrier design was to prevent passage. Therefore, a passage was designed for only when the barrier is up. When the barrier is down, the six bays should adequately provide passage, certainly for the low flow range. There is no need for a passage channel at very low flows in the river other than if it is necessary to have a separate off river passageway. There is barely any drop, or velocity through the bypass with the barrier down. Therefore, a passage channel would not provide any additional benefit, particularly for low river flows.

To provide separate passage, not using the bypass bays at all for passage, for a flow of 500 to 5000 ft^3/s with the barrier both up and down presents the issue of a short channel with no slope for the low flows, and a long sloping channel with exit points at various elevations along the way and a maximum differential of 8.27 ft. Also, with the current design, the bridge deck and wall heights of the passage channel are at El. 81.50 ft. These elevations were set so that 2500 ft^3/s could be passed with the initial 4 bay bypass design and keep the sill crest dry. These elevations have not been optimized for the new lower 6 bay bypass upstream water surfaces. To the contrary, fish passage to 5000 ft^3/s would require that the walls be raised and access to any elevation bridge deck be revised.

Conclusions

The 6-bay barrier weir and fish passage, bridge, and wall designs allow for passage from 1000 to 2500 ft^3/s with the barrier up and passage through the 6 bay bypass channel with the barrier down. This is where the replacement barrier design with flow rates for upstream passage were when the project was shelved after issuance of the drawings and specifications in 2002.

A new direction was taken with the Nimbus Hatchery Weir Replacement Project at this time. David Robinson became the new project manager in the Central California Area Office and took over the project. Based upon the comments from the Resource Agencies it seemed probable that an in-river structure was not going to be acceptable. Therefore, some flume and ladder alternatives were investigated in concept for discussion. A PASS (Project Alternative Solutions Study) was performed in 2006 to get consenses on the basic design to proceed forward with into final design.

Appendix

Attraction Flow Observations 4-Bay Bypass Structure with juvenile Fish Channel

Attraction Flow Observations 4-Bay Bypass Structure with juvenile Fish Channel

Observations of ladder entrance attraction flows were made for flow rates of 1500, 2500, 5000, and 7000 ft^3/s with the bypass gates down and with all gates up as in Chinook gathering season. With the bypass gates down and all flow through the bypass is when steelhead and juveniles would be passing either up the ladder to the hatchery or up the ladder past the barrier structure. The flow through the ladder is always the same amount is as currently used, about 30 ft^3/s.

The following five figures 1-5 show the general flow characteristics with a flow rate of 1,500 ft^3/s in the river and various entrance openings utilized. In general, with the bypass gates down, the attraction flow from the river is forced downstream, near the south bank for about 200 ft then begins traveling more towards the middle of the river channel. With flow over the entire barrier, the velocities are less across the structure, including adjacent to the ladder. The attraction flow still generally heads downstream along the bank, but a minimal amount of attraction flow is drawn upstream and across then weir, then downstream.

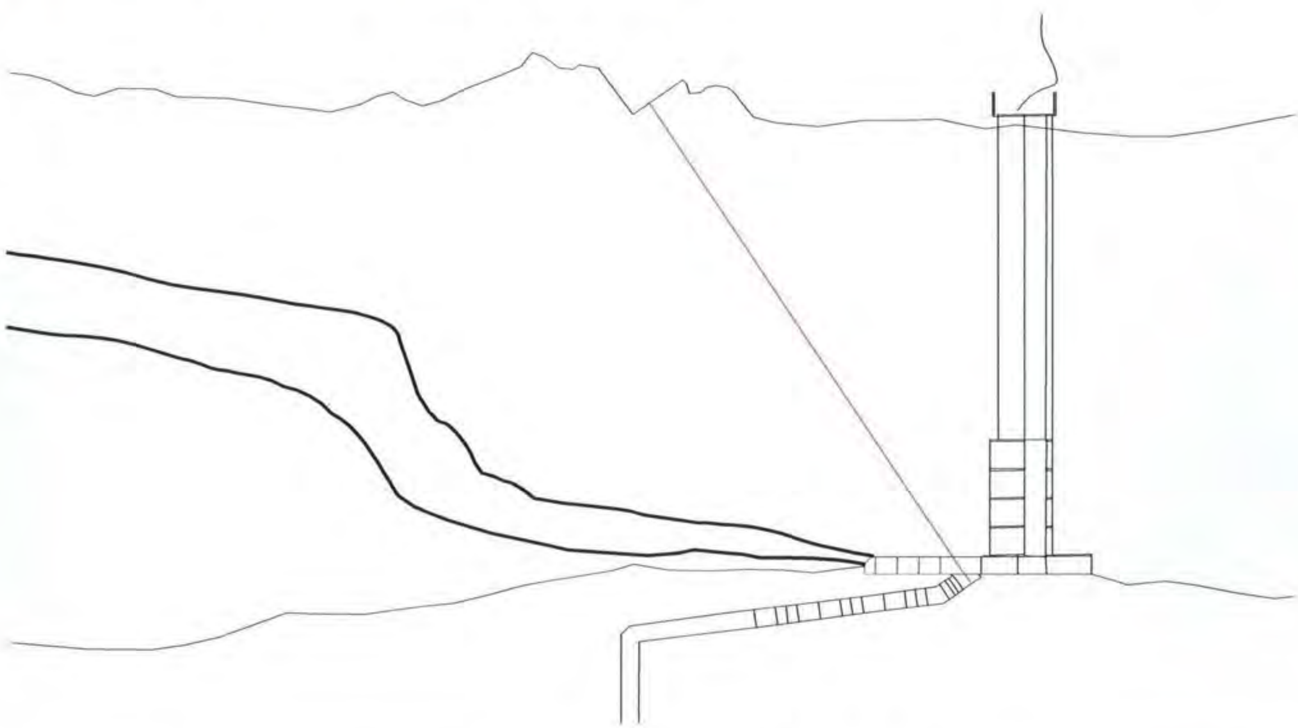

Figure 24.- Ladder attraction flow with bypass only flow of 1500 ft^3/s, TW=76.48 ft and ladder end weir open.

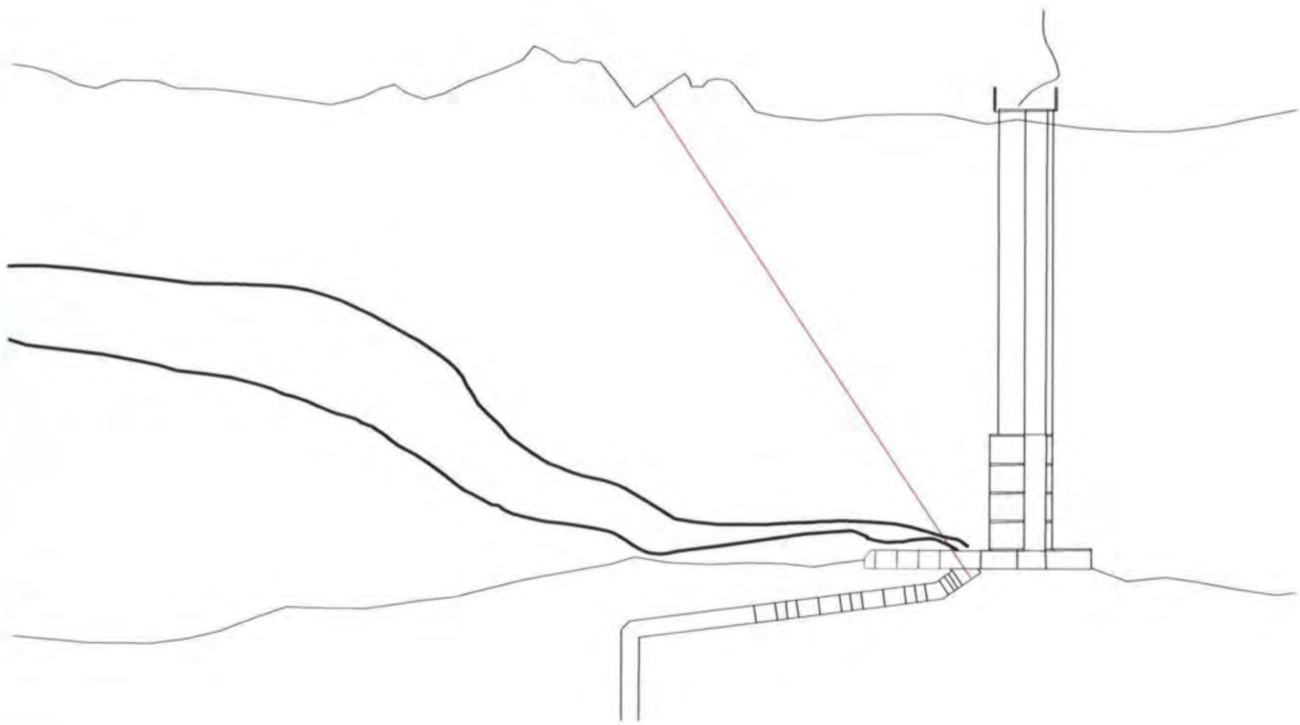

Figure 25.- Ladder attraction flow with bypass only flow of 1500 ft^3/s, TW=76.48 ft and ladder upstream orifice open.

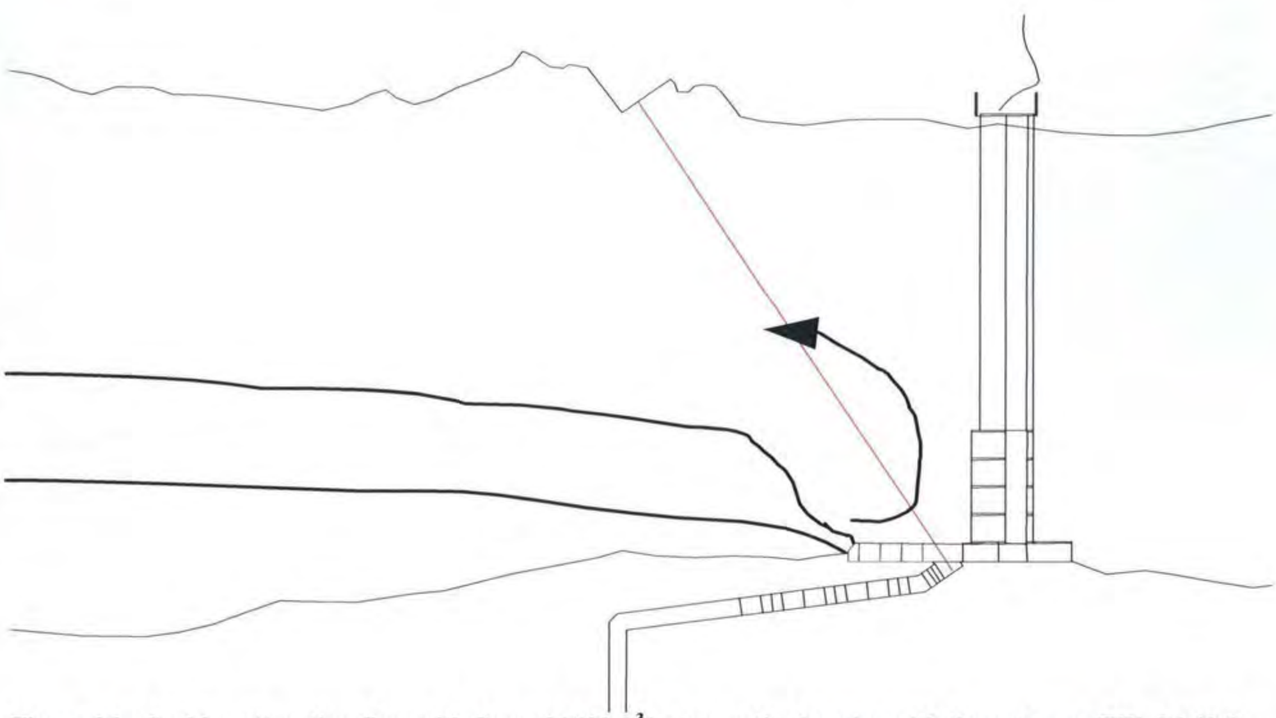

Figure 26.- Ladder attraction flow with flow of 1500 ft^3/s over entire barrier with the gates up, TW=76.48 ft and ladder end weir open. Some dye migrated upstream near bypass structure, then across the weir and downstream.

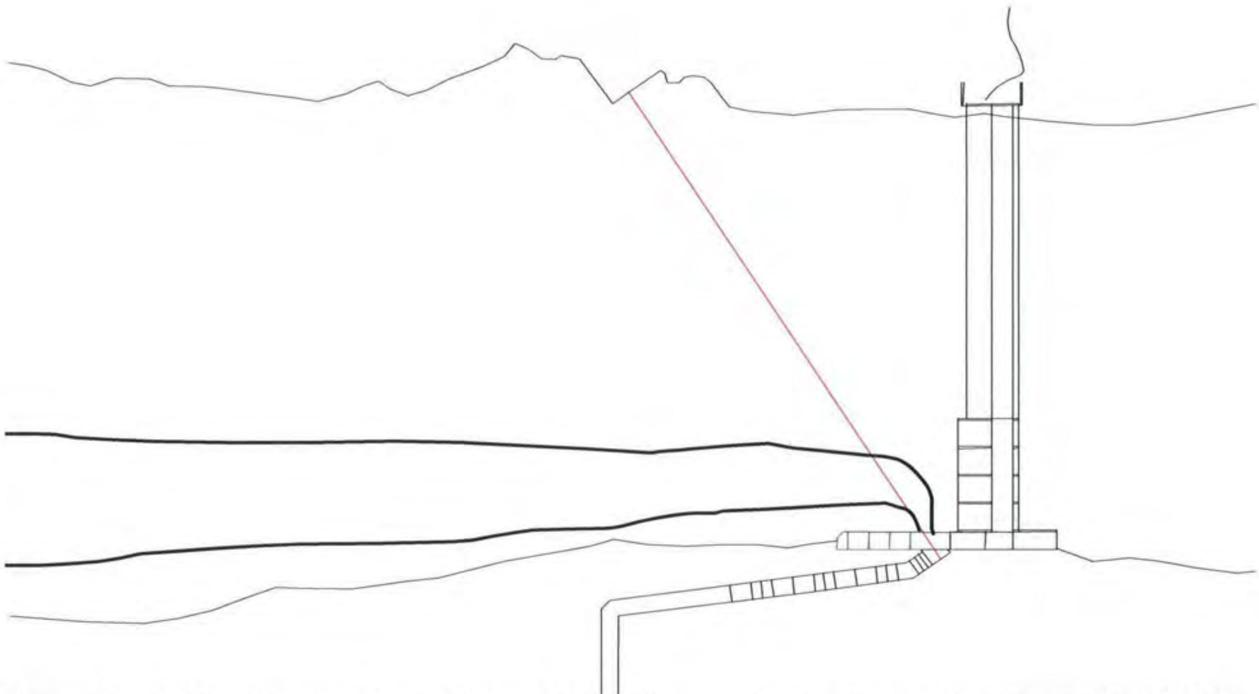

Figure 27. - Ladder attraction flow with flow of 1500 ft^3/s over entire barrier and the gates up, TW=76.48 ft and ladder upstream orifice open.

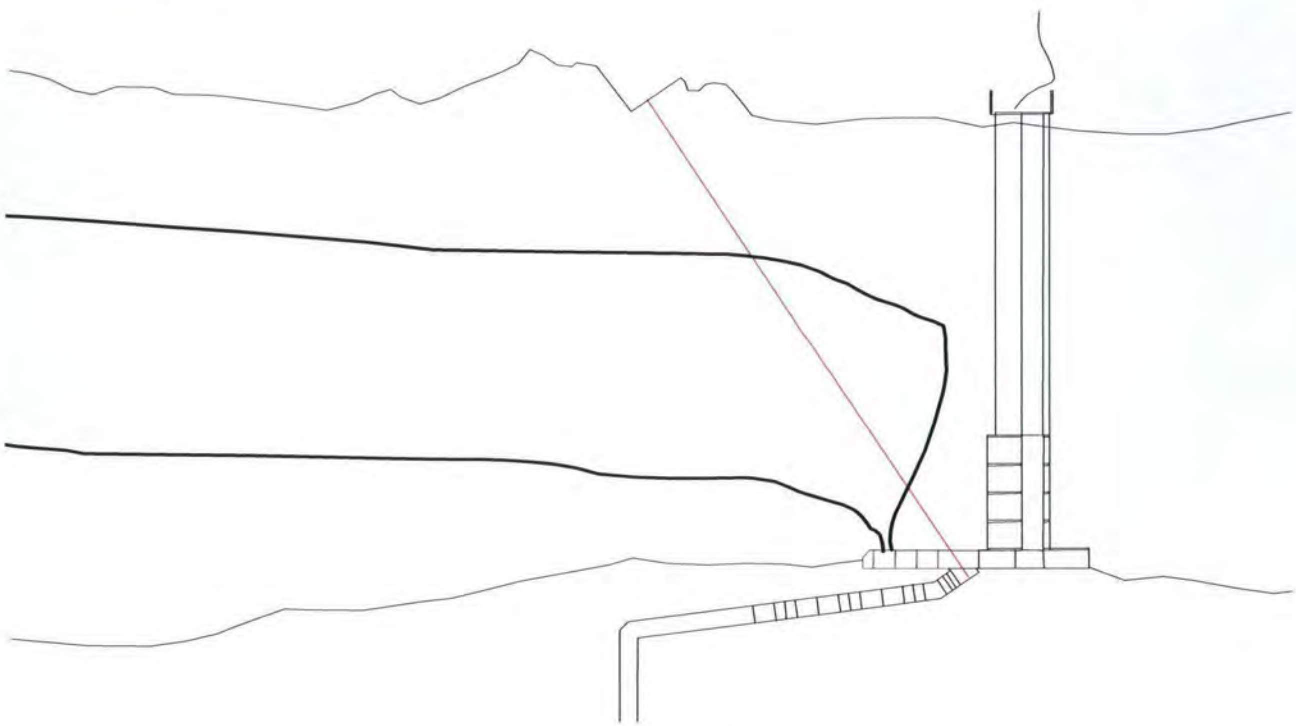

Figure 28. - Ladder attraction flow with flow of 1500 ft^3/s over entire barrier with the gates up, TW=76.48 ft and ladder downstream orifice open.

Figures 6 - 8 show the general flow characteristics with a flow rate of 2,500 ft^3/s in the river and various entrance openings utilized. In general, with the bypass gates down, the attraction flow from the river is forced downstream, near the south bank for about 200 ft then begins traveling more towards the middle of the river channel. With flow over the entire barrier, the velocities are less across the structure, including adjacent to the ladder. The attraction flow is mixed and slightly more is drawn upstream and across then weir, then downstream near the middle of the river. The majority of the flow still heads downstream along the bank.

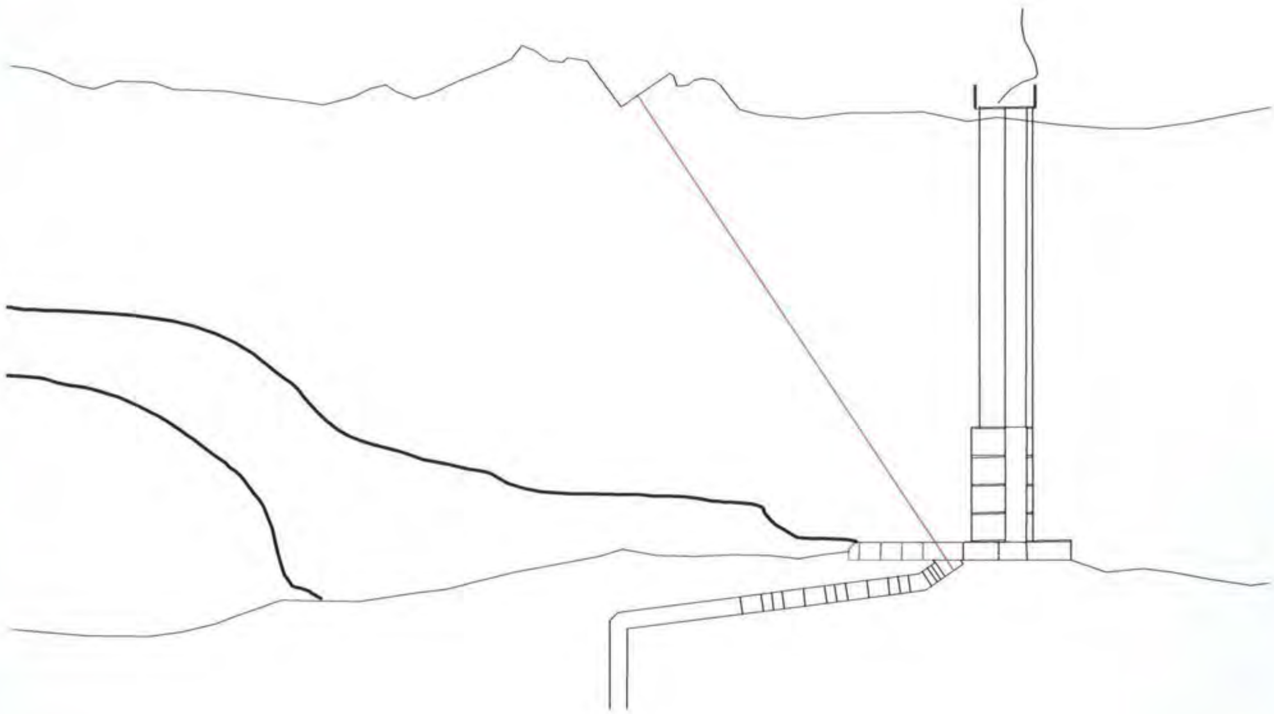

Figure 29. - Ladder attraction flow with a flow of 2,500 ft^3/s through the bypass only, TW=77.4 ft and ladder end weir open.

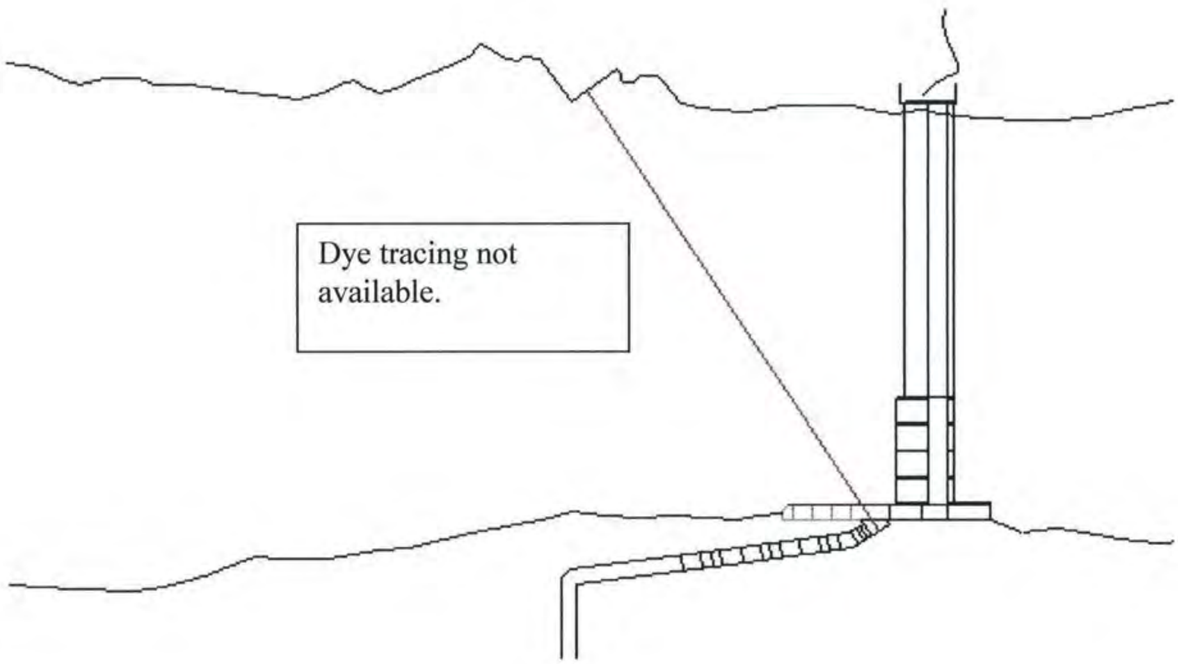

Figure 30. - Ladder attraction flow with flow of 2,500 ft^3/s over entire barrier with the bypass gates up or closed, TW=77.4 ft and ladder end weir open.

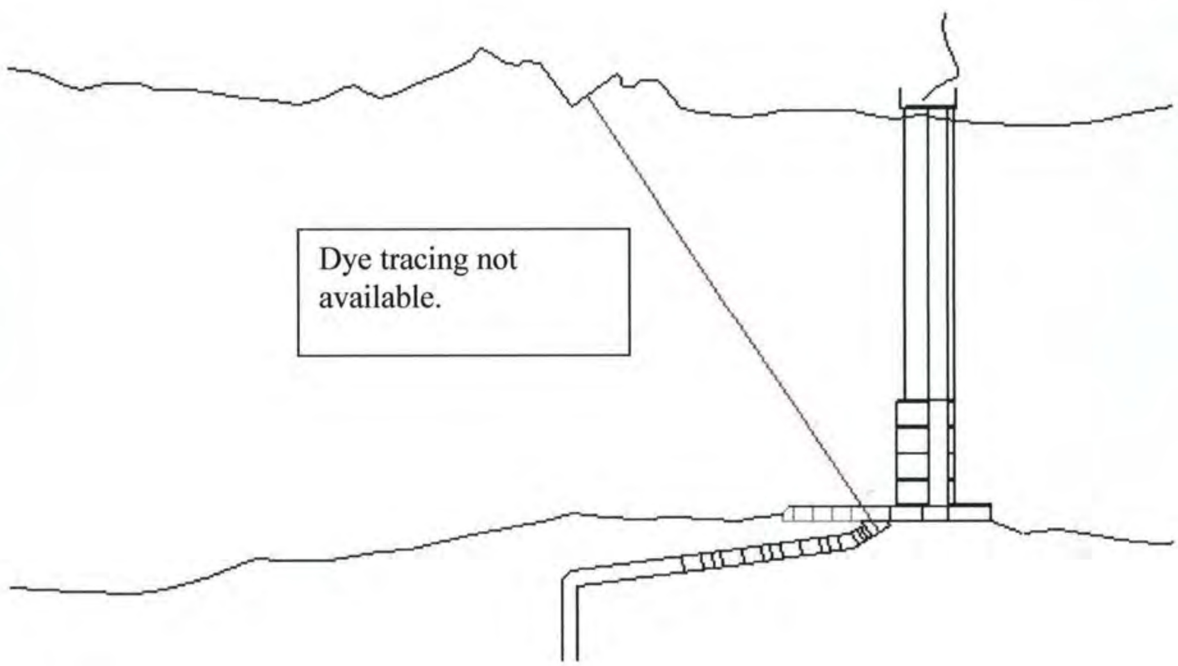

Figure 31. - Ladder attraction flow with flow of 2,500 ft^3/s over entire barrier with the bypass gates up or closed, TW=77.4 ft and the downstream orifice open.

With a discharge of 5,000 ft^3/s in the river and the bypass gates down or open water flows over the entire barrier but ladder attraction flow is forced downstream along the bank from either the end weir or the orifices. Figures 9-11depict the dye patterns from the end weir open, the downstream orifice open, and the upstream orifice open, respectively.

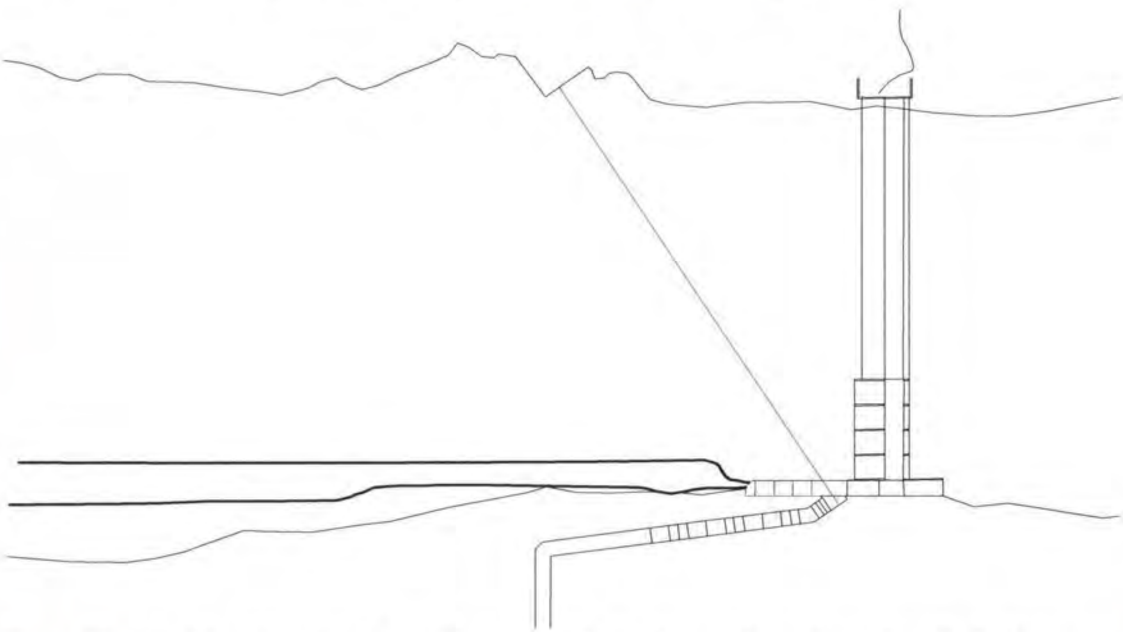

Figure 32. - Ladder attraction flow with flow of 5,000 ft^3/s over the entire weir with the bypass open, TW=79.03 ft and ladder end weir open.

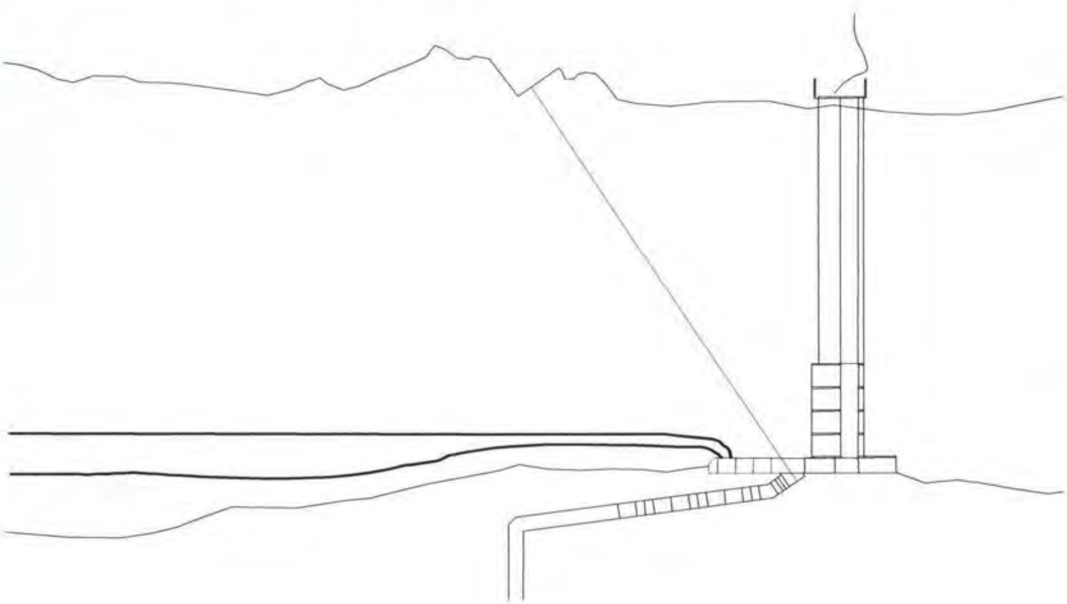

Figure 33. - Ladder attraction flow with flow of 5,000 ft^3/s over the entire weir with the bypass open, TW=79.03 ft and ladder downstream orifice open.

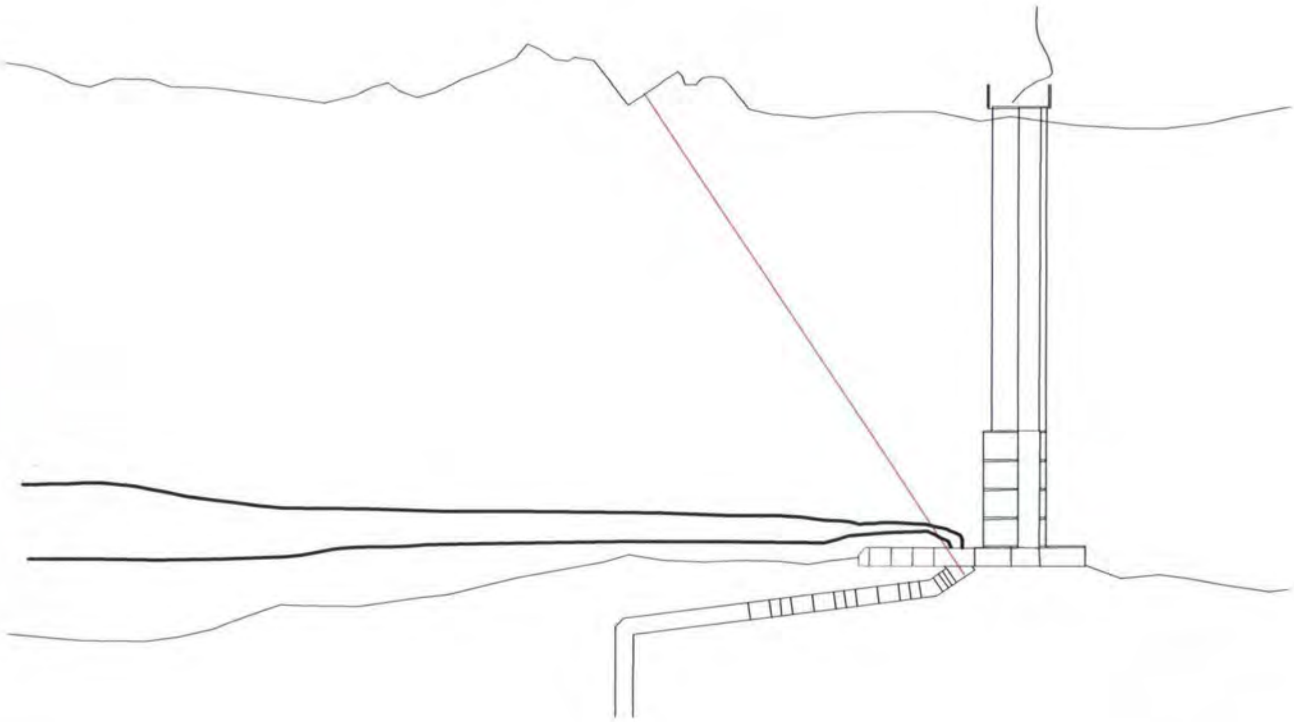

Figure 34. - Ladder attraction flow with flow of 5,000 ft^3/s over the entire weir with the bypass open, TW=79.03 ft and ladder upstream orifice open.

With a discharge of 5,000 ft^3/s in the river and barrier gates up the ladder attraction flow tends to spread more across the river for the end weir and downstream orifice openings. Although not shown, flow from the upstream orifices tends to be pushed more downstream along the bank. Figures 12 and 13 show the dye tracings for the downstream orifice open and the end weir open, respectively.

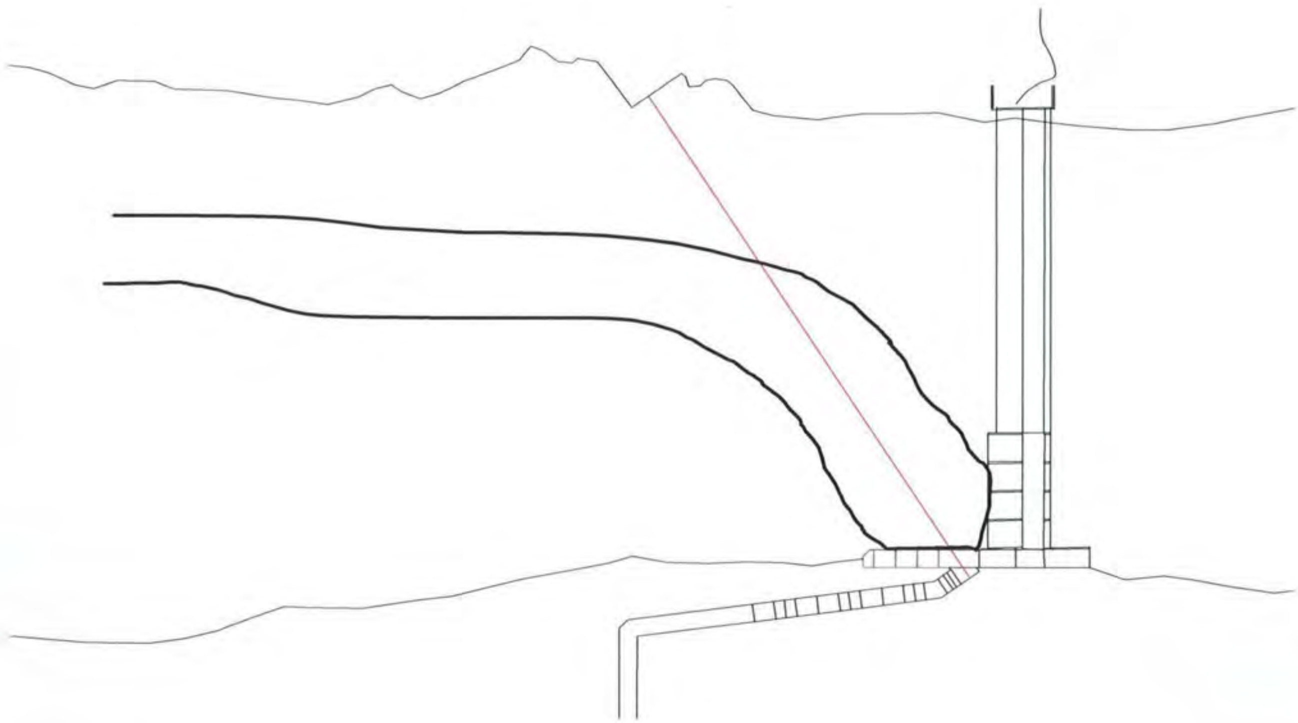

Figure 35. - Ladder attraction flow with flow of 5,000 ft^3/s over the entire barrier, bypass gates up, TW=79.03 ft and ladder downstream orifice open.

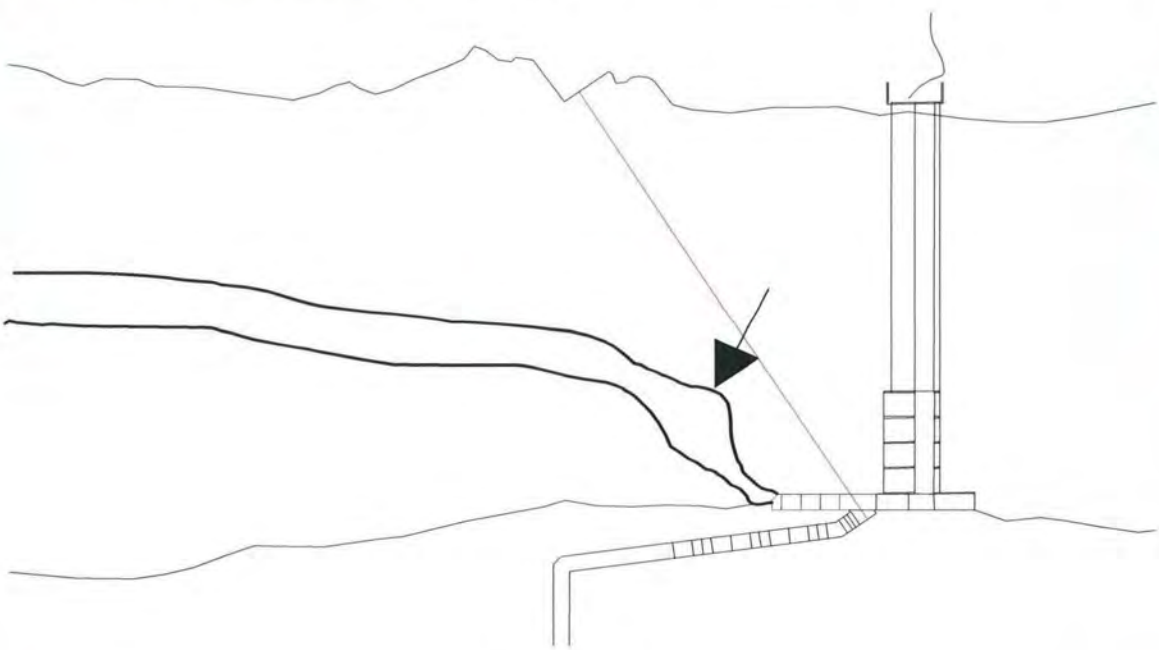

Figure 36.- Ladder attraction flow with flow of 5,000 ft^3/s over the entire barrier with the bypass gates up or closed, TW=79.03 ft and ladder end weir open. The arrow is pointing to a stagnant flow area.

With 7,000 ft^3/s in the river, flow goes over the entire weir with the bypass open. Figure 14 shows the attraction flow is forced downstream near the bank. Higher flow causes slightly more turbulent mixing and greater extent of the attraction flow for all entrance opening than with lower river flows.

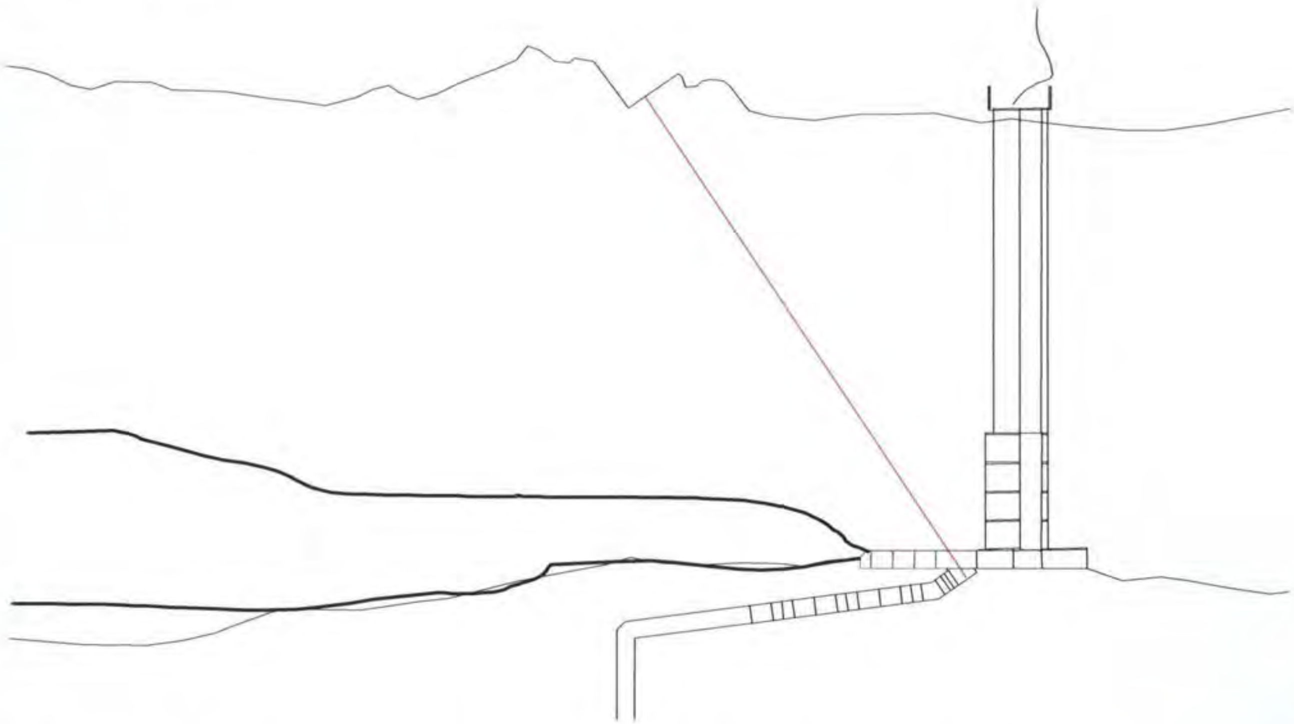

Figure 37. - Ladder attraction flow with flow of 7,000 ft^3/s over the entire weir with the bypass open, TW=80.03 ft and ladder end weir open.

Figures 15 - 17 show that with a discharge of 7,000 ft^3/s in the river over the entire barrier with the bypass gates up or closed, the attraction flow is mixed due to turbulence and spreads towards the middle of the river before being forced downstream.

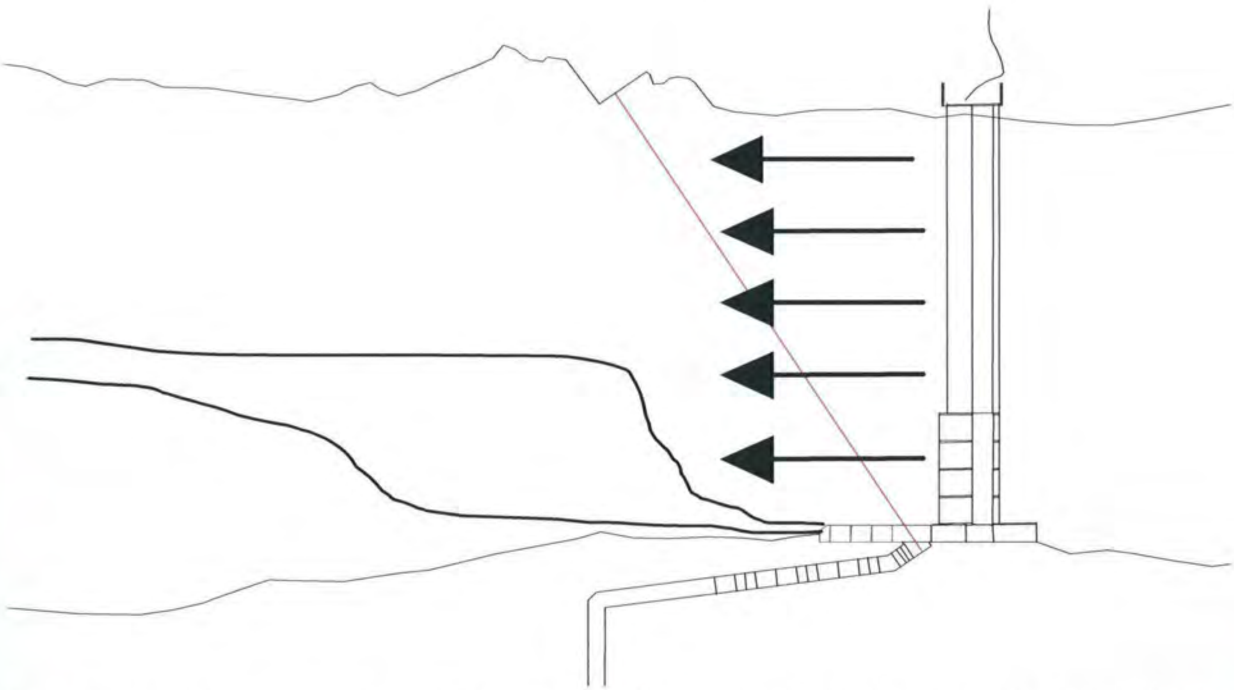

Figure 38. - Ladder attraction flow with flow of 7,000 ft^3/s over the entire barrier with the bypass gates up or closed, TW=79.03 ft and ladder end weir open.

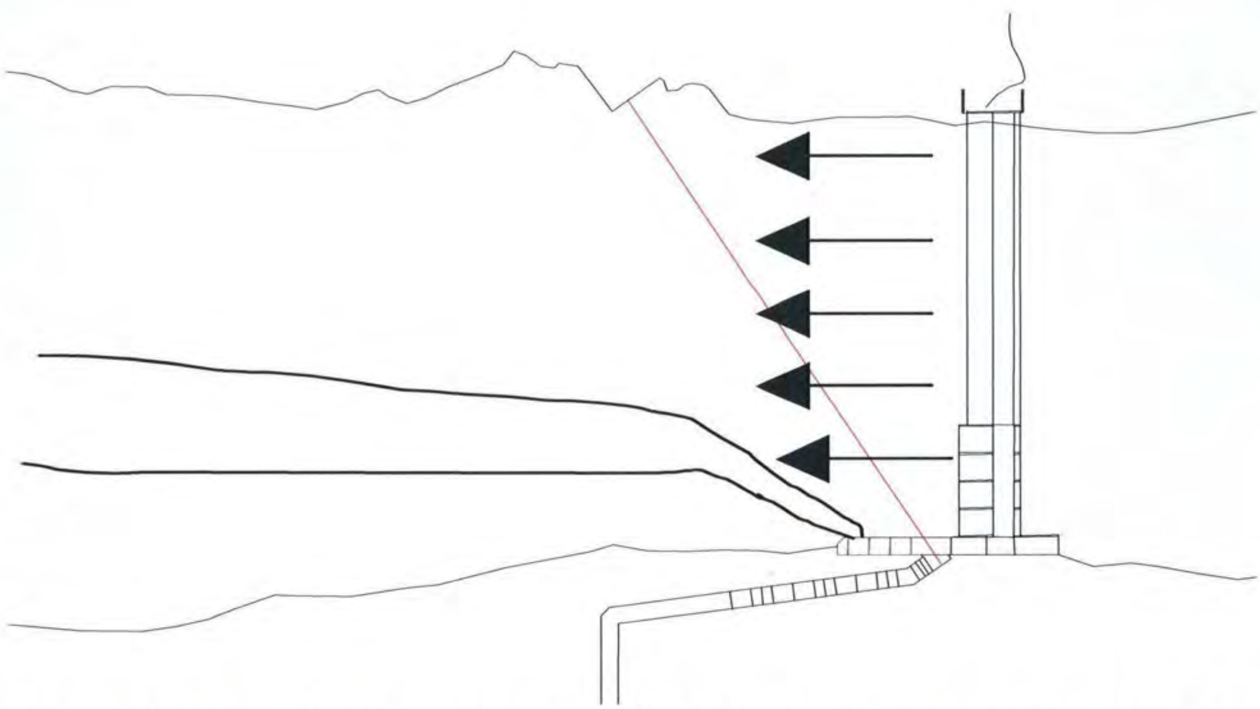

Figure 39. - Ladder attraction flow with flow of 7,000 ft^3/s over the entire barrier with the bypass gates up or closed, TW=79.03 ft and ladder downstream orifice open.

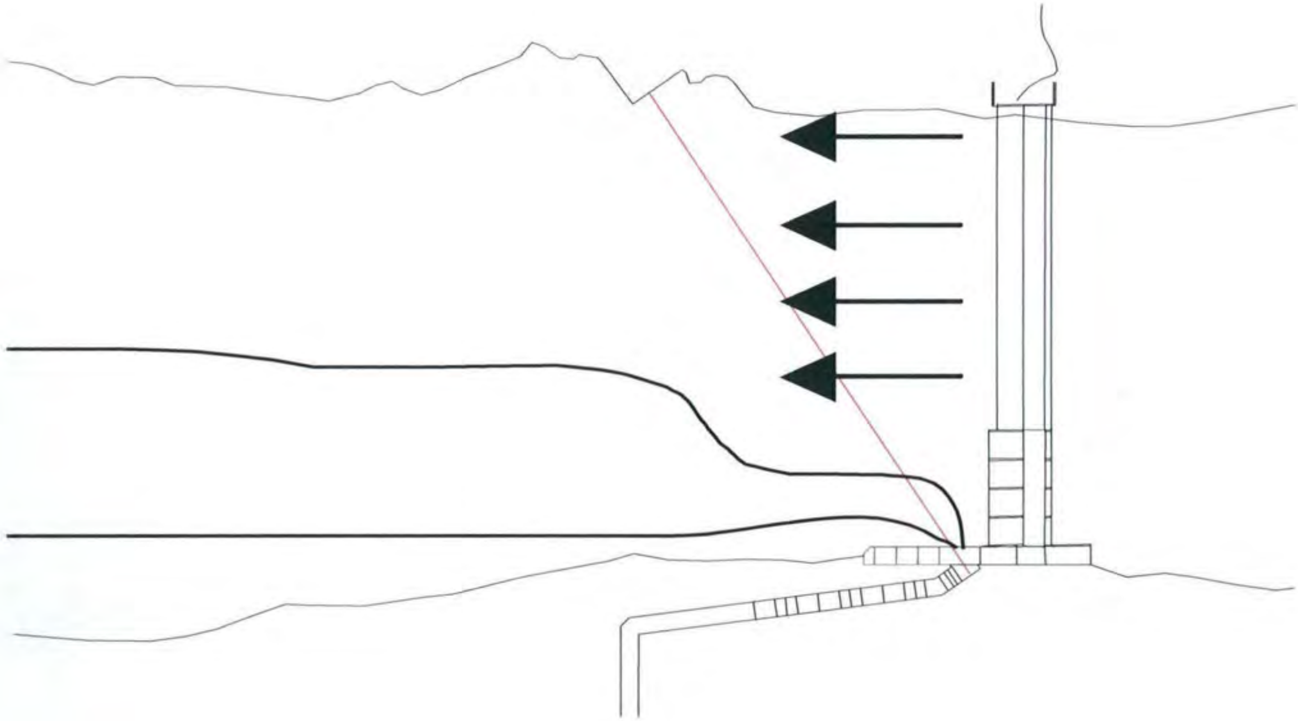

Figure 40. - Ladder attraction flow with flow of 7,000 ft^3/s over the entire barrier with the bypass gates up or closed, TW=79.03 ft and ladder upstream orifice open.