PAP-651

TECHNICAL SERVICE CENTER
Denver, Colorado

FINAL REPORT ON THE HYDRAULIC MODEL STUDIES KESWICK DAM STILLING BASIN MODIFICATIONS

by
Kathleen H. Frizell

U.S. Department of the Interior
Bureau of Reclamation

December 1994

RECLAMATION'S MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DEPARTMENT OF THE INTERIOR'S MISSION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering wise use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

Final Report on the Hydraulic Model Studies - Keswick Dam Stilling Basin Modifications

Introduction

Keswick Dam is located on the Sacramento River about 9 miles downstream from Shasta Dam. The dam, with a spillway, fishtrap, and powerplant, was constructed to regulate Shasta Dam releases and trap migrating salmon before they reach Shasta Dam and transport them upstream to the Coleman Hatchery.

The existing spillway end sill and exit channel are at higher elevations than the river channel downstream. During normal powerplant operation, the tailwater is lower in the river channel than the spillway end sill and exit channel. Therefore, the spillway exit channel, formed by a rock bench, isolates the stilling basin from the river channel. Historically, salmon have been stranded in the spillway stilling basin pool after spill events.

Fyke weirs in the shared spillway/fishtrap wall are intended to allow passage of stranded salmon from the spillway stilling basin to the fishtrap, and limit passage from the fishtrap to the stilling basin.

However, previous operation has shown that salmon will travel from the fishtrap into the stilling basin. There is no record of salmon leaving the basin through the fyke weir after they enter from the fishtrap.

Problem

Salmon are stranded in the spillway stilling basin after spillway operations or by passing through the fyke weir. Because salmon are an endangered species, a solution must be found to ensure that they cannot be stranded in the future. The solution should not interfere with the existing stilling basin or fishtrap performance.

Solutions

Two alternatives have been identified for further investigation (O'Haver, 1993).

- Test the effectiveness of a modified fyke weir in the field.

- Excavate a channel through the spillway stilling basin end sill and the downstream rock bench to maintain a permanent passage between the stilling basin and the river channel.

The Northern California Area Office has tested the performance of the modified fyke weir. The weir is still unsatisfactory because fish are able to pass from the fishtrap to the stilling basin. The Hydraulics Branch has model studied the proposed channel excavations linking the stilling basin and the river channel. The results are reported in this document.

Purpose

The purpose of the model study is to determine the effects of the proposed channel excavations on flow conditions in the spillway stilling basin and at the fishtrap entrance.

Hydraulic Model

The 1:30 scale hydraulic model is shown on figure 1. The model includes the gate controlled spillway with the end sill and downstream rock bench, and a simplified fishtrap and powerplant. The spillway model has a capacity of 100,000 ft^3/s, the fishtrap a capacity of 350 ft^3/s, and the powerplant a capacity of 12,000 ft^3/s. The upstream topography was minimized and the downstream topography was modeled according to specifications drawing 214-D-5670 and a detailed topographic map for the rock bench downstream of the spillway received from the Northern California Area Office.

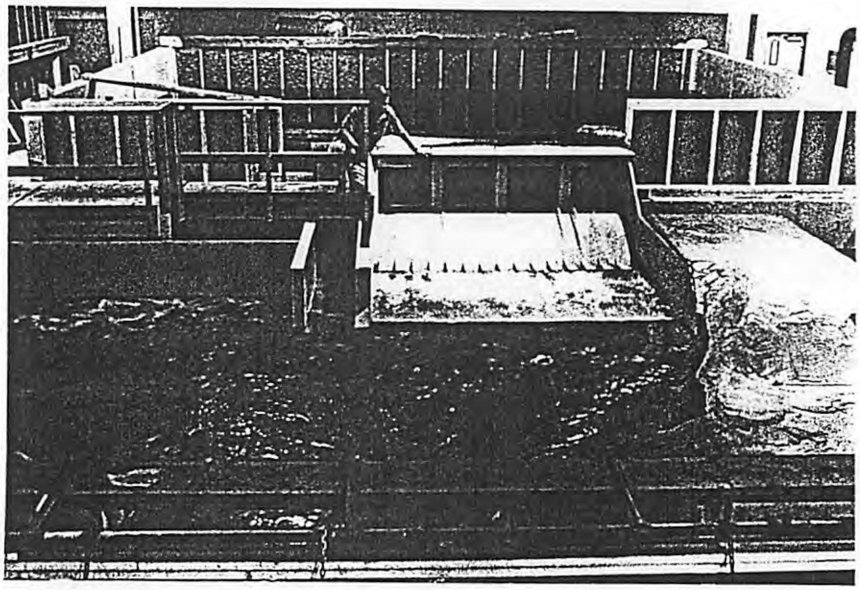

Figure 1. - Overall view of the 1:30 scale model of Keswick Dam.

Fish escape channel descriptions

Four fish escape channels were incorporated into the model end sill and rock bench downstream of the stilling basin. Channels cut through the end sill and rock bench were precut and refilled allowing for easy removal. The locations were chosen according to the map received with the model study approval and discussions with Greg O'Haver of the Northern California Area Office. All channel locations are shown on figure 2 and are designated as A, B, C, and D.

Channel A is a short, curved channel, located in the stilling basin end sill 57.5 ft to the left of the shared spillway/fishtrap wall. The channel exits about 88 ft downstream from the end of the basin at an angle of about 30° to the

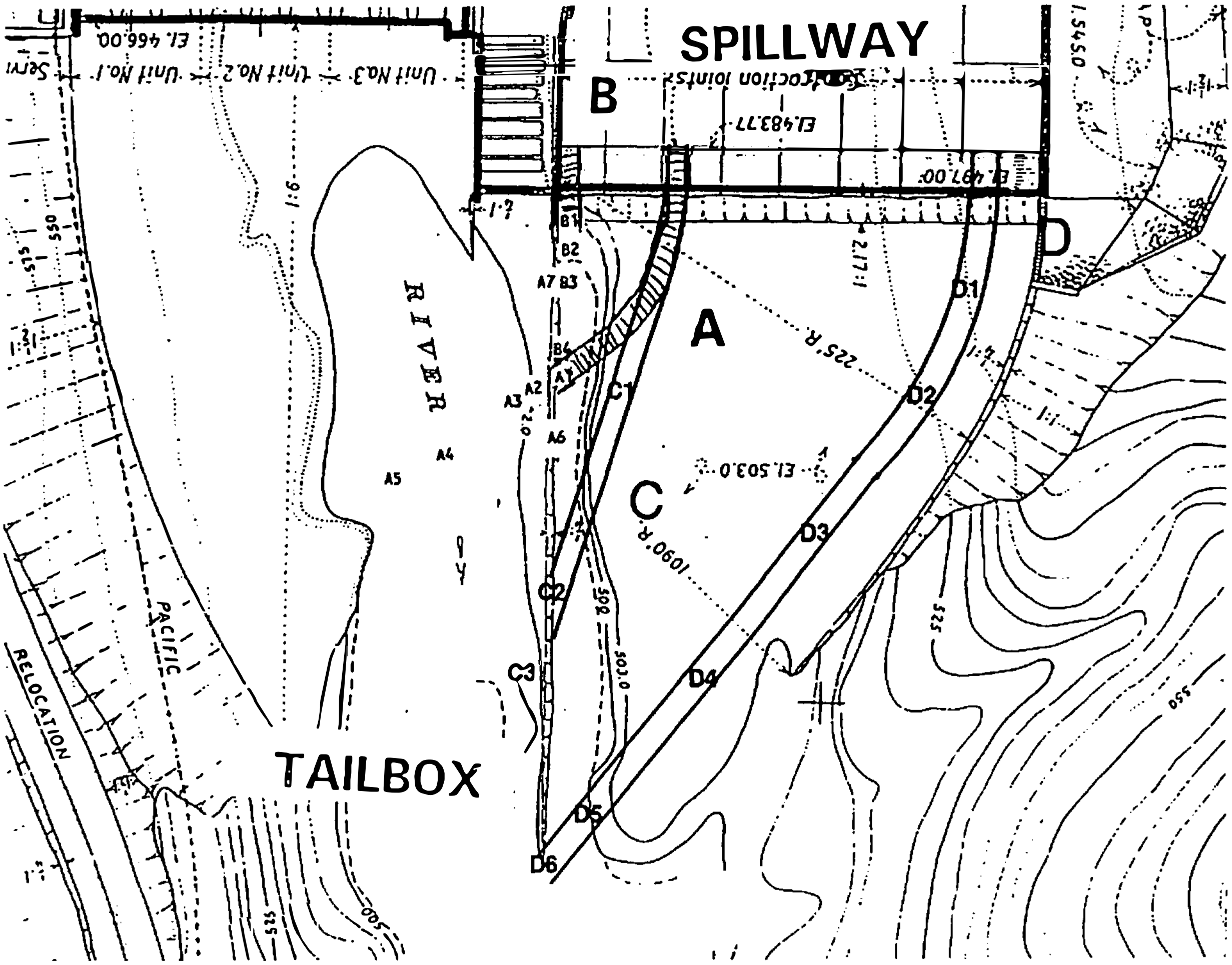

Figure 2. - Plan view of the stilling basin and downstream rock bench showing the channel locations that were tested.

river channel. Channel A is trapezoidal shaped with a 4-ft bottom width and 1/4:1 side slopes. The channel cuts through the end sill and curves around the concrete berm located at the right downstream end of the stilling basin.

The next channel investigated, B, is a straight channel, parallel to the shared spillway/fishtrap wall. Channel B is very short and is cut straight along the wall through the end sill and the concrete berm on the right side immediately downstream of the basin. This channel has a 4-ft bottom width, 1/4:1 left side slope and vertical right wall. The channel exits immediately next to the fishtrap and is directly aligned with the rock bench.

After completing the tests with channel A, channel C was formed by straightening channel A to exit more parallel with the river channel. The location of the cut through the end sill remained the same as channel A, but the channel cut was lengthened to exit about 200 ft downstream from the basin. Channel C also was trapezoidal shaped with 1/4:1 side slopes and a 4-ft-wide bottom.

Channel D is located 28.22 ft to the right of the left spillway stilling basin wall (looking downstream). The channel curves through the entire rock bench for a length of about 400 ft along the channel. The channel exits in the river channel about 330 ft downstream from the basin. The channel geometry was again trapezoidal with 1/4:1 side slopes and a 4-ft-wide bottom.

Operation

Normally, the powerplant is in operation and meets the downstream flow requirements. The powerplant has three units, each with a capacity of 4,000 ft^3/s for a total discharge of 12,000 ft^3/s. When the powerplant is operating, alone or with the fishtrap, the tailwater in the river channel is below that of the stilling basin end sill and downstream rock bench. The fishtrap doesn't operate continuously, only when fish are needed at the Coleman Hatchery.

The spillway only operates when the powerplant is inoperable or during flooding. Therefore, infrequent small discharges, in the range of 6,000-8,000 ft^3/s, are the most common spillway releases. Northern California Area Office personnel indicated that the maximum total release over the last few years was about 14,000 ft^3/s. The maximum discharge to be modeled was limited to 100,000 ft^3/s to model the fish escape channels at a reasonable scale. This was acceptable to the Northern California Area Office personnel since above about 80,000 ft^3/s flood damage downstream is excessive.

The model was operated primarily for frequently expected small discharges and accompanying low tailwater elevations. Initial model operations showed that the fish escape channels had the most effect on river flows under low discharge conditions. For some tests, the powerplant was assumed to be inoperable to model the "worst case" of low tailwater with maximum spillway releases for a given total discharge.

Summary and Conclusions

Excavating any of the proposed channels in the spillway end sill and downstream rock bench will not jeopardize the performance of the spillway stilling basin action. However, any channel excavation will lower the standing water level in the stilling basin to the level of the river channel. This will lower the stilling basin tailwater by about 15 ft under a minimum powerplant release of 3,000 ft^3/s and tailwater elevation 488 ft. Stilling basin performance will not be affected provided that the spillway gates are opened at a normal rate.

Channels B, C, and D performed adequately from a hydraulic standpoint. Given that channels C and D are located away from the side walls of the stilling basin, they may not provide acceptable entrances for fish guidance from the basin. Channel B seems to be ideally located when considering the fish entering the channel from the basin and for providing further attraction flow to the fishtrap entrance. However, structural and erosion concerns are major negative issues for channel B.

Flow from the curved channel (A) directs flow across the river channel at about a 30° angle. Under low flow and tailwater conditions, the jet from this channel extends entirely across the river channel. This jet could easily deter salmon from reaching the fishtrap.

Flow from the straight channel (B) next to the fishtrap is directed parallel to the rock bench and directly in line with the fishtrap flow. During spills, flow through channel B will provide a strong attraction flow toward the fishtrap entrance. Under the low flow conditions tested, the velocities within channel B are high enough to inhibit fish swimming into the stilling basin.

Flow from channel C enters the river channel at a small angle to the river channel, almost parallel to the rock bench. The jet goes slightly out into the river channel, but is not concentrated enough and is far enough away from the fishtrap that fish swimming upstream should not be hampered.

Channel D is very long and has varying flow conditions throughout its length. Topography changes and encountering the main spillway flow as the channel cuts across the rock bench produce fluctuating velocities within channel D. The channel enters the river channel at about a 30° angle; however, the jet soon dissipates in the deeper water of the river channel and does not cross the channel. Depending upon the total discharge and tailwater elevation, fish could swim in and out of the channel at any point along the journey upstream to the stilling basin. Channel D has varying flow conditions throughout the entire channel and may produce some confusion for fish that may be swimming through this channel during spillway releases.

Flow velocities in the excavated channels decrease for larger spillway releases. According to Bell's Fisheries Handbook (page 6.3) the sustained swimming speed of adult salmon is about 11 ft/s for Chinook, Coho, and Sockeye, and about 15 ft/s for Steelhead. Velocities measured for channels A and B, tables 1 and 2, exceed the sustained swimming speed of salmon through a discharge of 22,500 ft^3/s. Channel velocities measured for a discharge of 80,000 ft^3/s were less than the swimming speed of salmon. Measurements for channels C and D at 22,500 ft^3/s and no powerplant flow, tables 3 and 4, show that velocities at the end of channel C exceed the sustained swimming speeds. With powerplant flow, the velocities decrease in channel C and may allow fish to swim up the channel. The length and location of channel D produce some variability in velocities. The velocity exceeds the sustained swimming speed at some locations in the channel, then fluctuates below and again above the sustained swimming speed along the length of the channel.

The erosion potential of any of the cut sections immediately below the stilling basin end sill should be addressed. Erosion is a particular concern with channel B because the velocities are up to 20 ft/s downstream from the end sill and adjacent to the wall of the fishtrap. The potential for erosion should be addressed by project personnel familiar with the foundation and/or rock properties that will be exposed by the channel cuts.

Observations of single gate operations have been made for channel B. From this operation, assumptions can be made about operation of other gate and channel combinations. Operation of a gate in line with the excavated channel forces flow at a higher velocity through the channel; whereas operation of a gate away from the channel forces more flow over the rock bench and less flow through the cut.

In any case, a strong recirculating current (with direction determined by the location of the open gate) is maintained in the stilling basin pool.

Discussion of Results

The flow conditions through the channels were documented on photographs and video tape. An edited video tape will follow this report. Flow conditions through the channels produce different flow conditions in the river channel and near the fishtrap entrance. Confetti was used in the model to show major surface flow patterns. In general, small spillway flows, which concentrate flow in the channels, produce high velocities, 11 to 23 ft/s, through or at the end of the channels. This is because the height of the end sill and downstream rock bench prevent quick release of flows from the basin to the downstream river channel. As the spillway discharge increases, a greater portion of the flow leaves the basin over the rock bench and higher tailwater elevations minimize the presence of the jet from the excavated channels.

The following sections will describe the flow conditions in each channel as the total discharges investigated increased from 14,000 ft^3/s to 22,500 ft^3/s. Some mention will be made of flow conditions in channels where the total discharge reached 80,000 ft^3/s. Not all channels were tested under this large flow rate. The final section will discuss the single gate operations that were investigated only for channel B. Velocity measurements through the excavated channels and the river channel are discussed, and the data are shown in tables at the end of the report.

Channel A, the curved channel, directs a jet across the river channel. The area adjacent to the fishtrap is essentially unaffected by the channel and flow along the rock bench downstream of the curved channel exit is very calm. Figure 3 shows the flow conditions with a total of 14,000 ft^3/s, (TW = 498.25) with 9,000 ft^3/s from the powerplant, 350 ft^3/s from the fishtrap, and 4,650 ft^3/s from the spillway. This flow condition is typical of all flows where the tailwater elevation in the river channel is below the elevation of the rock bench. As the tailwater increases, the velocity of the jet across the channel decreases, and eventually the jet disappears as the total release reaches 80,000 ft^3/s. The measured velocities are given in table 1.

Channel B, the straight channel, directs the jet from the stilling basin parallel to the fishtrap wall. Near the fishtrap, the jet is narrow and follows the edge of the rock bench. Figure 4 shows this channel operating under a discharge of 14,000 ft^3/s, (TW = 498.25) with no powerplant flow, 350 ft^3/s from the fishtrap, and 13,650 ft^3/s from the spillway. As with channel A, the strength of this jet diminishes as discharge and tailwater increase. The measured velocities are given in table 2.

After completing work on channels A and B, the MP Regional Office requested that tests be done on channel C, a modification of channel A, and to test channel D on the far left side of the stilling basin.

Channel C passes through the end sill at the same location as channel A. The channel was straightened to release flow more nearly parallel to the river channel. Figure 5 shows channel C operating under a discharge of 14,000 ft^3/s,

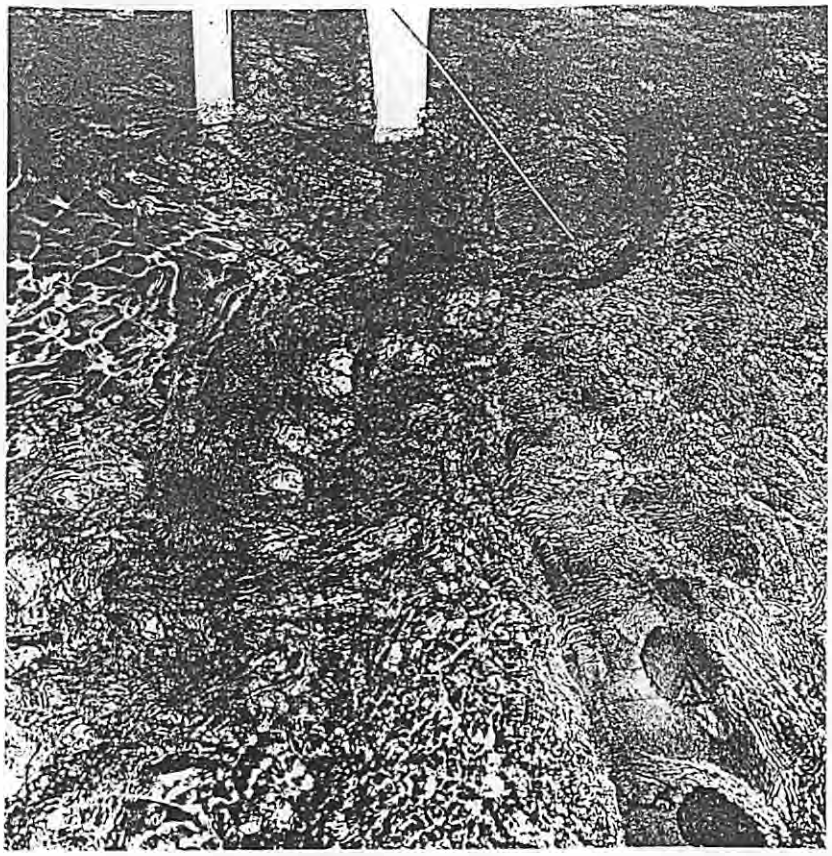

Figure 3. - Curved channel (A) exiting into the river channel downstream of the fishtrap, Q = 14,000 ft^3/s including 9,000 ft^3/s from the powerplant.

(TW = 498.25) with no powerplant flow, 350 ft^3/s from the fishtrap, and 13,650 ft^3/s from the spillway. The flow exits the channel at a slight angle to the river channel. Due to the length of the excavated channel and the amount of flow going over the rock bench immediately adjacent to the channel exit, the jet from the channel quickly dissipates and is redirected downstream parallel to the rock bench. Velocities are given in table 3.

Channel D, located on the left side of the stilling basin, cuts entirely across the rock bench downstream of the stilling basin to the river channel. The topography of the rock bench and the main flow from the stilling basin crossing the channel influence flow conditions in the channel.

Channel D is parallel to the flow leaving the stilling basin for about 40 ft. When the channel begins curving to the right toward the river channel, channel flow velocity increases. The channel then crosses a pool of deeper water formed by the lower elevation of the rock bench in this area. The main flow from the stilling basin crosses the channel at an angle through this area and channel flow velocity decreases. The channel then continues toward the river and enters a narrow area on the rock bench about 270 ft downstream from the basin. Almost the entire flow from the stilling basin, including that in the channel, travels through this constriction and the velocity in the channel increases again.

Channel D enters the river near the end of the rock bench. Therefore, the jet from the channel has a minimal effect on river channel flow because the entire basin flow is entering or has previously entered the river channel. Figure 6

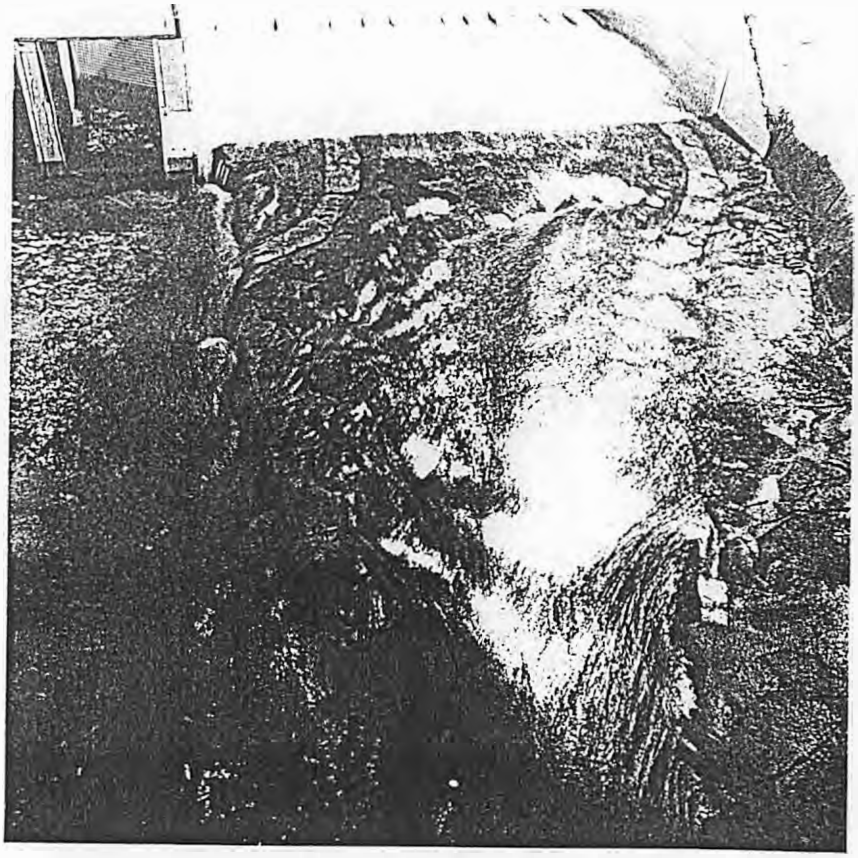

Figure 4. - Straight channel (B) exiting adjacent to the fishtrap, Q = 14,000 ft^3/s with no powerplant flow.

shows channel D, and the flow conditions over the rock bench for a discharge of 14,000 ft^3/s with 13,650 ft^3/s from the spillway, no powerplant flow, and 350 ft^3/s from the fishtrap. Average velocities for channel D are given in table 4.

For a total discharge of 14,000 ft^3/s, flow exiting all the channels was noticeable compared to the spillway flow entering the river channel. Tests under the high flow condition of 80,000 ft^3/s produced very little, if any, effects from the excavated channels. Therefore, intermediate flow conditions were investigated. A total discharge of 22,500 ft^3/s raised the tailwater elevation to that of the rock bench, El. 503. At this discharge, a comparison was made of the flow conditions with no channel excavations and then with channels A, B, C, and D cuts (figs. 7, 8, 9, 10, and 11). Flow conditions were observed and velocities measured for 22,150 ft^3/s through the spillway, and 350 ft^3/s through the fishtrap with no powerplant flow. Investigations were also made with 10,150 ft^3/s from the spillway, 350 ft^3/s from the fishtrap, and 12,000 ft^3/s from the powerplant. With initial powerplant flows there is even less effect in the river from the channel flows.

The flow conditions were observed for a discharge of 22,500 ft^3/s first under existing basin conditions with no channel excavations (fig. 7). This flow condition is used as a baseline for evaluating the effect of all of the channel cuts under a discharge of 22,500 ft^3/s. Under the existing condition, the flow spreads over the rock bench with no major concentrated jets entering the tailwater of the river channel. Obviously, with an excavated channel, a concentrated portion of the stilling basin flow travels through the cut. A

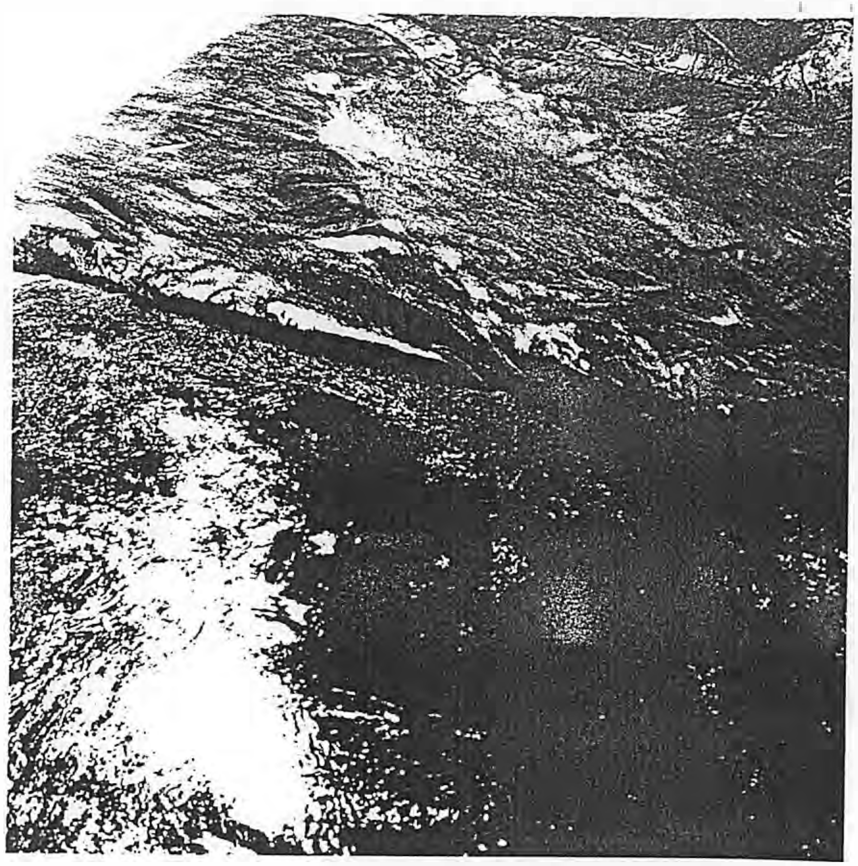

Figure 5. - Channel C exiting into the river channel about 200 ft downstream from the basin, Q = 14,000 ft^3/s with no powerplant flow.

strong concentrated flow may create unwanted attraction flow or impede migrating fish from reaching the fishtrap. Therefore, the channels were evaluated under the discharge of 22,500 ft^3/s with this in mind.

With channel A excavated, the jet entering the river channel is less pronounced when compared to the jet from smaller spillway flows (figs. 3, 8). However, the jet is still strong enough to likely affect migrating fish when compared to the present condition (figs. 7, 8). With channel B excavated, the jet entering the river channel appears to be about the same as that at smaller spillway flows (figs. 4, 9) and of significantly greater magnitude when compared to no channel excavation (figs. 7, 9). This observation is also confirmed by the velocity data.

With either channel C or channel D excavated flow conditions in the river channel are acceptable (figs. 10 and 11). Both exit far downstream from the fishtrap entrance, thus limiting their affects on river channel and fishtrap flows. Channel C parallels the main flow over the rock bench and the velocity from the channel greatly decreases upon entering the river channel. Channel C produces similar flow conditions to the original condition in the river channel with no effect on the fishtrap entrance (figs. 7 and 10).

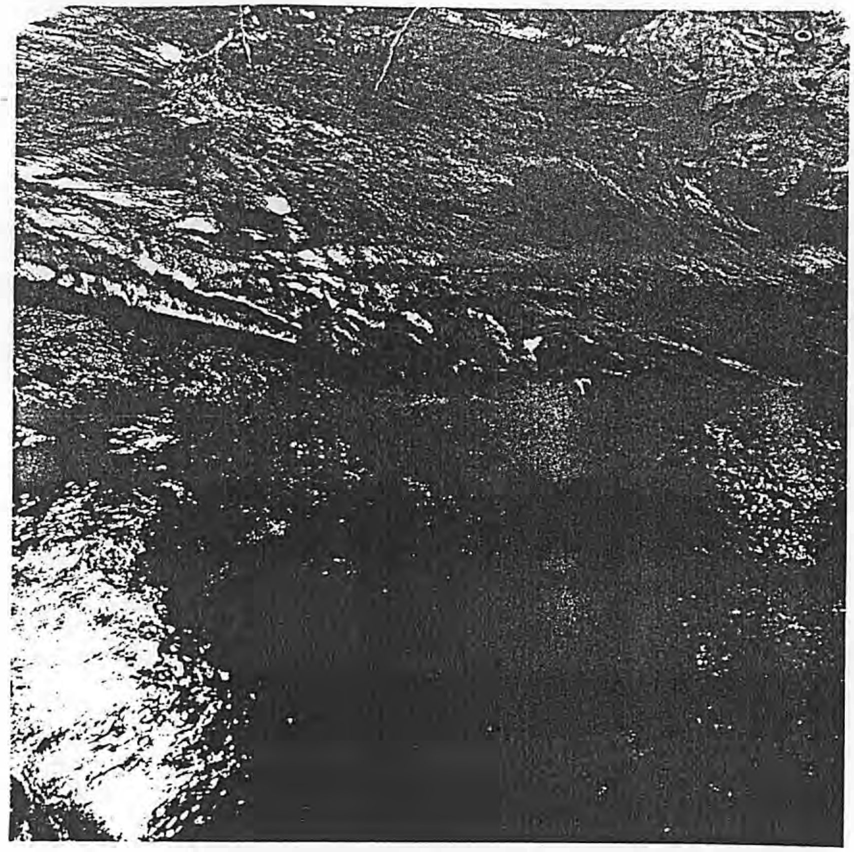

Figure 6. - Channel D carrying flow from the basin entirely across the rock bench before entering the river channel, Q = 14,000 ft^3/s with no powerplant flow.

Flows through channel D are more complicated as they are affected by the location of the channel with respect to the main flow leaving the basin and the topography of the rock bench. The channel flow velocity, however, quickly diminishes upon entering the river channel. Channel D enters the river far downstream from the stilling basin and fishtrap entrance. There is virtually no effect on river channel flows or at the fishtrap entrance.

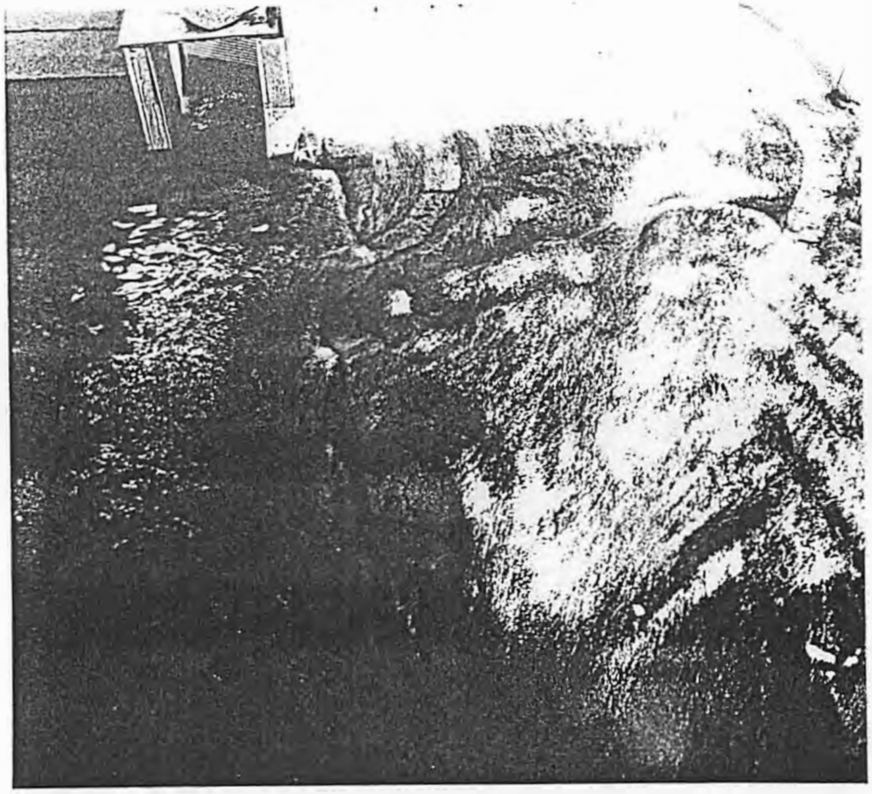

Figure 7a. - Flow conditions with no channel excavations, Q=22,500 ft^3/s with no powerplant flow.

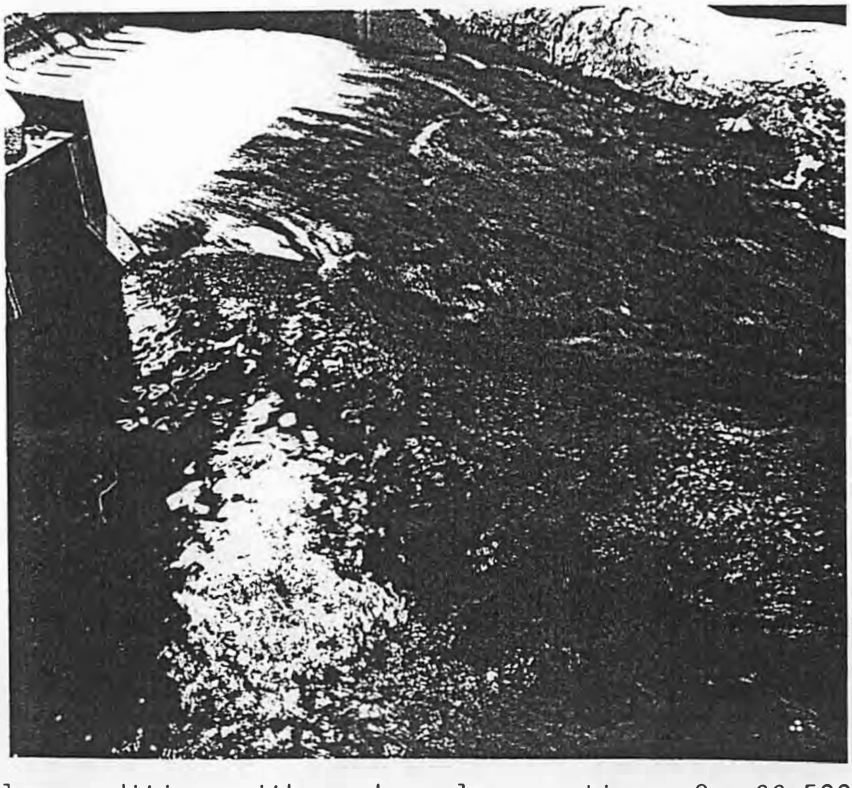

Figure 7b. - Flow conditions with no channel excavations, Q = 22,500 ft^3/s with no powerplant flow.

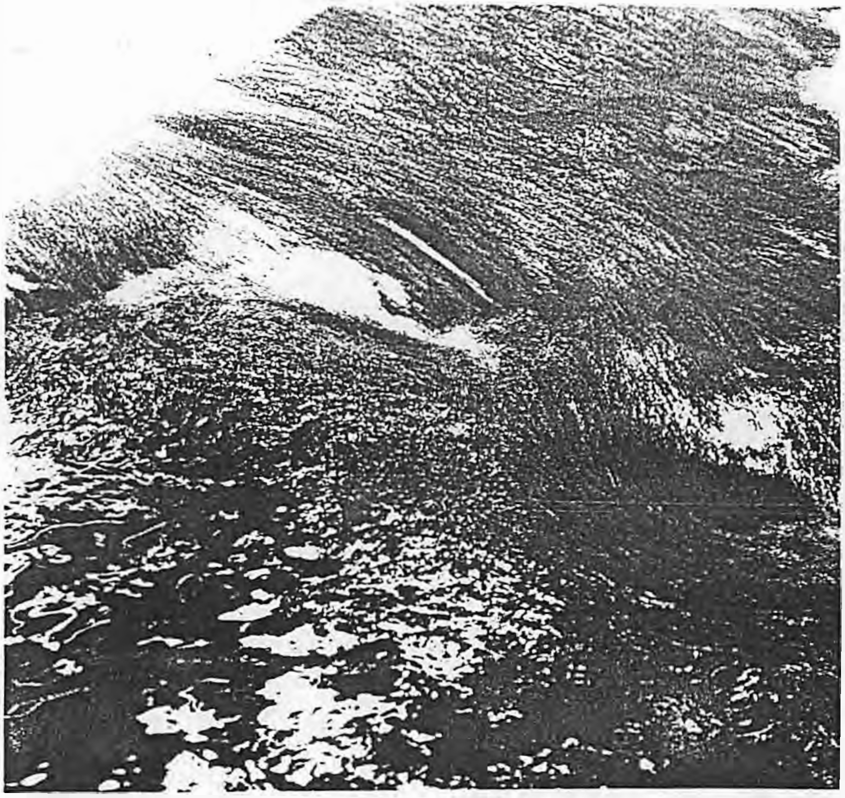

Figure 8. - Flow conditions through channel A, Q = 22,500 ft^3/s with no powerplant flow.

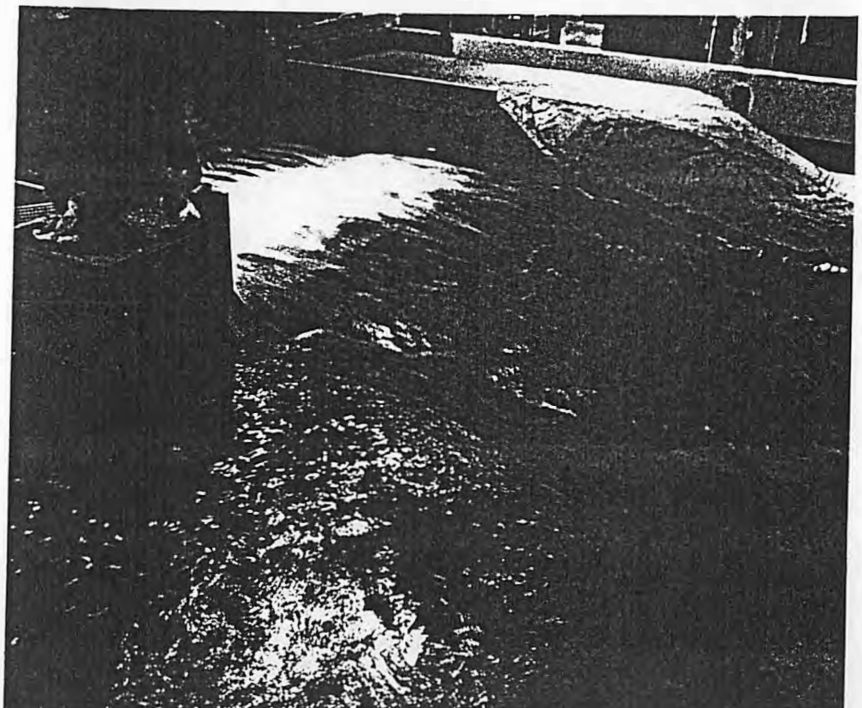

Figure 9. - Flow conditions through channel B, Q = 22,500 ft^3/s with no powerplant flow.

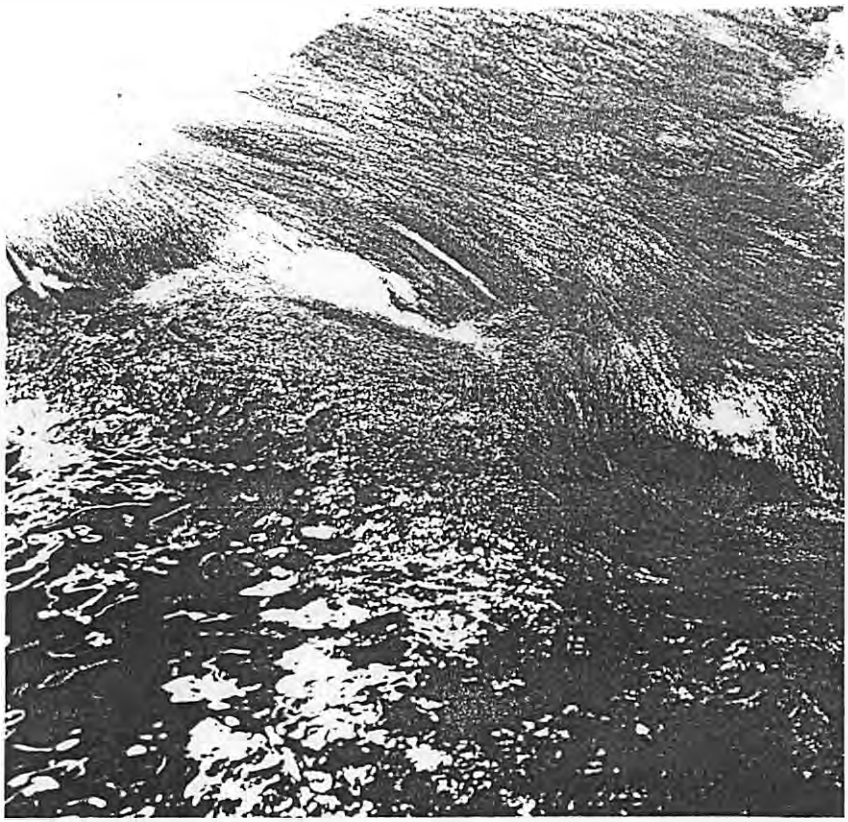

Figure 10. - Flow conditions through channel C, Q = 22,500 ft^3/s with no powerplant flow.

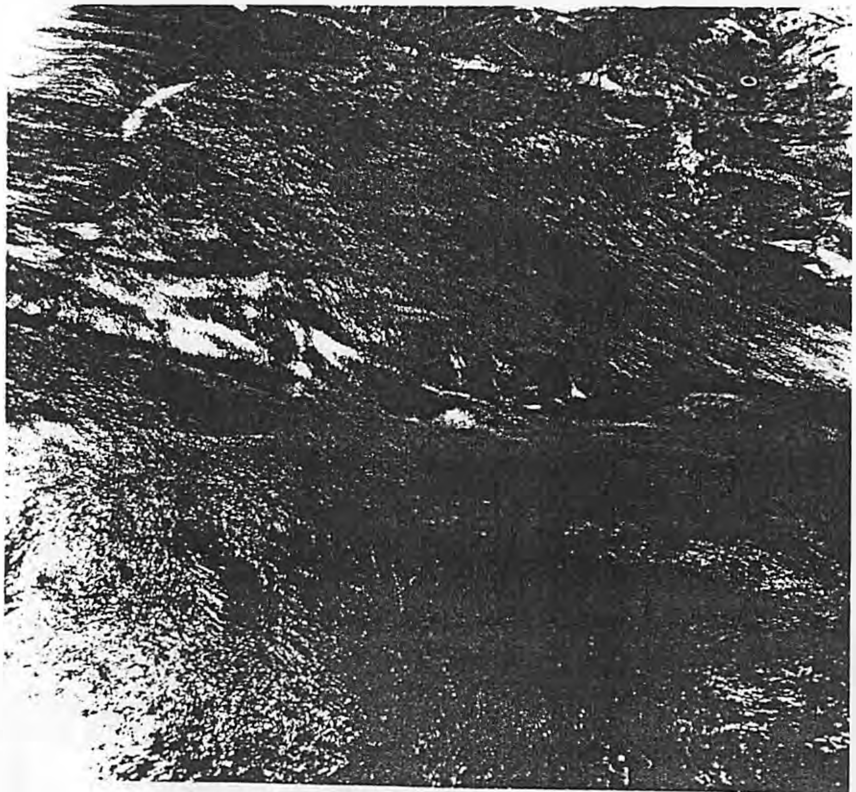

Figure 11. - Flow conditions through channel D, Q = 22,500 ft^3/s with no powerplant flow.

Single gate operations

Observations of single gate operation were made for channel B only. At the time of this test, only channels A and B were being investigated and channel B was the preferred channel. Single gate operation was investigated for a discharge of 8,000 ft^3/s, with no powerplant flow and 350 ft^3/s through the fishtrap. At this small discharge, the excavated channel carries a large portion of the flow. Only a small depth of flow exits the basin over the rock bench. As a result, when the far right gate (looking downstream) is open, the flow is directly in line with the channel producing a strong flow out the channel (fig. 12). The remaining flow recirculates (counterclockwise) in the basin and exits over the rock bench. When the far left gate is open, the flow from the gate is directed at the rock bench. Therefore, more flow passes over the rock bench and less flow passes through channel B. The flow still recirculates (clockwise this time) in the basin before exiting from the channel (fig. 13).

Figure 12. - Channel B with only the far right gate operating at 8,000 ft^3/s with no powerplant flow.

Figure 13. - Channel B with only the far left gate operating at 8,000 ft^3/s with no powerplant flow.

Velocities

Velocities were measured at various locations for all the channels investigated, including in the end sill cut, in channel, and in the downstream river at selected points, figure 2. Measurements were recorded at either 0.6 times the depth or 0.2 and 0.8 times the depth and averaged. The average velocities for the discharge conditions investigated are shown in tables 1-4. If needed for further analysis, the velocities at the specific measured depths are available upon request.

For comparison to the existing condition, velocities were measured immediately below the concrete berm along the rock bench, with all channels filled in. These velocities are given for a discharge of 22,500 ft^3/s in parentheses in table 2. As shown, velocities created by the existing spillway stilling basin releases are much less than those of flow exiting the channels.

These average velocities may be used to determine whether or not the channels will impede the ability of the salmon to swim upstream into the fishtrap during the flows reported. They may also be used to determine whether or not the fish will attempt to swim through the channels and into the stilling basin instead of the fishtrap during spill events. When there is no spillway discharge the only attraction into the basin would be from gate leakage. This would hopefully not exceed that of the fishtrap discharge and thereby not produce significant attraction flow. During spillway operation, channel velocities appear to be high enough to impede upstream movement of salmon into the basin until large spillway flows occur (note the velocities at 80,000 ft^3/s, table 2).

Average velocities measured in channels C, and D, are given in tables 3 and 4, respectively. These velocities are of similar magnitude to those of channels A and B and should discourage swimming upstream through the channels during spillway operation under the flow rates tested.

The fluctuating velocity trends through channel D are a result of the channel location on the far left side of the stilling basin and the varying topography across the rock bench. The velocities given in parentheses in table 4 show the velocity measured at 0.2 depth (referenced to water surface) pointed upstream toward the stilling basin (surface flow) averaged with the velocity measured at 0.8 depth directed up the channel (channel flow). As may be seen there is about the same average velocity flowing over the channel from the main spillway flow as that flowing through the channel.

The velocities are high enough that erosion damage could occur immediately downstream of the end sill. The rock in this area should be evaluated to determine the erosion potential based upon the velocities reported for each of the channels. In particular, the velocity and jet configuration of channel B next to the fishtrap wall could potentially undermine the fishtrap wall and the corner of the stilling basin floor.

References

Greg O'Haver, "Solutions to Keswick Stilling Basin Fish Entrapment - Report on Meeting Held On 4-7-93," Shasta Project Office, 1993.

Bell, Milo C., "Fisheries Handbook of Engineering Requirements and Biological Criteria," Fish Passage Development and Evaluation Program, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, 1990.

Table 1. - Velocities in ft/s measured through the curved channel (A) exiting at a 30° angle to the river channel about 88 ft downstream of the basin.

Location	Q=14,000 ft^3/s			Q=22,500 ft^3/s		
	Q_{sp}*=13,650 ft^3/s	Q_{ft}*=350 ft^3/s	Q_{pp}*=0 ft^3/s	Q_{sp}=22,150 ft^3/s	Q_{ft}=350 ft^3/s	Q_{pp}=0 ft^3/s
u/s end of sill cut	3.6					
d/s end of sill cut	7.4					
d/s end of channel A1	23.5			12.8		
15′ d/s of channel along same line A2	21.2			14.1		
50′ d/s of channel @ CL of fishtrap A3	12.8			3.5		
67.5′ d/s of channel on left side of river channel A4	11					
97.5′ d/s of channel on right side of river channel A5	8.5					
30′ d/s of channel exit along rock bench A6	1.9					
45′ u/s of channel exit along rock bench A7	3.8					

* Q_{sp} = spillway discharge
Q_{ft} = fishtrap discharge
Q_{pp} = powerplant discharge

Table 2. - Velocities in ft/s measured through the straight channel (B) parallel to the fishtrap. All velocities were measured in the centerline of the channel or as close to the rock bench as possible.

Location	Q=14,000 ft^3/s			Q=14,000 ft^3/s			Q=22,500 ft^3/s			Q= 22,500 ft^3/s		
	Q_{sp}=4,650 ft^3/s	Q_{ft}=350 ft^3/s	Q_{pp}=9,000 ft^3/s	Q_{sp}=13,650 ft^3/s	Q_{ft}=350 ft^3/s	Q_{pp}= 0 ft^3/s	Q_{sp}=22,150 ft^3/s	Q_{ft}=350 ft^3/s	Q_{pp}=0 ft^3/s	Q_{sp}=10,150 ft^3/s	Q_{ft}=350 ft^3/s	Q_{pp}=12,000 ft^3/s
u/s end of sill cut	2.7			3.8			---			---		
d/s end of sill cut	8.8			7.9			10.4			7.5		
13.75' d/s of basin B1	15.4			16.5			16.9			12.0		
23.75' d/s of basin B2	16.6			20.9			20.1 (8.6)			11.9		
43.75' d/s of basin B3	5.7			16.7			15.8 (4.4)			8.3		
82.5' d/s of basin B4	---			15.1			14.4			---		

Table 2. - continued.

Location	Q= 80,000 ft^3/s		
	Q_{sp}=70,650 ft^3/s	Q_{ft}=350 ft^3/s	Q_{pp}=9,000 ft^3/s
u/s end of sill cut	7.9		
d/s end of sill cut	5.7		
13.75' d/s of basin B1	7.3		
23.75' d/s of basin B2	6.6		
43.75' d/s of basin B3	3.3		
82.5' d/s of basin B4	4.4		

Table 3. - Velocities in ft/s measured through channel C, the straightened channel A.

Location	Q=14,000 ft^3/s			Q=22,500 ft^3/s			Q=22,500 ft^3/s		
	Q_{sp}=13,650 ft^3/s	Q_{tt}=350 ft^3/s	Q_{pp}=0 ft^3/s	Q_{sp}=22,150 ft^3/s	Q_{tt}=350 ft^3/s	Q_{pp}= 0 ft^3/s	Q_{sp}=10,150 ft^3/s	Q_{tt}=350 ft^3/s	Q_{pp}= 12,000 ft^3/s
u/s end of sill cut	2.5			2.7			3.4		
d/s end of sill cut	6.7			7.8			8.1		
117.5' d/s of basin in channel C1	13.0			14.3			13.4		
207.5' d/s of basin at end of channel C2	21.4			16.3			13.4		
52.5' d/s of channel along same line C3	9.4			11.2			5.0		

Table 4. - Velocities in ft/s measured through channel D located 28.22 ft left of the left stilling basin wall.

Location	Q=14,000 ft^3/s			Q=22,500 ft^3/s			Q=22,500 ft^3/s		
	Q_{sp}=13,650 ft^3/s	Q_{tt}=350 ft^3/s	Q_{pp}=0 ft^3/s	Q_{sp}=22,150 ft^3/s	Q_{tt}=350 ft^3/s	Q_{pp}= 0 ft^3/s	Q_{sp}=10,150 ft^3/s	Q_{tt}=350 ft^3/s	Q_{pp}=12,000 ft^3/s
u/s end of sill cut	3.7			3.5			1.9		
d/s end of sill cut	5.3			6.9			3.0		
38.75' d/s of basin in channel D1	7.9			9.1			6.0		
92.5' d/s of basin in channel D2	11.9			11.9			9.2 (8.9)		
188.75' d/s of basin in channel D3	9.0			9.8			7.5 (8)		
270' d/s of basin in channel D4	14.2			15.7			11.0 (11.1)		
360' d/s of basin in channel D5	20.9			18.0			10.0 (9.4)		
397.5' d/s of basin @ end of channel D6	17.1			12.2 (13.1)			7.0 (7.6)		

Amendment

Introduction

The initial model study results provided the necessary information to evaluate four channel locations based upon flow conditions and channel velocities. The best option from the fish migration, excavation, and flow condition standpoint proved to be channel B, the short, straight channel along the shared spillway/fishtrap wall. However, selecting channel B raised questions about the structural stability of the wall and the potential for erosion at the end of the wall.

The fish escape channel must ultimately provide an adequate means for the salmon to swim out of the spillway stilling basin. Therefore, these design criteria, based upon the fish migration needs, were established for the channel:

Minimum channel width of 4 ft with a maximum abrupt offset of 1 ft.
Fish escape channel invert elevation equal to 486 ft.
Channel should begin parallel and adjacent to the fishtrap wall.
Maximum bend in the channel should be 30°.
Channel should have provisions for stoplogs.

These design criteria, with the results of the initial model testing, and concerns about the structural stability of the spillway/fishtrap wall, were used to determine several fish escape channel compromise geometry options.

The options were a modification of the channel next to the fishtrap wall, channel B, that was determined to be the optimum location from the fish migration standpoint and acceptable from the hydraulic standpoint. Because the final options were all close to the fishtrap wall, the wall stability was major factor in selecting the geometry of the final options.

This amendment discusses model results for the final options determined to best meet the needs of the salmon, including flow conditions in front of the fishtrap, and the stability of the fishtrap wall and channel.

Additional fish escape channel options tested:

Option B1 - A 4-ft-wide fish escape channel parallel to the fishtrap wall at El. 486 with vertical walls. The wall extension, downstream of the fishtrap wall, would be excavated to El. 486 allowing flow downstream, through the concrete berm, and to the right from the fish escape channel. Figure A1 shows the end of the spillway/fishtrap wall with the proposed modification B1.

Option B2 - This option is described as serpentine. A 4-ft-wide channel starting 1 ft away from the fishtrap wall, then angling left at 30° through the end sill to the upstream edge of the downstream concrete berm. At this point the channel would go straight through the berm then angle at 15° back to the river channel. The entire channel would be at El. 486. (The downstream angle was then changed to 11° to reduce downstream excavation.) Figure A2 shows Option B2, the serpentine design adjacent to the spillway/fishtrap wall.

Purpose

The purpose of the further testing was to visually determine which options provided acceptable flow conditions and to determine hydrostatic loading conditions on the spillway/fishtrap wall.

Results and Discussion

Option B1, with the wall extension at the downstream end of the spillway/fishtrap wall removed to El. 486, the level of the fish escape channel, did not perform well. Flow from the fish escape channel and the spillway in general, spread out in front of the fishtrap potentially deterring salmon from swimming upstream to the fishtrap.

Option B2, the serpentine option, starting next to the spillway/fishtrap wall angling 30° to the left and then heading downstream and toward the right to the river channel, performed adequately. The entrance to the channel is offset only 1 foot from the wall which should allow easy access for fish entering the channel. The mass of spillway end sill remaining near the wall provides stability. The channel exit, whether entering the river channel at 15° or 11° to the river channel is also acceptable (figure A3). The entire channel will be concrete lined to prevent erosion.

The water surface differential on either side of the fishtrap/spillway wall was determined for channel B2 for three different flow conditions. The "worst case" scenario is a small powerplant flow (one unit) with the fishtrap operating at 350 ft^3/s and a small spillway flow. For a total discharge of 17,000 ft^3/s, with tailwater El. 500, the differential at the end of the wall is 7 ft. As the powerplant and spillway flows increase, the water surface differential decreases because the tailwater builds above the elevation of the rock bench downstream of the spillway. This conclusion is based upon measured flow depths on either side of the spillway/fishtrap wall that showed the water surface differential decreasing to about 2 ft for a total flow rate of 80,000 ft^3/s. Under normal flow conditions, with only the powerplant and fishtrap operating, the fish escape channel will allow the spillway water surface to follow the tailwater.

Velocities through the channel were not measured but will be slightly higher than given previously in table 2, because the vertical wall on the left side of the channel produces a slightly smaller flow area.

Summary

The serpentine channel, Option B2, was selected as the final fish escape channel to be constructed. The structural analysis, and design and construction considerations are given in Reclamation's KES-3110-FE-TM-94-1 prepared by the Waterways and Concrete Dams Group 1, D-8131.

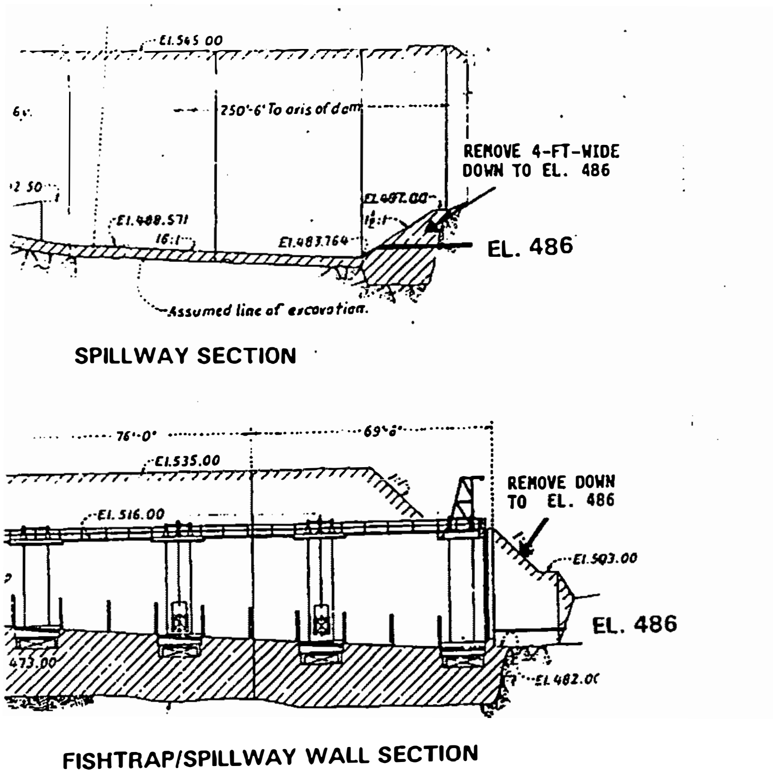

Figure A1. - Option B1, removal of the extension at the end of the spillway/fishtrap wall down to the floor of the fish escape channel (El. 486).

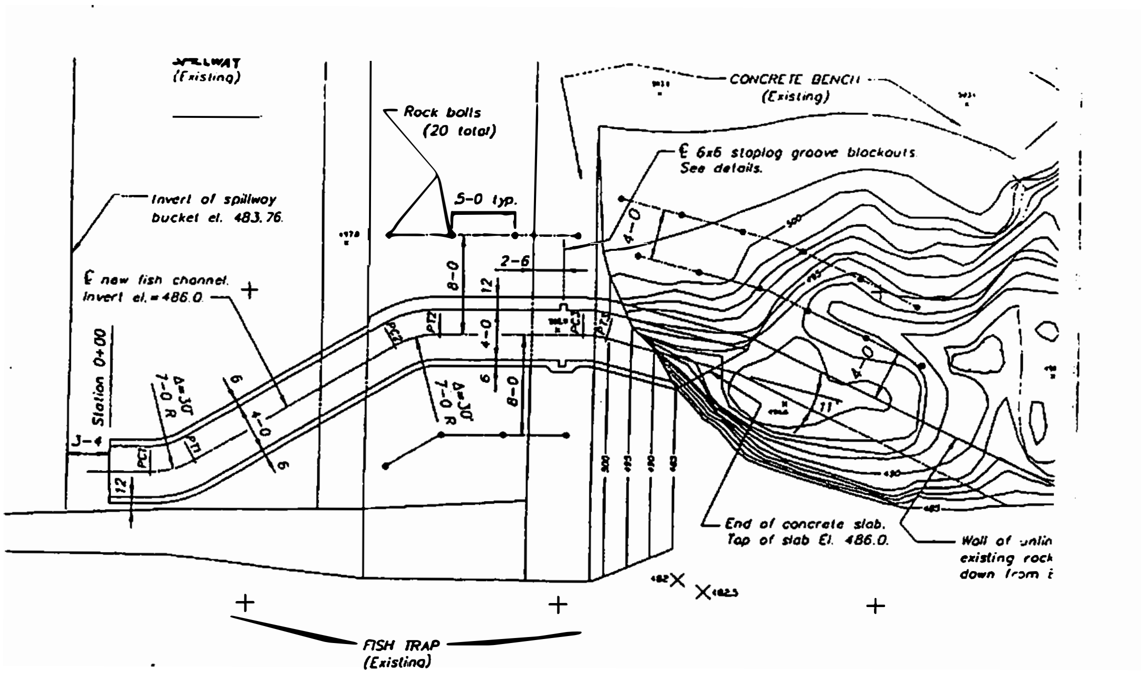

Figure A2. - Option B2, excavation of a 4-ft-wide serpentine channel through the spillway end sill and exiting to the river channel at an 11° angle.

Figure A3. - The final serpentine fish escape channel shown operating with a total discharge of 14,000 ft^3/s.