Monitoring the Behavior of Acoustically Tagged Chinook and Steelhead Smolts Approaching Rocky Reach Dam on the Columbia River

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ABSTRACT

Acoustic tags were used to monitor the swimming patterns of downstream migrating salmonid smolts approaching Rocky Reach Dam on the Columbia River. Fish were tracked in three-dimensions as they approached and passed into the turbine intakes and surface bypass channel entrances at the dam during the 1999 and 2000 spring and summer outmigrations. Approximately 775 chinook and steelhead smolts were surgically implanted with acoustic tags. The size of the juvenile salmonids ranged from 132 mm to 245 mm. The tags were approximately 7 mm in diameter by 21 mm in length, operated at 300 kHz, and weighed approximately 1.5 gm in freshwater. As many as 25 passive hydrophones with omni-directional beams were used to monitor the transmitted pulse from the tagged fish. The arrival time of the transmitted signal at each hydrophone was used to calculate the three-dimensional position of each fish while they were present in the hydrophone array.

A variety of fish behaviors were observed, with most fish passing the dam within 6 hours of release. Tagged fish exhibited four general swimming patterns: 1) moving directly to the fish's ultimate passage route, 2) milling in a circular trajectory that followed the flow pattern in the powerhouse forebay, 3) milling directly in front of either or both of the surface collector intakes, and 4) a general milling behavior that showed no distinct pattern.

Three-dimensional tracks of fish approaching the turbine intakes and surface bypass channel are presented. The fish's three-dimensional path was also superimposed with fine-scale water velocity and flow data from hydraulic modeling, to draw inferences for improving the design, and thus bypass effectiveness, of the surface bypass system. Examples of three-dimensional fish tracks and movement/flow comparisons are presented.

BACKGROUND

Salmon and steelhead (*Oncorhynchus* spp.) runs on the Columbia River and its tributaries have been declining since the 1800's due to several factors. One factor has been the operation of hydroelectric dams. While most downstream migrating juvenile salmon and steelhead pass safely through a single dam, the cumulative mortality that results from fish passing through several dams can be substantial (Bell et al. 1967).

Throughout the last two decades, considerable effort has been devoted to exploring ways to protect and restore these salmon and steelhead runs. Chelan County Public Utility District No. 1 has been evaluating bypass methods to increase levels of survival of downstream migrants passing Rocky Reach and Rock Island dams.

To assess the effectiveness of current bypass methods, the HTI *Model 290 Acoustic Tag Tracking System* was deployed in 1999 and 2000. A total of 775 fish were released and tracked as they approached the dam and passed through their ultimate passage location (Steig and Timko 2000, Steig et al. 2001).

Site Description

Rocky Reach Dam is located on the Columbia River 7 miles north of Wenatchee, Washington at river mile 475. The dam's spillway is perpendicular and its powerhouse parallel to river flow (Figure 1). The powerhouse is 1,088 ft long and contains 11 vertical Kaplan turbines numbered from south to north. Turbine Units 1-7 have a rated generating capacity of 116 MW each. Units 8-11 are rated at 125 MW each. Each turbine has three rectangular intakes, 20 ft wide by 50 ft high at the headgate slot. The spillway is over 750 ft long and has 12 automatic spill gates. Each gate is 50 ft wide and approximately 60 ft deep to the spill gate ogee.

MATERIALS AND METHODS

Tagging fish with active acoustic transmitters provided their three-dimensional location by triangulation between three or more fixed hydrophones (passive transducers). Assuming the precise location of each hydrophone is known (+- 5 cm), the location of the acoustic tag (within 1 m) was determined for each received pulse. Up to 40 tagged fish were simultaneously tracked over an area the size of the forebay of Rocky Reach Dam.

The tracking system utilized for the 1998 Rocky Reach study used four fixed, wide-beam hydrophones with overlapping beams (Steig et al. 1999). The hydrophones were placed in known locations and were mapped within a three-dimensional grid. As an acoustic tag passed through the four beams, the difference in the arrival time of each pulse was used to triangulate the exact location of the tag. In this way, a swimming path for each tagged fish was mapped and presented in a three-dimensional display. For the 1999 study at Rocky Reach Dam, 12 omnidirectional hydrophones were used to monitor the entire powerhouse forebay. For the 2000 study, 25 omnidirectional hydrophones were used to monitor the entire powerhouse and spillway forebay.

Acoustic tags selected for these studies were encapsulated, omnidirectional pingers. The tags were 21 mm long and 7 mm in diameter. The weight in air for each tag was 2.5 g and weight in water was 1.5 g. Transmit frequency was 300 kHz. Transmit power level was approximately 157 dB uPa @ 1 m. Pulse rate and pulse width were programmable. Nominal pulse rate was 1 pulse/sec with a transmit pulse width of 1-3

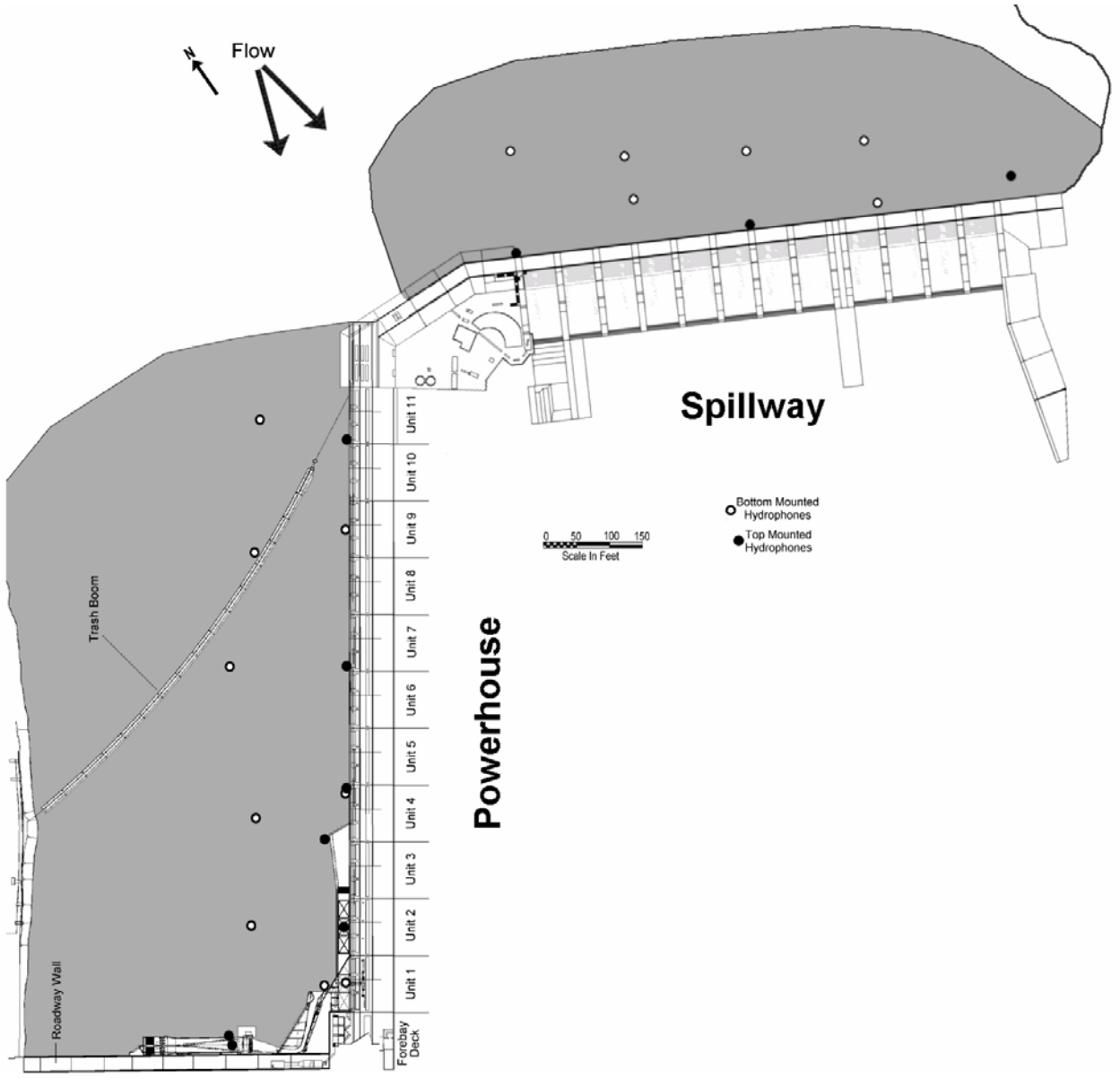


Figure 1. Plan view showing the approximate hydrophone coverage area in the forebay of Rocky Reach Dam in 1999 and 2000.

msec. The useful life of the tag, once activated, was on average 10-12 days.

The tags were surgically implanted into the chinook and steelhead smolts after making a small incision into the body cavity. The incision was stitched after implanting the tag. The tagged fish were held 44-48 h before release to insure fish survival and tag retention. Acoustically tagged fish were released approximately 3.5 km upstream of Rocky Reach Dam in the center of the river, detected, and tracked within the coverage area.

The HTI *Model 290 Acoustic Tag Tracking System* was used for this study. The acoustic tag receiver was designed to receive on up to 16 separate channels. One channel was assigned for each hydrophone. Received signals were synchronized in order to determine time of arrival for each detected pulse. Arrival time of the pulse at each hydrophone was used to determine the location of the tag moving through the forebay. This data was saved in digital format and a tracking program was used to track the received signal from the 16 separate hydrophones.

The three-dimensional tracks were presented with an HTI software program called *ACOUSTIC TAG*. The *ACOUSTIC TAG* program is an animated, interactive display that allows the user to view individual pulses, large groups of pulses, or the entire trace for each fish. The display provides a three-dimensional background showing a representation of the coverage area including important structures such as the surface collector entrances, the entrances to Turbine Units 1-11, and the secondary de-watering screen for Surface Collector 1. Figure 2 provides a view from within the *ACOUSTIC TAG* program with labels on the significant structures. While actively viewing fish traces within the program, the user can adjust the field of view to move spatially within the program (forward, backward, up, or down). This allows several different perspectives to be taken for any given fish trace.

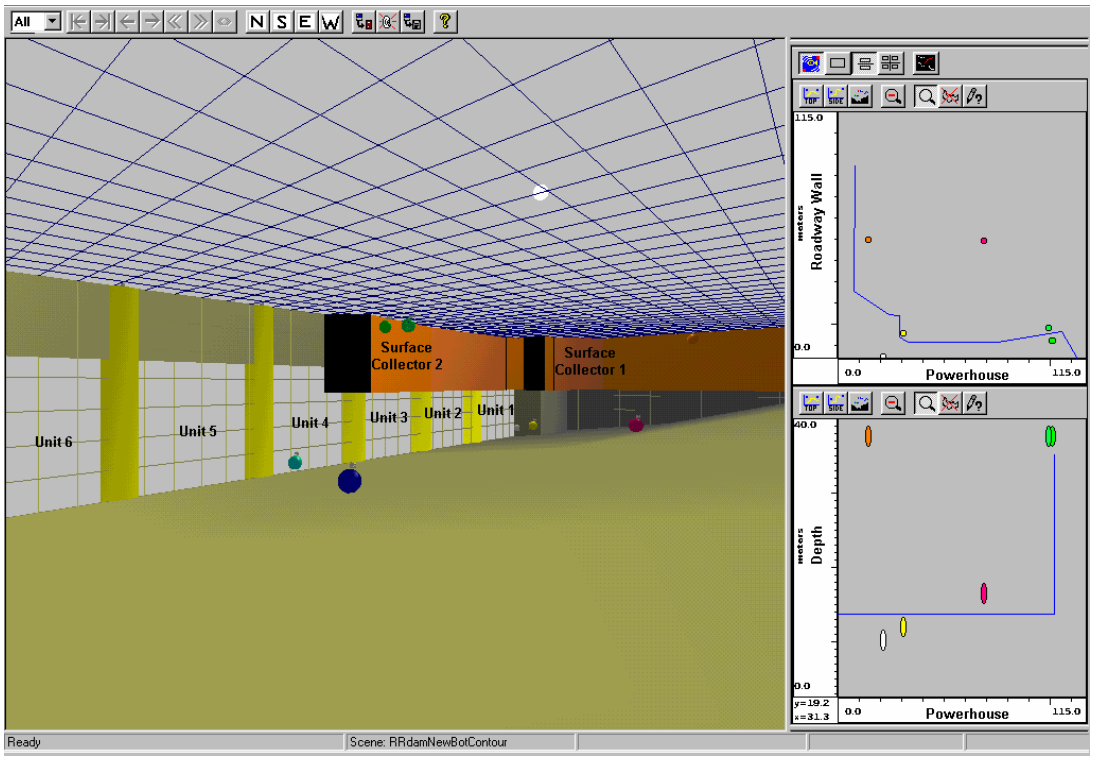


Figure 2. Typical view as seen in the *Acoustic Tag* program showing the significant structures and hydrophone locations.

RESULTS AND DISCUSSION

During the 1999 and 2000 outmigrations, approximately 775 chinook and steelhead smolts were surgically implanted with acoustic tags. The size of the juvenile salmonids that were tagged during these studies ranged from 132 mm to 245 mm in length.

Horizontal Distribution Across the Powerhouse and Spillway

The proportion of fish passage was calculated for each turbine, spillbay, and surface collector. Percentage distributions were calculated as a function of the species (chinook and steelhead). The proportion of fish passage for all of the various passage locations for the chinook juveniles is presented in Figure 3. Surface Collector 1 passed the largest proportion of tagged chinook smolts with 21%. Unit 1 passed 8% and Unit 4 passed 9% of the tagged chinook smolts.

The proportion of fish passage for all of the various passage locations for the steelhead juveniles is presented in Figure 4. Surface Collector 1 passed the largest proportion of tagged steelhead with 36%. Unit 1 passed 15% and Unit 4 passed 7% of the tagged steelhead smolts.

The proportion of chinook passing through the powerhouse and surface collectors was 86% as compared to those fish passing through the spillway (14%). The proportion of steelhead passing through the powerhouse and surface collectors was 90% as compared to those fish passing through the spillway (10%).

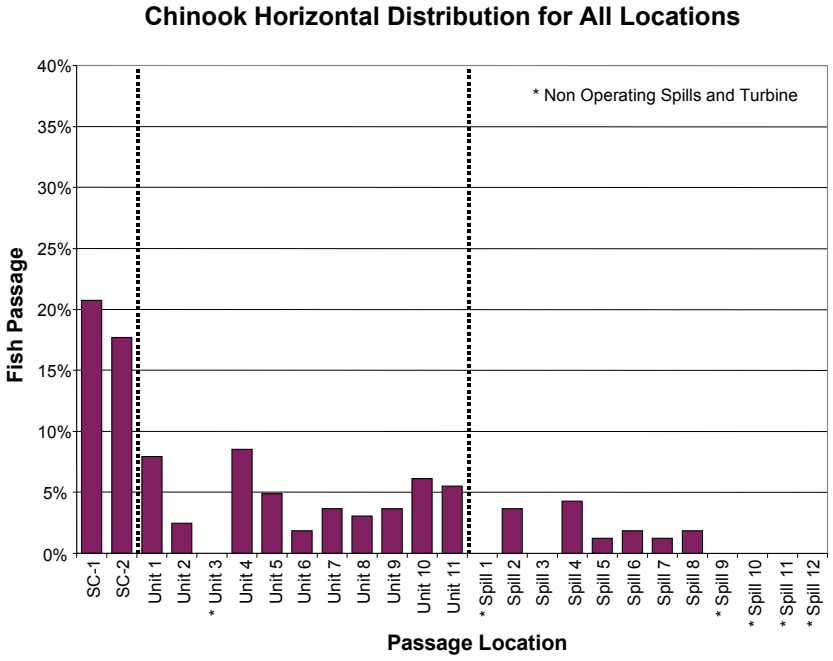


Figure 3. Chinook horizontal distribution for all the passage locations (Rocky Reach Dam, 2000).

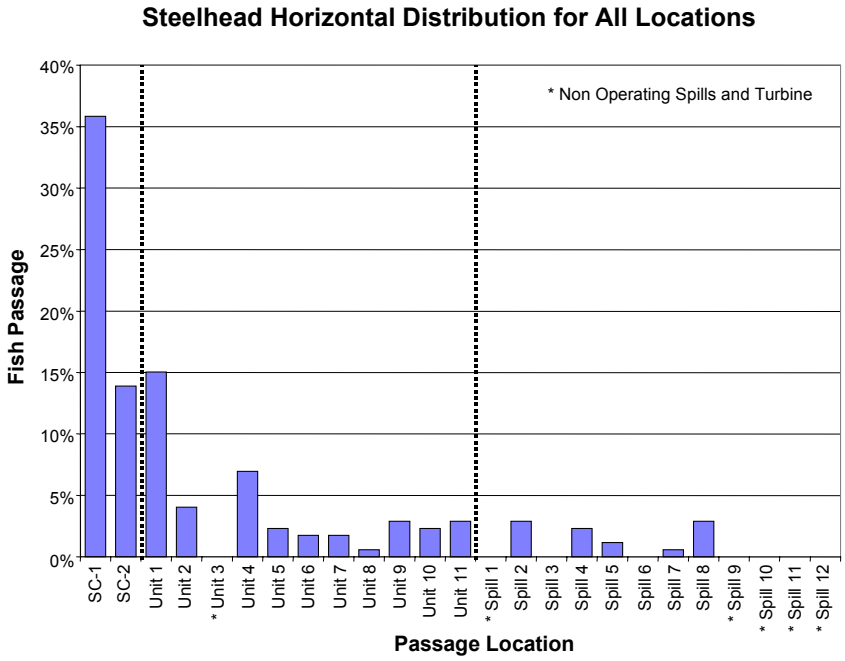


Figure 4. Steelhead horizontal distribution for all the passage locations (Rocky Reach Dam, 2000).

Hourly Fish Passage

Hourly fish passage data was determined by calculating the proportion of tagged chinook and steelhead smolts that passed through the dam each hour of the day. These results are presented in Figure 5. In general, chinook passage was variable throughout the daytime hours, with peak passage occurring at 2300 h. Peak chinook passage was followed by low chinook passage from 0100 h to 1000 h. Steelhead passage gradually increased from 0100 h to 1800 h with peak passage at 2100 h. Similar hourly fish passage distributions have been reported in previous active hydroacoustic studies conducted at Rocky Reach Dam (Adeniyi and Steig 1995).

Powerhouse and Spillway Fish Swimming Behavior

One of the unique features of the Acoustic Tag System is the ability to determine individual fish passage routes and fish paths. Observed individual fish paths were classified, based on swimming behavior (i.e., swimming pattern), into one of two major categories: straight path behavior or milling path behavior.

Straight Path Swimming Behavior

Straight path swimming behavior is defined as a fish swimming in a relatively straight path in the x-y plane. These fish may have exhibited vertical dives (in the z-plane) but did not meander in the x-y plane. An example of this type of behavior in the

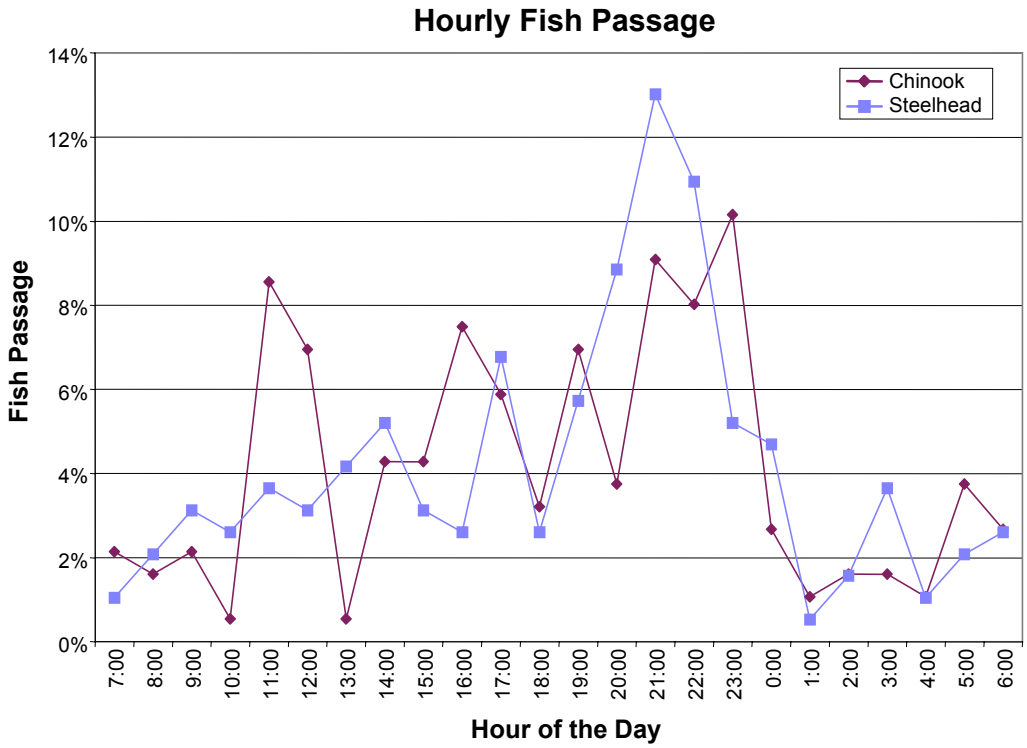


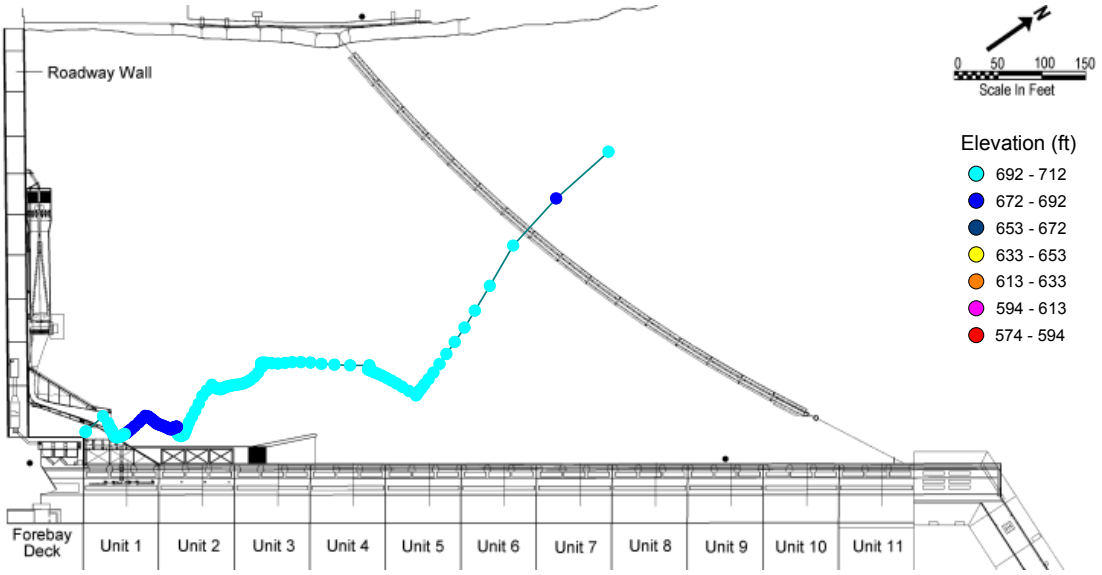
Figure 5. Hourly percent chinook and steelhead passage at Rocky Reach Dam in 2000.

powerhouse is shown in Figure 6. Figure 6 shows the path of a steelhead smolt released on the afternoon of 1 June 2000. This fish made a path toward Unit 5, before changing direction and eventually entering Surface Collector 1. The residence time for this fish was 215 min.

Figure 7 shows the path of a chinook smolt released on the afternoon of 11 May 2000. This fish made a relatively direct path to Spill 4. The residence time for this fish was 43 min. The majority of the fish that were detected and passed in the spillway, exhibited this straight path swimming behavior.

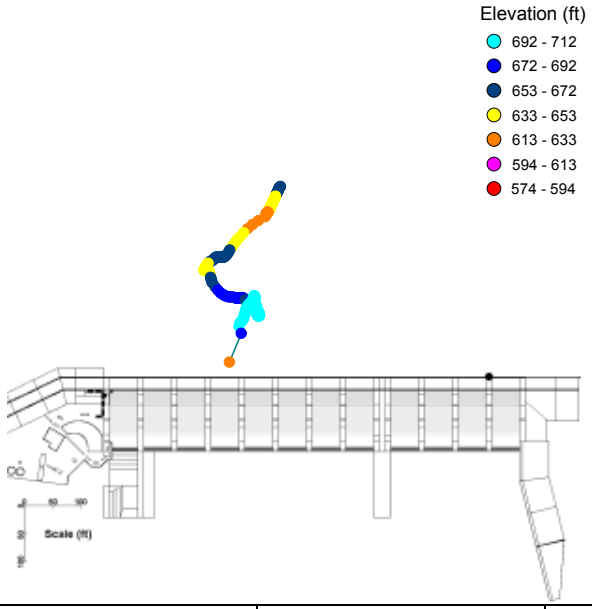
Milling Behavior

Milling behavior is defined as a fish swimming in an area for extended periods. This includes staying stationary in one area, as well as swimming to multiple areas over long time periods. Figure 8 shows the path of a steelhead smolt released on the morning of 26 April 2000. This fish made a path along the powerhouse wall, before milling in front of and on the west side of Surface Collector 1. The fish eventually passed into Unit 1 and had a residence time of 118 min. Figure 9 shows the path of a steelhead smolt released on the morning of 6 May 2000. This fish swam in a circular pattern in the forebay to the west of Surface Collectors 1 and 2. Eventually this fish entered Surface Collector 1.



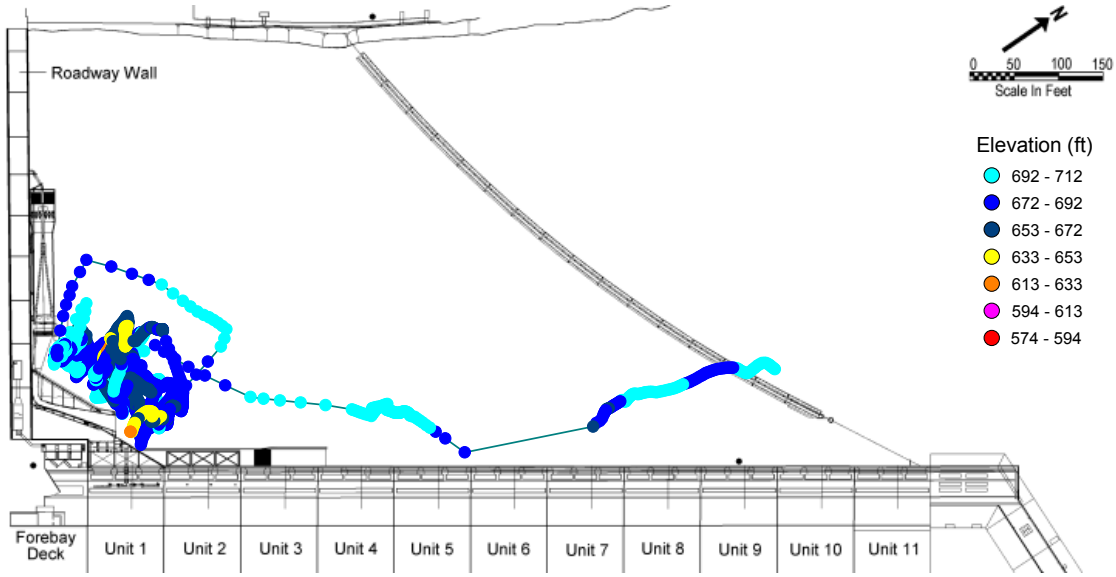
Species:	Steelhead	Residence Time:	215 min
Type of Release:	Afternoon	Passage Route:	Surface Collector 1
Release Date:	6/1/00	Fish Length:	194 mm

Figure 6. Steelhead swimming path exhibiting the straight path swimming behavior at Rocky Reach Dam in 2000.



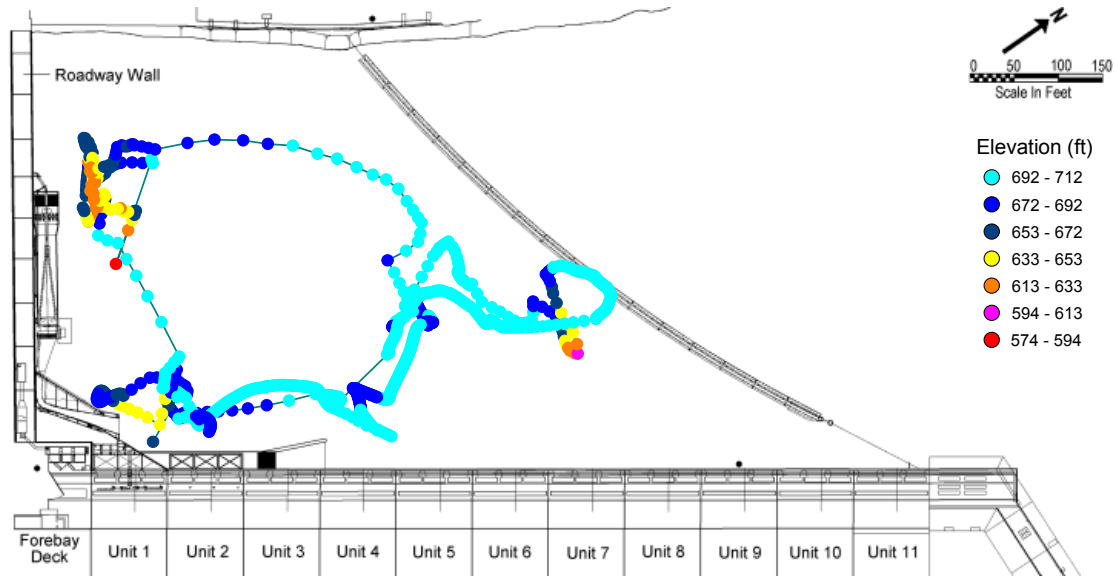
Species:	Chinook	Residence Time:	43 min
Type of Release:	Afternoon	Passage Route:	Spill 4
Release Date:	5/11/00	Fish Length:	173 mm

Figure 7. Chinook swimming path exhibiting the straight path swimming behavior at Rocky Reach Dam in 2000.



Species:	Steelhead	Residence Time:	118 min
Type of Release:	Morning	Passage Route:	Unit 1
Release Date:	4/26/00	Fish Length:	195 mm

Figure 8. Steelhead swimming path exhibiting the entrance milling behavior at Rocky Reach Dam in 2000.



Species:	Steelhead	Residence Time:	748 min
Type of Release:	Morning	Passage Route:	Surface Collector 1
Release Date:	5/6/00	Fish Length:	194 mm

Figure 9. Steelhead swimming path exhibiting the circular milling behavior at Rocky Reach Dam in 2000.

Merging Flow Data with Fish Travel Data

The fish swimming data was merged with the water velocity and acceleration data. The water velocity and acceleration data came from the kinematic model developed for Chelan County PUD (Hay and Company 1999 and HTI 1999). The water velocity is represented by color, with the blue color shades corresponding to 0-1 ft/sec (0-0.3 m/sec in the figure), the green color shades 1-2.5 ft/sec (0.3-0.8 m/sec), and the yellow/red color shades 2.5-3 ft/sec (0.8-1.0 m/sec).

Figure 10 shows the path of a steelhead smolt released on the afternoon of 21 May 1999. This fish followed the water velocity contour of 2.5 ft/sec downstream to the Surface Collector 2 entrance, and then milled in front of Surface Collector 2. It traversed west across the forebay to the slower water velocity (< 1 ft/sec) and circled along the roadway wall until it ultimately passed into Unit 1. Figure 11 shows the path of a steelhead smolt released on the morning of 13 May 1999. This fish followed the water velocity contour of 2.5 ft/sec downstream to near the entrance to Surface Collector 2. It then traveled perpendicular to water flow and ultimately entered Unit 1.

CONCLUSIONS

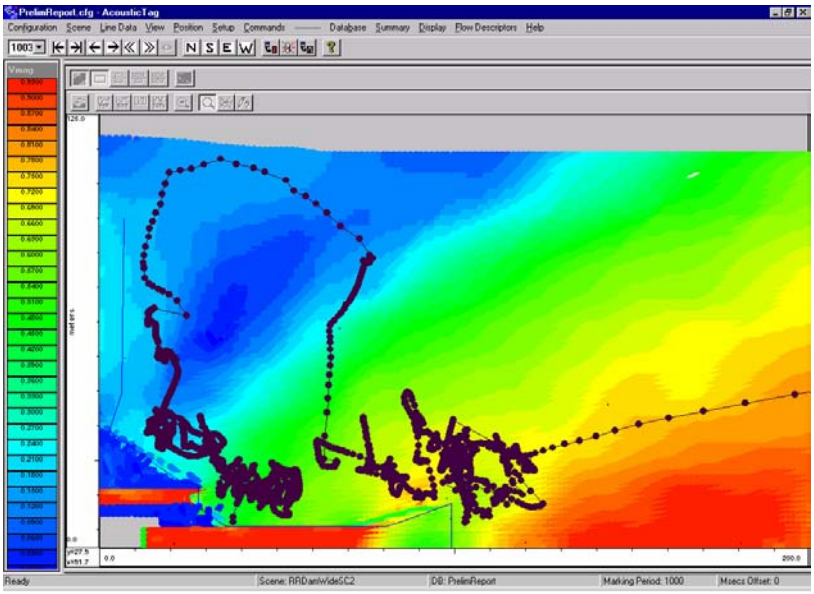
In 1999, a total of 344 fish were tagged, released, and tracked. Of these fish, there were 207 chinook (108 released during the spring and 99 released during the summer), 134 steelhead, and three northern pike minnows. In 2000, a total of 425 fish were tagged and released, comprised of 213 chinook and 212 steelhead.

The proportion of chinook passage for all of the various passage locations showed that Surface Collector 1 passed the largest proportion with 21%. Unit 1 passed 8% and Unit 4 passed 9% of the tagged chinook smolts. The proportion of steelhead passage for all of the various passage locations showed that Surface Collector 1 passed the largest proportion with 36%. Unit 1 passed 15% of the tagged steelhead smolts.

The proportion of tagged chinook juveniles passing through the powerhouse and surface collectors was 86% as compared to those fish passing through the spillway (14%). The proportion of tagged steelhead juveniles passing through the powerhouse and surface collectors was 90% as compared to those fish passing through the spillway (10%).

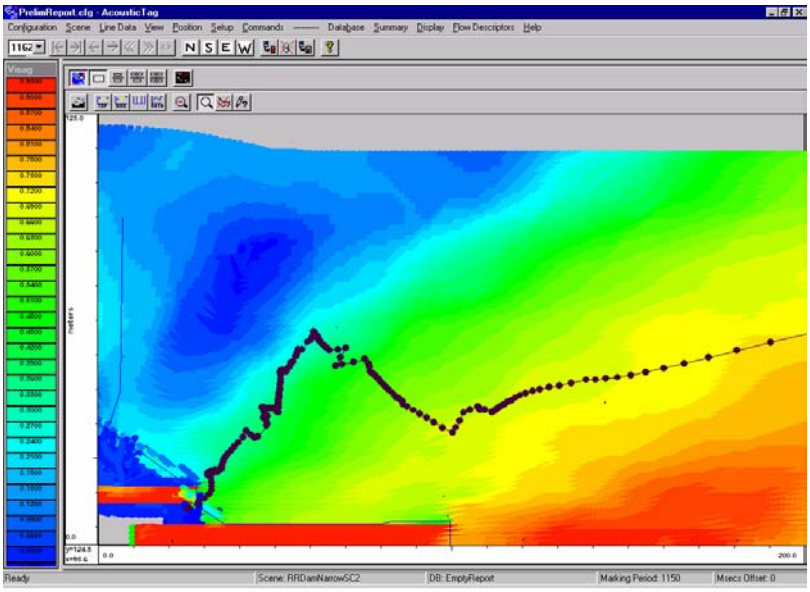
In general, the chinook passage was variable throughout the daytime hours, with the peak passage occurring at 2300 h. The peak chinook passage was followed by low chinook passage from 0100 h to 1000 h. The steelhead passage gradually increased from 0100 h to 1800 h with the peak passage at 2100 h.

Tagging fish with acoustic tags is a powerful tool for monitoring salmon behavior, especially in front hydroelectric projects. Combining the behavioral results with hydraulic data provides information about environmental cues to which the fish are reacting.



Species:	Steelhead	Residence Time:	97 min
Type of Release:	Afternoon	Passage Route:	Unit 1
Release Date:	5/21/99	Fish Length:	198 mm

Figure 10. Steelhead swimming path overlaid by the water velocity contours as it approaches the powerhouse at Rocky Reach Dam in the spring of 1999.



Species:	Steelhead	Residence Time:	9 min
Type of Release:	Morning	Passage Route:	Unit 1
Release Date:	5/14/99	Fish Length:	182 mm

Figure 11. Steelhead swimming path overlaid by the water velocity contours as it approaches the powerhouse at Rocky Reach Dam in the spring of 1999.

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