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Prepared for the U.S. Department of Energy
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FINAL REPORT

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September 2009

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Summary

This report documents the results of a steelhead kelt (*Oncorhynchus mykiss*) passage study conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers Portland District, Portland, Oregon at Bonneville Dam in early spring of both 2007 and 2008. The second powerhouse at Bonneville Dam (B2) has a surface flow outlet (SFO), termed the "corner collector" (B2CC), which has been operated routinely since 2004 as a route for juvenile salmonids to pass the dam during downstream migration. Because surface flow outlets readily pass juvenile salmonid migrants, they may also be an effective non-turbine passage route for steelhead kelt moving downstream in early spring before the main juvenile emigration season. B2CC operation, however, reduces the amount of discharge by 5,200 cfs available for hydropower production. The goal of this project was to inform management decisions regarding B2CC operations by estimating the number of kelt using the B2CC for downstream passage at Bonneville Dam prior to the juvenile spring migration season. We performed hydroacoustic studies from March 2 to April 10, 2007 and from March 13 to April 15, 2008. The study objectives for both years were as follows:

1. Fish Passage – For each year, measure the hourly passage rates of kelt-sized fish[1] moving downstream into the B2CC and apply these data to

- estimate the total number and daily rate of kelt passage
- estimate run timing and diel temporal distributions and vertical spatial distributions immediately upstream of the B2CC.

2. Fish Behavior – Characterize kelt swim paths and behaviors immediately upstream of the B2CC.
3. Interpretive Data – Interpret fish passage and behavior data relative to ancillary data on

- kelt passage observed in the Juvenile Bypass System,
- passage of kelt tagged with passive integrated transponders in the B2CC conveyance channel,
- hydraulic conditions in the B2CC forebay.

We used a fixed-location hydroacoustic technique to estimate passage rates. Six side-looking split-beam transducers were arrayed vertically and deployed from a barge anchored to the dam south of the B2CC entrance. The transducers were aimed across and slightly downstream of the region immediately upstream of the weir to sample steelhead kelt passage into the B2CC. In 2008, we used acoustic imaging technology (Dual Frequency Identification Sonar (DIDSON)) to describe kelt swim paths and behavior.

Estimates of steelhead kelt passage were 174 (± 8, 95% confidence interval) and 223 (± 7, 95% confidence interval) fish during the 2007 and 2008 sampling periods, or 4 and 7 fish per sample day, respectively. Run timing on a daily basis was sporadic, with daily passage ranging from 0 to 18 fish per day in 2007 and 0 to 31 fish per day in 2008. Fish were observed passing the dam from the beginning of the sampling periods in early March through the end of sampling in mid-April. Annual passage peaks occurred on April 8, 2007, and April 5, 2008. Diel distributions were variable with no distinct patterns

[1] Kelt-sized fish were defined as fish with a mean target strength less than -36 dB || 1μPa at 1 m. This corresponds to a fish length of about 35 cm (Love, RH. 1971. "Dorsal aspect target strength of an individual fish." J. Acoustical Soc. Amer. 49:816-832.).

apparent either year. The time periods with highest passage were 1100 to 1200 during 2007 and 1800 to 1900 during 2008. The 2007 vertical distribution of fish was somewhat skewed toward the surface, with the highest passage proportion (0.29) in the surface stratum (2 to 5 ft) and the lowest (0.09) in the deepest stratum (20 to 25 ft), out of the five depth strata analyzed. During 2008, the passage proportion in the 10-to-15-ft depth stratum was highest (0.43), whereas the shallowest depth stratum (3 to 5 ft) had the lowest passage proportion (0.14) of the four depth strata analyzed. During the same period in 2007 and 2008, 16 and 5 adult steelhead, respectively, passed through the B2 Juvenile Bypass System (JBS) while 4 and 17, respectively, were detected at the B2CC using passive integrated transponders (PIT).

A total of 172 kelt-sized targets were observed in the DIDSON™ videos. Of the 172 kelt observed, 83 passed through the region ensonified by the DIDSON™ into the B2CC, while the other 89 were viewed swimming toward the B2CC, but subsequently swimming back upstream away from the B2CC entrance. DIDSON™ imaging showed that flows in front of the B2CC were too high for kelt to mill around, so fish either passed quickly into the B2CC or fought the flows to move back upstream. As a result of our inability to track the fish that moved back upstream, we do not know whether these fish eventually passed into the B2CC or by an alternate route. All salmon smolt detected passed into the B2CC.

Interpretive data include counts of kelt in the JBS and detections of PIT-tagged steelhead kelt in the B2CC channel, along with hydraulic data from computational fluid dynamics modeling. During our sampling periods in 2007 and 2008, 16 and 5 steelhead kelt, respectively, were counted passing through the B2 JBS. During 2003, before the B2CC was installed, 595 steelhead kelt were counted in the JBS. During the 2007 and 2008 study periods, 4 and 17 steelhead kelt, respectively, tagged with passive integrated transponders were detected in the B2CC conveyance channel, confirming that kelt were passing through the B2CC surface flow outlet.

The computational fluid dynamics model data showed that when most B2 units were in operation, a large eddy formed on the south side of the forebay upstream of the B2CC entrance. Water at the face of the southern half of the B2 powerhouse moved directly toward the B2CC. This hydraulic pattern concentrates fish horizontally and increases the opportunity for fish to discover the B2CC flow net.

The B2CC, which has been known to effectively pass smolt with high survival (~100%; Counihan et al. 2006), is also likely a safe passage route for steelhead kelt, although a steelhead kelt survival study at the B2CC has not been conducted. Indeed, steelhead kelt passage at the B2CC is another example of the benefits of creating surface flow outlets as non-turbine routes to pass salmonids through a dam. All 13 dams on the mainstem Columbia and Snake rivers have installed or are developing surface flow outlets to pass juvenile salmonids. Fisheries and hydrosystem managers are responsibly considering the use of these structures to deter adult salmonids from passing through hydropower turbines.

Preface

This study was funded as part of the Anadromous Fish Evaluation Program (AFEP) for the U.S. Army Corps of Engineers (USACE). The study was funded to support management decisions on operations of Bonneville Dam. The AFEP study codes are ADS-00-1 (Evaluation of adult salmon and steelhead delay and fallback at dams on the Snake and Columbia rivers and ADS-P-00-6 (Evaluation of steelhead kelt passage through the Columbia and Snake river dams). The study was conducted by the Pacific Northwest National Laboratory (PNNL) for the USACE Portland District, whose technical lead was David Clugston (503-808-4751). The PNNL project manager was Mark Weiland (509-427-5923). The data are archived at PNNL offices in North Bonneville, Washington. The final version of this report is the project deliverable (PNNL Project No. 52785).

Acknowledgments

The authors are thankful to all who contributed to this study, including the following:

- Portland District personnel at Bonneville Dam: Jon Rerecich, Ben Hausman, Tammy Mackey, and the Rigging Crew
- Portland District personnel at the Portland District: Dave Clugston, Mike Langeslay, Bob Wertheimer
- PNNL: Ross Carper, Aaron Cushing, Dennis Dauble, Susan Ennor, Eric Fischer, James Hughes, Julie Hughes, Tyrell Monter, Mike Parker, Matt Wilberding, and Shon Zimmerman
- Precision Acoustic Systems: Alan Wirtz.

Acronyms and Abbreviations

AFEP	Anadromous Fish Evaluation Program
B1	Bonneville Dam First Powerhouse
B2	Bonneville Dam Second Powerhouse
B2CC	B2 Corner Collector
BON	Bonneville Dam
CFD	computational fluid dynamics
cfs	cubic feet per second
d	day(s)
DART	Data Access in Real Time
dB	decibel(s)
DIDSON	Dual Frequency Identification Sonar
EL	elevation
fps	feet per second
ft	foot/feet
h	hour(s)
JBS	Juvenile Bypass System
kcfs	thousand cubic feet per second
kHz	kiloHertz
m	meter(s)
min	minute(s)
msl	mean sea level
NMFS	National Marine Fisheries Service
PAS	Precision Acoustic Systems
PIT	passive integrated transponder
PITAGIS	PIT Tag Information System
PNNL	Pacific Northwest National Laboratory
pps	pings per second
PSMFC	Pacific States Marine Fisheries Commission
s	second(s)
SFO	surface flow outlet
μPa	micro-Pascal
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

This report documents the results of a steelhead (*Oncorhynchus mykiss*) kelt passage study conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers Portland District, Portland, Oregon (Portland District) at the Bonneville Dam Second Powerhouse (B2) during early spring 2007 and 2008. The goal of the study was to quantify the rate of kelt passage into the B2 Corner Collector (B2CC) to inform management decisions on its operation.

1.1 Background

The Portland District of the U.S. Army Corps of Engineers is committed to increasing survival rates for salmonids passing its projects on the Columbia River. This commitment includes steelhead kelt. These adult salmonids spawn in freshwater areas and then repeat the downstream migration to marine waters and back, unlike salmon, which die after spawning. Repeat spawning is called iteroparity. Successful downstream migration of iteroparous steelhead, however, may be limited by migration delay and passage events associated with navigating through hydroelectric dams (Wertheimer and Evans 2005). Bonneville Dam, the lowermost hydroelectric project on the Columbia River, is the only project in the Federal Columbia River Power System that impacts both winter (ocean-maturing) and summer (stream-maturing) steelhead varieties (Busby et al. 1996). Studies indicate that both steelhead varieties spawn in tributaries of the Bonneville Dam pool from December to April (Howell et al. 1985; McMillan 2001; Bair and Weiman 1995), prior to the onset of operations to pass juvenile salmon at Bonneville Dam in April. Because some steelhead outmigrate immediately after spawning (Shapovalov and Taft 1954), providing optimal migration routes through Bonneville Dam should enhance return rates from these fish (Wertheimer and Evans 2005). However, operation of non-turbine passage routes such as the spillway and surface flow outlets (sluiceway of the Bonneville First Powerhouse [B1] and B2CC) reduces the potential for hydropower production. The goal of this study was to quantify the extent to which kelt use the B2CC prior to the onset of operations for the juvenile salmon passage season. The data will be used by river and resource managers to prescribe operations for the B2CC in early spring.

The National Marine Fisheries Service (NMFS) recognized the potential value of kelt for achieving rebuilding goals for steelhead (NMFS 2008) and has mandated that research be conducted to evaluate and reduce dam passage mortality of kelt. The study reported here addressed Reasonable and Prudent Alternative 53, which presented the following instructions to the Portland District: "…*In addition to current operations (generally April 10 – August 31), evaluate operation of the Bonneville PH2 corner collector from March 1 through start of spill as a potential means to provide a safer downstream passage route for steelhead kelt, and implement if warranted.*"

1.2 Study Periods and Objectives

The study periods were from March 2 through April 10, 2007 and from March 13 through April 15, 2008. The study objectives were as follows:

1. Fish Passage – For each year, measure the hourly passage rates of kelt-sized fish moving downstream into the B2CC and apply these data to

- estimate the total number and daily rate of kelt passage

- estimate run timing and diel temporal distributions and vertical spatial distributions immediately upstream of the B2CC.

2. Fish Behavior – Characterize kelt swim paths and behaviors immediately upstream of the B2CC.
3. Interpretive Data – Interpret fish passage and behavior data relative to ancillary data on

- kelt passage observed in the Juvenile Bypass System
- passage of kelt tagged with passive integrated transponders in the B2CC conveyance channel
- hydraulic conditions in the B2CC forebay.

1.3 Study Area

We conducted the study in the immediate forebay of the B2CC at Bonneville Dam. Bonneville Dam consists of a complex set of concrete structures and islands approximately 146 miles from the mouth of the Columbia River (Figure 1.1). Moving from the Oregon shore to the Washington shore (south to north), the dam's concrete structures include a large navigation lock, a small lock, B1, a spillway, and B2. Bradford Island separates B1 and the spillway. Cascades Island separates the spillway from B2. Adult fishways (ladders) are positioned at the northern ends of B1 and B2 and the northern and southern ends of the spillway (four total fishway entrances). Exits from the adult fishways are located on the south side of Bradford Island and the Washington shore.

Bonneville Dam is located in a natural and man-made braided channel area (Figure 1.1). Upstream of the dam about 1 mile, the river channel is narrow (~1,000 ft wide). Then, the river splits into three main channels: B1, spillway, and B2. B1 is at the end of a relatively narrow forebay channel and is thus largely isolated from the other passage routes. The B2 forebay is influenced more by spillway operations than the B1 forebay because of B2's proximity to the spillway. At the dam, the river is about 1 mile wide. Approximately 1 mile downstream, the three channels merge and the river is relatively narrow again (~1,200 ft wide).

From 1998 through 2003, the original ice and trash sluice chute at B2 was developed into a surface flow outlet (B2CC) for juvenile salmonids because of the substandard fish guidance efficiency of the intake screen bypass system at B2 (e.g., Monk et al. 1999). The B2CC design was based on observations by Portland District and various fisheries agency biologists that forebay hydraulic patterns appeared to concentrate fish in a prominent eddy in the forebay of the sluice chute. A new entrance gate, conveyance channel, and outfall were also developed (Johnson et al. 2008). This bioengineering effort culminated in the B2CC (Figure 1.2).

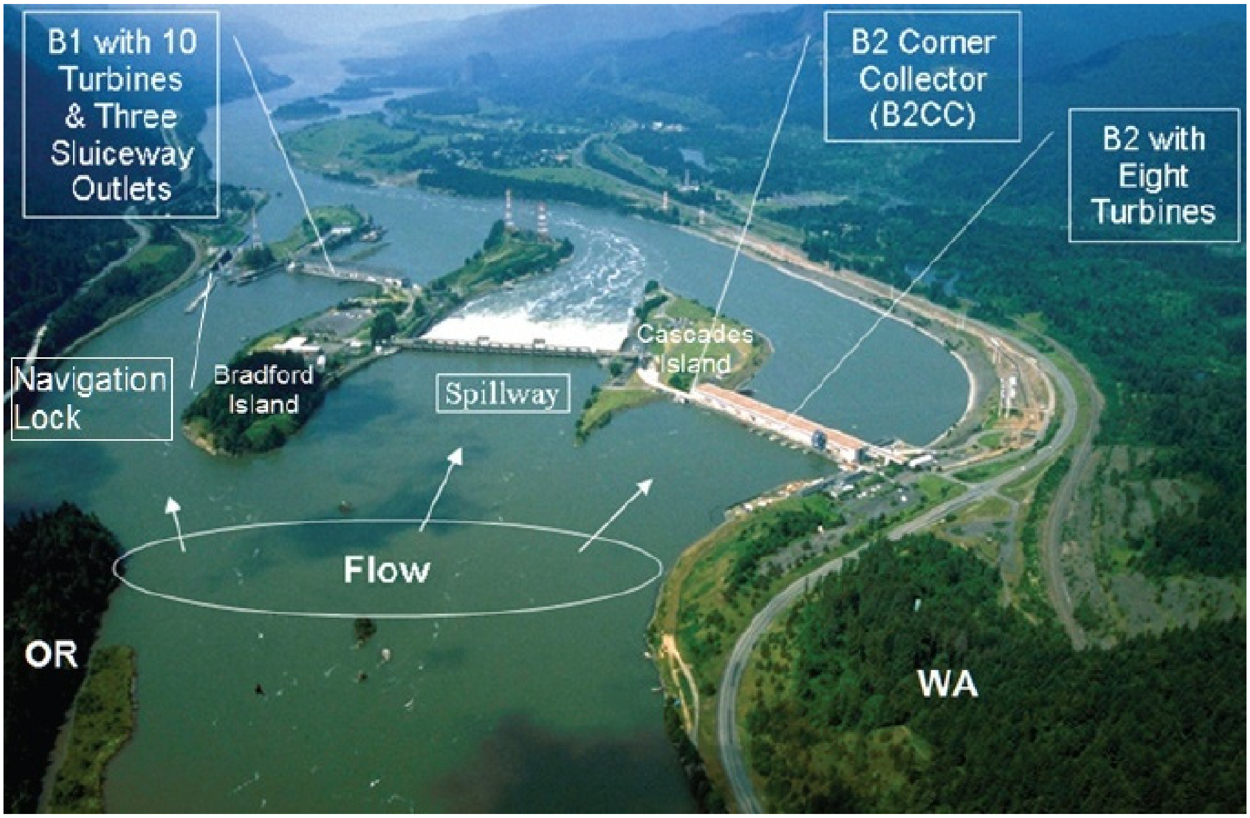

Figure 1.1. Plan Diagram of Bonneville Dam Showing the Location of the B2CC. The view is downstream (east to west). (Photo obtained with permission from Ploskey et al. [2007].)

Figure 1.2. Aerial Photograph of the B2CC. Shown are the location of the entrance in the forebay, the conveyance channel along Cascades Island, and the outfall 0.5 miles downstream of B2. (Photo obtained with permission from Sweeney et al. [2007])

The characteristics of the B2CC include the following: entrance flow of ~5,200 cfs (depending on forebay elevation), mean entrance velocity ~15 fps at the weir (EL 52 ft above msl), and entrance dimensions 15 ft wide and 23 ft deep. The rating curve (forebay elevation versus discharge) is shown in Figure 1.3. The equation[1] for the relationship between forebay elevation and B2CC discharge is as follows:

$$B2CC\ Q = \frac{27.404 * \left(\left(FBAY\ ELEV - 52 \right)^{1.6817} \right)}{1000} \tag{1.1}$$

[1] Based on personal communication with L. Ebner, U.S. Army Corps of Engineers, Portland District.

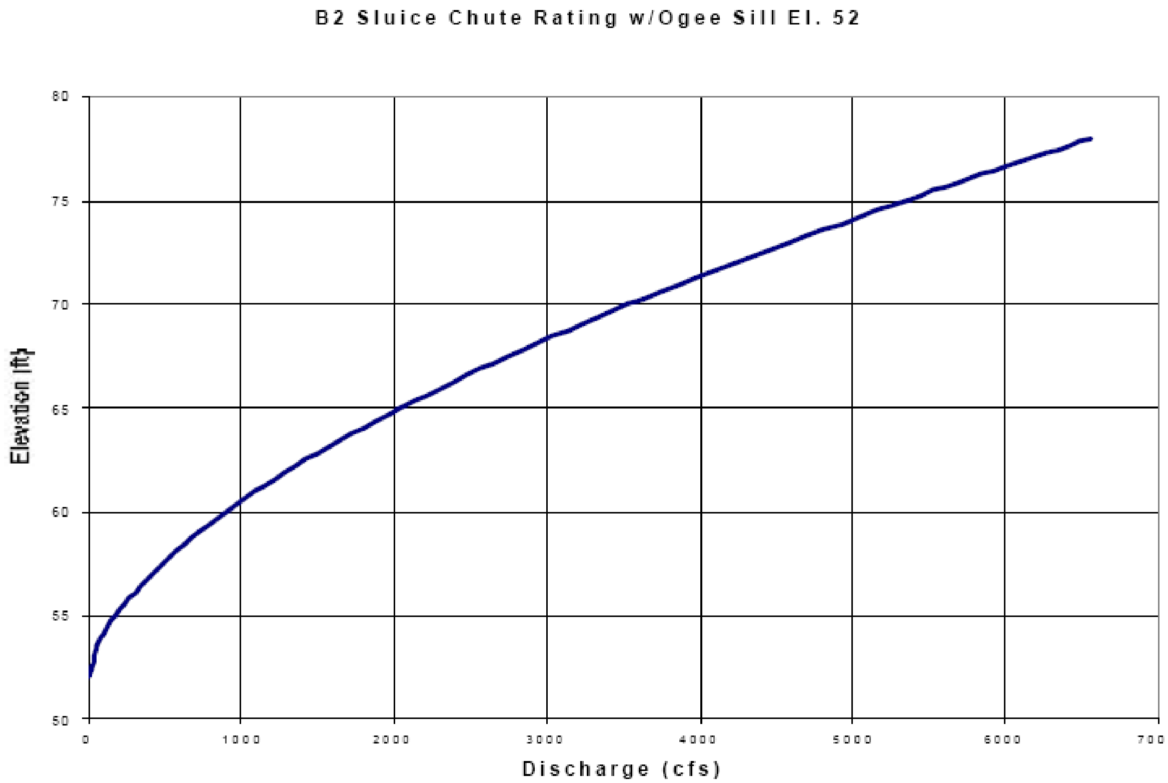

Figure 1.3. B2 Sluice Chute Rating Curve (Graph provided by L. Ebner, Portland District)

1.4 Report Contents

The ensuing sections of this report contain study methods (Section 2), results (Section 3), discussion and conclusions (Section 4), and literature cited (Section 5). There are no appendices.

2.0 Methods

The methods section includes descriptions of the general approach, fixed-location hydroacoustics for fish passage, acoustic imaging for fish behavior, and PIT and hydraulic data to aid data interpretation.

2.1 General Approach

During the study, we collected and analyzed B2CC kelt-passage data from multiple sources. We used fixed-location hydroacoustic techniques (Thorne and Johnson 1993) to collect and analyze fish passage data and acoustic imaging techniques (Belcher et al. 1999) to characterize fish behavior. In both cases, instruments were deployed in the B2CC forebay adjacent to Cascades Island (Figure 2.1) such that hydroacoustic sample volumes were positioned immediately upstream (within 10 m) of the B2CC weir.

We also obtained data regarding river conditions (Data Access in Real Time [DART]; http://www.cbr.washington.edu/dart/), detections of PIT tags in fish (PIT Tag Information System [PITAGIS]; http://www.psmfc.org/), and hydraulic conditions from computational fluid dynamics (CFD) modeling results.

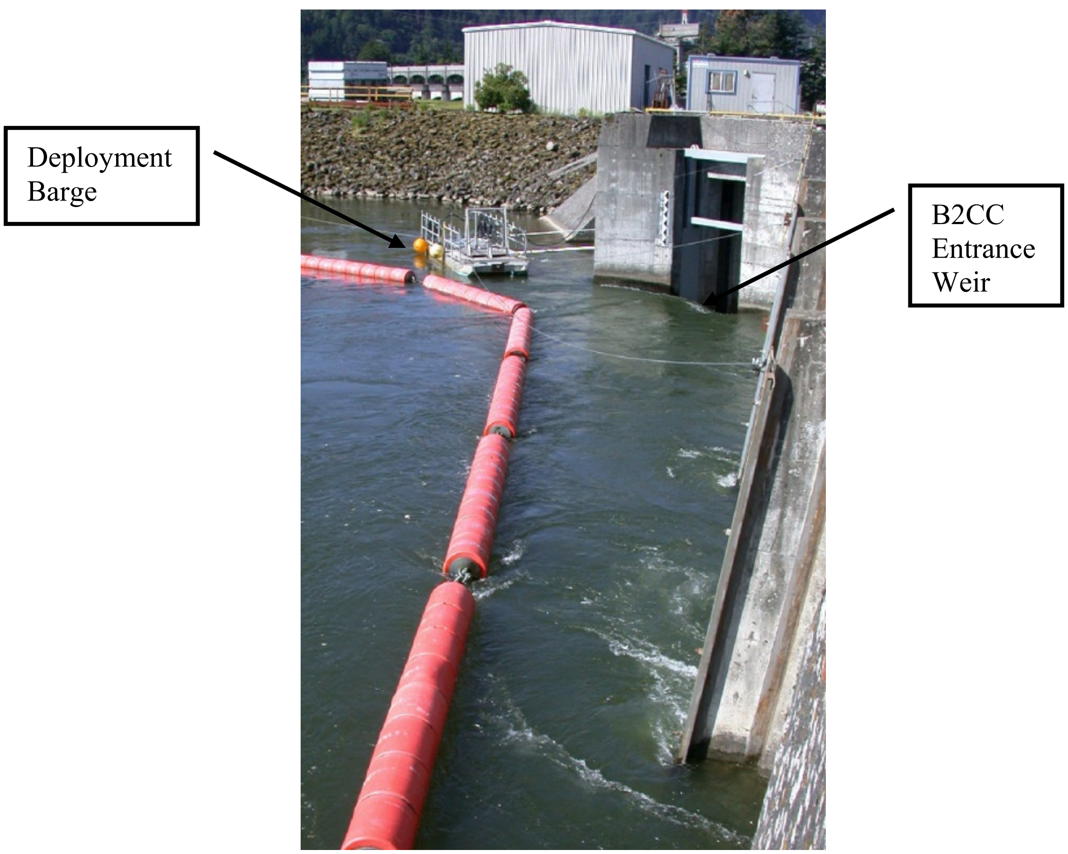

Figure 2.1. Forebay of the B2CC Showing the Surface Flow Outlet Entrance Weir and the Deployment Barge (Photograph courtesy of G. Ploskey, PNNL.)

2.2 Fish Passage

In this section, we describe hydroacoustic systems used for sampling fish passage, transducer locations and orientations, detectability of fish passage, data collection, data processing, and analysis.

2.2.1.1 Hydroacoustic Systems

We sampled kelt entering the B2CC with hydroacoustic equipment using the same methods used in 2004 and 2005 to monitor smolt passage (Ploskey et al. 2005). Data collection involved the use of three Precision Acoustic Systems (PAS) split-beam hydroacoustic systems, all of which operated at 420 kHz. The data collection systems had Harp-SB (split beam) Data Acquisition/Signal Processing software installed on a personal computer controlling a PAS-103 Multi-Mode Scientific Sounder. The PAS-103 sounders controlled transducers deployed from a barge. Six split-beam transducers were installed. All systems used a -56 dB (re: 1 µPa at 1 m) voltage output threshold. Echo sounder transmission rates were 33 pings per second (pps).

2.2.1.2 Transducer Locations and Orientations

The transducers were arranged on a vertical pipe (Figure 2.2) on a barge (Figure 2.1) positioned approximately 20 ft southeast of the entrance of the B2CC. The acoustic beams were aimed horizontally across the entrance (Figure 2.3); the pipe supporting a vertical array of six transducers was adjusted to aim the acoustic beams about 12 to 15 ft upstream of the entrance. Thus, fish were detected mostly in side-aspect, thereby maximizing signal-to-noise ratios and fish detection. The upper two split-beams had nominal 3-degree acoustic beams to minimize volume reverberation, which is typically worst near the surface. The lower four transducers had nominal 6-degree acoustic beams.

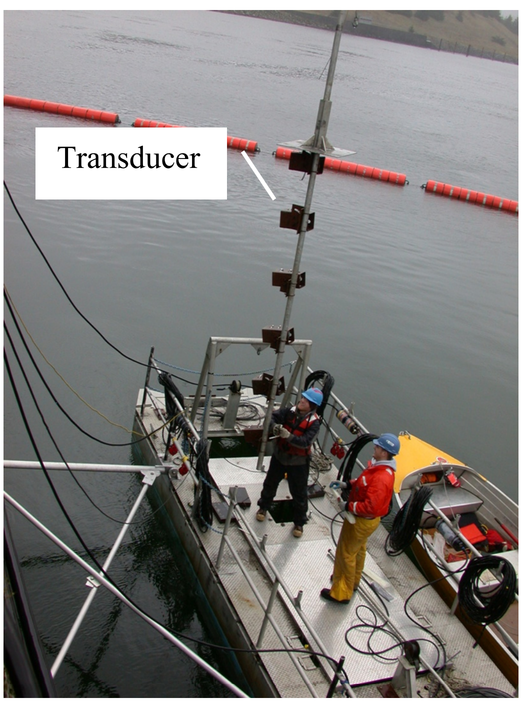

Figure 2.2. Vertical Array of Transducers

Whenever forebay elevations ranged from EL 74.1 to 76.0 ft, the deployment provided passage distribution data within eleven 1.85-ft vertical strata in the upper 20.35 ft of the water column and within one variable 1.85-to-3.75-ft stratum below that depth. When forebay elevations were between EL 70.5 and 74.1 ft, the deployment provided passage distribution data within 10 1.85-ft vertical strata in the upper 18.5 ft of the water column and within a 4.5-ft stratum below 18.5 ft. The vertical resolution was possible because tracked fish could be classified as being in the upper or lower one-half of a beam. Laterally, the deployment provided estimates of passage distribution to the nearest 0.5 ft across the 15-ft-wide entrance.

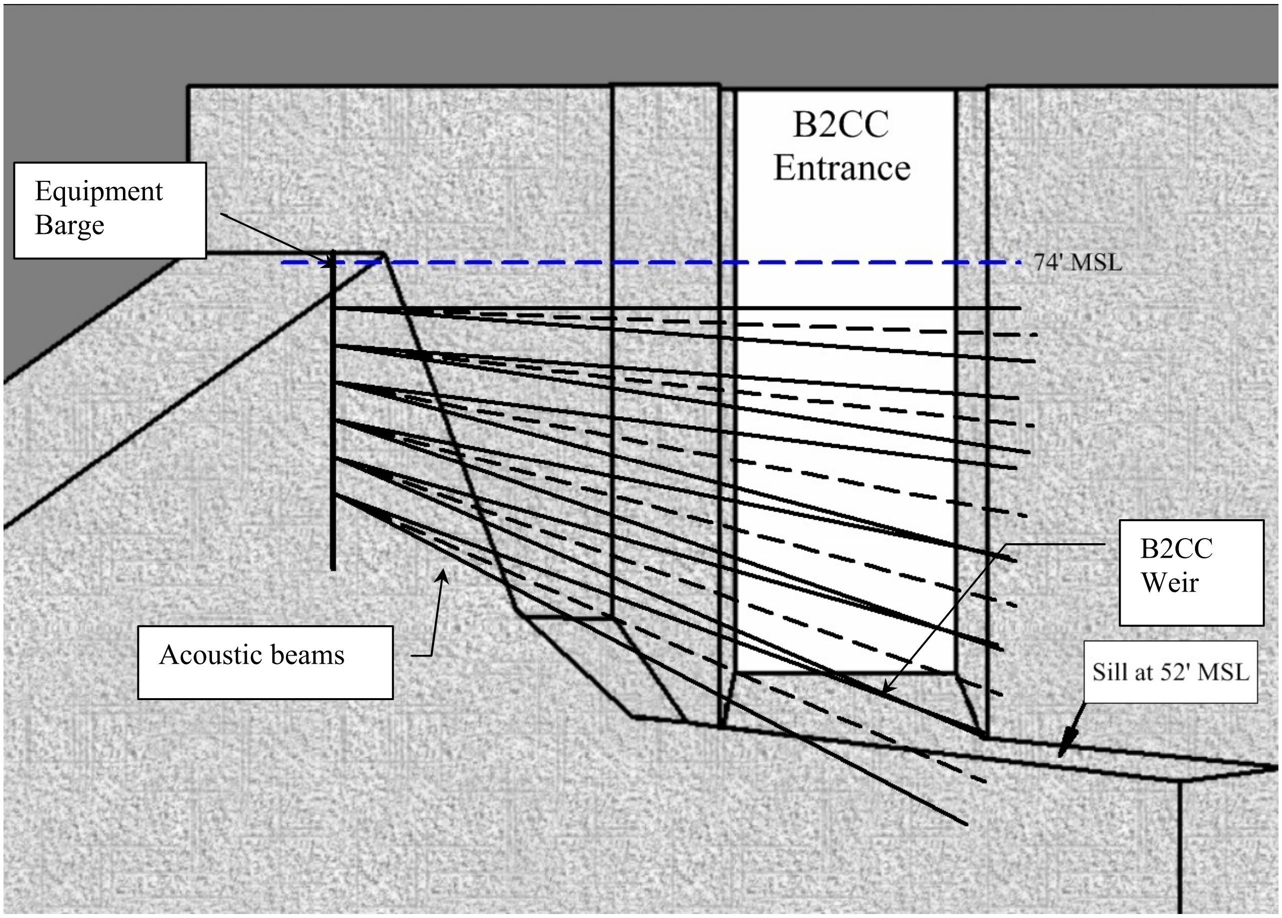

Figure 2.3. Schematic of a Front View of the B2CC Entrance. This figure shows the acoustic beams for six split-beam transducers deployed from a barge east of the B2CC entrance. Depending upon the beam, minimum and maximum ranges for tracking fish were ~4.6 and ~9.5 m, respectively.

2.2.2 Detectability

We sampled in locations with flow high enough entrain smolts and possibly kelt (8 to 10 fps) but low enough to allow adequate detectability. With a ping rate of 33 pps, a fish moving 10 fps through the center of an acoustic beam would provide 7 echoes if it passed into the entrance on the south side and 13 echoes if it passed on the north side of the intake. Four echoes are the minimum required to classify an echo trace as a fish.

2.2.2.1 Data Collection

Samples were collected systematically; i.e., same order among sampling locations each hour, at 1-min intervals 24 h/d. The clocks on the three hydroacoustic systems were synchronized using LANtastic®[1] networking software. The two transducers of each system were slow multiplexed at on minute intervals. Each location was sampled 30 times per hour.

[1] LANtastic is a registered trademark of Artisoft, Inc.

Data were downloaded daily. Files were backed up and archived such that at least two copies were stored in separate locations.

2.2.2.2 Data Processing and Analysis

After the acoustic echo data were collected and archived at the field site, they were processed in order to extract fish tracks. At this stage in the analysis, we were careful to set the tracking parameters to include all fish at the expense of including spurious tracks. Next, to separate acceptable from unacceptable tracks, we filtered the data using fish track characteristics such as speed. The data were quite “noisy” because of hydraulic vortices at comparable target strengths to kelt-sized targets. Therefore, we deleted tracks with mean target strengths greater than -25 dB and smaller than -36 dB; this corresponds to a range in fork length of about 35 to 115 cm (Love 1971). Thus, while the general data processing and reduction process was similar to that used by Ploskey et al. (2005), we applied custom-designed filters for this study. Technicians manually checked the data to assure that valid fish tracks were included (Figure 2.4).

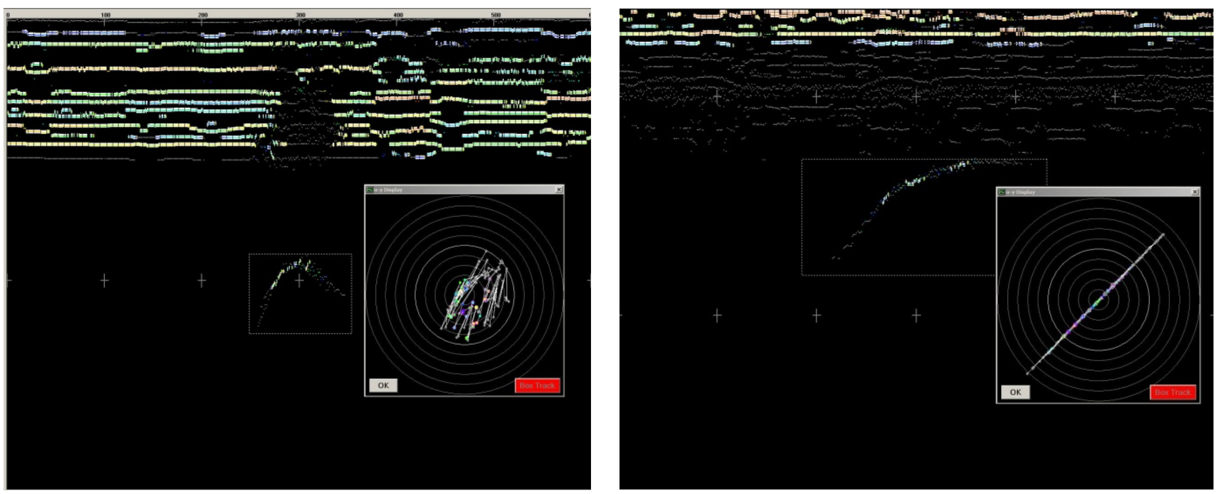

Figure 2.4. Example Echograms With Fish Tracks: Actively Swimming Target (Left) and Passive Target (Right). The inset boxes show the movements of the target in a barrel view of the transducer beam. The left box shows the target moving back and forth in the beam, indicating swimming fish. The right box shows the target moving straight through the beam, indicating passive drift of debris. The lines at the top of each echogram are echoes from the concrete side wall of the B2CC entrance.

The process we used to estimate passage rates from filtered tracked fish involved spatial and temporal extrapolations. Briefly, each fish track that survived the filtering process was weighted spatially to account for the sample width of the acoustic beam at the target’s mid range relative to the width of the depth bin it sampled; i.e., fish passage at unsampled portions of the B2CC entrance was estimated by extrapolating from the sampled areas. The sum of these weighted fish was then extrapolated temporally by the hourly sampling fraction (60/total hourly sample time per location).

The hourly passage rate data for each transducer were used to estimate various performance metrics, including fish passage distribution at the spillway. Equations for each estimator follow.

Let x_{ijky} be the expanded fish passage count in the i^{th} transducer ($i = 1,...,6$) during the j^{th} hour ($j = 1,...,24$) of the k^{th} day ($k = 1,...,d_y$) during y^{th} year, where d_y is the number of study-days in the y^{th} year (2007 or 2008).

Total kelt passage for the y^{th} year was estimated by the formula

$$\hat{TP}_y = \sum_{i=1}^{6}\sum_{j=1}^{24}\sum_{k=}^{d_y} x_{ijky} \tag{2.1}$$

Daily kelt passage for the y^{th} year for analysis of run timing was estimated by the formula

$$\hat{DP}_{ky} = \sum_{i=1}^{6}\sum_{j=1}^{24} x_{ijky} \tag{2.2}$$

Hourly kelt passage for the y^{th} year for analysis of diel distribution was estimated by the formula

$$\hat{HP}_{jy} = \sum_{i=1}^{6}\sum_{k=1}^{d_y} x_{ijky} \tag{2.3}$$

Vertical kelt passage for the y^{th} year for analysis of vertical distribution was estimated by the formula

$$\hat{VP}_{iy} = \sum_{j=1}^{24}\sum_{k=1}^{d_y} x_{ijky} \tag{2.4}$$

2.3 Fish Behavior

We used a DIDSON acoustic camera mounted on a barge located southeast of the B2CC entrance to record kelt swim paths and behaviors immediately upstream of the B2CC. We used methods similar to those used in 2004 to evaluate passage of salmon smolt into the B2CC (Ploskey et al. 2005). The DIDSON™ camera was oriented across the intake just upstream of the weir and aimed in the same direction as the hydroacoustic transducers but sampled a different proportion of the water column (Figure 2.5). A rotator was used to adjust the orientation of the camera relative to the B2CC entrance because of changes in forebay water level. Data was collected in high resolution mode. Frame rate was 9 frames/s.

The behavioral data from the DIDSON™ video files were processed manually during playback of the recordings. For each fish in the beam, we identified direction of travel, common movement patterns, behavior, and movement duration. This analysis was descriptive, and all DIDSON™ videos were processed.

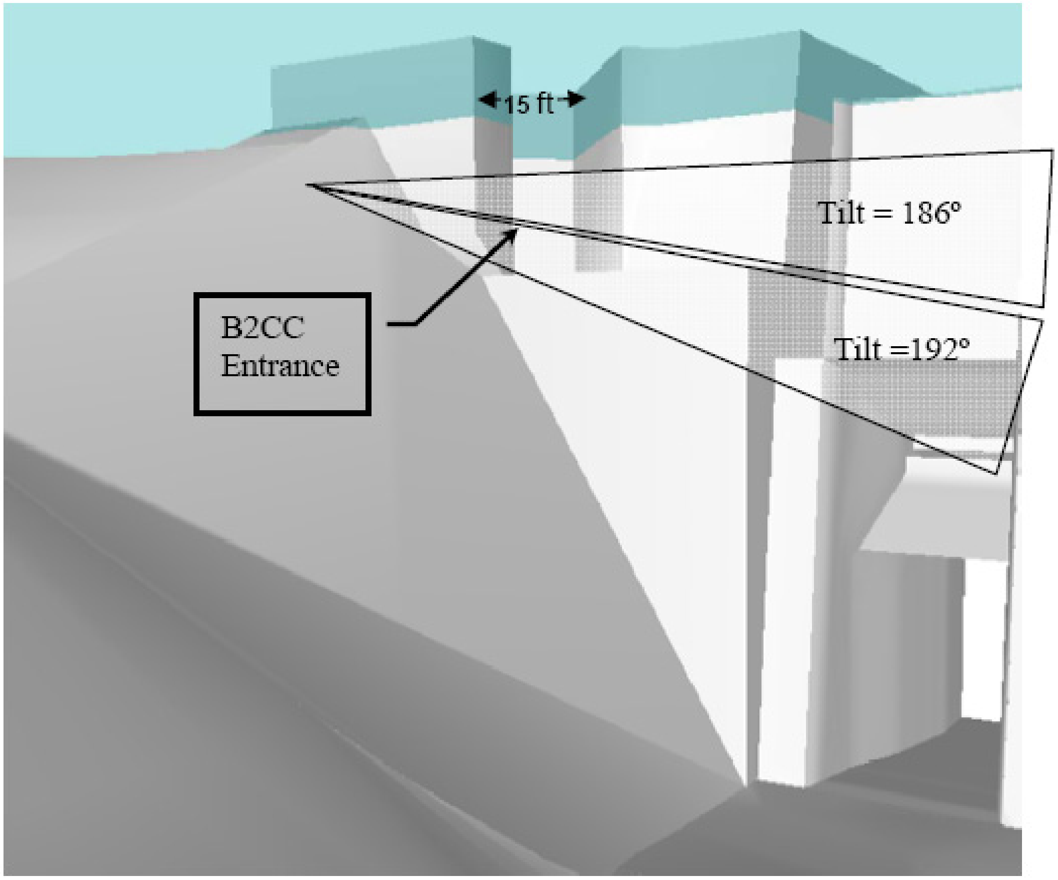

Figure 2.5. Orientation of the DIDSON™ Camera Sample Volume Relative to the B2CC Entrance. The DIDSON™ camera was mounted on the same barge as described above for fixed-location hydroacoustics and aimed in two different vertical aiming angles, 6º (tilt 186º) and 12º (tilt 192º) off horizontal, respectively.

2.4 Interpretive Data

We obtained PIT tag detection data from PITAGIS (http://www.psmfc.org/) on kelt passage in the B2 JBS and the B2CC conveyance channel. In addition, D. Ballinger (Pacific States Marine Fisheries Commission [PSMFC]) provided data on counts made by observers at the B2 JBS facility. These data confirm whether or not steelhead kelt were passing B2 during the 2007 and 2008 study periods.

Forebay flow fields were quantified and visualized using outputs from a three-dimensional CFD model developed as part of other Portland District studies (Rakowski et al. 2001 and 2005) and were provided by the PNNL Hydrology Group. A commercially available CFD code, STAR-CD,[1] was used to perform the simulations. The model included the full Bonneville project forebay (B1, B2, and spillway) and the approach channel extending approximately one mile upstream of the dam. An unstructured computational mesh consisting of about 1.5 million cells was used. The model was validated by comparing simulated velocities with velocities measured in the field using an acoustic Doppler current profiler.

[1] STAR-CD is a product of CD-adapco.

3.0 Results

After a description of environmental conditions below, the study results are organized by objective: fish passage, fish behavior, and interpretive data.

3.1 Environmental Conditions

Total river discharge at Bonneville Dam ranged from ~145 to ~300 kcfs during the 2007 kelt passage study (Figure 3.1). During the 2008 study, total discharge was ~120 to ~200 kcfs (Figure 3.2). During 2007, spill discharge (10 to 80 kcfs) occurred from March 20 through April 6. During both the 2007 and 2008 studies, regular spill (100 kcfs) for juvenile salmonids started on April 10.

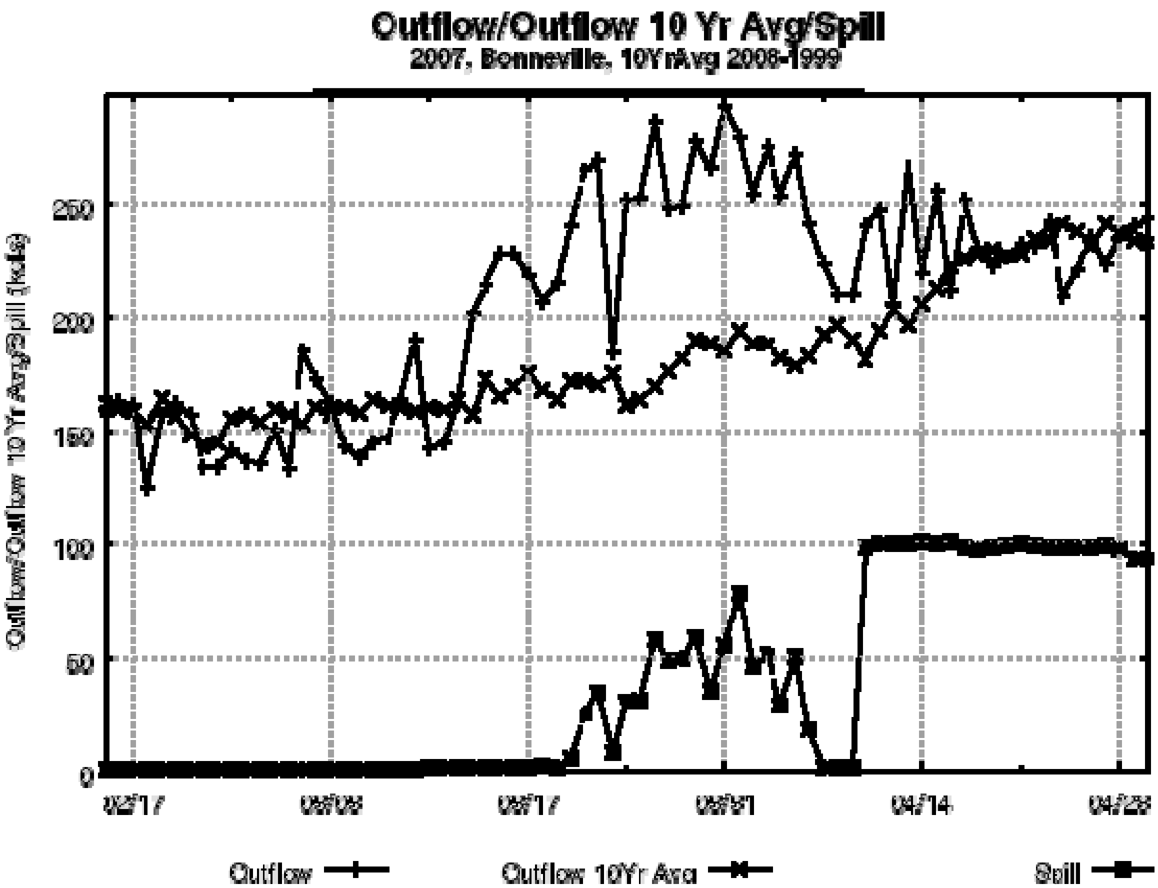

Figure 3.1. Total Outflow, 10-Year Average Outflow, and Spill Discharges (kcfs) at Bonneville Dam During Early Spring 2007. The thick line at the top of the graph indicates the study period. (Figure from Columbia River DART, School of Aquatic & Fishery Sciences, University of Washington (http://www.cbr.washington.edu/ dart/dart.html), accessed on January 13, 2009.)

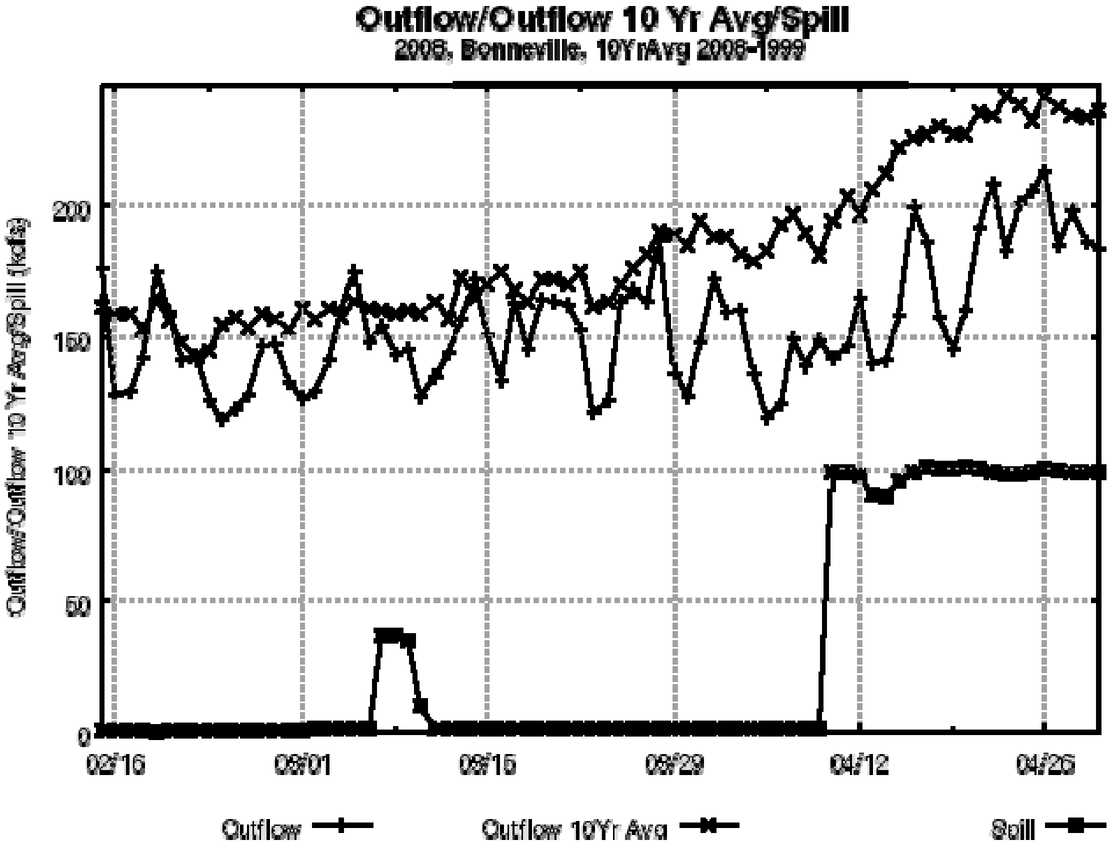

Figure 3.2. Total Outflow, 10-Year Average Outflow, and Spill Discharges (kcfs) at Bonneville Dam During Early Spring 2008. The thick line at the top of the graph indicates the study period. (Figure from Columbia River DART, School of Aquatic & Fishery Sciences, University of Washington (http://www.cbr.washington.edu/ dart/dart.html), accessed on January 13, 2009.)

During both 2007 and 2008, B2 was the priority powerhouse; i.e., B2 was operated to capacity and any excess water beyond that routed to B2 and the spillway was discharged through B1. At B2, the turbine units were operated in the following order of priority (high to low): 11, 18, 15, 12, 17, 14, 13, and 16. The submersible traveling screens in the B2 turbine intakes were in place during the studies, but the turbine intake extensions were not.

During the 2007 study period, discharge at the B2CC ranged from 3.96 to 5.86 kcfs with a mean of 5.01 kcfs (Figure 3.3a). Forebay elevation averaged 74.1 ft above msl and ranged from 71.3 to 76.6 ft above msl (Figure 3.3a).

During the 2008 study period, discharge at the B2CC ranged from 0 to 5.86 kcfs with a mean of 4.93 kcfs (Figure 3.3b). Forebay elevation averaged 74.6 ft above msl and ranged from 72.43 to 76.3 ft above msl (Figure 3.3b).

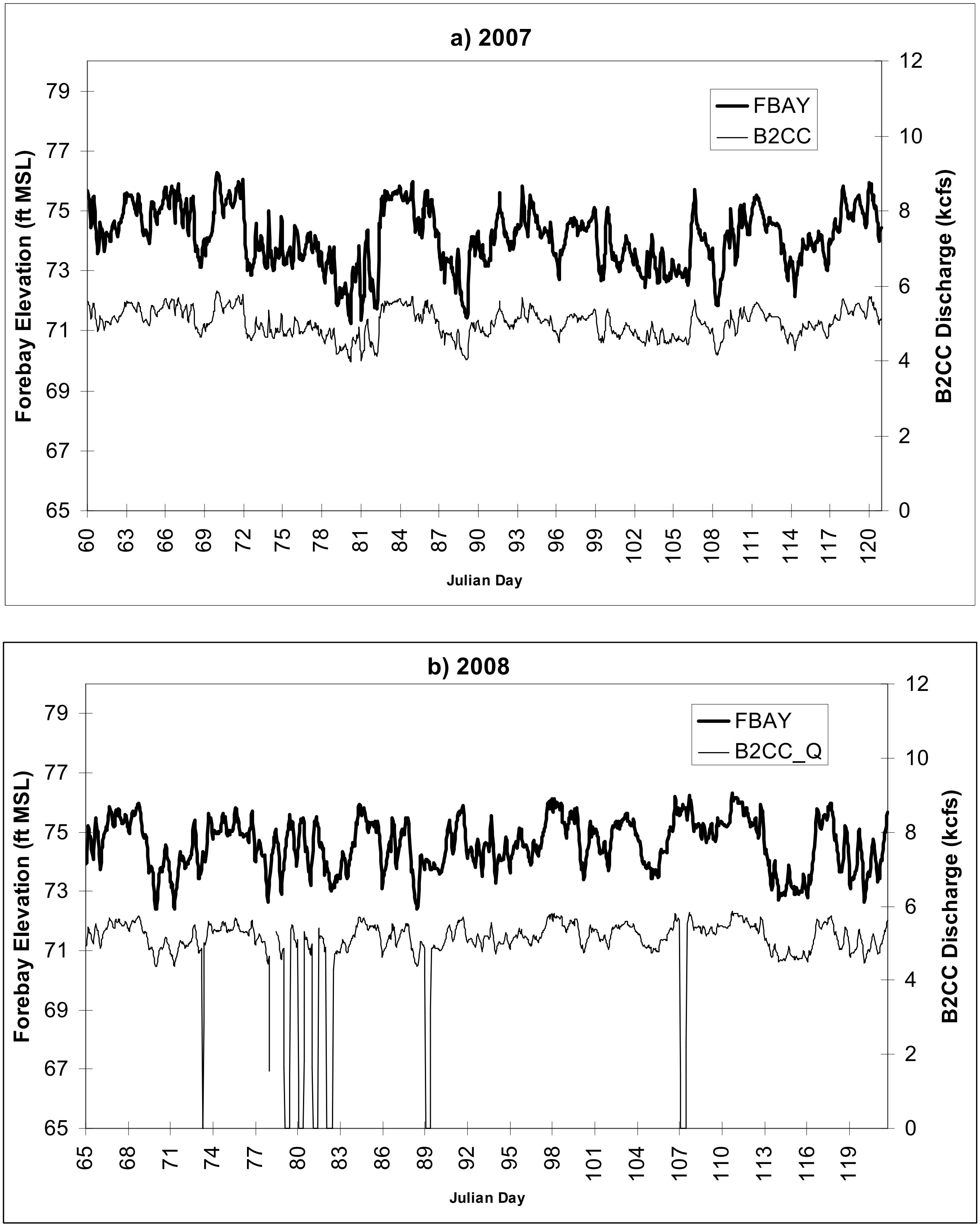

Figure 3.3. Forebay Elevation (Ft Above Msl) and B2CC Discharge (Kcfs) During Study Periods a) 2007 and b) 2008

3.2 Fish Passage

Fish passage results include fish target characteristics, total passage estimates, run timing, diel distribution, and vertical distribution.

3.2.1 Fish Target Characteristics

For the 2007 and 2008 studies, 79 and 129 fish targets were used in the respective analyses (Table 3.1). The mean number of echoes per track was 10 for 2007 and 17 for 2008. The mean speed was 6.63 fps in 2007 compared to 3.12 fps in 2008. Mean target strengths, however, were comparable between years at about -28 dB. Other statistics for echo count, speed, and target strength are presented in Table 3.1.

The frequency distributions were uni-modal during both 2007 and 2008 (Figure 3.4). The 2008 data were more skewed to the large target strengths than the 2007 data. The target strength distributions indicate that we were sampling the kelt-sized fish of interest.

Table 3.1. Fish Target Characteristics

	Echo Count		Speed (fps)		Mean Target Strength (dB)	
	2007	2008	2007	2008	2007	2008
Mean	9.55	16.46	6.63	3.12	-28.78	-28.03
Standard Error	1.07	1.13	0.56	0.23	0.23	0.18
Median	6.00	13.00	5.15	2.30	-28.70	-27.63
Kurtosis	16.40	5.70	-2.66	12.14	-0.22	-0.16
Skewness	3.51	2.09	2.13	6.23	-0.28	-0.75
Range	61	69	16.60	13.88	8.84	9.28
Minimum	4	4	0.26	0.20	-33.87	-34.41
Maximum	65	73	16.86	14.07	-25.03	-25.13
Count	76	129	76	129	76	129

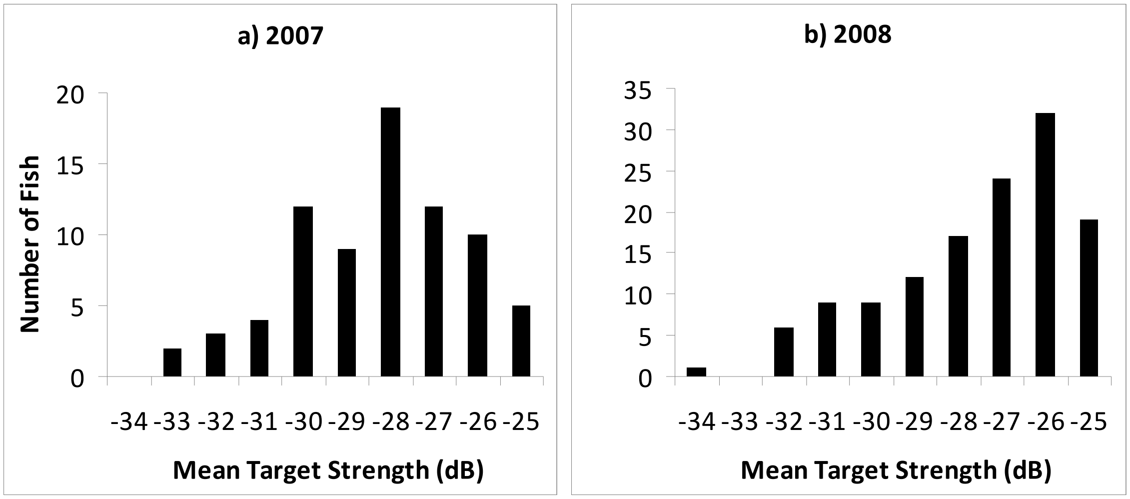

Figure 3.4. Frequency Distributions of Mean Target Strength for a) 2007 and b) 2008. Descriptive statistics for these distributions are contained in Table 3.1.

3.2.2 Total Passage and Passage Rates

The number of kelt-sized fish targets per year estimated to have passed into the B2CC during early spring 2007 and 2008 ranged from 172 to 223 (Table 3.2). The mean number of kelt-sized fish passing per day was 4 to 7 fish (Table 3.2).

Table 3.2. Total Kelt-Sized Fish Passage (with 95% confidence interval) and Mean Daily Passage Rates During the 2007 and 2008 Study Periods

	2007 (March 2 through April 10)	2008 (March 13 through April 15)
Total Passed During Study Period	172 ± 8	223± 7
Mean Number Passed per Study-Day	4	7

3.2.3 Run Timing

Run timing, expressed on a daily basis, was sporadic (Figure 3.5). Daily passage ranged from 0 to 18 fish per day in 2007 and 0 to 31 fish per day in 2008. Kelt-sized targets were detected passing into the B2CC on the first day of each study year. In both 2007 and 2008, the highest daily passage rates were observed during April.

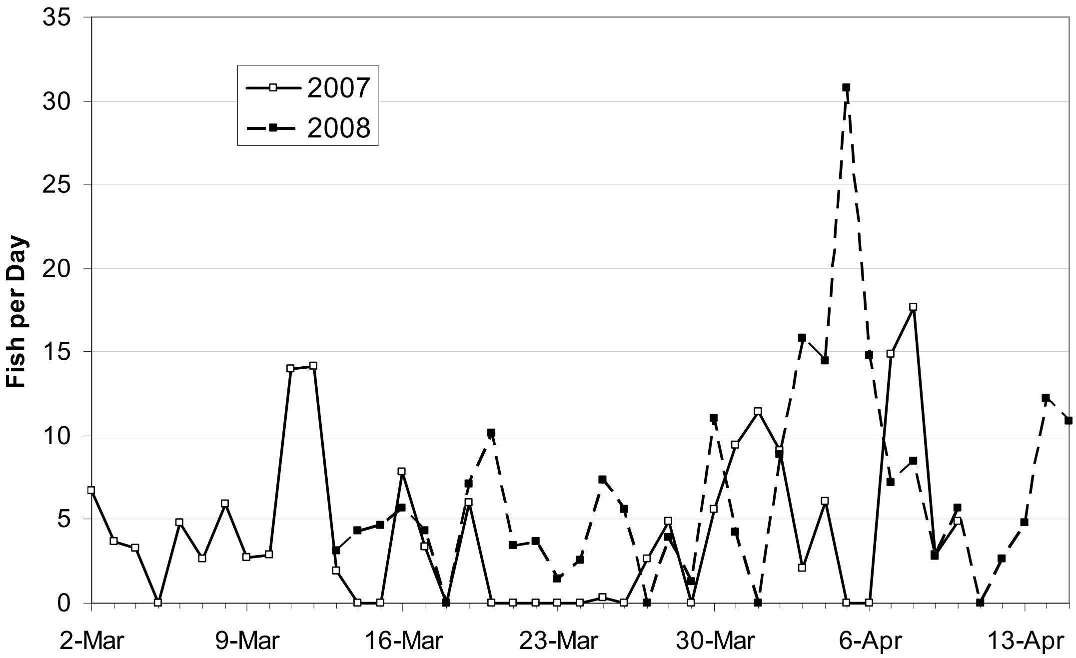

Figure 3.5. Run Timing for Steelhead Kelt at B2CC During Early Spring 2007 and 2008

3.2.4 Diel Distribution

Diel distributions were variable, with no distinct patterns apparent during either year (Figure 3.6). During 2007, the highest hourly proportion of kelt-sized fish passage occurred between 1100 and 1200. During 2008, the highest hourly passage proportion occurred between 1800 to 1900.

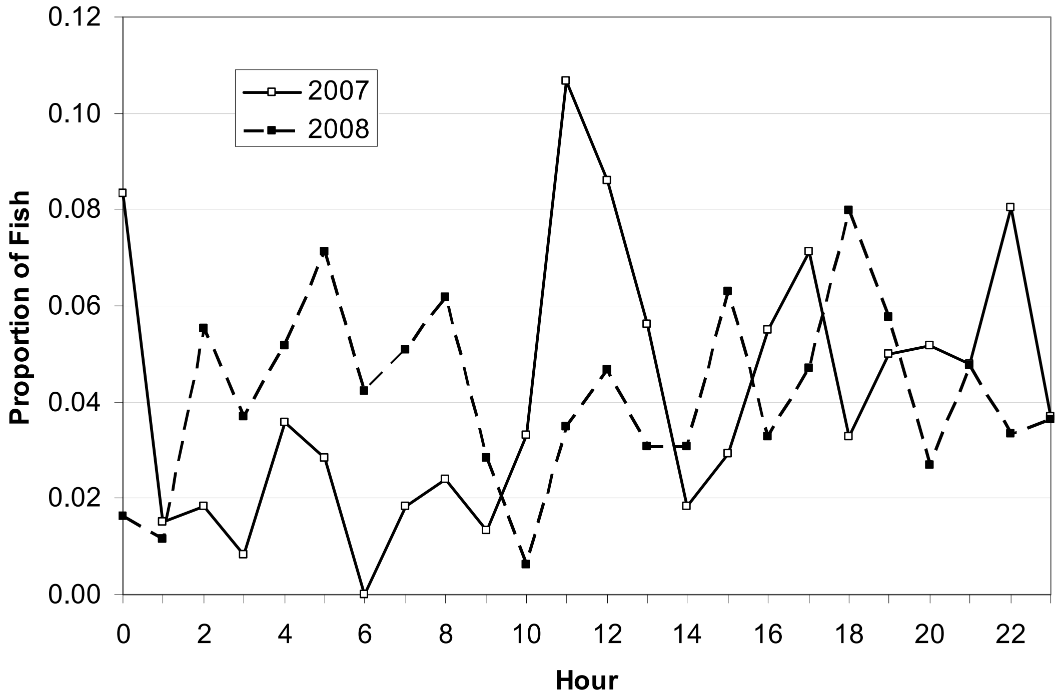

Figure 3.6. Diel Distribution for Steelhead Kelt at B2CC During Early Spring 2007 and 2008

3.2.5 Vertical Distribution

The 2007 vertical distribution of kelt-sized fish was somewhat skewed toward the surface with the highest passage proportion in the surface bin and the lowest in the deepest bin (Figure 3.7). During 2008, the passage proportion in the 1015-ft depth bin was highest, whereas the shallowest depth bin had the lowest passage proportion.

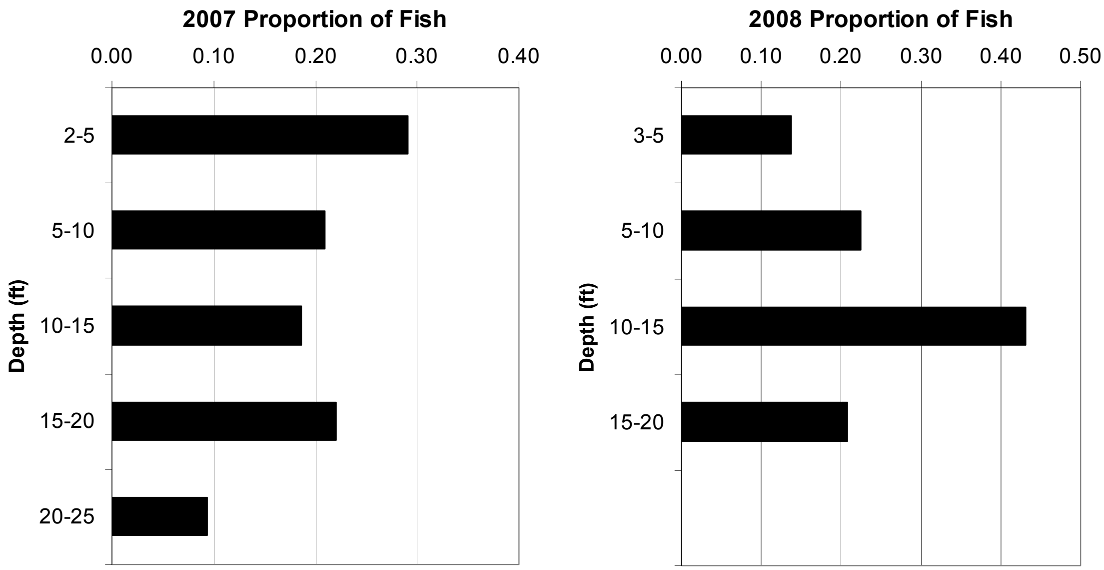

Figure 3.7. Vertical Distribution for Steelhead Kelt at B2CC During Early Spring 2007 and 2008

3.3 Fish Behavior

In 2008, a total of 172 kelt-sized targets were observed in the DIDSON™ videos. Figure 3.8 shows a single frame of a DIDSON™ video. The image is that of a kelt swimming upstream of the B2CC. Of the 172 kelt observed, 83 passed through the region ensonified by the DIDSON™ into the B2CC, while the other 89 were viewed swimming toward the B2CC, but subsequently swimming back upstream away from the B2CC entrance. The kelt passing back upstream spent more time in the DIDSON™ field of view than fish that passed into the B2CC (Figure 3.8). Fish swimming upstream generally put a lot of effort into swimming away from the B2CC entrance.

Some of the kelt moved back upstream soon after detecting flows of about 4 fps, while others did not begin fighting the flows until velocities were about 10 fps (Figure 3.9). As a result of the water velocity in front of the B2CC, no milling behavior was observed. Kelt approached the B2CC either from directly upstream of the B2CC or from Unit 11. Kelt approaching from upstream backed tailfirst downstream into the B2CC, whereas fish approaching from in front of Unit 11 approached headfirst until they detected the high flows in front of the B2CC. At this time, they turned and headed downstream tailfirst. Median time that kelt remained within the ensonified field of the DIDSON™ in the near field of the B2CC was 2 seconds for fish passing into the B2CC and 3 seconds for fish that did not pass. Maximum detection time for passed and unpassed fish was 8 and 27 seconds, respectively.

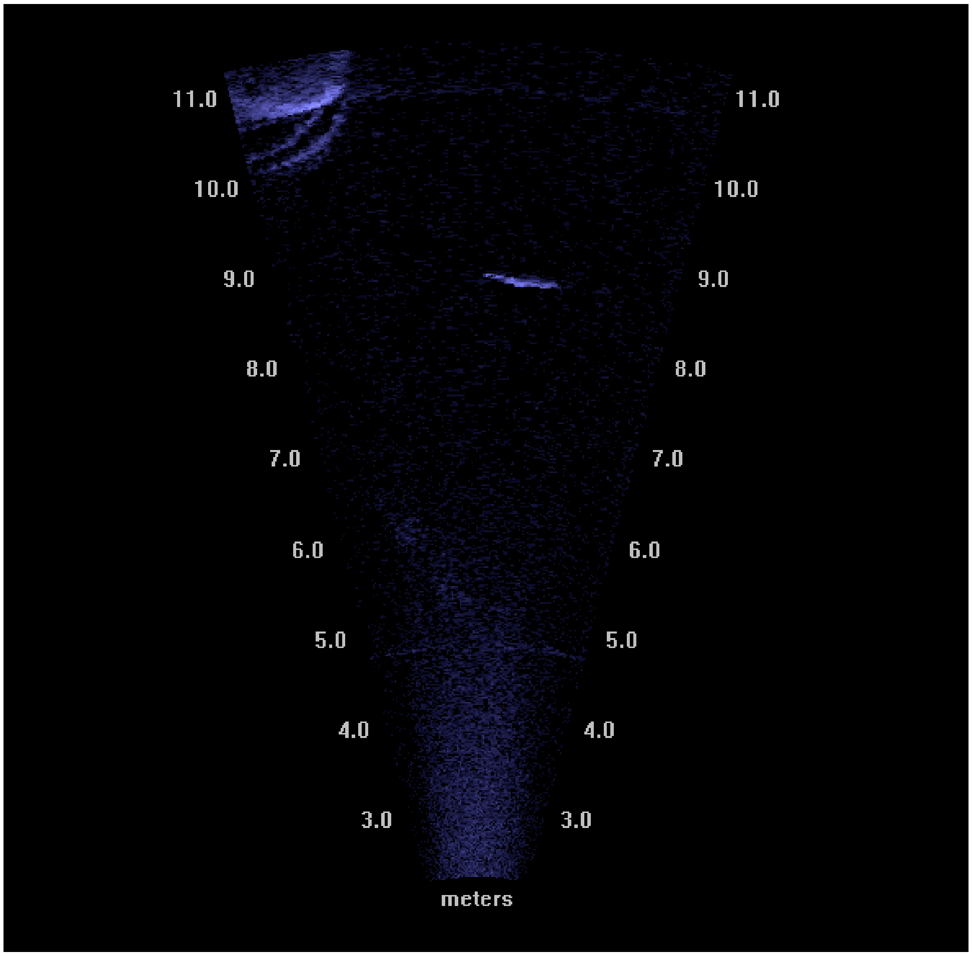

Figure 3.8. Single Frame From the DIDSON™ Video. The image shows a kelt at about 9 m range. The far corner of the B2CC is in the in the upper left corner of the image.

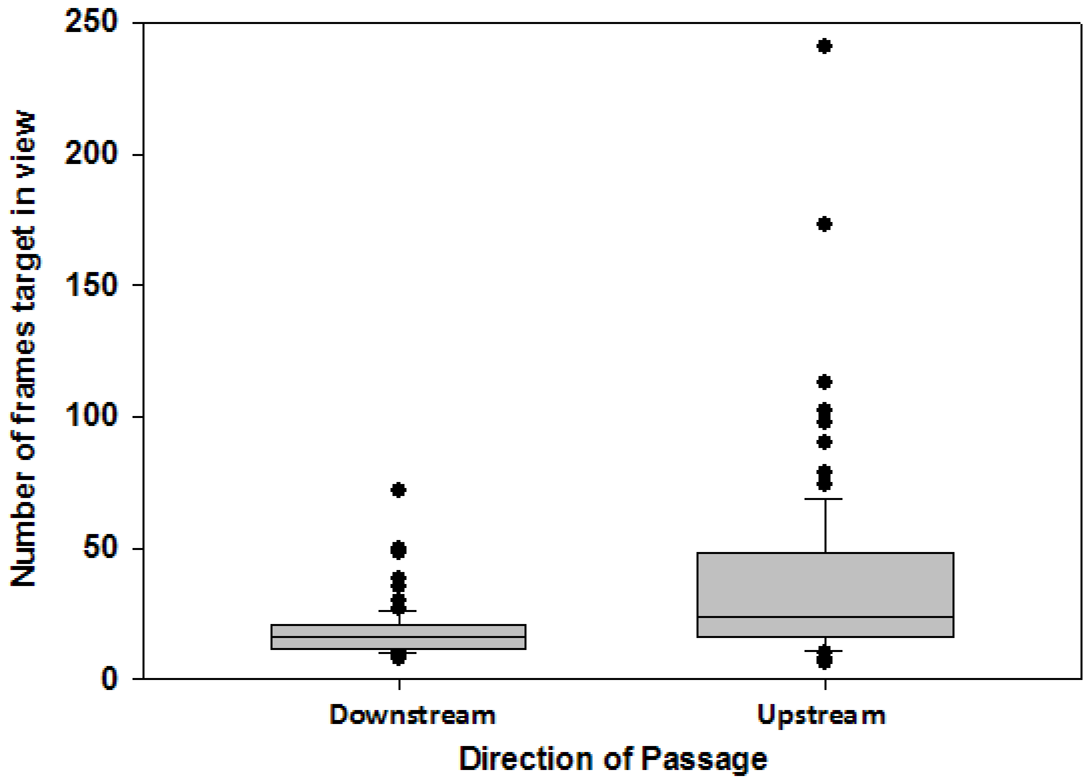

Figure 3.9. Plan Views of CFD Results (Water Velocity) From the B2CC Forebay. a) Units 11 and 17 on (~14 kcfs) and the others off; b) all units except Unit 16 on.

3.4 Interpretive Data

Interpretive data include counts of kelt in the JBS and detections of PIT-tagged steelhead kelt in the B2CC channel along with hydraulic data from CFD modeling. During our sampling periods in 2007 and 2008, 16 and 5 steelhead kelt, respectively, were counted passing through the B2 JBS (Table 3.3). During 2003, before the B2CC was installed, 595 steelhead kelt were counted in the JBS. During the 2007 and 2008 study periods, 4 and 17 PIT-tagged steelhead kelt, respectively, were detected in the B2CC conveyance channel.

Table 3.3. Steelhead Kelt Counts in the B2 JBS (Data courtesy of D. Ballinger, PSMFC)

Year	Adult Steelhead Count in the JBS
2003	595
2004	59
2005	160
2006	46
2007	16
2008	5

Contour plots of water velocity from the CFD model showed the rapid acceleration of flow near the B2CC weir (Figure 3.10). Flow patterns in the near field of the B2CC, and hence approach flows for fish, are dependent on B2 powerhouse operations; there is a forebay eddy when most units are on (Figure 3.10b) compared to the situation when only Units 11 and 17 are on (Figure 3.10a). During our study periods, six or seven of the eight B2 turbine units were usually on; hence, a strong eddy was present (Figure 3.10b).

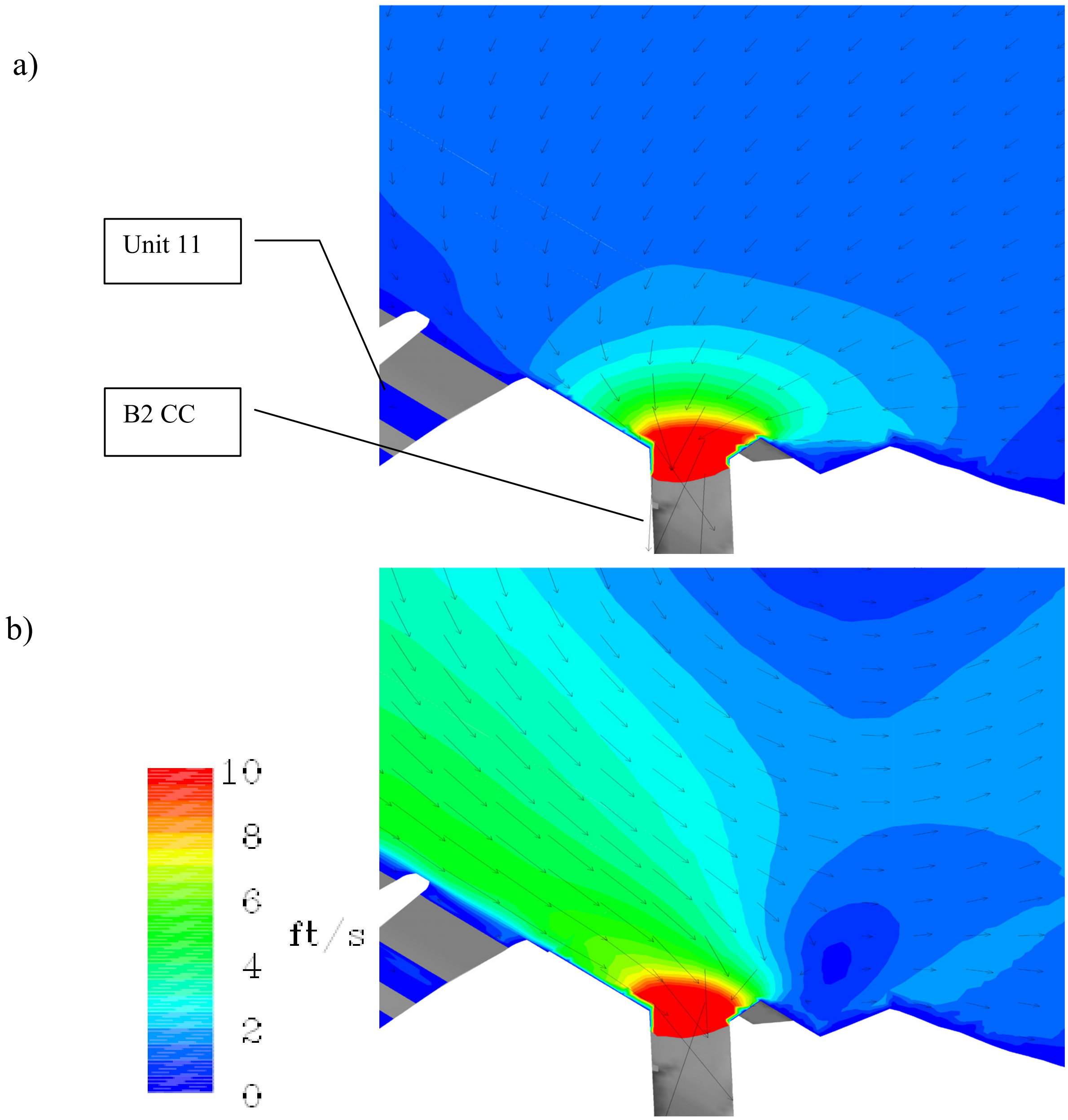

Figure 3.10. Plan Views of CFD Results (Water Velocity) From the B2CC Forebay. a) Units 11 and 17 on (~14 kcfs) and the others off; b) all units except Unit 16 on. Data are from a slice at EL 70 ft above msl. Scale: the width of the B2CC entrance is 15 ft. (Data provided by M. Richmond, PNNL Hydrology Group)

4.0 Discussion and Conclusions

Since 2004, the corner collector at the Bonneville Dam Second Powerhouse has been routinely operated as a surface flow outlet to pass juvenile salmonids. Because SFOs readily pass juvenile salmonid migrants (Johnson and Dauble 2006), they may also be an effective non-turbine passage route for steelhead kelt moving downstream in early spring before the main juvenile emigration season. Operation of the B2CC, however, reduces the amount of discharge (5,200 cfs) available for hydropower production. Thus, this study was designed to inform management decisions about B2CC operations by estimating the number of kelt using the B2CC for downstream passage at Bonneville Dam prior to the juvenile spring migration season.

We used a fixed-location hydroacoustic technique to estimate fish passage rates at the B2CC. This technique was useful because it enabled continuous sampling over time during the study periods. Furthermore, the array of transducers covered approximately 75% of the area of the B2CC entrance. The high level of temporal and spatial sampling minimized the variance in total passage estimates. The main difficulty in applying the hydroacoustic approach for detecting B2CC kelt passage was acoustic interference from turbulence caused by sporadic vortices in the B2CC flow net. We overcame this difficulty by using rigorous data filters based on target characteristics that differentiated between tracks from fish and those from turbulence. This process emphasized the exclusion of false positives, i.e., non-kelt tracks. Thus, this study's estimates of total kelt passage are conservative.

Estimates of steelhead kelt passage were 172 ± 8 and 223 ± 7 fish (95% confidence intervals) during the 2007 and 2008 sampling periods, or 4 and 7 fish per sample day, respectively. These values are consistent with counts from the B2 JBS, where a total of 595 kelt were counted during the entire kelt outmigration during 2003, before the new B2CC became operational. The dramatic reduction in bypass counts after the B2CC came online is strong circumstantial evidence that the B2CC is passing steelhead kelt. In fact, during the 2007 and 2008 study periods, many more steelhead kelt were detected passing into the B2CC entrance than were observed in the JBS. The detections of PIT-tagged kelt in the B2CC conveyance channel during the 2007 and 2008 study periods confirmed that kelt were passing through the B2CC SFO. Wertheimer (2007) estimated that over 80% of total kelt passage at B2 during spring 2004 was through the B2CC, corroborating the importance of the B2CC as a non-turbine passage route for downstream migrating steelhead kelt at Bonneville Dam.

Steelhead kelt daily passage was sporadic, with passage rates ranging from 0 to 18 and 0 to 31 fish per day in 2007 and 2008, respectively. Most importantly, kelt were observed passing the dam from the beginning of the sampling periods in early March through the end of sampling periods in mid-April, although passage peaks occurred in April each year. Operation of the B2CC during March resulted in passage of steelhead kelt.

Diel distributions were variable with no distinct patterns apparent for either year. The hours with highest passage were 1100 to 1200 h during 2007 and 1800 to 1900 h during 2008. Because a clear trend in diel passage was not evident, we cannot recommend a daily time period for opening the B2CC to pass kelt or conversely to save water by closing it.

DIDSON™ imaging showed that flows in front of the B2CC were too high for kelt to mill around and fish either passed quickly into the B2CC or fought the flows to move back upstream. As a result of our inability to track the fish that moved back upstream, we do not know whether these fish eventually passed into the B2CC or by an alternate route. As determined previously (Ploskey et al. 2005), the high flows at the B2CC entrain all salmon smolt in the near field of the entrance.

Hydraulic patterns in the B2CC forebay are conducive to passing steelhead kelt given that these fish seem to prefer surface routes compared to non-surface routes (Wertheimer 2007). The CFD model data showed that when most B2 units were in operation, a large eddy formed on the south side of the forebay upstream of the B2CC entrance. Water at the face of the southern half of the B2 powerhouse moved directly toward the B2CC. This hydraulic pattern concentrates fish horizontally and increases the opportunity for fish to discover the B2CC flow net (Sweeney et al. 2007). The relatively abrupt acceleration at the entrance weir entrained and passed kelt downstream.

The B2CC, which has been known to effectively pass smolt with a high rate of survival (~100%; Counihan et al. 2006), is also likely a safe non-turbine passage route for steelhead kelt, although a steelhead kelt survival study at the B2CC has not been conducted. The improvements to the old B2 sluice chute to create the B2CC included a new entrance gate with a larger opening to increase SFO discharge to 5,200 cfs, the addition of an ogee immediately downstream of the entrance weir to smooth the transition to the channel, a conveyance channel with smooth walls to minimize damage to fish, and a new high-flow outfall with a deep plunge pool and orientation at the end of Cascades Island to allow ready and safe egress in the tailrace (Johnson et al. 2008). These improvements should benefit steelhead kelt as well as they do for juvenile outmigrants, and increased survival of kelt during downstream passage may contribute positively to iteroparity rates (Wertheimer 2007).

Steelhead kelt passage at the B2CC is another example of the benefits of using SFOs as a non-turbine route to pass salmonids through a dam. All 13 dams on the mainstem Columbia and Snake Rivers have installed or are developing SFOs to pass juvenile salmonids. Fisheries and hydrosystem managers are responsibly considering the use of these structures to protect adult salmonids from hydropower turbines (NMFS 2008).

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