Boundary Hydroelectric Project (FERC No. 2144)

Study No. 12

Fish Entrainment and Habitat Connectivity Study

Interim Report

Prepared for
Seattle City Light

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Study No. 12: Fish Entrainment and Habitat Connectivity Study Interim Report Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Study No. 12, the Fish Entrainment and Habitat Connectivity Study, is being conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144. The Project is identified in the Revised Study Plan (RSP) submitted by Seattle City Light (SCL) on February 14, 2007 (SCL 2007), and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This is the interim report for the 2007 study efforts of the Fish Entrainment and Habitat Connectivity Study.

2 STUDY OBJECTIVES

The goal of the Fish Entrainment and Habitat Connectivity Study is to estimate the number, size, species, and timing of fish that may be entrained within the Project turbine intakes and spillways. The limited frequency, duration of use, and flow conditions associated with use of the sluiceways, and the discontinued use of the skimmer gate, reduce the need to quantify the number of fish potentially entrained through these pathways. For this reason, the assessment of the potential impact of fish entrainment at the Project will focus on entrainment through the turbine and spillway pathways (SCL 2007). Fish entrainment through the turbine and spillway pathways is being monitored at the Project from spring 2007 to spring 2009 to quantify potential impacts to the resource. Study results will be used to estimate the effects of powerhouse and spillway operations on hourly, daily, diel, and seasonal entrainment of fish at Boundary Dam.

Study 12 uses complementary hydroacoustic and net sampling techniques to describe fish passage through the Boundary powerhouse and spillways. Hydroacoustics provide high temporal and spatial coverage at each potential passage route and are used to quantify project entrainment. Entrainment is estimated as total passage by route over differing time-scales with associated confidence intervals. Hydroacoustic data collection was initiated at Boundary Dam on May 2, 2007. The results of monitoring efforts through October 15, 2007, are presented in this report.

Systematic netting is used in the Fish Entrainment and Habitat Connectivity Study to validate the acoustic counts and for fish species identification. A fyke net was deployed in the Unit 54 draft tube gatewell in late September and early October 2007. To date, the net has been deployed on three occasions: October 6, October 27, and December 1, 2007; the net sampling effort has failed and has been redesigned each time. Net sampling with another modified design will recommence in January 2008 and is scheduled to continue through 2008. Netting information collected from January to September 15, 2008, will be summarized in the Updated Study Report, including statistical comparisons of all concurrent hydroacoustic and net sampling. The results

of hydroacoustic and net sampling at Boundary Dam between September 16, 2008, and the conclusion of the study on May 2, 2009, will be provided to relicensing participants (RPs) in August 2009.

A detailed description of each objective addressed in the Fish Entrainment and Habitat Connectivity Study 12 is provided in the Fish Entrainment Study Methods Outline document dated July 17, 2007, and provided as Appendix 1. Study methods were discussed with relicensing participants in a workgroup meeting at Metaline Falls, Washington, on July 24, 2007.

3 STUDY AREA

The Study 12 sampling area encompasses the Boundary Dam and associated structures, the turbine intake forebay, and the reservoir immediately upstream of the spillway. The hydroacoustic monitoring study area is located immediately upstream of Units 51 through 56 in the Boundary forebay and in front of the two spill gates (Figure 3.0-1). Fyke net sampling has been conducted in the draft tube gatewell at Unit 54 of the powerhouse.

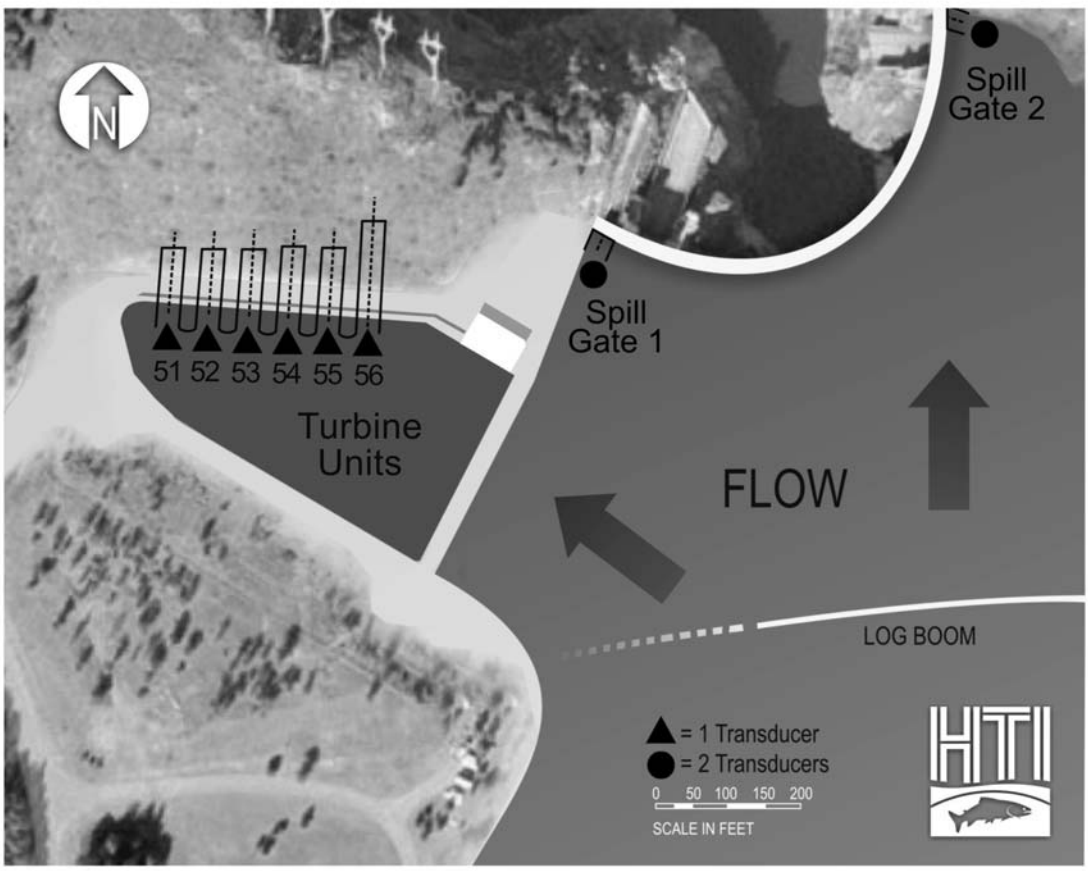

Figure 3.0-1. Plan view of the proposed Boundary Dam hydroacoustic system transducer deployment, showing the six 6°x10° beam width transducers monitoring the powerhouse and the four 15 beam width transducers installed at the spillway.

3.1. Boundary Project Description and Operations

Boundary Dam is configured with six deep-water turbine intakes 30 feet wide by 34 feet high (horseshoe-shaped in cross section) located at an invert elevation of 1,907 feet North American Vertical Datum (NAVD) 88[1] (1,903 feet National Geodetic Vertical Datum [NGVD] 29) in the Boundary forebay (Figure 3.0-1). The six turbine intakes/units are referred to as Units 51-56, with Unit 51 located at the west end of the powerhouse (Figure 3.0-1). The maximum turbine flow capacity of the Project is 55,000 cubic feet per second (cfs), which is more than twice the average annual flow of the Pend Oreille River near Boundary Dam (SCL 2006).

The floor of the forebay intake channel beneath the turbine intakes is located at elevation 1,904 feet NAVD 88 (1,900 feet NGVD 29), and the top of the turbine intakes are located at elevation 1,941 feet NAVD 88 (1,937 feet NGVD 29).

Boundary Dam has two spillways, one on either side of the main arch dam section (Figure 3.1-1). Both spill gates are bottom-opening tainter gates, 50 feet high by 45 feet wide. When fully closed, the top of the gates are at an elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29), which corresponds to the normal maximum pool elevation of Boundary Reservoir in the forebay area.

Spillway 1 is on the left bank looking downstream, and Spillway 2 on the right bank.
The spillway gates are opened to pass flows downstream when the powerhouse flows reach capacity (55,000 cfs) during higher flow or flood conditions. Spill events typically occur during April through July.

Boundary Dam also includes seven sluiceways located at about mid-height of the dam that discharge into the plunge pool below the dam. The sluiceways are generally used to supplement the spill flow during extreme high-flow events.

The Project is operated using a load-following strategy, meaning the power plant adjusts its power output as demand for electricity fluctuates throughout the day (SCL 2006). Load following power plants typically run during the day and early evening, and then either shut down or greatly curtail output during the night and early morning, when the demand for electricity is the lowest. The exact hours of operation depend on multiple factors.

The normal maximum reservoir water surface at the Project is at elevation 1,994 feet NAVD 88 (1,990 feet NGVD 29). The reservoir has relatively little active storage (about 43,000 acre-feet) within the maximum drawdown of 40 feet (active storage from elevation 1,994 to elevation 1,954 feet NAVD 88 [1,990-1,950 feet NGVD 29]) authorized under the current license. During the summer recreation season (approximately Memorial Day weekend through Labor Day weekend); SCL voluntarily restricts the water surface fluctuations to a 10-foot range (between elevations 1,984 feet and 1,994 feet NAVD 88 [1,980-1,990 feet NGVD 29]) to facilitate

[1] SCL is converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

reservoir access and related recreational activities during daytime hours. For the remainder of the year, the water surface generally fluctuates between elevations 1,994 feet and 1,974 feet NAVD 88 (1,990 to 1,970 feet NGVD 29). Storage between elevation 1,974 feet and elevation 1,954 feet NAVD 88 (1,970 to 1,950 feet NGVD 29) is reserved for extreme system load requirements. Flood storage is not provided, and other than the operating goals noted above, there are no seasonal or minimum flow requirements (SCL 2006).

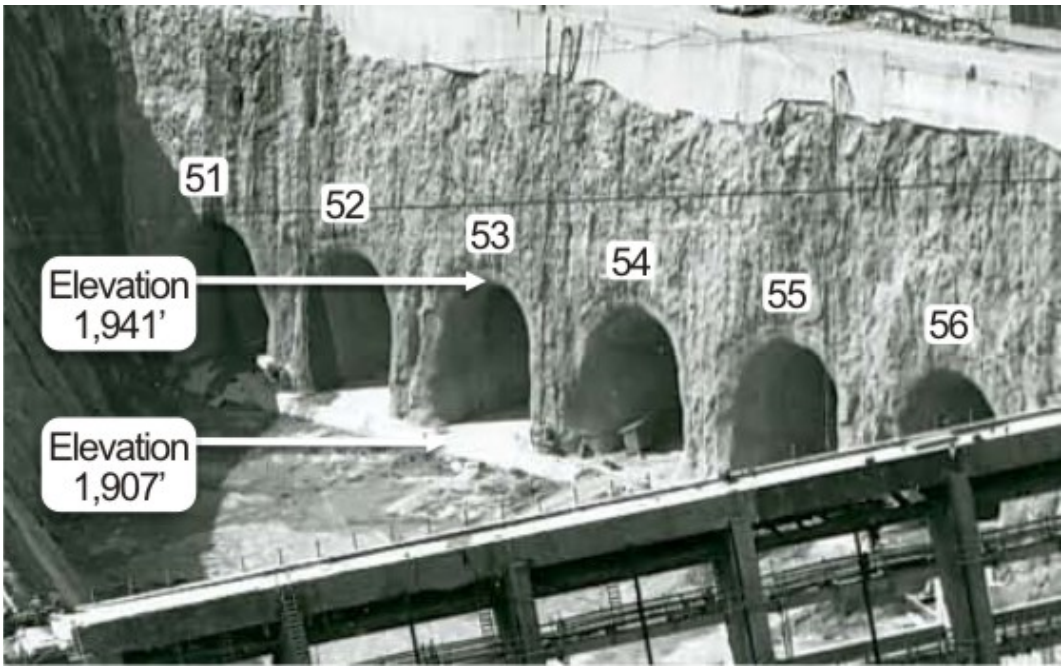

Figure 3.1-1. Photograph of the powerhouse during Project construction, showing the six turbine unit intakes. Elevations use NAVD 88 datum.

4 METHODS

The data collection methods used in the Fish Entrainment Study are described in detail in the Study 12 Methods Outline, which is included as Appendix 1 in this report. An overview of the hydroacoustic data collection methods is summarized below in Section 4.1.

The Fish Entrainment Study consists of separate turbine and spillway components. Information on entrainment from both components is summarized to estimate total target entrainment through the Project over time. Turbine entrainment is estimated using both hydroacoustic and fyke netting techniques. Spillway entrainment is estimated using only hydroacoustic sampling, although periodic gill netting is conducted near the spillway to provide complementary information on species composition. (See Study No. 9, Fish Distribution, Timing, and Abundance Study interim report - Task 1, SCL 2008.)

4.1. Hydroacoustic Sampling Methods

Hydroacoustic target entrainment data are collected and analyzed using split-beam target tracking techniques as described by Ehrenberg and Torkelson (1996), and following the scientific acoustic sampling principles outlined in MacLennan and Simmonds (1992). The principle of fixed-location, split-beam hydroacoustic techniques is based on placing one or more transducers on fixed structures and sampling targets as they pass through the insonified acoustic beams. The targets produce characteristic echo returns that are processed to produce estimates of total passage. Additional information that describes target passage rates, direction of movement, size, velocity, vertical distributions, and other parameters is also available from the hydroacoustic data set.

The hydroacoustic equipment required for a quantitative fixed-location study includes a scientific-quality echo sounder/transceiver, transducers, and a computer-based echo processor. The primary component of a hydroacoustic data collection system is the scientific echo sounder. When triggered, the echo sounder emits a short electrical pulse of known frequency, duration, and transmit power. The transducer then converts the electrical pulse into mechanical energy (sound pulse with the same characteristics as the electrical pulse). In fixed-location applications, the transducers typically have relatively narrow beam widths so they can be aimed close to physical boundaries (such as the face of a dam) and maximize sampling coverage in specific areas of interest, such as a turbine intake.

Echoes are reflected back to the transducer when the sound waves encounter fish or other targets. The transducer then converts the sound energy back into electrical energy and sends it back to the receiver portion of the echo sounder. The echo signals are relayed to a computer-based echo processor, which records each detection to a computer file for subsequent analysis.

4.1.1. Hydroacoustic Powerhouse Entrainment

The Boundary powerhouse consists of six turbine units, numbered Units 51 through 56. Vertically-oriented 6˚x10˚ nominal beam width[2] transducers are mounted on the centerline of each turbine intake at elevation 1,972 feet NAVD 88 (1,968 feet NGVD 29) and aimed down to monitor the water column immediately upstream of each turbine intake opening (Figure 4.1-1). The transducers operate at a sampling frequency of 200 kilohertz (kHz) and use split-beam technology to track the direction of individual targets in three-dimensional space. Only targets that exhibit net movement into the intake are considered entrained. The six transducer turbine intake monitoring array is sampled continuously, 24 hours per day. Individual transducers at each turbine intake are sequentially-sampled in 2.5-minute increments across the powerhouse within each 1-hour data replicate, such that each location is monitored 10 minutes per hour. All entrained target detections are weighted for unsampled time and space, and the resulting estimates represent total hourly target passage at each location.

[2] The actual beam pattern plots and other parameters that describe each transducer are measured during laboratory calibrations and referenced in each transducer's calibration file. These values are used in the weighting of raw detections (among other things) to provide entrainment values. A more detailed discussion of transducer characteristics and their function can be found in MacLennan and Simmonds (1992).

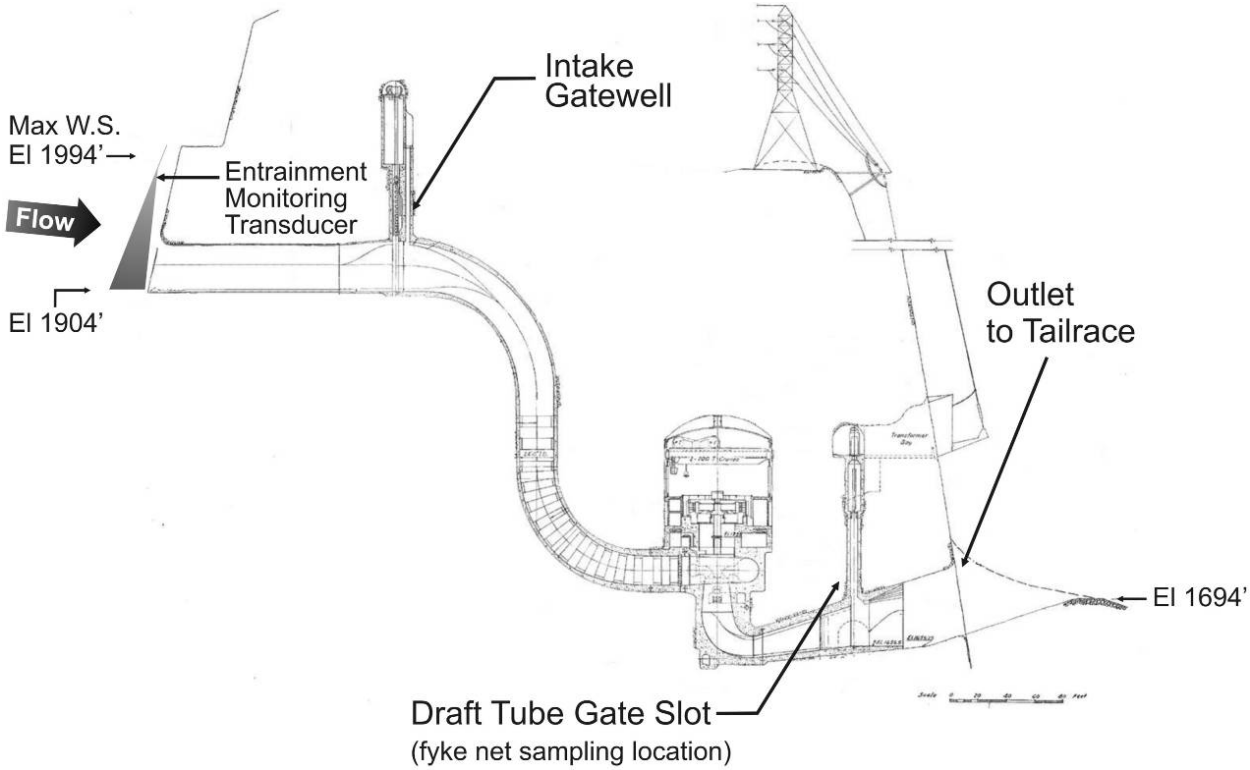

Figure 4.1-1. Schematic showing the location of the hydroacoustic transducers at the turbine unit intakes, relative to the fyke net sampling location in the draft tube gate slot at Boundary Dam. Elevations use NAVD 88 datum.

Each transducer monitors approximately 40 percent of the intake cross-sectional area, and the sampling volume axis is aligned with the intake centerline. Target detections are weighted for unsampled area in the intake based on the total intake width at the depth where the target was observed divided by the width of the transducer beam at that depth. This spatial weighting expands the observed counts to total turbine entrainment estimates and considers the variable width of the arched turbine intakes with depth. The acoustic sampling volume is 5.9 feet wide at the top of the turbine intake opening (30.8 feet below each transducer). The acoustic volume at the bottom of each intake (69 feet below each transducer) is 13.3 feet wide, relative to a total base intake width of 30 feet. Range-weighting of each detected target corrects for the increasing sample volume with range and provides an estimate of total turbine entrainment. Turbine unit operations are also referenced during the analysis, such that only targets moving into operating turbines are included in the hydroacoustic entrainment estimates.

An acoustic sampling (ping) rate of 12 pings per second (pps) is used at all turbine units. This relatively fast ping rate provides high acoustic detectability (multiple echo returns) of individual entrained targets. Target detectability at the Boundary turbine intakes was modeled before the data collection period, based on the transducer beam widths, sampling ranges, and maximum water velocities at the site. A minimum echo detection threshold of -52 decibels (dB) was used

for monitoring at the Boundary powerhouse, equivalent to a minimum fish detection length of 43 millimeters (mm) (1.7 inches) based on Love (1971), an empirical formula relating backscattered acoustic energy to fish length. Hydroacoustic data were subsequently filtered in post-processing to include only detections with a mean target strength (acoustic size) of more than -45 dB, equivalent to an estimated minimum fish detection length of 100 mm (4 inches) using Love (1971). The acoustic system uses a relatively narrow broadcast pulse width (PW) of 0.2 ms to optimize detection of closely spaced individual targets.

The installation is configured to allow remote control of the hydroacoustic system for monitoring and data transfer. The hourly hydroacoustic target passage data files are transferred on a daily basis to SCL for ongoing data review and analysis.

Each hydroacoustic detection was filtered using multiple criteria to minimize the potential for inclusion of detections from debris, entrained air, and non-fish targets in the hydroacoustic entrainment summaries. Targets that reflect less energy than expected from a 4-inch long fish (less than -45 dB mean target strength) were excluded from the data record. If suspended debris was present in the study area, the majority of this debris would be anticipated to return target strength values less than -45 dB and would be removed by this filtering. Only echo returns with pulse widths within +/- 50 percent of the 0.2 ms transmitted signal (values of 0.08 to 0.29 ms, as measured at the echo half-amplitude point) were considered during target tracking. Debris typically returns echo widths wider than the transmitted signal because of the variable shape and aspect of debris targets. The widths of echoes reflected from individual fish typically are similar to the transmitted pulse. In addition, only targets located at depths below the top of the turbine intakes (more than 30.8 feet below each transducer) and that exhibit consistent movement downstream into the intakes were considered in the acoustic counts. Targets must have a significant difference in density from the surrounding water to be detected by the acoustic system. In fish, the air-filled swim bladder is responsible for more than 90 percent of the energy reflected from the target (Foote et al. 1986). Debris incorporating sufficient air to return echoes with amplitudes high enough to be detected by the acoustic system would tend to be positively buoyant and would not be present at depths below the intake opening. Lastly, each target was required to be detected a minimum of six times as it transited through the acoustic sampling volume, and these detections had to occur sequentially and be located in close spatial proximity. This echo detection redundancy minimized the potential of false detections caused by noise or small particles, which are typically variable in position relative to returns from fish.

4.1.2. Hydroacoustic Spillway Entrainment

The Boundary Dam spillway consists of two spill bays, each 45 feet in height and 50 feet in width, located at each end of the arch dam (see Figure 3.0-1). Spill Gate 1 is located at the dam's left abutment, closest to the powerhouse forebay intake channel. Spill Gate 2 is located at the far end of the arch dam, at the right abutment and adjacent to the east shoreline of the reservoir.

Two vertically oriented 15˚ nominal beam width transducers are deployed at each spill bay (four transducers in total) to maximize spatial sampling coverage across each spill gate opening in monitoring targets as they pass through the spill bays during spill events. Each spill bay is conceptually divided into two halves to estimate entrainment, with one down-looking transducer

located equidistantly in each half. The spillway transducers are deployed at an elevation of 1,988 feet NAVD (1,984 feet NGVD 29) and are aimed down vertically to monitor the water column immediately upstream of each spill gate opening.

Each spill bay transducer is sampled for six 5-minute time intervals per hour during all periods when spill is occurring at the Project. This sampling design provides 60 minutes of sampling time within each spill bay per hour (30 minutes per hour in each half of the spill bay opening). The transducers operate at a sampling frequency of 200 kHz and use split-beam technology to track the direction of individual targets in three-dimensional space. Only targets that exhibit movement into the spill bays are considered in the entrainment counts. All entrained target detections are weighted for unsampled time and space, and the resulting estimates represent total target passage at each location. Spillway operations were considered during the analysis, such that only targets moving into the operating spill bays were included in the hydroacoustic entrainment estimates.

The spillway monitoring transducers are sampled using a ping rate of 15 pps, which provides high acoustic detectability of individual entrained targets. Target detectability at the Boundary Dam spillway was modeled before the data collection period, based on the transducer beam widths, sampling ranges, and maximum water velocities estimated in the region upstream of the spill gates. The higher potential water velocity in the spill bays relative to the turbine intakes indicated the use of a relatively higher ping rate at the former location. Target detectability is equivalent at the monitored Boundary Dam turbine intake and spill gate locations, based on the model results.

Estimated hydroacoustic target entrainment at the spillway is summarized and presented in an identical manner as at the turbine intakes (Section 4.1.1). The same target detection filtering criteria applied at the powerhouse (a -45 dB minimum mean target strength, echo width bounds, and six minimum echo returns) were used at the spillway to minimize the potential impact of echo returns from suspended debris or air bubbles in the entrainment estimates.

4.1.3. Spillway Gill Netting

Gill nets were deployed approximately once per month at a distance of 100 to 400 feet upstream of Spill Gate 2, located on the east side of the dam, between March and October 2007. Four separate gill nets, 100 feet long by 8 feet wide, were deployed vertically in the upper 100 feet of the water column. Each net had a different mesh size (0.5-, 1.0-, 1.5-, and 2.0-inch square mesh). In addition, a net was deployed horizontally along the channel bottom upstream of Spill Gate 2. This horizontal multi-panel gill net was 200-foot wide by 8-foot long, with the same mesh sizes as previously described. The location of each gill net set was standardized to the extent practicable. Variations in monthly deployment locations were tracked using handheld global positioning system (GPS) units and marked on high-resolution aerial photographs. All standard gill net sampling occurred between approximately 1 hour before sunset and approximately 2 hours after sunrise. Set duration ranged from 3 to 9 hours. The spillway nets were not deployed in April, as reservoir inflow conditions prevented the Boundary Powerhouse operator from locking out the spillway gates during this period.

4.2. Fyke Net Sampling Methods

The purpose of the fyke net sampling is to verify the concurrent hydroacoustic passage estimates at Unit 54 and to provide information on fish species composition. A fyke net sampling array was installed in the draft tube gatewell of Turbine Unit 54 at Boundary Dam in September 2007. Figure 4.1-1 shows the locations of the hydroacoustic monitoring transducer and the fyke net sampling frame at Unit 54. The fyke net array consists of two frames of eight net panels each and is designed to screen the entire draft tube downstream of Turbine Unit 54. Each frame measures 17 feet wide by 28 feet high. The frames are massive, weighing approximately 8,200 pounds apiece. The gantry crane at the draft tube stop log is used to deploy the net frames. The gantry crane is located approximately 135 feet above the sill of the draft tube gatewell. Crews fish the fyke nets from the deck of draft tube gate maintenance chamber, located approximately 92 feet above the draft tube gatewell sill.

A dive crew spent 3 weeks installing the fyke net frame guide rails during late September and early October 2007. Subsequently, there have been three efforts to deploy the nets. The first effort was made on October 6, 2007; the second on October 27, 2007; and the third on December 1, 2007.

Although each effort to deploy nets in the draft tube has failed, understanding of the complex fishing environment has increased. After each effort, the nets and frames were modified in response to the observed failure modes.

Ideally, the fyke net fishing would occur while the turbine produced 140 megawatts, the point where typically another unit is brought on line if more generation is to occur. This operating load is associated with a flow of approximately 7,000 cfs. Because all nets deployed were damaged or lost at this flow, the hydroacoustic data were queried to determine if there was a lower operating level that provided adequate numbers and a similar size distribution of hydroacoustic targets. A lower operating level would reduce the forces on the fishing gear and still provide data on species composition. The second fishing effort on October 27 began with a flow of 90 megawatts (approximately 5,000 cfs). This flow was the cut-off point indicated in the hydroacoustic data where the full complement of sizes of entrained targets present at higher flows was evident. The forces at this flow still exceeded the capacity of the netting system, and all nets failed. Interestingly, the nets in the frame nearest the left bank were inverted during both fishing efforts in October, indicating that flow was reversed on one side of the draft tube, flowing toward the turbine. A camera was mounted above an empty net bay during the third effort on December 1, 2007, which began with a turbine load of 45 megawatts (approximately 3,000 cfs). A light was attached to a line so that flow direction could be observed during net deployment. In this manner, it was discovered that, counterintuitively, the water actually moved in the direction of the turbine during the entire fishing period. This finding leads to the conclusion that water is drawn from the tailrace through the back of one net frame, adding to the flow discharge from the turbine. All nets deployed on December 1 failed during the sampling event.

The reverse water flow in half of the draft tube has significant implications for the sampling effort. The frame and guide rails were designed to function at 1.5 times the average velocity of water passing through the entire flow area. With all of the flow passing through half of the flow

area, plus an unknown amount of water drawn in from the tailrace, the actual velocity could be 3 to 5 times what was expected.

Ultimately, it may prove impossible to hold nets in place over the entire cross-section of the draft tube sampling area. Therefore, partial netting of the draft tube cross-sectional area, coupled with a statistical approach to verify net capture efficiency, is under consideration for sampling efforts that will begin in January 2008. Fishing under a reduced flow regime may also be required. This option, however, may inhibit the program's ability to ascertain the full complement of sizes and species. Alternative methods for identifying species composition are therefore under review. Alternative methods for correlating the hydroacoustic target information are also under review, should it be determined that fyke netting in the draft tube gatewell is not possible. Details of the fishing efforts envisioned for 2008 are included in Section 7.

A detailed description of the fyke net sampling methods for the Fish Entrainment and Habitat Connectivity Study is provided in the Study 12 Methods Outline document previously provided to relicensing participants, dated July 17, 2007 (see Appendix 1).

5 RESULTS

5.1. Hydroacoustic Powerhouse Distributions

5.1.1. Total Estimated Entrainment

Estimated total hydroacoustic target entrainment at the powerhouse was summarized on a monthly and study period basis for evaluation and comparison. Two entrainment rates were also calculated and compared to evaluate potential effects of variable turbine operations on target entrainment. Entrainment rates expressed as the number of targets per hour of unit operation and targets per megawatt hour (MWH) were estimated on a monthly and study period basis. The former metric described entrainment as a mean hourly rate and the latter as the number of targets per MWH of power produced. At any given pool elevation, unit MWH is proportional to turbine flow, and rates of entrainment per MWH provide a relative measure of passage per unit of water volume. This relationship may be biased by summarizing results collected at different pool elevations over time, and target per MWH estimates should be considered as relative measures of entrainment. Unit MWH measures can be converted to total intake flow and water velocities, and this information may be considered in future entrainment analyses.

Table 5.1-1 shows the estimated total entrainment of hydroacoustic targets through all turbine units for the May 2 through October 15, 2007, sampling period, with the associated 90 percent confidence intervals (CI). The table also includes the total megawatts produced by all units; estimated targets passed per MWH, and estimated targets per hour of unit operation over the period.

A total of 169,752 targets were estimated to have passed downstream through Units 51 through 56 over the 2007 monitoring period considered in this report (approximately 5.5 months in duration). On average, this number was equivalent to 13.22 targets per unit operating hour, or 0.1 target per MWH of power production. These estimates include only targets equal to or

greater than 10 centimeters (cm) in length (approximately 4 inches), assuming the targets to be fish and applying the Love (1971) relationship.

Table 5.1-1. Total estimated target entrainment, megawatt hours (MWH) produced, mean targets per MWH, and mean targets per hour of turbine operation for the May 2-October 15, 2007, study period.

Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour of Operation
169,752	10,941	4,782	1,735,946	0.10	13.22

Total estimated monthly entrainment at the powerhouse, entrainment per MWH produced, and entrainment per hour of turbine unit operation in 2007 is presented in Figures 5.1-1, 5.1-2, and Figure 5.1-3 and summarized in Table 5.1-2.

Monthly estimated entrainment was relatively consistent for the first 3 months of the study period (May to July), varying from 33,379 to 37,051 targets (Figure 5.1-1 and Table 5.1-2). Project generation and total outflow decreased over this period, from 595,228 MWH in May to 237,259 MWH in July. Monthly entrainment did not appear to be correlated with total Project generation. Monthly estimated powerhouse entrainment declined in August to 9,682 targets and in September to 10,418 targets. Project generation also decreased in August (120,139 MWH) and September (144,808 MWH), relative to May through July. A peak in monthly estimated entrainment of 43,571 targets was observed in October, despite the abbreviated sampling period (only data through October 15 were evaluated). Total power production for the abbreviated October monitoring period was 127,361 MWH, comparable to the total monthly MWH values for August and September. The majority of target entrainment in October (approximately 87 percent of the total for the 15 day monitoring period reported for the month) occurred during the first week.

Hydroacoustic target entrainment on a per-MWH and per-hour of unit operation basis was similar for the May to June and August to September periods (Figures 5.1-2 and 5.1-3). Approximately 0.06 to 0.08 targets were estimated to have been entrained per MWH of power produced during these months, or 8.46 to 10.40 targets per hour of unit operation. A slight increase in entrainment rates was observed in July, when 0.15 targets per MWH and 17.86 targets per unit operating hour were estimated. The highest entrainment rates observed during the 2007 monitoring period occurred during the first half of October (0.34 targets per MWH and 43.48 targets per hour of unit operation).

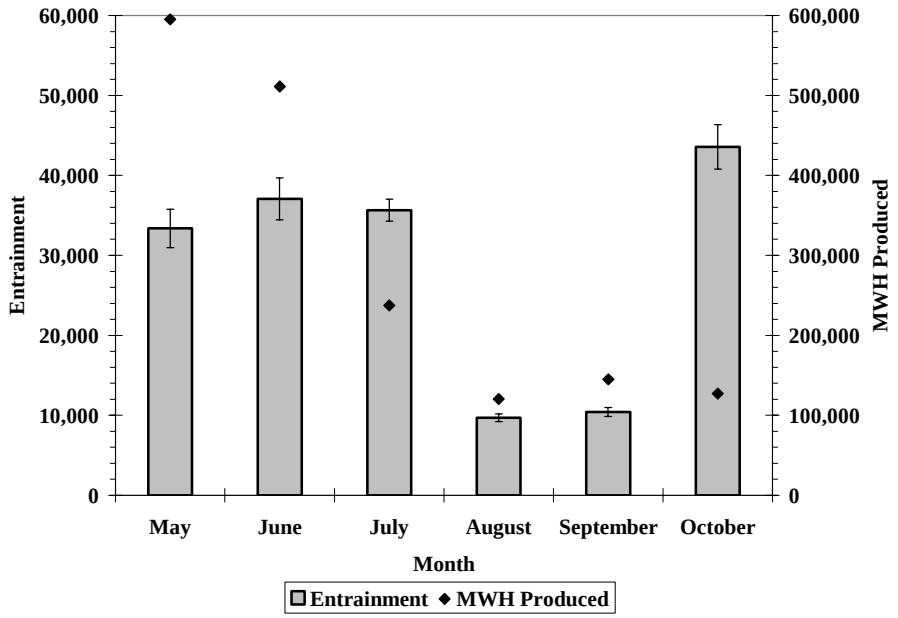

Figure 5.1-1. Estimated hydroacoustic target entrainment per month, with 90% CI, and total megawatt hours (MWH) produced for all turbine units combined over the May 2-October 15, 2007, study period. Note: Only a 15 day monitoring period is reflected in the October monthly estimate.

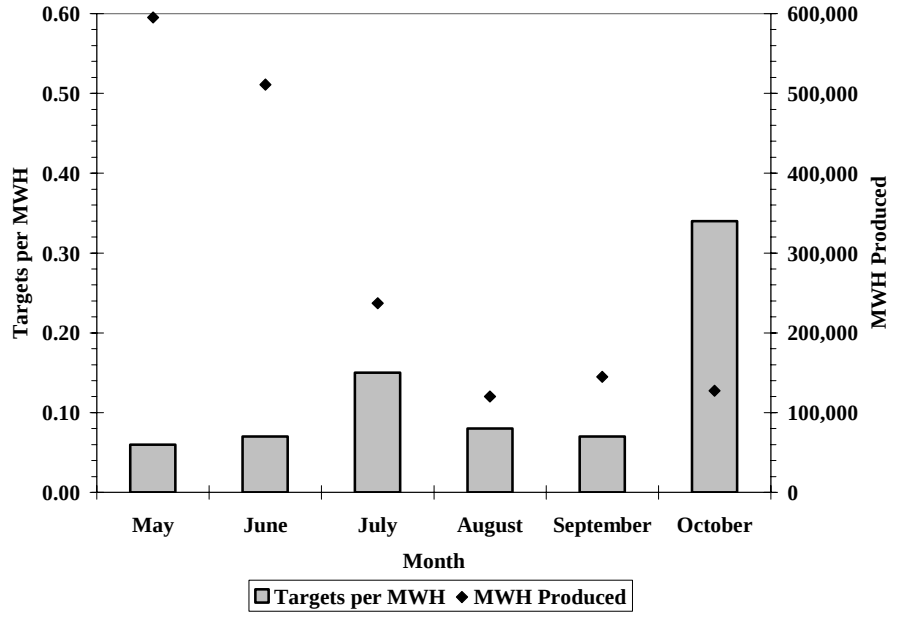

Figure 5.1-2. Estimated monthly hydroacoustic target entrainment per megawatt hour (MWH) produced, and total MWH produced for all turbine units combined over the May 2-October 15, 2007, study period. Note: Only a 15 day monitoring period is reflected in the October monthly estimate.

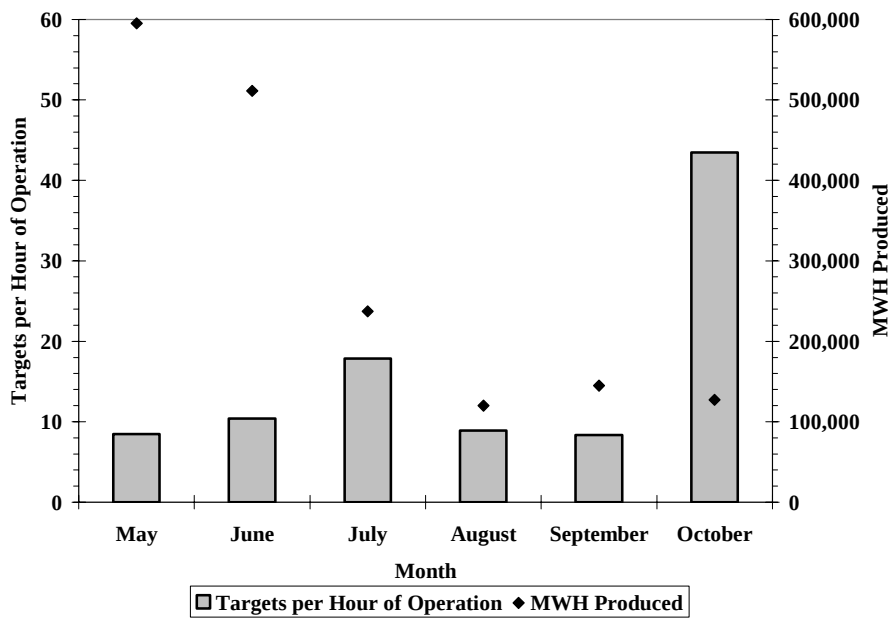

Figure 5.1-3. Total estimated hydroacoustic target entrainment per hour of operation for each month, and total megawatt hours (MWH) produced for all turbine units combined over the May 2-October 15, 2007, study period. Note: Only a 15 day monitoring period is reflected in the October monthly estimate.

Table 5.1-2. Monthly total estimated target entrainment with 90 percent CI, total megawatt hours (MWH) produced, mean targets per MWH, and mean targets per hour of turbine operation for the May 2-October 15, 2007, study period. Note: Only a 15 day monitoring period is reflected in the October monthly estimate.

Month	Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour of Operation
May	33,379	2,424	2,396	595,228	0.06	8.46
June	37,051	3,015	2,629	511,152	0.07	10.40
July	35,651	1,954	1,379	237,259	0.15	17.86
August	9,682	527	485	120,139	0.08	8.91
September	10,418	591	547	144,808	0.07	8.34
October	43,571	2,430	2,793	127,361	0.34	43.48

5.1.2. Entrainment Timing

Weekly estimates of hydroacoustic target entrainment for all turbine units combined were estimated on a weekly basis and compared over the 2007 study period to evaluate temporal passage trends (Figure 5.1-4 and Table 5.1-3). Total powerhouse generation in MWH was also summarized on a weekly basis and plotted to explore potential relationships between entrainment

and total powerhouse flow. Entrainment rates, expressed as targets per MWH and hour of unit operation, were also calculated on a weekly basis and are shown in Table 5.1-3.

Hydroacoustic sampling commenced on Week 18, and total weekly target entrainment for all turbines combined varied between 3,843 and 10,287 targets for the first 14 weeks of the study (through August 4). Total estimated weekly turbine entrainment decreased to 322 and up to 5,159 targets during Weeks 15 through 23 (August 5 to October 6). A substantial increase in estimated weekly entrainment (33,531 targets) was observed in Week 41 (October 7 to 13), near the end of the reported 2007 study period. The increase in entrainment during Week 41 was also reflected in the passage rates of number of targets per MWH (0.53), and in the number of targets per hour of unit operation (68.22).

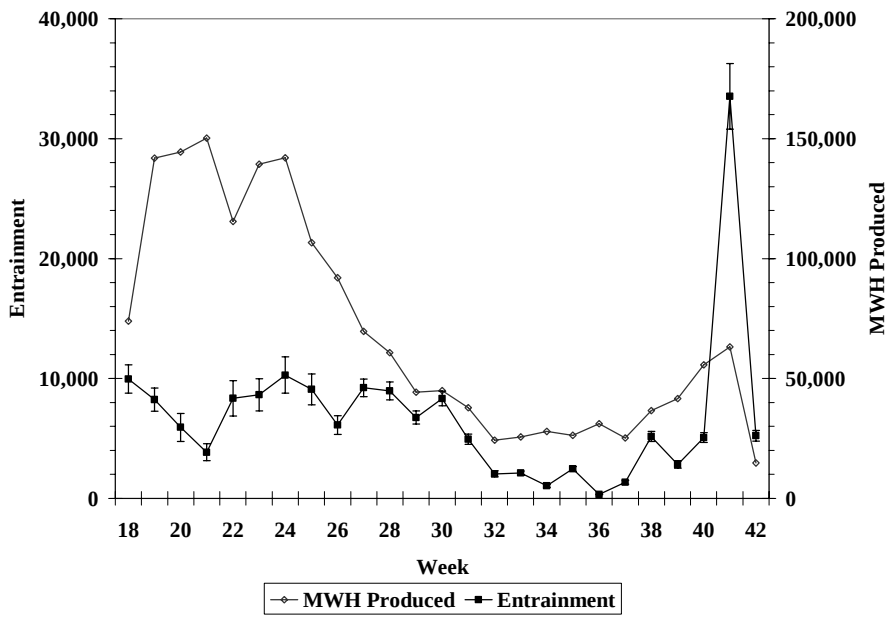

Figure 5.1-4. Total estimated number of targets entrained, with 90 percent CI, and total MWH produced by week, for the May 2-October 15, 2007, study period.

Table 5.1-3. Weekly estimated entrainment, with 90 percent CI, total megawatt hours produced, targets per MWH and targets per hour of unit operation for the May 2-October 15, 2007, study period. Weekly mean lake elevation is also presented (Elevations use NAVD 88 datum). Weeks are numbered sequentially with Week 1 beginning at January 1, 2007.

Week	Date	Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour of Operation	Mean Reservoir Elevation
18	5/2-5/5	9,952	594	1,181	73,963	0.13	19.52	1,981.96
19	5/6-5/12	8,235	588	967	141,981	0.06	9.11	1,982.90
20	5/13-5/19	5,918	512	1,157	144,438	0.04	6.24	1,978.88
21	5/20-5/26	3,843	296	710	150,271	0.03	3.91	1,983.33
22	5/27-6/2	8,346	672	1,472	115,550	0.07	10.17	1,984.08
23	6/3-6/9	8,630	685	1,346	139,412	0.06	9.31	1,985.84
24	6/10-6/16	10,287	892	1,505	142,024	0.07	11.17	1,985.22
25	6/17-6/23	9,098	766	1,287	106,683	0.09	11.89	1,985.51
26	6/24-6/30	6,121	434	778	92,060	0.07	8.41	1,985.09
27	7/1-7/7	9,219	504	746	69,618	0.13	15.69	1,985.60
28	7/8-7/14	8,961	495	760	60,724	0.15	17.23	1,982.65
29	7/15-7/21	6,743	365	559	44,327	0.15	18.67	1,984.57
30	7/22-7/28	8,325	452	606	44,916	0.19	22.55	1,985.24
31	7/29-8/4	4,930	281	429	37,814	0.13	14.73	1,985.28
32	8/5-8/11	2,048	110	251	24,246	0.08	8.78	1,985.50
33	8/12-8/18	2,113	114	173	25,665	0.08	9.60	1,986.05
34	8/19-8/25	1,052	57	129	27,894	0.04	4.27	1,981.37
35	8/26-9/1	2,457	131	204	26,241	0.09	10.03	1,986.24
36	9/2-9/8	322	19	29	31,088	0.01	1.13	1,976.23
37	9/9-9/15	1,352	79	162	25,211	0.05	6.23	1,977.77
38	9/16-9/22	5,159	292	413	36,608	0.14	16.49	1,984.71
39	9/23-9/29	2,827	161	302	41,609	0.07	7.94	1,985.07
40	9/30-10/6	5,061	282	404	55,726	0.09	11.74	1,982.16
41	10/7-10/13	33,531	1,877	2,732	63,190	0.53	68.22	1,983.64
42	10/14-10/15	5,223	283	444	14,690	0.36	42.38	1,985.57

5.1.3. Entrainment by Turbine Unit (Horizontal Distribution)

Estimated hydroacoustic target entrainment was summarized for each turbine unit on a monthly and study period basis and compared to evaluate relative passage trends across the powerhouse (Figure 5.1-5 and Table 5.1-4).

Over the entire study period of May 2 through October 15, 2007, Unit 51 demonstrated the highest estimated target entrainment (39,127, or 23 percent), followed by Unit 54 (34,614, or 20 percent) and Unit 52 (29,839, or 18 percent). The two units farthest away from the forebay entrance (Units 51 and 52) entrained approximately 41 percent of all hydroacoustic targets, even though Units 53 through 56 had higher MW loadings over the period. Total entrainment by turbine did not appear to be absolutely correlated with unit loading. Unit 53 had similar total MW loading, as did Units 54 to 56, but demonstrated lower relative entrainment (15,073, or 9

percent). Minimum target detection sensitivity at Unit 53 was equivalent to the other turbine units based on a review of the hydroacoustic sampling parameters and system calibration data.

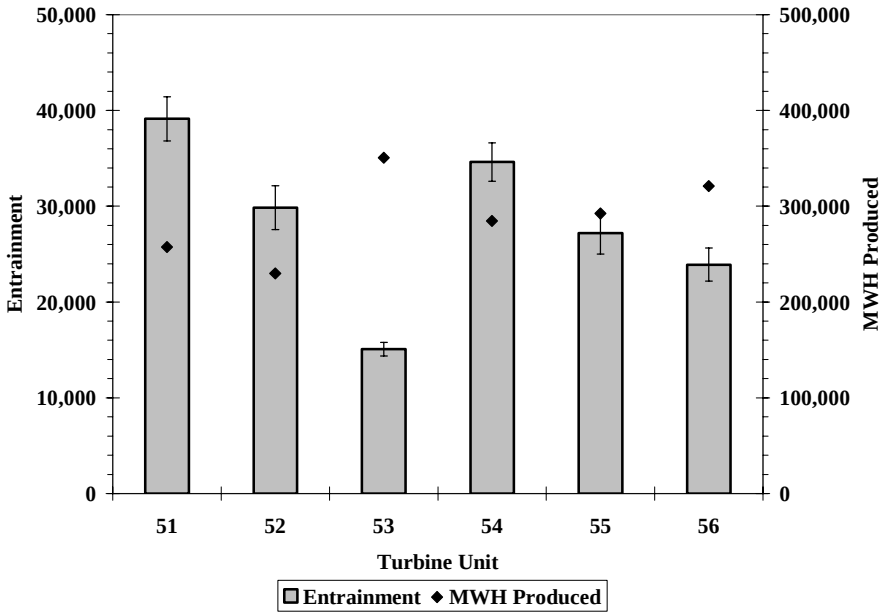

Figure 5.1-5. Horizontal distribution of total estimated hydroacoustic entrainment by turbine unit over the May 2 through October 15, 2007, study period, with 90 percent CI. The total MWH produced at each unit of the powerhouse is shown on the secondary Y-axis.

Table 5.1-4. Horizontal distribution of total estimated hydroacoustic entrainment at each turbine unit over the May 2 through October 15, 2007, study period, with 90 percent CI. Total MWH produced at each unit and entrainment rates (targets per MWH and targets per hour of unit operation) are also presented.

Turbine Unit	Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour of Operation
51	39,127	2,204	2,304	257,565	0.15	18.84
52	29,839	1,819	2,291	229,972	0.13	16.98
53	15,073	898	698	350,604	0.04	5.09
54	34,614	2,522	2,006	284,608	0.12	14.48
55	27,197	1,901	2,188	292,299	0.09	15.67
56	23,901	1,597	1,740	320,898	0.07	12.44

Figures 5.1-6 and 5.1-7 and Table 5.1-5 show estimates of target entrainment by turbine unit on a monthly basis. The study period estimate of relative turbine entrainment was affected by high passage at Units 51 and 52 during the first 2 weeks of October. Approximately 84 percent of all targets estimated to have passed through Unit 52 during the 2007 study period did so in October. At Unit 51, 68 percent of the 2007 study period entrainment at that location occurred in October. During the months of May through August, the largest percentage of targets was observed to pass via Units 54 through 56, and Unit 54 was recommended as the optimal unit for fyke net placement based on these results. (See the Study 12 Fyke Net Placement Memorandum Report, submitted to SCL on November 2, 2007.) The shift from relatively higher entrainment at Units 54 to 56 observed during the first 4 months of the 2007 study to increased relative entrainment at Units 51 and 52 during the months of September and October may have been a result of changes in the pattern of turbine operations. Unit 55 was undergoing service in September and October and was essentially not operated during this period. This downtime resulted in a relative increase in turbine operations at Units 51 to 53. The percentage of total powerhouse generation through Units 51 to 53 for May through August varied between 43 and 47 percent, but increased to 64 to 66 percent in September and October. Increased flow through the lower-numbered units at the Boundary powerhouse in September and October may have affected target distributions in the forebay intake channel and subsequent patterns of entrainment by unit.

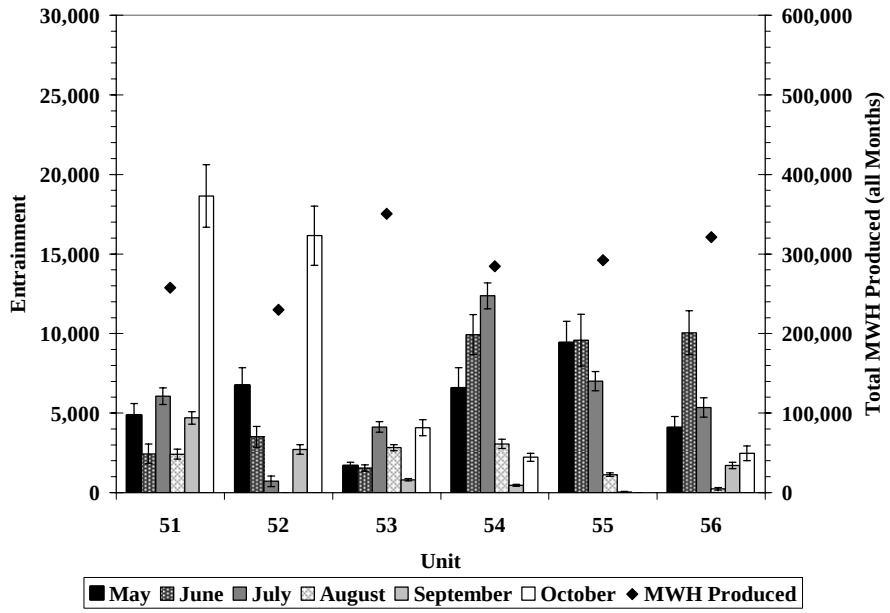

Figure 5.1-6. Horizontal distribution of estimated hydroacoustic target entrainment at each turbine unit on a monthly basis over the May 2 through October 15, 2007, study period, with 90 percent CI. Total MWH for each unit is presented on the secondary Y-axis. Note: Unit 52 did not operate in August. Unit 55 operated minimally during September and did not operate in October.

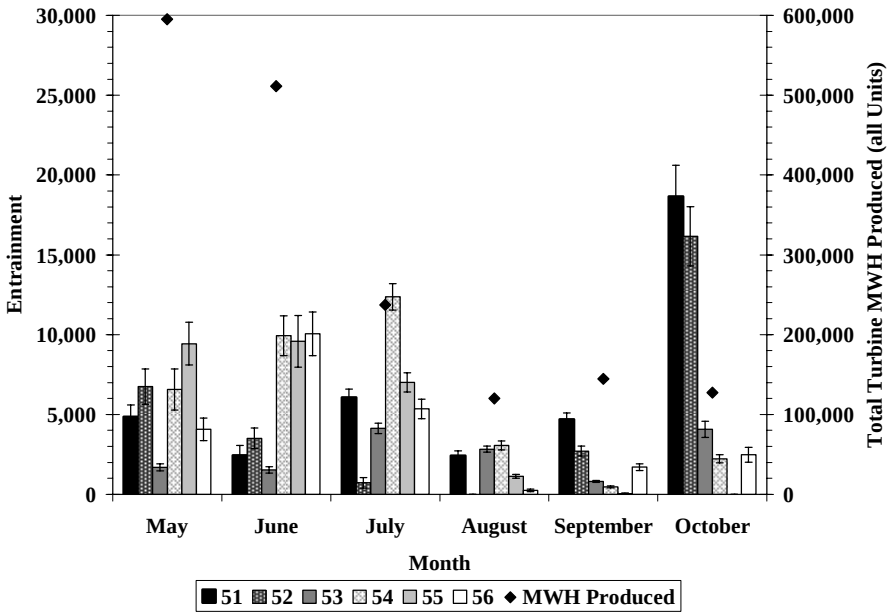

Figure 5.1-7. Monthly hydroacoustic target entrainment estimates by turbine unit over the May 2 through October 15, 2007, study period, with 90 percent CI. Total MWH (all units combined) for each month is presented on the secondary Y-axis. Note: Unit 52 did not operate in August. Unit 55 operated minimally during September and did not operate in October.

Table 5.1-5. Total estimated monthly hydroacoustic entrainment by unit over the May 2 through October 15, 2007, study period, with 90 percent CI. Total MWH produced at each unit and entrainment rates (targets per MWH and targets per hour of unit operation) are also presented on a monthly basis. Note: Unit 52 did not operate in August. Unit 55 operated minimally during September and did not operate in October.

Month	Unit	Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour Operations
May	51	4,860	306	745	81,351	0.06	8.18
May	52	6,750	456	1,100	95,014	0.07	9.84
May	53	1,695	131	223	90,176	0.02	2.50
May	54	6,571	551	1,284	84,276	0.08	10.38
May	55	9,433	685	1,337	122,423	0.08	13.93
May	56	4,069	295	711	121,987	0.03	6.03
June	51	2,436	168	617	69,212	0.04	4.69
June	52	3,510	247	649	83,863	0.04	5.61
June	53	1,539	116	202	85,998	0.02	2.30
June	54	9,930	963	1,253	82,119	0.12	15.50
June	55	9,583	771	1,621	98,140	0.10	16.77
June	56	10,053	750	1,376	91,821	0.11	18.69
July	51	6,069	327	526	40,645	0.15	16.56
July	52	720	41	334	6,396	0.11	11.84
July	53	4,128	228	328	55,544	0.07	7.91
July	54	12,371	685	817	52,921	0.23	24.47
July	55	7,010	382	609	48,637	0.14	21.67
July	56	5,354	291	613	33,116	0.16	24.56
August	51	2,413	131	312	13,135	0.18	18.77
August	52	0	0	0	0	0.00	0.00
August	53	2,825	151	194	39,264	0.07	7.38
August	54	3,062	170	286	36,673	0.08	8.58
August	55	1,133	61	118	21,959	0.05	7.30
August	56	250	14	79	9,109	0.03	3.94
September	51	4,697	260	397	26,542	0.18	19.07
September	52	2,708	158	304	19,527	0.14	15.54
September	53	812	46	63	50,221	0.02	1.75
September	54	458	27	60	11,566	0.04	4.16
September	55	38	2	39	1,140	0.03	4.45
September	56	1,705	98	208	35,812	0.05	6.97
October	51	18,652	1,012	1,969	26,680	0.70	84.11
October	52	16,152	917	1,857	25,172	0.64	76.55
October	53	4,074	226	500	29,401	0.14	16.82
October	54	2,222	126	255	17,053	0.13	15.35
October	55	0	0	0	0	0.00	0.00
October	56	2,471	149	462	29,054	0.09	13.56

Comparisons of estimated entrainment as a function of unit MWH loading (entrained targets per MWH) for the entire study period is presented in Figure 5.1-8. Unit 51 had the highest entrainment rate (0.15 targets per MWH) over the study period. Unit 52 had the next highest rate (0.13 targets per MWH), followed by Unit 54 (0.12 targets per MWH). Units 55, 56 and 53 had progressively lower rates 0.09, 0.07, and 0.04 targets per MWH, respectively.

Figure 5.1-9 shows entrainment rates per hour of turbine unit operation for the entire study period. The general trend between turbines was similar to that observed in the comparisons of targets per MWH in Figure 5.1-8, except that the relative hourly rates at Units 55 and 56 were slightly elevated because of the higher capacity of these units. Units 51 and 52 had the highest rates of target entrainment per operating hour (18.84 and 16.98) over the 2007 study period. The lowest rate of hourly entrainment (5.09 targets per hour) was observed at Unit 53.

As discussed above, the elevated entrainment rates at Units 51 and 52 over the 2007 study period were caused by the spike in estimated entrainment that occurred at these locations in September and October. Based on the May through August monitoring period, the highest entrainment rates were observed at Unit 54, as reported in the Study 12 Fyke Net Placement Memorandum Report submitted to SCL and dated November 2, 2007.

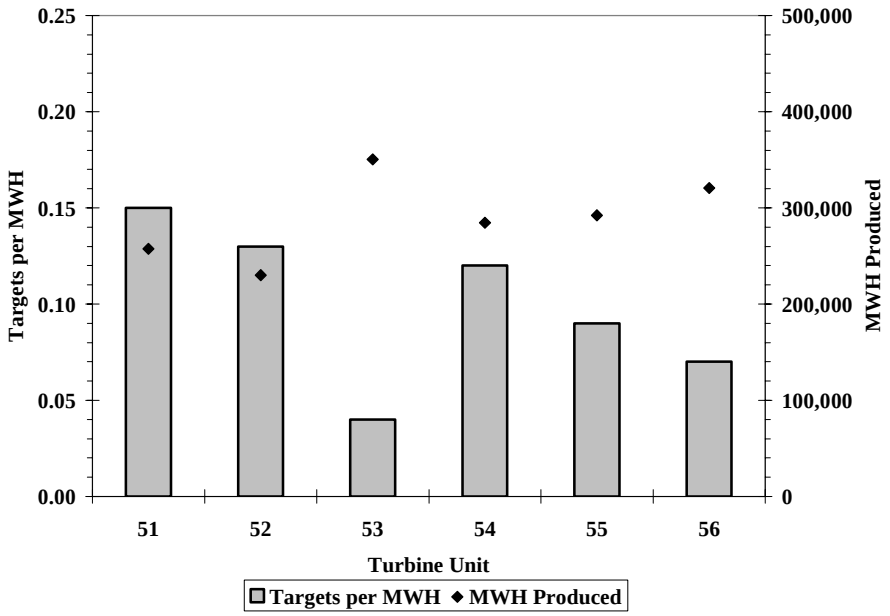

Figure 5.1-8. Total estimated hydroacoustic target entrainment per MWH of operation at each turbine unit and total MWH produced at each unit over the May 2 through October 15, 2007, study period.

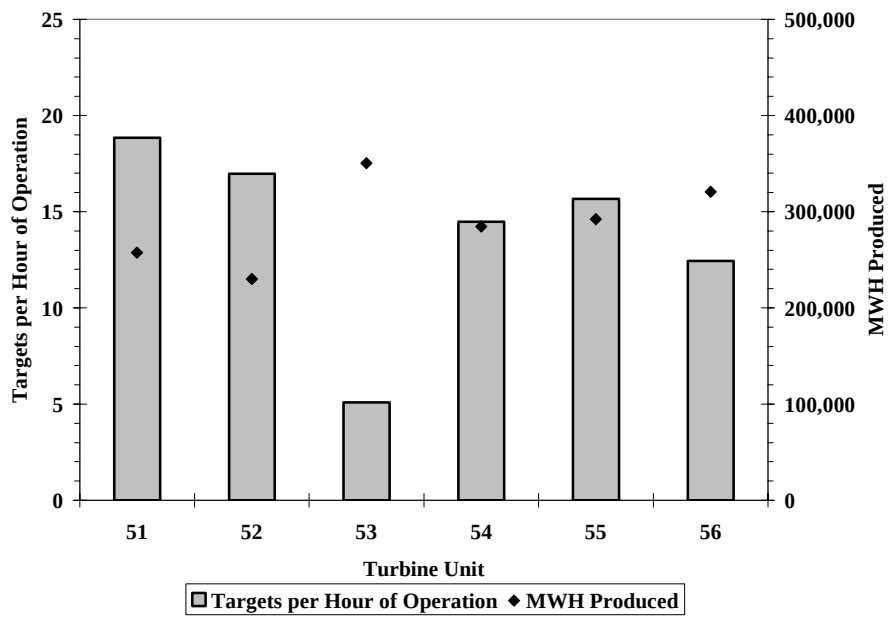

Figure 5.1-9. Total estimated hydroacoustic target entrainment per hour of unit operation at each turbine and total MWH produced at each unit over the May 2 through October 15, 2007, study period.

5.1.4. Temporal Entrainment Distributions

Temporal (mean entrainment over a 24-hour period) distributions of hydroacoustic target entrainment for all turbines combined were summarized over the entire study period of May 2 through October 15, 2007. These results are shown in Figures 5.1-10 and 5.1-6. The hours designate the start time of each sample: 0600 h passage occurred between 0600 and 0700 hours.

Over a 24-hour period, hydroacoustic target entrainment was highest in the early afternoon through the early evening hours. Approximately 53 percent of all targets entrained at the powerhouse passed over the 8-hour period between 1200 hours and 1900 hours. A peak in entrainment was observed during the early morning at 0600 hours, coinciding with an increase in project generation. About 6 percent of total Project entrainment occurred during the 0600 hours. Increased numbers of targets were observed to pass the powerhouse as units came on-line to meet morning power demands. On a per-MWH basis, the 0600 hour had the highest number of targets per MWH (0.17, Table 5.1-6). The second-highest period of entrainment during the day occurred between 1200 and 1900 hours, when generally uniform rates of between 0.10 and 0.12 target per MWH. Rates of entrainment per operating unit hour were 21.67 targets per hour during the 0600 hour and 14.33 to 17.42 targets per hour between 1200 and 1900 hours.

The magnitude of total hourly target entrainment over the 2007 study period was observed to generally follow patterns of generation at the Project. Relatively fewer turbine units are operated during nighttime hours at Boundary Dam (from approximately 2200 to 0600 hours) than during the day. Fewer targets were observed passing via the Boundary Dam turbines during the night than the day, presumably a result of decreased unit operations during the night.

There appeared to be a strong relationship between MWH produced and target counts. This relationship may interfere with identifying the temporal distribution of fish passage, although Project operations typically follow a consistent pattern over a 24-hour period. In order to evaluate temporal patterns of passage that were minimally influenced by differences in Project generation, 24-hour total target passage distributions were estimated for a 5-day period from June 7 to 11, 2007. Inflow to the reservoir was relatively high during this time, and all six turbine units operated at essentially full capacity over this period. The temporal distribution of target passage through the entire Boundary powerhouse from June 7 to 11, 2007 is shown in Figure 5.1-11 and Table 5.1-7. Mean sunrise (0456 hours) and sunset (2046 hours) times for the period are shown in the graphic.

For the 5-day period in June with relatively consistent generation, hourly target passage was generally higher during daylight hours than was observed at night. The pronounced spike in passage observed at 0600 hours for the entire 2007 study period (Figure 5.1-10) was less evident during the period of consistent 24-hour generation (Figure 5.1-11), indicating that this increase in entrainment was primarily a result of the increase in Project generation that occurs around this time. During the June 7 to 11 period of uniform generation, 81 percent of total target passage occurred during the approximately 18 hours of daylight (75 percent of the 24-hour day) and 19 percent of total passage occurred during the six nighttime hours (25 percent of the 24-hour day). On average, the proportion of targets passing via the turbine units per hour was slightly higher during daylight hours than at night, but the magnitude of this difference was relatively small.

Patterns of turbine unit operation appeared to influence the magnitude of powerhouse entrainment over a 24-hour period. During a period of generally uniform turbine operation across the powerhouse, a higher proportion of entrained targets were observed per hour during daylight hours than at night, indicating that day/night period also had an effect on passage rates.

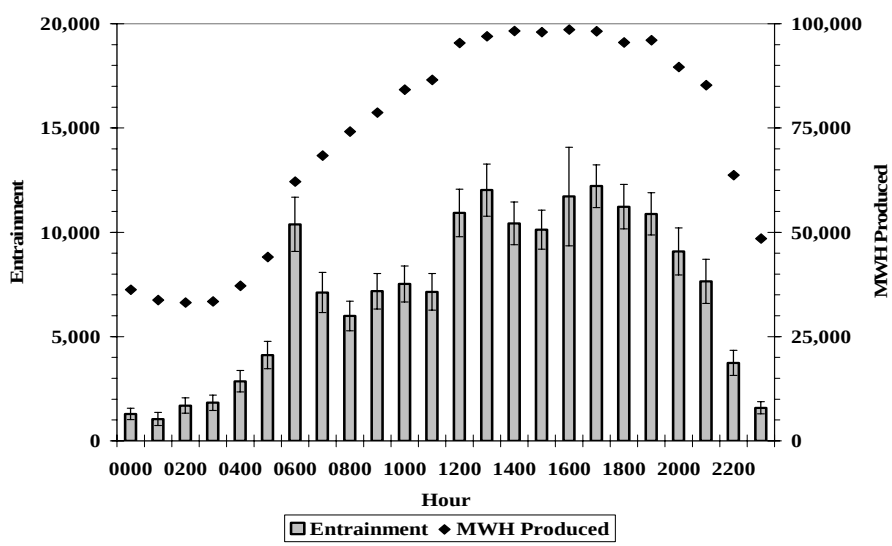

Figure 5.1-10. Diel (24 h) distribution of hydroacoustic target entrainment at the powerhouse (all units combined) over the May 2 through October 15, 2007, study period, with 90 percent CI. Total MWH produced at the Project by hour over the period is displayed on the secondary Y-axis.

Table 5.1-6. Diel (24 h) distribution of hydroacoustic targets entrained at the powerhouse (all units combined) over the May 2 through October 15, 2007, study period, with 90 percent CI. Total MWH produced at all turbine units and entrainment rates (targets per MWH and targets per hour of unit operations) are shown for each hour.

Hour	Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour of Operation
0000	1,288	97	274	36,264	0.04	4.47
0100	1,046	79	315	33,748	0.03	4.10
0200	1,694	122	372	33,177	0.05	6.74
0300	1,829	140	370	33,453	0.05	7.15
0400	2,859	215	510	37,192	0.08	10.05
0500	4,115	294	660	44,052	0.09	11.19
0600	10,383	716	1,297	62,131	0.17	21.67
0700	7,114	456	961	68,408	0.10	13.76
0800	5,981	389	710	74,145	0.08	10.79
0900	7,176	471	853	78,671	0.09	12.38
1000	7,524	481	866	84,172	0.09	12.39
1100	7,143	491	880	86,509	0.08	11.33
1200	10,931	692	1,140	95,401	0.11	15.99
1300	12,023	764	1,256	96,967	0.12	17.42
1400	10,427	697	1,020	98,270	0.11	14.89
1500	10,125	637	940	98,015	0.10	14.33
1600	11,716	714	2,362	98,564	0.12	16.54
1700	12,212	730	1,028	98,186	0.12	17.22
1800	11,232	675	1,065	95,483	0.12	16.01
1900	10,883	655	1,012	96,070	0.11	15.70
2000	9,081	566	1,125	89,624	0.10	13.85
2100	7,648	507	1,061	85,256	0.09	12.39
2200	3,735	235	605	63,721	0.06	7.31
2300	1,586	118	286	48,469	0.03	4.04

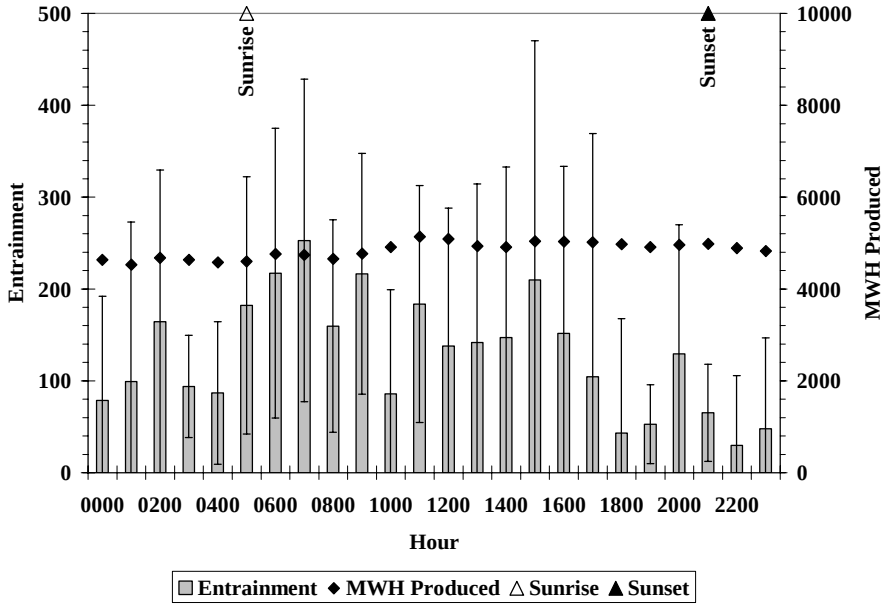

Figure 5.1-11. Diel (24 h) distribution of hydroacoustic target entrainment at the powerhouse (all units combined) from June 7-11, 2007, with 90 percent CI. Turbine unit operations were relatively consistent over the period. Total MWH produced at the Project by hour over the period is displayed on the secondary Y-axis.

Table 5.1-7. Diel (24 h) distribution of hydroacoustic target entrainment at the powerhouse (all units combined) from June 7-11, 2007, with 90 percent CI. Hourly turbine unit operations (MWH produced) were consistent over the 5 day period. Entrainment rates are shown for each hour as targets per MWH and targets per hour of unit operations.

Hour	Entrainment	N	CI 90 Percent (+/-)	MWH Produced	Targets per MWH	Targets per Hour of Operation
0000	79	7	114	4,635	0.02	2.62
0100	99	7	173	4,530	0.02	3.31
0200	164	13	165	4,680	0.04	5.48
0300	94	8	56	4,632	0.02	3.13
0400	87	8	78	4,575	0.02	2.89
0500	182	13	140	4,597	0.04	6.07
0600	217	16	158	4,761	0.05	7.24
0700	253	17	176	4,739	0.05	8.43
0800	160	11	116	4,654	0.03	5.32
0900	217	14	131	4,773	0.05	7.22
1000	86	7	113	4,914	0.02	2.86
1100	184	17	129	5,135	0.04	6.12
1200	138	11	150	5,090	0.03	4.60
1300	142	14	173	4,933	0.03	4.72
1400	147	14	186	4,914	0.03	4.90
1500	210	19	261	5,036	0.04	6.99
1600	152	15	182	5,035	0.03	5.06
1700	105	10	265	5,015	0.02	3.49
1800	43	7	124	4,975	0.01	1.44
1900	53	6	43	4,912	0.01	1.76
2000	129	12	141	4,961	0.03	4.31
2100	65	5	53	4,979	0.01	2.17
2200	30	4	76	4,890	0.01	1.00
2300	48	6	99	4,823	0.01	1.59

Total hydroacoustic target entrainment data at the powerhouse over the reported May 2 to October 15, 2007, study period was segregated into four groups, defined as daytime (0800-1759 h), nighttime (2200-0459 h), sunrise (0500-0759 h), and sunset (1800-2159 h) to examine potential diel differences in entrainment (Figure 5.1-12; Table 5.1-8). Entrainment rates per hour of unit operation were compared to minimize the effect of the different day/night patterns of generation that typically occur at the Project. Entrainment rates per hour of unit operation were observed to be lower during the nighttime than during the day, sunrise, and sunset periods. Entrainment rates during the latter three periods were generally equivalent. These findings were consistent with the diel patterns of total entrainment observed when all units were operated consistently over a 24-hour period (Figure 5.1-11).

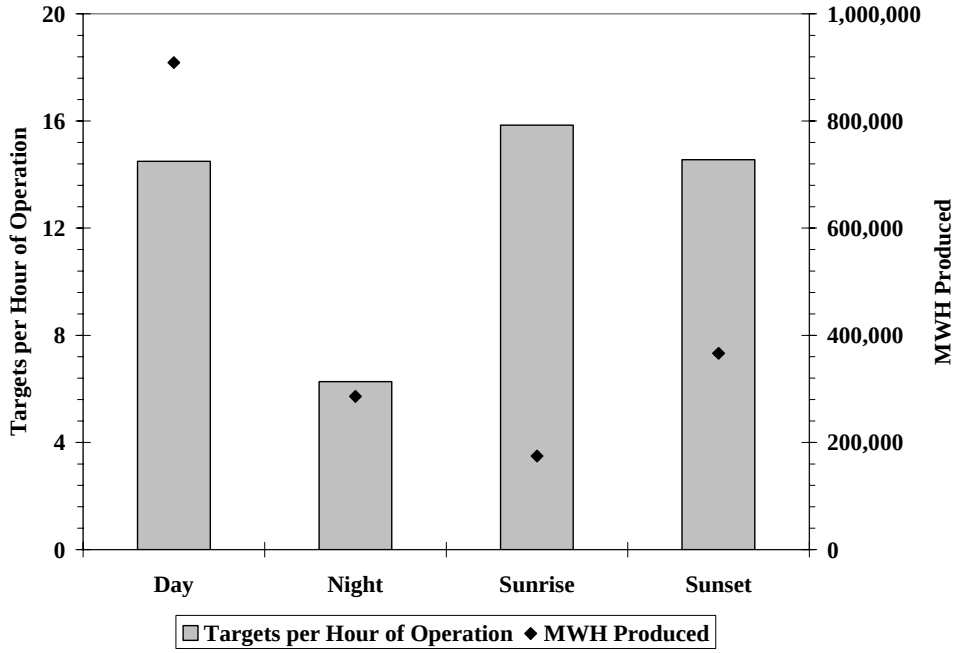

Figure 5.1-12. Diel (24 h) distribution of hydroacoustic target entrainment on a per hour of unit operation at the powerhouse (all units combined) from May 2-October 15, 2007. Total MWH produced at the Project is displayed on the secondary Y-axis.

Table 5.1-8. Diel (24 h) distribution of hydroacoustic target entrainment at the powerhouse (all units combined) from May 2-October 15, 2007, with 90 percent CI. Entrainment rates are shown for each hour as targets per hour of unit operations.

	Hours	Entrainment	N	CI 90% (+/-)	Targets per Hour of Operation
Day	0800-1759	95,257	6,066	3,759	14.50
Night	2200-0459	14,038	1,006	1,042	6.27
Sunrise	0500-0759	21,614	1,466	1,742	15.85
Sunset	1800-2159	38,844	2,403	2,069	14.56

5.1.5. Target Strength Distributions

Target strength (TS) is a measure of the ratio of reflected sound energy to the energy incident on the target and is related to fish length. In general, physically larger targets reflect greater proportions of the transmitted sound, resulting in higher TS values. Mean TS values were transformed to estimated fish lengths in cm using an equation published by Love (1971), which considered multiple fish species monitored in dorsal aspect. Length frequency distributions, median, and mean target strength values of all entrained detections were calculated for each turbine unit on a monthly and study period (May 2 through October 15, 2007) basis. As the fyke net sampling had not been successful as of the end date of the data presented in this report, the

hydroacoustic targets have not been validated as fish. The fish length measures derived from the mean TS estimates are presented for reference only.

Comparisons of mean TS were used to evaluate if significant (α=0.10) differences in the mean size of entrained targets were observed between turbine units. Significant differences that were observed and that were consistent over time might indicate potential differences in the size composition of targets entrained at different intakes. These differences may bias species apportionment of the hydroacoustic counts based on fyke net samples collected at a single turbine location.

Length frequency distributions calculated from the hydroacoustic TS measurements for the powerhouse (all units combined) were summarized by month (Figure 5.1-13; Table 5.1-9), on a weekly basis (Figure 5.1-14; Table 5.1-10), and by turbine unit over the entire 2007 sampling period (Figure 5.1-15; Table 5.1-11). In addition, TS was evaluated by turbine unit on a monthly basis to assess potential changes in target strength by location over time (Figure 5.1-16; Table 5.1-12). Diel (24-hour) distributions of target strength for all turbine units combined over the May 2 through October 15, 2007, study period are given in Figure 5.1-17 and Table 5.1-13. The 90 percent confidence intervals surrounding each TS and length estimate are shown (where appropriate) in each figure and table.

Length frequency histogram distributions at the turbine units were similar on a seasonal basis (Figure 5.1-13; Table 5.1-9). Median length values ranged from 13.46 cm (5 inches) in July to 15.89 cm (6 inches) in October.

The mean TS of hydroacoustic detections at the powerhouse for all turbines combined was similar between May and August and then showed a minor (but significant) increase during September and October (Table 5.1-9). This change indicated an increase in mean fish size in the late summer and early fall period.

As discussed above, positive identification of the entrained hydroacoustic targets has not yet been accomplished and is pending successful fyke net sampling. If the hydroacoustic targets are assumed to be fish, the mean monthly TS values would result in estimated mean fish lengths of approximately 16 to 21 cm (6 to 8 inches), with a median estimated fish length of 18 cm (7 inches).

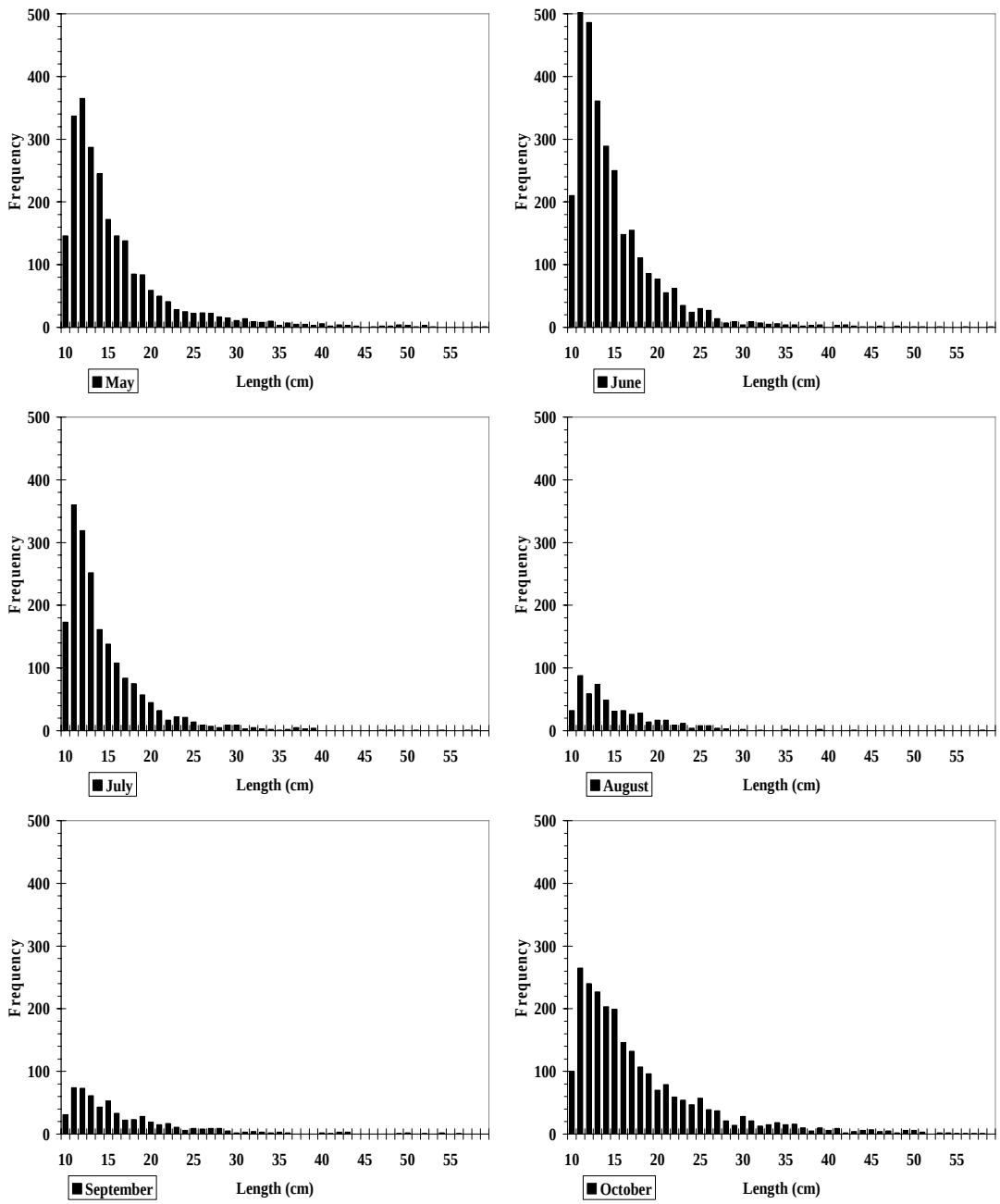

Figure 5.1-13. Monthly estimated fish length frequency (based on Love 1971) distributions of all entrained hydroacoustic targets, for all turbine intakes combined over the entire May 2 through October 15, 2007, study period.

Table 5.1-9. Monthly median and mean target strength (TS) estimates and corresponding estimated mean fish length (based on Love 1971) for all turbine units combined over the May 2 through October 15, 2007, study period. The 90 percent CI bounds surrounding each monthly TS and length estimates are included.

Month	N	Median TS (dB)	Mean TS (dB)	Mean TS CI 90 Percent (+/-)	Median Length (cm)	Mean Length (cm)	Mean Length CI 90 Percent (+/-)
May	2,430	-41.99	-39.82	0.47	14.32	18.61	1.09
June	3,019	-42.27	-40.85	0.21	13.85	16.44	0.43
July	1,955	-42.51	-41.04	0.28	13.46	16.06	0.54
August	528	-42.08	-40.55	0.49	14.17	17.04	1.04
September	592	-41.47	-38.85	0.69	15.26	20.91	1.81
October	2,430	-41.13	-38.82	0.30	15.89	21.00	0.78

On a weekly basis, mean TS was generally consistent over the 2007 study period, approximately -40 to -41 dB. These mean TS values were equivalent to estimated fish lengths of 16 to 18 cm, or 6 to 7 inches, based on Love (1971). Minor, but significant, increases in the mean TS of acoustic detections occurred during Week 21 (May 27 through June 2), and Weeks 36-40 (September 2 through October 6). During these weeks, mean TS was approximately -38 to -39 dB, equivalent to estimated fish lengths of 20 to 24 cm (8 to 9 inches) based on Love (1971). Hydroacoustic targets have not yet been verified as fish, and the length values are presented for reference only.

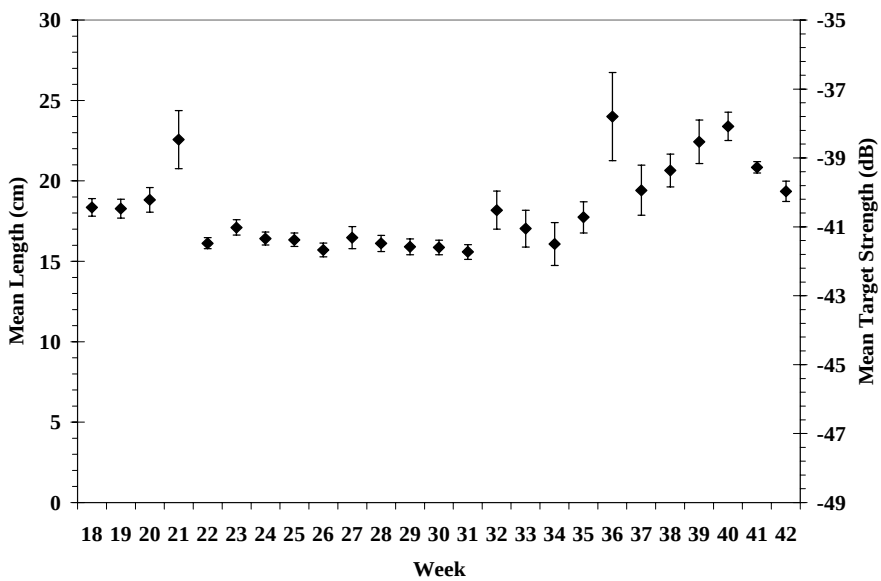

Figure 5.1-14. Weekly mean target strength (TS) and corresponding estimated mean fish length (based on Love 1971) for all turbine units combined over the May 2 through October 15, 2007, study period. The 90 percent CI bounds surrounding each weekly TS and length estimate are shown.

Table 5.1-10. Weekly mean target strength (TS) and corresponding estimated mean fish length (based on Love 1971) for all turbine units combined over the May 2 through October 15, 2007, study period. The 90 percent CI bounds surrounding each weekly TS and length estimate are shown.

Week	Date	N	Mean TS (dB)	TS CI 90 Percent (+/-)	Mean Length (cm)	Length CI 90 Percent (+/-)
18	5/2-5/5	594	-39.93	0.56	18.35	1.27
19	5/6-5/12	591	-39.97	0.59	18.27	1.34
20	5/13-5/19	513	-39.72	0.76	18.83	1.81
21	5/20-5/26	297	-38.22	1.80	22.56	5.48
22	5/27-6/2	673	-41.01	0.34	16.12	0.68
23	6/3-6/9	686	-40.52	0.48	17.10	1.02
24	6/10-6/16	894	-40.86	0.41	16.42	0.83
25	6/17-6/23	766	-40.90	0.42	16.34	0.86
26	6/24-6/30	435	-41.23	0.44	15.70	0.85
27	7/1-7/7	504	-40.83	0.69	16.47	1.43
28	7/8-7/14	496	-41.01	0.50	16.11	1.01
29	7/15-7/21	365	-41.13	0.49	15.90	0.98
30	7/22-7/28	452	-41.14	0.45	15.86	0.88
31	7/29-8/4	281	-41.29	0.47	15.58	0.90
32	8/5-8/11	110	-40.01	1.19	18.18	2.80
33	8/12-8/18	114	-40.55	1.15	17.03	2.53
34	8/19-8/25	57	-41.03	1.33	16.08	2.79
35	8/26-9/1	132	-40.22	0.97	17.74	2.21
36	9/2-9/8	19	-37.71	2.74	24.00	9.38
37	9/9-9/15	79	-39.47	1.56	19.42	4.01
38	9/16-9/22	293	-38.95	1.02	20.65	2.71
39	9/23-9/29	161	-38.27	1.35	22.43	3.98
40	9/30-10/6	282	-37.92	0.88	23.39	2.62
41	10/7-10/13	1,877	-38.88	0.35	20.85	0.91
42	10/14-10/15	283	-39.50	0.63	19.35	1.53

The mean TS of hydroacoustic targets entrained at each turbine intake was similar on a study period basis (Figure 5.1-15, Table 5.1-11). The mean TS values were between approximately -39 to -41 dB, equivalent to estimated mean fish lengths of 17 to 20 cm, or about 7 inches. Mean TS at Unit 53 was slightly, but significantly, higher than at the other turbine units (-39 dB, equivalent to an estimated mean fish length of 20 cm, or 8 inches). The decrease in the frequency of targets with estimated lengths of 10 to 11 cm in Figure 5.1-15 and Table 5.1-11 is caused by the 4-inch minimum target size "cutoff" applied to the hydroacoustic entrainment data set to exclude targets smaller than the minimum size of interest. A length of 4 inches is equivalent to 10.2 cm, resulting in a reduced total bin size relative to the remaining 1-cm length bins. The length frequency distribution of the 2007 Boundary Dam hydroacoustic data set was evaluated without applying a 4-inch minimum target size threshold to confirm the threshold effect, and the frequency of entrained targets was observed to increase with diminishing target size for estimated lengths at and below 4 inches.

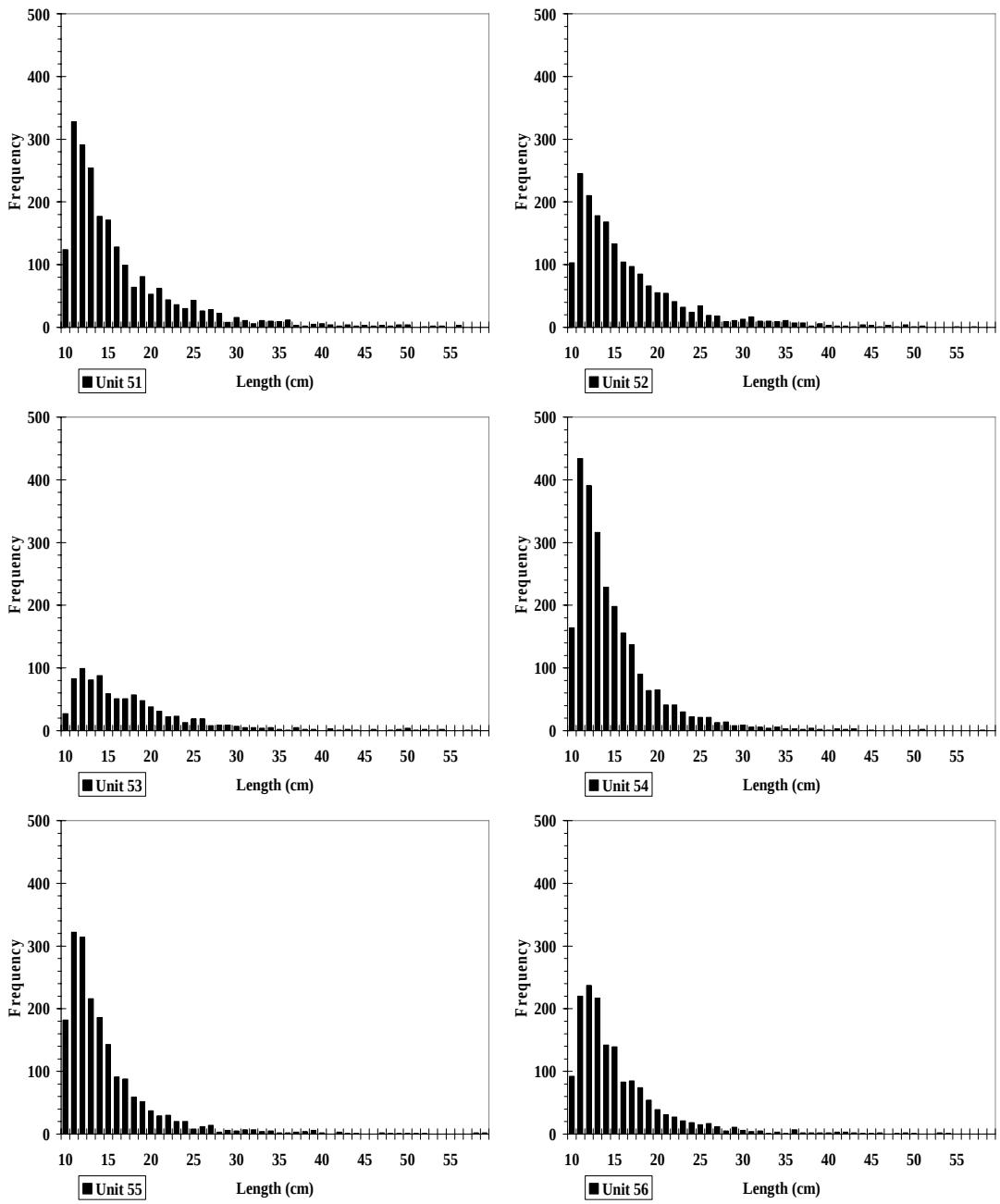

Figure 5.1-15. Estimated fish length frequency distributions (based on Love 1971), of all entrained hydroacoustic targets, at each turbine intake opening over the entire May 2 through October 15, 2007, study period.

Table 5.1-11. Median, mean target strength and calculated mean length (based on Love 1971) with corresponding 90 percent CI, by unit, at the powerhouse for the May 2 through October 15, 2007, study period.

Unit	N	Median TS (dB)	Mean TS (dB)	Mean TS CI 90 Percent (+/-)	Median Length (cm)	Mean Length (cm)	Mean Length CI 90 Percent (+/-)
51	2,206	-42.05	-39.69	0.32	14.22	18.89	0.74
52	1,822	-42.11	-39.43	0.34	14.12	19.51	0.83
53	901	-42.31	-39.05	0.47	13.79	20.42	1.18
54	2,522	-42.47	-40.78	0.25	13.51	16.57	0.51
55	1,904	-41.46	-40.24	0.59	15.27	17.69	1.30
56	1,599	-41.11	-40.25	0.36	15.93	17.66	0.78

Figure 5.1-16 and Table 5.1-12 show mean TS by turbine unit on a monthly basis over the study period. Length frequency histograms by turbine unit on a monthly basis over the study period are given in Appendix 2. Mean TS by unit was similar between May and August, with slightly higher mean TS observed at Unit 53 relative to the other turbines. Mean TS generally increased at all units in September and October. Turbine Units 53 and 54 exhibited increased mean TS during September relative to the other units, but these differences were not significant at α=0.10. Observed differences in mean TS between turbine units on both a monthly and study period basis were deemed minor and unlikely to indicate a potential difference in the size composition of targets entrained at different intakes.

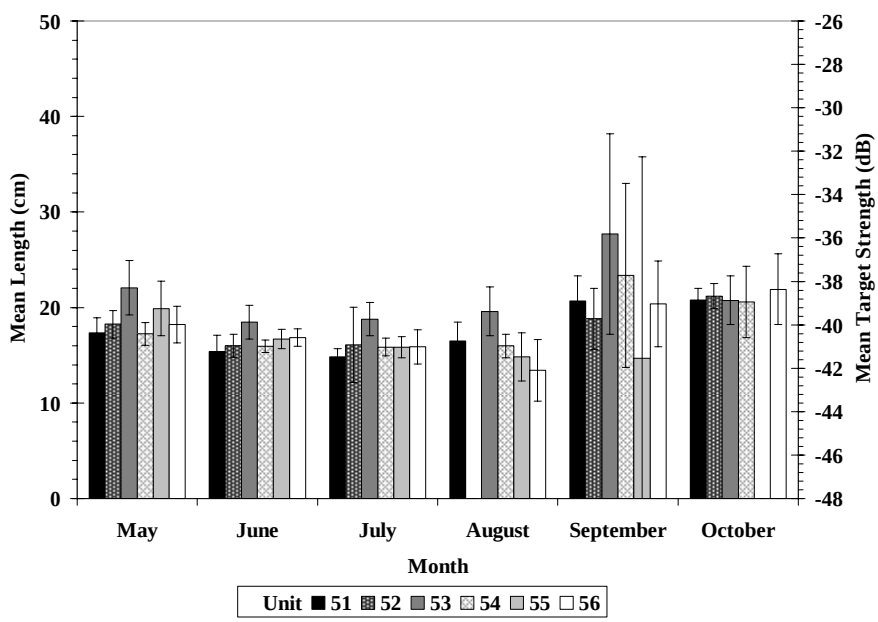

Figure 5.1-16. Monthly mean target strength (TS), and corresponding estimated mean length based on Love (1971) by turbine unit over the May 2 through October 15, 2007, study period. The 90 percent CI bounds surrounding each estimate are shown. Note: Unit 52 did not operate in August and Unit 55 was not operational during the October sampling period.

Table 5.1-12. Monthly mean target strength (TS), and corresponding estimated mean length based on Love (1971) by turbine unit over the May 2 through October 15, 2007, study period. The 90 percent CI bounds surrounding each estimate are shown. Note: Unit 52 did not operate in August and Unit 55 was not operational during the October sampling period.

Month	Unit	N	Mean TS (dB)	Mean TS CI 90 Percent (+/-)	Mean Length (cm)	Mean Length CI 90 Percent (+/-)
May	51	307	-40.40	0.72	17.35	1.58
May	52	457	-39.99	0.63	18.24	1.44
May	53	132	-38.41	1.01	22.07	2.84
May	54	551	-40.45	0.55	17.24	1.18
May	55	687	-39.27	1.11	19.88	2.85
May	56	296	-40.00	0.83	18.21	1.91
June	51	169	-41.41	0.89	15.37	1.73
June	52	249	-41.08	0.60	15.99	1.20
June	53	116	-39.89	0.76	18.46	1.78
June	54	963	-41.10	0.33	15.96	0.65
June	55	771	-40.72	0.49	16.69	1.02
June	56	751	-40.65	0.43	16.84	0.90
July	51	327	-41.71	0.46	14.82	0.85
July	52	41	-41.03	1.81	16.09	3.92
July	53	228	-39.74	0.74	18.79	1.74
July	54	685	-41.15	0.47	15.86	0.93
July	55	383	-41.15	0.57	15.84	1.13
July	56	291	-41.13	0.89	15.89	1.79
August	51	131	-40.81	0.93	16.51	1.97
August	52	0	0	0	0	0
August	53	152	-39.39	1.01	19.60	2.53
August	54	170	-41.08	0.62	15.98	1.24
August	55	61	-41.70	1.30	14.83	2.52
August	56	14	-42.53	1.79	13.43	3.23
September	51	260	-38.94	0.99	20.70	2.62
September	52	158	-39.73	1.31	18.81	3.21
September	53	47	-36.52	2.66	27.70	10.48
September	54	27	-37.93	2.86	23.36	9.63
September	55	2	-41.78	7.38	14.68	21.08
September	56	98	-39.07	1.65	20.37	4.48
October	51	1,012	-38.90	0.48	20.78	1.23
October	52	917	-38.74	0.49	21.19	1.29
October	53	226	-38.92	0.96	20.75	2.55
October	54	126	-38.99	1.38	20.57	3.73
October	55	0	0	0	0	0
October	56	149	-38.46	1.30	21.92	3.71

Hydroacoustic target data at the powerhouse was segregated into four groups, defined as daytime (0800-1759 h), nighttime (2200-0459 h), sunrise (0500-0759 h), and sunset (1800-2159 h) to examine diel differences in entrainment. Length frequency histograms for each of these periods are given in Figure 5.1-17. The estimated mean lengths are based on the TS-length relationship published by Love (1971). From May 2 to the conclusion of the reported 2007 study period on October 15, the time of sunrise varied by 1 hour and 37 minutes, and sunset by 2 hours and 1 minute (as measured at Spokane). The periods that define sunrise and sunset used for these analyses encompassed the actual times of these events over the study

Over the study period of May 2 through October 15, 2007, significant differences in mean TS and the corresponding estimated target lengths were not observed on a diel (24-hour) basis for all turbine units combined (Table 5.1-13). On average, the estimated length distribution of entrained targets at the powerhouse was similar over a 24-hour period.

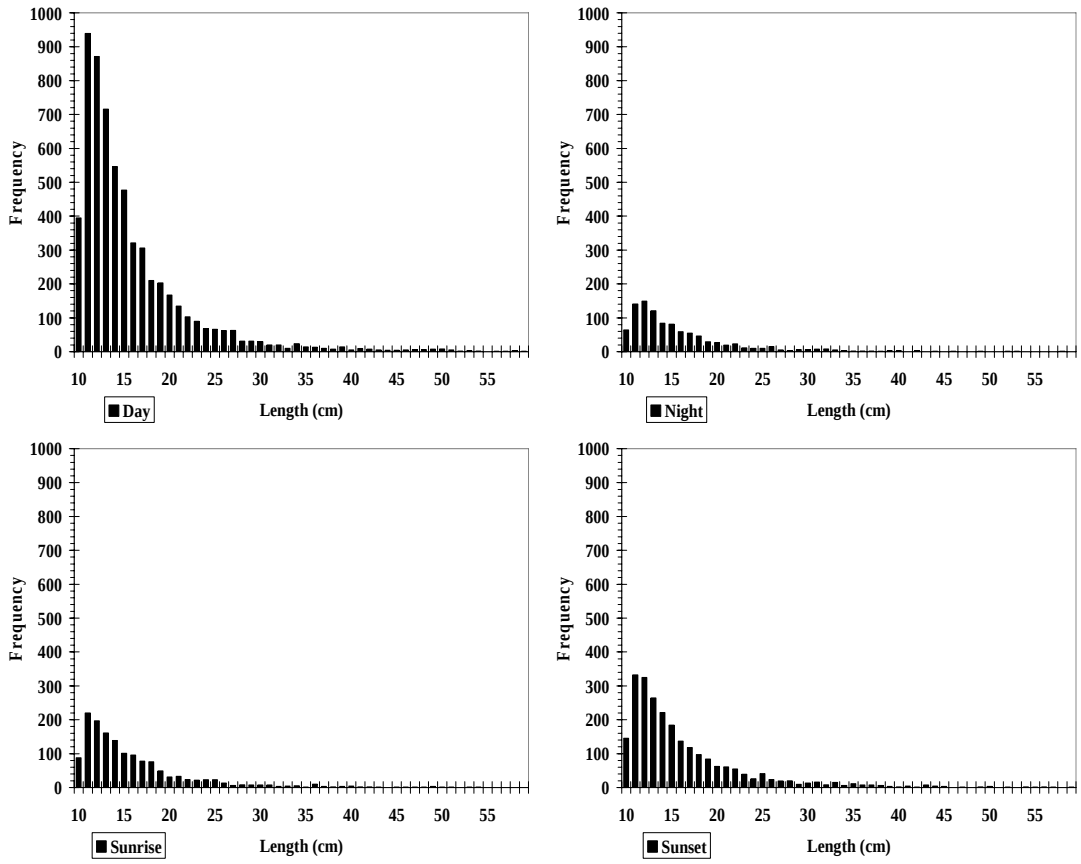

Figure 5.1-17. Estimated length frequency distributions for the daytime, nighttime, sunrise and sunset periods computed from the mean TS of all hydroacoustic targets at the powerhouse over the May 2 through October 15, 2007, study period. The estimated mean lengths are based on the TS-length relationship published by Love (1971).

Table 5.1-13. Diel (24 h) distribution of the median and mean TS of hydroacoustic targets at all turbine units combined over the May 2 through October 15, 2007, study period, with surrounding 90 percent CI. The estimated mean lengths are based on the TS-length relationship published by Love (1971).

	Hours	N	Median TS (dB)	Mean TS (dB)	Mean TS CI 90 Percent (+/-)	Median Length (cm)	Mean Length (cm)	Mean Length CI 90 Percent (+/-)
Day	0800-1759	6069	-42.07	-40.06	0.11	14.19	18.07	0.24
Night	2200-0459	1012	-41.99	-40.22	0.16	14.33	17.72	0.36
Sunrise	0500-0759	1468	-41.96	-40.00	0.16	14.38	18.20	0.36
Sunset	1800-2159	2405	-41.77	-39.71	0.14	14.70	18.86	0.32

5.1.6. Target Approach Distributions

The manner in which entrained targets were distributed in the monitored area immediately upstream of the turbine intakes was quantified using percent vertical distributions, target approach vectors with depth, and horizontal distributions of targets across the intake openings.

5.1.6.1. Vertical Distributions

The vertical distributions of entrained hydroacoustic targets entrainment are summarized by turbine unit over the May 2 through October 15, 2007, sampling period in Figures 5.1-18 and Figure 5.1-19. These distributions show the percentage of total target entrainment by 3.3 foot (1-m) range (depth) strata at each turbine intake over the entire study period (Figure 5.1-18) and for all turbine units combined on a monthly basis (Figure 5.1-19). For reference, the top of each turbine intake was located 30.8 feet (9.4 m) below the monitoring transducers, and the bottom of each intake was located at a range of between 59.0 to 65.6 feet (18 to 20 m). The vertical distributions represent the percentage of all targets observed in each 3.3 foot (1-m) depth stratum within the acoustic sampling volumes, which were aligned with the centerline of each turbine unit. All targets were weighted to account for spreading of the acoustic volume with range, as described in Section 4.1.1.

The percent vertical distribution of targets entering the intakes was similar for all six turbines over the entire May 2 through October 15, 2007, study period. The majority of targets entered the intake in the upper 13 to 16 feet (4 to 5 m) of the intake openings, and percent entrainment gradually decreased with increasing depth below that point. The relative decrease in percent entrainment observed in the 29-foot (9-m) stratum at all intakes (relative to the deeper 33-foot (10-m) stratum was a result of the reduced size of the uppermost stratum. Targets above the 30.8 feet (9.4 m) range (the top of each intake) were not included in the acoustic counts, resulting in an approximately 2-foot (0.6-m)-tall area in Stratum 9, relative to a 3.3-foot (1-m) area for the remaining strata. The skewed percent vertical distributions observed at all turbine intakes are consistent with entrainment of surface-oriented targets.

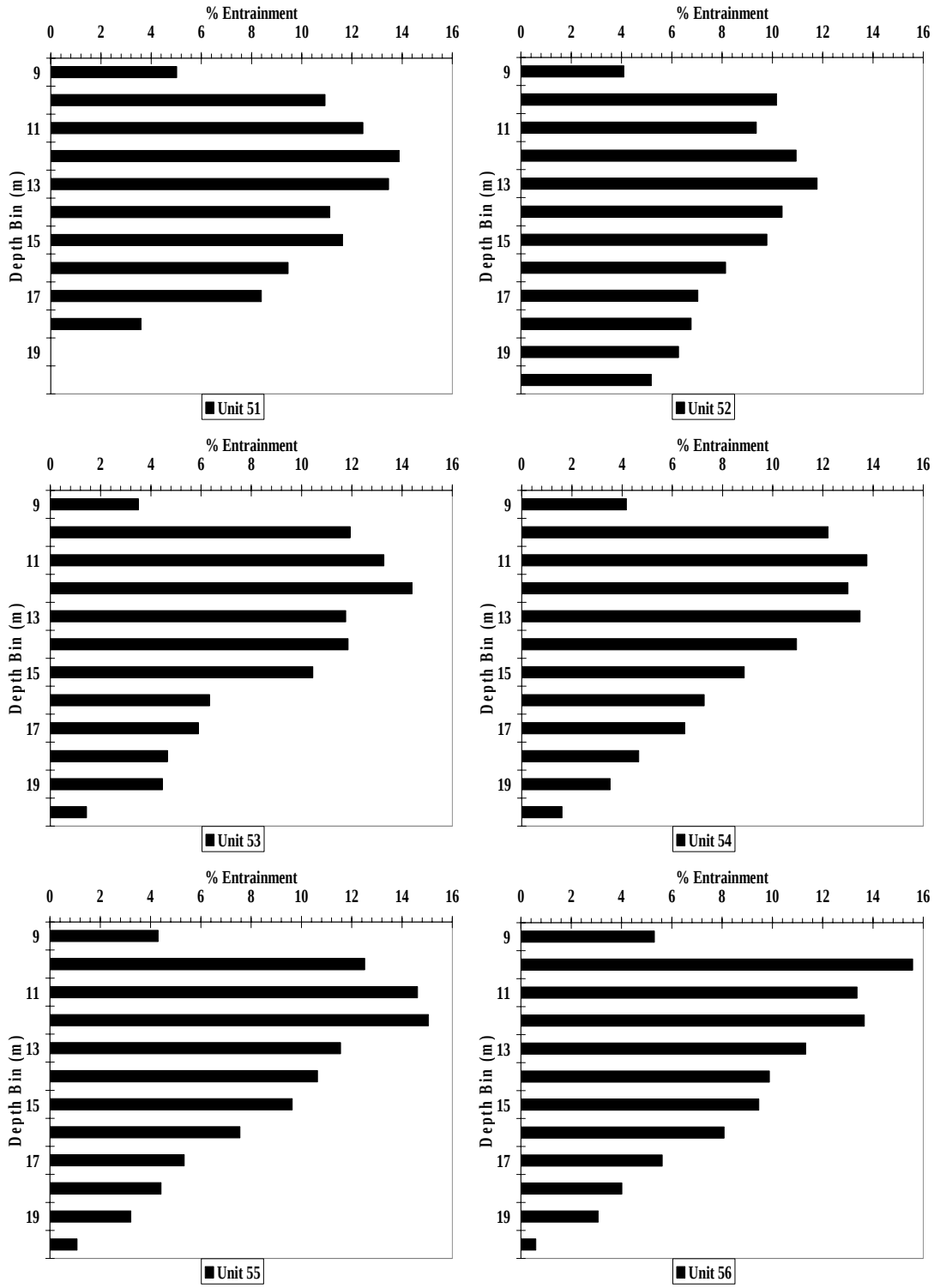

Figure 5.1-18. Percent vertical distribution of all entrained hydroacoustic targets at each turbine intake opening over the entire May 2 through October 15, 2007, study period. Estimates represent the percentage of all targets passing each 1-m range stratum from the top to bottom of each intake. Note: The 9 m range stratum only extends from 9.4 to 10.0 m, encompassing only a 0.6 m high sample.

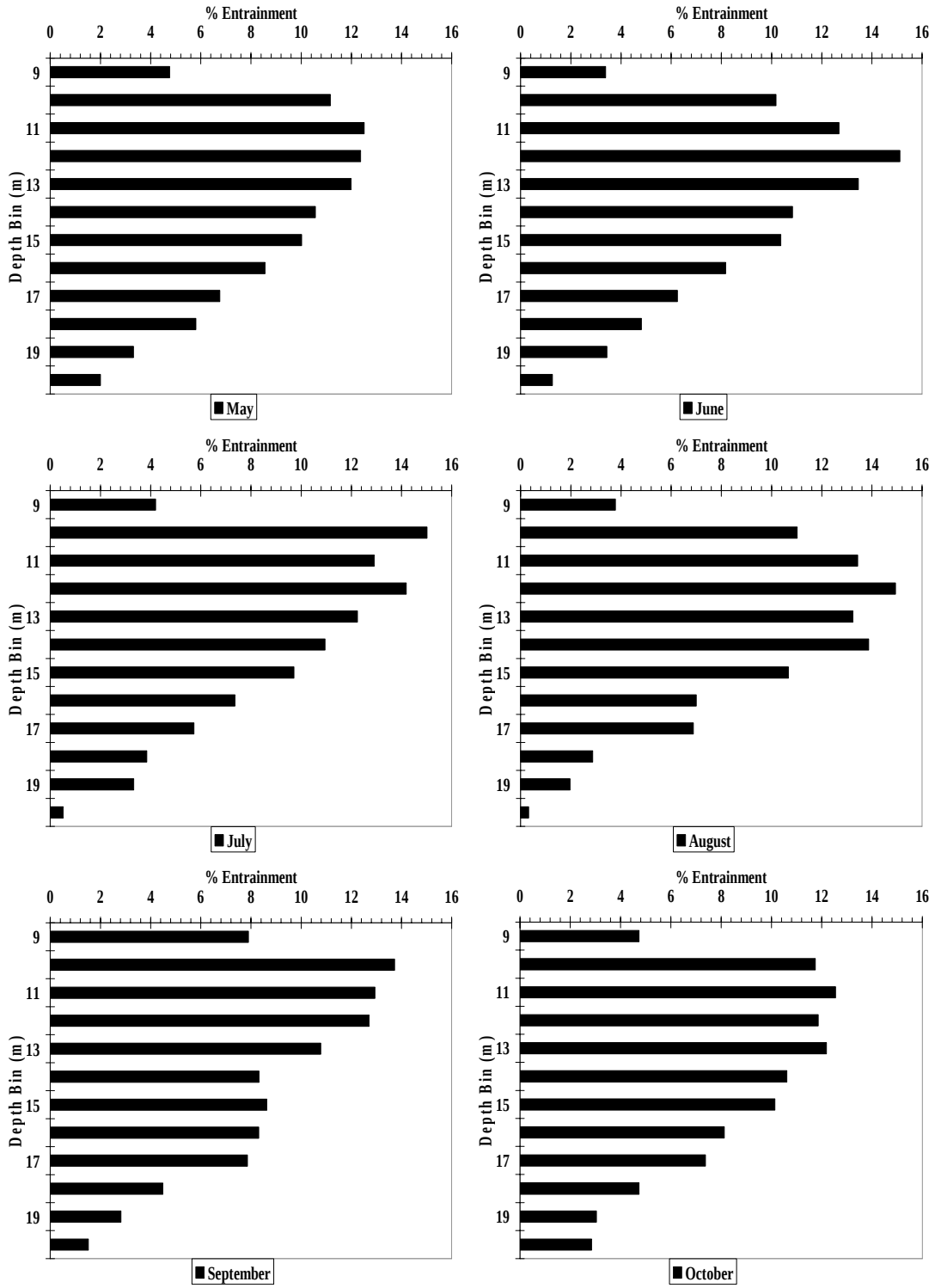

Figure 5.1-19. Percent vertical distribution of all entrained hydroacoustic targets at all turbine units combined on a monthly basis over the May 2 through October 15, 2007, study period. Estimates represent the percentage of all targets passing each 1-m range stratum from the top to bottom of each intake. Note: The 9 m range stratum only extends from 9.4 to 10.0 m, encompassing only a 0.6 m high sample.

5.1.6.2. Intake Approach Vectors

The mean vertical approach vectors of targets transiting the acoustic sampling volumes at each turbine intake are summarized for each 3.3-foot (1-m) range stratum in Figure 5.1-20, Figure 5.1-21, Figure 5.1-22, Figure 5.1-23, Figure 5.1-24, and Figure 5.1-25. The target approach angles perpendicular to the intake face (transducer Y-axis) were summarized with depth (transducer Z-axis) to quantify the approach patterns of entrained detections. Each color coded vector represents the corresponding percentage of targets within a given stratum approaching at the shown angle.

Target approach vectors with depth were generally similar at all turbine intakes. Targets observed near the top of each intake tunnel tended to descend in the water column, consistent with movement from the surface into the intake. Detections entering the intake at intermediate depths tended to have little vertical movement, as evidenced by their relatively horizontal approach vectors. Targets moving into the intake at depth, near the bottom of each intake (at ranges exceeding approximately 56 feet (17 m)) tended to have ascending vectors, consistent with movement up into the intake from near the bottom of the forebay intake channel. Maximum sampling ranges to the bottom were approximately 69 feet (21 m) for all intakes, with the exception of Unit 51. The sampling range at Unit 51 was 59 feet (18 m), presumably a result of debris that had accumulated at the base of that intake, which is located at the terminal end of the forebay intake channel.

The approach distributions were consistent with targets entrained in flow, and probably describe the hydraulic conditions present in the area immediately upstream of the intake openings.

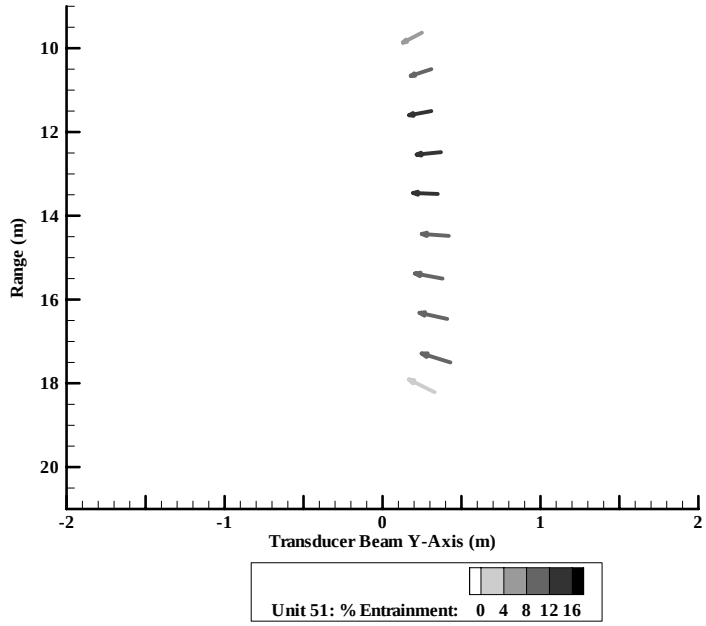

Figure 5.1-20. Target approach vectors considering all targets entrained at Unit 51 over the May 2 through October 15, 2007, study period. The X-axis units are in meters relative to the transducer axis, with positive values indicating increasing distance upstream from the intake opening.

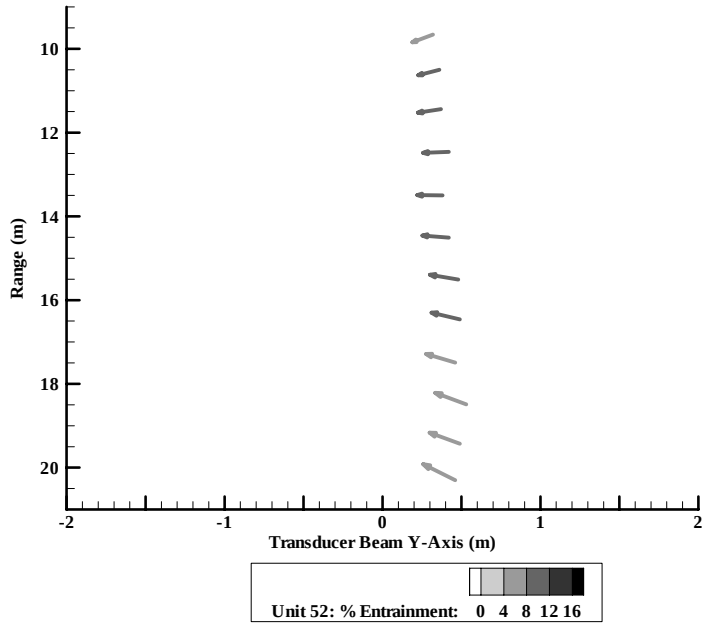

Figure 5.1-21. Target approach vectors considering all targets entrained at Unit 52 over the May 2 through October 15, 2007, study period. The X-axis units are in meters relative to the transducer axis, with positive values indicating increasing distance upstream from the intake opening.

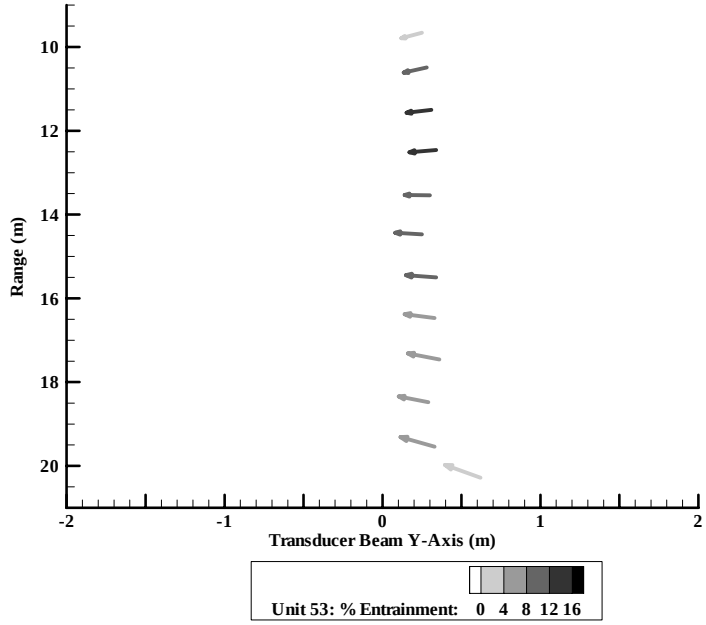

Figure 5.1-22. Target approach vectors considering all targets entrained at Unit 53 over the May 2 through October 15, 2007, study period. The X-axis units are in meters relative to the transducer axis, with positive values indicating increasing distance upstream from the intake opening.

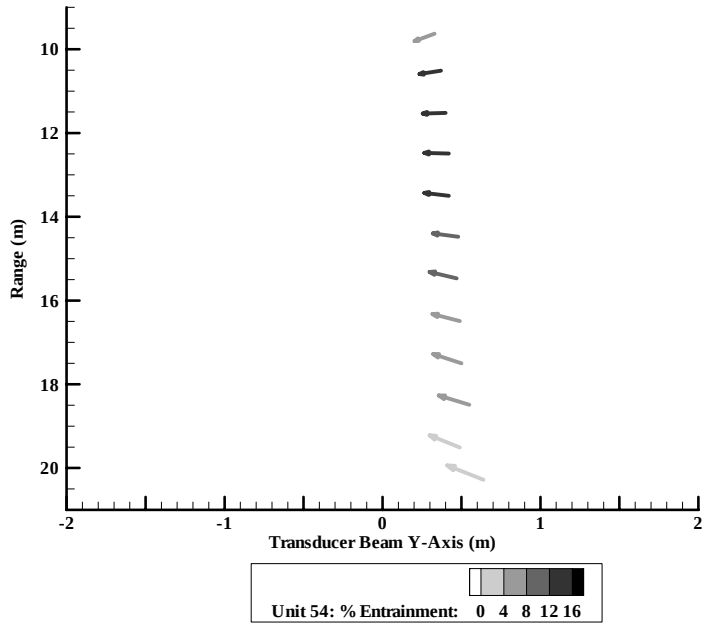

Figure 5.1-23. Target approach vectors considering all targets entrained at Unit 54 over the May 2 through October 15, 2007, study period. The X-axis units are in meters relative to the transducer axis, with positive values indicating increasing distance upstream from the intake opening.

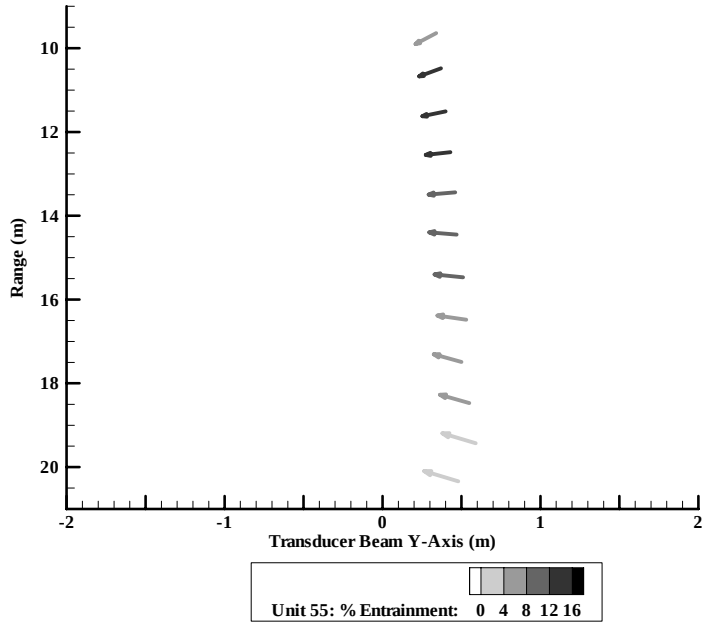

Figure 5.1-24. Target approach vectors considering all targets entrained at Unit 55 over the May 2 through October 15, 2007, study period. The X-axis units are in meters relative to the transducer axis, with positive values indicating increasing distance upstream from the intake opening.

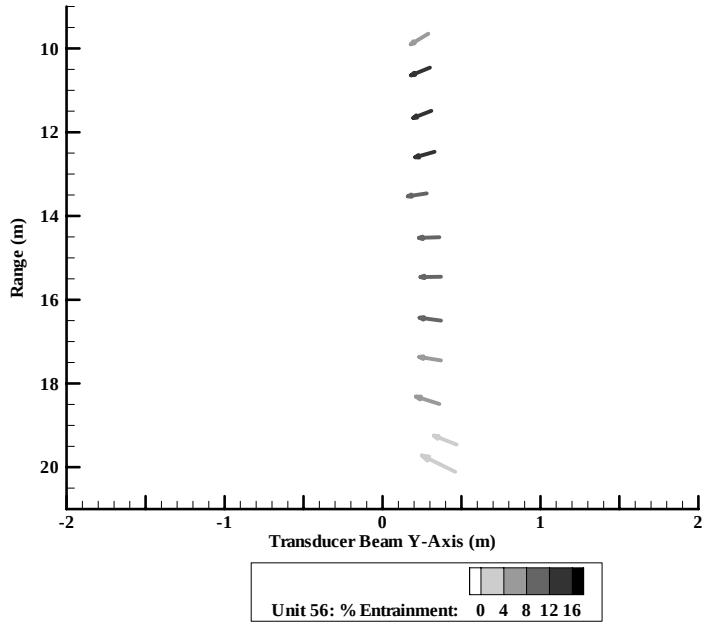

Figure 5.1-25. Target approach vectors considering all targets entrained at Unit 56 over the May 2 through October 15, 2007, study period. The X-axis units are in meters relative to the transducer axis, with positive values indicating increasing distance upstream from the intake opening.

5.1.6.3. Spatial Distribution of Turbine Entrainment

Distributions of target entrainment in the transducer X-axis (horizontal or left-right position relative to the transducer centerline) were evaluated to assess if detections passed into the units in a uniform manner, or were skewed within the intake opening. Each hydroacoustic detection was positioned in three-dimensional space as it entered the turbine intakes. The mean X-axis position of all targets as they entered each turbine was calculated and compared with a normal (random) distribution. The objective of this evaluation was to assess whether the assumption of normal distribution of targets across the turbine intakes used to weight hydroacoustic detections to total unit passage was valid. The results of the analysis could be used to refine the spatial weighting assumptions used to extrapolate the hydroacoustic detections to total entrainment, which currently assume uniform target distribution across the total turbine intake width.

Figure 5.1-26 and Table 5.1-14 present a cumulative percent distribution of all entrained hydroacoustic targets observed at all six turbine intakes over the May 2 through October 15, 2007, study period. The X-axis represents the intake width, with the origin located at the left side of the intake opening, facing upstream (that is, the side of the intake closest to the forebay trash racks). The Y-axis represents the cumulative percentage of all entrained targets that passed into the intake at any given point moving from left-to-right across the intake. The dotted line represents the expected distribution if fish entered the intakes in a randomly distributed manner across the X-axis, so that 50 percent of all targets were entrained on either side of the unit centerlines. The vertical line represents the transducer axis, which was oriented with the unit centerlines.

The cumulative percent distribution suggests that the distribution of acoustic targets as they enter the turbine intakes is slightly skewed to the upstream or eastern side of the intakes, with 62 percent of all targets being detected in the left side of the acoustic beam. The results shown in Figure 5.1-26 indicate that most targets are passing into the turbine intakes in the upstream left-hand side of the intakes. These results are consistent with the contour plot of target entrance into the turbine intakes shown in Figure 5.1-27. This latter figure presents relative densities of targets in 100 spatial bins across each intake opening. The X-axis represents horizontal distance across each turbine intake, with the origin located at the eastern edge of the intakes, and the Y-axis represents range from the transducer (with the top of each intake located at a depth of 29.5 feet [9 m]). The contour plot indicates that the largest percentage of targets entered the turbines in the upper half of the intakes and was skewed toward the eastern (upstream) side.

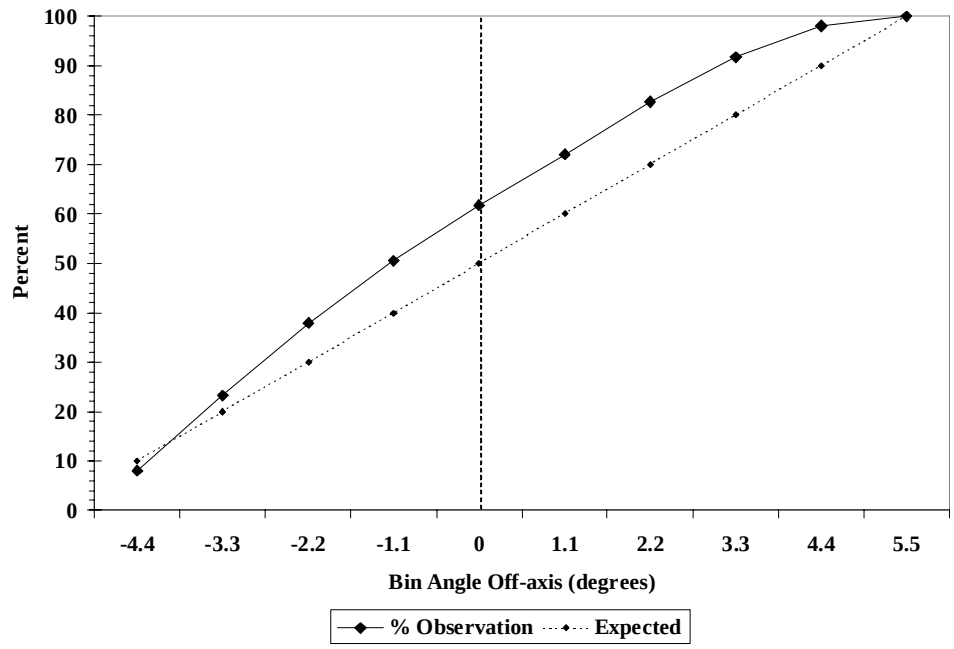

Figure 5.1-26. Cumulative percent distribution of entrained hydroacoustic targets, and expected distribution of targets at the powerhouse for the May 2 through October 15, 2007, study period.

Table 5.1-14. Horizontal distribution (angle off X-axis) of hydroacoustic targets entering all turbine intakes over the May 2 through October 15, 2007, study period. The percent and cumulative percent of all targets within each horizontal bin are given. The -5.5 degree bin represents the eastern (upstream) edge of the transducer beams and the 5.5 degree bin the western (downstream edge).

Bin Angle Off-axis (degrees)	-5.5	-4.4	-3.3	-2.2	-1.1	0	1.1	2.2	3.3	4.4	5.5
Actual Observations	0	799	1536	1475	1260	1133	1028	1063	914	638	191
Percent Observation	0.00	7.96	15.30	14.70	12.55	11.29	10.24	10.59	9.11	6.36	1.90
Cumulative Percent Observation	0.00	7.96	23.26	37.96	50.51	61.80	72.04	82.63	91.74	98.10	100.00

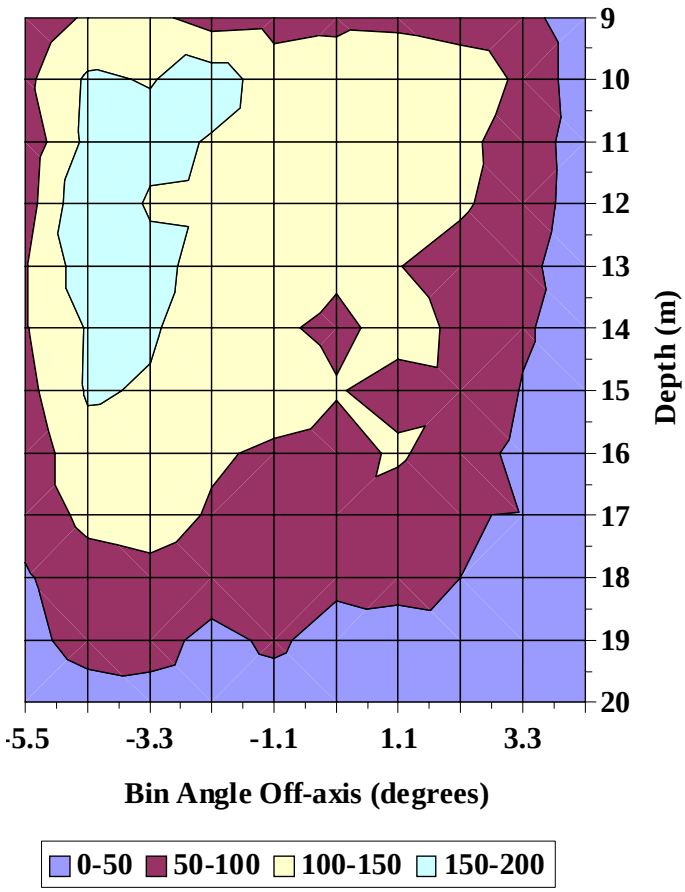

Figure 5.1-27. Density distribution plot of all hydroacoustic targets entrained at the powerhouse (all turbines combined) across the X-axis (left-right across the intakes) and with depth (Z-axis). All observations over the May 2 through October 15, 2007, study period are considered. Projection is looking out to the forebay from inside of the turbine intake openings, with the plot origin located on the eastern edge.

5.2. Hydroacoustic Spillway Distributions

Spillway entrainment distributions based on the hydroacoustic monitoring are presented below in Sections 5.2.1 to 5.2.3. The results of the spillway gill net sampling are summarized in Section 5.2.4 of this report and are described in greater detail in the Study No. 9 Fish Distribution, Timing, and Abundance Study interim report (SCL 2008).

5.2.1. Total Estimated Entrainment

Estimated total hydroacoustic target entrainment was summarized for each spill event by individual spill bay and examined for trends in relative entrainment. Entrainment rates per unit of flow were also calculated and compared to evaluate potential effects of variable spill levels on target entrainment by spill gate. The number of targets per hour of spill gate operation was evaluated as a relative measure of passage per unit of water volume.

Nine spill events occurred during June 2007, totaling 37 hours of spill (Table 5.2-1). Various spill patterns were examined using different spill levels at the two gates. These spill levels varied from 1,000 to 10,000 cfs per gate. Spill generally occurred concurrently from both spill gates during the nine spill events, but was restricted to a single gate in some tests. A total of 29 hours of spill occurred at Spill Gate 1 (the west gate, closest to the powerhouse), and 28 hours occurred at Spill Gate 2 (closest to the east shore of the reservoir).

Table 5.2-1. Time, duration and spill target level (cfs) for each spill gate, for all spill events at Boundary Dam, June 2007.

Test No.	Start Date	Start Time	End Date	End Time	Spill Gate #1	Spill Gate #2	Hours of Spill
1	8 June	00:00	8 June	04:00	---	10,000	4.0
2	8 June	23:00	9 June	03:00	2,000	8,000	4.0
3	9 June	03:00	9 June	07:00	5,000	5,000	4.0
4	9 June	07:00	9 June	11:00	10,000	---	4.0
5	13 June	11:00	13 June	16:00	5,000	---	5.0
6	17 June	19:00	17 June	23:00	---	5,000	4.0
7	17 June	23:00	18 June	03:00	1,000	4,000	4.0
8	18 June	03:00	18 June	07:00	2,500	2,500	4.0
9	15 June	00:00	15 June	04:00	7,500	7,500	4.0

5.2.2. Spillway Entrainment Distributions

Figure 5.2-1 shows total estimated target passage at each spill gate relative to the total gate spill passing that gate (in million cubic feet, or mcf) for the nine 2007 spill events. A linear relationship is fitted to the data for reference. Although there was a generally positive correlation between increased spill volume and entrainment, the two variables were not significantly associated (α=0.10). Spillway entrainment was variable between tests during the relatively short period of spill evaluated in 2007.

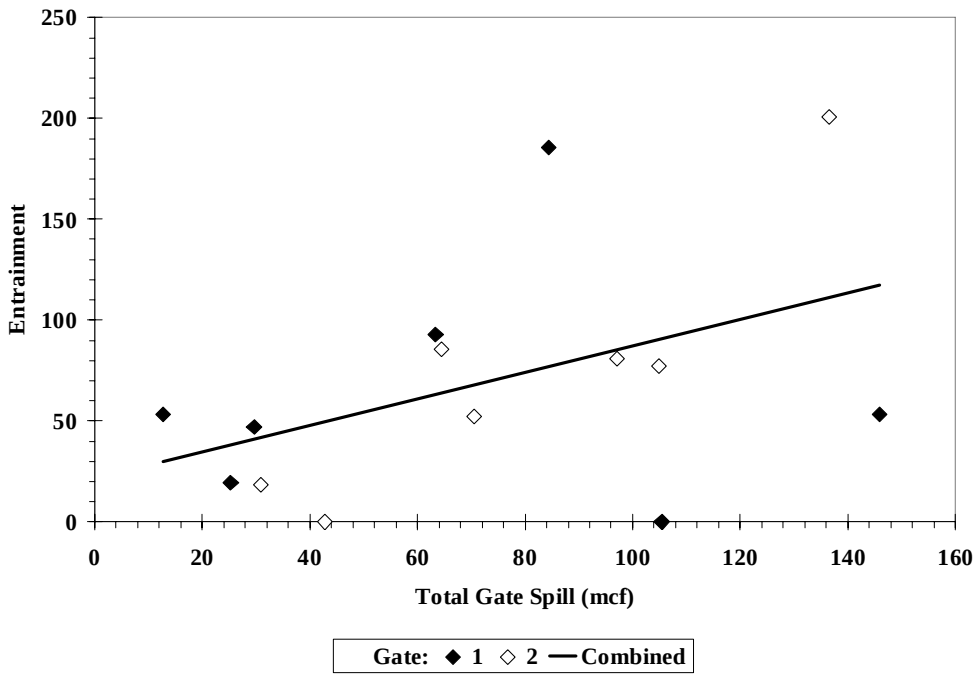

Figure 5.2-1. Estimated spillway entrainment by total gate spill volume (mcf) for all nine spill tests conducted at Boundary Dam, June 2007.

A total of 967 targets were estimated to have passed downstream through both spill gates in 2007 (Figure 5.2-2 and Table 5.2-2). On a per gate basis, this number was equivalent to 16.96 targets per operating gate hour (57 total spill gate operating hours, 29 hours at Spill Gate 1, and 28 hours at Spill Gate 2). This mean rate was higher than the passage rates observed at the powerhouse during June 2007 (10.4 targets per operating turbine hour). Mean spillway entrainment per unit flow for both gates combined was estimated as 0.95 targets per mcf of water passed (Table 5.2-2).

Total hydroacoustic target entrainment was similar between Spill Gates 1 and 2 over the entire spill period, with 47 percent of entrained targets passing through Gate 1 and 53 percent passing through Gate 2 (Figure 5.2-2; Table 5.2-2). Estimated entrainment per unit volume of spill was also similar between the two gates, with 0.97 targets per million cubic feet (mcf) passing through Gate 1 and 0.94 targets per mcf passing through Gate 2.

Estimated mean entrainment rates per hour of spill were higher at Spill Gate 2 (18.39 targets/h) than at Spill Gate 1 (15.58 targets/h). For both gates combined, mean passage was estimated as 16.96 targets per hour of gate spill.

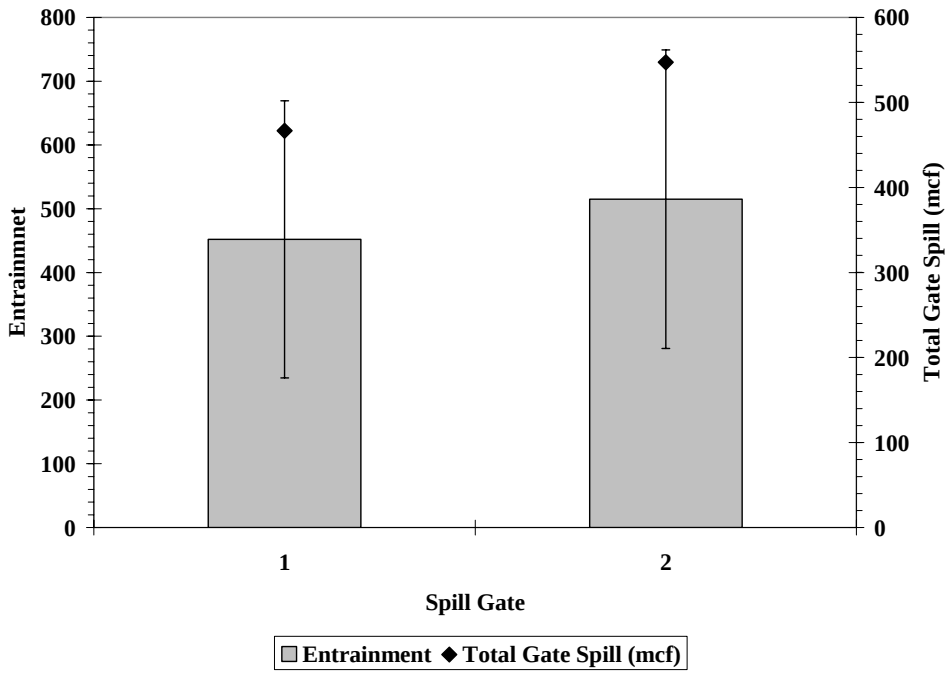

Figure 5.2-2. Total estimated number of entrained hydroacoustic targets, with 90 percent CI, and mean discharge (cfs) at each spill gate in June 2007.

Table 5.2-2. Total estimated target entrainment by spill gate, with 90 percent CI, entrainment mcf of spill, total entrainment per hour of spill, and mean discharge (cfs) for all spill events in June 2007.

Gate	N	Entrainment	CI 90 Percent Entrainment (+/-)	Mean Gate Opening (feet)	Total Gate Spill Volume (mcf)	Mean Gate Spill (cfs)	Entrainment /mcf	Entrainment /Hour of Spill
1	36	452	217	3.12	467	4,724	0.97	15.58
2	46	515	234	3.81	547	6,000	0.94	18.39
Combined	82	967	317	3.46	1,014	5,350	0.95	16.96

Hydroacoustic target entrainment through the spillway did not appear to be directly correlated with volume of spill during the limited testing conducted in June 2007 (Figure 5.2-3; Table 5.2-3). The highest hydroacoustic target entrainment through the spillway occurred at Spill Gate 2 during Test 5, with 201 targets passing at a mean gate spill level of 9,480 cfs, or an estimated entrainment rate of 50.15 targets per hour of spill. The highest passage estimate per unit volume of spill (4.19/mcf), was observed during Test 7 at Gate 1, when the mean gate spill level was 881 cfs.

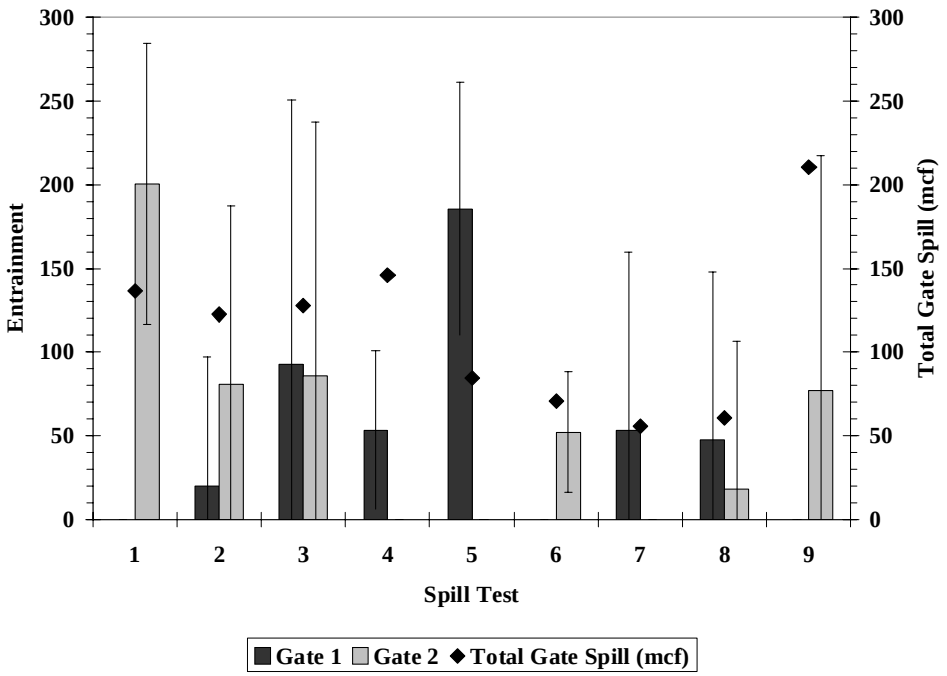

Figure 5.2-3. Total estimated entrainment at the spill gates for each spill test, conducted in June 2007. Total gate spill (mcf) is shown on the secondary Y-axis.

Table 5.2-3. Total estimated number of hydroacoustic targets entrained with 90 percent CI, entrainment per mcf, entrainment per hour of spill, and mean discharge (cfs) by spill test for each spill gate in June 2007.

Gate	Spill Test	N	Entrainment	CI 90 Percent Entrainment (+/-)	Mean Gate Opening (ft)	Total Gate Spill (mcf)	Mean Gate Spill (cfs)	Entrainment /mcf	Entrainment /Hour of Spill
1	1	0	0	0	0	0	0	0	0
1	2	2	20	77	1.25	25	1,756	0.77	4.90
1	3	5	93	158	3.08	63	4,401	1.47	23.23
1	4	5	53	47	6.73	146	10,136	0.36	13.30
1	5	21	186	76	3.31	84	4,686	2.20	37.15
1	6	0	0	0	0	0	0	0	0
1	7	2	53	107	0.75	13	881	4.19	13.30
1	8	1	47	100	1.69	30	2,057	1.59	11.80
1	9	0	0	0	4.99	105	7,320	0.00	0.00
2	1	17	201	84	6.15	137	9,480	1.47	50.15
2	2	10	81	107	4.78	97	6,744	0.83	20.25
2	3	8	86	152	3.13	64	4,477	1.33	21.43
2	4	0	0	0	0	0	0	0	0
2	5	0	0	0	0	0	0	0	0
2	6	2	52	36	3.4	71	4,901	0.74	13.04
2	7	0	0	0	2.51	43	2,969	0.00	0.00
2	8	2	18	88	1.76	31	2,141	0.59	4.56
2	9	7	77	140	4.96	105	7,290	0.74	19.29

5.2.3. Target Strength Distributions by Spill Bay

Mean target strength (TS) values were calculated for all entrained detections at each spill bay for all spill events. Mean TS and calculated mean length (cm), with associated 90 percent CI, for each spill gate is given in Figure 5.2-4 and Table 5.2-4.

Estimated mean TS at Spill Gate 1 was higher than at Spill Gate 2, but the difference was not significant at α=0.10 (Table 5.2-4). Mean TS estimates for each individual test conducted at the spillway in June 2007 are given for each spill gate in Table 5.2-5. Mean TS was observed to be variable across spill tests and gates, possibly a result of the relatively small sample sizes observed during the abbreviated spill periods.

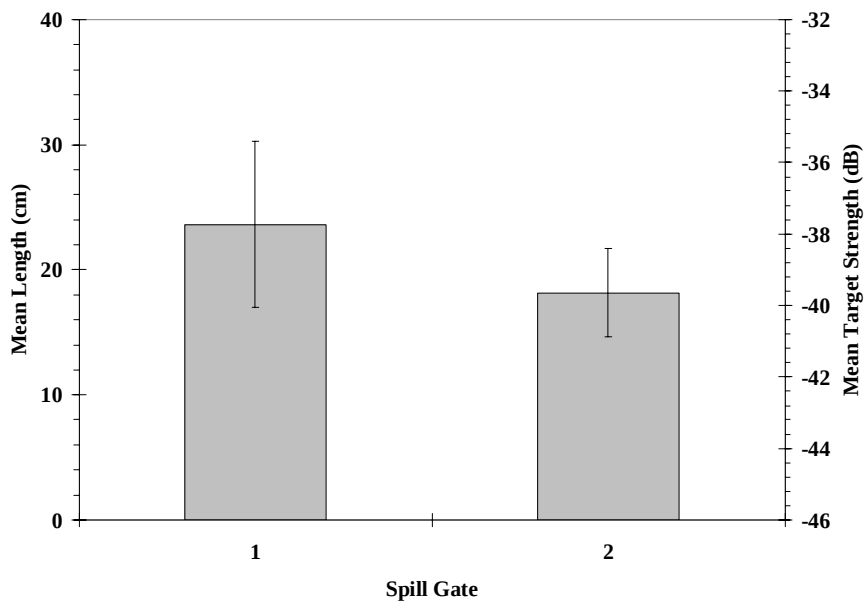

Figure 5.2-4. Mean target strength (dB) and mean length (cm), with corresponding 90 percent CI, at the two spill gates during spill tests conducted in June 2007.

Table 5.2-4. Mean target strength and mean length, with corresponding 90 percent confidence intervals at the two spill gates during spill testing conducted in June 2007.

Gate	N	Mean TS (dB)	CI 90 Percent TS (+/-)	Mean Length (cm)	CI 90 Percent Mean Length (+/-)
1	36	-37.84	2.05	23.63	6.62
2	46	-40.03	1.48	18.15	3.54
Combined	82	-38.93	1.32	20.72	3.57

Table 5.2-5. Mean target strength (TS) and estimated mean length, with corresponding 90 percent CI, for each spill gate and test combination evaluated during June 2007.

Gate	Spill Test	N	Mean TS (dB)	CI 90 Percent TS (+/-)	Mean Length (cm)	CI 90 Percent Mean Length (+/-)
1	1	0	0	0	0	0
1	2	2	-43.76	0.82	11.58	1.21
1	3	5	-37.09	6.35	25.86	29.77
1	4	5	-33.87	4.19	38.12	25.03
1	5	21	-39.24	2.76	19.96	7.87
1	6	0	0	0	0	0
1	7	2	-43.18	0.19	12.42	0.29
1	8	1	-36.76	0.00	26.91	0.00
1	9	0	0	0	0	0
2	1	17	-41.66	2.32	14.91	4.81
2	2	10	-41.19	2.38	15.78	5.25
2	3	8	-40.22	2.27	17.73	5.59
2	4	0	0	0	0	0
2	5	0	0	0	0	0
2	6	2	-36.48	33.42	27.83	1,535.68
2	7	0	0	0	0	0
2	8	2	-34.91	1.10	33.64	4.79
2	9	7	-39.44	2.64	19.47	7.28

5.2.4. Results of Spillway Gill Netting

During the monthly spillway gillnet sampling, a total of 35 separate gill net sets were deployed for a combined effort of 219 hours per 1,000 square feet (ft^2) net (Table 5.2-6). In addition, during the spill event of June 7, 11 nets were set for a combined effort of 56 hours per 1,000 ft^2 net. Only one northern pike minnow was captured during the entire period. The specimen was captured near the surface in a net situated in the center of the log boom during the June 7 spill event.

Table 5.2-6. Summary of gillnetting efforts conducted near the spillway of Boundary Dam during March through October sampling.

Date	Number of Nets Deployed	Total Effort (hours/1,000 ft^2 net)	Fish Captured
March 11	5	15	0
May 21	5	31	0
June 7	11	56	1 (northern pike minnow)
June 12	5	42	0
July 31	5	29	0
August 15	5	23	0
September 31	5	31	0
October 20	5	48	0

5.3. Fyke Net Sampling at Turbine Unit 54

A fyke net array was deployed in the Unit 54 draft tube in early October 2007, in accordance with the study plan schedule. The net was deployed on October 6, October 27, and December 1, 2007. Technical difficulties were experienced during initial testing of the fyke net array, and the fyke nets could not be effectively fished. To date, full fyke net sampling has not taken place, and no fish have been captured in the fyke net. The turbine fyke net array is being redesigned and will be re-deployed in January 2008 after Unit 54 comes back on line after its annual maintenance. The results of the 2008 fyke net sampling program will be presented in the updated study report. Additional details on the turbine fyke net sampling in 2007 and plans for modifications to the array in 2008 are discussed in Sections 4.2, 7.2, and 7.3 of this report.

6 SUMMARY

A total of 169,752 targets were estimated to have been entrained at the Boundary Dam turbine intakes over the 5.5-month monitoring period between May 2 and October 15, 2007. This number was equivalent to an average entrainment of 13.2 targets per hour at each operating unit. Total target entrainment at the powerhouse was variable over time. Monthly total powerhouse entrainment was relatively consistent during May through July (33,379 to 37,051 targets per month), decreased during August and September (9,682 to 10,418 targets per month), and peaked in early October (43,571 targets over a 2-week period).

The magnitude of entrainment varied between turbines, but the relationship may have been affected by unit operations. Between May and August, Units 54 to 56 were observed to pass approximately 68 percent of the total estimated powerhouse passage. In September and October, only 13 percent of the total estimated powerhouse entrainment passed via Units 54 to 56. Unit 55 was not operated in September and October and may have affected patterns of flow in the forebay intake channel. Unit 53 demonstrated generally lower entrainment than the other units over the 2007 monitoring period. The minimum target size detection threshold at Unit 53 was equivalent to the other powerhouse sampling locations, based on a review of system sampling parameters and laboratory calibration data. Additional investigations into potential causes for the decreased relative entrainment at Unit 53 are ongoing, and the findings will be discussed in the updated study report. Between-unit variability in entrainment was observed at other times during the study. During the period of peak detections in early October, the entrainment rates for Units 51 and 52 (on a per MWH basis) were 4.6 to 7.8 times higher than Units 53, 54, and 56. Ongoing monitoring is anticipated to help understand the observed variability in detection rates among the turbine units over time.

On a diel (24-hour) basis over the 2007 study period, total entrainment at the powerhouse was positively correlated with the magnitude of Project generation. Total passage was relatively low during nighttime hours (2200 to 0500 hours), when fewer units were operating. A peak in entrainment was observed between 0600-0700 hours, when generation load typically increased. However, increases in entrainment were not observed during 0500 to 0600 hours, when additional units started to come on-line. During the day, total powerhouse entrainment was generally uniform on an hourly basis, and was greatest between 1200 and 1700 hours, when total mean generation at the Project was highest. Rates of powerhouse entrainment per operating unit

hour were compared over four diel periods (day, night, sunrise, and sunset) to assess diel patterns of entrainment independently of potential turbine operating influences. Powerhouse entrainment rates were least at night, relative to the daytime, dawn, and dusk periods. This pattern of lower entrainment at night was also observed during a period of uniform 24-hour powerhouse operations that occurred from June 7 to 11, 2007, although the magnitude of the day/night differences during this period was not large.

The mean TS of hydroacoustic detections at the powerhouse was generally consistent across units for the study period as a whole and on a monthly basis, indicating that hydroacoustic detections entrained into all turbines were of similar mean size at any point in time. Applying Love (1971) and assuming that the hydroacoustic detections are fish, the mean estimated length of targets entrained at individual turbine units over the 2007 monitoring period varied from 17 to 20 cm.

Length-frequency distributions were derived by converting the mean target strength of individual detections to estimated fish lengths using Love's (1971) relationship (Figures A.2-1 through A.2-6, Appendix 2). Estimated fish length distributions were generally consistent between turbine units on a monthly basis. Between May and July, estimated length frequency distributions generally had a single mode and the majority of entrained targets were relatively small, with length modes varying between 12 and 16 cm (4.7 and 6.3 inches). Fewer targets were observed at all turbines in August and September, and distinct length modes were less evident in the distributions. Estimated lengths during these months varied between 10 cm (4 inches) to approximately 50 cm (19.7 inches), although targets exceeding 30 cm (11.8 inches) were relatively infrequent. Entrained targets observed in October passed predominantly through Units 51 and 52 and were predominantly smaller in estimated length. Estimated length modes at Units 51 and 52 in October occurred at 12 cm, similar to the length distributions observed during May through July.

Hydroacoustic targets entrained at the powerhouse tended to enter the turbines in the upper half of the intakes and on the upstream (east) side of the openings. This distribution is consistent with surface-oriented targets moving down the face of the powerhouse from upstream (the trash rack or east end of the turbine forebay intake channel) and encountering the flow into each turbine. This skewed pattern of entrainment into the turbine intakes may indicate a review of the spatial fish weighting assumptions used to extrapolate the hydroacoustic detections to estimates of total entrainment. The applied weighting factors currently assume that targets entering the turbine intakes are uniformly distributed across the openings. These assumptions may remain valid, as increased entrainment on one-half of the intake may be compensated during the weighting process by lower entrainment in the other half. The effect of entrained target distributions within the turbine intake on total entrainment estimates is currently being investigated and could result in adjustments to the total powerhouse entrainment described in this document.

Investigations of the spatial distribution of fish entering the Boundary Dam turbine intakes were also conducted using a DIDSON acoustic imaging system on June 28, 2007 (Appendix 3). The DIDSON system was deployed at Unit 54 and provided high-resolution sampling across the entire width of the upper intake area. The results of this sampling, although relatively short in

duration, were consistent with the observations from the split-beam transducers deployed at the powerhouse. Targets were observed to enter the intakes primarily from the upstream (east) side and typically increased in range as they passed into the penstock. Water movement patterns in front of the turbine intakes may be affected by pool level, the amount of water column available above the intake. The lake elevation during the June 28 sampling period was 1,989 feet NAVD 88 (1,985 feet NGVD 29) and the top apex of the turbine intake opening is located at an elevation of 1,941 feet NAVD 88 (1,937 feet NGVD 29), resulting in 48 feet of water above the intake ceiling. During the monitored period, a majority of the observed targets appeared to originate in the upper water column and descend toward the intake opening.

Spill was infrequent at Boundary Dam in 2007 relative to historical patterns of spill at the Project. Inflow rates to the reservoir during spring 2007 rarely exceeded Project generation demand. Nine spill events of relatively brief duration (4 to 5 hours each) occurred between June 8 and 18, 2007, and all were monitored by the acoustic system. In aggregate, 967 hydroacoustic targets were estimated to have passed downstream via both spillways during all 2007 spill events, resulting in a mean estimate of 16.96 targets per hour of individual spill gate operation. Over approximately equal periods of spill gate operation, Spill Gate 1 (the west gate closest to the powerhouse) was estimated to have passed 452 targets (15.6 targets per operating hour), and Spill Gate 2 (closest to the east shoreline of the reservoir) was estimated to have passed 515 targets (18.39 targets per operating hour). However, these differences in estimated passage were not significant between spill gates at α=0.10.

7 VARIANCES FROM THE FERC-APPROVED STUDY PLAN

7.1. Hydroacoustic Sampling

To date, the hydroacoustic portion of the Fish Entrainment and Habitat Connectivity Study has proceeded in accordance with the FERC-approved study plan, and variances have not occurred.

7.2. Fyke Net Program

The study plan called for the fyke net sampling program to be initiated in October 2007 and initial results to be presented in the interim study report of 2007. The fyke net array was deployed in accordance with the study plan schedule, but three successive attempts to sample the fyke net array have failed. Challenges posed by the technical complexity of fishing the fyke nets in the draft tube have not been overcome as of December 2007. Consequently, there are no fish capture data to report for 2007. The turbine fyke net array is being redesigned and will be re-deployed in January 2008. The results of the 2008 fyke net sampling program will be presented in the updated study report.

7.3. Recommended Sampling Modifications

The following are recommendations for refining sampling efforts during 2008. These recommendations are not considered variances from the FERC-approved study plan.

7.3.1. Hydroacoustic Sampling Modifications

No modifications are recommended to the hydroacoustic sampling plan in 2008.

7.3.2. Fyke Net Program Modifications

Questions surrounding the viability of the draft tube fyke net sampling program should be answered in January 2008. The following modifications to the existing sampling arrangement will be incorporated and evaluated at that time:

- The length of the nets will be increased by approximately 15 feet. This increase will nearly double the surface area of each net and will increase their filtration capacity. It will also increase the drag and the possibility for nets to tangle during sampling.
- The longer nets will deployed incrementally (two at a time) while gradually increasing flow through the draft tube.
- If the capacity of the frame to hold nets is reached (based on deflection measurements and visual inspections) before all of the net bays are filled, a statistical program will be developed to determine the net capture efficiency of the deployed nets.
- If the longer nets cannot be successfully fished, a larger mesh net will be employed in a subsequent test. Although this larger net may hinder the studies' ability to establish species composition for smaller fish, it would provide validation of the hydroacoustic target counts for larger fish.
- If larger mesh nets can not be fished successfully, an alternative plan will be employed.

If it is concluded that the draft tube gatewell cannot be successfully fished, alternatives will be pursued to meet the twin study objectives: hydroacoustic target verification, and determination of species composition.

Deployment of a DIDSON acoustic camera is under consideration to assist in verifying hydroacoustic targets. The camera would be positioned at depth in the forebay intake channel and oriented to maximize resolution of individual targets moving into the Unit 54 intake. When deployed appropriately, the DIDSON camera can provide high-resolution images of fish and other targets within a range of approximately 15 m, allowing a one-to-one correspondence of the DIDSON images with hydroacoustic targets. In this manner, the nature of the hydroacoustic targets could be verified. A DIDSON camera was evaluated at Boundary Dam in June 2007. The results of this evaluation and a description of the capabilities of the instrument are described in Appendix 3 of this report.

Also under consideration is a combination of ongoing and new netting programs in the forebay intake channel or possibly the tailrace area.

Any changes anticipated in the fyke netting program will be discussed with the relicensing participants at the Fish and Aquatics Workgroup Meeting scheduled for February 28, 2008.

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Appendix 1: Draft Boundary Dam Fish Entrainment Methods Outline

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 12
Fish Entrainment Study
Methods Outline Report

Prepared for
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Final Report: July 17, 2007

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Study No. 12: Fish Entrainment Study
Methods Outline Report
Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Study No. 12, the Boundary Dam Fish Entrainment Study, is being conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (SCL) on February 14, 2007 and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This document presents the methods outline for the 2007-2009 fish entrainment study.

2 STUDY OBJECTIVES

The goal of the Fish Entrainment and Habitat Connectivity Study is to estimate the number, size, species, and timing of fish that may be entrained within the Boundary Project turbine intakes and spillways. The limited frequency, duration of use, and flow conditions associated with the use of the sluiceways, and the discontinued use of the skimmer gate, eliminates the need to estimate the number of fish potentially entrained though these pathways. Fish entrainment through the turbine and spillway pathways is being monitored at the Boundary Project to estimate total downstream fish passage at the dam. Study results will be used to estimate the effects of Boundary Project operations on hourly, daily, diel, and seasonal entrainment of fish within the Boundary Reservoir.

The Boundary Dam hydroacoustic study will monitor fish passage through the spillways and powerhouse for purposes of estimating entrainment through these routes. Passage estimates and associated confidence intervals will be calculated for various time periods within the study period, e.g., weeks, months, seasons and years. Strategic use of fyke net sampling in the draft tube gatewells will be used to determine the accuracy of the turbine passage information generated by hydroacoustics and to monitor species composition over time. Hydroacoustic data collection was initiated at Boundary Dam on May 2, 2007 and is currently scheduled to continue through May 2, 2009. Fyke net sampling is scheduled to begin in September 2007 and continue through April 2009.

As the entrainment study plan was developed there was concern that the hydroacoustic work might not be underway during spring of 2007. This would leave decision makers with only the data from one spring (spring 2008) on which to base their decisions. Consequently, data collection through May 2009 was envisioned. Because spring data was gathered in 2007 it may be possible to curtail the hydroacoustic and fyke net effort at the end of 2008. This decision, to be made in cooperation with the relicensing participants, would be taken if sufficient data has been gathered at the end of 2008 to allow an informed development of the PLP.

3 STUDY AREA

The total fish entrainment study area encompasses Boundary Dam and associated structures, the forebay and the Pend Oreille River in the vicinity of the Boundary Dam tailrace. The hydroacoustic monitoring study area is located immediately upstream of Units 51-56 in the Boundary Dam forebay, and in front of the two spill gates (Figure A3-1).

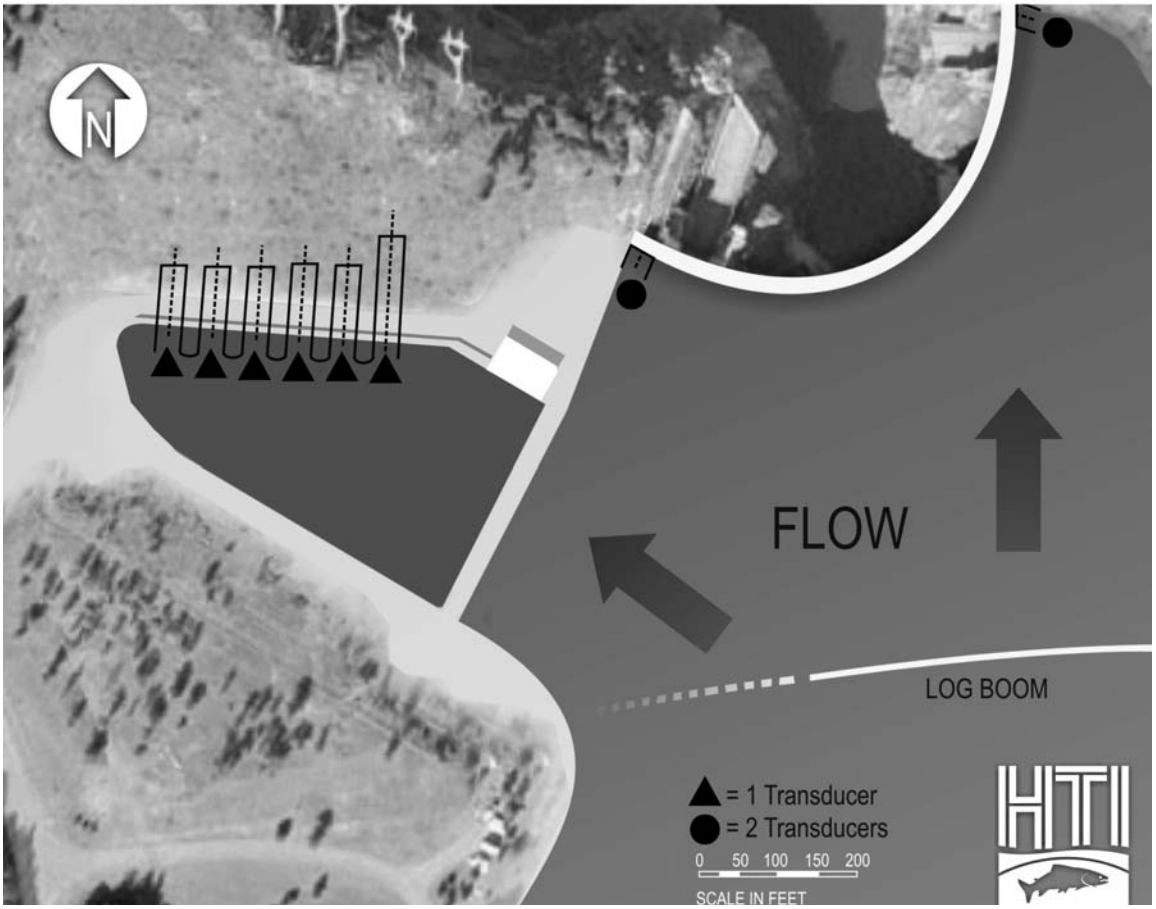

Figure A3-1. Plan view of the proposed Boundary Dam hydroacoustic system transducer deployment, showing the six 6°x10° transducers monitoring the powerhouse and the four 15° transducers installed at the spillway.

4 DATA COLLECTION METHODS

The Boundary Dam Fish Entrainment Study consists of separate turbine and spillway components, which are described below. The information from both components will be summarized to estimate fish entrainment through the Boundary Project over time. Turbine

entrainment monitoring includes both hydroacoustic and fyke netting techniques. Spillway entrainment will be monitored using hydroacoustic sampling methods.

4.1. Turbine Entrainment

Hydroacoustic monitoring will be used to estimate the number, size, and timing of fish entrained within the Boundary Project turbine intakes. Fyke net sampling within the draft tube gatewells will be used to verify whether hydroacoustic targets are fish and identify the species composition of entrained fish. In addition, fish entrainment estimates derived from the fyke nets will be used to ground truth concurrent hydroacoustic passage estimates at the turbines. The fyke net will be deployed during fixed time periods and will be sampled concurrently with the ongoing hydroacoustic sampling. A one-to-one correspondence in fish entrainment estimates derived from the netting and hydroacoustic estimates is anticipated for fish sizes susceptible to capture by the fyke net. Algorithms used to distinguish fish from other hydroacoustic targets would be reassessed in the event that the correspondence between the hydroacoustic and the fyke net data is not one-to-one. The fyke nets will select for fish larger than 4.0 inches because the net design calls for a 1 inch mesh size. This mesh size reflects a trade-off between capturing fish of a given size or larger and consideration of the potential for net damage and the frequency of checking and cleaning nets that would be required to sample smaller fish. Fyke net capture results will be statistically-evaluated relative to the hydroacoustic target counts and target strength (acoustic fish size) information over the study period.

Gill nets deployed in the Forebay Reach as part of the Fish Distribution, Timing and Abundance Study (Study No. 9) will indicate the relative number, size and species of fish in the general vicinity of the spillway and trash rack structures. However, they will not identify whether those fish were likely to have passed downstream through the dam. Fyke net arrays deployed downstream (i.e., the draft tube gatewells) of selected turbine intake(s) are expected to be the most effective method of collecting fish that have been entrained into the turbines. Four potential fyke net locations were described in the RSP:

1) in front of the turbine intake tunnel
2) within the intake gatewell slot,
3) within the draft tube gatewell slot and;
4) at the turbine outfall.

The objective was to design the fyke net array to subsample all portions of the water column. Engineering, operational, safety and sample design assessments of each location were considered for each of the potential sampling sites. The draft tube gatewell slot location (Option 3) was selected for the following reasons.

All of the sites considered for fyke net deployment present engineering, operational and logistical challenges. Three of the four potential locations had limitations that precluded effective sampling.

1) The sampling location in front of the turbine intake tunnel (Option 1) was rejected because water velocities were insufficient to ensure fish capture over the range of Project turbine operational conditions.

2) The intake gatewell slot (Option 2) was rejected due to Project safety considerations. This slot must be kept accessible for a bulkhead gate designed for emergency turbine shutdown in the event of wicket gate failure. Obstructing the intake gatewell slot with a fyke net sampling frame would prevent the ability to shut down the unit under such conditions.

3) The turbine outfall site (Option 4) was rejected due to physical structures that could interfere with net sampling and safety concerns. Overhanging rock presents the danger of rock fall injuries to personnel manning the nets. Metal structure (rubble and rebar) left in the tailrace after the initial construction near the outfall of the draft tube presents a high likelihood of net snagging, which would interfere with effective net sampling.

4.2. Fyke Net Array within the Draft Tube Gatewell Slot

Fyke net deployment within the turbine draft tube gatewell slot (Option 3) provides the best opportunity for effective fish sampling This location was deemed to have the highest probability of providing unbiased entrained fish estimates for comparison with the hydroacoustic sampling results. Deploying a fyke net in the draft tube gatewell slot presents challenges related to personnel access, high water velocities and turbulence. It is anticipated that these challenges can be addressed in the engineering and planning processes.

If estimates of fish abundance and size are found to differ between the hydroacoustic and fyke net methods, the netting results will be considered to better represent actual entrainment rates. Both hydroacoustic and fyke net sampling provide imperfect estimates of fish entrainment. Statistical comparisons between the results of both sampling methods will be conducted to identify potential biases and will improve overall sampling effectiveness.

A single turbine intake will be monitored with two fyke net frames (one in each draft tube gatewell slot) beginning in September 2007. Sampling will be conducted during four 24-hour periods each month. Selection of the turbine intake will be based on physical site constraints, project operational considerations, frequency of turbine use, and distribution of fish between turbine intakes based on earlier hydroacoustic sampling results.

Units 51 and 56 present physical site constraints. Unit 51 has a sump pump deck that blocks the work area needed to store the draft tube gate and to fish the fyke nets. Unit 56 is constrained by circulation patterns in the tailrace that deposit rock at the gate sill during spill events. This can keep the gate or fyke net frame from properly seating. Additionally, Unit 56 has a TDG measuring well pipe installed in the gate slot. Another site constraint for consideration is the higher flows in the two larger units (55 and 56). The flow to these units is 30 percent higher than the other units. The flow area however is the same. Consequently the velocities are higher, and the turbulence greater in the larger units. The fishing conditions will be worse in the larger units

than in the smaller units. Project operational considerations include scheduled maintenance outages. According to conversations with the Boundary Project Chief Operator, turbine use is for the most part uniform. Units 55 and 56 are usually turned on first, while Unit 51 is turned on last. Hydroacoustic target analysis is currently underway. Decisions on fyke net placement will be made in cooperation with the relicensing participants and will be fully documented in the first initial study report.

If the ongoing hydroacoustic monitoring reveals a significant shift in the passage distribution across the intakes by season, and if a non one-to-one correspondence between the hydroacoustic targets and fyke net data is unexplainable, a second fyke net may be installed at another turbine intake in May-June, 2008. This decision, made in cooperation with the relicensing participants, will be taken in the first quarter of 2008, using data gathered through December 2007. The decision on installation of a second fyke net will be fully documented in the 2008 study report.

4.3. Hydroacoustic Sampling Methods

Hydroacoustic fish entrainment data will be collected and analyzed using split-beam target tracking techniques (Ehrenberg and Torkelson 1996) and following the acoustic sampling principles outlined in MacLennan and Simmonds (1992). Fixed-location hydroacoustics has been used to evaluate fish passage at dams for over 25 years. Hydroacoustics provides high sampling coverage that is difficult to obtain with more traditional means of fish sampling. The principle of fixed-location, split-beam hydroacoustic techniques is based on placing one or more transducers on a fixed structure and sampling fish as they pass through the insonified acoustic beams. The fish produce characteristic echo returns that can be processed to produce estimates of fish passage rates, direction of movement, size, velocity, and other parameters.

The hydroacoustic equipment required for a quantitative fixed-location study includes a scientific-quality echo sounder/transceiver, transducers, and a PC-based echo processor. The primary component of a hydroacoustic data collection system is the scientific echo sounder. When triggered, the echo sounder emits a short electrical pulse of known frequency, duration, and transmit power. The transducer then converts the electrical pulse into mechanical energy (i.e., a sound pulse with the same characteristics as the electrical pulse). In fixed-location applications, the transducers typically have relatively narrow beam widths so they can be aimed close to confined areas of interest.

When the sound waves encounter fish, echoes are reflected back to the transducer. The transducer then converts the sound energy back into electrical energy and sends it back to the receiver portion of the echo sounder. The echo signals are relayed to a computer-based echo processor, which records each detection to a computer file for subsequent analysis.

The Boundary Dam powerhouse consists of six turbine units, numbered Units 51-56. A vertically-oriented 6˚x10˚ nominal beam width transducer is placed on the centerline of each turbine intake at elevation 1968 ft and aimed down to monitor the water column immediately upstream of each turbine opening. The transducers operate at a sampling frequency of 200 kHz and use split-beam technology to track the direction of individual fish in three-dimensional space. Only fish exhibiting movement into the intake are considered to be entrained. The six

transducer turbine monitoring array is sampled continuously, 24 h/d. Individual transducers at each turbine are sequentially-sampled in 2.5-min increments across the powerhouse within each 1-hour data replicate, such that each location is sampled 10 min/h. All entrained fish detections are weighted for unsampled time and space, such that the resulting estimates represent total fish passage at each location. Turbine unit operations are considered during the analyses, such that only fish moving into the intakes of operating turbines are included in the hydroacoustic entrainment estimates.

Boundary Dam has two spill bays, which are monitored using two 15˚ nominal beam width split-beam transducers at each location (four transducers in total). Two transducers are deployed equidistantly at each spill bay to maximize spatial sampling coverage of fish passing the openings during spill. Each spill bay was conceptually subdivided vertically into two halves with one down-looking split-beam transducer located in each half. Each transducer will randomly sample six 5-min time intervals per hour, 24-hour/day, during all periods when spill is occurring at the Project. This sampling design provides 60 min of sampling time within each spill bay per hour.

Acoustic sampling (ping) rates of 12.5 pings per second (pps) are used at the turbine units. Ping rates of 15 pps are implemented for the spillway monitoring. These relatively high ping rates are used to provide high acoustic detectability of individual entrained fish at both locations. Fish detectability was modeled before the data collection period at the turbine and spillway locations, based on the transducer beam widths, sampling ranges, and water velocities at the site. The higher potential water velocity in the spillways relative to the turbine intakes indicated use of a relatively higher ping rate at the former location. A minimum on-axis echo detection threshold of -52 decibels (dB) is used for monitoring at the Boundary Dam powerhouse and spillways, equivalent to a minimum on-axis fish detection length of 86 mm (2.8 inches) across the full nominal beam width, based on Love (1971). Hydroacoustic data are subsequently filtered in post-processing to only include detections equivalent to 100 mm (4 inches) in length or greater. A relatively narrow broadcast pulse width (PW) of 0.2 ms is used to optimize detection of closely-spaced individual fish targets.

The installation is configured to allow remote control of the hydroacoustic systems for monitoring and data transfer purposes. The hourly hydroacoustic fish passage data files are transferred on a daily basis to Seattle for ongoing data review and analysis.

4.4. Fyke Net Sampling Plan

The fyke net sampling within the draft tube of a turbine will be used to verify hydroacoustic targets and identify the species composition of entrained fish. Fyke net sampling will be conducted for four 24-hour periods each month using a stacked fyke net assembly consisting of an array of multiple fyke nets within the turbine draft tube.

During a sampling period, three types of information will be collected:

1) Total fish numbers by net location and full array.
2) Fish length data by net location and full array.
3) Species composition by net location and full array.

It is anticipated that fish numbers will differ by net location. It is less clear whether size and species composition will be net-dependent. If estimates of fish numbers derived from the fyke net and hydroacoustics are consistent and fish size and composition are homogeneous across nets, the number of nets in the array may be reduced in the future for purposes of monitoring species composition. These decisions will be made in cooperation with relicensing participants. Decision criteria for possible modifications to the fyke net sampling plan are described in Section 4.4.2.

4.4.1. Fyke Net Array Installation

A stacked fyke net assembly, consisting of an array of multiple net frames, will be used to sample one turbine draft tube concurrently with the hydroacoustic monitoring. Access to the Boundary Project intakes will be gained through the draft tube gatewell slot. Based on the success of the initial fyke net installation and comparisons with the hydroacoustic data record, modifications to the 2008 fyke net sampling plan may occur. This decision will be made in coordination with relicensing participants.

4.4.2. Fyke Net Sampling

As discussed in Section 4.2, selection of the turbine intake for fyke net installation will be based on entrainment trends at the Boundary Dam Powerhouse in May-June 2007, physical site constraints, project operational considerations, and turbine frequency of use. Fyke netting at a single turbine intake is scheduled to begin in September, 2007, and may continue through April, 2009. A second fyke net may be installed at another turbine intake, based on the results of the 2007 hydroacoustic monitoring and demonstrated effectiveness of the initial fyke net deployment. This decision will be made in January, 2008, based on results from the aggregated May- December, 2007 monitoring period. These decisions will be made in cooperation with the relicensing participants and be fully documented in the annual reports.

Two arrays of fyke nets will sample 100 percent of the flow in both slots of a single turbine draft tube. These arrays will consist of two rows of four vertically-stacked nets. Sampling is expected to occur for at least four 24-hour periods per month. Fyke net operation will require that the sampled turbine be shut down during deployment and recovery of the array. The length of time of exposure to flows will initially be set at 1-hour, but may vary based on concurrent estimates of fish entrainment by hydroacoustic system and the degree of debris loading on the nets. Depending on the rate of fish and debris build-up in the cod end of the fyke nets, nets may be fished continuously for multiple hour periods, or split into shorter time intervals. Initially the nets will be fished continuously, except during periods when the turbine units are shut down to remove and deploy the net frames for sample recovery and cleaning. Planned nighttime generation and planned spill events may be required during some months to provide adequate comparisons between daytime and nighttime periods and evaluation of spillway hydroacoustic passage. Sampling may not be possible during periods of maintenance or repair of the turbine(s) selected for fyke net sampling.

The fyke net sampling design will be adaptive because of uncertainties related to fish passage distributions over time and equipment performance. For maximum statistical power, the target

total fish counts of all nets per sampling period will be a minimum of 30 fish, with 50 fish preferred (> 100 mm total length for all species) per sampled temporal strata. Initial sampling strata will be one 24-hour period per week. To obtain the minimum required number of captured fish per 24-hour sampling period, the number and/or the length of net samples may be increased within 24-hour sampling periods. Sampling regimes may be aggregated into two 2-day periods or four continuous days per month, based on ongoing review of the hydroacoustic counts, associated target strengths and temporal changes in fyke net catches. If these data suggest little temporal variability in species and size composition, sampling regimes may be simplified. The results of the first two months of routine fyke net sampling (eight 24-hour sample periods) will be used to determine if aggregating fyke net sampling is appropriate during subsequent monitoring. If the four weekly 24-hour fyke net sample entrainment estimates are not significantly different, future sampling may occur on adjacent days. If 24-hour samples differ significantly within a month, weekly sampling spacing will be maintained. This evaluation process may be continued on a seasonal basis for the duration of the study period, as differing patterns of river flow and fish movement over the year may require changes in sampling frequency over time.

In the same manner, the number of individual net frames sampled within each fyke net array may be reduced in 2008, if fish distribution within each turbine intake slot is shown to be statistically equivalent. For example, nets might be sampled in four of the eight frames in 2008, based on the results observed during the September-December 2007 fyke netting sampling period. Reduced net coverage within an intake slot will be considered only if:

a. Adequate numbers of fish (a minimum of 30-50 fish per sample) can be captured within a reduced set of nets to estimate entrainment rates and surrounding confidence intervals,
b. Significant (α=0.10) differences in spatial patterns of fish capture within the eight nets in each array are not observed within the initial September-December 2007 netting period, and
c. Logistical considerations, such as high net debris loading or the magnitude of total fish entrainment, restrict the ability to effectively sample with fyke nets.

This adaptive fyke net sampling approach will allow in-season flexibility to quantify fish entrainment under variable environmental conditions.

4.4.3. Fish Handling

All fish collected during fyke net sampling will be identified to species and their total length will be measured to the nearest millimeter (mm). All captured salmonids will be scanned for tags, including passive integrated transponder (PIT) tags. Protocols for handling and disposition of any bull trout carcasses that may be collected are described in the US Fish and Wildlife Service scientific collecting permit. An example of the proposed fyke net data entry form is shown in Figure A4.4-1.

page_____ of _____ **Boundary Dam Fyke Net Data Form**

Date:
Sample Location:
Personnel On-site:
Sample Number:
Net Deployment Time:
Unit Start Time:
Unit Shutdown Time:
Net Removal Time (on deck):

Comments:

Top of net frame

net number	
1	2
3	4
5	6
7	8

Turbine Slot #1 Frame (upstream)

Net Number	Species Code	Total Length (mm)	Comments

Figure A4.4-1. Proposed fyke net data entry form.

5 DATA ANALYSIS METHODS

5.1. Hydroacoustic Data

Data are automatically transferred from the Boundary Dam hydroacoustic monitoring systems on a daily basis and manually-processed. Each data file is manually-reviewed and individual fish detections are marked and entered into Microsoft ACCESS® data files for subsequent analyses. Unit operations and other ancillary data (e.g., TDG, fyke net data, etc.) are also downloaded on a regular basis.

The hydroacoustic data analyses are conducted within a SQL/ACCESS database software framework and final data summaries for reporting are conducted in EXCEL® spreadsheet files.

Individual entrained targets must meet fixed criteria to be counted as fish. Each target must return a minimum of four consecutive echo returns as it passes through the acoustic volume at each turbine intake opening. To be considered an entrained fish, the target must demonstrate consistent movement into the intake tunnel and return a mean target strength (TS) value > -45 dB. This minimum TS value is equivalent to a minimum fish length of 10 cm (4 inch), based on Love (1971), a published formula relating fish TS and length. These minimum number of echo return, TS and direction-of-movement criteria are used to minimize the potential of counting debris or non-entrained fish in the acoustic counts.

Reported fish passage distributions will describe total fish passage per monitored location over varying time scales. In addition, fish acoustic size (target strength) and diel (day/night) passage

distributions will be presented for the same periods. Target strength estimates will be converted to estimated fish lengths using Love (1971).

The hydroacoustic monitoring system covers slightly over 40% of the cross-sectional area of each turbine and spillway opening. Total fish passage is extrapolated to the full intake and spillway widths based on the hourly observations within the sampled areas. Hydroacoustic sub sampling also occurs over time. Each turbine intake location is sampled for four 2.5 minute periods each hour, or 10 minutes total. These samples are weighted to account for unsampled time at each location within each hour. The hourly fish passage estimates account for unsampled time and area at each monitored location. The specific details of the hydroacoustic fish entrainment weighting and data analysis procedures are described below in Sections 5.1.1-5.1.8.

5.1.1. Estimating Powerhouse Passage

Hydroacoustic fish passage into the turbine units considers 1-hour sampling block replicates. Each turbine location is sampled four times within each 1-hour replicate. Daily fish passage is estimated by summarizing the hourly samples from 0000-2359 h.

The sampling at the powerhouse can be envisioned as stratified random sampling within unit-hours. Fish passage is independently estimated within each unit-hour, and these unit-hours are summed over time and location to estimate total passage. The formula used to estimate total fish passage at the Boundary Dam Powerhouse is given below.

x_{ijkl} = expanded fish count in the *i*th sample $(i = 1,\ldots,a)$ in the *j*th hour $(j = 1,\ldots,24)$ of the *k*th day $(k = 1,\ldots,D)$ at the *l*th turbine unit $(l = 1,\ldots,6)$;

a = number of samples monitored per hour at a turbine unit (nominally, a = 4);

A = total number of possible sampling units within an hour at a turbine unit (nominally, A = 24).

Then, total fish passage at the powerhouse over *D* days, across all six turbine units, is estimated by:

$$\hat{P} = \sum_{i=1}^{6}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{A}{a}\sum_{i=1}^{a} x_{ijkl}\right]. \quad (1)$$

Special cases of $\hat{P}$ may include estimating passage at a single turbine unit over time, i.e.,

$$\hat{P}_l = \sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{A}{a}\sum_{i=1}^{a} x_{ijkl}\right]. \quad (2)$$

The variance of $\hat{P}$ can be expressed as:

$$\mathrm{Var}\left(\hat{P}\right) = \sum_{l=1}^{6}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{A^2\left(1-\frac{a}{A}\right)S_{x_{jkl}}^2}{a}\right]$$

and estimated by:

$$\widehat{\mathrm{Var}}\left(\hat{P}\right) = \sum_{l=1}^{6}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{A^2\left(1-\frac{a}{A}\right)s_{x_{jkl}}^2}{a}\right], \quad (3)$$

where:

$$s_{x_{jkl}}^2 = \frac{\sum_{i=1}^{a}\left(x_{ijkl} - \overline{x_{jkl}}\right)^2}{(a-1)} \quad (4)$$

and where:

$$\overline{x_{jkl}} = \frac{\sum_{i=1}^{a} x_{ijkl}}{a}. \quad (5)$$

5.1.2. Estimating Spillway Passage

Two equidistantly-spaced transducers are used to sample each spillway, due to the relatively wide (15.2 m, or 50 ft) horizontal extent of the gates. Fish detected by each transducer are weighted to account for unsampled area to the midpoint of each spill gate, and the two estimates are summed to provide total entrainment values. As at the turbine intakes, 1-hour time blocks are used as the basic data replicate. The two halves of the spillway are considered to be different spatial strata and a stratified random sampling design is used to estimate passage variance. The formula used to estimate total spill bay passage is given below:

y_{ijklm} = expanded fish count in the *i*th sample $(i = 1,\ldots,a)$ in the *j*th hour $(j = 1,\ldots,24)$ of the *k*th day $(k = 1,\ldots,D)$ at the *l*th vertical stratum $(l = 1,2)$ within the *m*th spillbay $(m = 1,2)$;

b = number of samples monitored per hour at a spill bay location (nominally, $b = 6$);

B = total number of possible sampling units within an hour at a spill bay location (nominally $B = 12$).

The total fish passage at the spillway over *D* days, across all locations, is estimated by:

$$\hat{S} = \sum_{m=1}^{2}\sum_{l=1}^{2}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{B}{b}\sum_{i=1}^{b} y_{ijklm}\right]. \qquad (6)$$

Special cases of $\hat{S}$ may include estimating passage at a single spill bay over time, i.e.,

$$\hat{S}_m = \sum_{l=1}^{2}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{B}{b}\sum_{i=1}^{b} y_{ijklm}\right]. \qquad (7)$$

The variance of $\hat{S}$ can be expressed as:

$$\hat{\mathrm{Var}}(\hat{S}) = \sum_{m=1}^{2}\sum_{l=1}^{2}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{B^2\left(1-\frac{b}{B}\right)S^2_{y_{jklm}}}{b}\right]$$

and estimated by:

$$\hat{\mathrm{Var}}(\hat{S}) = \sum_{m=1}^{2}\sum_{l=1}^{2}\sum_{k=1}^{D}\sum_{j=1}^{24}\left[\frac{B^2\left(1-\frac{b}{B}\right)s^2_{y_{jklm}}}{b}\right], \qquad (8)$$

where:

$$s^2_{y_{jklm}} = \frac{\sum_{i=1}^{b}\left(y_{ijklm} - \overline{y_{jklm}}\right)^2}{(b-1)} \qquad (9)$$

and where:

$$\overline{y_{jklm}} = \frac{\sum_{i=1}^{b} y_{ijklm}}{b}. \qquad (10)$$

5.2. Hydroacoustic Performance Measures

Over the course of the investigation, various salient summaries of fish passage at Boundary Dam are required. This section summarizes some of the more important metrics that may be estimated from the hydroacoustic investigation.

5.2.1. Passage Counts

The estimator $\hat{P}$ [Eq. (1)] and associated variance estimator (3) provide information on total fish passage at the powerhouse for a selected length of time. Similarly, estimator $\hat{S}$ [Eq. (6)] and associated variance estimator (8) provide information on total fish passage at the spillway for a selected length of time. Total project passage (*T*) can then be estimated by:

$$\hat{T} = \hat{P} + \hat{S} \qquad (11)$$

with associated variance estimator

$$\hat{\mathrm{Var}}(\hat{T}) = \hat{\mathrm{Var}}(\hat{P}) + \hat{\mathrm{Var}}(\hat{S}). \qquad (12)$$

Asymptotic $(1-\alpha)$ 100% confidence interval can be calculated as

$$\hat{\theta} \pm Z_{1-\frac{\alpha}{2}} \sqrt{\hat{\mathrm{Var}}(\hat{\theta})}$$

For any parameter θ and where $Z_{1-\frac{\alpha}{2}}$ is a standard normal deviate defined by:

$$P\left(|Z| > Z_{1-\frac{\alpha}{2}}\right) = 1 - \alpha \,.$$

For example, for a 90% confidence interval, $Z_{0.975} = 1.645$.

5.2.2. Proportional Spillway Passage

The proportion of the total fish passage at Boundary Dam that goes through the spillway (*PS*) is estimated by the quantity:

$$\widehat{PS} = \frac{\hat{S}}{\hat{S} + \hat{P}} \,. \quad (13)$$

with associated variance estimator

$$\widehat{\mathrm{Var}}\left(\widehat{PS}\right) = \widehat{PS}^2 \left(1 - \widehat{PS}\right)^2 \left[\frac{\widehat{\mathrm{Var}}\left(\hat{S}\right)}{\hat{S}^2} + \frac{\widehat{\mathrm{Var}}\left(\hat{P}\right)}{\hat{P}^2}\right]. \qquad (14)$$

5.2.3. Fractional Spill Bay Passage

The fraction of total spillway passage that goes through a specific spill bay $\left(FS_m\right)$ can be estimated by:

$$\widehat{FS}_m = \frac{\hat{S}_m}{\hat{S}}, \quad (15)$$

where $\hat{S}$ is the estimated total spillway passage and $\hat{S}_m$ is the estimated passage for the *m*th spill bay $(m = 1, 2)$. The response $\widehat{FS}_m$ has the variance estimator:

$$\widehat{\mathrm{Var}}\left(\widehat{FS}_m\right) = \left(\widehat{FS}_m\right)^2 \left(1 - \widehat{FS}_m\right)^2 \left[\frac{\widehat{\mathrm{Var}}\left(\hat{S}_1\right)}{\hat{S}_1^2} + \frac{\widehat{\mathrm{Var}}\left(\hat{S}_2\right)}{\hat{S}_2^2}\right]. \qquad (16)$$

5.2.4. Fractional Powerhouse Passage

Similarly, the fraction of total powerhouse passage through the *g*th turbine unit $\left(FP_g\right)$ can be estimated by:

$$\widehat{FP}_g = \frac{\hat{P}_g}{\hat{P}}, \quad (17)$$

where $\hat{P}$ is the estimated total powerhouse passage and $\hat{P}_g$ is the estimated passage for the *g*th turbine unit. The response $\left(\widehat{FP}_g\right)$ has the variance estimator:

$$\left(\widehat{FP}_g\right) = FP_g^2\left(1 - FP_g\right)^2 \left[\frac{\widehat{\mathrm{Var}}\left(\hat{P}_g\right)}{\hat{P}_g^2} + \frac{\sum_{\substack{h=1 \\ h\neq g}}^{6} \widehat{\mathrm{Var}}\left(\hat{P}_h\right)}{\sum_{\substack{h=1 \\ h\neq g}}^{6} \hat{P}_h} \right]. \quad (18)$$

5.2.5. Rate of Passage Through Time

Total passage estimates can be converted to a passage number per unit of time by dividing the total fish passage by total time (*t*) of monitoring, e.g.,

$$\widehat{\mathrm{rate}} = \frac{\hat{S}}{t} \qquad (19)$$

with associated variance estimator:

$$\widehat{\mathrm{Var}}\left(\widehat{\mathrm{rate}}\right) = \frac{\widehat{\mathrm{Var}}\left(\hat{S}\right)}{t^2}. \qquad (20)$$

5.3. Fyke Net Data

The size, number and species of fish entrained within the Project intakes will be correlated with the duration, timing and magnitude of generation. Hydroacoustic target counts and target strengths will be translated into the number and size of entrained fish using the results of the fyke net sampling if abundance numbers from the two sampling methods are similar. If the

abundance numbers are dissimilar, the algorithms used to distinguish fish from other hydroacoustic targets would be reassessed. The results of fyke net sampling will also be used to identify the relative proportion of species entrained into the intakes.

5.3.1. Analysis and Data Processing

Data analysis will be conducted by HTI with raw data counts and operations data transferred in a MS ACCESS database following data entry and QA/QC procedures.

5.4. Fyke Net and Hydroacoustic Statistical Comparisons

5.4.1. Comparison of Size Frequencies

Within a sampling period, the fish length distribution from fyke net and hydroacoustics sampling will be compared over a length range of 4 inches to 39 inches (10 cm to 1 meter). This fish length comparison range is based on the fish size detection threshold of the hydroacoustic system and the capture efficiency of the fyke net arrays. Both methods are designed to have comparable fish detection/capture within this fish length range. Cumulative size frequency curves will be plotted for both fyke net and hydroacoustic data (Figure A5.4-1). Statistical comparison of the size distribution data will be based on a Kolmogorov-Smirnov (KS) test for equal distributions (Conover 1980). The results across periods will be summarized using a meta-analysis where the overall *P*–value is calculated from:

$$\lambda = -2\sum_{i=1}^{k} \ln P_i$$

where:

P_i = *P*-value for the *i*th analysis,

k = number of trials,

and where λ is chi-square distributed with $2k$ degrees of freedom, such that the overall significance is:

$$P = P\left(\chi^2_{2k} \geq \lambda\right). \quad (21)$$

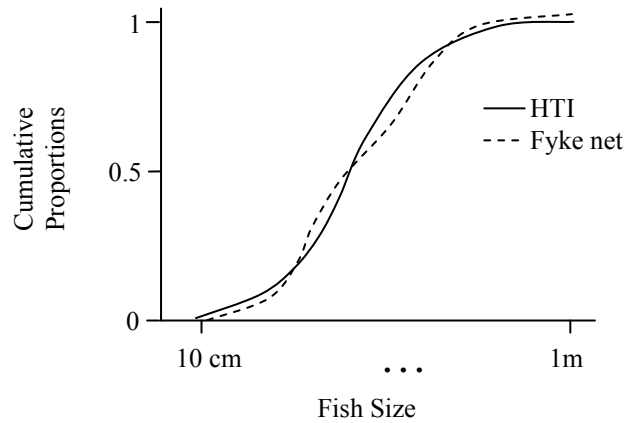

Figure A5.4-1. Schematic of cumulative distribution curves for fish size illustrating homogeneity of the hydroacoustic and fyke net samples.

Comparison of size distributions among the different fyke nets within the array can be compared using an R × C contingency table test of homogeneity of the size-class data. The comparison of fyke net data with the hydroacoustic target-strength information will be based on the pooled netting data. Homogeneity of size distributions among the nets within the array may permit eventual entrainment monitoring using only a subset of the full array. For comparison of size frequencies, the fyke net sampling should be performed such that a minimum of 30-50 fish per trial are captured.

5.4.2. Comparison of Passage Abundance

The hydroacoustic monitoring will estimate passage abundance on an hourly basis. Fyke net sampling will be carefully coordinated with the hydroacoustic monitoring to ensure passage estimates are calculated over identical time periods. Using multiple sampling periods within a day and across days within a month, a regression analysis will compare passage counts between hydroacoustic and fyke net techniques of the form:

$$y_i = \beta_1 x_i + \varepsilon_i \qquad (22)$$

where:

y_i = hydroacoustic passage estimate for the *i*th sampling period,

x_i = fyke net passage count for the *i*th sampling period,

ε_i = random error term.

The test of equality of passage counts between methods is then equivalent to a test of slope, where:

$$H_o: \beta_1 = 1$$

vs.

$$H_a: \beta_1 \neq 1.$$

If the null hypothesis is true, a data plot of hydroacoustic counts vs. fyke net counts should produce a 45° line through the origin (Figure A5.4-2). Across seasons, results of tests of equality can be combined using the meta-analysis equation (21).

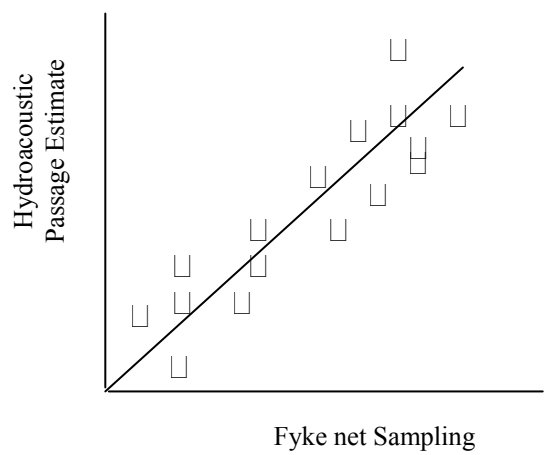

Figure A5.4-2. Schematic of a 1:1 relationship between fyke net and hydroacoustic passage estimates (i.e., $\beta_1 = 1$).

5.4.3. Species Composition and Abundance Estimates

Species composition data collected from the fyke net sampling will be summarized on a monthly basis. The percentage of each species within the total fyke net capture for the month will be used to apportion the total hydroacoustic estimates. For any monthly time period, the proportion of fish of a specific species group will be estimated by:

$$\hat{p}_i = \frac{x_i}{n} \qquad (23)$$

where:

x_i = number of fish belonging to species i,

n = total number of fish collected by fyke net.

The estimates of species proportions (22) will have an associated standard error of:

$$\hat{\mathrm{SE}}\left(\hat{p}_i\right) = \sqrt{\frac{\hat{p}_i\left(1-\hat{p}_i\right)}{n-1}}. \quad (24)$$

An asymptotic $(1-\alpha)$ 100% confidence interval will be calculated for p_i as follows:

$$\hat{p}_i \pm Z_{1-\frac{\alpha}{2}} \sqrt{\frac{\hat{p}_i\left(1-\hat{p}_i\right)}{n-1}}. \quad (25)$$

Bar charts or pie charts will be used to illustrate species composition over time.

An estimate of entrainment abundance for a particular species using the hydroacoustic estimate of total entrainment $(\hat{N})$ and the fyke net estimate of species proportions $(\hat{p}_i)$ can be computed as the product:

$$\hat{N} \cdot \hat{p}_i \quad (26)$$

with the associated variance estimator:

$$\hat{\mathrm{Var}}\left(\hat{N} \cdot \hat{p}_i\right) = \hat{N}^2 \cdot \hat{\mathrm{Var}}\left(\hat{p}_i\right) + \hat{p}_i^2 \cdot \hat{\mathrm{Var}}\left(\hat{N}\right) - \hat{\mathrm{Var}}\left(\hat{p}_i\right) \cdot \hat{\mathrm{Var}}\left(\hat{N}\right). \quad (27)$$

6 REPORTING

6.1. 2007 Annual Interim Study Report

The draft Annual Interim Study Report for 2007 will be completed and shared with relicensing participants in January 2008. It will be submitted to FERC in March 2008.

6.2. 2008 Annual Interim Study Report

The Annual Interim Study Report for 2008 will be completed and shared with relicensing participants in December 2009. It will be submitted to FERC in March 2009.

6.3. Addendum Data Report

If a decision is taken as described in Section 2, to extend the data collection efforts into the spring of 2009, an addendum report will be available in July of 2009. In the addendum report, fish passage distributions from the final 8.5 months of data collection will be summarized and compared to those in the final 2008 Annual Interim Report. Significant differences in results between the two sampling periods will be noted.

7 REFERENCES

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Appendix 2: Length Frequency Histograms

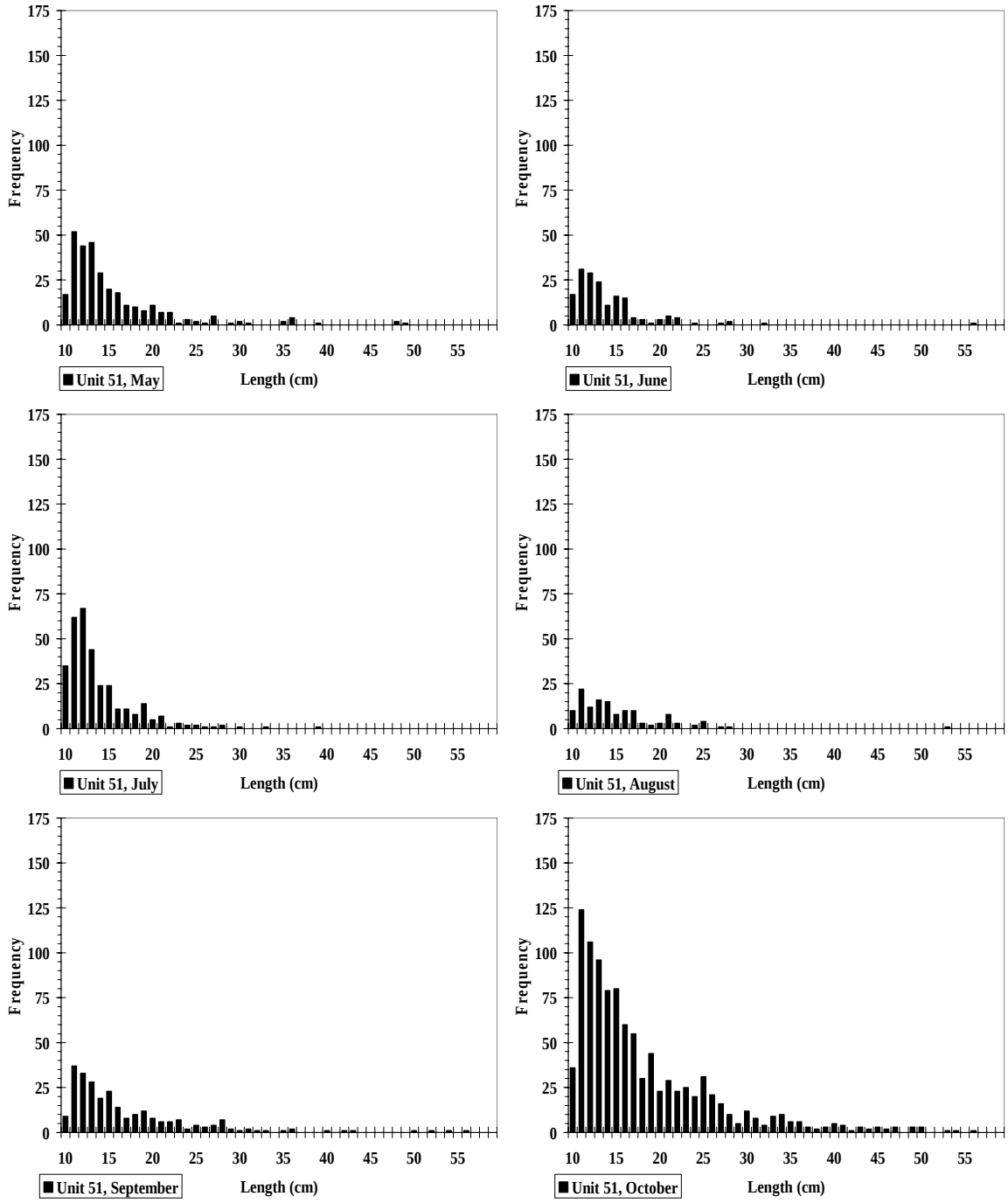

Figure A.2-1. Monthly length frequency histograms of all detections at Unit 51 for the May 2 through October 15, 2007, study period. Lengths are estimated using the TS-Length relationship developed by Love (1971).

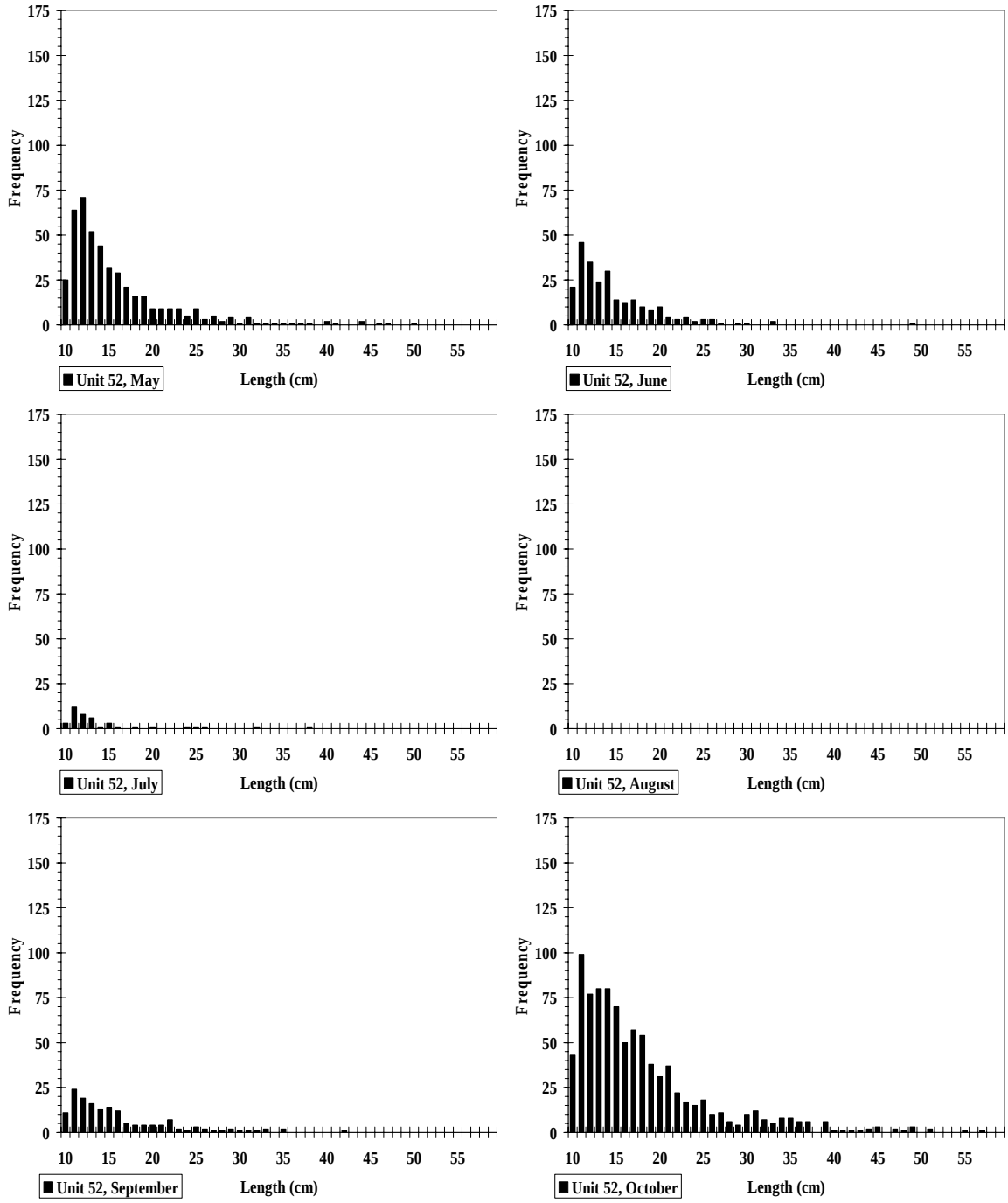

Figure A.2-2. Monthly length frequency histograms of all detections at Unit 52 for the May 2 through October 15, 2007, study period. Lengths are estimated using the TS-Length relationship developed by Love (1971). Note: Unit 52 did not operate during the month of August.

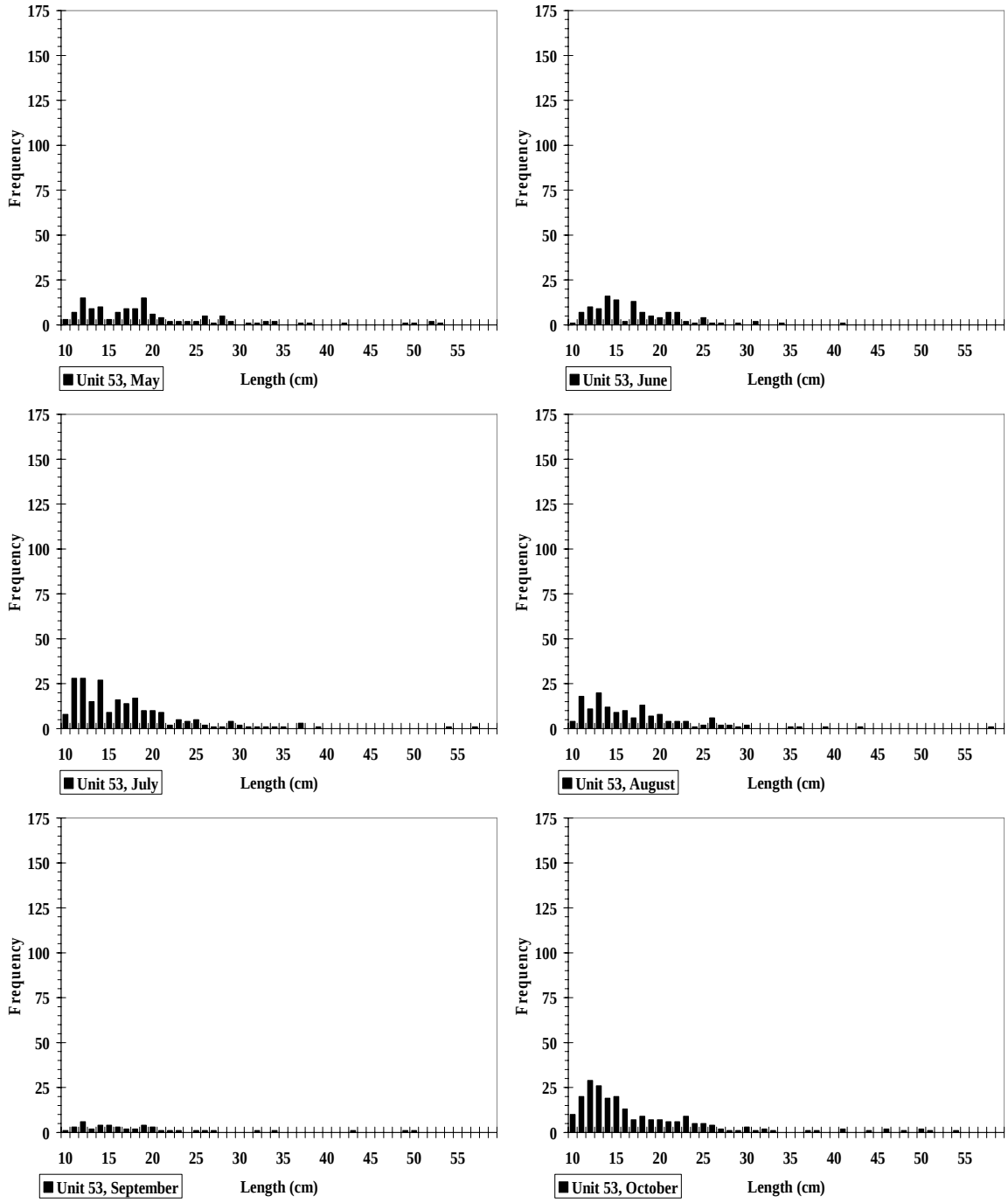

Figure A.2-3. Monthly length frequency histograms of all detections at Unit 53 for the May 2 through October 15, 2007, study period. Lengths are estimated using the TS-Length relationship developed by Love (1971).

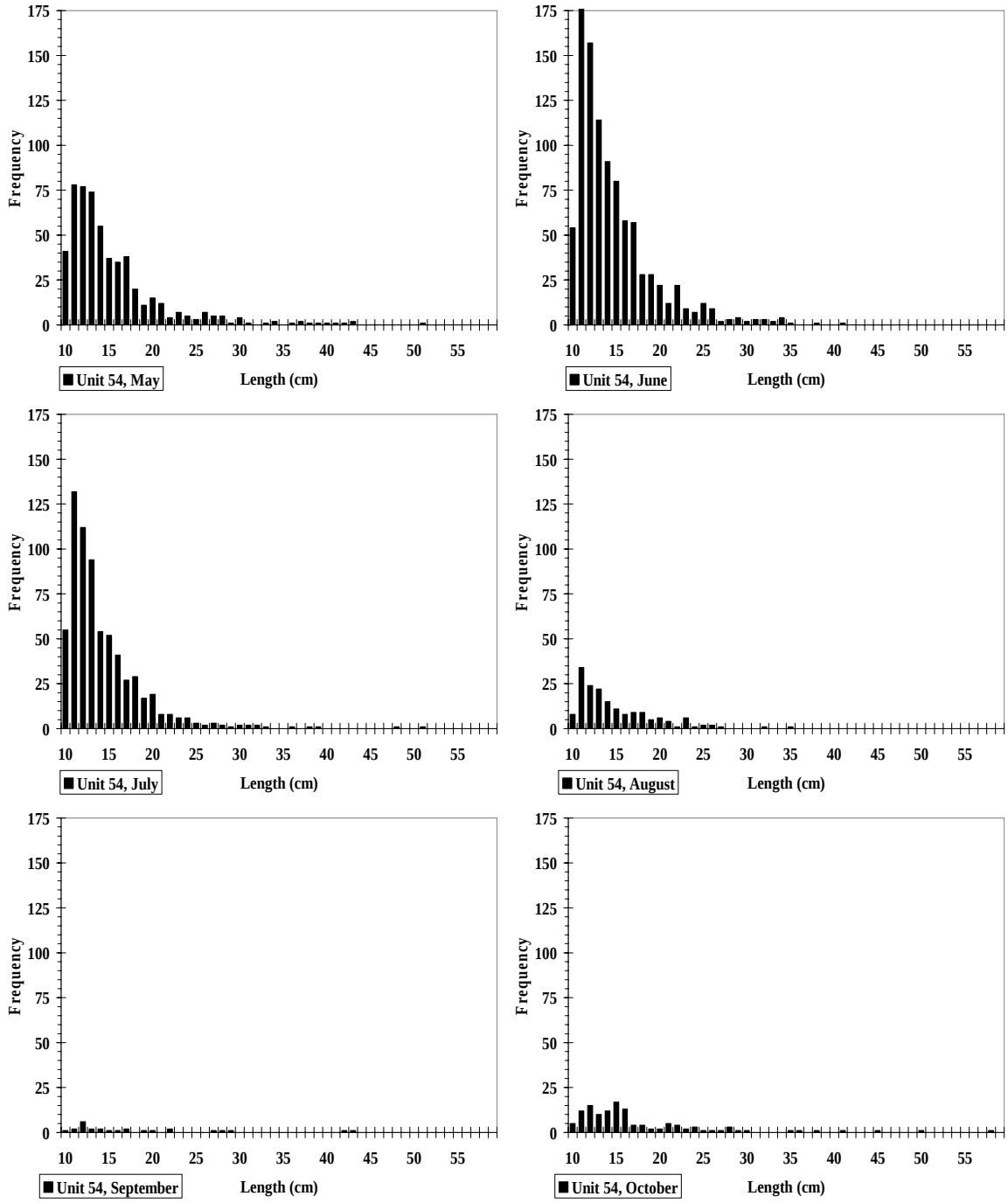

Figure A.2-4. Monthly length frequency histograms of all detections at Unit 54 for the May 2 through October 15, 2007, study period. Lengths are estimated using the TS-Length relationship developed by Love (1971).

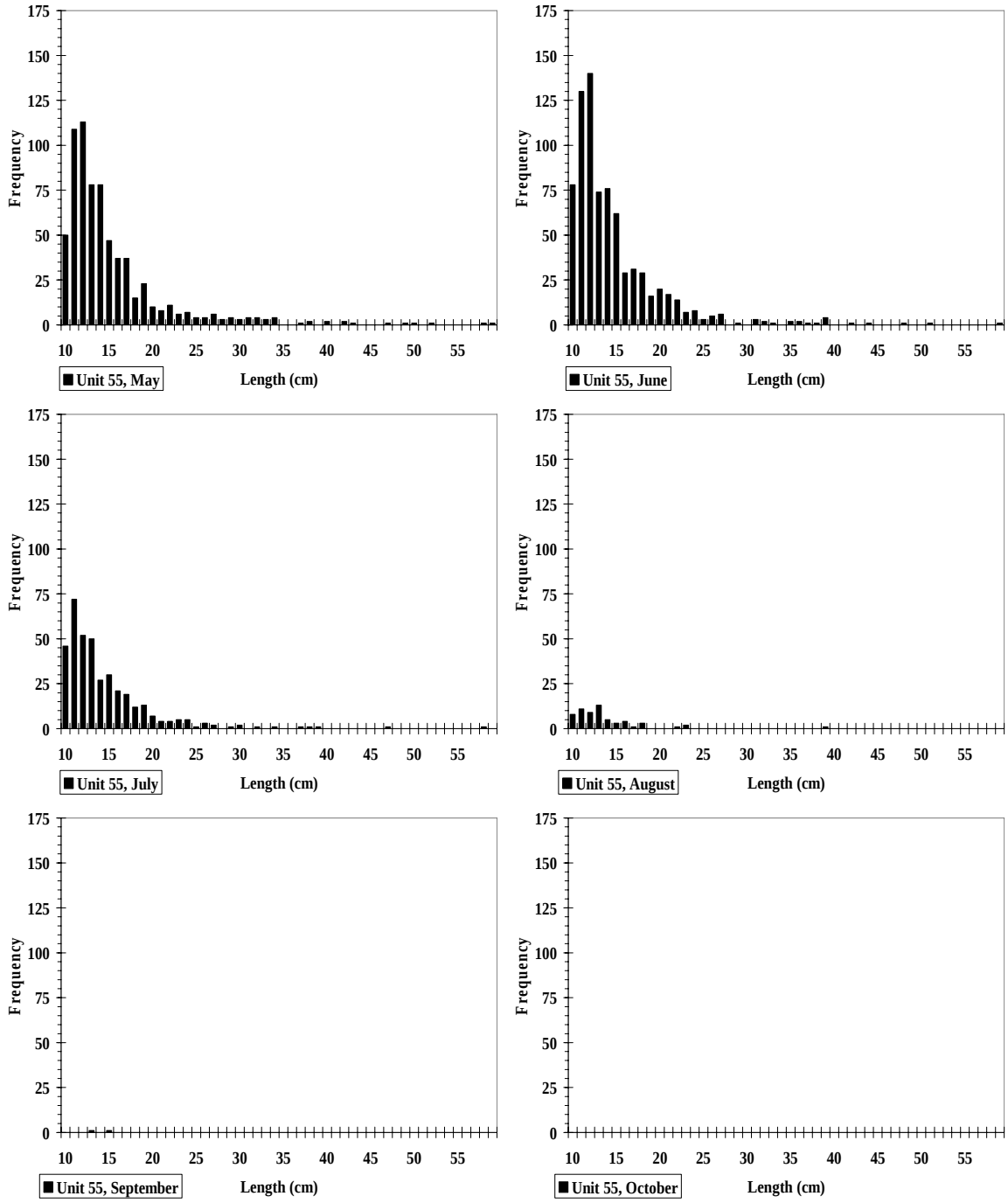

Figure A.2-5. Monthly length frequency histograms of all detections at Unit 55 for the May 2 through October 15, 2007, study period. Lengths are estimated using the TS-Length relationship developed by Love (1971). Note: Unit 55 did not operate during the month of October.

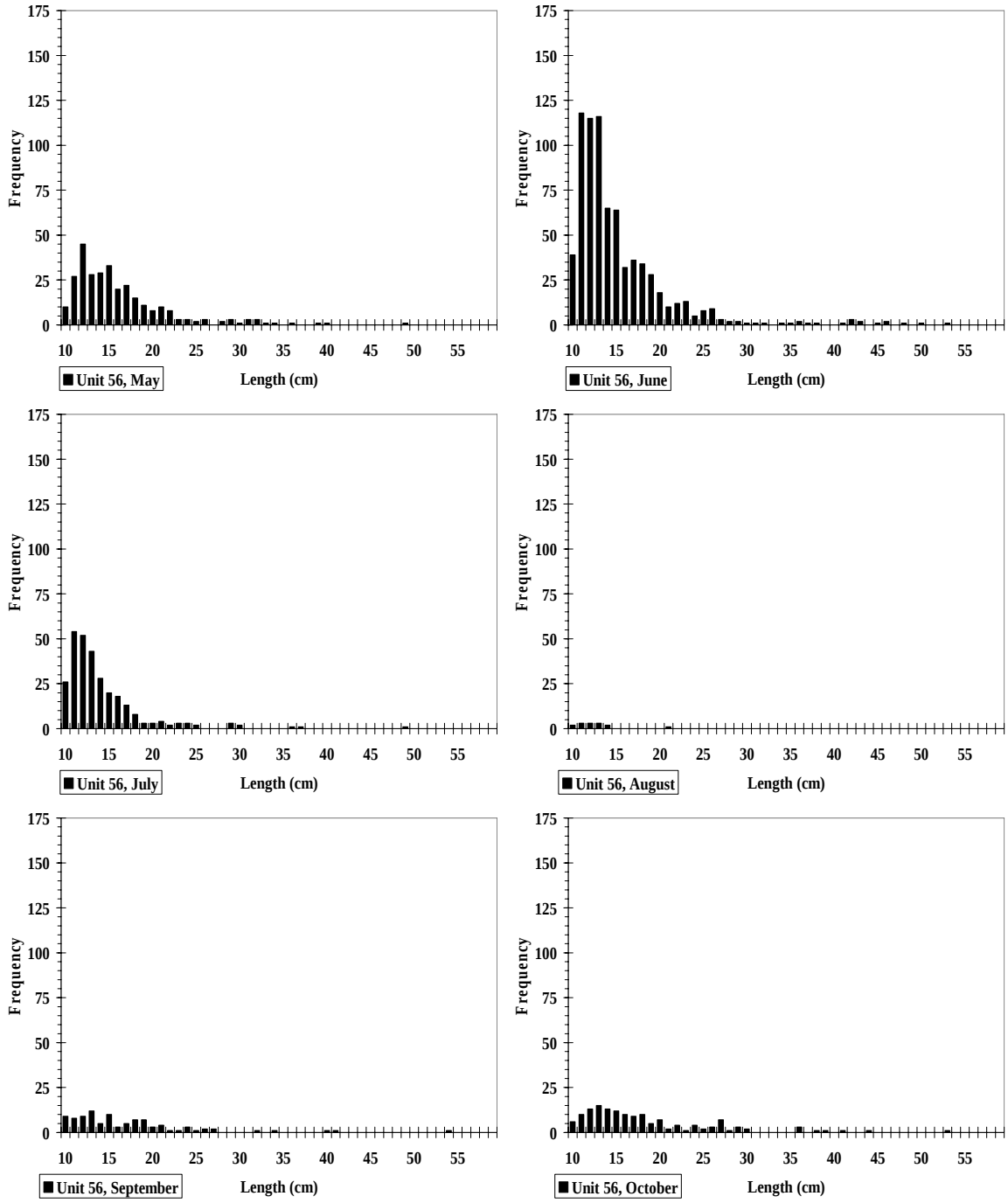

Figure A.2-6. Monthly length frequency histograms of all detections at Unit 56 for the May 2 through October 15, 2007, study period. Lengths are estimated using the TS-Length relationship developed by Love (1971).

Appendix 3: DIDSON Imaging SONAR Memorandum

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 12

Fish Entrainment and Habitat Connectivity Study

DIDSON Imaging SONAR Memorandum

Prepared for
Seattle City Light

Prepared by
Hydroacoustic Technology, Inc.
715 NE Northlake Way
Seattle, WA 98105

November 16, 2007

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Study No. 12: Fish Entrainment and Habitat Connectivity
DIDSON Imaging SONAR Memorandum
Boundary Hydroelectric Project (FERC No. 2144)

1 BACKGROUND

Study No. 12, the Fish Entrainment and Habitat Connectivity Study, is being conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by FERC in its Study Plan Determination letter dated March 15, 2007. This memorandum describes the testing conducted at the Boundary powerhouse in 2007 using a Dual Frequency Identification Sonar (DIDSON) acoustic imaging system. The DIDSON was deployed to evaluate the spatial distributions of fish entering the turbine intakes. This information was intended to assess if the area surrounding the intake centerline that was monitored by the split-beam transducers used to estimate turbine entrainment at the Project was representative of entrainment across the entire intake opening. If spatial biases in the number of fish moving into the intake were observed across the opening, the weighting assumptions used to extrapolate the split-beam target detections to total entrainment estimates may not be valid. A secondary objective of the DIDSON evaluations was to assess if the system could positively identify entrained targets as fish.

The DIDSON was deployed at Boundary Dam on 27 and 28 June 2007 to assess the number and spatial distribution of fish entering one or more of the turbine intakes. It was also anticipated that if sufficient numbers of fish were detected entering the intake, the DIDSON data could be used to evaluate the fish weighting assumptions used to extrapolate the split-beam data used in the routine hydroacoustic data analysis. The split-beam weighting assumptions currently assume that the acoustic sample collected along the vertical centerline of each intake, is representative of the distribution of fish entering the entire intake opening. The split-beam transducers deployed at the turbine units sample approximately 40 percent of the total cross-sectional intake area.

The DIDSON is a multi-beam sonar that uses an acoustic lens system to provide high resolution, video-like images. The DIDSON image is formed using 96 beams that are 0.3^{o} wide, providing nominal sampling beam angles of 29° parallel with the water surface by 14° perpendicular to the water surface. The system uses a broadcast pulse width (PW) of 0.32 ms.

The DIDSON operates at either a high-frequency (HF) setting of 1.8 megahertz (MHz) or a low-frequency (LF) setting of 1.1 MHz. The 1.8 MHz HF operating frequency provides the highest image resolution, but with a reduced effective sampling range, typically between 10-12 m. Using the LF setting, the instrument can sample to a maximum range of approximately 20 m, but with reduced image resolution, since physically smaller targets do not return sufficient echo amplitudes to be resolved at the lower frequency.

The DIDSON is capable of sampling at frame rates of 4-21 frames/sec. Each DIDSON HF frame, or image, is formed as a composite of the 96 interleaved transducer beams, constructed across an 8-ping interval. Additional descriptions of the DIDSON system architecture, specifications and operation are given in Belcher et al. (2001, 2002).

2 METHODS

The DIDSON camera was first deployed at Unit 56 of Boundary Dam, on 27 June 2008. The DIDSON camera was attached to a man basket via a pole mount and was deployed in the forebay using a crane (Figure A.3-1). The man basket was then lowered to the water surface, so that the DIDSON camera was approximately 1m below the water surface, and positioned approximately 15 m upstream of the centerline of the intake of Unit 56. The camera was aimed approximately 75° downstream (toward the intake opening).

For the Boundary Dam evaluation, initial DIDSON sampling was conducted using the HF (1.8 MHz) sampling frequency, with a frame rate of approximately 20 frames per second. It was anticipated that these settings would maximize the number of detections for each target in the relatively high-velocity environment in front of the operating turbine intake.

However, testing at Unit 56 could achieve sample ranges of only approximately 12 m at the high-frequency setting, and full coverage of the intake opening could not be achieved. The DIDSON system was subsequently moved to Unit 54 and deployed in a similar manner as at Unit 56, but using the LF frequency (1.1 MHz) setting. This configuration allowed the upper area of the intake opening to be clearly resolved, to the maximum possible sampling range of the DIDSON (20 m at the LF setting). Sampling at Unit 54 commenced on 28 June at approximately 0822 hours and continued until approximately 1300 hours. The data collected at Unit 54 were analyzed to determine the distribution of entrained targets across the unit intake.

Figure A.3-1. The DIDSON unit was deployed from a man basket using a pole mount, and lowered into the forebay of Boundary Dam via crane on 27-28 June 2007.

3 RESULTS

A total of approximately 4.5 hours of DIDSON data were collected on 28 June and reviewed for this study, identifying approximately 70 targets. From this total sample, a sub-sample of 50 targets demonstrating high fidelity (multiple acoustic returns) was selected for further analysis. An example of a target identified in the visual analysis is shown as a six-frame series in Figure A.3-2.

The sampling range of the DIDSON at the LF setting used for data collection was 20 m, and the crane basket deployment at the surface resulted in a 14-m range to the top of the Unit 54 intake. The signal amplitude return from targets was observed to diminish with range caused by absorption of the high-frequency DIDSON transmissions. Most of the Unit 54 intake opening could be resolved, but targets were observed only within the upper 6 meters of the intake. Spatial distributions of targets within the upper 6 m area of the Turbine Unit 54 intake were generated for the total 4.5-hour sampling period. These data were used to evaluate the approach routes of entrained targets entering the intake.

This analysis defined the direction of travel of targets entering the turbine intake as either along the left (east) wall, along the right (west) wall, or straight down (a diving entrance through the intake centerline).

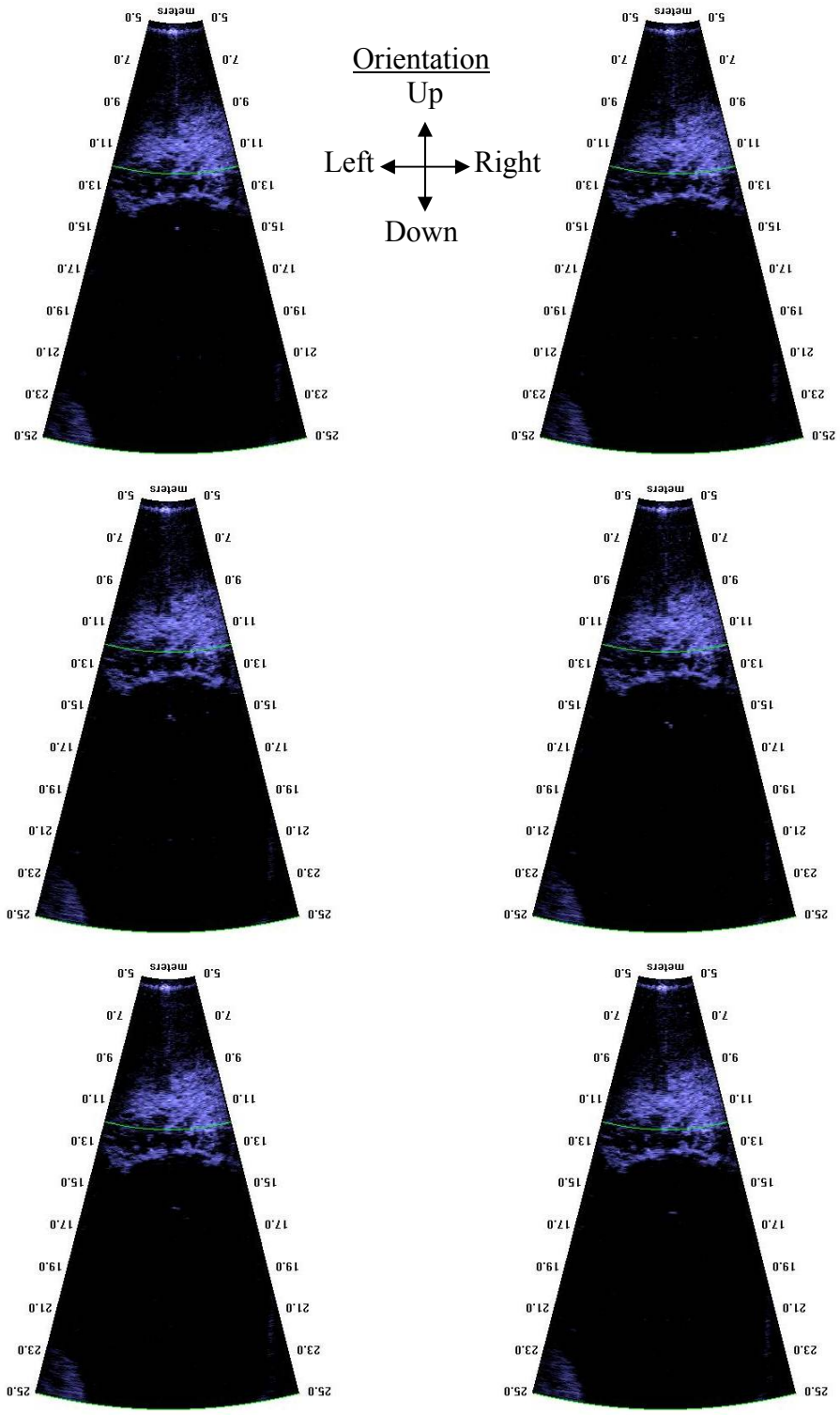

Figure A.3-2. Six sequential DIDSON sample images showing a target at a range of approximately 16 m at Turbine Unit 54 at Boundary Dam on 28 June 2007.

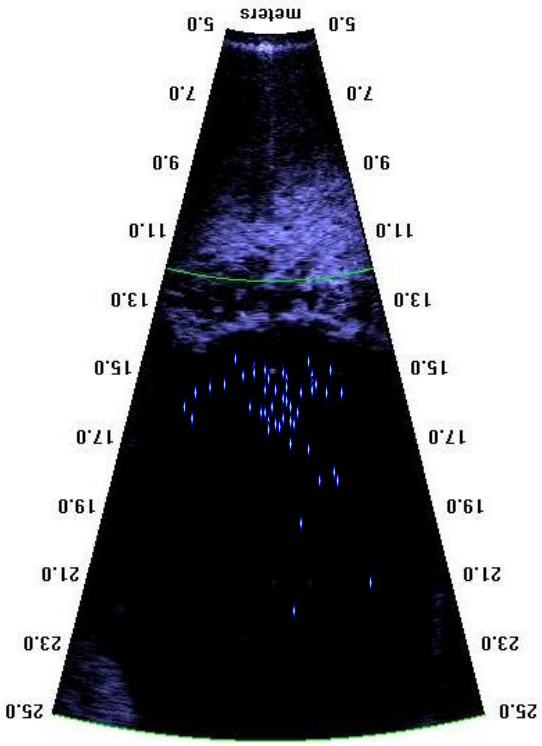

Figure A.3-3. Relative final target location of the fifty entrained targets detected passing into the Unit 54 intake during the DIDSON sampling conducted on 28 June 2007.

Of the 50 targets considered in the analysis, 25 of the targets entered the turbine along the center-axis of the intake, 19 entered along the left (east) wall of the intake, and the remaining six entered from along the right (west) side wall (Figure A.3-3). Targets appeared to be positively entrained with flow. Evidence of lateral fish swimming movement was observed in several targets, but all targets within the sampling volume appeared to ultimately pass downstream into the penstock.

Targets entering from the left (east side) typically transited toward the middle of the intake opening before they disappeared into the penstock, resulting in a final position closer to the intake centerline. The average depth of the final location of all 50 measured targets was 14.58 m, close to the observed maximum effective sampling range of the DIDSON system. The top of the turbine intake opening was located at a depth of approximately 14 m, and the bottom of the intake beyond 25 m depth, but no targets were observed at a range greater than approximately 22 m, due to absorption of the high-frequency DIDSON signal. The intensity of the acoustic target

returns typically diminished with depth. This loss in resolution precluded any observations of target behavior at the lower intake depths.

4 SUMMARY

Given the relative short sampling period and limited range resolution of the DIDSON system, the results of the 2007 investigations are qualitative in nature. Targets were observed entering the upper area of the Unit 54 intake and could be spatially located in that region. Based on the limited sample, a greater proportion of targets appeared to enter the intake toward the east side of the opening, and dive toward unit center. These passage vectors are consistent with targets "sweeping" from upstream to downstream along the face of the powerhouse with flow, and then entering the intakes as they are intercepted by flow into the units. Several of the monitored targets appeared to resist entrainment, as demonstrated by lateral movement across the intake, but all targets appeared to be ultimately entrained into the penstock.

The depth of target image resolution within the intake opening could have been improved if it were possible to mount the DIDSON closer to the top of the opening, but this was not possible in the 2007 test. The crane basket deployment arrangement and limited (50 feet) DIDSON cable length mandated a surface deployment. In addition, the vertical (downlooking) DIDSON sampling angle required because of the surface deployment was not optimal for resolving target features. Target features (such as fish body shape) are visible when the DIDSON is deployed at relatively oblique angles to the target and when the target is located at relatively close range (within approximately 10 to 12 m). Consequently, the targets observed during this study could not be positively identified as fish.

If future DIDSON evaluations at Boundary Dam are considered, designing an installation that permits deployment of the unit at depth to allow using the higher resolution HF setting should enhance the quality of the data collected. The DIDSON also functions best when the area of interest is insonified at a more oblique angle (not vertical) than was used for this study. To achieve this placement at the Boundary Dam turbine intakes would require placing the instrument off shore of the intake openings, and at depth.

5 REFERENCES

Belcher, E.O., B. Matsuyama, and G.R. Trimble. 2001. Object identification with acoustic lenses. MTS/IEEE Oceans 2001, Honolulu, Hawaii.

Belcher, E.O., W. Hanot, and J. Burch. 2002. Dual-Frequency Identification Sonar. Proceedings of the 2002 International Symposium on Underwater Technology, Tokyo, Japan. April 16-19, 2002, pp. 187-192.