Peace River Project Water Use Plan

W.A.C. Bennett Dam Entrainment

Reference: GMSMON-4

Hydro-accoustic Monitoring - Final

BioSonics

December 31, 2012

BioSonics

MONITORING PROGRAM NO. GMSMON-4
WAC Bennett Dam Entrainment
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Project Final Report:

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Submitted to:

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1.0 Introduction

Several pages of reference text that are included below were extracted from "Peace Project Water Use Plan – Peace Spill Protocol, Monitoring Program Terms of Reference" and provide a concise introduction to this monitoring program. These extracted sections are shown in *italics*.

1.1 Monitoring Rational

1.1.1 Background

The Peace River Water Use Plan Committee (hereafter known as the Committee) recognized that fish are entrained through the spillway during the spill events and consequently recommended that a monitoring program be implemented to track this fish entrainment issue during spill releases at the Williston Project. The WAC Bennett Dam Entrainment study addresses two management plans, the Peace Spill Protocol (PSP) and the Peace River Flood Pulse Plan (BC Hydro 2003). Both positive and negative impacts are expected from a spill and this monitoring program will focus on the negative impact of fish loss through entrainment. As part of the PSP, this study will address the uncertainty of (i) the relative magnitude of fish entrained through the spillway, (ii) the relationship between discharge rate and numbers of fish entrained, (iii) acute fish mortality caused by spillway entrainment, and (iv) the relative impact to reservoir populations. As part of the PCR Flood Pulse Plan, the results from this monitoring program may act as a weighting against the ecological merits of flood pulses. The monitoring programs within both of these management plans will be conducted opportunistically as no planned spill release is proposed. Spill events on the Peace system exceeding generation capacity of 70,000 cfs are rare, occurring only four times since 1968. Four additional spill events have occurred for other reasons during this period (BC Hydro 2003). These eight spills, in total, roughly equate to a spill occurring on average once every five years.

Two previous studies, in 1996 and 2002, have attempted to quantify entrainment. The 1996 study consisted of two components: (i) hydroacoustic assessment and (ii) mark-recapture study. The single beam hydroacoustic assessment quantified number of fish moving through the spillway (average of 15,000/day), location where most fish in the water column (<10 m), and the time of day when entrainment was greatest (twilight and evening hours) (Ebel 1996). The hydroacoustic assessment occurred in the last five days of a spill event that extended over a two-month period. As a result, the *study did not collect sufficient data to estimate the relationship between discharge and numbers of fish entrained as initial stages of the spill were not assessed nor was a wide range of spill discharges observed during the study. Additionally, the single beam hydroacoustic equipment was unable to provide adequate information to categorize entrainment by size class. The assessment, however, determined that fish could escape entrainment at spill discharges below 40,000 cfs. The second part of the study, the mark-recapture component was designed to estimate the number of fish killed by the spillway operation. Estimation of entrainment mortality in the system was difficult as assumptions of the mark-recapture could not be met and netting of fish was limited to the water surface. The 2002 entrainment study (BC Hydro 2002) focused efforts on a mark-recapture program similar to the 1996 study. This study provided estimates of mortality but no estimate of entrainment rate. In both the 1996 and 2002 studies, lake whitefish experienced the greatest mortality.*

1.2 Management Questions

The key management questions are:

1. *What is the magnitude of fish entrainment through the spillway during a spill event?*
2. *Is there a relationship between spill discharge rate and numbers of fish entrained through the spillway?*
3. *What species and sizes of fish are entrained through the spillway?*
4. *What rate of mortality is occurring in fish entrained through the spillway?*

The first management question will be addressed din this study by estimating the number of fish entrained and acquiring information from other studies within the Peace Water Use Plan (WUP) (i.e. Williston Fish Index); however, no ecological hypothesis will be tested to address this question. The purpose of the second management question is to establish a relationship between spill discharge rate and numbers of fish entrained, which would then be useful for predicting the impact of future spills on fish in Williston Reservoir. Also important is to establish if certain species or size classes of fish appear to be more susceptible to entrainment. Lastly, determining the mortality rate will establish if large numbers of fish are suffering acute mortality when entrained or if fish survive to then inhabit the environment downstream of the dam.

1.3 Detailed Hypotheses about the Ecological Impacts

The primary hypotheses to be tested are:

**H_1: There is a correlation between spill discharge rate and the number of fish entrained over the spillway;*

**H_2: The diel distribution of fish entrained through the spillway is not uniform;*

**H_3: Spatial distribution of fish entrained through spillway is not uniform in the water column;*

**H_4: Acute mortality results in fish entrained through the spillway.*

The first hypothesis will test for a correlation between spill discharge rate and the number of fish entrained. If possible, the hypothesis can be examined more specifically (i.e. by species, life stage, etc.,) based on the level of information gathered. The latter two hypotheses were investigated in the 1996 study, so analysis of new data will be an opportunity to substantiate the previous finding. Based on these previous findings, fish are expected to have higher entrainment rates in the twilight and evening hours and be entrained within the first 10 meters of the water column.

**For clarity, the hypotheses are stated as the alternate hypotheses. Analyses will test the null hypotheses of no effect or difference.*

1.4 Key Water Use Decision Affected

The key water use decisions affected by the results of the monitoring program are the revision of future spill strategies and the necessity of flood pulse events to maintain side channel and riparian habitat. In addition to the information from this monitoring program, other studies within the Peace Spill Protocol and the Peace River Flood Pulse Plan will influence these water use decisions. These decisions have important implications for power generation and ecological values, including fish, wildlife, and vegetation diversity and abundance downstream of the Peace Canyon Dam.

1.5 Monitoring Objectives and Scope

The objective of the monitoring program is to:

1. *Estimate the number of fish, size, and species of fish entrained through the spillway into Dinosaur Reservoir*
2. *Determine the relationship between spill discharge rate and number of fish entrained through the spillway during spill releases at WAC Bennett Dam*
3. *Determine the level of correlation between diel/spatial variables (e.g., time of day, fish depth in water column) and number of fish entrained through the spillway during spill releases at WAC Bennett Dam*
4. *Estimate the rate of acute mortality in fish entrained through the spillway*

Monitoring of fish entrainment will occur at the spillway of the WAC Bennett Dam during the entire period of a spill or some statistically representative period of time should there be time constraints. Results of the monitoring program will be used to determine the relationship between numbers of fish entrained and spill discharge, as well as diel and spatial variation. The rate of fish mortality will be estimated using a pilot study in the first spill event. In the event of a second spill within the 10-year study period, the pilot study would be expanded/modified accordingly based on the initial results. The study would be broadened to examine factors influencing mortality rate such as variation in spill discharge and fish species.

Implementation of this study is conditional on the opportunistic occurrence of a spill event where spill discharge (Q_{sdi})>7240 cfs (205 cms) at WAC Bennett Dam occurs for two days or longer. The study will be implemented for each spill event that meets this criterion.

1.6 Research Roles

BioSonics, Inc. of Seattle was contracted to measure fish entrainment using scientific acoustic techniques, and to investigate relationships between entrainment rates and other covariates (spill discharge, diel/spatial variables). LGL Limited (Corporate Office in King City, Ontario) was contracted to complete limnological and biological sampling in Williston Reservoir, and to estimate population abundance and distribution in Williston Reservoir. Catch data was collected to provide species apportionment to the acoustic entrainment data. The cooperative research products of these teams were integrated together to fulfill the monitoring study requirements (GMSMON-4).

1.7 2012 Conditions and Consequences

Inflows into Williston Reservoir were heavy in 2012, triggering a Project Spill Event. The Peace Project Water Use plan – Peace Spill Protocol Monitoring Program defines a daily average 205 cms spill threshold, which was surpassed when inflows steadily used all available storage capacity of Williston Reservoir. This study provides the methodology and results of the resulting fish monitoring study.

2.0 Methods

The general approach was to deploy split beam transducers to estimate fish entrainment rates and estimate vertical and horizontal distribution of fish in spill bays. Transducer sampling volumes were positioned as close to the face of the spill gate as possible to minimize ambiguity in fish passage routes and the potential for multiple detections of the same fish. Each transducer created in essence an “acoustic curtain.” Fish passing through the curtain were detected and counted. The curtain partially sampled the flow through the spill gate, so the fish counts were spatially extrapolated into unsampled flow.

2.1 Equipment

The monitoring equipment consisted of two BioSonics 420 kHz DT-X scientific split beam research echosounders, each collecting signals through a pair of split beam transducers. Each of the four transducers was interrogated at a pulse repetition rate of 5 pings per second (pps) and pulse duration of 0.4 mSec. This relatively fast pulse repetition rate was achieved by programming each echosounder to transmit at a rate of 10 pps, sampling each transducer on alternate pings. System cross-talk between transducers and between the two systems was eliminated by installing the pair of transducer from “System A” in opposite sides of Spillway 2, and the pair of transducer from “System B” in Spillways 1 and

3. Each transducer had a nominal beam width of about 6° (full beam width 3 dB down from maximum intensity). Additional details of the acoustic system are presented in Appendix A.

2.2 Installation

The Eastern spill gate was designated as Gate #1 in the analysis of the acoustic data. The center gate was divided into Eastern and Western sections called Gate 2E and 2W for purposes of extrapolating fish counts. The Western gate, furthest from the gravity dam, was designated Gate 3. The gate numbering is consistent with values shown on project blueprints.

Following a site visit by BioSonics personnel, an installation crew completed the deployment of the acoustic systems at the WAC Bennett Dam Spillways on June 23rd, and data collection commenced immediately.

Each transducer was attached to a slider mount clamped onto the stoplog guide rail and lowered by rope into position (Table 1). To maximize acoustic sample volume and target detectability, the installation depth of each mount was set as high as existing water levels would allow. The beam was oriented about 5° toward the spill gate to place the sampling volume as close to the gate opening as possible. Figure 1 is a line drawing of the spillway cross-section, and shows the approximate mounting position and beam orientation.

Table 1. Transducer Installation Elevations

Location	Elevation (ft)	Elevation (m)
Gate 1	2192.6	668.3
Gate 2E	2196.0	669.3
Gate 2W	2192.9	668.4
Gate 3	2192.6	668.3

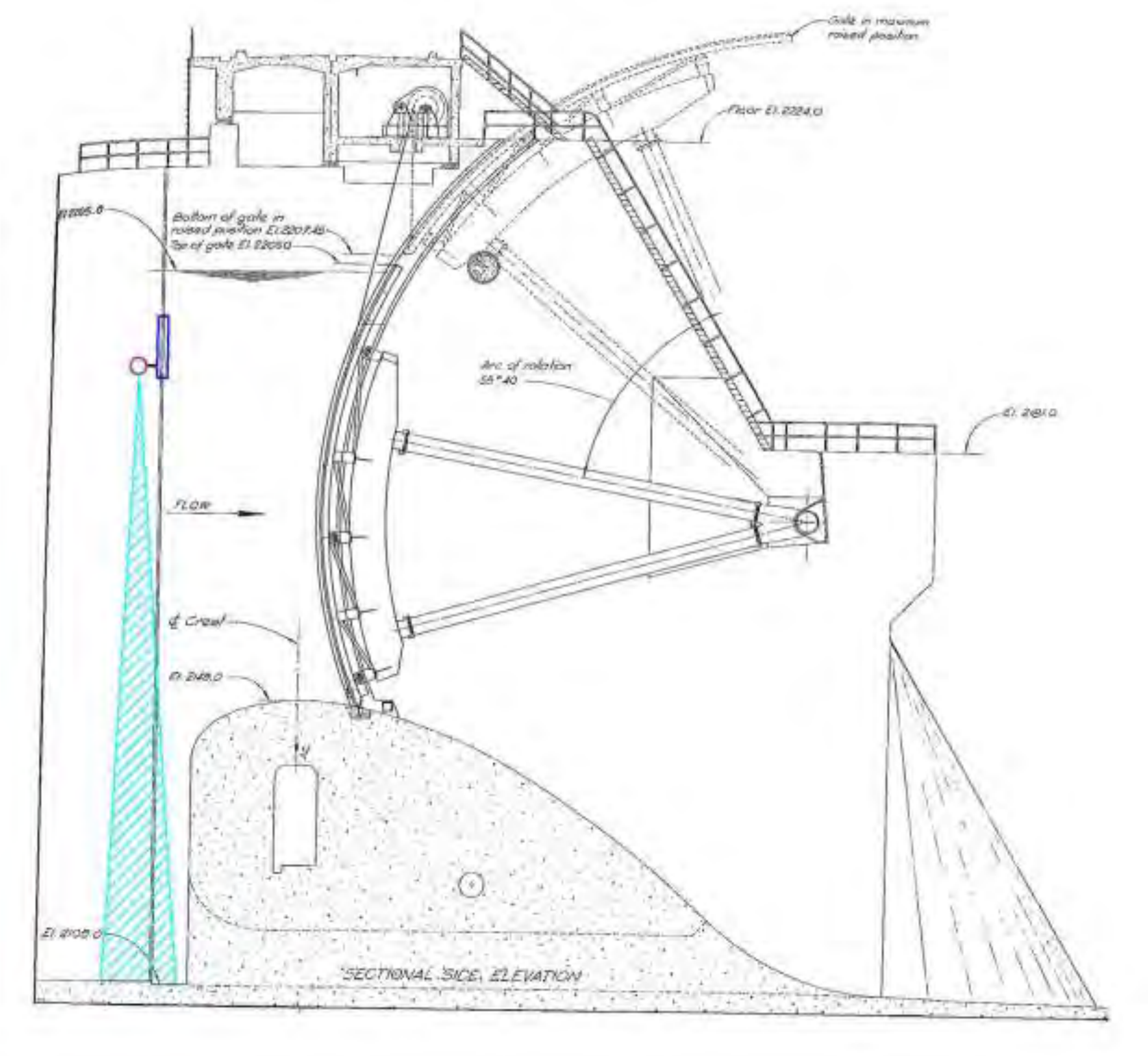

Figure 1. Cross-Sectional Drawing of Tainter Gate Showing Acoustic Sample Volume

Figure 2 presents a plan view showing the sample locations of the four transducers installed to monitor the spill region of WAC Bennett Dam.

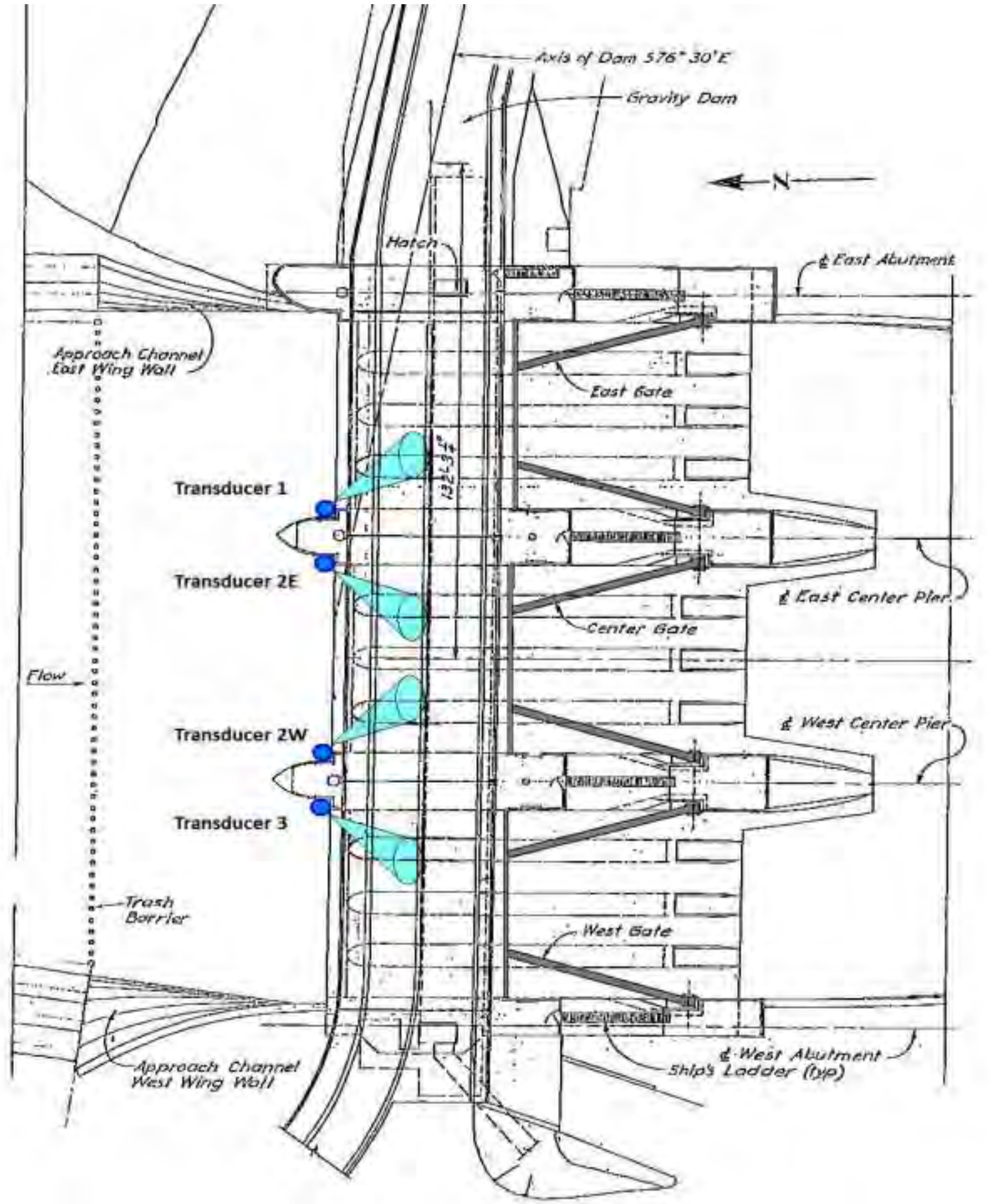

Figure 2. Plan View of Spillways 1-3, Showing Acoustic Sample Volumes

Each transducer was rotated away from the side wall about 5° to minimize interference from structures. The figure indicates that the beams were orientated downstream toward the gates; the drawing intends to make the beams appear to be aimed under the roadway structure. The center gate was sampled continuously by two transducers, while the East and West gates were sampled continuously each by a single transducer.

Transducer cables were routed up to the top of the pier nose and through a window into the hoist gallery immediately under the roadway. Both BioSonics DT-X echo sounder systems were located on a folding table adjacent to the window, and connected to AC power and a phone line for remote access. A "watchdog" system continuously monitored several system parameters, such as incoming line voltage and file sizes, and was programmed to shut down or restart the data collection sequence based on interruptions in power. The system emailed a status report to project personnel each night to report on watchdog activities.

2.3 Data Collection

Data collection was initiated late on June 23rd. The acoustic signal was evaluated on the following day to determine and optimize data collection parameters. Spill flows began at about 11:00 on June 26th, as shown in Table 2 below. Spill discharge in this table is expressed as mean and median hourly spill discharge, with upper and lower bounds supplied. The NA value for "Median" flow is supplied when only two values exist. The table also provides total daily spill volume in million cubic meters for each gate where available, and a sum for all gates for each date. Spill levels changed in an opportunistic manner, reacting to changes in reservoir elevation. The spill events were required when it was ascertained that the reservoir was approaching full pool, and steps were needed to reduce the risk of an uncontrolled spill. The four transducers attached to the scientific acoustic system were installed and sampling throughout all spill periods, except for events described below.

On July 3rd, a large log fouled and entangled itself with one of the transducer cables suspended over Spill Bay 2. The specific transducer was disabled at 09:00 and the cable was physically disconnected from the acoustic system to insure that the log could not drag the echo sounder out the window. On July 12th, the log was removed from the spill bay. The transducer cable was reconnected, and while distorted and twisted, operated as designed. The transducer was enabled and data were collected from it for the duration of the study.

Table 2. Itemized Spill Events by Date

Summary Spill Table												
			Spill	Mean Hourly	Median Flow	Lower Range	Upper Range	Spill Volume (million m^3)				
Date	Hour Range	# Hours	Category	Flow (cms)	of Flow (cms)	of Flow (cms)	of Flow (cms)	Gate 1	Gate 2	Gate 3	Total
6/26/2012	11:00-12:00	2	1	55.64	NA	2.9	108.4	0.15	0.15	0.40	0.70
6/26/2012	13:00-24:00	12	2	567.32	567.3	566.4	568.5	9.06	6.39	9.06	24.51
6/27/2012	00:00-12:00	12	2	568.94	569.3	565.2	570.1	8.98	6.62	8.98	24.58
6/27/2012	13:00-14:00	2	3	986.02	NA	875.2	1096.8	2.37	2.37	2.37	7.10
6/27/2012	15:00-16:00	2	4	1375.26	NA	1312.6	1438.0	3.36	3.18	3.36	9.90
6/27/2012	17:00-18:00	2	3	1164.24	NA	1146.2	1182.3	3.09	2.20	3.09	8.38
6/27/2012	19:00-24:00	6	4	1473.75	1473.4	1473.0	1475.0	11.73	8.38	11.73	31.83
6/28/2012	00:00-09:00	9	4	1476.31	1476.2	1475.6	1477.2	17.62	12.59	17.62	47.83
6/28/2012	10:00	1	3	1250.05	1250.1	1250.1	1250.1	1.64	1.22	1.64	4.50
6/28/2012	11:00	1	5	2133.12	2133.1	2133.1	2133.1	2.62	2.44	2.62	7.68
6/28/2012	12:00-13:00	2	3	1026.99	1027.0	823.1	1230.9	2.73	1.94	2.73	7.39
6/28/2012	14:00-17:00	4	5	2348.06	2288.7	1949.6	2865.3	12.15	9.50	12.15	33.81
6/28/2012	18:00-24:00	7	4	1479.92	1479.7	1479.4	1480.7	13.74	9.81	13.74	37.29
6/29/2012	00:00-24:00	24	4	1484.19	1484.3	1481.0	1486.7	47.25	33.73	47.25	128.23
6/30/2012	00:00-24:00	24	4	1489.08	1488.9	1486.3	1492.2	47.41	33.84	47.41	128.66
7/1/2012	00:00-24:00	24	4	1493.26	1493.3	1490.3	1494.9	47.54	33.94	47.54	129.02
7/2/2012	00:00-24:00	24	4	1496.98	1497.2	1495.3	1498.5	47.66	34.02	47.66	129.34
7/3/2012	00:00-24:00	24	4	1500.20	1500.5	1498.4	1501.4	47.76	34.09	47.76	129.62
7/4/2012	00:00-24:00	24	4	1502.26	1502.3	1500.8	1503.8	47.83	34.14	47.83	129.80
7/5/2012	00:00-24:00	24	4	1504.45	1504.6	1502.9	1505.7	47.90	34.18	47.90	129.98
7/6/2012	00:00-24:00	24	4	1505.86	1505.8	1505.0	1507.1	47.95	34.21	47.95	130.11
7/7/2012	00:00-24:00	24	4	1506.90	1507.2	1505.6	1508.0	47.98	34.24	47.98	130.20
7/8/2012	00:00-24:00	24	4	1507.52	1507.4	1507.1	1508.1	48.00	34.25	48.00	130.25
7/9/2012	00:00-15:00	15	4	1507.90	1507.8	1507.5	1508.8	30.01	21.41	30.01	81.43
7/9/2012	16:00-24:00	9	3	1050.10	1044.1	1043.8	1098.6	12.56	8.90	12.56	34.02
7/10/2012	00:00-24:00	24	3	1045.20	1045.3	1044.2	1045.9	33.35	23.61	33.35	90.30
7/11/2012	00:00-07:00	7	3	1046.02	1046.0	1045.8	1046.2	9.73	6.89	9.73	26.36
7/11/2012	8:00	1	2	470.82	470.8	470.8	470.8	0.63	0.44	0.63	1.69
7/24/2012	10:00	1	1	121.59	121.6	121.6	121.6	0.15	0.09	0.19	0.44
7/24/2012	11:00-24:00	14	2	579.12	579.2	578.6	579.6	10.82	7.55	10.82	29.19
7/25/2012	00:00-24:00	24	2	579.36	579.3	579.2	579.6	18.56	12.94	18.56	50.06
7/26/2012	00:00-24:00	24	2	579.54	579.6	579.2	579.8	No Data	No Data	No Data	50.07
7/27/2012	00:00-24:00	24	2	580.15	580.2	579.8	580.5	No Data	No Data	No Data	50.13
7/28/2012	00:00-24:00	24	2	580.57	580.6	580.3	580.9	No Data	No Data	No Data	50.16
7/29/2012	00:00-24:00	24	2	580.73	580.7	580.5	580.9	No Data	No Data	No Data	50.18
7/30/2012	00:00-24:00	24	2	580.81	580.9	580.5	581.0	No Data	No Data	No Data	50.18
7/31/2012	00:00-24:00	24	2	580.78	580.8	580.4	581.2	No Data	No Data	No Data	50.18
8/1/2012	00:00-24:00	24	2	580.59	580.6	580.3	580.9	No Data	No Data	No Data	50.16
8/2/2012	00:00-14:00	14	2	571.46	580.4	454.6	580.7	10.68	7.45	10.68	28.80

Data were collected continuously in the form of acoustic data files recorded to the computer hard drive in a proprietary compressed binary format. Each data file represented 15 minutes of data and contained two channels of digitized signals, one for each transducer. When both channels of data were recorded to a file, the file size was about 60 kB per 15 minutes, for a daily total of almost 6 gigabytes in 96 files. Data were recorded to RAID disks, which featured mirrored disk pairs for data redundancy and security. Each file name used the following naming convention:

C:\Data\DTXA\YYYYMMDD_HHmmSS.ext, where

C = the data drive selected for data storage
Data = the data folder created for data storage
DTXA = a code indicating whether the data came from System A or System B
YYYY = year, 4 digits
MM = month, 2 digits
DD = day, 2 digits
HH = Hour, 2 digits
mm = minute, 2 digits
SS = seconds, 2 digits
Ext = file extension, RTPX for Ethernet structure or DT4 for database structure.

The date and time used to create the file name represents the time that the file was opened. Each file contained the digitized waveform of the acoustic signal received from each of the 2 transducers, along with the split beam samples used to calculate the position of each echo in the beam. Data collection was terminated on August 2nd, when spill discharge ended at 14:00 hours. A total of 8184 data files were collected during the study, with a total content of 234 gigabytes.

2.4 Data Processing

Data Processing consisted of a series of steps, each described as follows:

2.4.1 Data Selection

Data files were collected from the time that spill started on June 26th to mid-day on August 7th, a period encompassing 43 days. The science team, including personnel from BC Hydro, LGL, and BioSonics, selected a subset of data for analysis that coincided with flow up-ramping and down-ramping periods, days with flow rates stabilized, and days corresponding to mobile surveys and gill netting efforts in the reservoir. The following days were selected for analysis:

Table 3. Days Selected for Analysis

Date	# Files	Variable
6/26	112	Flow Up-ramping Period
6/27	192	Flow Up-ramping Period
6/28	192	Variable Discharge Period (up and down)
6/29	192	Stabilized Period
6/30	192	Stabilized Period
7/01	192	Stabilized Period
7/09	192	Flow Down-ramping Period
7/10	192	Stabilized Period
7/11	192	Flow Down-ramping Period
7/15	192	Mobile Transect Period
7/16	192	Gillnetting and Mobile Transect Period
7/17	192	Gillnetting and Mobile Transect Period
7/18	192	Mobile Transect Period
7/24	192	Flow Up-ramping Period
7/25	192	Stabilized Period
8/02	192	Flow Down-ramping Period

2.4.2 Trace (Fish) Extraction

As fish passed through the acoustic curtain and were detected, they produced a pattern called a "trace". Fish traces were extracted from the binary acoustic files by means of the "Echoview" software created by Myriax Pty. Ltd. of Tasmania (http://www.echoview.com/). This package reads native BioSonics binary data files and displays them visually to the operator in a post-processing environment. The operator has the choice of programing the software for automatic trace formation, or of manually forming fish traces. For this study, all fish traces were extracted manually, using these general guidelines:

4 or more echoes in a trace (3 echoes for some traces at very close range)
Extract all traces above the elevation of the spill ogee (2145')
Extract only traces from below the elevation of the spill ogee that displayed upward trajectories
Reject milling fish (i.e., those with hundreds of echoes) detected below the ogee elevation
During selected periods without flow, no milling or drifting targets were selected.

Trace formation procedures are further detailed in Appendix B.

The output of the trace formation step was a file stored in CSV (comma separated variable) format, with each trace represented by a single row of data. Each row included 39 fields of descriptive variables, including date/time, start/stop ping number, number of echoes, mean Target Strength (TS), system and channel identifiers (pointing to the transducer location), direction of travel, and fish range or depth. Output files were concatenated into a single daily file containing fish traces from all four transducers.

Note that extraction of a fish trace from a data file does not imply that it is included in the entrainment estimates. The direction of travel is also evaluated to determine if the fish is moving with or against entrainment flows (See Section 2.4.6.5 below).

2.4.3 Acoustic Size Categories

Prior to data analysis, scientists from BC Hydro, LGL, and BioSonics discussed and agreed upon the three length range groups shown in Table 4. Fish acoustic size categories were established by using Target Strength as a surrogate for fish length. Target strength values were calculated from Love's (1971) dorsal aspect model for each of the three size categories, and adjusted for the (420 kHz) frequency used during this study.

Based on catch data provided by LGL, fish <80 mm were not sampled by the gill net. Based on habitat and foraging preferences, the two most likely juvenile fish species in the 40-75mm size class were Peamouth Chub and Lake Whitefish and a smaller number of juvenile Kokanee, but a precise apportionment between these species is not suggested. Kokanee are numerically superior to Peamouth Chub, Lake Whitefish, and Bull Trout in the 75 to 465 mm size class. Fish larger than 465 mm must be either Bull trout or Lake Trout, as no other species found in Williston Reservoir reach lengths over 465 mm.

Table 4. Fish Size Categories

Category	Length Range	Target Strength Range	Predominant Species
Small	40-75 mm	-60 to -47.5 dB	Peamouth Chub/Lake Whitefish
Medium	75-465 mm	-47.5 to -32.5 dB	Kokanee
Large	>465 mm	>-32.5 dB	Bull Trout/Lake Trout

2.4.4 Flow Categories

Mean hourly discharge rates varied from values of 2.86 cms to 2865.3 cms. However, the bulk of the values were in or near the ranges of 500, 1000, or 1500 cms (Figure 3).

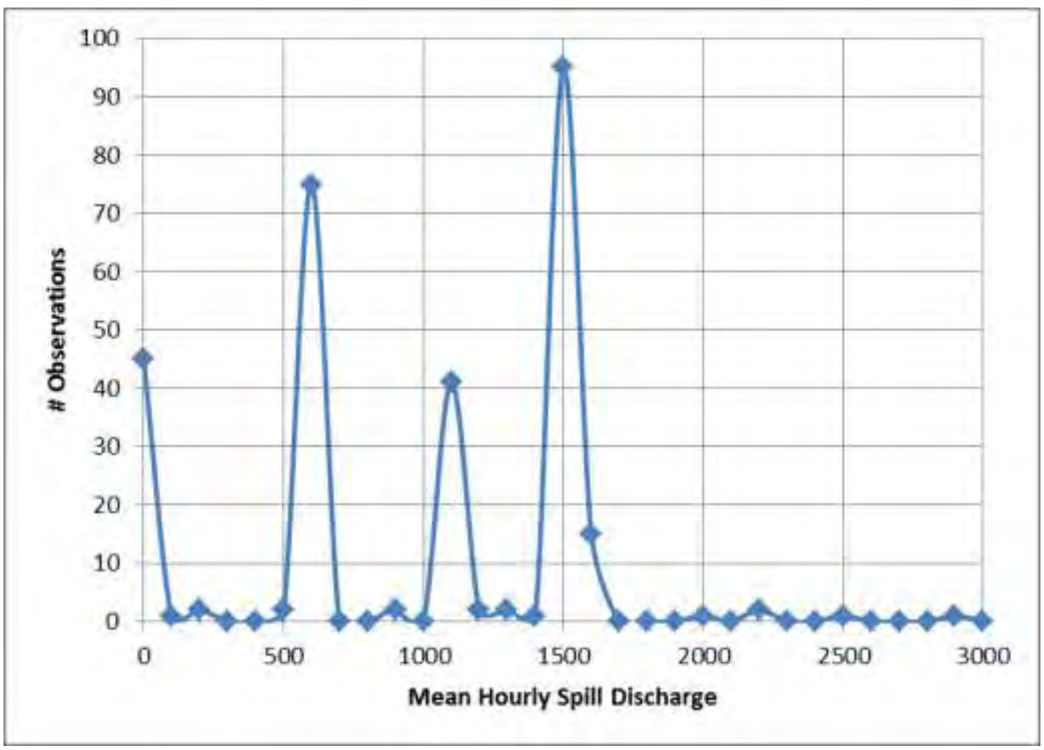

Figure 3. Distribution of Hourly Spill Discharge Levels

Therefore, flow levels were categories into the following classes in Table 5, indicating the number of sample hours analyzed within each spill category:

Table 5. Flow/spill Categories

Spill Category	Lower Boundary (cms)	Upper Boundary (cms)	# Hours Analyzed
1	>0	300	48
2	300	700	77
3	700	1300	47
4	1300	1700	111
5	1700	+	5

2.4.5 Day/Night Time Boundary

The spatial distribution of fish in the reservoir is strongly affected by light level. The time of sunrise and sunset changed throughout the 43 day study period. The application accessed at "www.sunrisesunset.com/calendar.asp" for Fort St. John gives mean July sunrise near 04:30 and sunset around 21:30. Shadowing effects of the canyon walls likely produce a later sunrise and an earlier sunset. Since the hourly summaries of entrainment start on the hour, we used 05:00 to 21:00 as the daytime period.

2.4.6 Analytical Methods for Entrainment Estimation

The core of the data analysis process is a spreadsheet containing all detected fish traces (23,394). The initial descriptive fields are generated by the Echoview software. The acoustic beam is viewed as a "detection curtain" or cross-sectional area through which the fish passes. Since the acoustic beam is narrower than the width of the spill gate, the fish detection process can be considered as "spatial subsampling". Detections are extrapolated into un-sampled flow by calculating a weighting factor for each fish trace indicating the ratio of the gate width to the effective beam width for that fish. Additional detail is presented in the following sections.

Following creation of the spreadsheet that contains descriptive fields for all traces, we calculate several "derived" fields:

1. Gate Code

2. Beam Pattern Compensation
3. Effective Half Angle
4. Effective Beam Width
5. Spatial Weighting Factor
6. Hour
7. Date (MDD for Month, Day)

With these derived fields included in the spreadsheet, it is straightforward to select any subset of the project data and run an analysis on it.

2.4.6.1 Gate Assignment

One of the fields that Echoview provides is the name of the source data file. This name is parsed out to determine if the particular trace record was detected on System A (DTXA) or System B (DTXB). Echoview also provides a channel number corresponding to Transducer 1 or 2. Based on the installation locations, each of the four combinations is given a gate assignment code:

1. System A, Channel 1 = Gate 2E
2. System A, Channel 2 = Gate 2W
3. System B, Channel 1 = Gate 1
4. System B, Channel 2 = Gate 3

2.4.6.2 Effective Beam Width

The width of the acoustic beam varies with the size of target detected – the system can detect a large fish farther out toward the beam edge, where a small fish in the same location may be below threshold or masked by interference. By using the mean Target Strength of each fish and the detection threshold, a beam pattern value is calculated. The beam pattern value is mapped to the directivity plot of the transducer to convert it to an Effective Beam Angle. By selecting the target range field and using standard trigonometry, an effective beam width is calculated. The details of these steps are discussed in Appendix D.

2.4.6.3 *Spatial Weighting Factor*

The Effective Beam Width calculated for each fish is divided into the spillway width to generate the Spatial Weighting Factor for that fish. For example, say that a fish trace detected at a range of 10 m yielded an Effective Beam Width of 2 m. The width of each gate is 15.2 m. By detecting this fish, we know that we sampled a 2-m wide swath out of a total width of 15.2 m. Assuming uniform distribution across the gate opening, this fish would have a spatial weighting factor of 15.2/2 or a value of 7.6 (illustrated in Figure 4). This process can be restated by saying that if the beam covered the entire width of the spillway, we would have (statistically) counted 7.6 fish.

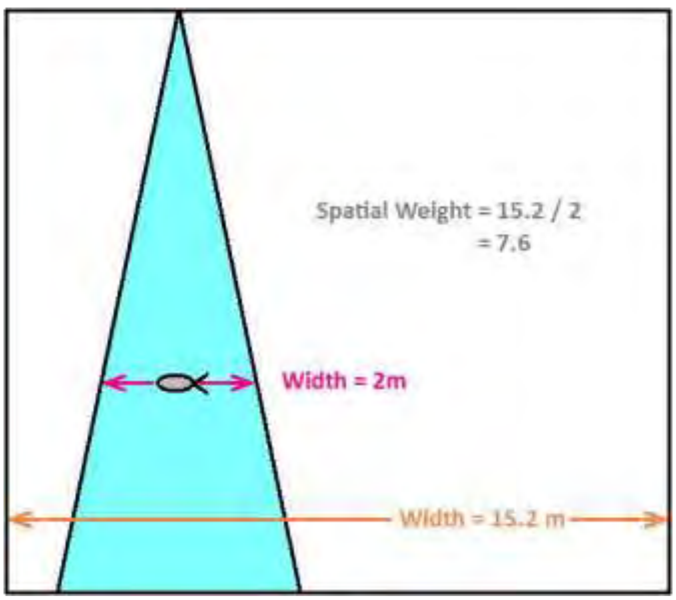

Figure 4. Illustration of Spatial Expansion Concept

During normal operation of System A in Gate 2, the gate width was divided into two equal widths of 7.62 m, and all fish traces detected by System A used this value when spatial expansion was calculated. During the time period when one transducer was disabled due its cable being fouled by a log, the data from the remaining transducer was spatially extrapolated across the entire width of 15.2 m.

Fish entrainment was calculated by summing the weighting factors for each size category and hour. A data filtering engine was built in the spreadsheet to allow filtering of data subsets based on a set of criteria. For example, we could select the daytime hours on June 26 through July 1 and calculate fish entrainment within the three size categories.

2.4.6.4 Data Selection Fields

The data filtering function in the spreadsheets allows extraction of data blocks based on Sample Day, Hour of Day, Gate, Depth Limits, Target Strength, # Echoes per Track, and 6 other descriptive or derived field values. Summaries, means, and distributions are then calculated on the extracted data block to isolate the effects of selected variables.

2.4.6.5 Direction of Travel Selection

In 1996, acoustic measurements of fish entrainment at the WAC Bennett Dam Spill Bays were completed by BioSonics. In this study, single-beam transducers were used to detect fish. The study concluded that fish could escape entrainment at discharge rates below 40,000 cfs (1133 cms). This statement must be viewed as preliminary because of three reasons:

- The transducer orientation in the 1996 study is understood to be similar to the 2008 and 2012 studies, where the axis is essentially perpendicular to fish trajectories
- Single-beam transducers used in 1996 can only detect direction of travel if a change in range is involved, unless the transducer is aimed in a direction approximately parallel to the fish trajectory.
- Single-beam transducers cannot directly measure fish target strength

For these reasons, we further evaluated the flows in the spill intake canal in the 2012 study. We first estimated the cross sectional area of the flow in the area adjacent to the transducers by taking the water depth (from surface to spill ogee) times spill bay width (3 bays, 50 feet each). We divided the mean daily flow (including hours with flow greater than 25 cms) by the cross-sectional area to calculate flow in m/s. The resulting water velocity estimates in all sample days ranged from 0.69 to 0.75 m/s, except for the mid-July dates. On July 9, water velocity was 1.9 m/s. and on July 10-11 ranged between 1.22 and 1.32 m/s. Table 6 shows the mean discharge rates for these days, along with the mean water velocity.

Table 6. Estimated Water Velocities

Date	Mean Daily Discharge (cms)	Mean Velocity (m/s)
6/27/2012	532.0	0.72
6/28/2012	567.4	0.75
6/29/2012	567.6	0.75
6/30/2012	567.8	0.74
7/1/2012	568.0	0.74
7/9/2012	1508.4	1.91
7/10/2012	1045.2	1.32
7/11/2012	974.1	1.23
7/24/2012	548.6	0.66
7/25/2012	579.4	0.70
8/2/2012	571.5	0.69

The 1983 paper by Ruggles and Murray documents visual observations of fish swimming behavior in a flume as a function of current velocity. "At slow velocities of about 0.4 m/s, most of the fish entered the flume swimming downstream headfirst. At intermediate velocities of about 0.8 m/s, sockeye smolts appeared to be transported passively downstream. Although the individuals of a school maintained their position relative to one another, the direction in which they were orientated with respect to the current appeared to be random. At velocities of about 1.2 m/s, juveniles were carried downstream tailfirst and entered the flume orientated head upstream." These observations suggest that smaller fish do not actively resist entrainment flows (by swimming upstream) until the current is somewhere between 0.8 and 1.2 m/s. It is likely that all fish in the small size group and most in the intermediate group are entrained, as they do not start to resist entrainment flow until it is of a magnitude that they cannot resist it. It is also likely that some proportion of the larger kokanee and whitefish in the intermediate size group may be able to escape entrainment.

To further evaluate fish behavior, we then used the split-beam capability to estimate the direction of travel for each fish detected while spill gates were open. A frequency histogram was created to evaluate how the fish population was moving relative to flow. A value of 0° corresponds to movement directly toward the dam (please refer to Appendix B for further discussion on calculation of direction of travel). Figure 5 shows three panels corresponding to small, medium and large size classes respectively.

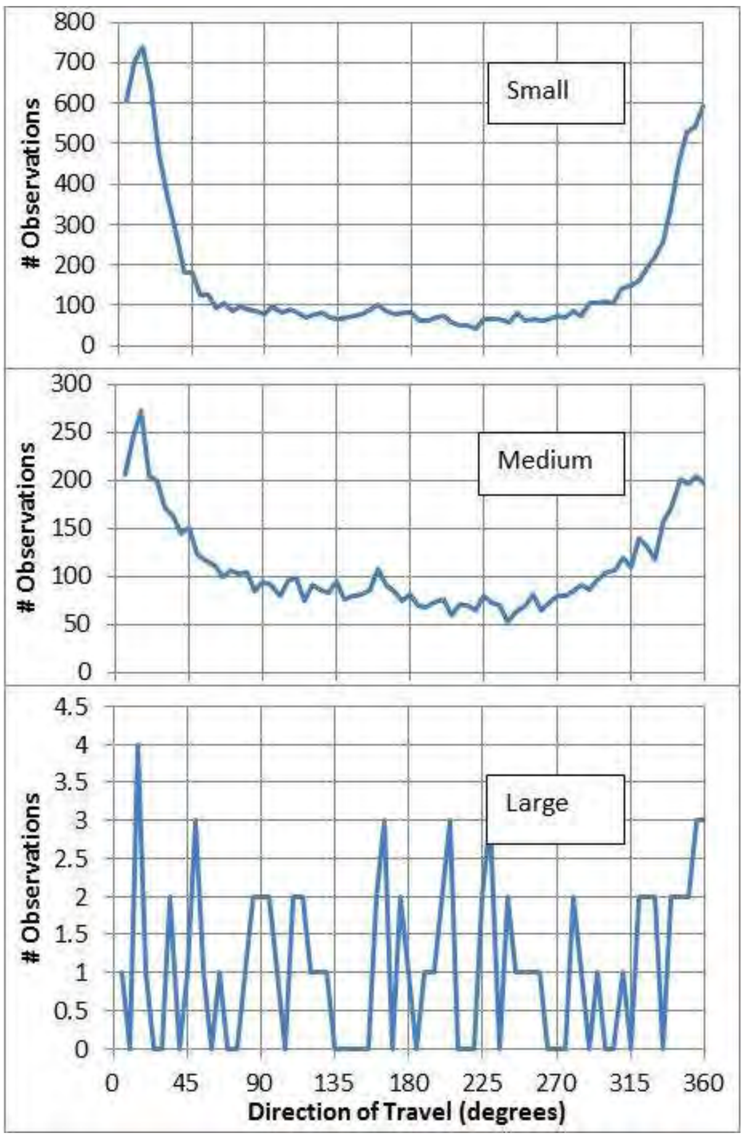

Figure 5. Direction of Travel by Size Category

The distributional pattern for small and medium size categories are similar, indicating a high proportion of fish moving downstream. These panels indicate an increasing ability to resist downstream movement with increasing fish size. The pattern observed for the large size category is distorted due to small sample size. A "baseline" of counts in the smaller two categories (indicating at least 50-100 observations at any angle) is partially due to noise effects on the split-beam data. In all three plots, the highest value is observed at about 15 degrees. We therefore concluded that this value was the most accurate empirical estimate of true downstream passage. We selected all fish moving at 15° ± 90° as fish that were being entrained (i.e., those traveling between 285° and 360° and between 0° and 105°), and rejected those moving in the opposite direction. We suggest that this is a reasonable approach for all size categories. The relationship between flow rates and numbers of large fish entrained is discussed in Section 3.1.

2.4.6.6 Distributional Analyses

Target strength and vertical distribution data were described by using Excel's Frequency Distribution function to generate distributions. For the target strength analysis, we built a distribution based on 1 dB categories. The vertical distributions were described using 1 m bins. Following extraction of the vertical distribution frequency distribution, the data were normalized for depth. This step is required because the acoustic beam spreads with range (depth) – it would detect more fish deeper in the case of fish being uniformly distributed vertically. This depth bias in the acoustic sampling is removed by dividing the sum of weights in each 1 m bin by the mid-depth or mid-range of that bin.

2.4.6.7 Extrapolation of Fish Entrainment into Spill Days Not Analyzed

Spill discharge rates were examined for each day that was not analyzed. The seven days bounded by July 2 and 8 experienced an almost constant hourly spill discharge rate of about 1500 cms, defined as spill category 3. The seven days bounded by July 26 and August 1 showed a very constant spill discharge rate of about 580 cms, or spill category 2. The polynomial function derived from the analyzed data were based on entrainment rates and spill category number. This function was used to extrapolate the hourly fish entrainment rate for both time blocks in the non-analyzed data set. The proportion of entrainment by gate was estimated for the July 2-8 block by calculating a mean proportion for each gate from the surrounding (June 26-July 1 and July 9-11) data values. The total daily entrainment estimate was the hourly value calculated from the polynomial function times the number of hours per day. The entrainment estimate for each gate was the product of the daily total times the mean gate proportion. Likewise, the estimates for July 26-August 1 used values averaged from July 24-25 and August 2.

The standard deviation about each daily mean entrainment value was calculated for each of the days analyzed using standard statistical methods. A 95% confidence limit was approximated by a value of two standard deviations. The standard deviation about the daily estimate for each non-analyzed period was estimated by taking the mean standard deviation from the preceding and subsequent days (June 26 through July 1 and July 9-11 were used to calculate standard deviations for the non-analyzed period of July 2-8, and July 24-25 and August 2 were used to calculate standard deviations for July 26-August 1).

3.0 Results and Discussion

3.1 Daily Entrainment Tables by Size Class

Table 8 summarizes the daily entrainment totals in each of the size categories, based on counting all fish moving toward the gate and excluding all fish swimming upstream from the gate. Observe that the spill gates were closed on July 15-18, and therefore no fish entrainment occurred. Except for some trace interpretation differences (See Appendix C), the analytical procedures used on this data set were identical to those used on data collected when gates were open.

Table 7. Daily Entrainment Estimates by Size Class

Summary of Fish Entrainment Estimates through Spill Gates 1-3, WAC Bennett Dam, June 26 - August 2, 2012

	Entrainment by Size Class				
Date	**Small**	**Medium**	**Large**	**Daily Total**	**Comments**
Length Range	40-75 mm	75-465 mm	>465 mm		
TS Range	-60 to -47.5 dB	-47.5 to -32.5 dB	>-32.5 dB		
June 26, 2012	3,656	739	0	4,395	Gates Open, partial day sampled
June 27, 2012	9,608	2,010	15	11,633	Gates Open, Full Day Sampled
June 28, 2012	6,759	1,134	11	7,904	"
June 29, 2012	3,636	936	1	4,572	"
June 30, 2012	12,765	2,089	0	14,855	"
July 1, 2012	17,201	2,764	7	19,972	"
July 9, 2012	25,094	3,888	18	29,001	"
July 10, 2012	24,715	2,819	78	27,612	"
July 11, 2012	5,733	1,148	0	6,881	Gates Open, partial day sampled
July 15, 2012	6,187	16,883	377	23,447	Gates Closed, no Entrainment
July 16, 2012	3,582	6,627	172	10,381	"
July 17, 2012	2,539	4,807	107	7,453	"
July 18, 2012	3,027	4,749	44	7,821	"
July 24, 2012	6,621	2,929	2	9,553	Gates Open, partial day sampled
July 25, 2012	16,831	8,510	10	25,351	Gates Open, Full Day Sampled
August 2, 2012	1,872	1,085	12	2,969	Gates Open, partial day sampled
Total Entrainment, gates open	134,490	30,051	155	164,696	

For the days selected for analysis and reporting, hourly estimates of entrainment by size class are provided in Appendix E. Note that the estimates of fish entrainment are based on counting those exhibiting a downstream direction of travel. Comparisons of body length to entrainment current speed correlate well to the observed direction of travel plots: smaller fish are being swept downstream, intermediate sizes are also moving downstream but at a lesser rate, and large fish show almost equal numbers of downstream and upstream direction values. It was determined that out of 284 large fish, 129 were determined to be moving upstream, producing a net downstream entrained number of 155 large fish.

Daily entrainment numbers exceeded 25,000 fish per day on July 9th and 10th and July 25th, and equaled essentially 20,000 fish on July 1st. In all of these cases, the numbers in the small size category exceeded the totals of the medium and large categories. The highest estimate of daily entrainment of fish in the medium size class occurred on July 25th. Entrainment of fish in the large size class peaked on July 10th. In general terms, the estimates of small fish entrained were between 4-5 times higher than the estimates of medium sized fish, and approximately 3 orders of magnitude larger than the numbers of large fish.

Entrainment numbers are discussed in context of reservoir population estimates in Section 3.7.

3.2 Day and Night TS Distributions, Spill Gates Opened

All daytime and nighttime target strength data from hours where spill gates were open were used to generate frequency distribution plots (Figure 6).

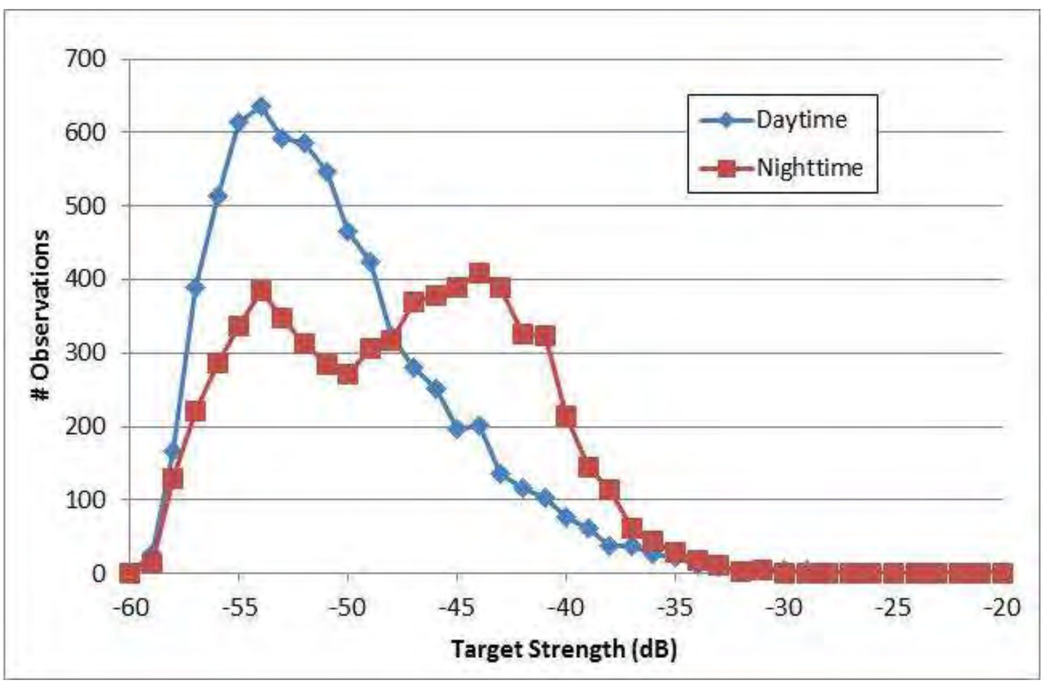

Figure 6. Day and Night Target Strength Distributions, All Days with Spill Gates Open

These plots show fewer fish in the medium and large size categories available to the acoustic gear in the daytime. Daytime sample size (6868) is comparable with numbers of nighttime samples (6440), although sample time is not equivalent (16 daytime sample hours and 8 nighttime hours).

3.3 Vertical Distribution, Spill Gates Opened

Vertical distribution of fish is described by selecting the day or night fish data set collected during hours with spill gates open, and generating a frequency distribution. The values shown have been normalized to remove the vertical sampling bias. Numbers are then converted to percentages to facilitate comparisons between groups. Vertical distributions by fish size category are presented for daytime and nighttime hours in Figures 7 and 8 respectively. The sample sizes are shown in parentheses and should not be compared to entrainment numbers as they represent values normalized by depth to compensate beam spreading.

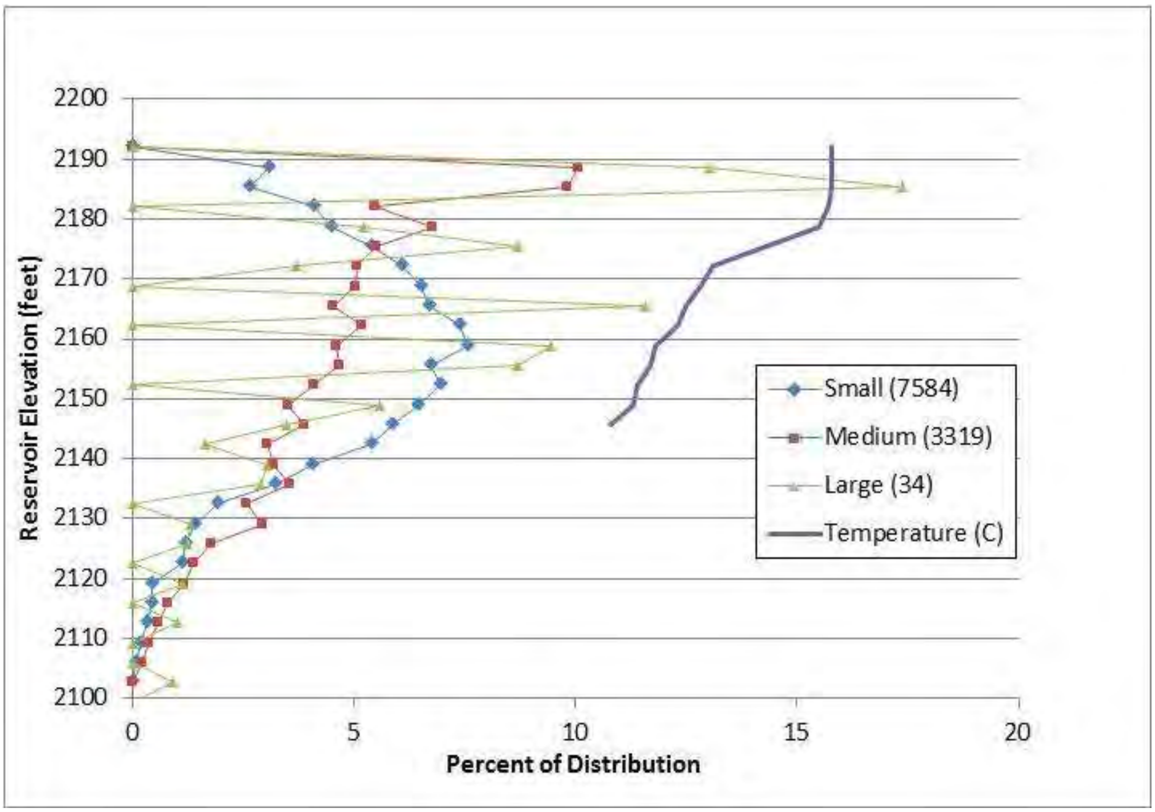

Figure 7. Daytime Vertical Distribution by Size Category, All Days with Spill Gates Open.

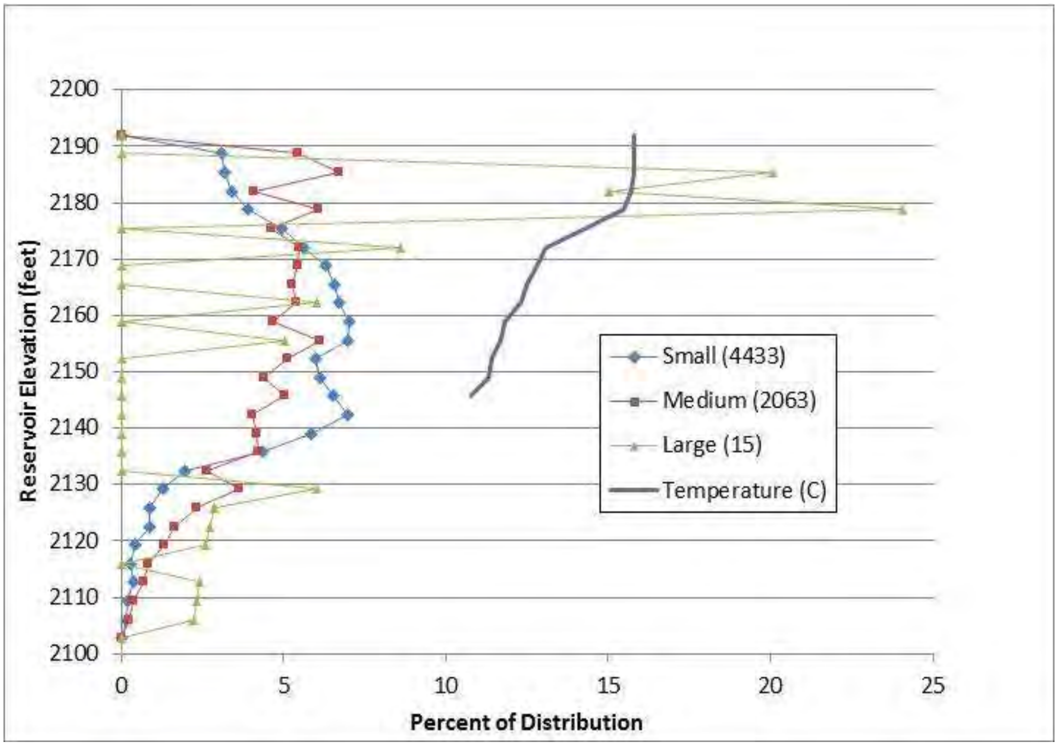

Figure 8. Nighttime Vertical Distribution by Size Category, All Days with Spill Gates Open.

In these two figures, the Y-axis is expressed as Reservoir Elevation, in feet. This selection of units provides a straightforward means to view vertical distribution in the context of the project blueprints, where most elevation values are expressed in feet. Note that the temperature profile is plotted on the same X axis; in the case of this variable, the axis should be considered as degrees Centigrade. This profile was obtained at 56° 02.113' N by 122° 13.310' W, a location about 1.7 km upstream from the spill gates. The constancy of this profile as the water is entrained from offshore into the spill bay canal is not known.

The nighttime distributional peak of small fish coincides closely with the highest flow vectors, as the spill gate is lifted off of a point with elevation of 2144.12 feet. With fewer visual cues available at night, the vertical distribution of fish may have a similar appearance to the vertical distribution of water velocities. A slight but noticeable shift upward by the small fish is observed in daylight hours: although the majority of the distribution is still between 2135 and 2185 feet, the central tendency has moved up about 20 feet. The medium size fish also move up in the daytime, which may correlate either to a higher distribution in the water column as fish approach the dam, or a flow-induced behavior that causes fish to swim toward the surface when a certain water velocity is encountered. The low sample size of large fish produces poorly defined distribution shapes, making biological interpretation of their vertical distribution uncertain. At night, a higher proportion of the large fish are above the weak thermocline.

The data showing vertical distribution of size classes by day and night must be interpreted within the context of water clarity, which affects light penetration. Historical limnological studies using Secchi disk measurements have indicated that the lowest water clarity exists in late summer and fall, and in the forebay of WAC Bennett Dam. We can expect that water transparency was at its lowest value when and where this entrainment study was completed. Typical Secchi disk readings ranged from 3.3 to 4.2 m in the 1999 study by Stockner. If we assume that light was extinguished at two times the Secchi depth, then all fish below about 7 meters were in perpetual darkness. It is more likely that MOST light is extinguished at twice the Secchi depth, as studies of sockeye diurnal vertical migrations in Lake Washington, Seattle, show fish responding to day/night transitions at depths up to 50 m. The day and night vertical distributions shown in Figures 7 and 8 show distinctive changes down to a depth of 2142 feet, which is 50 feet (15.24 m) below the face of the transducer. This observation indicates that any fish above the depth of the spill ogee is able to sense and respond to changing light levels between day and night hours. It is clear that the times defined as day and night will vary with depth due to the relatively low water transparency in the region. However, given that no direct Secchi disk measurements were made in the spill intake canal, day/night boundaries for all fish entrainment estimates have been referenced to light levels at the reservoir surface.

3.4 Horizontal Distribution (by gate)

Horizontal distribution refers to the distribution of entrainment values across the three spill gates. Since Gate 2 is sampled on each side by separate transducers, the entrainment estimates from each side are summed into a single value to evaluate and display horizontal distribution. Figures 9 - 11 provide the day and night horizontal distribution for fish in the small, medium, and large size categories respectively. Observe that the nighttime distribution percentages are shown as negative values to improve comparison of day and night values and between-gate values; the true nighttime value is the absolute value of the graphical value shown on the chart.

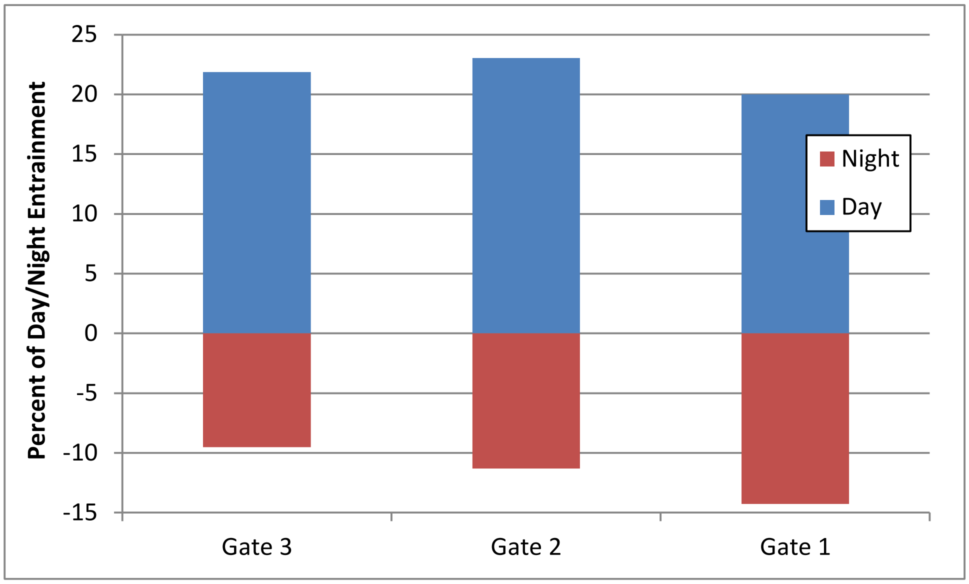

Figure 9. Horizontal Distribution of Small Size Class Fish across the Spill Bays

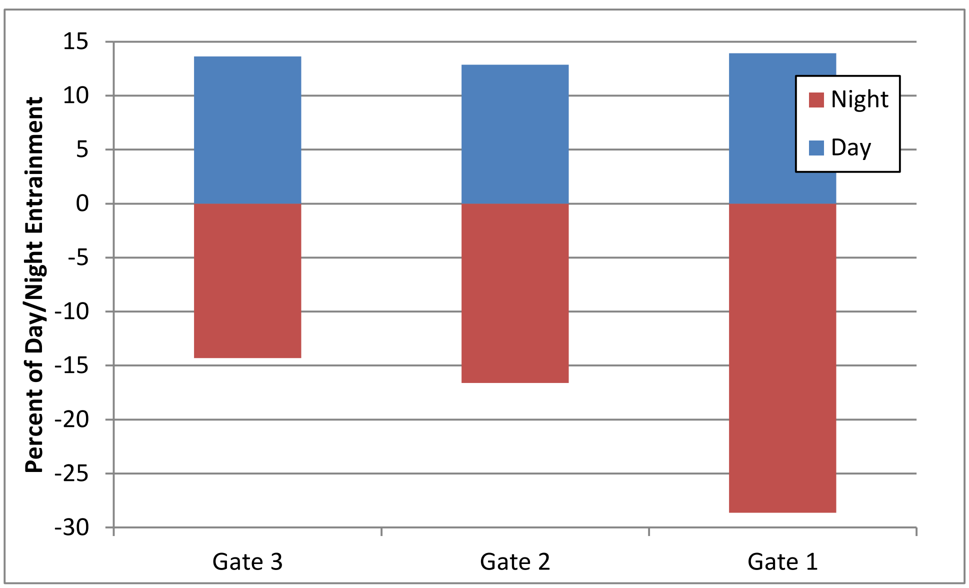

Figure 10. Horizontal Distribution of Medium Size Class Fish across the Spill Bays

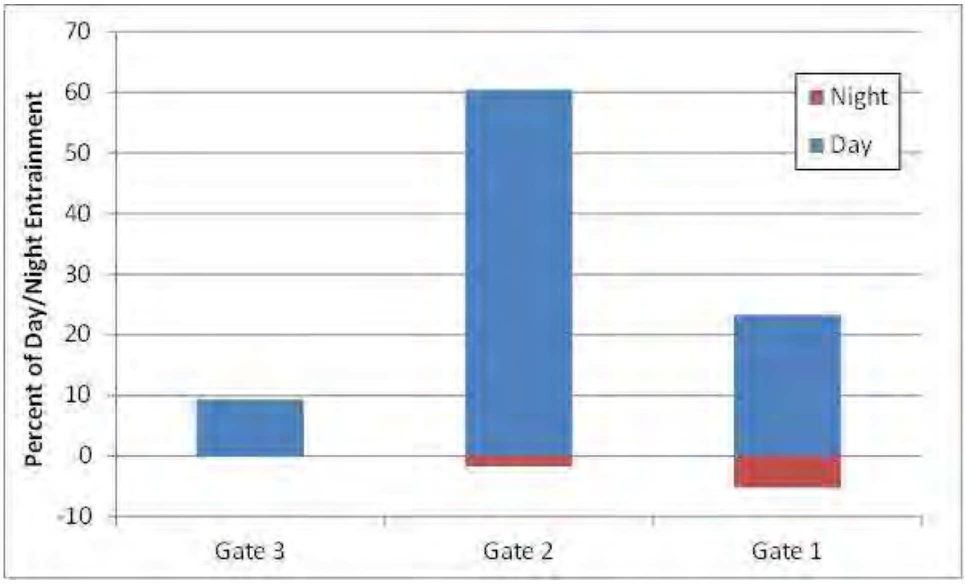

Figure 11. Horizontal Distribution of Large Size Class Fish across the Spill Bays

If entrainment is random across time, there is an expectation that the daytime entrainment values should be two times greater than the nighttime values, given that there are 16 daytime hours and 8 nighttime hours. For the small size category, entrainment values are higher at all gates during daytime, but not twice as high. Fish in the medium size class show lower entrainment in daytime hours for all gates. Two explanations would explain this observation: first, behavior of fish in the medium size category elicits an avoidance to spill flows; and second, the daytime fish distribution in the forebay, most likely vertical distribution, causes medium size fish to be less available to the entrainment flows generated by the lifting of spill gates. While the day and night entrainment values of large fish appear very different, this observation must be viewed in the context of a small sample size (224). Yet, daytime entrainment numbers are an order of magnitude higher than nighttime values.

3.5 *Hypothesis Testing*

The hypotheses were presented earlier in this report in an alternate form for clarity. In the following analyses, the null hypothesis of no effect or difference is tested. We will test the null hypotheses in reverse order to isolate any diel or distributional effects prior to testing the relationship between entrainment and flow; if significant differences are found, the data will be grouped by the significant parameter prior to testing for correlation between entrainment and flow.

3.5.1 Null Hypothesis H3: Spatial distribution of fish entrained through spillway is uniform in the water column.

This hypothesis evaluates the vertical distribution of fish as they are detected prior to entrainment through the spill gates. We will also evaluate a related hypothesis: H_{3a}: Spatial distribution of fish entrained through the spillway is uniform across the three spill gates.

3.5.1.1 Vertical Distribution Testing

The vertical distribution of fish with spill gates open is documented in Section 3.3. After normalizing for beam spread, the day and night vertical distributions were transformed into cumulative distributions. The null hypothesis was tested for day and night samples by comparing the respective cumulative distribution function for each size class with a function representing a uniform vertical distribution (a straight line starting at zero and ending at one, Figure 12).

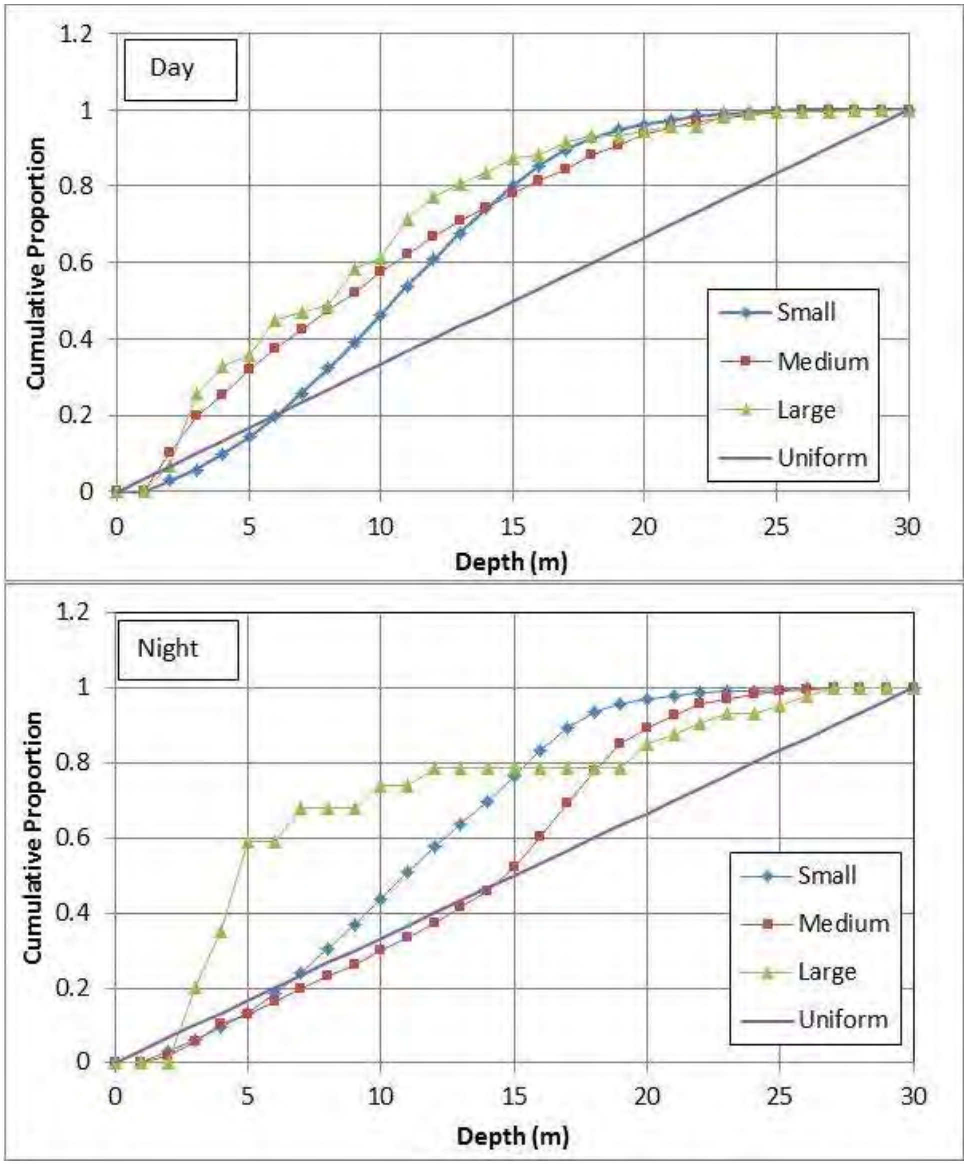

Figure 12. Cumulative Day, Night, and Uniform Vertical Distributions by Size Class

For both day and night tests, the Kolmogorov-Smirnov (K-S) “D” statistic was calculated for a variety of comparisons: daytime and nighttime vertical distributions of small, medium, and large fish against a uniform vertical distribution; daytime and nighttime vertical distribution between the three size classes; and daytime versus nighttime vertical distributions within each size class. The D statistic is shown against the Critical D value and acceptance or rejection of the null hypothesis (vertical distributions are not significantly different from uniform or from each other) in Table 8.

Table 8. Kolmogorov-Smirnoff Vertical Distribution Test Results

Comparison	D Statistic	Critical D	Null Hypothesis
Day, Small vs Uniform	0.3284	0.3454	Accepted
Day, Medium vs Uniform	0.2826	0.3454	Accepted
Day, Large vs Uniform	0.3736	0.3454	Rejected
Night, Small vs Uniform	0.3357	0.3454	Accepted
Night, Medium vs Uniform	0.2289	0.3454	Accepted
Night, Large vs Uniform	0.4445	0.3454	Rejected
Day, Small vs Medium	0.1789	0.3454	Accepted
Day, Medium vs Large	0.1058	0.3454	Accepted
Day, Large vs Small	0.2543	0.3454	Accepted
Night, Small vs Medium	0.2411	0.3454	Accepted
Night, Medium vs Large	0.4795	0.3454	Rejected
Night, Large vs Small	0.4558	0.3454	Rejected
Small, Day vs Night	0.0428	0.3454	Accepted
Medium, Day vs Night	0.2962	0.3454	Accepted
Large, Day vs Night	0.2343	0.3454	Accepted

In all daytime comparisons of uniformity, the test results showed that the vertical distributions were not significantly different from a uniform vertical distribution. The nighttime vertical distributions of large fish were shown to be significantly non-uniform. Additionally, the nighttime vertical distribution of large fish was significantly different from those of medium and small size classes. These significant differences are attributed in part to differing distributions, but are also affected by low sample sizes of large fish.

3.5.1.2 *Spatial Distribution Testing*

We also examined the spatial distribution of fish by examining the relative proportions passing through the three spill gates. The following six tables summarize an ANOVA test for gate preference by Day/Night and by fish size.

Table 9. ANOVA Test Results, Small Fish Gate Preference, Daytime

Day, Small fish

Date	Gate 1	Gate 2	Gate 3
626	1143	525	857
627	2050	1748	2865
628	840	1511	1253
629	412	950	1046
630	2130	3008	3804
701	2905	5999	5604
709	3587	5724	3218
710	8606	8025	6832
711	451	588	197
724	1787	1110	2126
725	2525	1508	1249
802	445	299	343

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Gate 1	12	26880.04	2240.003	5095199
Gate 2	12	30995.71	2582.975	6600136
Gate 3	12	29392.72	2449.393	4432377

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	717273.2	2	358636.6	0.066712	0.935591	3.284918
Within Groups	1.77E+08	33	5375904			
Total	1.78E+08	35				

Table 10. ANOVA Test Results, Small Fish Gate Preference, Nighttime

Night, Small fish

Date	Gate 1	Gate 2	Gate 3
626	987	86	58
627	1426	683	836
628	1809	1209	137
629	381	421	425
630	1678	1066	1079
701	1315	1062	317
709	3870	4587	4109
710	628	300	323
711	1410	1939	1148
724	751	458	390
725	4762	3124	3662
802	175	290	321

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Gate 1	12	19192.67	1599.389	1900804
Gate 2	12	15224.08	1268.673	1818359
Gate 3	12	12805.46	1067.121	1861308

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1733221	2	866610.4	0.46588	0.631647	3.284918
Within Groups	61385180	33	1860157			
Total	63118401	35				

Table 11. ANOVA Test Results, Medium Fish Gate Preference, Daytime

Day, Medium fish

Date	Gate 1	Gate 2	Gate 3
626	180	42	118
627	367	168	326
628	100	128	190
629	84	139	162
630	316	351	688
701	306	874	800
709	472	619	539
710	995	719	686
711	139	18	6
724	422	257	288
725	645	373	180
802	160	182	111

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Gate 1	12	4184.937	348.7447	69968.63
Gate 2	12	3870.986	322.5822	76710.17
Gate 3	12	4093.361	341.1134	71628

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4344.485	2	2172.242	0.029851	0.970616	3.284918
Within Groups	2401375	33	72768.93			
Total	2405719	35				

Table 12. ANOVA Test Results, Medium Fish Gate Preference, Nighttime

Night Medium fish			
Date	Gate 1	Gate 2	Gate 3
626	334	42	23
627	793	191	164
628	330	234	153
629	269	189	93
630	328	176	231
701	421	288	76
709	773	702	782
710	195	153	70
711	300	264	421
724	1120	522	320
725	3484	2054	1774
802	259	177	196

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Gate 1	12	8605.829	717.1524	838078.8
Gate 2	12	4993.081	416.0901	297675.7
Gate 3	12	4303.07	358.5891	241661.1

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	890049.8	2	445024.9	0.969261	0.389902	3.284918
Within Groups	15151571	33	459138.5			
Total	16041621	35				

Table 13. ANOVA Test Results, Large Fish Gate Preference, Daytime

Large Day fish			
Date	Gate 1	Gate 2	Gate 3
626	0	0	0
627	5	5	0
628	8	3	0
629	0	0	0
630	0	0	0
701	4	1	0
709	4	4	10
710	12	62	4
711	0	0	0
724	0	2	0
725	3	7	0
802	0	9	0

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Gate 1	12	36.03038	3.002532	15.44026
Gate 2	12	93.45426	7.787855	296.0816
Gate 3	12	14.35299	1.196082	9.197206

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	278.4562	2	139.2281	1.302337	0.285505	3.284918
Within Groups	3527.909	33	106.9063			
Total	3806.366	35				

Table 14. ANOVA Test Results, Large Fish Gate Preference, Nighttime

Large Night fish			
Date	Gate 1	Gate 2	Gate 3
626	0	0	0
627	5	0	0
628	0	0	0
629	0	1	0
630	0	0	0
701	0	2	0
709	0	0	0
710	0	0	0
711	0	0	0
724	0	0	0
725	0	0	0
802	3	0	0

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Gate 1	12	8.065185	0.672099	2.70378
Gate 2	12	2.682737	0.223561	0.286949
Gate 3	12	0	0	0

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.811529	2	1.405765	1.410122	0.25844	3.284918
Within Groups	32.89802	33	0.99691			
Total	35.70955	35				

In all six cases, the ANOVA parameters show that the null hypothesis is accepted, thus indicating that there is no significant difference in gate usage in the daytime or nighttime by small, medium, or large sized fish.

3.5.2 Null Hypothesis H2: No correlation exists between time of day and the numbers of fish entrained over the spillway.

3.5.2.1 Small Fish Testing

Time of day was expressed as either daytime or nighttime (please see Section 2.4.5). An Analysis of Variance (ANOVA) was used to determine if the total entrainment numbers within each hour were significantly different between day and night for each size class of fish (Section 2.4.3). Table 15 provides the tested data values and the ANOVA results for the small fish category.

Table 15. ANOVA Test of Time of Day Effect on Small Fish Entrainment

Small Fish Entrainment by Hour of Day

Day	Night
2862	4524
2544	4560
1807	5490
4323	4765
3316	4778
3488	11168
4203	6943
7254	4995
7472	
7096	
9705	
14382	
4502	
5431	
5166	
3718	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
day	16	87267.85	5454.241	10103564
Night	8	47222.44	5902.805	5153003

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1073119	1	1073119	0.125829	0.726174	4.300949502
Within Groups	1.88E+08	22	8528386			
Total	1.89E+08	23				

The ANOVA results indicate that there is no significant difference between daytime and nighttime entrainment rates of small fish.

3.5.2.2 Medium Fish Testing

The correlation between time of day and entrainment of medium-sized fish was analyzed using an ANOVA, and the results are presented below in Table 16.

Table 16. ANOVA Test of Time of Day Effect on Medium Fish Entrainment

Medium Fish Entrainment by Hour of Day

Day	Night
742	2507
445	2637
465	2458
391	2055
301	1736
367	2059
463	2295
1104	2156
1120	
1276	
987	
1872	
560	
690	
745	
622	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
day	16	12149.69	759.3558	176291.5
Night	8	17901.8	2237.725	86754.79

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11656398	1	11656398	78.86466	1E-08	4.300949502
Within Groups	3251656	22	147802.6			
Total	14908055	23				

The ANOVA results indicate that the null hypothesis rejected, and we conclude that a significant difference exists between daytime and nighttime entrainment of medium-sized fish.

3.5.2.3 Large Fish Testing

A test of entrainment difference between nighttime and daytime was completed for the large fish observed during the monitoring period, as documented below in Table 17.

Table 17. ANOVA Test of Time of Day Effect on Large Fish Entrainment

Large Fish Entrainment by Hour of Day

Day	Night
5	0
0	0
0	2
0	0
14	3
1	0
0	4
10	3
12	
0	
18	
2	
8	
24	
49	
0	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
day	16	143.8376	8.989851	169.6924
Night	8	10.74792	1.34349	2.391791

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	311.8231	1	311.8231	2.677504	0.116002	4.300949502
Within Groups	2562.129	22	116.4604			
Total	2873.952	23				

The ANOVA analysis shows that the null hypothesis is accepted, indicating no significant difference between entrainment of large fish and hour of day.

3.5.3 Null Hypothesis H1: No correlation exists between spill discharge rate and the number of fish entrained over the spillway.

If we test for a correlation between spill discharge rates and fish entrainment, the results will be confounded by the significant correlation between the medium sized fish and time of passage. We will therefore isolate this variable by testing for a correlation between spill flow and entrainment for day and night populations separately.

Table 5 has previously introduced the spill categories experienced during the monitoring period. The total entrainment by size class is shown for these categories in Table 18:

Table 18. Entrainment by Size Class and Spill Category

Flow Class	1	2	3	4	5
Small	166	33727	49449	50013	1135
Medium	60	14429	6133	9294	136
Large	2	28	87	38	0

These numerical estimates of entrainment are based on all detected fish being entrained, however additional discussion has been provided concerning the ability of large fish to resist entrainment. The correlation between entrainment and spill category (flow class) was tested for significance with a Single Factor ANOVA test. As the ANOVA test uses the entries in each group as replicates, we used the hourly entrainment totals that were observed within each spill level category under day and night treatments. The test output results are shown below (Tables 19, 20) for daytime hours and nighttime hours respectively.

Table 19. ANOVA Test Output for Correlating Flow and Entrainment, Daytime Hours

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	20	228.1005	11.40503	1053.605
2	53	19905.66	375.5784	110521.3
3	31	36307.32	1171.204	5066423
4	71	41849.78	589.4335	564374.9
5	5	1270.527	254.1053	19659

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19923249	4	4980812	4.416851	0.001998	2.423286
Within Groups	1.97E+08	175	1127684			
Total	2.17E+08	179				

Table 20. ANOVA Test Output for Correlating Flow and Entrainment, Nighttime Hours

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	1	0	0	#DIV/0!
2	24	28278.14	1178.256	912160.2
3	16	19361.4	1210.087	5298665
4	40	17495.45	437.3862	118575.3
5	1	0	0	#DIV/0!

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12661518	4	3165380	2.319421	0.064382	2.490447
Within Groups	1.05E+08	77	1364728			
Total	1.18E+08	81				

The number of hourly 'replicates' in each group can be seen in the 'Count' column. The table values from these two ANOVA tests indicate that the null hypothesis is rejected during daylight hours but not during nighttime hours. We expect that the failure to reject the null hypothesis during nighttime hours is due primarily to the lack of sample data in spill categories 1 and 5 at night. When all data are pooled, the ANOVA table indicates that we reject the null hypothesis that no correlation exists between fish entrainment and spill discharge rate (Table 21).

Table 21. ANOVA Test Output for Correlating Flow and Entrainment, All Hours Pooled

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	20	228.1005	11.40503	1053.605
2	77	48183.79	625.7636	491712.4
3	47	55668.72	1184.441	5032361
4	111	59345.23	534.6417	406565.3
5	5	1270.527	254.1053	19659

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	23815335	4	5953834	4.840058	0.000887	2.407043
Within Groups	3.14E+08	255	1230116			
Total	3.37E+08	259				

The tables above indicate that a significant correlation exists between fish entrainment and spill discharge rates for the entire population of observed fish, and for all fish during daytime hours. This observation introduces an obvious question: what is the relationship between fish entrainment and spill discharge rate. To evaluate this function, we first divided the total number of fish entrained within a flow category by the number of hours in which that flow occurred. This calculation was necessary to normalize out the different sample sizes between the flow categories (see Figure 3, Table 5). The relationship between number of fish entrained and spill discharge was evaluated for each size class of fish. The overall patterns in general were similar, so entrainment numbers from all three fish size classes were pooled to generate a relationship for all data. Figure 13 shows a plot of these normalized values (# entrained per hour) as a function of flow category, and are also expressed as numbers per volume of water spilled (#/m^3). The entrainment numbers are also plotted against total spill volume in the figure.

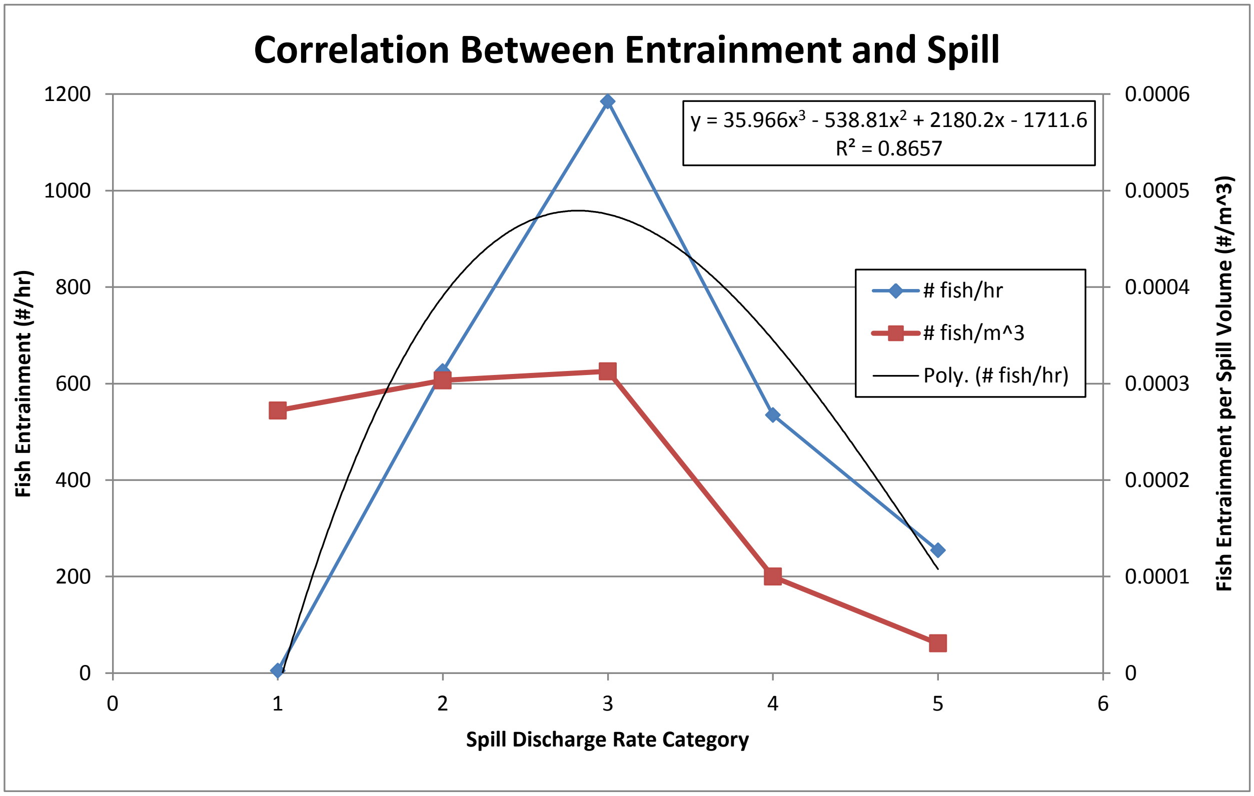

Figure 13. Correlation between Entrainment and Spill Category

The three-order polynomial correlation relating hourly entrainment numbers to spill discharge category is shown above for discussion purposes only; however, this function was used to extrapolate entrainment estimates into days not selected for analysis. The correlation that we might intuitively expect would exhibit increasing numbers of entrained fish with increased spill discharge rates. Such a correlation might become discernible if longer periods of spill in each category were used. With the opportunistic spill levels used in this study, the spill level likely interacted with the high daily variability observed in fish numbers, masking the expected correlation. However, the observed correlation might be valid. Fish might be able to sense entrainment flows much further from the dam when discharge rates are high, and move nearer to shore or closer to the bottom to resist the flow. Additionally, the high discharge rates might cause initial high entrainment numbers, but essentially reduce the numbers of fish available to entrainment quickly and thereafter experience low entrainment rates throughout the period of spill at that level (the "vacuuming effect"). The relationship between entrainment numbers and spill volume show a relatively constant entrainment density (#/volume) through the first three categories, with entrainment density lower for categories 4 and 5. While this observation supports the "vacuuming effect" suggested above, additional research should be completed to insure that no measurement (fish detection) bias is modifying the relationship.

3.6 Relationship Between Changes in Spill Discharge Rate and Entrainment

Initial field observations suggested that entrainment rates spiked when gates were first opened or when the gate opening was changed. This phenomenon has been observed at other hydroelectric dams. To explore this hypothesis, we used changes between spill categories as the indicator of change in spill discharge rate, and correlated mean hourly entrainment rates of all fish to number of hours since a spill category change occurred. Figure 14 illustrates this relationship.

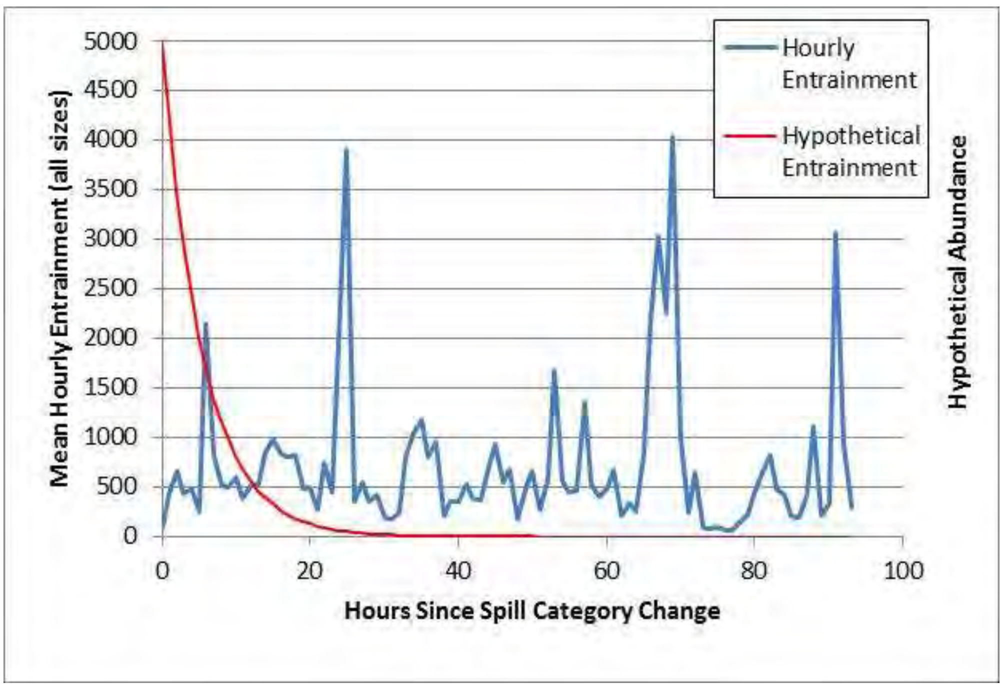

Figure 14. Entrainment Rates as a Function of Time After Gate Level Change

If entrainment numbers were higher at first gate opening (or level change), we would expect to see a relationship like the one shown in red, with highest entrainment numbers at the left of the plot and values decreasing to the right. The observed time series shown in blue does not show this trend, but shows random peaks which are associated with patchiness of fish densities in the forebay, day/night effects, and perhaps turbine operation effects. Since no trend of decreasing entrainment with time after change is observed, we did not statistically test the hypothesis.

3.7 Extrapolating Total Entrainment

The data tables and figures above present entrainment estimates by size class for each day that was fully analyzed. Spill discharge occurred on other days that were not analyzed. The extrapolated fish entrainment rates are presented along with the calculated entrainment rates in Table 22.

Table 22. Total Spill Gate Fish Entrainment Estimates

Summary of Total Fish Entrainment, WAC Bennett Dam, June 26 - August 2, 2012										
	Entrainment by Size Class									
Date	Small		Medium		Large		Daily Total	Spill Hours	Hours Analyzed
Length Range TS Range	40-75 mm -60 to -47.5 dB	±2 St. Dev.	75-465 mm -47.5 to -32.5 dB	±2 St. Dev.	>465 mm >-32.5 dB	±2 St. Dev.			
June 26, 2012	3,656	±(338)	739	±(130)	0		4,395	14	14
June 27, 2012	9,608	±(576)	2,010	±(114)	15	±(2)	11,633	24	24
June 28, 2012	6,759	±(535)	1,134	±(84)	11	±(7)	7,904	24	24
June 29, 2012	3,636	±(137)	936	±(74)	1		4,572	24	24
June 30, 2012	12,765	±(831)	2,089	±(138)	0		14,855	24	24
July 1, 2012	17,201	±(1,831)	2,764	±(283)	7	±(2)	19,972	24	24
July 2, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 3, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 4, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 5, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 6, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 7, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 8, 2012	16,140	±(1,669)	2,591	±(303)	19	±(10)	18,751	24	0
July 9, 2012	25,094	±(3,407)	3,888	±(468)	18	±(6)	29,001	24	24
July 10, 2012	24,715	±(4,701)	2,819	±(425)	78	±(36)	27,612	24	24
July 11, 2012	5,733	±(938)	1,148	±(259)	0		6,881	8	8
July 24, 2012	6,621	±(800)	2,929	±(596)	2		9,553	15	15
July 25, 2012	16,831	±(1,197)	8,510	±(919)	10	±(6)	25,351	24	24
July 26, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
July 27, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
July 28, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
July 29, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
July 30, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
July 31, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
August 1, 2012	15,258	±(1,369)	7,546	±(1,020)	15	±(10)	22,819	24	0
August 2, 2012	1,872	±(144)	1,085	±(101)	12	±(9)	2,969	14	14
Totals	354,280	±(57,974)	101,013	±(22,119)	394	±(350)	455,685 ± (80,443)	579	243

Values shown in black in the table represent calculated values based on processed acoustic data, while red values represent extrapolated values. The table shows unchanging values of entrainment and variance (SD) for all days in the first block of non-analyzed spill days, and again in the second block. The reason is that the spill discharge rates were essentially constant throughout both periods. A comparison of Tables 7 and 22 indicate that 164,696 of the 455,685 entrained fish were based on measurements, while the remainder were based on extrapolated values. Seasonal totals are shown in blue.

Population abundance data supplied by LGL is presented in Table 23.

Table 23. Abundance Estimates in the Peace Reach and Forebay Region of Williston Reservoir

Forebay		
Year	Population Estimate	STDEV
1988	328,014	301,956
2000	411,997	108,628
2008	597,144	85,408
2012	1,064,311	427,989
Peace Reach		
Year	Population Estimate	STDEV
1988	2,088,623	1,256,273
2000	1,410,900	197,526
2008	3,239,700	515,112
2012	3,743,744	1,534,935

The 2012 population estimate for the Peace Reach region is viewed as highly speculative, as it is based on the three transects closest to Bennett Dam. The total numbers of fish entrained in the 26 days (and 579 hours) of spill were estimated at 455,685, standard deviation 40,222. In general terms, these data suggest that in about 1 month of spill, about one half of the forebay population would exit Williston Reservoir through entrainment, or about 15% of the population in the Peace Arm.

3.8 *Observations with Spill Gates Closed*

During July 15-18, 2012, acoustic mobile surveys and gill net captures were completed in Williston reservoir above WAC Bennett Dam. The fish counts were extracted from the data files collected on these dates, and several descriptive measurements are presented below for comparison with data collected in these other study components.

3.8.1 Numerical Observations

As stated in Section 2.4.1, fish counts were extracted from the data files collected during these four days, but traces from drifting targets and milling fish were excluded. No fish were excluded due to their direction of travel. The fish detections were then spatially extrapolated over the full spill bay width using the same methodology as for analysis of entrainment. Numerical values are expressed as Numbers or Counts as opposed to Entrainment, as spill gates were closed. Table 23 provides the spatially expanded counts of fish by hour for the day and night samples.

Table 24. Spatially Expanded Fish Numbers with Spill Gates Closed

	Day				Night			Totals
Hour	Small	Medium	Large		Small	Medium	Large	
0					217	548	24	789
1					443	790	3	1236
2					421	528	38	987
3					637	668	51	1357
4					579	1480	56	2115
5	447	2036	39					2522
6	601	2197	12					2810
7	1325	2739	21					4085
8	1389	2860	70					4319
9	541	1800	23					2363
10	1540	2155	19					3714
11	1084	1621	12					2717
12	489	1561	41					2091
13	980	1278						2258
14	413	1390	19					1821
15	477	1576	31					2084
16	996	1360	98					2454
17	380	1392	51					1823
18	405	988	9					1403
19	262	1088	4					1354
20	564	921	47					1531
21					516	850	15	1381
22					459	838	13	1310
23					167	402	7	576
Totals	11893	26962	494	0	3441	6104	206	49101

The numbers shown in the table are the sum of the weighted counts from the four sample days. Units of counts per hour would be obtained by dividing each table entry by a value of 4.

3.8.2 Target Strength Distributions, Spill Gates Closed

The target strength distributions for all targets observe during daytime and nighttime hours are shown in Figure 15.

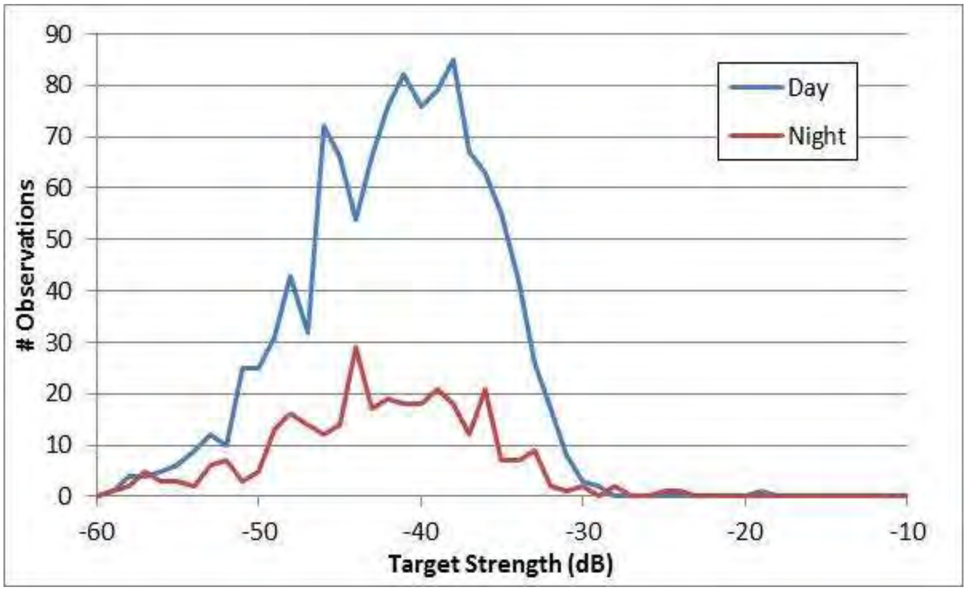

Figure 15. Day and Night Target Strength Distributions, Gates Closed

The day and night target strength distributions appear to be essentially the same, except that nighttime values are considerably lower than daytime values. As discussed previously, there are twice as many observations (hours) during daytime as there are at night. These data indicate that the same fish population inhabits the region near the spill gates at night as during daytime hours. The data also suggest that the numbers of fish in the small and large size categories is numerically overwhelmed by the numbers in the medium size category. This observation is expected for large fish, as they are relatively scarce throughout the study time and location. The lack of small fish may indicate that they prefer the pelagic habitat rather than the near-shore habitat, and occur in the regions of the spill bays only when drawn in by spill flow. A comparison of measured target strength distributions with those observed in the 1996 and 2008 acoustic studies would have provided valuable insights. This was not possible, as the 1996 study used single-beam techniques, and the 2008 study did not report target strength data. Additionally, the 2008 report presented fish counts for the 15 hours of data collected on July 11, but the counts were not presented in spatially expanded form as the spill gates were not opened. In the 2008 study, 75 fish tracks were observed in the 15 data hours collected from 3 transducers, for a value of 1.7 fish per hour per transducer. It is not possible to directly compare the current study with the 2008 study, as the earlier report was based on an echo sounder with an entirely different design, and the older study did not report the system values such as the echo counting threshold. On July 11, 2012, a total of 1373 fish tracks were observed in 24 hours on four transducers (14.3 fish per hour per transducer). The order of magnitude increase suggests a significant increase in the acoustic system sensitivity as much as a change in population size.

3.8.3 Vertical Distribution, Spill Gates Closed

Vertical distributions of fish are calculated for non-spill conditions in the same manner as when spill gates are open. A frequency distribution is obtained from the raw observations of fish traces, and this distribution is then corrected for beam spread by dividing by the stratum depth. Figures 16 and 17 show the day and night vertical distributions of fish in the vicinity of the closed spill gates.

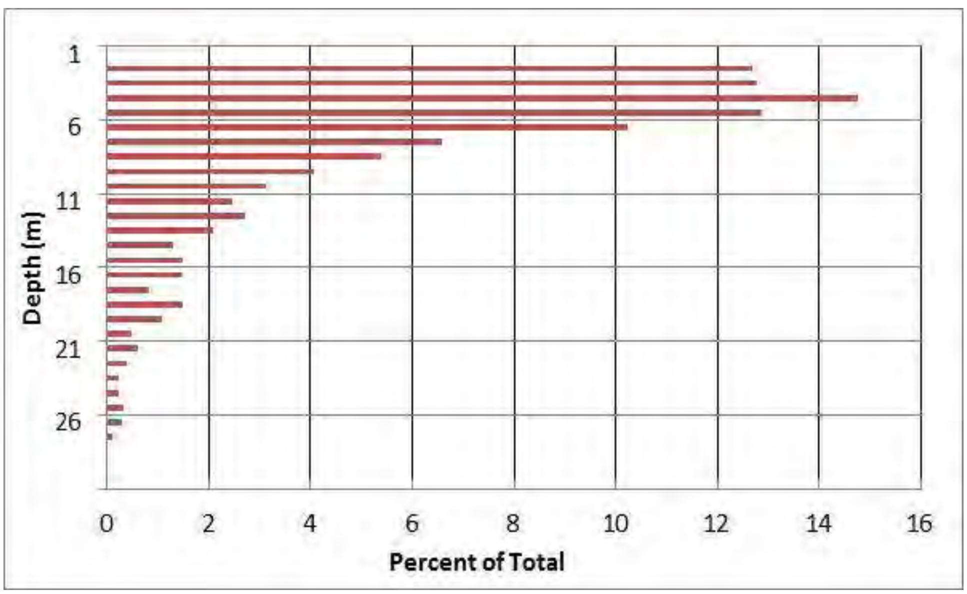

Figure 16. Daytime Vertical Distribution of Fish with Spill Gates Closed

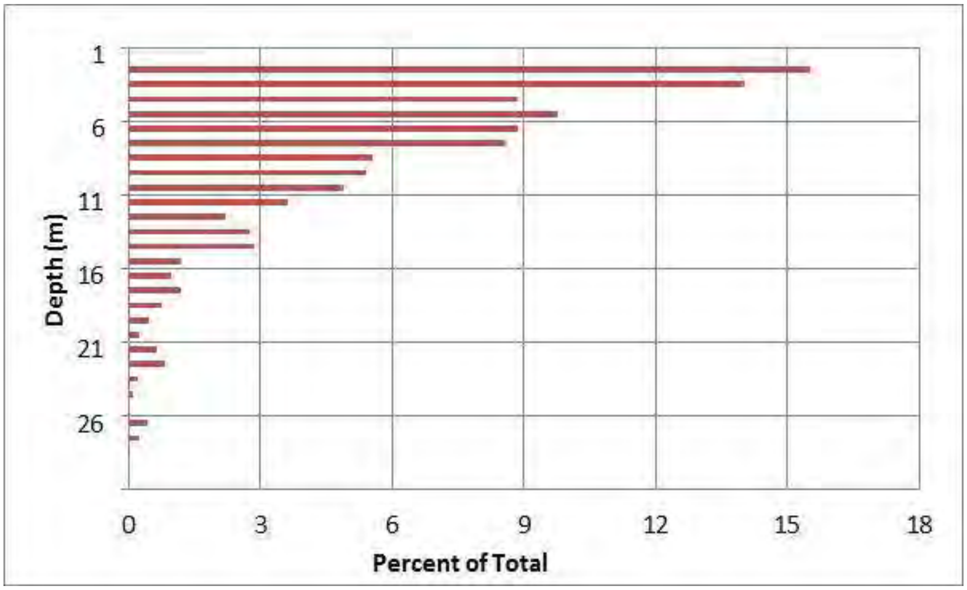

Figure 17. Nighttime Vertical Distribution of Fish with Spill Gates Closed

Both day and night distributions show that fish tend to be surface oriented and have a similar vertical distribution. Figure 18 plots both day and night values together to facilitate comparison.

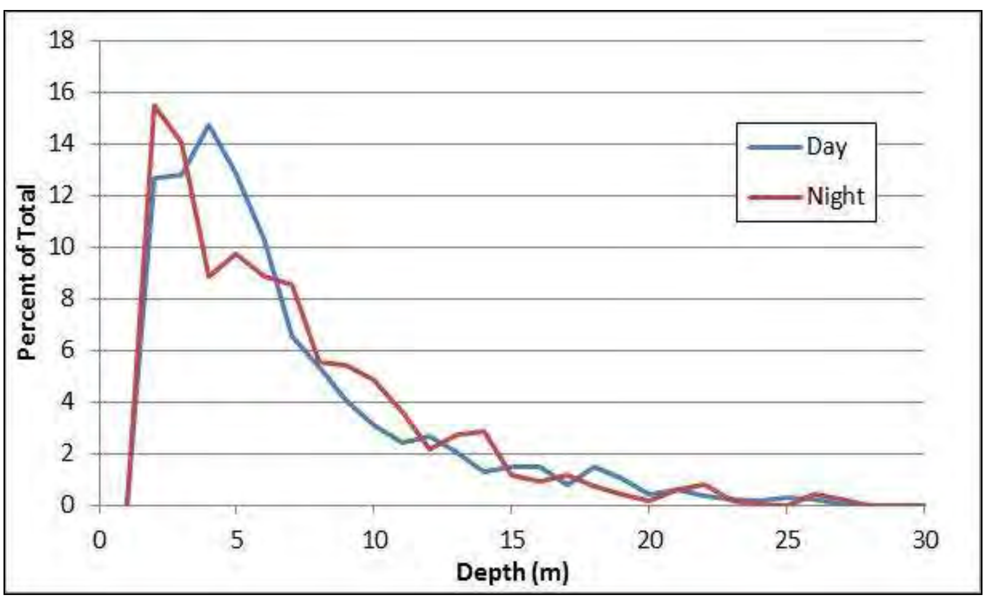

Figure 18. Comparison of Day and Night Vertical Distributions, Spill Gates Closed

This plot confirms that the day and night distributions are similar. There is a slightly higher percentage of nighttime observations at or above 3 meters, while the daytime distribution peaks at a depth of 4 meters. These distributions are more surface oriented than those collected during spill (Section 3.3). One interpretation of this observation is that fish may tend to distribute deeper when they sense flow.

3.8.4 Direction of Travel, Gates Closed

We evaluated the swimming directions of fish near the spill gates when they were closed. Figure 19 shows that the direction of travel for all nighttime fish detections is approximately random. A slight peaking around 160° corresponds to fish moving in a general upstream direction, or more precisely, nearly parallel to the Western shoreline.

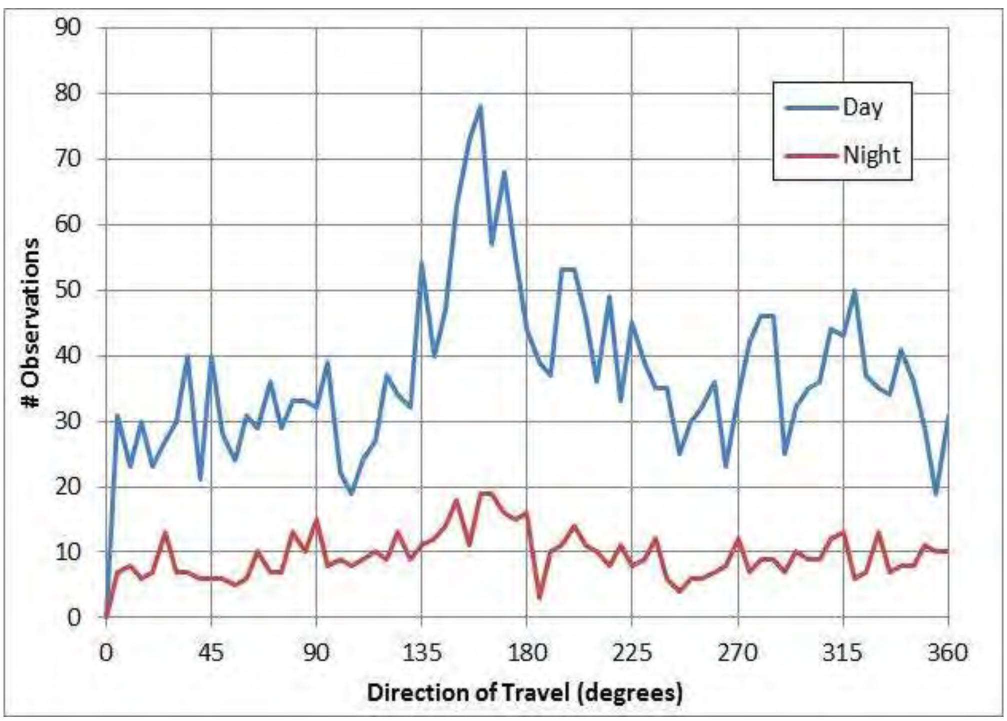

Figure 19. Distribution of Direction of Travel Values, Gates Closed

The direction of travel when gates are closed contrasts starkly with the direction of travel data observed when gates are open. All discussion of acoustic data naturally refers to fish detected essentially in a plane bordered by the stop log rails, representing the transducer mounting positions. At this location, in is easily concluded that the primary driving force on fish behavior is spill discharge flow, not dam structures or local bathymetry.

4.0 Conclusions and Recommendations

The primary goal of the GMSMON-4 Monitoring Program was to investigate whether a relationship exists between fish entrainment numbers and spill discharge rate. This monitoring program used four split beam transducers to sample the three spillways at WAC Bennett Dam. Transducers were mounted near Elevations 2192 – 2196 feet and aimed down just upstream from the spill gates. All fish detections were spatially weighted to extrapolate into the un-sampled width of the spillway.

The study plan formed the monitoring objectives into four null hypotheses:

H_1: *No correlation exists between spill discharge rate and the number of fish entrained over the spillway;*

H_2: *No correlation exists between time of day and number of fish entrained through the spillway;*

H_3: *Spatial distribution of fish entrained through spillway is uniform in the water column;*

H_4: *No acute mortality is imposed on fish entrained through the spillway.*

The fourth hypothesis was not studied using hydroacoustic techniques. The emphasis in this report has been placed on understanding numbers of fish entering the spillway and direction of fish travel so as to determine a reliable estimate of fish entrained. Fish passing through the spillway into the Bennett Dam tailrace plunge pool face an 80m+ free-fall, and past Bennett Dam spill studies (Wilby 1997) have confirmed that acute mortality of adult fish results from entrainment. However, the mortality rate of these entrained fish would not affect the losses to the Williston Reservoir fish population as there is no means for fish to return to the reservoir, hence the focus in 2012 was to understand rate of entrainment as it relates to operations.

The hypotheses were tested in reverse order, so that if a significant correlation were found with diel passage or spatial distribution, this correlation could be isolated from the tests of correlation between spill discharge and entrainment. The third hypothesis was expanded to evaluate both vertical and horizontal distributional trends. For small, medium, and large fish, the correlation between entrainment numbers and spill gate selection was not significant during daytime or nighttime hours. The day and night vertical distributions were tested against a uniform distribution function and no significant correlation was found. Therefore, the third null hypothesis was accepted.

The second null hypothesis tested for significance in correlation between passage rate and hour. Daytime data from 05:00 to 21:00 were pooled, as were the remaining data into a nighttime category. Statistical testing using ANOVA showed that no significant difference exists between daytime passage of small or large fish. However, the data showed that daytime entrainment numbers were significantly different from nighttime entrainment numbers of medium sized fish. Therefore, the second null hypothesis was rejected.

Because the null hypothesis #2 was rejected, the primary objective of correlating entrainment numbers with spill discharge rate was tested for daytime and nighttime samples separately. The table values from these two ANOVA tests indicate that the null hypothesis is rejected during daylight hours but not during nighttime hours. We expect that the failure to reject the null hypothesis during nighttime hours is due primarily to the lack of sample data in spill categories 1 and 5 at night. When all data are pooled, the ANOVA table indicates that we reject the null hypothesis that no correlation exists between fish entrainment and spill discharge rate.

With the rejection of null hypothesis #1 for the pooled day and night data, we evaluated the function relating spill discharge rate to entrainment numbers for all data collected when spill gates were open. The investigation showed that highest mean hourly entrainment rate, across all size classes, occurred when spill levels were around 1000 cms, and that entrainment numbers were lower for spill categories of 500 cms and 1500 cms. This function is described as a third order polynomial with X representing spill discharge rate and Y equal to fish entrainment:

$$y = 35.966x^3 - 538.81x^2 + 2180.2x - 1711.6$$

This relationship may be due in part to fish avoidance of the spillway when flows are very high. On the other hand, some masking of small targets may have occurred due to turbulence generated by the high flows. The variance associated with each of the five spill levels is provided in the ANOVA Table 19 above. The variance in Spill Category 3 (n=47) is an order of magnitude larger than the variance in Category 2 (n=77) or Category 4 (n=111).

During spatial extrapolation across the spillway width, we used the assumption of uniform distribution. It would be possible to build a function of horizontal distribution across all spillways and use this function for spatial extrapolation instead of the uniform distribution assumption. However, the test of the null hypothesis of uniform horizontal distribution was not rejected, and therefore the data indicate that the assumption is reasonable.

The down-looking orientation of the four transducers and their mounting elevations (2,192-2,196 feet) allow for a possibility that the near-surface waters were under-sampled. While this bias may exist, the vertical distributions observed during spill discharge showed higher entrainment numbers in mid-water column, and lower values near surface. If this study were to be repeated, we recommend that both up-looking and down-looking split beam transducers be installed in each spillway. While this methodology increases cost, it allows for evaluation of and compensation for any bias resulting from under-sampling surface waters.

A comparison of the vertical distribution of fish when spill gates are open with the vertical distribution when gates are closed shows that fish are much more surface oriented when flow is removed. This observation greatly weakens the hypothesis that fish swim upward when encountering high flow nets.

5.0 Acknowledgements

Several people provided needed assistance that allowed this project to succeed in the time frame that was available.

Thank you, Kim Hawkins for the on-the–ground knowledge and support during the site visit, installation of the acoustic systems, arranging for a telephone line for remote access, visiting the system during data collection, and facilitating the gear removal at the end of the monitoring period.

Thank you, Aileen Grant, Michael McArthur of BC Hydro and Elmar Plate of LGL Consultants for development of the study plan, review of data collection and processing methods, and assistance on development of the report structure and content.

Thank you, Mike Burger and Brian Moore for surviving an ordeal at Customs during transportation of the acoustic systems to the site, and for successfully installing the systems within a time frame that was impossibly short.

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Appendix A: Detailed Acoustic Specifications

A1) Equipment and Calibration

System A: DTX-09-208

Transducer 1: DT-420-0615-0067

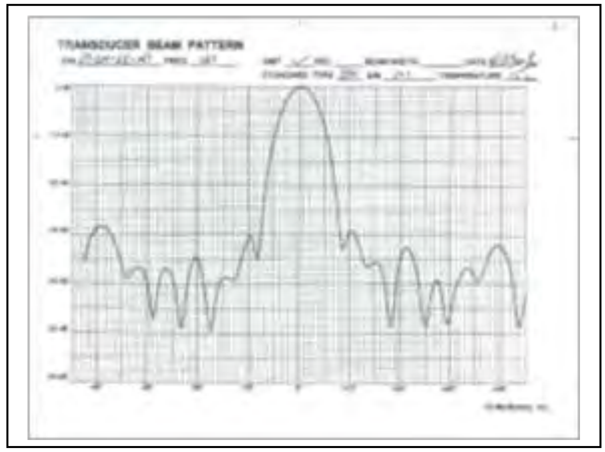
Source Level: 219.5 dB||μPa

Receive Sensitivity: -62.1 dBCount/μPa

Transducer Cable: 141-07-1681

Cable Length: 160 feet

Installation Elevation: 2192.9 feet



Transducer 2: DT-420-0615-0063

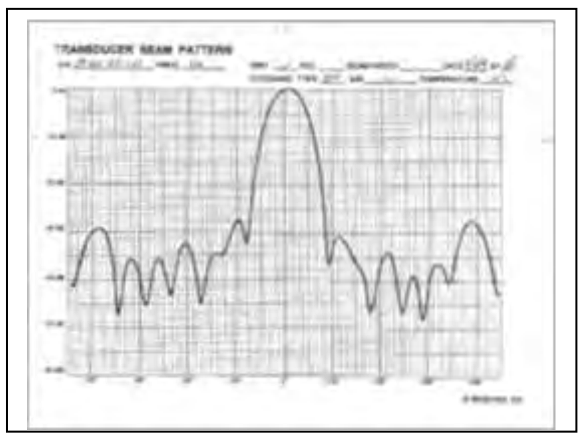
Source Level = 220.2dB||μPa

Receive Sensitivity = -63.5 dBCount/μPa

Transducer Cable: 141-07-1704

Cable Length: 200 feet

Installation Elevation: 2196.0 feet



System B: DTX-08-166

Transducer 1: DT-420-0615-0046

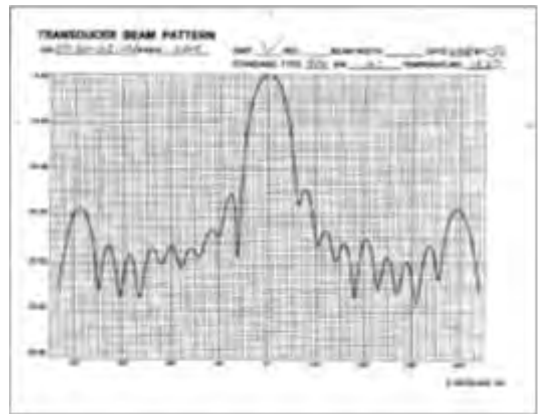
Source Level: 220.9dB||μPa

Receive Sensitivity: -56.6 dBCount/μPa

Transducer Cable: 141-07-1694

Cable Length: 100 feet

Installation Elevation: 2192.6 feet



Transducer 2: DT-420-0615-0069

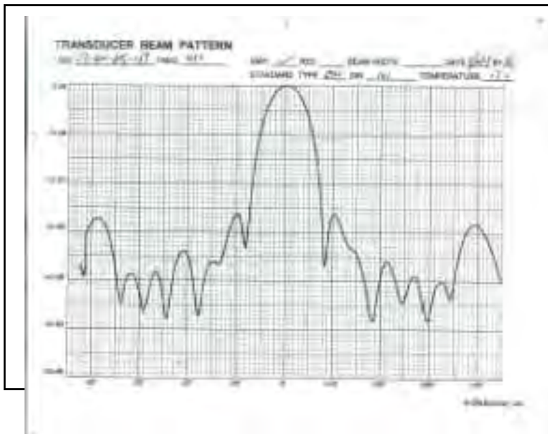
Source Level = 218.5dB||μPa

Receive Sensitivity = -63.8dBCount/μPa

Transducer Cable: 141-97-1118

Cable Length: 150 feet

Installation Elevation: 2192.6 feet



Appendix B: Split Beam Technology

The split beam technology is implemented to solve the position-in-beam dilemma: a small fish near the center of the beam gives the same echo level output as a large fish near the outer edge of the beam. The split beam design divides up the transducer face into four quadrants (Figure 20):

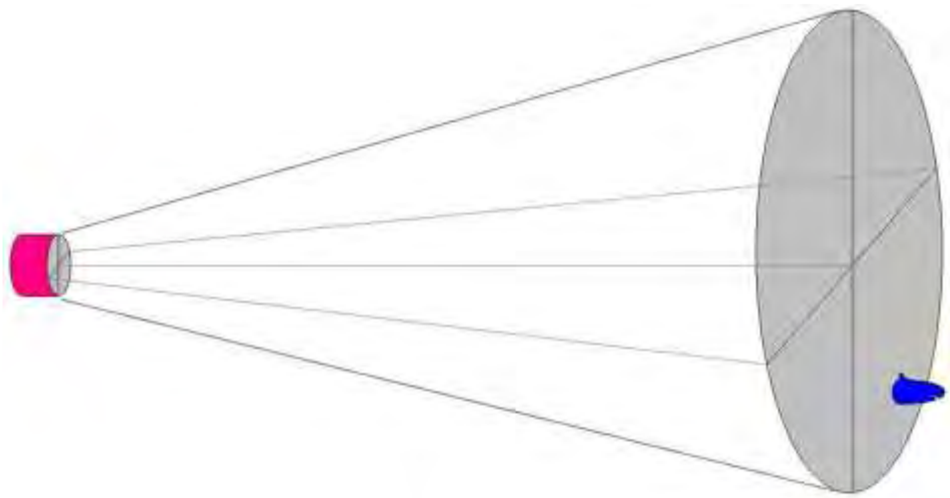


Figure 20. Split beam Transducer Showing 4 Quadrants

Each of the quadrants has a separate receiver, allowing processing of four echoes from a single target. If a fish is positioned at the beam center (or acoustic axis), the four echoes arrive at precisely the same time to the transducer face. However, if a fish is away from the beam center, the path length from the fish to each quadrant is different, and the arrival time of the echo at each of the quadrants is slightly different. The individual receivers measure the arrival time by comparing time shifts in the sine wave of the acoustic pressure wave. Based on the physical design of the transducer, these delay times can be mapped to X and Y angles. At this point, we have the X, Y, and Z (range) positions of the fish. The split beam data allows a correction for the weaker return from the non-centered position, providing a direct measure of the Target Strength (TS) of that echo.

As a fish passes through the acoustic sound field, it is "pinged on" for several successive transmissions of the echosounder. When the X, Y, and Z positions of each echo are known, echoes that are spatially correlated in time and space can be associated into a trace (or in crude terms, the dots are connected).

By forming fish traces, we can measure several components of the behavior of the fish, such as the velocity through the beam and the direction that the fish is moving. Figure 21 illustrates this procedure:

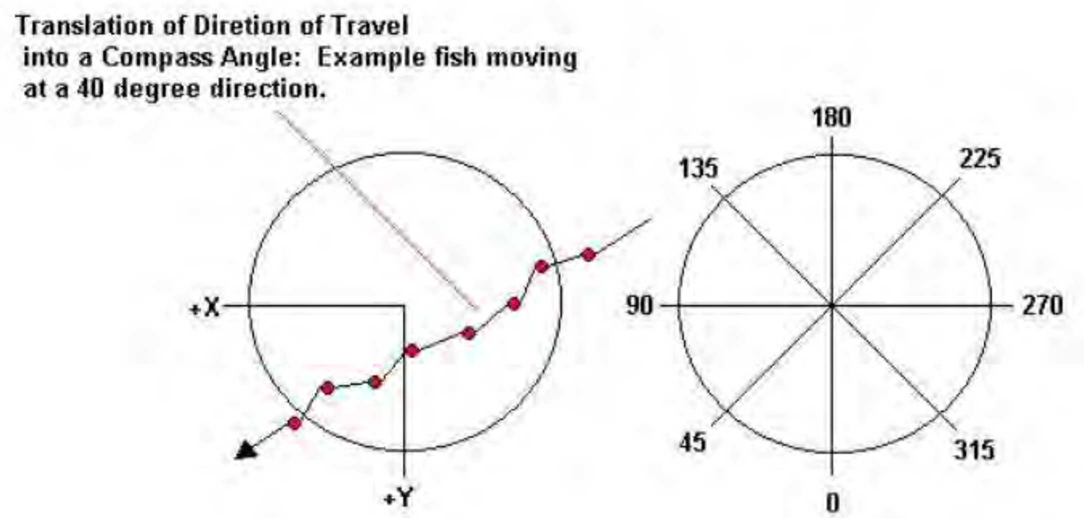


Figure 21. Details of the Calculation of Direction of Travel

The circle represents a cross-section through the conical acoustic beam, and the red dots in the left circle indicate individual echoes detected as a fish passes through the beam. By connecting the dots into a trace and calculating the slope of the trace, that slope can be expressed as a "compass angle", as shown by the circle at the right. In the example shown, the fish is moving from right to left and from top to bottom. Restated, the fish is moving from +X to –X and +Y to –Y: this trajectory corresponds to a Direction of Travel of about 40°.

The split beam transducers were installed in the WAC Bennett Dam Spillbays with 0° oriented to downstream flow and 180° pointing up-reservoir.

Appendix C: Interpretation Rules for Echoview Processing of Acoustic Files

Since fish traces were manually extracted from the acoustic data files, it was necessary to establish clear and consistent rules of interpretation for trace selection. These rules are summarized as:

1. Traces with mean Target Strength < -60 dB were rejected
2. A trace deeper than 10 m must have 4 or more echoes
3. A trace above 10 m must have 3 or more echoes
4. All traces above a range of 18 m were extracted
5. All traces below a range of 18 m but showing an upward direction were extracted
6. Traces with low intensity, total linearity, and extremely steep slopes were excluded (bubbles)

When spill gates were closed, several new categories of target behavior were observed. In these conditions, the behaviors below were included with those previously mentioned:

1. Extremely long linear traces were excluded (as drifting objects)
2. Long traces with intermittent detection, appearing as a line of dashes, were rejected (as a rolling or twirling drifting object)
3. Long traces that were generated by milling fish were rejected

The figures below illustrate many of these interpretational principles graphically.

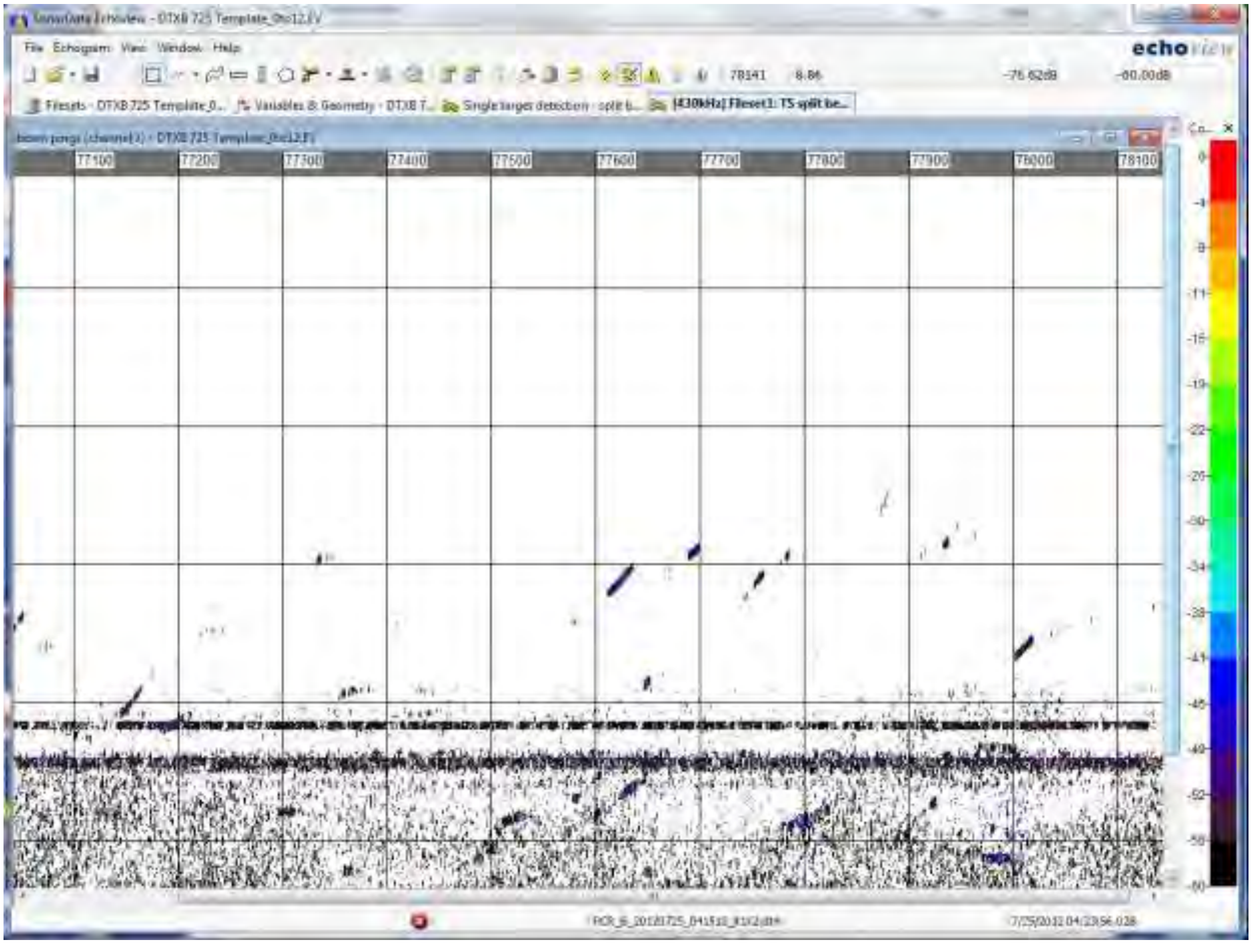


Figure 22. Echogram View Showing Fish Targets

An echogram is a time series of pings, with time (usually in Number of Pings) on the X-Axis and Range from transducer on the Y-Axis. This figure represents about 3.5 minutes of data. The black horizontal line and the black stippling below it are interference patterns from the structures below the spill opening.

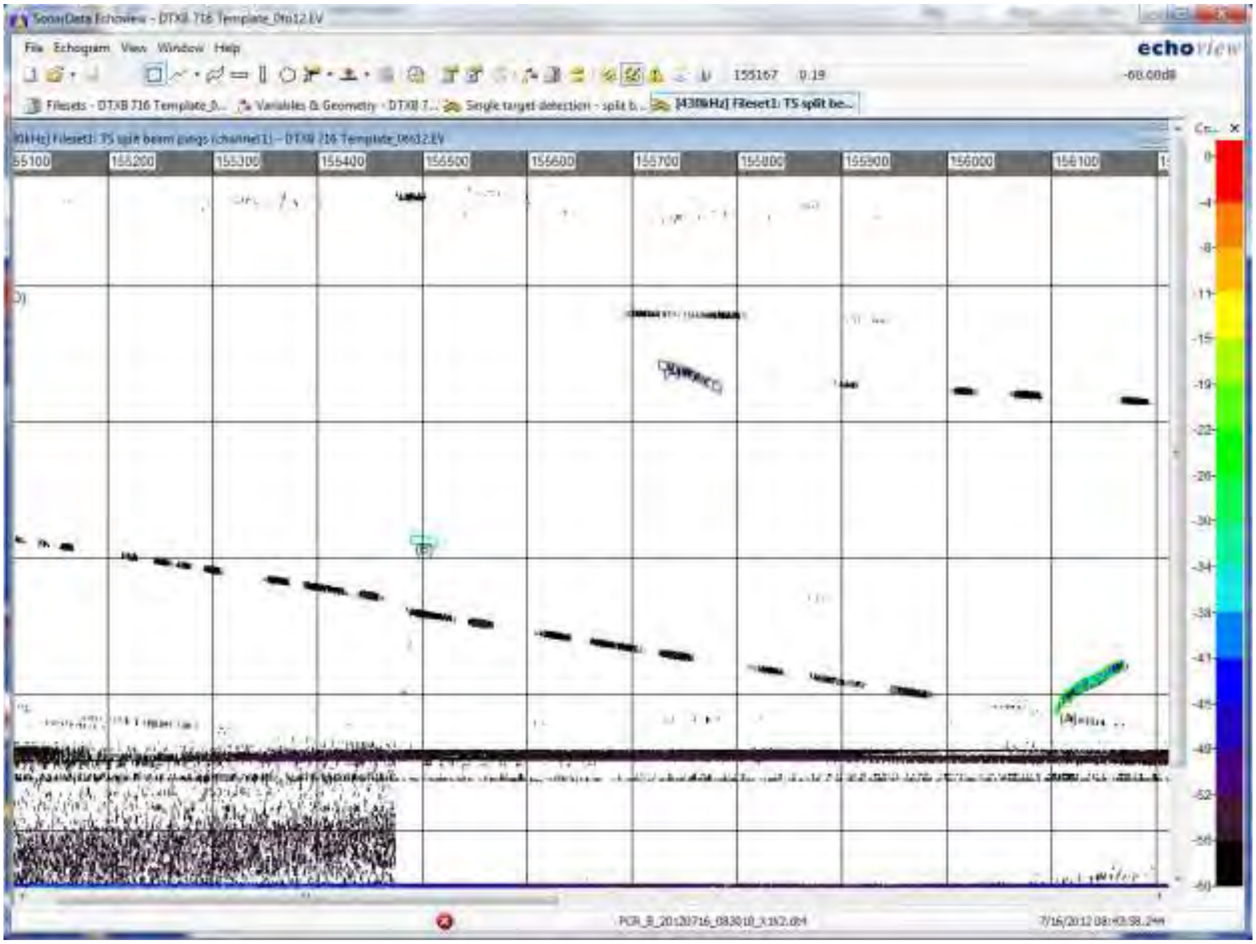


Figure 23. Echogram View Showing Drifting Objects and Marked Fish

In this data segment, we observe long tracks with periodic gaps, creating the appearance of a dashed line. This phenomenon is produced when an object drifts slowly through the beam and rotates in a periodic fashion, exposing a side or facet that is more reflective. Fish targets also appear – some are marked by enclosing them in a colored border and labeling them with the channel number. Another fish trace is marked but not shown – it was detected on the second channel.

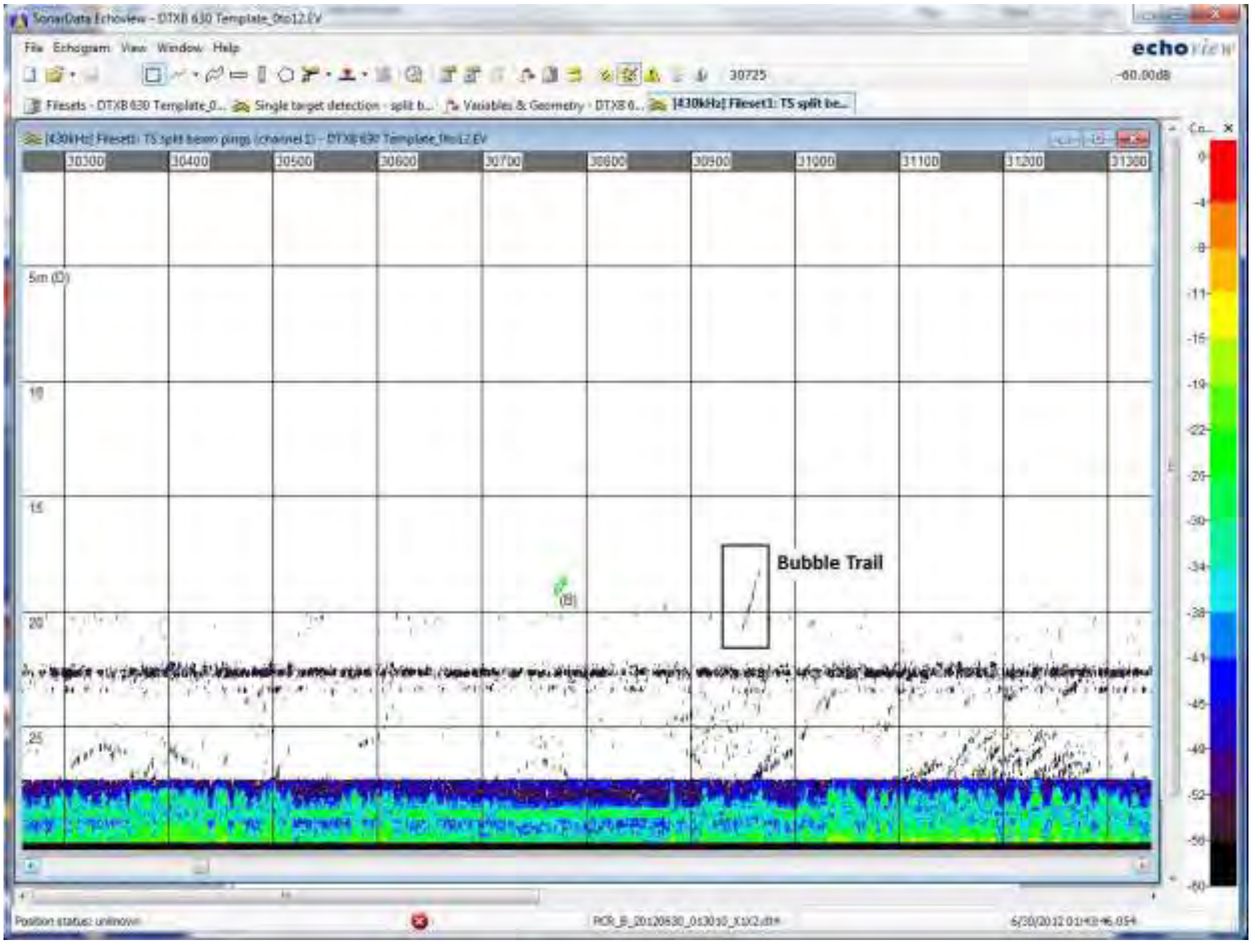


Figure 24. Echogram View Showing Rising Bubbles

Several target traces were characterized by low intensity, steep slope, and high linearity. Examination of the project blueprints showed components called "Bubblers" that were located almost directly below the transducer locations. Communication with project personnel indicated that these structures were potential sources of air bubbles. The acoustic characteristics of these steep target traces are consistent with those produced by air bubbles, so this type of trace was excluded from the analysis.

Appendix D: Estimation of Effective Beam Width

In many acoustic surveys, one of the analytical goals is to estimate the acoustic sample volume. In the fixed-aspect technique used in this study, fish traces are counted instead of fish echoes. As a result, the acoustic sample volume becomes an acoustic cross section. The detection of fish may be compared to counting objects passing through a plane which is perpendicular to their direction of travel. The vertical dimension of this plane is fully and continuously sampled, as the acoustic beam projects downward. However, the beam subsamples the width of the spill bay. Each detection must therefore be spatially extrapolated across the width of the spill bay to provide an estimate of total entrainment.

The spatial extrapolation process calculates a weighting factor for each fish detection. This weight is the spill bay width (or half width when sampled by two transducers) divided by the effective width of the beam. The effective width is, in turn, a function of the acoustic size or target strength of the detected fish. Therefore, the effective beam width is calculated independently for each fish detection, allowing calculation of the weighting factor for that fish. The weighting factor represents the number of fish that would have been detected if the entire spill bay were sampled. Summing of the weights by size category over an hour provides an estimate of total entrainment.

The process of estimating the effective beam width uses the following steps:

D1) Determine Beam Pattern Reduction for each fish

Each fish passes through the beam by entering one side, moving across the center region, and passing out the opposite side. The regions of entry and exit have lower intensity values than the center regions due to the transducer's directivity (high intensity on axis, lower near the edges). We determine the mean or effective reduction in the reflected intensity of that fish by:

BP = (Echo Level - Threshold)/2, where

Echo Level = the mean measured reflected intensity of the fish trace (or collection of echoes), and

Threshold = Intensity level over which a trace is counted and below which it is excluded. A trace counted over a -60 dB threshold and having an Echo Level of -40 dB would have a BP of 10 dB.

D2) Convert Beam Pattern Reduction (in dB) to Effective Beam Angle

Each transducer has a relationship between Intensity and Angle. The highest intensity is on the acoustic axis , and intensity drops as one moves away from the axis. This effect, called Directivity, is shown for each transducer in Appendix A. By reading values from these plots and fitting a curve to the values, a function can be established for the purpose of converting Intensity to Angle. Figure 25 shows such a process:

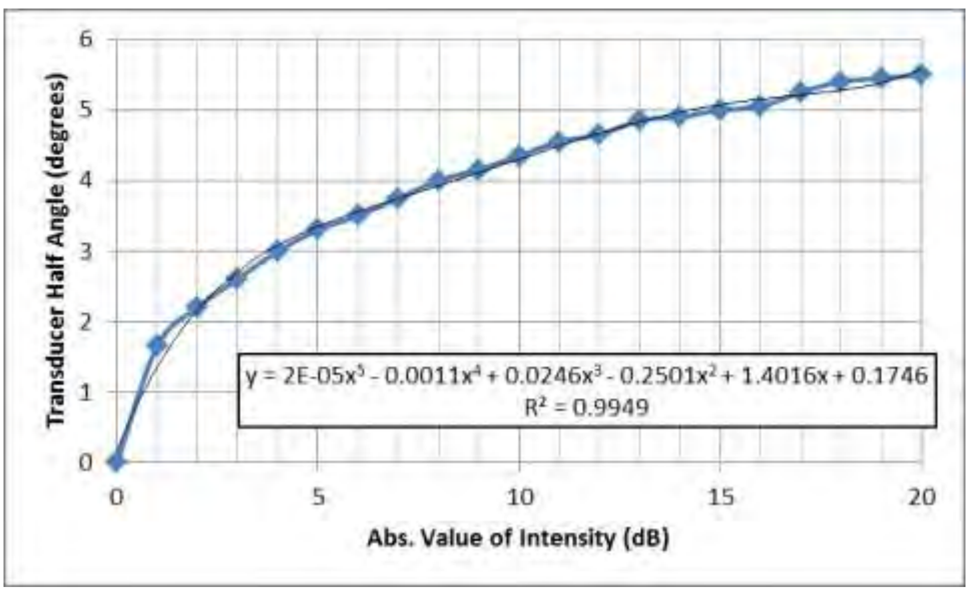


Figure 25. Directivity Function to Convert dB to Hafl Angle

The 5-order polynomial is used to convert the Beam Pattern Reduction from Step 1 for each fish into an Effective Half Angle.

D3) Calculate Effective Beam Width

The range to each fish (in m) is measured by the echosounder. Using standard trigonometry, the range and Effective Beam Angle are used to calculate the Effective Beam Width:

Effective Beam Width (m) = 2 x Range (m) x tangent(Effective Half Angle)

The spatial weighting factor is simply the width of the spill bay divided by the Effective Beam Width.

Appendix E: Daily Entrainment Estimates by Hour and Size Class

Tables 20 through 35 provide hourly estimates of entrainment by size class for each day selected for analysis. Again, the data from July 15-18 represents spatially extrapolated fish detections instead of entrainment estimates as spill gates were closed on those dates. Each table also presents entrainment as a function of flow. First, fish entrainment per hour is presented as a function of hourly discharge rate ((#/hr)/cms), and second, hourly fish entrainment numbers are expressed as a function of total hourly discharge (#/million cubic meters).

Table 25. Fish Entrainment by Hour and Size Category, June 26, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	126	7		2.862	44.0726	2.4612	0.0000	12242.3788	683.6542	0.0000
11	17	17		108.409	0.1530	0.1580	0.0000	42.4898	43.8834	0.0000
12	295	51		566.386	0.5208	0.0907	0.0000	144.6567	25.1976	0.0000
13	145			566.458	0.2565	0.0000	0.0000	71.2566	0.0000	0.0000
14	151	17		566.656	0.2661	0.0292	0.0000	73.9158	8.0983	0.0000
15	444	14		566.998	0.7835	0.0248	0.0000	217.6322	6.8796	0.0000
16	239	31		567.249	0.4212	0.0546	0.0000	116.9932	15.1691	0.0000
17	326	52		567.322	0.5750	0.0924	0.0000	159.7229	25.6785	0.0000
18	468	54		567.285	0.8249	0.0956	0.0000	229.1275	26.5606	0.0000
19	297	22		567.392	0.5230	0.0390	0.0000	145.2714	10.8226	0.0000
20	17	75		567.608	0.0293	0.1313	0.0000	8.1256	36.4725	0.0000
21	205	20		567.862	0.3613	0.0345	0.0000	100.3514	9.5952	0.0000
22	321	140		568.185	0.5658	0.2462	0.0000	157.1672	68.3890	0.0000
23	605	239		568.49	1.0635	0.4204	0.0000	295.4258	116.7722	0.0000
	3656	739	0							

Total Entrainment, June 26 = 4395

Table 26. Fish Entrainment by Hour and Size Category, June 27, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	346	251		568.652	0.6077	0.4416	0.0000	168.7947	122.6669	0.0000
1	244	165		568.76	0.4291	0.2907	0.0000	119.2018	80.7583	0.0000
2	373	169		568.922	0.6559	0.2965	0.0000	182.1874	82.3582	0.0000
3	621	135		569.157	1.0917	0.2374	0.0000	303.2367	65.9439	0.0000
4	509	94		569.389	0.8932	0.1644	0.0000	248.1154	45.6798	0.0000
5	302	33	5	569.462	0.5298	0.0574	0.0089	147.1565	15.9454	2.4857
6	64	97		569.696	0.1121	0.1704	0.0000	31.1357	47.3244	0.0000
7	24	61		569.947	0.0418	0.1065	0.0000	11.6096	29.5804	0.0000
8	1319	52		569.983	2.3141	0.0908	0.0000	642.8044	25.2243	0.0000
9	186	28		570.055	0.3265	0.0488	0.0000	90.6856	13.5505	0.0000
10	81	23		568.055	0.1432	0.0398	0.0000	39.7810	11.0546	0.0000
11	326	32		565.227	0.5767	0.0569	0.0000	160.2000	15.8020	0.0000
12	171	41		875.22	0.1954	0.0470	0.0000	54.2742	13.0485	0.0000
13	808	85	3	1096.812	0.7369	0.0771	0.0023	204.6978	21.4244	0.6463
14	705	44		1312.554	0.5371	0.0336	0.0000	149.2033	9.3384	0.0000
15	536	53		1437.959	0.3725	0.0367	0.0000	103.4784	10.2057	0.0000
16	386	90	2	1182.254	0.3269	0.0765	0.0020	90.7960	21.2477	0.5685
17	172	35		1146.225	0.1504	0.0305	0.0000	41.7727	8.4822	0.0000
18	338	43		1473.488	0.2293	0.0294	0.0000	63.6844	8.1727	0.0000
19	560	64		1473.343	0.3803	0.0436	0.0000	105.6333	12.1179	0.0000
20	684	81		1473.047	0.4643	0.0552	0.0000	128.9713	15.3364	0.0000
21	207	78		1473.343	0.1402	0.0531	0.0000	38.9394	14.7537	0.0000
22	226	82	3	1474.322	0.1532	0.0558	0.0018	42.5426	15.5104	0.5038
23	420	173	3	1474.959	0.2848	0.1175	0.0017	79.1065	32.6515	0.4722
	9608	2010	15							

Total Entrainment, June 27 = 11633

Table 27. Fish Entrainment by Hour and Size Category, June 28, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	193	133		1475.596	0.1308	0.0901	0.0000	36.3325	25.0302	0.0000
1	300	155		1475.791	0.2032	0.1048	0.0000	56.4426	29.1163	0.0000
2	466	74		1475.694	0.3159	0.0504	0.0000	87.7361	14.0132	0.0000
3	941	107		1475.938	0.6377	0.0728	0.0000	177.1412	20.2295	0.0000
4	1019	18		1476.232	0.6903	0.0121	0.0000	191.7554	3.3625	0.0000
5	461	46		1476.576	0.3120	0.0311	0.0000	86.6795	8.6472	0.0000
6	211	15		1476.772	0.1429	0.0103	0.0000	39.6955	2.8731	0.0000
7	193	25		1476.968	0.1307	0.0172	0.0000	36.3022	4.7791	0.0000
8	484	47		1477.213	0.3275	0.0318	0.0000	90.9655	8.8406	0.0000
9	139	9		1250.05	0.1110	0.0068	0.0000	30.8320	1.9002	0.0000
10	222	11		2133.119	0.1042	0.0051	0.0000	28.9377	1.4145	0.0000
11	592	21		1230.908	0.4805	0.0172	0.0000	133.4856	4.7755	0.0000
12	29	4		823.074	0.0348	0.0053	0.0000	9.6650	1.4639	0.0000
13	283	16		2406.882	0.1175	0.0068	0.0000	32.6402	1.8834	0.0000
14	17	20		2865.319	0.0058	0.0070	0.0000	1.6161	1.9500	0.0000
15	257	22		2170.421	0.1184	0.0102	0.0000	32.8957	2.8321	0.0000
16	356	66		1949.609	0.1827	0.0339	0.0000	50.7592	9.4183	0.0000
17	139	31	8	1479.663	0.0942	0.0210	0.0053	26.1773	5.8304	1.4627
18	41	10	3	1479.467	0.0277	0.0066	0.0019	7.6901	1.8377	0.5150
19	147	63		1479.416	0.0994	0.0424	0.0000	27.6057	11.7713	0.0000
20	34	11		1479.564	0.0227	0.0075	0.0000	6.3105	2.0782	0.0000
21	59	66		1480.005	0.0400	0.0449	0.0000	11.1013	12.4789	0.0000
22	83	53		1480.642	0.0558	0.0360	0.0000	15.5089	10.0134	0.0000
23	94	109		1480.691	0.0635	0.0738	0.0000	17.6515	20.5012	0.0000
	6759	1134	11							

Total Entrainment, June 28 = 7904

Table 28. Fish Entrainment by Hour and Size Category, June 29, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	117	97		1481.035	0.0793	0.0654	0.0000	22.0292	18.1800	0.0000
1	116	162		1481.67	0.0786	0.1093	0.0000	21.8387	30.3699	0.0000
2	250	96		1482.111	0.1687	0.0648	0.0000	46.8736	18.0048	0.0000
3	115	31		1482.503	0.0777	0.0206	0.0000	21.5780	5.7335	0.0000
4	68	13		1482.847	0.0455	0.0085	0.0000	12.6456	2.3484	0.0000
5	55	11		1483.141	0.0370	0.0072	0.0000	10.2806	2.0071	0.0000
6	105	7		1483.63	0.0709	0.0048	0.0000	19.6873	1.3305	0.0000
7	84	5		1484.17	0.0569	0.0032	0.0000	15.7994	0.8935	0.0000
8	55	13		1484.415	0.0371	0.0090	0.0000	10.3178	2.5008	0.0000
9	263	21		1484.071	0.1769	0.0144	0.0000	49.1379	4.0063	0.0000
10	310	37		1483.778	0.2087	0.0251	0.0000	57.9836	6.9667	0.0000
11	117	25		1483.63	0.0787	0.0168	0.0000	21.8565	4.6561	0.0000
12	133	39		1483.826	0.0895	0.0266	0.0000	24.8572	7.3785	0.0000
13	132	41		1484.561	0.0891	0.0278	0.0000	24.7464	7.7351	0.0000
14	248	63		1485.05	0.1673	0.0427	0.0000	46.4817	11.8573	0.0000
15	236	9		1485.297	0.1587	0.0058	0.0000	44.0839	1.6032	0.0000
16	146	17		1485.297	0.0986	0.0118	0.0000	27.3781	3.2641	0.0000
17	160	16		1485.101	0.1075	0.0109	0.0000	29.8746	3.0319	0.0000
18	129	29		1485.15	0.0870	0.0198	0.0000	24.1646	5.5031	0.0000
19	97	39		1485.101	0.0654	0.0264	0.0000	18.1713	7.3443	0.0000
20	138	10		1485.346	0.0927	0.0065	0.0000	25.7571	1.7987	0.0000
21	182	26		1485.835	0.1228	0.0176	0.0000	34.1020	4.8898	0.0000
22	198	55	1	1486.276	0.1334	0.0372	0.0007	37.0558	10.3244	0.1982
23	180	72		1486.718	0.1212	0.0484	0.0000	33.6711	13.4452	0.0000
	3636	936	1							

Total Entrainment, June 29 = 4572

Table 29. Fish Entrainment by Hour and Size Category, June 30, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	202	115		1486.618	0.1359	0.0774	0.0000	37.7412	21.4996	0.0000
1	158	64		1486.276	0.1061	0.0431	0.0000	29.4685	11.9793	0.0000
2	239	99		1486.424	0.1609	0.0668	0.0000	44.6822	18.5632	0.0000
3	447	94		1487.256	0.3005	0.0633	0.0000	83.4655	17.5959	0.0000
4	274	33		1488.041	0.1843	0.0221	0.0000	51.1937	6.1445	0.0000
5	74	16		1488.53	0.0495	0.0109	0.0000	13.7527	3.0377	0.0000
6	69	29		1488.726	0.0465	0.0195	0.0000	12.9164	5.4242	0.0000
7	200	13		1488.627	0.1341	0.0089	0.0000	37.2569	2.4779	0.0000
8	235	25		1488.285	0.1578	0.0171	0.0000	43.8364	4.7584	0.0000
9	354	36		1488.089	0.2379	0.0245	0.0000	66.0869	6.7991	0.0000
10	631	80		1488.138	0.4239	0.0535	0.0000	117.7567	14.8505	0.0000
11	448	65		1488.579	0.3012	0.0434	0.0000	83.6776	12.0623	0.0000
12	445	60		1489.265	0.2990	0.0406	0.0000	83.0600	11.2648	0.0000
13	1048	109		1489.706	0.7033	0.0731	0.0000	195.3747	20.3132	0.0000
14	1470	291		1489.853	0.9867	0.1953	0.0000	274.0715	54.2491	0.0000
15	745	100		1489.706	0.5003	0.0669	0.0000	138.9795	18.5831	0.0000
16	960	183		1489.364	0.6446	0.1227	0.0000	179.0608	34.0765	0.0000
17	210	23		1489.167	0.1410	0.0157	0.0000	39.1668	4.3677	0.0000
18	784	134		1489.706	0.5264	0.0902	0.0000	146.2179	25.0493	0.0000
19	1034	178		1490.735	0.6934	0.1195	0.0000	192.6016	33.1969	0.0000
20	235	11		1491.911	0.1576	0.0075	0.0000	43.7703	2.0961	0.0000
21	558	21		1492.156	0.3739	0.0140	0.0000	103.8480	3.8860	0.0000
22	1530	153		1491.666	1.0254	0.1027	0.0000	284.8267	28.5188	0.0000
23	416	155		1491.029	0.2789	0.1040	0.0000	77.4824	28.8972	0.0000
	12765	2089	0							

Total Entrainment, June 30 = 14855

Table 30. Fish Entrainment by Hour and Size Category, July 1, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	296	162		1490.343	0.1987	0.1088	0.0000	55.1821	30.2138	0.0000
1	303	171		1490.491	0.2031	0.1144	0.0000	56.4172	31.7865	0.0000
2	1138	211	2	1491.518	0.7631	0.1417	0.0011	211.9659	39.3645	0.3021
3	457	76		1492.4	0.3065	0.0508	0.0000	85.1451	14.1034	0.0000
4	336	70		1492.744	0.2248	0.0467	0.0000	62.4449	12.9790	0.0000
5	400	88		1492.841	0.2681	0.0591	0.0000	74.4641	16.4229	0.0000
6	648	32		1492.939	0.4341	0.0217	0.0000	120.5777	6.0331	0.0000
7	165	47		1492.744	0.1106	0.0312	0.0000	30.7337	8.6544	0.0000
8	269	71		1492.4	0.1804	0.0472	0.0000	50.1041	13.1232	0.0000
9	218	33		1492.89	0.1458	0.0222	0.0000	40.5085	6.1638	0.0000
10	791	49	1	1493.869	0.5297	0.0329	0.0010	147.1494	9.1326	0.2649
11	2094	57		1494.213	1.4014	0.0381	0.0000	389.2689	10.5849	0.0000
12	2793	241		1493.92	1.8693	0.1614	0.0000	519.2401	44.8428	0.0000
13	1944	320		1493.624	1.3018	0.2140	0.0000	361.6037	59.4493	0.0000
14	3361	677		1493.283	2.2504	0.4537	0.0000	625.1188	126.0263	0.0000
15	898	104	4	1493.135	0.6016	0.0696	0.0024	167.1090	19.3278	0.6776
16	197	52		1493.234	0.1322	0.0346	0.0000	36.7247	9.6056	0.0000
17	592	62		1493.869	0.3960	0.0417	0.0000	110.0062	11.5725	0.0000
18	48	54		1494.557	0.0320	0.0363	0.0000	8.8885	10.0895	0.0000
19	45	41		1494.751	0.0302	0.0271	0.0000	8.3844	7.5301	0.0000
20	45	51		1494.703	0.0298	0.0344	0.0000	8.2901	9.5681	0.0000
21	32	26		1494.507	0.0214	0.0172	0.0000	5.9472	4.7726	0.0000
22	33	29		1494.507	0.0224	0.0192	0.0000	6.2253	5.3396	0.0000
23	98	41		1494.85	0.0656	0.0275	0.0000	18.2094	7.6472	0.0000
	17201	2764	7							

Total Entrainment, July 1 = 19972

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Table 31. Fish Entrainment by Hour and Size Category, July 9, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	143	81		1508.061	0.0950	0.0539	0.0000	26.3936	14.9815	0.0000
1	303	134		1508.061	0.2010	0.0888	0.0000	55.8355	24.6539	0.0000
2	430	221		1507.8	0.2850	0.1463	0.0000	79.1647	40.6328	0.0000
3	459	358		1507.538	0.3043	0.2375	0.0000	84.5297	65.9658	0.0000
4	321	164		1507.581	0.2129	0.1090	0.0000	59.1506	30.2700	0.0000
5	389	29		1507.581	0.2581	0.0189	0.0000	71.6816	5.2587	0.0000
6	186	24		1507.581	0.1234	0.0157	0.0000	34.2783	4.3682	0.0000
7	112	77		1507.538	0.0741	0.0510	0.0000	20.5882	14.1739	0.0000
8	389	28		1507.625	0.2582	0.0185	0.0000	71.7210	5.1459	0.0000
9	1065	37	4	1507.8	0.7060	0.0247	0.0029	196.1144	6.8717	0.8071
10	178	34		1507.843	0.1181	0.0226	0.0000	32.8132	6.2735	0.0000
11	290	42		1508.107	0.1920	0.0279	0.0000	53.3351	7.7622	0.0000
12	2535	528	10	1508.236	1.6810	0.3502	0.0066	466.9311	97.2658	1.8317
13	797	141		1508.368	0.5286	0.0936	0.0000	146.8382	25.9950	0.0000
14	274	22		1508.762	0.1819	0.0147	0.0000	50.5161	4.0963	0.0000
15	413	78	4	1098.564	0.3756	0.0711	0.0033	104.3225	19.7445	0.9182
16	1352	221		1044.199	1.2945	0.2118	0.0000	359.5960	58.8241	0.0000
17	2086	137		1044.199	1.9977	0.1310	0.0000	554.9134	36.3911	0.0000
18	1010	83		1044.142	0.9676	0.0798	0.0000	268.7870	22.1764	0.0000
19	1329	121		1043.994	1.2729	0.1158	0.0000	353.5735	32.1643	0.0000
20	124	29		1043.788	0.1185	0.0275	0.0000	32.9182	7.6261	0.0000
21	8253	1109		1043.788	7.9069	1.0624	0.0000	2196.3605	295.1138	0.0000
22	2523	158		1043.935	2.4171	0.1517	0.0000	671.4296	42.1473	0.0000
23	133	32		1044.288	0.1277	0.0306	0.0000	35.4629	8.5101	0.0000
	25094	3888	18							

Total Entrainment, July 9 = 29001

Table 32. Fish Entrainment by Hour and Size Category, July 10, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	242	38		1044.788	0.2318	0.0363	0.0000	64.3869	10.0914	0.0000
1	67	36		1044.788	0.0643	0.0341	0.0000	17.8704	9.4600	0.0000
2	228	58		1044.583	0.2182	0.0555	0.0000	60.6031	15.4245	0.0000
3	159	56		1044.406	0.1522	0.0537	0.0000	42.2685	14.9229	0.0000
4	71	44		1044.229	0.0682	0.0424	0.0000	18.9580	11.7831	0.0000
5	87			1044.376	0.0837	0.0000	0.0000	23.2598	0.0000	0.0000
6	370	44		1044.613	0.3539	0.0423	0.0000	98.3179	11.7432	0.0000
7	133	18		1044.788	0.1270	0.0169	0.0000	35.2774	4.6916	0.0000
8	573	14		1045.024	0.5486	0.0136	0.0000	152.3890	3.7877	0.0000
9	252			1045.318	0.2414	0.0000	0.0000	67.0561	0.0000	0.0000
10	459	6		1045.7	0.4387	0.0061	0.0000	121.8498	1.7005	0.0000
11	48	48		1045.906	0.0460	0.0462	0.0000	12.7732	12.8375	0.0000
12	86	55		1045.524	0.0818	0.0524	0.0000	22.7338	14.5592	0.0000
13	1523	209		1045.288	1.4570	0.1998	0.0000	404.7275	55.5059	0.0000
14	533	77		1045.288	0.5103	0.0739	0.0000	141.7588	20.5257	0.0000
15	6058	533	11	1045.258	5.7954	0.5100	0.0102	1609.8439	141.6583	2.8464
16	10492	945		1045.611	10.0339	0.9039	0.0000	2787.2047	251.0706	0.0000
17	489	97		1045.936	0.4674	0.0926	0.0000	129.8368	25.7351	0.0000
18	998	150	22	1045.847	0.9543	0.1431	0.0206	265.0795	39.7367	5.7337
19	620	76	46	1045.465	0.5927	0.0723	0.0440	164.6267	20.0711	12.2130
20	744	129		1045.288	0.7114	0.1229	0.0000	197.6060	34.1486	0.0000
21	116	29		1045.347	0.1106	0.0279	0.0000	30.7220	7.7623	0.0000
22	159	73		1045.524	0.1521	0.0701	0.0000	42.2471	19.4805	0.0000
23	209	84		1045.788	0.1996	0.0806	0.0000	55.4347	22.3860	0.0000
	24715	2819	78							

Total Entrainment, July 10 = 27612

Table 33. Fish Entrainment by Hour and Size Category, July 11, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	1165	288		1045.936	1.1136	0.2749	0.0000	309.3248	76.3558	0.0000
1	1549	353		1045.906	1.4813	0.3379	0.0000	411.4722	93.8622	0.0000
2	994	240		1045.847	0.9500	0.2292	0.0000	263.8839	63.6562	0.0000
3	363	70		1045.995	0.3468	0.0669	0.0000	96.3251	18.5961	0.0000
4	427	34		1046.052	0.4085	0.0330	0.0000	113.4791	9.1583	0.0000
5	176	21		1046.17	0.1687	0.0837	0.0000	46.8560	23.2539	0.0000
6	541	54		1046.229	0.5167	0.0000	0.0000	143.5305	0.0000	0.0000
7	518	88		470.817	1.1009	0.0000	0.0000	305.8139	0.0000	0.0000
8				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	5733	1148	0							

Total Entrainment, July 11 = 6881

Table 34. Fish Detections by Hour and Size Category with Gates Closed, July 15, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	185	254		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	269	427		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	169	279	23	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	220	335	10	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	309	742	18	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	279	758	31	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	236	1024	11	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	538	1656	9	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	587	1715	47	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	279	1131	23	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	506	837		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	409	758	6	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	277	840	14	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	433	968		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	125	646		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	59	812	31	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	361	756	58	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	196	630	22	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	190	569	9	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	176	575	4	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	97	440	47	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	71	356		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	189	256	13	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	27	118		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	6187	16883	377							

Total Counts, July 15 =	23447

Table 35. Fish Detections by Hour and Size Category with Gates Closed, July 16, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	25	64	19	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	31	179		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	134	37	15	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	267	111	23	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	201	544	23	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	123	704	4	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	197	533		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	504	277	11	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	594	445	14	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	176	384		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	302	545		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	282	417		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	40	375	25	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	47	128		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	25	250	2	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	80	176		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	70	389		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	10	306	27	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	89	156		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	30	104		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	137	87		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	69	162	10	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	136	177		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	15	79		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3582	6627	172							

Total Counts, July 16 = 10381

Table 36. Fish Detections by Hour and Size Category with Gates Closed, July 17, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	7	157	5	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	143	123		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	118	8		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	150	114	18	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	69	153	15	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	40	381		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	163	251		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	270	474		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	176	429		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	86	211		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	120	168		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	10	187	5	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	5	84		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	308	49		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	204	292	17	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	293	483		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	64	74	39	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	28	248		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	26	119		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	29	152		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	37	250		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	65	164		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22		168		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	126	68	7	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	2539	4807	107							

Total Counts, July 17 = 7453

Table 37. Fish Detections by Hour and Size Category with Gates Closed, July 18, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0		73		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1		62	3	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2		203		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3		108		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4		40		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	6	194	4	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	5	390	2	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	13	331		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	31	272	9	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9		74		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	612	605	19	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	383	259		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	167	262	2	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	192	133		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	57	203		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	46	104		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	502	141		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	146	209	2	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	100	145		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	27	256		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	293	144		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	312	169	4	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	134	238		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23		138		0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3027	4749	44							

Total Counts, July 18 = 7821

Table 38. Fish Entrainment by Hour and Size Category, July 24, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	23	36	2	121.592	0.1898	0.2951	0.0185	52.7301	81.9659	5.1431
10	460	65		579.089	0.7946	0.1119	0.0000	220.7173	31.0905	0.0000
11	191	93		579.089	0.3290	0.1603	0.0000	91.3813	44.5316	0.0000
12	340	36		579.181	0.5865	0.0617	0.0000	162.9158	17.1399	0.0000
13	309	24		579.243	0.5335	0.0409	0.0000	148.1933	11.3609	0.0000
14	240	64		579.275	0.4148	0.1111	0.0000	115.2308	30.8605	0.0000
15	34	16		579.243	0.0588	0.0275	0.0000	16.3367	7.6316	0.0000
16	110	235		579.259	0.1899	0.4065	0.0000	52.7571	112.9209	0.0000
17	327	99		578.981	0.5656	0.1710	0.0000	157.1234	47.5108	0.0000
18	1419	96		578.657	2.4530	0.1662	0.0000	681.3819	46.1754	0.0000
19	525	44		578.641	0.9066	0.0769	0.0000	251.8355	21.3552	0.0000
20	1044	158		578.827	1.8042	0.2733	0.0000	501.1805	75.9131	0.0000
21	110	132		579.121	0.1893	0.2273	0.0000	52.5791	63.1518	0.0000
22	626	891		579.429	1.0808	1.5377	0.0000	300.2107	427.1313	0.0000
23	863	940		579.645	1.4884	1.6216	0.0000	413.4423	450.4392	0.0000
	6621	2929	2							

Total Entrainment, July 24 = 9553

Table 39. Fish Entrainment by Hour and Size Category, July 25, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	1739	1182		579.569	3.0011	2.0399	0.0000	833.6336	566.6494	0.0000
1	1362	1320		579.351	2.3505	2.2790	0.0000	652.9197	633.0436	0.0000
2	1168	1166		579.291	2.0163	2.0129	0.0000	560.0951	559.1382	0.0000
3	980	988		579.275	1.6915	1.7064	0.0000	469.8485	474.0065	0.0000
4	1631	1133		579.291	2.8160	1.9563	0.0000	782.2303	543.4114	0.0000
5	824	365		579.413	1.4224	0.6298	0.0000	395.1040	174.9388	0.0000
6	261	97		579.569	0.4495	0.1670	0.0000	124.8586	46.3921	0.0000
7	330	79		579.461	0.5695	0.1356	0.0000	158.1987	37.6548	0.0000
8	752	126		579.229	1.2979	0.2179	0.0000	360.5205	60.5203	0.0000
9	629	63	7	579.167	1.0863	0.1086	0.0126	301.7589	30.1792	3.4911
10	127	38		579.229	0.2191	0.0663	0.0000	60.8732	18.4057	0.0000
11	64	37		579.429	0.1113	0.0640	0.0000	30.9192	17.7765	0.0000
12	348	6		579.569	0.6009	0.0104	0.0000	166.9293	2.8957	0.0000
13	261	90		579.569	0.4496	0.1554	0.0000	124.8966	43.1537	0.0000
14	96			579.413	0.1657	0.0000	0.0000	46.0382	0.0000	0.0000
15	85	59		579.275	0.1462	0.1016	0.0000	40.6138	28.2176	0.0000
16	143	31		579.305	0.2462	0.0543	0.0000	68.3975	15.0793	0.0000
17		7		579.321	0.0000	0.0116	0.0000	0.0000	3.2189	0.0000
18	195	36		579.337	0.3374	0.0615	0.0000	93.7170	17.0820	0.0000
19	513	97	3	579.383	0.8860	0.1680	0.0051	246.1152	46.6658	1.4068
20	655	67		579.367	1.1298	0.1157	0.0000	313.8201	32.1337	0.0000
21	1447	552		579.259	2.4980	0.9527	0.0000	693.8989	264.6404	0.0000
22	1244	660		579.197	2.1470	1.1390	0.0000	596.3865	316.3800	0.0000
23	1977	310		579.259	3.4138	0.5354	0.0000	948.2673	148.7229	0.0000
	16831	8510	10							

Total Entrainment, July 25 = 25351

BioSonics

Table 40. Fish Entrainment by Hour and Size Category, August 2, 2012

Hour	small #/hr	medium #/hr	large #/hr	flow rate cms	small (#/hr)/cms	medium (#/hr)/cms	large (#/hr)/cms	small #/million m^3	medium #/million m^3	large #/million m^3
0	80	159		580.264	0.1386	0.2746	0.0000	38.5007	76.2819	0.0000
1	157	77		580.25	0.2712	0.1327	0.0000	75.3218	36.8647	0.0000
2	204	123		580.264	0.3512	0.2128	0.0000	97.5685	59.1203	0.0000
3	222	139		580.264	0.3832	0.2394	0.0000	106.4391	66.5053	0.0000
4	122	133	3	580.264	0.2101	0.2290	0.0050	58.3484	63.6016	1.3806
5	94	134		580.358	0.1614	0.2304	0.0000	44.8280	63.9917	0.0000
6	90	45		580.496	0.1547	0.0770	0.0000	42.9704	21.3829	0.0000
7	48	53		580.528	0.0834	0.0920	0.0000	23.1782	25.5433	0.0000
8	246	14		580.574	0.4245	0.0244	0.0000	117.9157	6.7712	0.0000
9	187	38		580.712	0.3227	0.0654	0.0000	89.6491	18.1740	0.0000
10	102	17		580.744	0.1764	0.0288	0.0000	49.0092	7.9998	0.0000
11	17	26		580.65	0.0295	0.0445	0.0000	8.1859	12.3678	0.0000
12	80	41		580.48	0.1372	0.0707	0.0000	38.1035	19.6494	0.0000
13	221	86	9	454.582	0.4872	0.1885	0.0209	135.3227	52.3489	5.7941
14				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23				0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	1872	1085	12							

Total Entrrainment, August 2 = 2969