PNWD-3567

Effects of Turbine Loading on Fish Guidance Efficiency at McNary Dam in 2004

R.A. Moursund
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Final Report
October 20, 2005

Prepared for the U.S. Army Corps of Engineers
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Prepared for the U.S. Army Corps of Engineers
Walla Walla District, Walla Walla, Washington
Under Contract DACW68-020D-0001 Task Order No. 05

Battelle–Pacific Northwest Division
Richland, Washington 99352

Summary

Battelle Pacific Northwest Division conducted the study described in this report in 2004 for the U.S. Army Corps of Engineers, Walla Walla District (Corps) to evaluate fish guidance efficiency at McNary Dam. This study was a comparison of the effect of two turbine loading treatments on fish guidance efficiency (FGE), fish trajectories, and fish distributions at the powerhouse. The District funded concurrent research on juvenile salmonids at McNary Dam in 2004, including a radio telemetry study by the U.S. Geological Survey's Biological Resources Division and a fish injury study by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries) to examine general passage trends and gatewell environment effects, respectively.

Pairs of split-beam transducers sampled both guided and unguided fish at each slot of Units 2, 3, and 4. A total of 18 transducers were deployed and they collected data from April 15 to July 15, 2004. The planned turbine discharge study design called for a randomized block design with two treatments: a low-discharge (LQ) treatment at the upper end of 1% peak efficiency, approximately 12,200 cubic feet per second (cfs), and a high-discharge (HQ) treatment of approximately 16,400 cfs. The treatment conditions were met as planned; however, the treatment schedule was cancelled early in spring due to unexpected fish injury rates that were measured in the concurrent NOAA Fisheries study. Therefore only a limited number of statistical blocks of the treatment test were conducted in early spring.

The trend was for a slight increase in FGE with increased flows from 90.0% at the LQ treatment to 91.6% at the HQ treatment (Table S.1), but they were not statistically different ($p = 0.33$). We found that FGE did not decrease during high discharge treatments, suggesting that high discharge conditions are unlikely to increase turbine passage. Fish trajectories and vertical distributions also did not change significantly under the two discharge conditions. Fish velocities, however, did increase significantly at higher flows and may help explain the mechanisms producing injuries noted in the concurrent studies (Table S.2).

Table S.1. Fish Guidance Efficiency during low (LQ) and high (HQ) discharge treatments

	LQ	HQ	OVERALL
Spring	90.0	91.6	84.6
Summer	n/a	n/a	84.2

Table S.2. Fish velocities in ft/s during low (LQ) and high (HQ) discharge treatments

	LQ	HQ
Guided	4.89	5.68
Unguided	5.41	6.56

Acknowledgments

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> Mark Smith for overall project oversight; Steven Sipe, James Gale, and Dave Coleman for research coordination activities at the dam; Roger Golladay and the McNary Dam operators for safety clearances and outage coordination; Brad Eby, the project biologist, for his help throughout the project; Bill Prewitt and maintenance staff (riggers, mechanics, and electricians) for their support on the forebay deck; Mike Remington for dive safety coordination; dive inspectors Steve Thompson and Gale Morgan; all of the above for their common commitment to safety; and Martin Ahmann for providing hydraulic engineering information on the intake environment.

We would also like to thank the following Battelle staff:

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We wish to acknowledge Global Diving and Salvage, Inc., for providing the divers who installed and removed the transducers mounted on the trashracks, and Honald Crane for providing on-site mobile crane support.

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1.0 Introduction

This report presents results of a hydroacoustic study of juvenile salmonids funded by the Walla Walla District of the U.S. Army Corps of Engineers (Corps) and conducted at McNary Dam on the Columbia River from March to July of 2004 by a team of researchers from Battelle, Pacific Northwest Division. This study was a comparison of the effect of two turbine loading treatments on fish guidance efficiency, fish trajectories, and fish distributions at the powerhouse. Pairs of split-beam transducers sampled both guided and unguided fish at the slots of three turbine units during two turbine loading treatments: a low-discharge (LQ) treatment of approximately 12,200 cfs (cubic feet per second) and a high-discharge (HQ) treatment of approximately 16,400 cfs. The District funded concurrent research on juvenile salmonids in 2004, including a radio telemetry study by the U.S. Geological Survey's Biological Resources Division (USGS BRD) and a gatewell fish injury study by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS now known as NOAA Fisheries).

1.1 Background

The U.S. Army Corps of Engineers (Corps) is committed to improving fish passage and increasing survival rates for fish passing its hydroelectric projects on the Snake and Columbia Rivers. Strategies at McNary Dam have included the use of voluntary spill, transportation, and extended length submerged bar screens (ESBS) as part of a juvenile bypass system. The conversion of the ice and trash sluiceway to become the collection channel of the juvenile bypass system occurred in 1993-1994 after which the sluiceway gates were replaced with permanent concrete bulkheads. Fish are now routed from the turbine intakes into the gatewell slot and through orifices to the sluiceway, which is now a collection channel for the juvenile bypass system.

Construction of McNary Dam began in 1947, the third dam on the Columbia River after Grand Coulee and Bonneville. The structure was completed in 1954 and turbine units were installed between 1954 and 1957. This equipment is still in service and much of the hydro generation machinery is now in need of rehabilitation or upgrade. The powerhouse modernization project aims to upgrade the hydro and electrical components to increase electrical generation efficiency and at the same time to make changes that benefit fish passage.

The Bonneville Power Administration (BPA) has proposed that the ±1% peak efficiency turbine operating rule be discontinued. The NMFS 2000 Biological Opinion included the requirement that turbine operations be limited to within ±1% of peak efficiency based upon the belief that the highest turbine passage survival of juvenile salmonids occurs at the highest turbine efficiency. New data and a recent review of the original data indicate that the basis for this operating rule is questionable. Additionally, results indicate that at McNary Dam there may actually be a fish survival benefit to operating at greater than 1% above peak efficiency. However, the effects of increased flow on the juvenile bypass system are not known. The turbine intake screens, vertical barrier screens, and gatewell conditions have all been tested (Corps et al. 2004) under 1% peak efficiency operating conditions. High flows can potentially create hydraulic conditions unfavorable to fish. In addition, high flows could increase debris loading and create environments that fall outside established operating criteria.

If fish guidance efficiency, fish injury rates, egress, and overall survival remain within acceptable bounds when tested outside of the 1% peak efficiency operating conditions, then it would be justified to consider running the powerhouse outside of +1% peak efficiency. This study provides baseline information on how fish are guided by the current ESBS structures and addresses the issue of fish guidance efficiency in relation to turbine loading. This information will be used to assist in determining future operations for fish passage at McNary Dam, which may include increased flow through turbines or new turbine designs.

1.2 Previous Studies

No previous hydroacoustic studies of fish passage have been conducted at McNary Dam. Radio tag-based passage and survival studies were conducted in 2002 and 2003 by NOAA Fisheries (Axel et al. 2004a and Axel et al. 2004b).

1.3 Study Goals and Objectives

The goal of this study was to collect FGE information for use in new turbine designs under the McNary Modernization Program. These data will also provide insights into current and potential operations of the turbine units at McNary Dam.

1. Estimate fish guidance efficiency (FGE) by hour for the dam for both spring and summer.

2. Describe diel and seasonal variations in FGE.

3. Test for statistically significant differences in FGE and fish velocities near the ESBS between existing and proposed test turbine operations. All intakes at three turbine units will be sampled.

4. Collect, compile, and report head differential across vertical barrier screens (VBS) in a format accessible to other researchers at the Corps. Correlate possible FGE changes with various differentials.

1.4 Study Site Description

McNary Dam, located at Columbia River mile 292, includes a navigation lock, a spillway, and a powerhouse. The dam is 7,365 feet long. There are 14 turbine units contained in the 1,422-ft long powerhouse. Turbine units are numbered 1 through 14 from the Oregon shore. Each turbine has three intakes designated A, B, and C. Main units have a nameplate capacity of 70 MW each. Two station service units are located south of Main Unit 1 and have a 3-MW capacity each. Extended length submerged bar screens (ESBS) are installed at all of the turbine unit intakes. The ice and trash sluiceway has been permanently walled off for use as the collection channel of the juvenile bypass system (JBS). The 1,130-ft spillway is comprised of 22 vertical lift gates, which are numbered sequentially from the Washington shore—the spill bay closest to the powerhouse is 22. The average forebay elevation during the fish passage season is 338.5 ft above mean sea level. In the forebay, the thalweg is upstream of the powerhouse, but in the tailrace it is downstream of the spillway (Figure 1.1). There is also a 10-MW hydropower unit located on the Washington shore incorporated into the adult fishway. The gravity-flow auxiliary water supply system has a turbine unit installed on it, and this unit is operated by the Northern Wasco County Public Utility District. The south ladder includes the powerhouse collection system and both gravity and pumped auxiliary water supply systems.

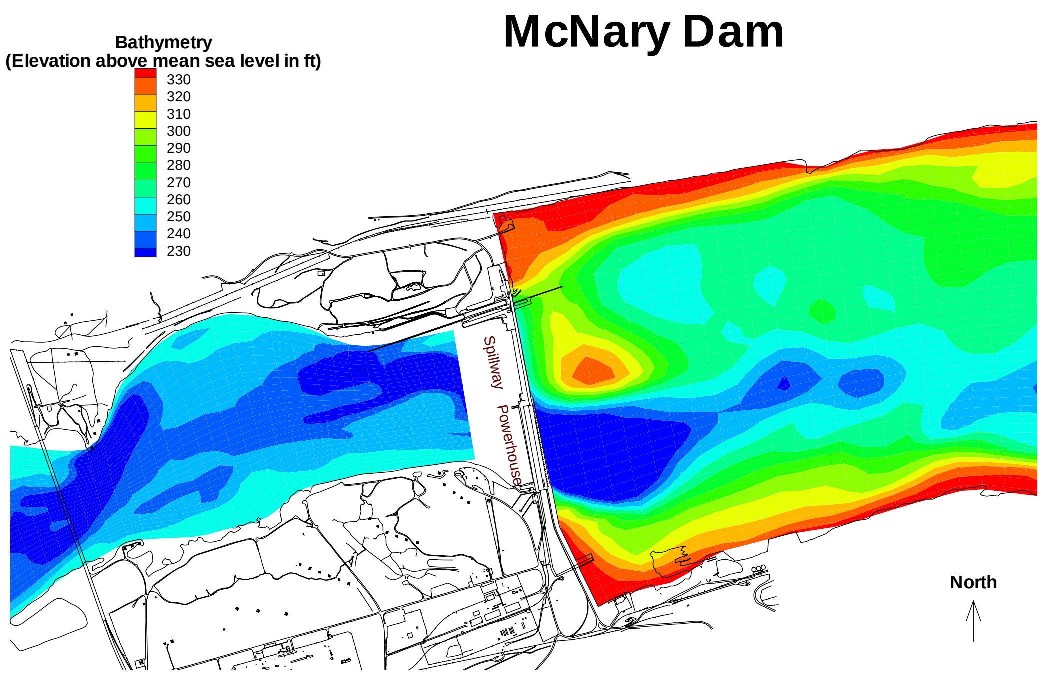


Figure 1.1. McNary Dam configuration and bathymetry

1.5 Overview of this Report

Chapter 2 contains a description of methods including the study design, sampling equipment used, deployment, and data analysis and processing. Chapter 3 provides results and discussion including site conditions during the study, seasonal fish passage, turbine loading treatment effects, intake sampling results, and head differential across the VBS. Chapter 4 provides our conclusions. Chapter 5 is references. Appendix A is equipment configuration. Appendix B is system calibrations. Appendix C is effective beam widths. Appendix D is raw data from dam operations during the study period; this data is provided on the attached CD.

2.0 Methods

2.1 Study Design

We monitored three turbine units (Units 2, 3, and 4) at McNary Dam with hydroacoustic equipment to sample FGE. The original study plan included a systematic block design (alternating between two treatments in a systematic manner) with the three test units in blocks of 4 days each with two treatments of 2 days each. The two treatments were as follows:

Low Discharge (LQ): The turbine unit operating at a 1% drop from peak efficiency on the high discharge or high power side of peak; approximately 12,200 cfs.

High Discharge (HQ): The maximum on-cam operation within cavitation limits; approximately 16,400 cfs.

The blocked design helped control for seasonal variation in fish passage and river conditions that were outside the control of river managers. The treatment design was scheduled to switch to a preferred randomized block design shortly after the season began; however, unexpected changes in planned operations eliminated that need. Due to changes in-season, only three and a half blocks were completed with all three turbines sampled. This was followed by three blocks with only one turbine sampled. This sampling schedule is shown in Table 2.1. The block treatments were conducted from April 16 to May 21, 2004.

During the spring tests, concerns regarding fish condition interrupted the planned test schedule and testing was halted by April 29. Testing resumed briefly on May 8, but for only one unit rather than the original three. Three blocks were tested with only turbine Unit 3 undergoing the discharge treatments through May 19. No discharge treatments were conducted after May 19. At this point, a few transducers were re-aimed to collect additional information about fish distributions in the intake. This additional sampling and all other sampling, under low discharge conditions, continued until July 15.

Table 2.1. Actual Treatment Schedule at McNary Dam Spring 2004. Entries are colored by alternate treatment blocks for ease of reading.

DATE	BLOCK	TREATMENT	UNITS
16 Apr 2004	1	High discharge (HQ)	2,3,4
17 Apr 2004	1	High discharge (HQ)	2,3,4
18 Apr 2004	1	Low discharge (LQ)	2,3,4
19 Apr 2004	1	Low discharge (LQ)	2,3,4
20 Apr 2004	2	High discharge (HQ)	2,3,4
21 Apr 2004	2	High discharge (HQ)	2,3,4
22 Apr 2004	2	Low discharge (LQ)	2,3,4
23 Apr 2004	2	Low discharge (LQ)	2,3,4
24 Apr 2004	3	High discharge (HQ) [1]	2,3,4
25 Apr 2004	3	High discharge (HQ)	2,3,4
26 Apr 2004	3	Low discharge (LQ)	2,3,4
27 Apr 2004	3	Low discharge (LQ)	2,3,4
28 Apr 2004	4	High discharge (HQ)	2,3,4
29 Apr 2004	4		
30 Apr 2004	4	Low discharge (LQ)	2,3,4
01 May 2004	4	Low discharge (LQ)	2,3,4
02 May 2004	5		
03 May 2004	5		
04 May 2004	5		
05 May 2004	5		
06 May 2004	6		
07 May 2004	6		
08 May 2004	7	High discharge (HQ)	3 only
09 May 2004	7	High discharge (HQ)	3 only
10 May 2004	7	Low discharge (LQ)	3 only
11 May 2004	7	Low discharge (LQ)	3 only
12 May 2004	8		
13 May 2004	8		
14 May 2004	9	High discharge (HQ)	3 only
15 May 2004	9	High discharge (HQ)	3 only
16 May 2004	9	Low discharge (LQ)	3 only
17 May 2004	9	Low discharge (LQ)	3 only
18 May 2004	10	High discharge (HQ)	3 only
19 May 2004	10	High discharge (HQ)	3 only
20 May 2004	10	Low discharge (LQ)	3 only
21 May 2004	10	Low discharge (LQ)	3 only

[1] Missing data prevents block 3 from being included in statistical comparisons.

2.2 Hydroacoustic Sampling System

Data collection relied solely on split-beam hydroacoustics and utilized five Precision Acoustic Systems, Inc. (PAS) split-beam systems (Figure 2.1). All systems operated at 420 kHz. Data collection was accomplished using Harp–SB Split-Beam Data Acquisition/Signal Processing Software controlling a PAS-103 Split-Beam Multi-Mode Scientific Sounder. The PAS-103 Sounder then communicated with a PAS-203 Split-Beam Remote 4-Channel Transducer Multiplexer. Finally, the PAS-203 Remote Transducer Multiplexer multiplexed a maximum of four PAS 420-kHz Split-Beam Transducers deployed at sampling locations within the turbine units. Appendix A describes the equipment layout in detail. Appendix B describes the calibration for each system.

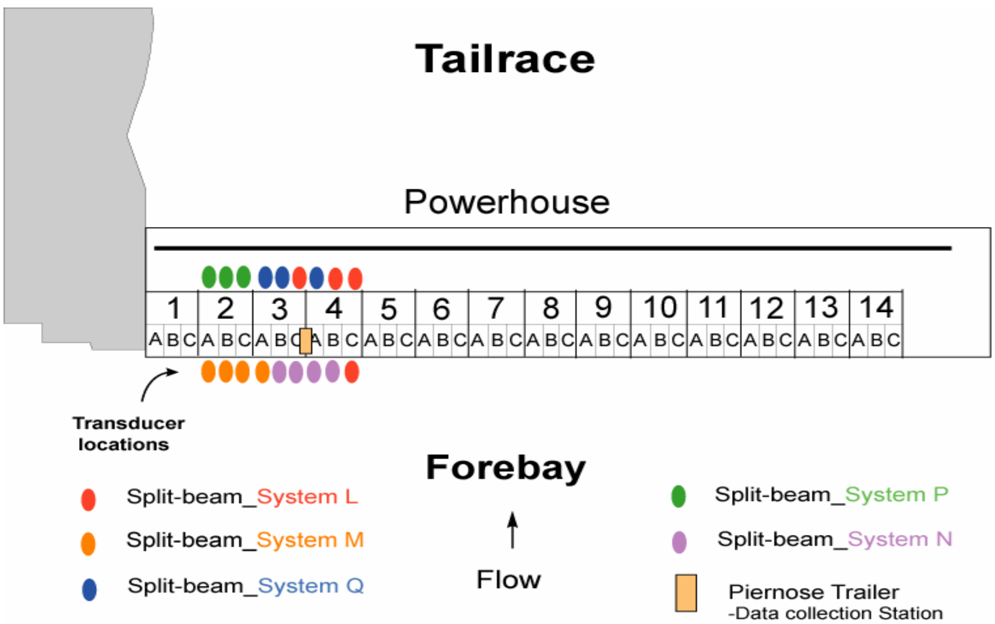


Figure 2.1. Plan view of the powerhouse showing each system and transducer location

2.3 Equipment Deployment

The details of equipment installations are described in this section. This includes the mounts and attachment points, as well as the physical locations on the dam. Data from all the systems were telemetered back to a central equipment trailer on the forebay deck. Both hydroacoustic and radar systems are addressed.

2.3.1 Hydroacoustic Transducers

Five PAS split-beam systems were used to monitor nine turbine intakes within three adjacent turbine units: 2A, B, C, 3A, B, C, and 4A, B, C (see Figure 2.1). Pairs of 6° split-beam transducers were placed within each intake, with one transducer mounted to the trashrack for sampling guided fish (those guided into the JBS system) and the second mounted to the ESBS for sampling unguided fish (those who enter the turbines). Split-beam systems L, M, and N sampled at a rate of 27 pings per second, slow multiplexing one transducer at 88-second intervals, 10 times per hour. Split-beam systems P and Q sampled at a rate of 27 pings per second slow multiplexing one transducer at 118-second intervals, 10 times per hour.

Intake transducer mounts (to detect guided fish) were designed to fit onto the horizontal support members of the trashrack. This design allowed divers to secure the mount to the horizontal member of the trashrack from the downstream side of the trashracks. The upper-most trashrack section was removed prior to each dive to allow the diver access to the downstream side of the trashracks from the forebay. This strategy eliminated the need for more costly and time-consuming penetration dives to access the downstream side of the trashracks. The transducer and mount were sent down with the diver. Once the diver found the desired location for placing the mount, a hole was created in the horizontal member at an elevation of 248 ft. Finally, when the transducer mount was secure and squarely looking downstream, the transducer cable was tied to the downstream face of the trashrack as it was routed up to the surface. Keeping the transducer cables secured to the downstream face of the trashracks protected the transducer cables from debris and trash raking. This trashrack deployment was intended to sample guided fish and was aimed up and in front of the ESBS screen tip at 12° from the plane of the trashrack.

ESBS transducer mounts (to detect unguided fish) were attached to the top horizontal support beam at an ESBS-deployed elevation of 270 ft. The fact that the ESBS is so long (40 ft) made a trashrack deployment impractical for monitoring unguided fish. An uplooking beam on the trashrack would be blocked by the screen tip before it would be able to sample behind the screen. Likewise, the short distance to the tip did not allow for the development of a reasonable sample volume from the trashrack location. Thus, the ESBS transducers were aimed behind the ESBS screen, upstream 24° from vertical.

Taking advantage of emergency screen repair intervals and underwater rotators, transducers were re-aimed on two occasions. On June 10, underwater rotators were used to re-aim the guided transducer at 4B to 42° downstream from the plane of the trashrack, and the guided transducer at 4C was re-aimed to 28° downstream from the plane of the trashrack. The remainder of the transducers continued to sample as originally deployed (Figure 2.2). The purpose of these re-aimed deployments was two-fold. The first was simply to test our ability to sample fish in these areas. The second was, assuming we were able to successfully collect samples, to begin to examine fish distribution over a larger proportion of the intake environment with the hopes of improving the understanding of the intake as a passage route.

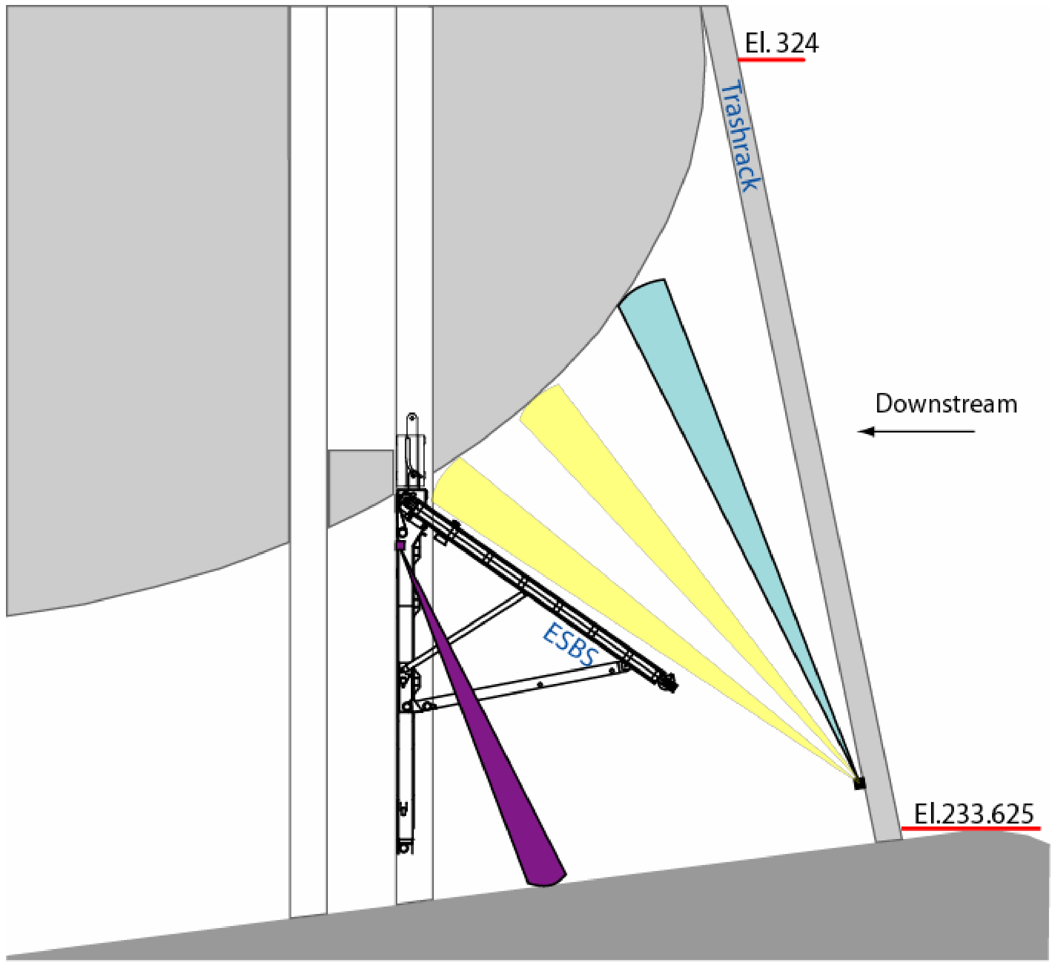


Figure 2.2. Transducer deployments and sampling volumes. Extended spatial sampling volumes (shown in yellow) when guided transducers at 4B and 4C were re-aimed downstream.

2.3.2 VBS Head Differential Sensors

Water levels on either side of the vertical barrier screens (VBS) were measured at various locations within the powerhouse. The difference between the two levels, or head differential, is low for clean screens and increases as debris accumulates on the screen. Head differential is currently used to determine acceptable screen occlusion criteria, beyond which the screens are pulled and washed clean. We deployed a total of 30 radar sensors along the powerhouse to continuously measure head differential in 15 gatewells: the A intake slot of every turbine unit plus intake slot B at turbine Unit 4. The A slots were chosen as representative because more flow goes into the A slot than into either the B or C slots. Slot 4B was also monitored because it was expected that the self-cleaning prototype traveling VBS in slot 4Awould not provide a good indication of debris in the other slots of that turbine unit.

Pairs of VEGA Pulsed Radar Level Transmitters were placed on each side of a VBS to simultaneously measure water elevations (Figure 2.3). Telemetry cables were routed strategically to avoid any interference with normal screen cleaning and other maintenance activities. Groups of six sensors were hard wired into NEMA-4 enclosures housing an Elpro Wireless I/O module, power supply, a battery backup system, and antenna attached to the gatewell safety railing at Units 2A, 4B, 7A, 10A, and 13A. (A radar wiring diagram for the dam is shown in Appendix A.) The NEMA 4 enclosure then transmitted the gatewell water level reading to an Elpro Wireless Gateway module stationed in the data collection trailer where a central computing station collected and archived all water level measurements. The data updated continuously in real time and hourly mean head values were broadcast every 4 hrs during the study via an automated email system.

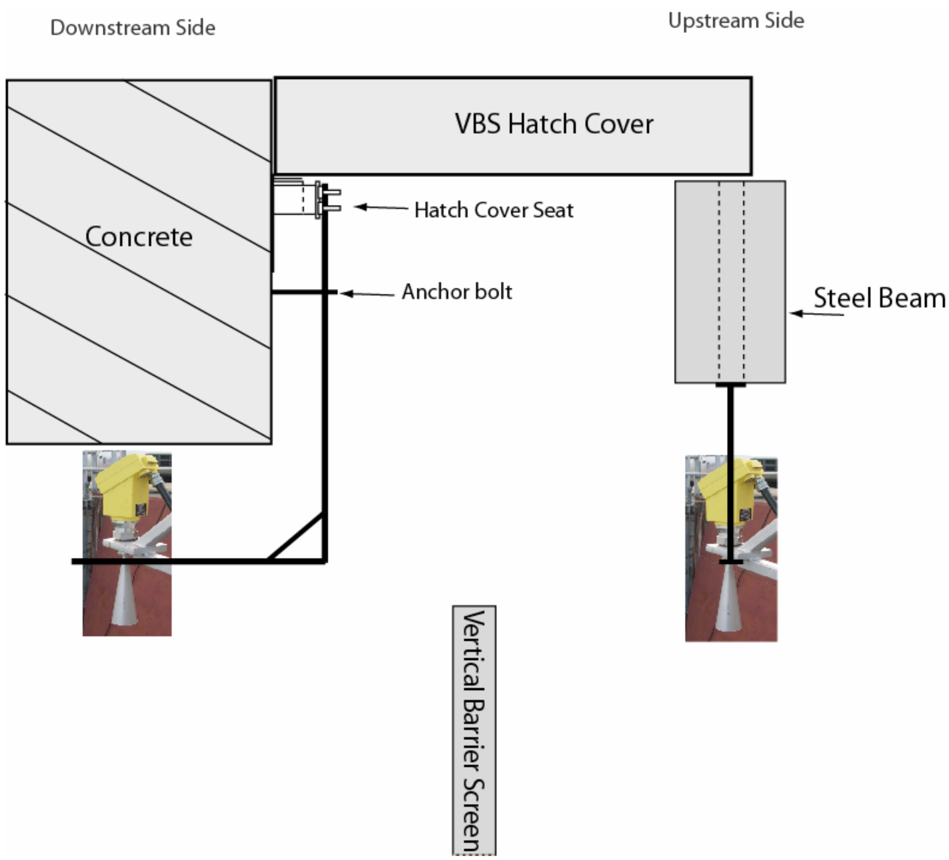


Figure 2.3. Cross-section view of gatewell and radar transmitters as deployed

2.4 Data Processing

This section describes the data processing steps used to produce the fish passage estimates. The output of sounders and transducers is in volts, not passage estimates. Understanding the data processing methods is important to understanding the nature, and quality, of the data.

2.4.1 Dam Operations

Dam operations data (e.g., discharge through each spill bay and turbine unit) were collected by the District on a 5-min basis (24/7) from data acquisition systems. This data is transferred and loaded into the fish passage database. During analysis, 5-minute dam operations were considered to determine whether a sample represented normal operating conditions. The entire season of dam operations data (4/9/04 – 8/31/04) is contained within Appendix D.

2.4.2 Autotracking

The data produced by both single- and split-beam transducers were processed with autotracking software, which was initially developed by the Portland District, but received major revision by Battelle in 2001. The autotracker identifies linear features in echograms. Linear traces that meet minimum criteria are saved as tracks. These criteria were based on fields contained in the track statistics output by the autotracker. Additional filters eliminate tracks that do not match the criteria established for fish committed to passing. These post-tracking filters were developed to eliminate tracks having characteristics inconsistent with a smolt-sized fish committed to passing the dam by the monitored route. The filtered tracks estimate the number of fish passing the sample volume covered by the effective beam of a transducer.

2.4.3 Detectability and Effective Beam Widths

Split-beam data of smolt movements (e.g., trajectory and speed distributions) through the beam were used as an input to a detectability model. The detectability model also originated from the Portland District. The detectability model simulates individual echoes for fish passing through a transducer beam. The fish movement and echo characteristics are simulated to match those measured in split-beam transducers. A simulated fish is tabulated as detected if enough echoes in a series exceed a minimum number of consecutive echoes and echo strength. The proportion of fish detected in the beam is used to compute an effective beam width. The effective beam width more accurately quantifies how well a beam is able to detect fish than the nominal beam width. Effective beam widths are computed for each meter because track characteristics such as angle and speed can change with distance from the transducer. Appendix C contains plots that illustrate effective beam widths across season, diel period, deployment type, and range.

2.4.4 Spatial and Temporal Expansion

Under the acoustic screen model, the number of tracks within the beam is expanded spatially and temporally to estimate total passage through a single passage route. Detected fish are adjusted for detectability and expanded for space and time not sampled. Hourly passage was estimated by expanding the fish that passed through the beam for the cross-sectional area sampled (Equation 1) and sampled fraction per hour (Equation 2). All remaining analyses and response variables derive from these fundamental data. Appendix D is a comma-delimited matrix of the raw hourly passage data that is provided on the CD included with this report.

$$W_{ij} = \frac{I_j}{2R_i \tan\left(\frac{\theta_j}{2}\right)} \quad (1)$$

where,

W_{ij} is the ith weighted fish at the jth location

I_j is the width (m) at the jth location

R_i is the midrange (m) of the ith fish

θ_j is the effective beam width of the transducer at the jth location

$$X_{jh} = \left(\frac{K}{k}\right)\sum_{i=1}^{n_{jh}} W_{ijh} \quad (2)$$

where,

X_{jh} is the fish passage at the jth location in the hth hour

W_{ijh} is the ith weighted fish at the jth location in the hth hour

n_{jh} is the number of fish at the jth location in the hth hour

K is the total number of sampling intervals in the hour

k is the number of intervals sampled in the hour.

2.5 Data Analysis

Data analysis consisted of estimating fish passage and integrating that with flow and other conditions for specific time periods and passage routes. These general analysis results were then summarized to address specific questions of interest. Care has been taken to account for both spatial and temporal variation in the sampling. The variances were calculated and carried through to the final estimates.

2.5.1 Organization

The analysis is divided into sections based on the scope of inference for each section. Seasonal fish passage estimates are presented for each season in the first section. Confidence intervals in this section are for estimation to this specific set of days based on within-day sampling variance (narrower scope of inference) due to not sampling every minute (temporal) and at every location (spatial). Treatment effects are dealt with in the following sections where between-experimental-unit variability needs to be included in order to assess treatment effects (broader scope of inference). In this study, the experimental unit is the pair of consecutive days. A series of ANOVAs was run on the various fish passage metrics such as fish passage efficiency, spill passage efficiency, and spill passage effectiveness. Graphical presentations were used to illustrate treatment effects on metrics for smaller time scales, such as trends among days or blocks.

2.5.2 Performance Measure

The following fish passage metric term is used extensively in this report, an understanding of the definition presented here is critical for interpretation of the results of the study. Fish guidance efficiency (FGE) is the proportion of fish entering a turbine unit that are guided into the juvenile bypass system by the intake screens (Equation 3). It is intended to be a measure of screen performance.

$$FGE \equiv \frac{\mathrm{X}_{guided}}{\mathrm{X}_{guided} + \mathrm{X}_{unguided}} \tag{3}$$

where X is the fish passage estimate for the indicated route.

3.0 Results and Discussion

The presentation of results begins with environmental conditions of the study, such as river flow and run timing by species (Section 3.1). Next, seasonal (spring and summer) estimates of fish passage are described (Section 3.2). This includes seasonal and daily trends of fish passage, but without reference to spill treatments. Section 3.3 deals exclusively with the analysis of the spill treatments. Fish trajectories and vertical distributions are described in Section 3.4 and VBS head differential dates are provided in Section 3.5.

3.1 Study Conditions

The environmental and dam operational characteristics during the 2004 study are described in this section. These data set the stage and context for the fish passage results that follow. Flows were somewhat below average with total outflow at 77% of normal over the study period.

3.1.1 River Discharge, Spill, and Temperature

River discharge during the study period averaged 200 kcfs, which was 77% of the 10-yr average. The minimum discharge was 135 kcfs on July 11 near the end of the study. The maximum discharge was 280 kcfs on June 5. Spring flows had below-normal average discharge (76% of the 10-yr average). Summer flows were 79% of the 10-yr average and exhibited the expected decreasing trend at the end of the season.

During the study, the powerhouse was running at normal load, which included operation up to capacity throughout much of the spring and early summer. This can be interpreted from the graph by the nearly constant difference between outflow and spill, and also the paired fluctuations between outflow and spill. Spill averaged 59 kcfs (58% of the 10-yr average). Spring spill levels were below normal at 74 kcfs (72% of the 10-yr average). Summer spill levels were well below normal at 46 kcfs (46% of the 10-yr average) and reached no spill for 18 days of the summer season. River temperature increased steadily over the study period, starting at 10.5°C, ending at about 20.9°C, and averaging 14.9°C. River temperature over the study period was 107% of the 10-yr average (Figure 3.1). Mean forebay elevation was 338.3 ft msl and varied 2.4 ft from 337.4 to 339.8 ft msl.

Figure 3.1. Daily river discharge, spill, and temperature for 2004 (solid lines) and the 10-yr average (dashed lines). Data from DART.

3.1.2 Species Composition and Run Timing

The passage monitoring period extended from April 15 to July 15. The transition from spring to summer occurred May 28 based on when the dominant species in the Smolt Monitoring Program at McNary Dam changed from yearling Chinook salmon to subyearling Chinook salmon (*Oncorhynchus tschawytscha*). In the middle of that transition period, May 21 to June 6, sockeye salmon (O. *nerka*) comprised 26% of the fish sampled at the juvenile fish facility, yearling Chinook salmon 31%, and subyearling Chinook salmon 32%. Steelhead (O. *mykiss*) and coho salmon (O. *kisutch*) comprised the remainder. For statistical tests, the spring period was April 15 to May 27 and the summer period was May 28 to July 15.

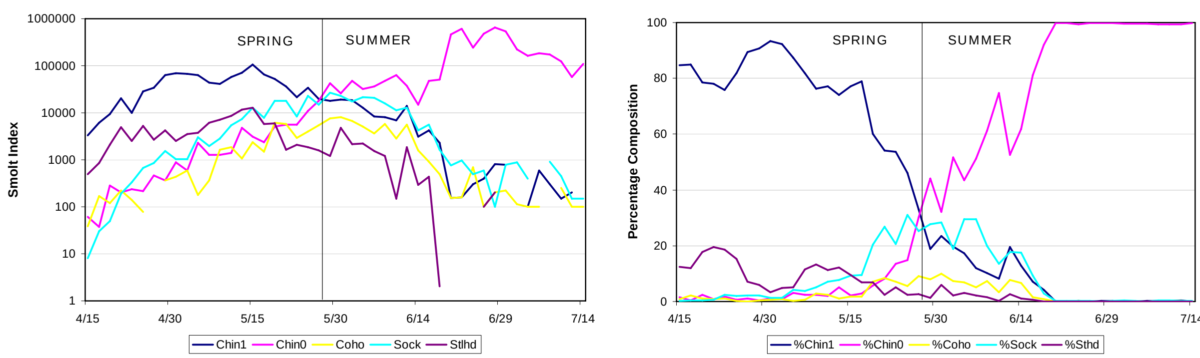


Figure 3.2. Species composition data from the McNary Dam Smolt Monitoring Facility. Data from DART.

3.1.3 Turbine Priorities

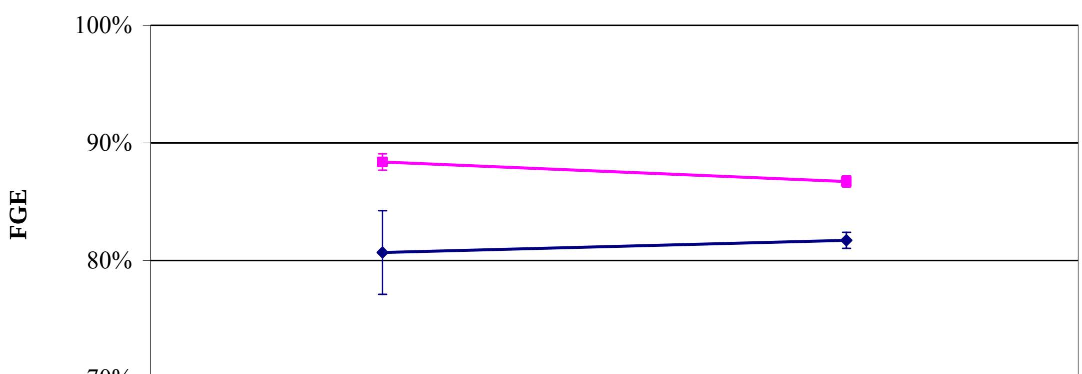
The 2004 Fish Passage Plan states that during juvenile fish facility (juvenile bypass system) operation, Units 1 through 4 will be operated first to provide positive downstream flows at the outfall. During summer, turbine operating priority may change to north loading if warm water temperatures (along the shoreline) indicate problems for juvenile salmonids. In this case the powerhouse is operated from 14 to 1 in order to maintain cooler water through the JBS. During our turbine loading tests, the tested units were operated continuously. The project made the switch to summer temperature-driven operations on July 22, after the end of this study.

3.2 Seasonal Fish Passage

This section describes fish passage at the dam over the entire sampling season. The intent is to illustrate the influence that varying river conditions, dam operations, and species composition may have, independent of any turbine loading treatments. Fish passage metrics were based on actual dam operations. All days are included, without regard to whether turbine treatment conditions were met. The statistical analysis of the treatment blocks is addressed in the next section. One caveat for the seasonal analyses is that the limited spatial extent of the sampled set of turbine units (we sampled only 3 of the 14 turbines) may not provide a result that is representative of the powerhouse as a whole.

3.2.1 FGE

FGE was calculated for each combination of season and diel period. Seasonal FGE estimates are simple averages over all of the days sampled (regardless of treatment or block). Fish guidance efficiency (FGE) at Units 2-4 as a group was 84.4%. Nighttime FGE was higher than daytime estimates. This is the reverse of findings at other projects and may be an artifact of the small proportion of the powerhouse that it represents and/or the lack of spill in the summer (Figure 3.3).



	Spring	Summer
Day	80.7%	81.7%
Night	88.4%	86.7%

Figure 3.3. Seasonal FGE. Error bars are 95% confidence intervals based on measurement uncertainty (Equation A29, Appendix A).

3.2.2 Daily Trend

The daily trend of FGE across the entire sampling season is shown in Figure 3.4. Treatments in effect for each day are shown to avoid the need for duplicating these graphics in the treatment effects section and to make the reader aware of their potential influence. FGE did not show the expected decline in summer until the end of the season. Estimates in the spring and during the treatments did not show any potential bias due to the timing of the treatments.

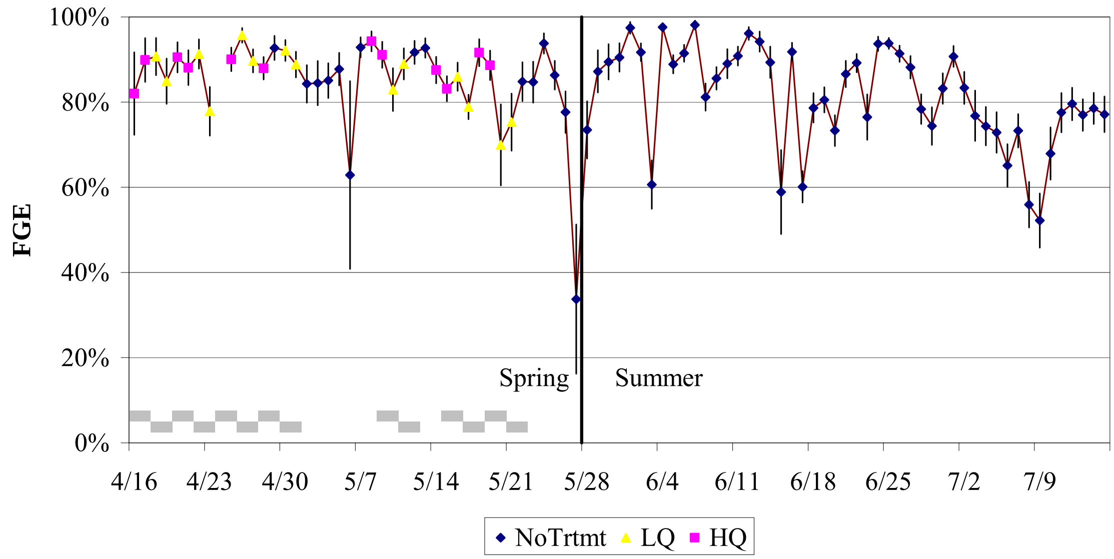
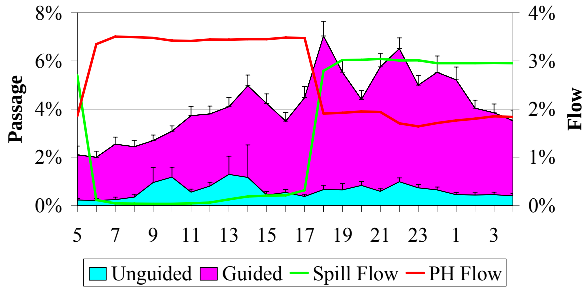


Figure 3.4. Daily estimates of FGE. Error bars are 95% confidence intervals based on measurement uncertainty (Equation A29, Appendix A).

3.2.3 Seasonal Diel Intake Passage

Passage trends over the 24-hour day showed both an increase in passage during the evening, and also better guidance of fish that passed in the evening hours. In the summer, with minimal spill levels, passage had a bimodal distribution with peaks at 1000 and 1700h (Figure 3.5). As shown in Figure 3.3, estimated FGE was higher during nighttime for both spring and summer. The peak passage in spring occurred in early evening, in spite of decreasing flow through the powerhouse at that time. A similar, but less pronounced peak was also evident in summer. This was consistent with passage trends in previous studies that demonstrated a general increase in fish passage in the early evening.



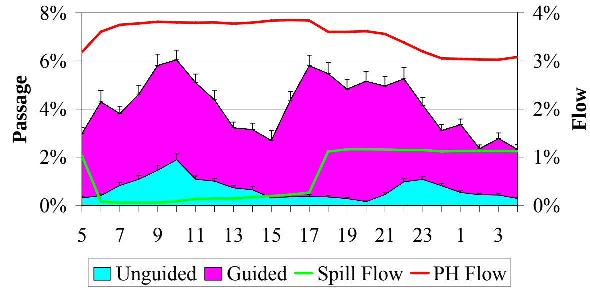


Figure 3.5. Diel trends of passage and flow for spring (left) and summer (right). Error bars are 95% confidence intervals based on measurement uncertainty (Equation A29, Appendix A).

3.2.4 Continuous Spill Curve vs. FGE

There was no obvious trend of FGE with spill at the three units we tested (Figure 3.6). We might expect to see a trend with FGE had the entire powerhouse been sampled. For example, previous studies showed a negative trend for FGE with increasing spill at both Ice Harbor (Moursund et al. 2004) and at John Day Dams (Moursund et al. 2003b) in 2003 and 2002, respectively. In these cases, a decrease in FGE occurred as spill proportion increased, presumably due to the spillway selectively passing surface-oriented fish at higher rates than those lower in the water column. The result would be fewer fish available to be guided at the powerhouse. In the current study, however, only 3 units of 14 were sampled and all were at some distance from the spillway. This finding does suggest that spill levels do not affect FGE at this distance (10 turbine units) from the spillway.

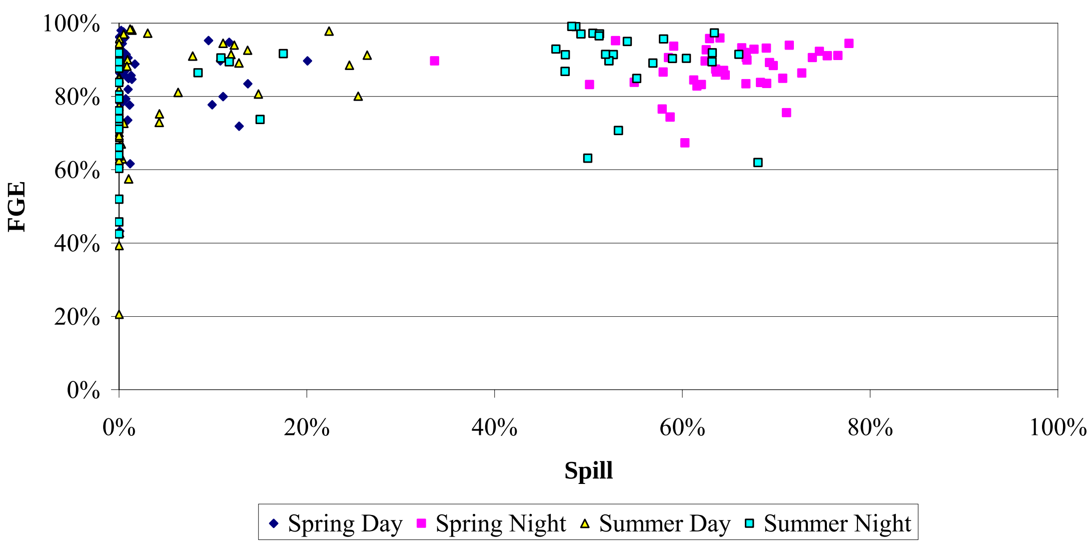


Figure 3.6. FGE versus percent spill

3.2.5 Seasonal Vertical Distributions

The vertical distributions are shown in Figure 3.7 by deployment, guided and unguided. In the guided deployment, a decrease in elevation of the fish population was evident in the summer compared to spring, although this trend did not carry through to the unguided deployment (Figure 3.7). Evident is the tendency for fish in the guided sample volume to travel near the intake ceiling and for fish in the unguided sample volume to travel lower after passing underneath the ESBS. The unguided deployment data showed no evidence of rapid redistribution of fish after they pass under the screen.

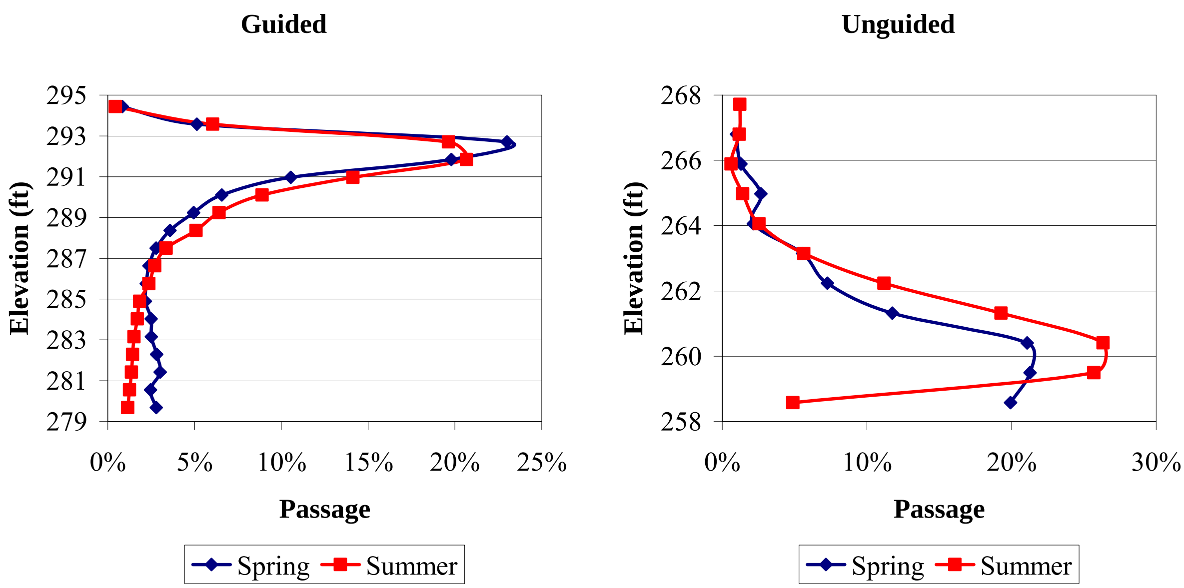


Figure 3.7. Vertical distributions by season

3.3 Turbine Loading Treatment Effects

The statistical analysis of the treatment blocks is addressed in this section. As stated previously, the early termination of treatment operations over the course of the study reduced the data available for analysis. (For the first 3.5 treatment blocks, between April 16 and May 1, Turbine Units 2, 3, and 4 were operated at the high and low discharge treatments; after May 2, only Turbine Unit 3 was operated at the high discharge treatment.) Just enough data was collected to run a statistical comparison. Those results are presented in this section.

3.3.1 Dam Operations by Block

Dam operations were reasonably consistent within the treatment periods. Generally both the low discharge (LQ) and high discharge (HQ) conditions were nominally met at about 12 kcfs and 16 kcfs, respectively. Because of this, no blocks were censored due to dam operations (Figure 3.8 to Figure 3.11). Block 3, however, was not included in the analysis due to lack of data. A large portion of one treatment condition within that block was lost due to power outages at the equipment shed; therefore, that block was censored in all of the remaining analyses. Blocks 5, 6, and 8 are not shown because they had no turbine discharge treatment periods (Table 2.1).

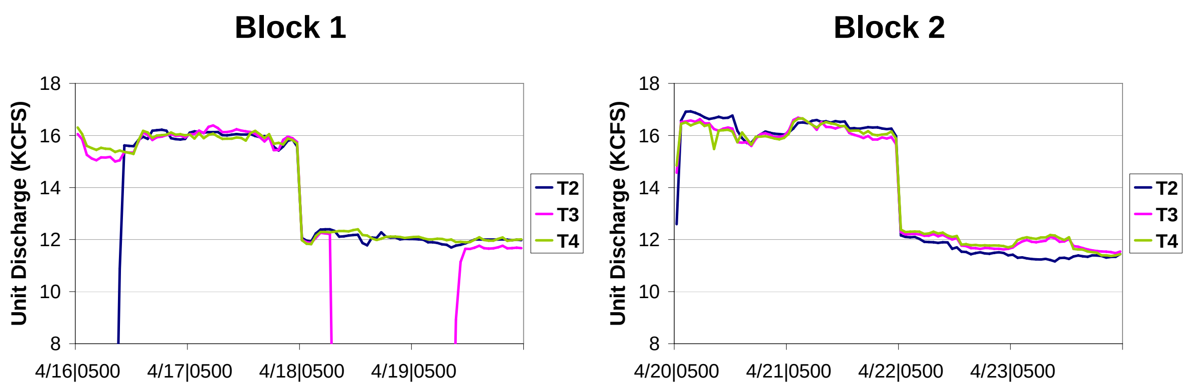


Figure 3.8. Block 1 and 2 turbine operations for Units 2-4

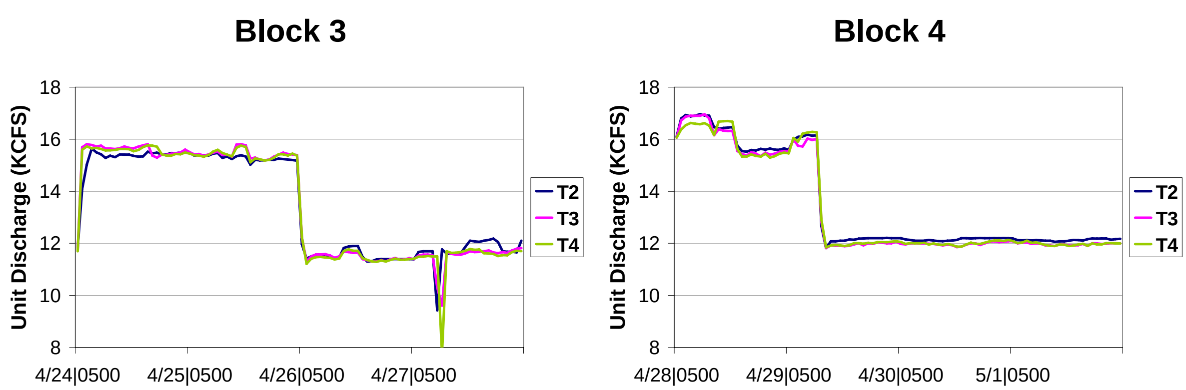


Figure 3.9. Block 3 and 4 turbine operations for Units 2-4

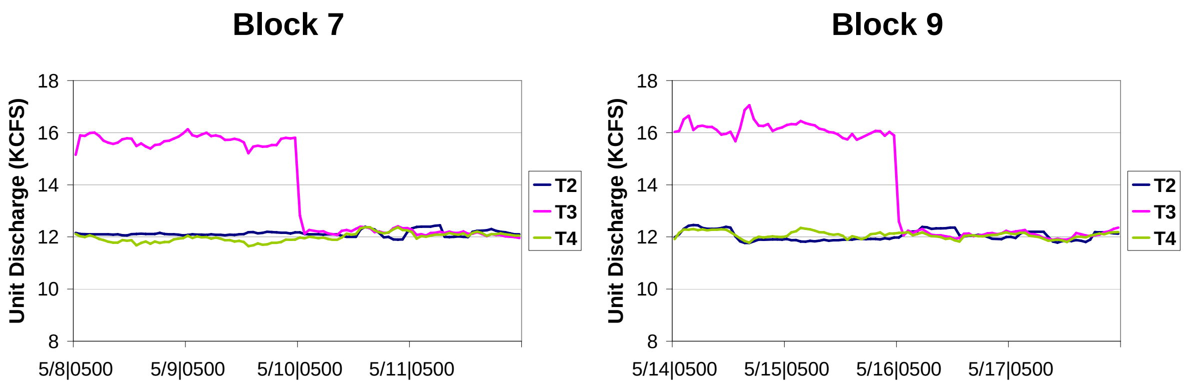


Figure 3.10. Block 7 and 9 turbine operations for Units 2-4 (Note in blocks 7 and 9 only Turbine Unit 3 had high discharge.)

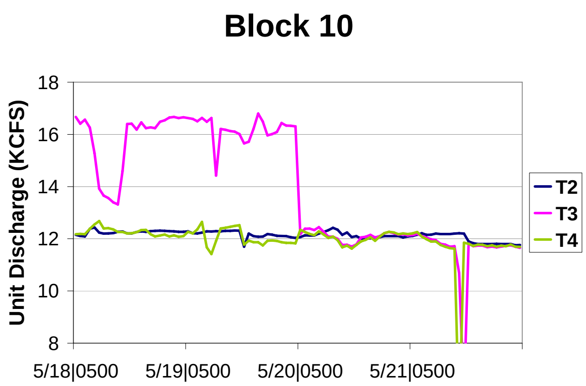


Figure 3.11. Block 10 turbine operations for Units 2-4 (Note in block 10 only Turbine Unit 3 had high discharge.)

3.3.2 Analysis of Variance

A two-way analysis of variance (ANOVA) was performed on FGE for both spring and summer. FGE values were arcsine transformed prior to analysis to stabilize the variance, consistent with previous studies of FGE. Because Units 2 and 4 were operated at the high turbine loading treatment level only during the first blocks (1 through 4), two ANOVAs were completed. The first included data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. The second included data from Unit 3 only. The ANOVA results were essentially the same regardless of which units were included. The estimates of FGE by block did not show a consistent trend among treatments over the course of the study (Figure 3.12). FGE did not differ significantly between turbine loading levels at an α-level of 0.05 (Figure 3.13 and Table 3.1). In fact, the trend was a slightly higher FGE during the HQ treatment, although the difference was not statistically significant.

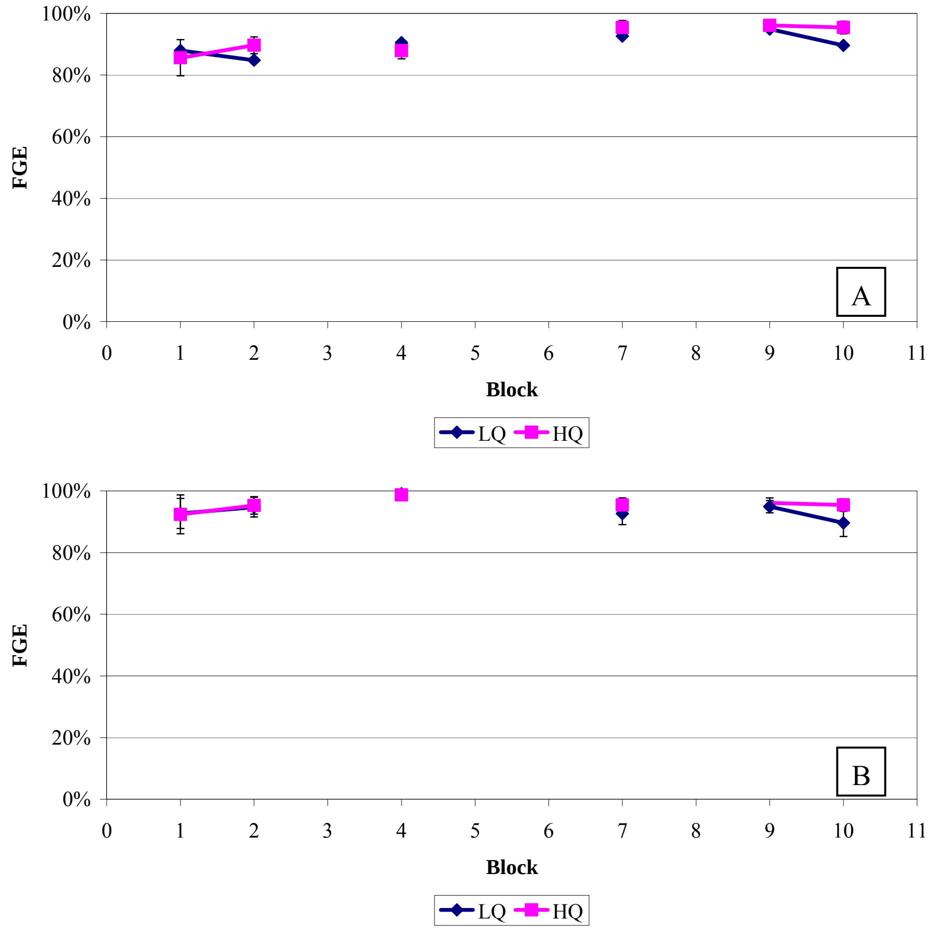


Figure 3.12. Mean FGE by block. Blocks 5, 6, and 8 did not have treatments. Block 3 had missing data and was not included as part of the treatment analysis. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on measurement uncertainty.

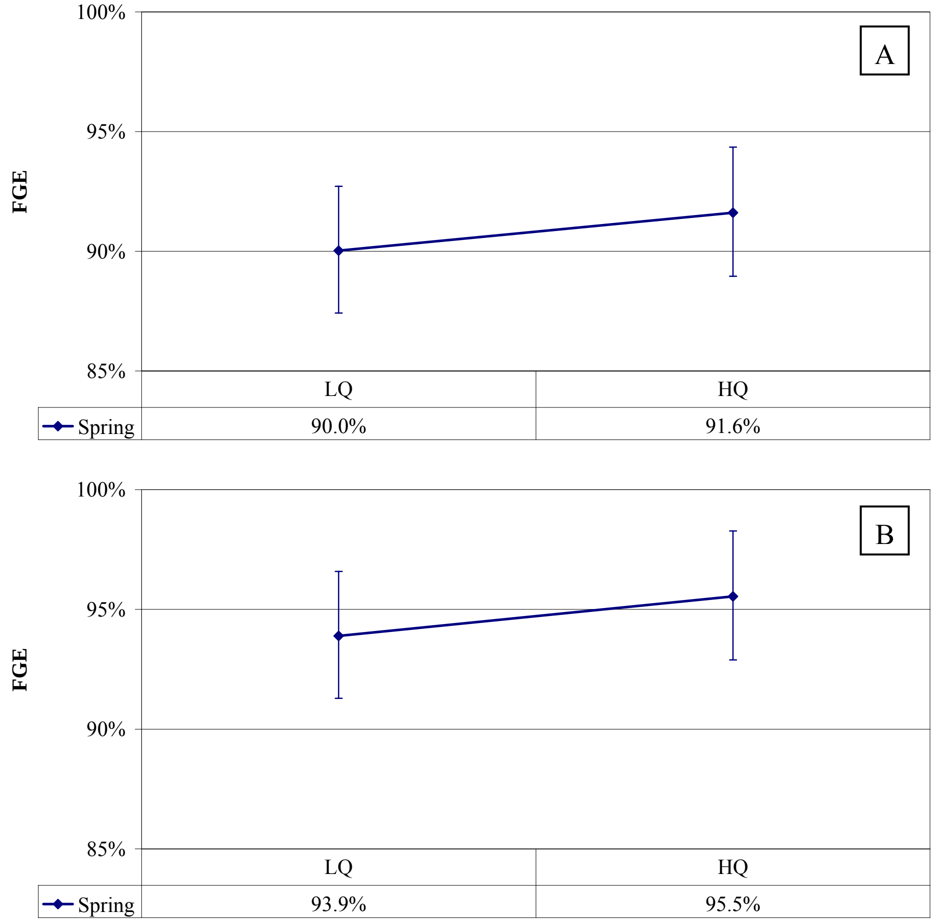


Figure 3.13. Mean FGE by treatment. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on ANOVA MSE.

Table 3.1. FGE ANOVA Table including Units 2, 3, and 4 for blocks 1, 2, and 4 and Unit 3 for blocks 7, 9, and 10

	DF	SS	MS	F	P
Units 2,3, and 4[1]					
Block	5	0.016	0.003	4.104	0.074
Treatment	1	0.001	0.001	1.163	0.330
Error	5	0.004	0.001		
Unit 3 only					
Block	5	0.006	0.001	4.020	0.077
Treatment	1	0.001	0.001	2.830	0.153
Error	5	0.001	0.000		

[1]Units 2 and 4 were operated at HQ discharge level only during blocks 1, 2, and 4.

3.3.3 Vertical Distributions

Although differences in FGE among treatments were not found to differ significantly, it is still useful to examine the vertical distribution of fish as they pass through these regions for a number of reasons. Analyses include visualizing the entire data set from which the single FGE metric is derived. For example, we can see that FGE in this case is relatively insensitive to the range cutoff for guided fish, a value which is estimated indirectly from the trajectories of fish and studies of behavior at the screen face. The abundance values that are represented as colors in the contour plot below show the similarity of the distributions, with most of the fish very near the intake ceiling in the guided sampling location. Fish passing underneath the screen are seen very distinctly as a group passing under the elevation of the screen tip (Figure 3.14). The fish velocity vectors have been left on this plot to avoid duplication of the graph and will be discussed in Section 3.3.4. The line graphs in Figure 3.15 describe the proportions of the fish by elevation during the treatments and are another way to visualize trends in abundance by elevation. Again, vertical distributions during the two treatments appear similar.

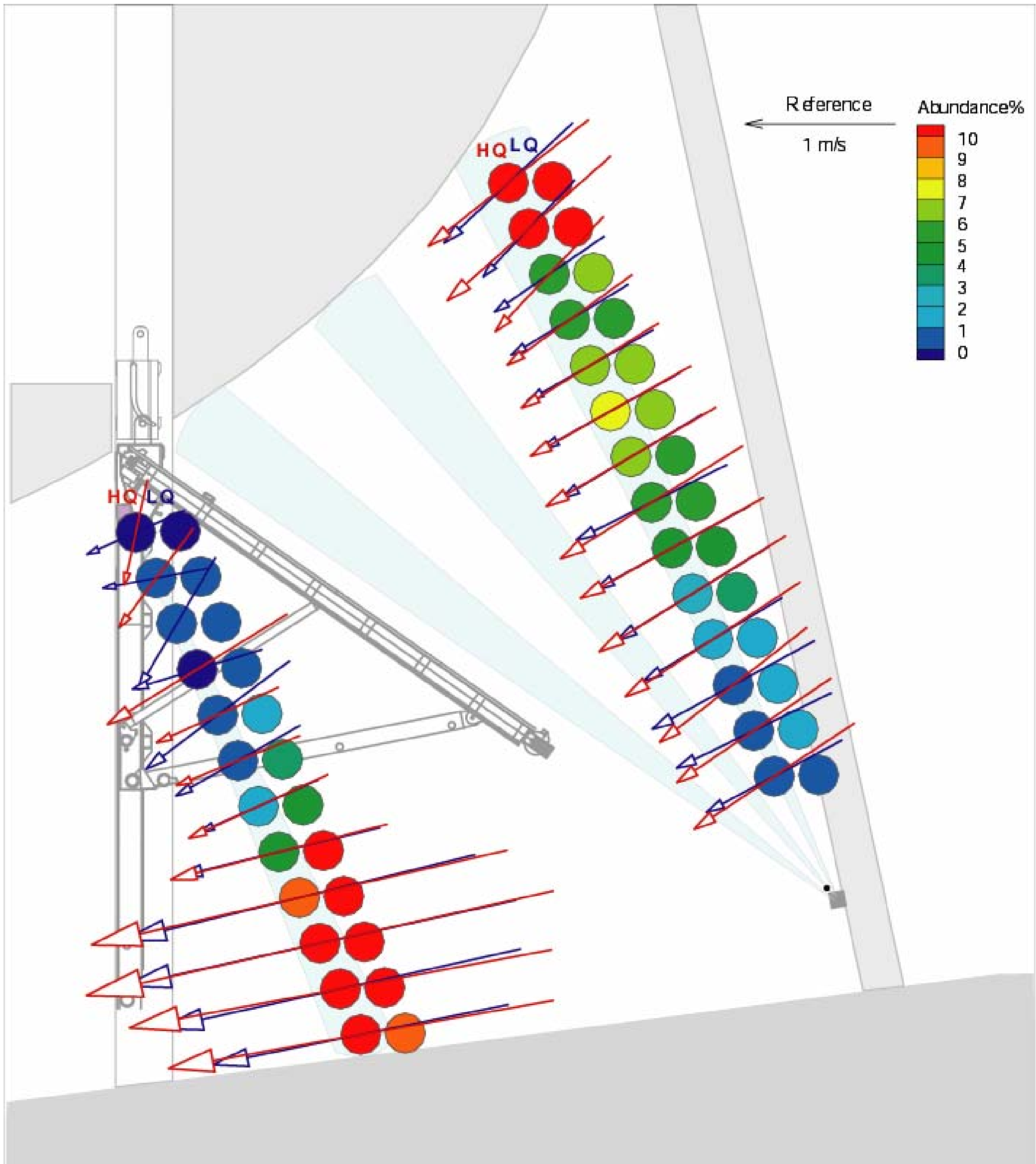


Figure 3.14. Contoured scatter plot of vertical distributions by treatment

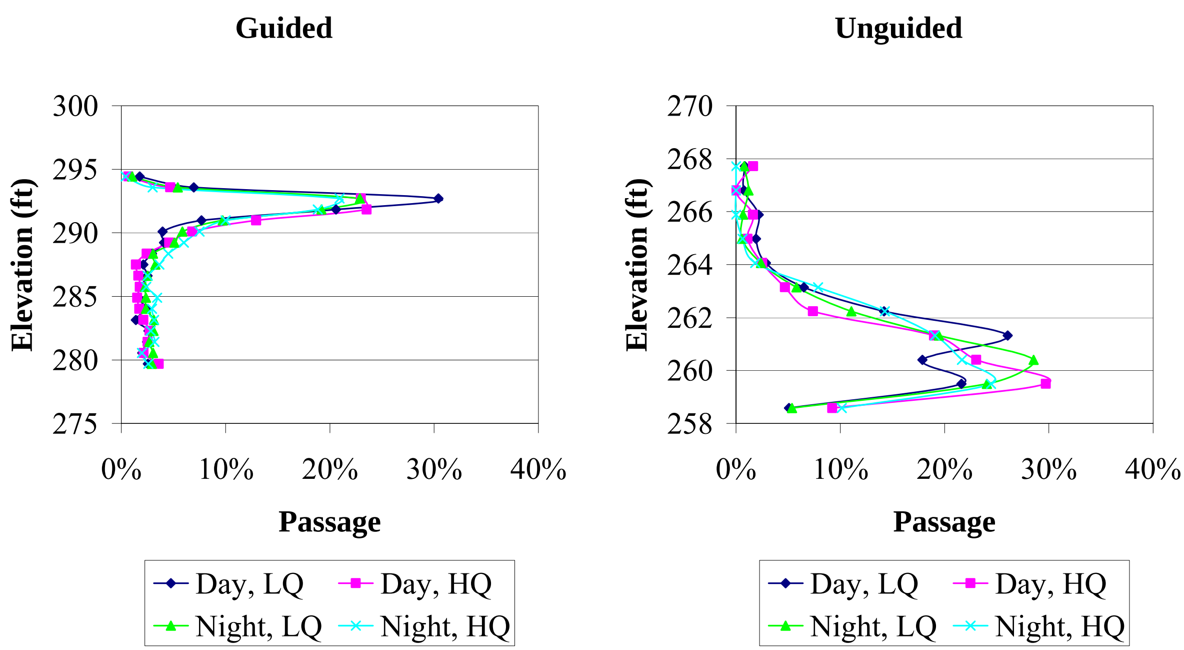


Figure 3.15. Vertical distributions by treatment (LQ/HQ) and diel period (Day/Night)

3.3.4 Trajectory Analysis

The extensive use of split-beam transducers in this study allowed for extension of the data beyond the simple range-abundance metrics. The potential benefits of this additional data are two-fold. One, these data increase our knowledge of fish behavior during intake passage. Two, these data may be more sensitive statistically to change than the FGE estimate. In particular, early results from the concurrent fish injury study suggested that fish may be injured (descaled) at higher rates during the abbreviated treatment schedule. In fact, it was the concern over that possibility that curtailed the study test conditions prematurely. Part of the impetus for these additional hydroacoustic analyses was to evaluate conditions that fish might experience in the intake under the treatment conditions.

Differences in plunge and speed were compared among treatments using ANOVA. Because Units 2 and 4 were operated at the high turbine loading treatment level only during the first blocks (1 through 4), two ANOVAs were completed. The first included data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. The second included data from Unit 3 only. The plunge angle (where plunge is the angle down from horizontal in the cross-section plane of an intake) for guided fish did not differ significantly among treatments with p-values of 0.19 and 0.60, for the first and second ANOVAs, respectively (Figure 3.16 and 3.17 and Table 3.2). The plunge angle for unguided fish (Figure 3.18 and 3.19 and Table 3.3) did not differ significantly among treatments with p-values of 0.46 and 0.26 for the first and second ANOVAs, respectively. Median velocities of guided fish, however differed significantly between treatments with p-values of <0.01 (Figure 3.20 and 3.21 and Table 3.4). Median velocities of unguided fish differed significantly ($p=0.04$) for the ANOVA including only Unit 3, but was only marginally significant ($p=0.09$) for the ANOVA including Units 2, 3, and 4 (Figure 3.22 and 3.23

and Table 3.5). Median velocities of fish were higher at all beam ranges under the HQ treatment (Figure 3.24). While this may be intuitive since the water velocities increased during the HQ treatment, it is nonetheless important to know that fish velocities respond in this manner. All of these changes in trajectories over the two treatments are summarized in Figure 3.25.

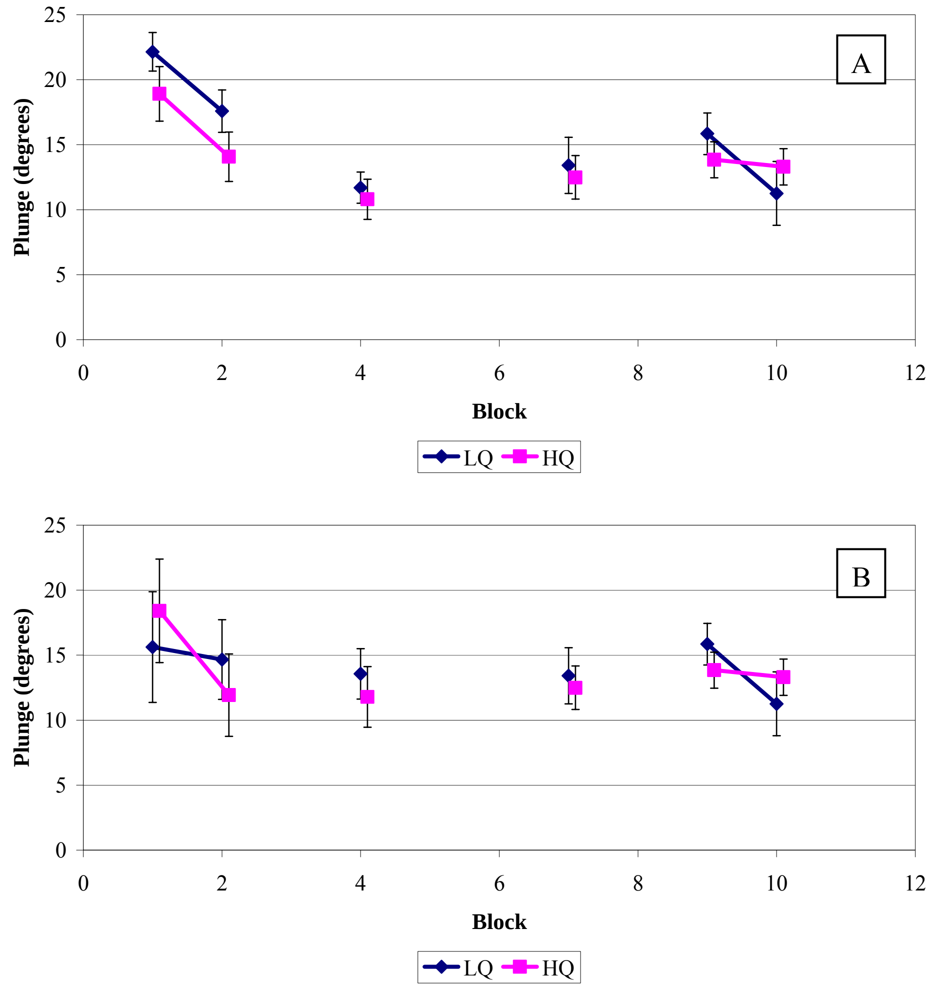


Figure 3.16. Mean plunge for guided fish by block. Blocks 5, 6, and 8 did not have treatments. Block 3 had missing data and was not included as part of the treatment analysis. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on measurement uncertainty..

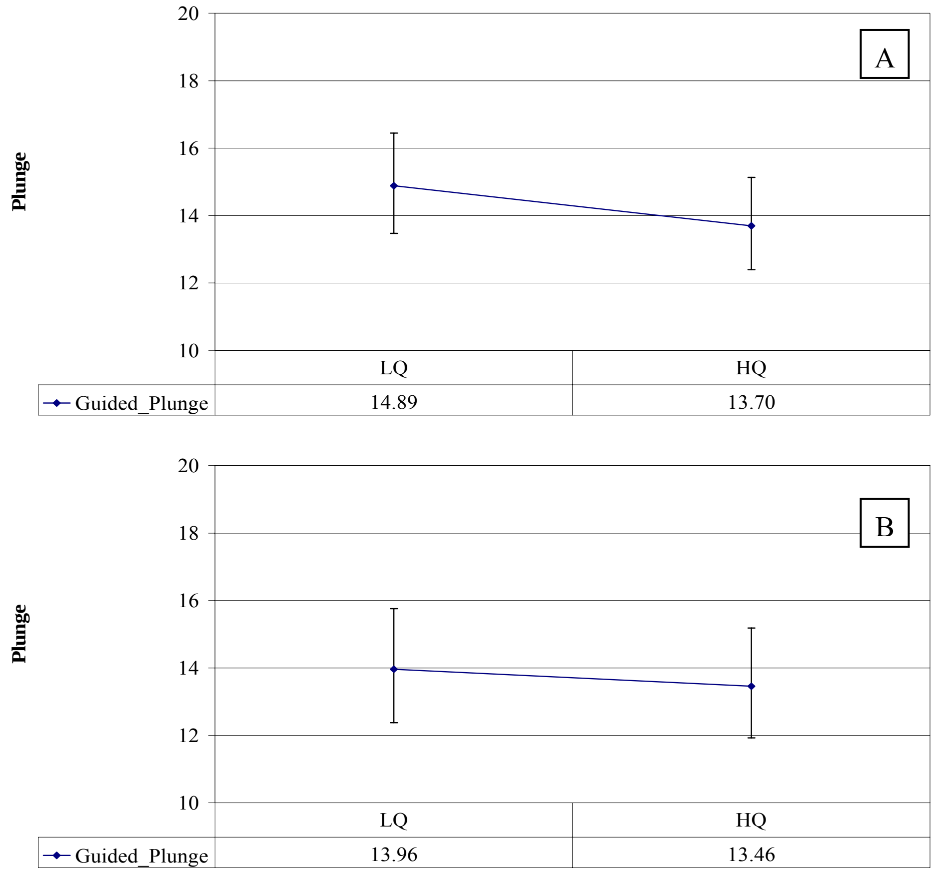
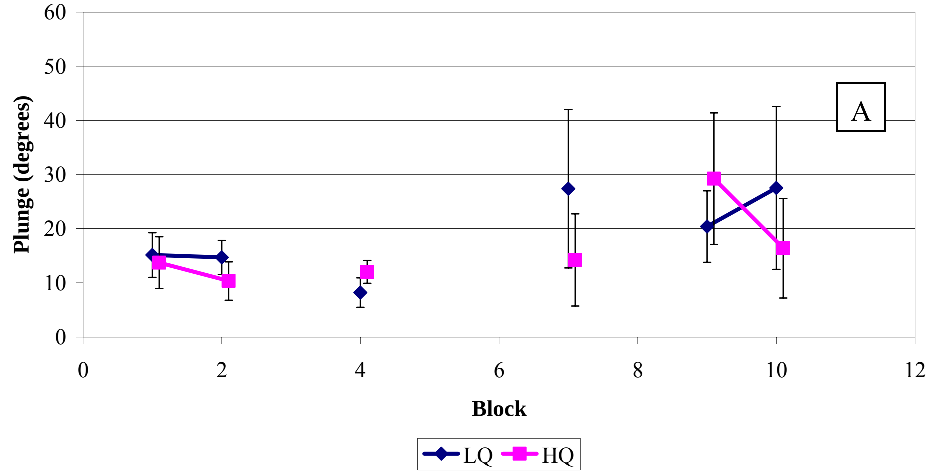


Figure 3.17. Mean plunge for guided fish by treatment. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on ANOVA MSE.

Table 3.2. Guided plunge ANOVA table

	DF	SS	MS	F	P
Units 2,3, and 4[1]					
Intercept	1	84.830	84.830	9399.247	0.000
Block	5	0.462	0.092	10.247	0.012
NominalTRT	1	0.021	0.021	2.307	0.189
Error	5	0.045	0.009		
Unit 3 only					
Intercept	1	82.243	82.243	6215.704	0.000
Block	5	0.151	0.030	2.279	0.193
NominalTRT	1	0.004	0.004	0.313	0.600
Error	5	0.066	0.013		

[1]Units 2 and 4 were operated at HQ discharge level only during blocks 1, 2, and 4. Blocks 7, 9, and 10 include only Unit 3.



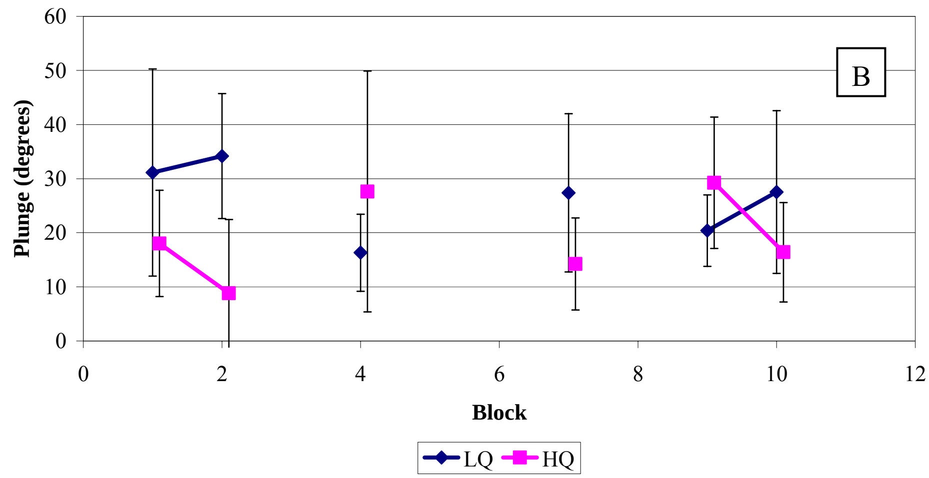


Figure 3.18. Mean plunge for unguided fish by block. Blocks 5, 6, and 8 did not have treatments. Block 3 had missing data and was not included as part of the treatment analysis. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on measurement uncertainty..

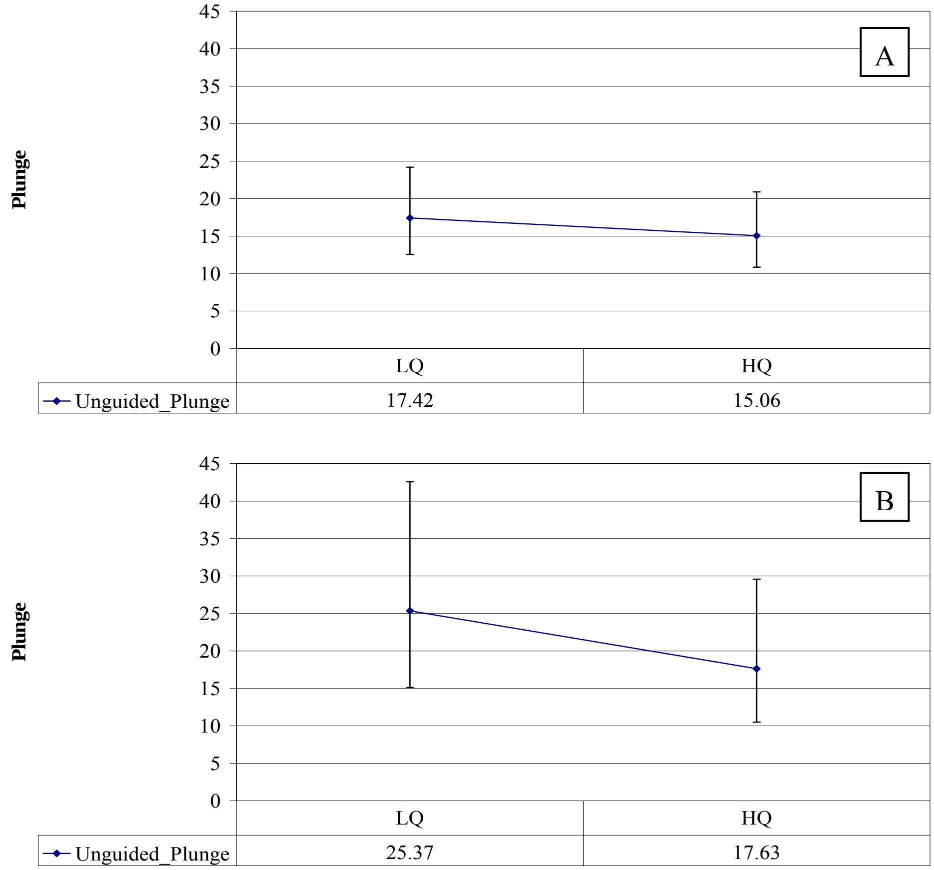


Figure 3.19. Mean plunge for unguided fish by treatment. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on ANOVA MSE.

Table 3.3. Unguided plunge ANOVA table

	DF	SS	MS	F	P
Units 2,3, and 4[1]					
Intercept	1	93.065	93.065	953.121	0.000
Block	5	1.220	0.244	2.499	0.169
NominalTRT	1	0.064	0.064	0.652	0.456
Error	5	0.488	0.098		
Unit 3 only					
Intercept	1	111.736	111.736	458.389	0.000
Block	5	0.154	0.031	0.126	0.980
NominalTRT	1	0.397	0.397	1.630	0.258
Error	5	1.219	0.244		

[1]Units 2 and 4 were operated at HQ discharge level only during blocks 1, 2, and 4. Blocks 7, 9, and 10 include only Unit 3.

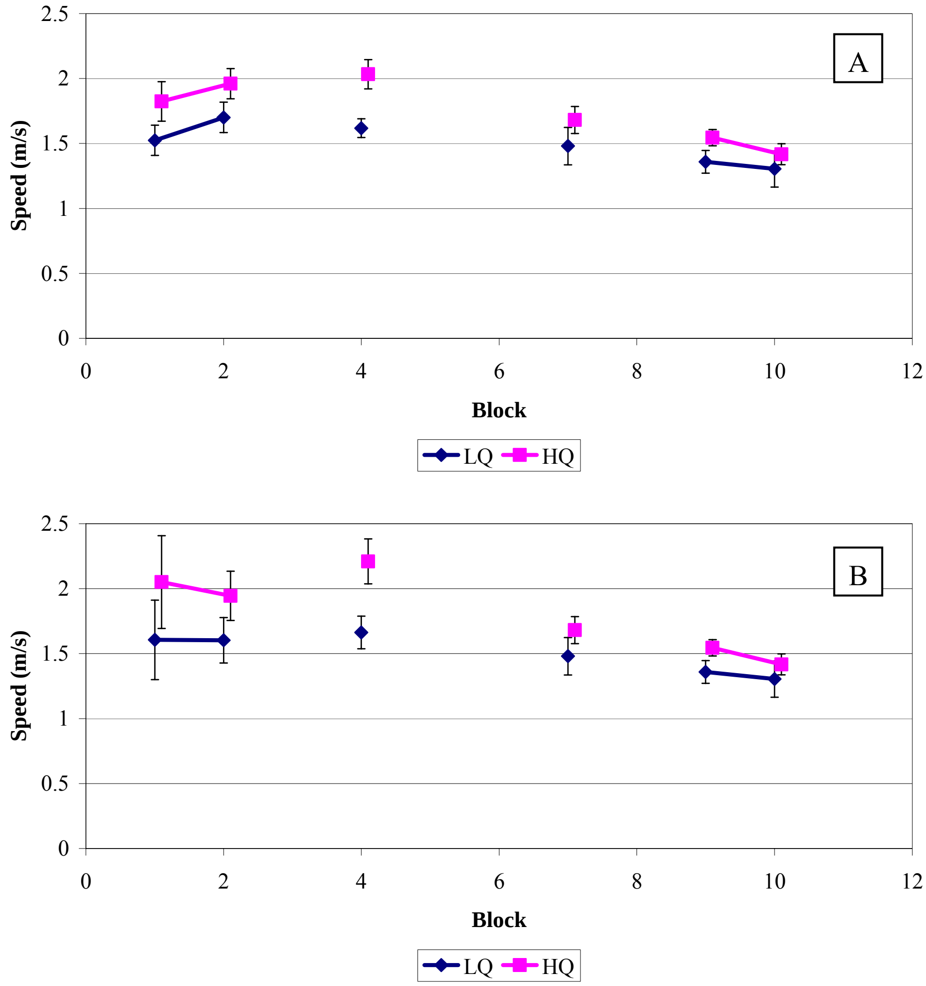


Figure 3.20. Mean speed for guided fish by block. Blocks 5, 6, and 8 did not have treatments. Block 3 had missing data and was not included as part of the treatment analysis. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on measurement uncertainty..

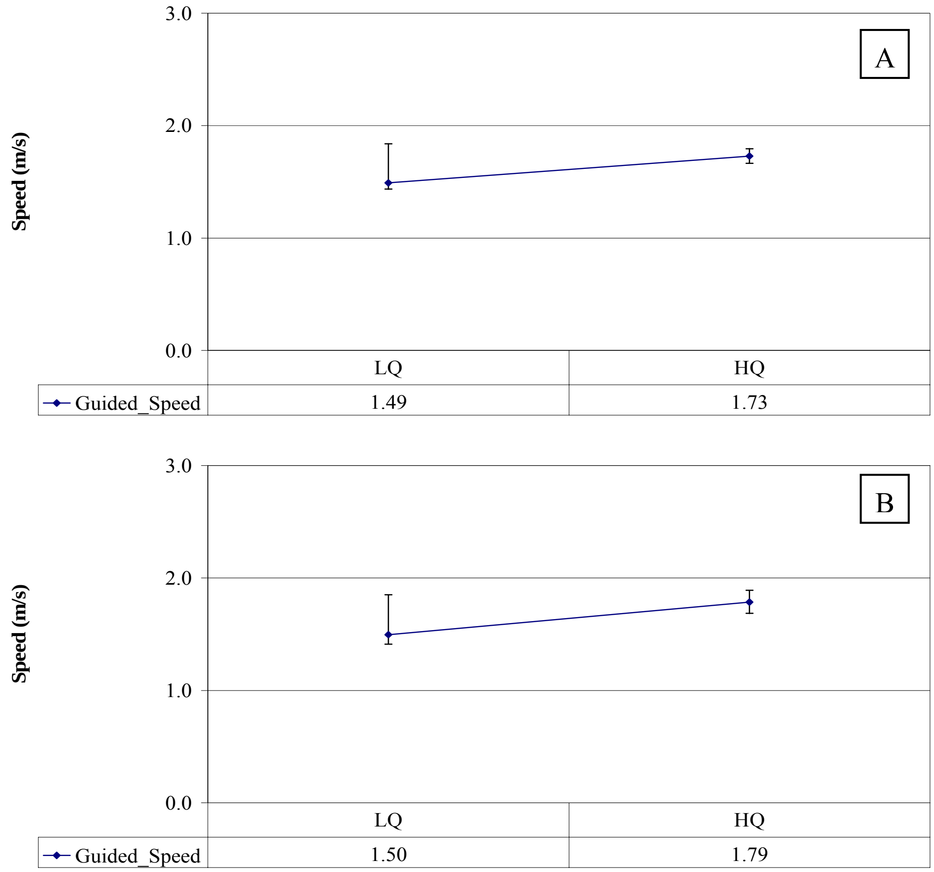


Figure 3.21. Mean speed for guided fish by treatment. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on ANOVA MSE.

Table 3.4. Guided speed ANOVA table

	DF	SS	MS	F	P
Units 2,3, and 4[1]					
Block	5	0.143	0.029	22.901	0.002
NominalTRT	1	0.066	0.066	52.919	0.001
Error	5	0.006	0.001		
Unit 3 only					
Block	5	0.184	0.037	12.359	0.008
NominalTRT	1	0.094	0.094	31.462	0.002
Error	5	0.015	0.003		

[1]Units 2 and 4 were operated at HQ discharge level only during blocks 1, 2, and 4. Blocks 7, 9, and 10 include only Unit 3.

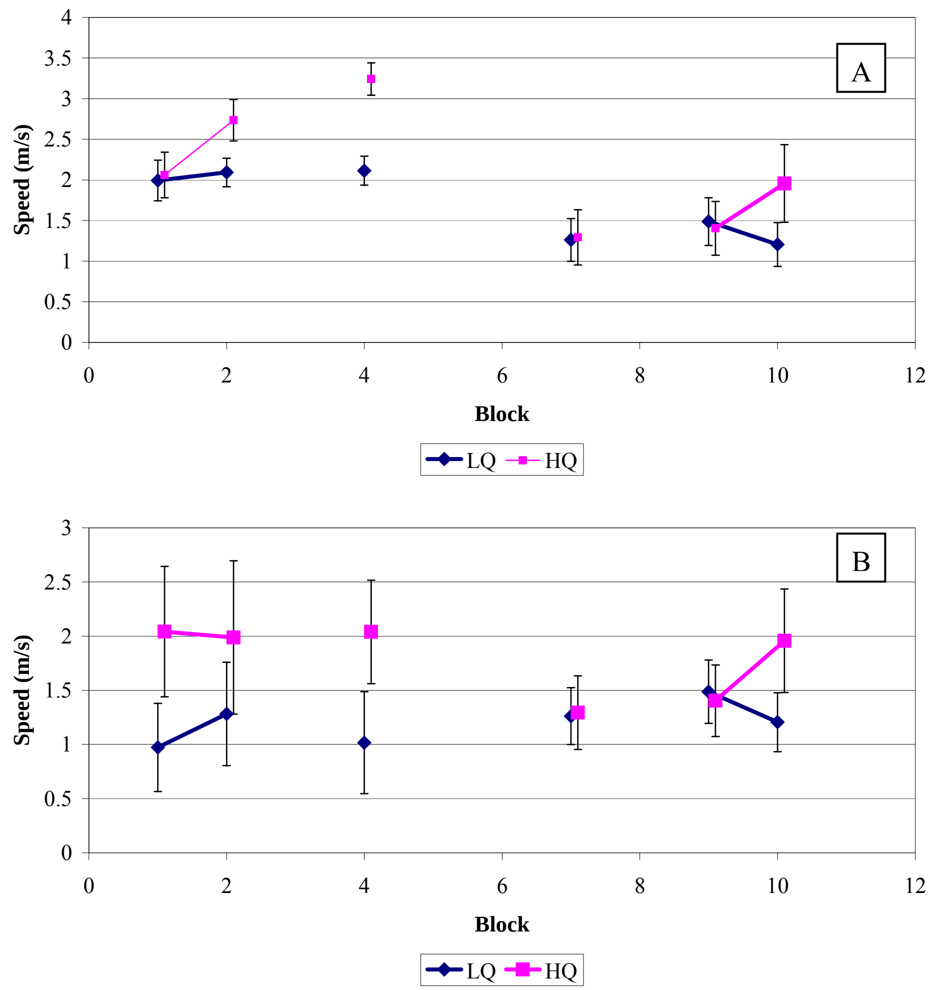


Figure 3.22. Mean speed for unguided fish by block. Blocks 5, 6, and 8 did not have treatments. Block 3 had missing data and was not included as part of the treatment analysis. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on measurement uncertainty.

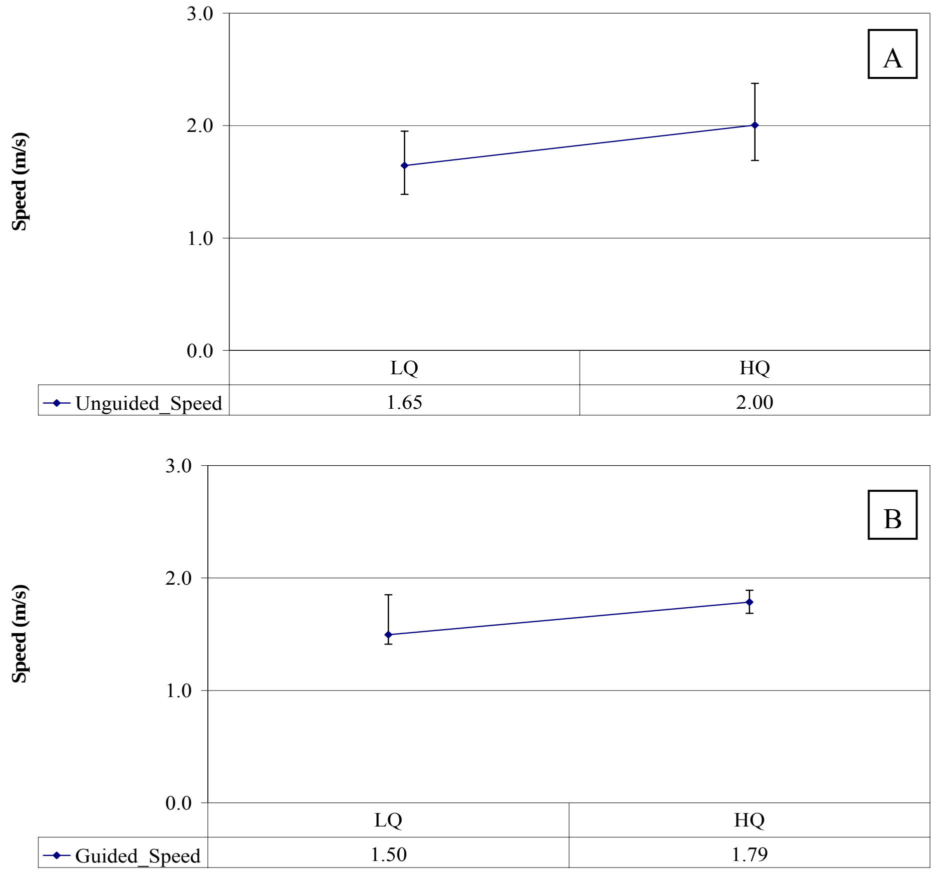


Figure 3.23. Mean speed for unguided fish by treatment. Panel A includes data from Units 2, 3, and 4 in blocks 1, 2, and 4 and for Unit 3 only in blocks 7, 9, and 10. Panel B includes data from Unit 3 only. Error bars are 95% confidence intervals based on ANOVA MSE.

Table 3.5. Unguided speed ANOVA table

	DF	SS	MS	F	P
Units 2,3, and 4[1]					
Block	5	0.851	0.170	6.498	0.030
NominalTRT	1	0.116	0.116	4.445	0.089
Error	5	0.131	0.026		
Unit 3 only					
Block	5	0.059	0.012	0.210	0.944
NominalTRT	1	0.452	0.452	8.051	0.036
Error	5	0.281	0.056		

[1]Units 2 and 4 were operated at HQ discharge level only during blocks 1, 2, and 4. Blocks 7, 9, and 10 include only Unit 3.

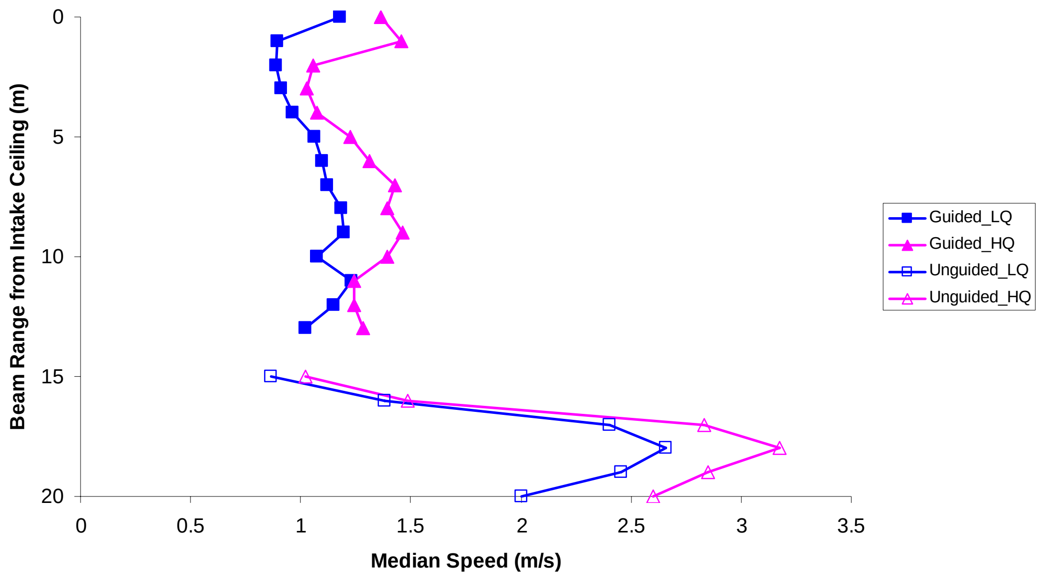


Figure 3.24. Median speed vertical distribution by treatment

3.4 Extended Spatial Intake Sampling

The discontinuation of turbine loading treatment conditions in the summer provided an opportunity to re-aim two guided transducers to sample closer to the ESBS face. This was not part of the original study, but could be accomplished on a limited basis without any operational changes due to the fact that some of the transducers were originally employed on underwater rotators to optimize aiming angles at the beginning of the season.

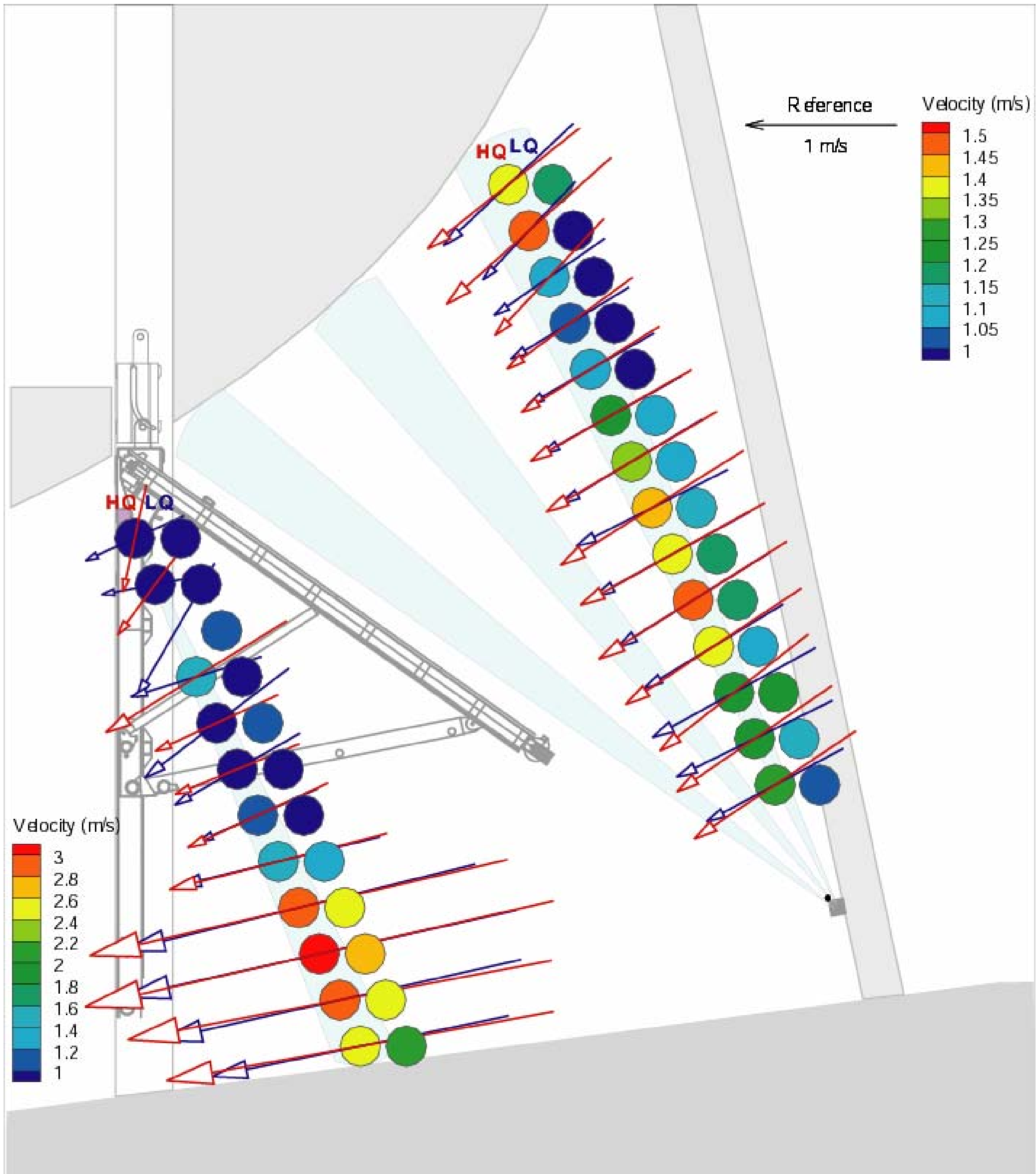


Figure 3.25. Comparison of fish trajectories by treatment; dot contours are by velocity to reinforce the differences in vector magnitude. The guided and unguided distributions and contouring are independent.

3.4.1 Fish Distributions Approaching an ESBS

To create the visualization in Figure 3.26, data from transducers at 4C (mid) and 4B (near ESBS) were overlain with data from all the remaining guided transducers (near trashrack). The result is a representative picture of the relative abundance of fish at different locations within the intake.

The distribution of fish spread abruptly very near the screen face. Salmonids are known to behaviorally avoid screens and *in-situ* video studies at the ESBS also suggest they actively avoid screen faces. Observations from these studies indicate that smolts are actively swimming away from the screen by the time they are observed with optical video (Moursund et al. 2003a; Nestler and Davidson 1995a and 1995b). Figure 3.27 is the same abundance and trajectory data, but in a more easily quantified line graph form by beam range. These two graphs highlight the influence of the screen on fish distribution and approach angle. The velocity distributions also changed on approach to the ESBS with velocities near the intake ceiling increasing as fish neared the gatewell (Figure 3.28). Presumably this was due to the influence of the flows going up the gatewell slot. Velocities underneath the screen were considerably higher (up to three times as high) as that of fish approaching the screen face. This result was generally consistent with modeled flow patterns from intakes at other projects.

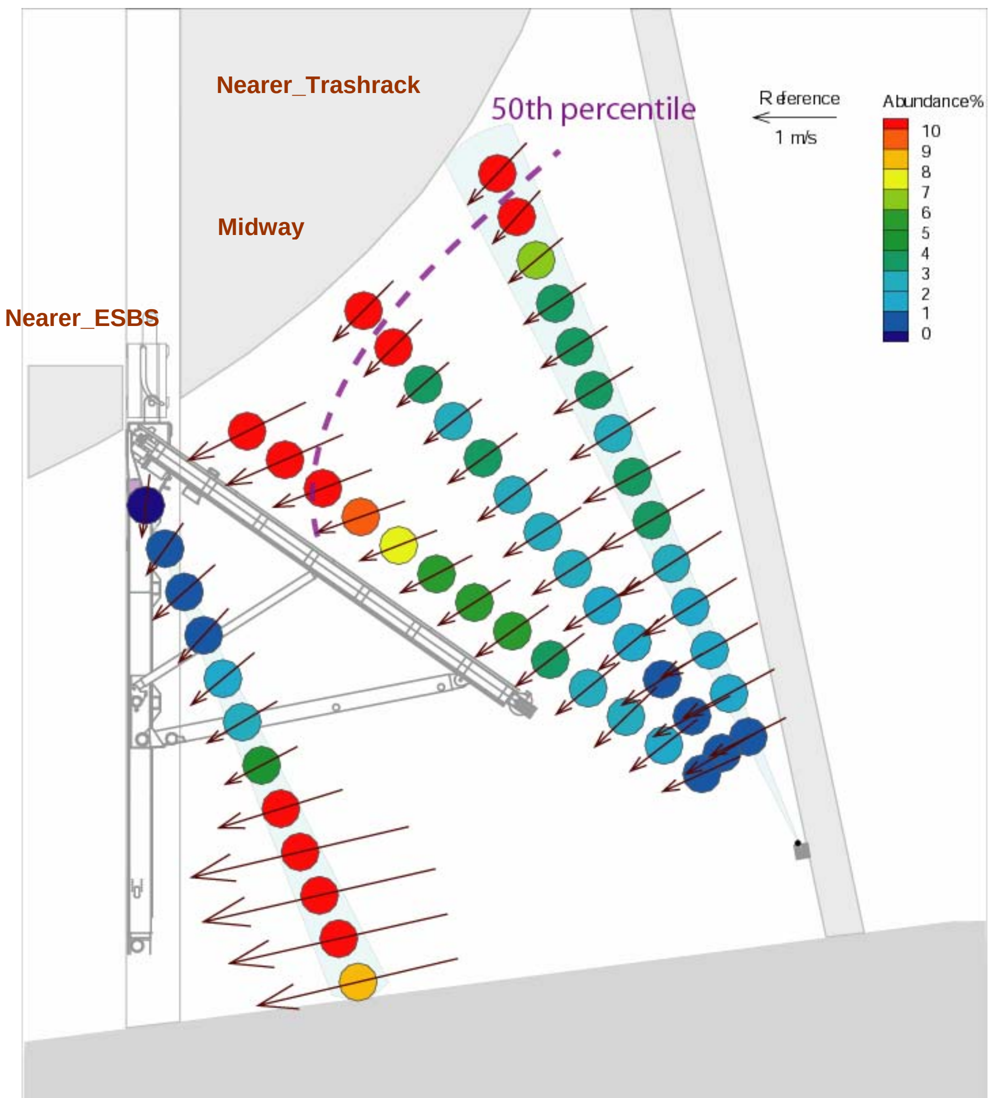


Figure 3.26. Fish abundance by sampling location. Beam distributions are independent. The median fish distribution line is shown in purple.

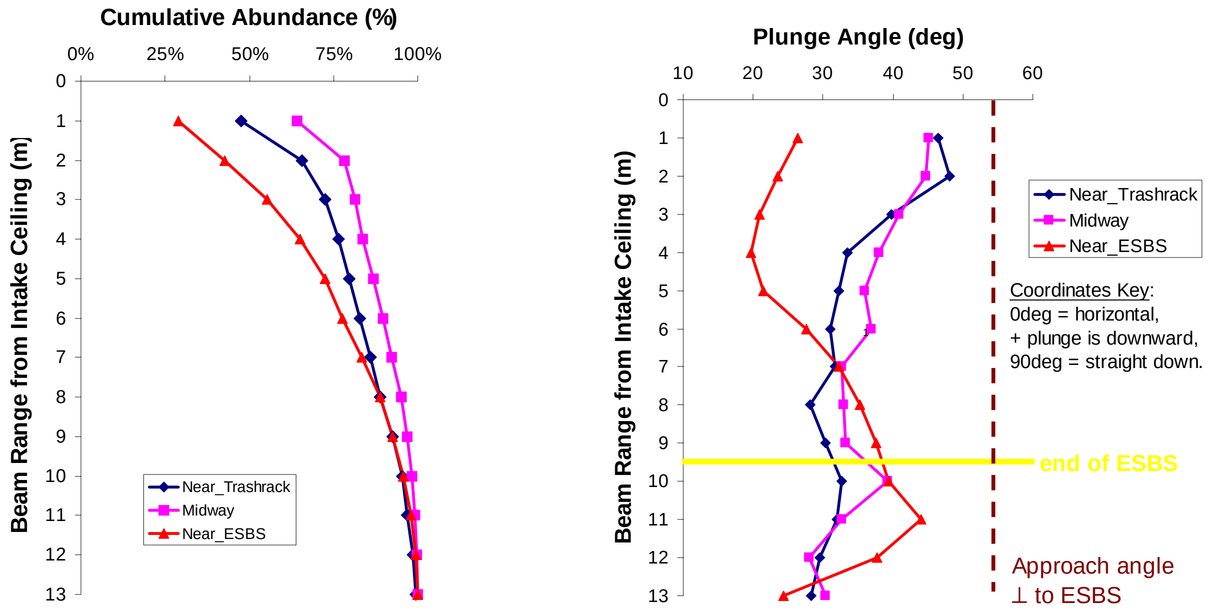


Figure 3.27. Abundance by range on approach showing most fish near the intake ceiling with the distribution more spread out near ESBS (left). Plunge angle distributions at the three locations show an upward shift in trajectory along the upper part of the ESBS (right). Points below yellow line are beyond end of ESBS.

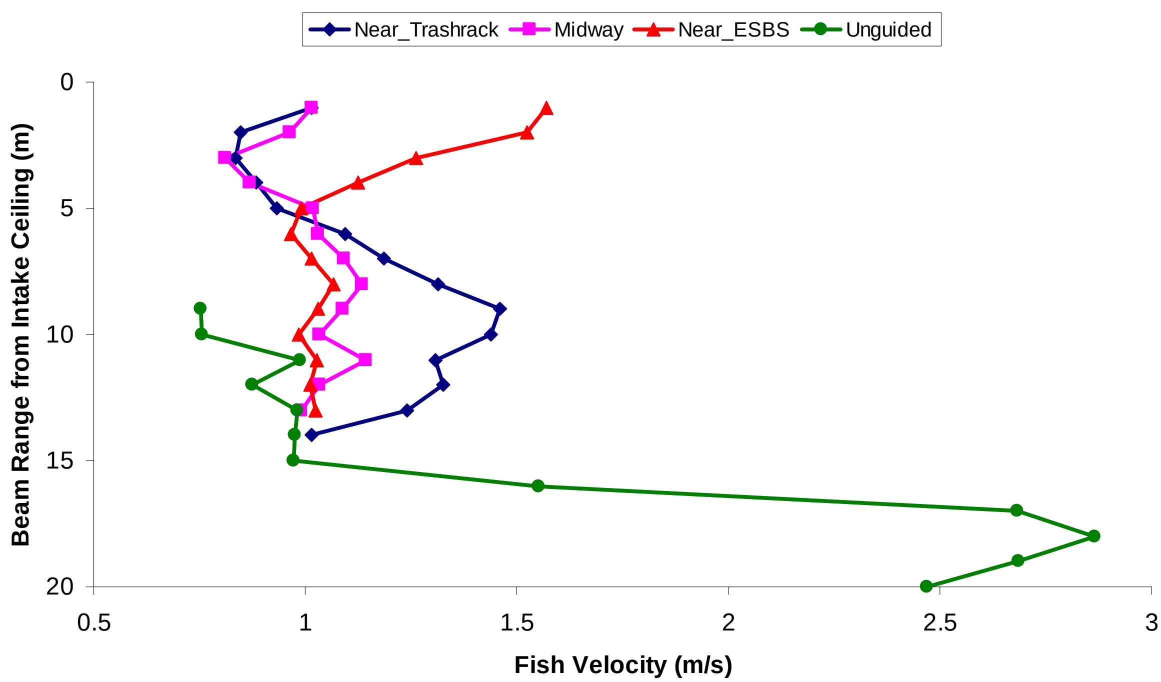


Figure 3.28. Velocity distributions in the summer

3.5 VBS Head Differential

While head differential across the VBS at the A-slot of every turbine unit and slot 4B were monitored over the season, emphasis is placed on Units 2, 3, and 4 for this section of the report. Units 2 through 4 contained a prototype VBS in the A slot of each and were also the units that were monitored for fish passage with hydroacoustic equipment. Slot 2A contained a vertically oriented bar VBS, 3A contained a horizontally oriented bar VBS, and 4A contained a traveling mesh VBS. 4B was also monitored, as previously stated, to represent this unit's standard fixed mesh type VBS. Based on the in-season debris performance characteristics and other factors, an improved VBS design will be constructed and tested in 2005.

3.5.1 Screen Type Comparison

The focus of this section is on the comparative performance of VBS screen type. Units 2-4 are highlighted as they contain all of the screen types and are a contiguous cluster that limits the amount of lateral debris variation along the powerhouse in the data interpretation. Only one instance of each screen type was constructed, so the performance of each may also be related to the location (turbine unit and slot) where it was installed.

During the HQ treatments, the higher flows into the gatewell caused a head differential increase of about 0.5 ft in the mesh-based screen (fixed mesh and traveling) beyond the LQ loading condition. This increase in head differential from increased flows was about an additional 1.0 ft head total for the bar screens beyond LQ loading. These differentials were taken from the beginning of the season when the screens were clean. Head differentials also dropped back down when flows were reduced.

Debris accumulation results in an increase in head differential. The more debris that accumulates on the screen, the more it impedes flow. The impeded flow causes an increase in the head differential which is then measured by the radar sensors. The order of the screen debris performance from worst to best was as follows: fixed mesh, horizontal bar, vertical bar, and traveling. The graphs below are in the same order (Figure 3.29 to Figure 3.32). It can be clearly seen that the debris clearing performance of the traveling VBS was excellent. It is probably most illustrative to compare this with the fixed mesh VBS in 4B since it is the same turbine unit. During the study, the fixed mesh screen in Unit 4 exceeded the 1.5-ft head criteria on numerous instances, while the traveling screen did not.

Operations were limited in the summer at these units as the project switched to temperature-limited operations which gives priority to mid-river (higher number) units. The summer does represent a question of interest for screen design. Spring conditions generally bring what is considered to be relatively coarse debris, such as sticks and other woody materials, down the river. Summer conditions are expected to bring finer debris in the form of broken plant material. The fixed mesh and horizontal VBS showed accumulation of debris in the late summer where the other two screen types did not. This performance division follows the trends in spring and the trend overall.

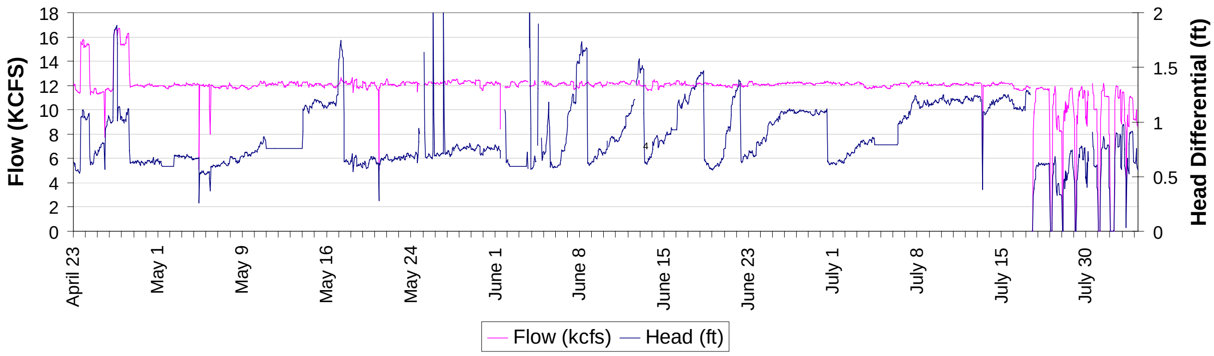


Figure 3.29. Fixed mesh VBS debris loading performance at slot 4B

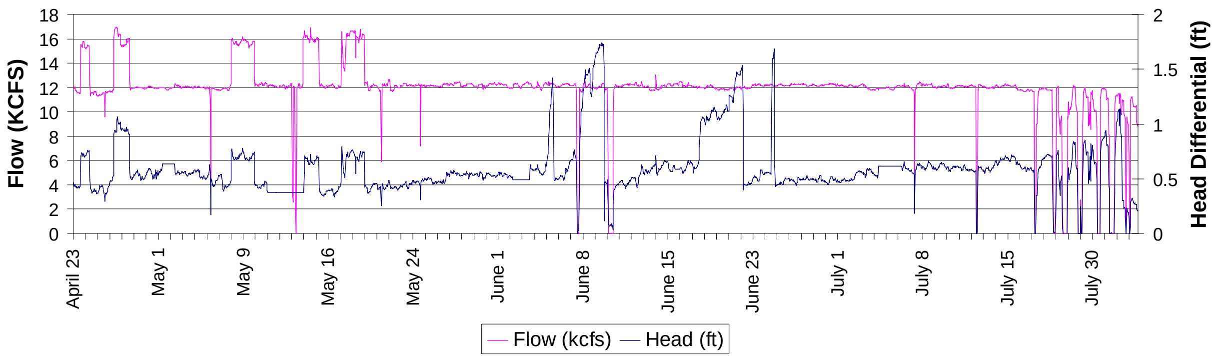


Figure 3.30. Horizontal bar VBS debris loading performance at slot 3A

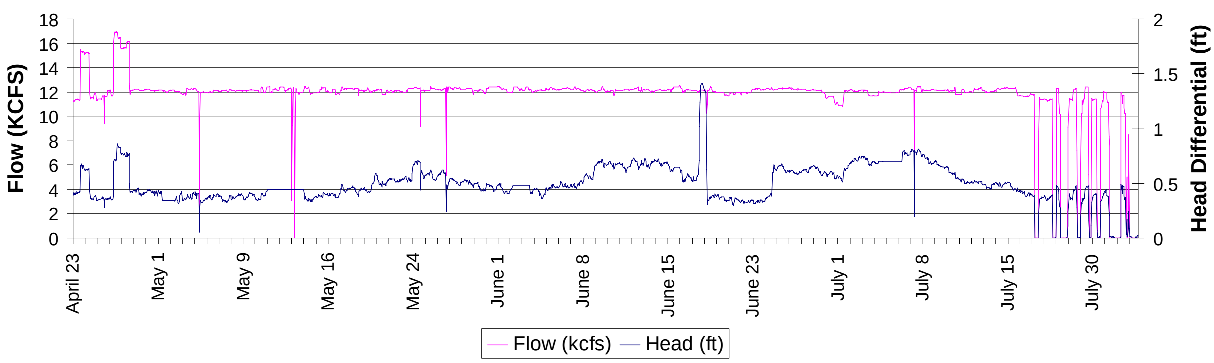


Figure 3.31. Vertical bar VBS debris loading performance at slot 2A

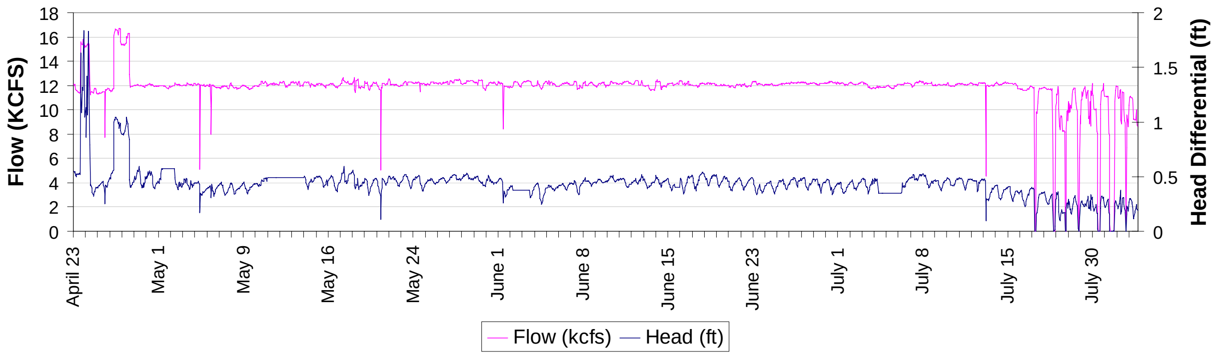


Figure 3.32. Traveling VBS debris loading performance at slot 4A

3.5.2 Correlation with FGE

We examined whether FGE was correlated with VBS head differential. Because FGE can be influenced by 24-hour cyles of dam operations or fish behavior, we used 24-hr mean values as the basis for examining correlations. FGE appeared to increase slightly as feet of head increased in summer (Figure **3.33**), but the lack of data at higher values of head makes any interpretation of a trend tenuous.

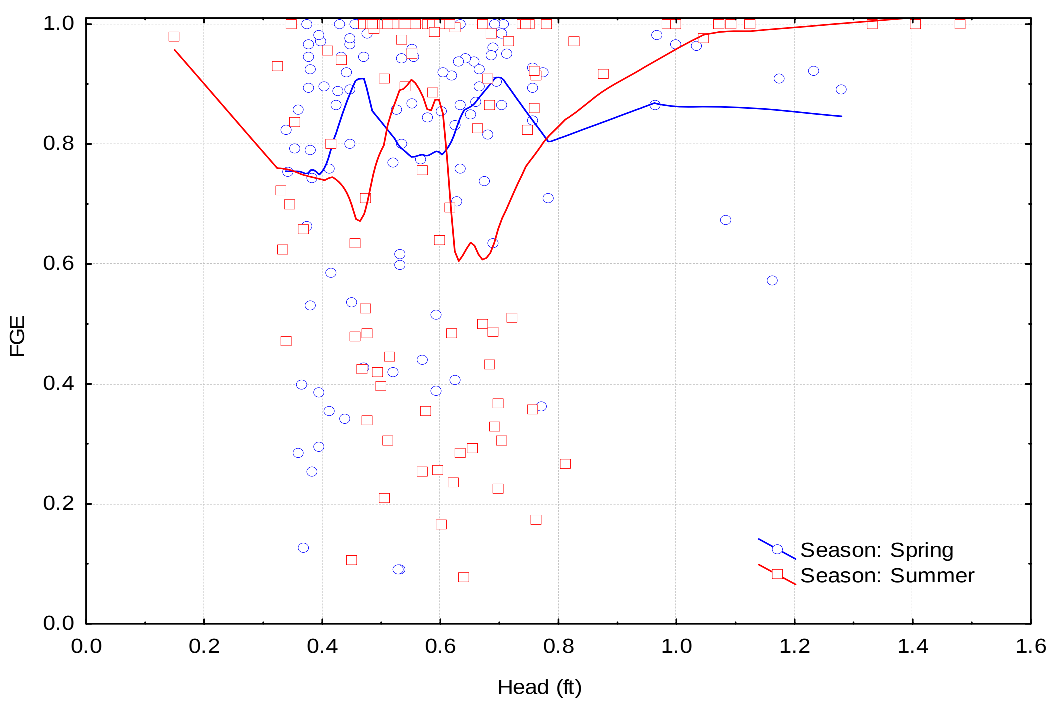


Figure 3.33. FGE versus feet of head with LOWESS fits (stiffness=0.25)

Many of the higher values for head were associated with the HQ treatment, and FGE generally decreases from spring to summer, so we expect there may be other influences on FGE beyond the head measured across the VBS. To address those possibly influential factors, we applied a stepwise multiple regression to find that group of factors with the greatest correlation with FGE (arcsine transformed). The only significant term in the regression was location (turbine unit and slot), no correlation was evident between head and FGE (see Figure 3.33). The early end to the HQ treatment is likely to have reduced our ability to examine whether flow (and associated head differences) was influencing FGE, but current results suggest that it will be necessary to account for influence of location in future investigations of head differences and FGE.

4.0 Conclusions

Individual run-of-the-river fish were quantified as they passed through Units 2, 3, and 4 intakes from April 15 to July 15. Overall, FGE was high at these units at about 84% and showed only a small decrease in FGE at the end of summer. The lack of change in the seasonal estimates of FGE with spill level suggests that these units are beyond the immediate influence of the spillway. In previous hydroacoustic studies that used equivalent techniques but included the full project at John Day and Ice Harbor Dams, dam operations such as spill and turbine loading influenced the timing and location of fish passage through a project.

The reduced number of blocks limited our ability to determine whether differences among treatment conditions were statistically significant, but the trends among treatments do not suggest a strong influence on FGE. The management implication is that these data do not suggest FGE itself is a cause for concern with high discharge operations, since FGE did not appear to differ greatly among treatments during the short test period.

Another study objective was to test for trajectory and velocity differences among treatments. While we did not find significant differences in the vertical abundance distributions or trajectories, we did see trends in median velocities among treatments. These differences were significant, or nearly so, even though the planned experimental design was not realized in its entirety (Table 4.1). This detailed fish velocity information is expected to be useful in linking fish behavior or fish injury to physical hydraulic models. Hydraulic models may be useful for explaining fish injury or to identify probable locations or mechanisms of injury.

Table 4.1. Mean discharge treatment velocity differences (ft/s) with Units 2, 3, and 4 included

	LQ	HQ	Difference
Guided	4.89	5.68	+0.79
Unguided	5.41	6.56	+1.15

Maximum velocities of fish passing underneath the screen were considerably higher (up to three times higher) than those of fish approaching the screen face. This finding is proportional to expected flow differences from model data. Our study showed that most of the fish in the sample volume remained in high velocity zones and under the influence of flows, based on vertical abundance distribution and trajectory data. Fish do not appear to be swept into vortices behind the screen in significant numbers. This has implications for turbine survival since fish entering low into the scroll case pass near the runner tip and have poorer survival probabilities than those entering high and passing the runner at mid or hub locations (USACE 2004).

5.0 References

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Appendix A

Equipment Configuration

Appendix A

Equipment Configuration

Table A.1. Sounder, transducer, and cable configuration of sampling equipment including locations and sample rates.

System MCN_M_Powerhouse SPB

Description	S/N	Xducer Type	Channel	Remote Mux. Port	Location	Cable Lengths 4 ch.	Cable Lengths 6 ch.	Total Length	SN	Mounting	Aiming angle	Elevation	Pings/ Second	Min./ Hr.
SPB Sounder	51													
Remote Multiplexer	23						470		140					
6-deg SPB xducer_1	450	6° split	0	0	Unit 3A	313		783	145	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_2	466	6° split	10	1	Unit 2C	313		783	142	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_3	460	6° split	20	2	Unit 2B	313		783	143	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_4	461	6° split	30	3	Unit 2A	313		783	144	uplooker/guided	12° from plane of trashrack	248 ft.	27	15

System MCN_N_Powerhouse SPB

Description	S/N	Xducer Type	Channel	Remote Mux. Port	Location	Cable Lengths 4 ch.	Cable Lengths 6 ch.	Total Length	SN	Mounting	Aiming angle	Elevation	Pings/ Second	Min./ Hr.
SPB Sounder	52													
Remote Multiplexer	24						470		146					
6-deg SPB xducer_1	462	6° split	0	0	Unit 4B	313		783	148	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_2	463	6° split	10	1	Unit 4A	313		783	149	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_3	464	6° split	20	2	Unit 3C	313		783	150	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_4	451	6° split	30	3	Unit 3B	313		783	152	uplooker/guided	12° from plane of trashrack	248 ft.	27	15

System MCN_L_Powerhouse SPB

Description	S/N	Xducer Type	Channel	Remote Mux. Port	Location	Cable Lengths 4 ch.	Cable Lengths 6 ch.	Total Length	SN	Mounting	Aiming angle	Elevation	Pings/ Second	Min./ Hr.
SPB Sounder	50													
Remote Multiplexer	22						470		133					
6-deg SPB xducer_1	453	6° split	0	0	Unit 4C	313		783	134	uplooker/guided	12° from plane of trashrack	248 ft.	27	15
6-deg SPB xducer_2	454	6° split	10	1	Unit 4C	313		783	135	downlooker/unguided	24° upstream of vertical	270 ft.	27	15
6-deg SPB xducer_3	455	6° split	20	2	Unit 4B	313		783	136	downlooker/unguided	27° upstream of vertical	270 ft.	27	15
6-deg SPB xducer_4	456	6° split	30	3	Unit 3C	313		783	137	downlooker/unguided	24° upstream of vertical	270 ft.	27	15

System MCN_P_Powerhouse SPB

Description	S/N	Xducer Type	Channel	Remote Mux. Port	Location	Cable Lengths 4 ch.	Cable Lengths 6 ch.	Total Length	SN	Mounting	Aiming angle	Elevation	Pings/ Second	Min./ Hr.
SPB Sounder	53													
Remote Multiplexer	25						470		151					
6-deg SPB xducer_1	469	6° split	0	0	Unit 2C	313		783	153	downlooker/unguided	24° upstream of vertical	270 ft.	27	20
6-deg SPB xducer_2	470	6° split	10	1	Unit 2B	313		783	154	downlooker/unguided	24° upstream of vertical	270 ft.	27	20
6-deg SPB xducer_3	471	6° split	20	2	Unit 2A	313		783	155	downlooker/unguided	24° upstream of vertical	270 ft.	27	20

System MCN_Q_Powerhouse SPB

Description	S/N	Xducer Type	Channel	Remote Mux. Port	Location	Cable Lengths 4 ch.	Cable Lengths 6 ch.	Total Length	SN	Mounting	Aiming angle	Elevation	Pings/ Second	Min./ Hr.
SPB Sounder	26													
Remote Multiplexer	11						230		156					
6-deg SPB xducer_1	473	6° split	0	0	Unit 4A	313		543	158	downlooker/unguided	24° upstream of vertical	270 ft.	27	20
6-deg SPB xducer_2	474	6° split	10	1	Unit 3B	313		543	159	downlooker/unguided	24° upstream of vertical	270 ft.	27	20
6-deg SPB xducer_3	475	6° split	20	2	Unit 3A	313		543	160	downlooker/unguided	24° upstream of vertical	270 ft.	27	20

Table A.2. Radar sensor configuration and location of all 30 sensors.

Appendix B

System Calibrations

Appendix B

System Calibrations

Table B.3. Equipment manufactured and calibrated by Precision Acoustic Systems, Seattle, Washington.

Static Transmit Power	Installed System	Channel	Echo-sounder Number	Trans-ducer Number and Phase (if split beams)	Calibrated Cable Length (ft)	Source Level (dB)	Maximum Output Voltage (dB)	Voltage of Largest On-axis Target at 20 dB per Volt (V)	40 logR Receiver Sensitivity (dB)	Target Strength of largest on-axis target of interest (db)	Calculated Receiver gain (dB)	Installed Cable Length (ft)	Difference in Cable Length Between Calibrated Cable and Installed Cable (ft)	Receiver Gain Adjusted for Difference in Cable Length (dB)	Source Level Adjusted for Difference in Cable Length (dB)	Receiver Sensitivity Adjusted for Difference in Cable Length (dB)	Target Strength of Smallest On-axis Target (dB)	Voltage of Smallest On-axis Target (dB)	Voltage of Smallest On-axis Target at 20 dB per Volt (V)
-4	L		50	453(x)	783	217.52	90	4.5	-104.74	-26	3.22	783	0	3.22	217.52	-104.74	-56	60	3.00
	L		50	453(y)	783	217.53	90	4.5	-104.78	-26	3.25	783	0	3.25	217.53	-104.78	-56	60	3.00
	L	00	50	453	783	217.53	90	4.5	-104.76	-26	3.23	783	0	3.23	217.53	-104.76	-56	60	3.00
-4	L		50	454(x)	783	217.46	90	4.5	-105.14	-26	3.68	783	0	3.68	217.46	-105.14	-56	60	3.00
	L		50	454(y)	783	217.46	90	4.5	-105.20	-26	3.74	783	0	3.74	217.46	-105.20	-56	60	3.00
	L	01	50	454	783	217.46	90	4.5	-105.17	-26	3.71	783	0	3.71	217.46	-105.17	-56	60	3.00
-4	L		50	455(x)	783	217.64	90	4.5	-105.18	-26	3.54	783	0	3.54	217.64	-105.18	-56	60	3.00
	L		50	455(y)	783	217.62	90	4.5	-105.18	-26	3.56	783	0	3.56	217.62	-105.18	-56	60	3.00
	L	02	50	455	783	217.63	90	4.5	-105.18	-26	3.55	783	0	3.55	217.63	-105.18	-56	60	3.00
-4	L		50	456(x)	783	217.63	90	4.5	-105.20	-26	3.57	783	0	3.57	217.63	-105.20	-56	60	3.00
	L		50	456(y)	783	217.59	90	4.5	-105.18	-26	3.59	783	0	3.59	217.59	-105.18	-56	60	3.00
	L	03	50	456	783	217.61	90	4.5	-105.19	-26	3.58	783	0	3.58	217.61	-105.19	-56	60	3.00
-4	L		50	452(x)	783	217.17	90	4.5	-105.44	-26	4.27	783	0	4.27	217.17	-105.44	-56	60	3.00
	L		50	452(y)	783	217.20	90	4.5	-105.48	-26	4.28	783	0	4.28	217.20	-105.48	-56	60	3.00
	L	spare	50	452	783	217.19	90	4.5	-105.46	-26	4.27	783	0	4.27	217.19	-105.46	-56	60	3.00
-4	M		20	450(x)	783	217.43	90	4.5	-105.10	-26	3.67	783	0	3.67	217.43	-105.10	-56	60	3.00
	M		20	450(y)	783	217.45	90	4.5	-105.12	-26	3.67	783	0	3.67	217.45	-105.12	-56	60	3.00
	M	00	20	450	783	217.44	90	4.5	-105.11	-26	3.67	783	0	3.67	217.44	-105.11	-56	60	3.00
-4	M		20	466(x)	783	217.59	90	4.5	-104.66	-26	3.07	783	0	3.07	217.59	-104.66	-56	60	3.00
	M		20	466(y)	783	217.63	90	4.5	-104.68	-26	3.05	783	0	3.05	217.63	-104.68	-56	60	3.00
	M	01	20	466	783	217.61	90	4.5	-104.67	-26	3.06	783	0	3.06	217.61	-104.67	-56	60	3.00
-4	M		20	460(x)	783	217.65	90	4.5	-104.82	-26	3.17	783	0	3.17	217.65	-104.82	-56	60	3.00
	M		20	460(y)	783	217.64	90	4.5	-104.84	-26	3.20	783	0	3.20	217.64	-104.84	-56	60	3.00
	M	02	20	460	783	217.65	90	4.5	-104.83	-26	3.19	783	0	3.19	217.65	-104.83	-56	60	3.00
-4	M		20	461(x)	783	217.50	90	4.5	-105.06	-26	3.56	783	0	3.56	217.50	-105.06	-56	60	3.00
	M		20	461(y)	783	217.47	90	4.5	-105.04	-26	3.57	783	0	3.57	217.47	-105.04	-56	60	3.00
	M	03	20	461	783	217.49	90	4.5	-105.05	-26	3.57	783	0	3.57	217.49	-105.05	-56	60	3.00
-4	N		27	458(x)	783	217.54	90	4.5	-104.84	-26	3.30	783	0	3.30	217.54	-104.84	-56	60	3.00
	N		27	458(y)	783	217.60	90	4.5	-104.84	-26	3.24	783	0	3.24	217.60	-104.84	-56	60	3.00
	N	Spare	27	458	783	217.57	90	4.5	-104.84	-26	3.27	783	0	3.27	217.57	-104.84	-56	60	3.00
-4	N		27	459(x)	783	217.64	90	4.5	-104.80	-26	3.16	783	0	3.16	217.64	-104.80	-56	60	3.00
	N		27	459(y)	783	217.64	90	4.5	-104.82	-26	3.18	783	0	3.18	217.64	-104.82	-56	60	3.00
	N	Spare	27	459	783	217.64	90	4.5	-104.81	-26	3.17	783	0	3.17	217.64	-104.81	-56	60	3.00
-4	N		27	462(x)	783	217.74	90	4.5	-104.54	-26	2.80	783	0	2.80	217.74	-104.54	-56	60	3.00
	N		27	462(y)	783	217.75	90	4.5	-104.54	-26	2.79	783	0	2.79	217.75	-104.54	-56	60	3.00
	N	00	27	462	783	217.75	90	4.5	-104.54	-26	2.80	783	0	2.80	217.75	-104.54	-56	60	3.00
-4	N		27	463(x)	783	217.94	90	4.5	-104.62	-26	2.68	783	0	2.68	217.94	-104.62	-56	60	3.00
	N		27	463(y)	783	217.94	90	4.5	-104.64	-26	2.70	783	0	2.70	217.94	-104.64	-56	60	3.00
	N	01	27	463	783	217.94	90	4.5	-104.63	-26	2.69	783	0	2.69	217.94	-104.63	-56	60	3.00
-4	N		27	464(x)	783	217.88	90	4.5	-104.66	-26	2.78	783	0	2.78	217.88	-104.66	-56	60	3.00
	N		27	464(y)	783	217.91	90	4.5	-104.66	-26	2.75	783	0	2.75	217.91	-104.66	-56	60	3.00
	N	02	27	464	783	217.90	90	4.5	-104.66	-26	2.77	783	0	2.77	217.90	-104.66	-56	60	3.00
-4	N		27	451(x)	783	217.54	90	4.5	-105.02	-26	3.48	783	0	3.48	217.54	-105.02	-56	60	3.00
	N		27	451(y)	783	217.55	90	4.5	-105.06	-26	3.51	783	0	3.51	217.55	-105.06	-56	60	3.00
	N	03	27	451	783	217.55	90	4.5	-105.04	-26	3.50	783	0	3.50	217.55	-105.04	-56	60	3.00
-4	N		27	458(x)	783	217.73	90	4.5	-104.78	-26	3.05	783	0	3.05	217.73	-104.78	-56	60	3.00
	N		27	458(y)	783	217.71	90	4.5	-104.80	-26	3.09	783	0	3.09	217.71	-104.80	-56	60	3.00
	N	Spare	27	458	783	217.72	90	4.5	-104.79	-26	3.07	783	0	3.07	217.72	-104.79	-56	60	3.00
-4	N		27	459(x)	783	217.81	90	4.5	-104.72	-26	2.91	783	0	2.91	217.81	-104.72	-56	60	3.00
	N		27	459(y)	783	217.82	90	4.5	-104.74	-26	2.92	783	0	2.92	217.82	-104.74	-56	60	3.00
	N	Spare	27	459	783	217.82	90	4.5	-104.73	-26	2.92	783	0	2.92	217.82	-104.73	-56	60	3.00
-4	P		22	469(x)	783	217.79	90	4.5	-104.98	-26	3.19	783	0	3.19	217.79	-104.98	-56	60	3.00
	P		22	469(y)	783	217.78	90	4.5	-105.02	-26	3.24	783	0	3.24	217.78	-105.02	-56	60	3.00
	P	00	22	469	783	217.79	90	4.5	-105.00	-26	3.22	783	0	3.22	217.79	-105.00	-56	60	3.00
-4	P		22	470(x)	783	217.94	90	4.5	-105.36	-26	3.42	783	0	3.42	217.94	-105.36	-56	60	3.00

Appendix C

Effective Beam Widths

Appendix C

Effective Beam Widths

The effective beam width is calculated from a detectability model. Inputs to this model include fish speeds and trajectories as well as the sensitivity and beam pattern of each transducer. These come from split beam data of actual fish paths and from the equipment calibration process, respectively. The output forms the basis for expanding the fish counts. As shown below, the effective beam width varies by range, diel, and season. Figures C.1 through C.4 below show the effective beam widths used in this study.

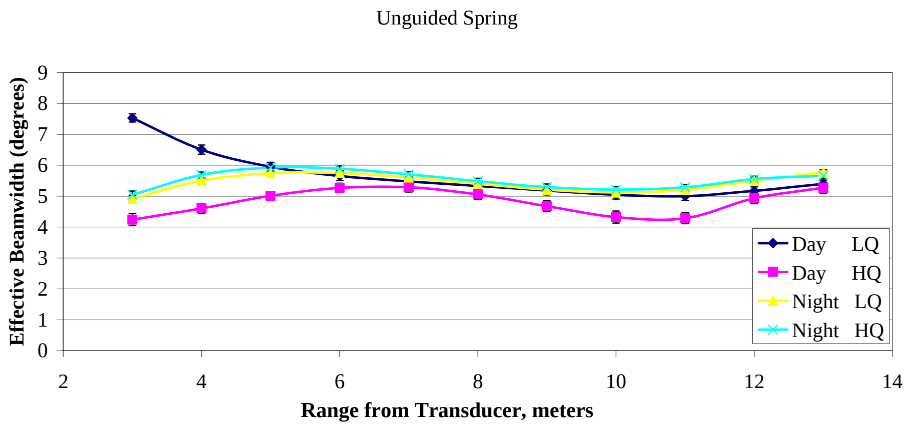

Figure C.1. Effective beamwidths for unguided transducers in spring. Error bars denote 95% confidence intervals for the mean.

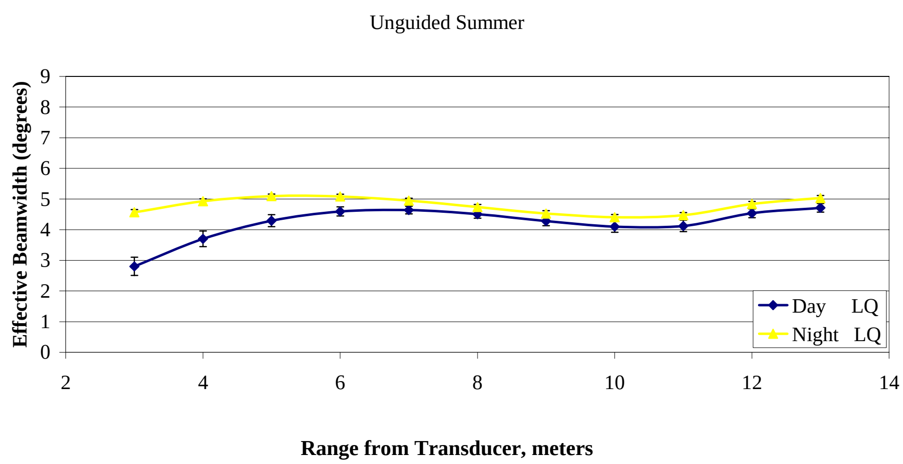

Figure C.2. Effective beamwidths for unguided transducers in summer. Error bars denote 95% confidence intervals for the mean.

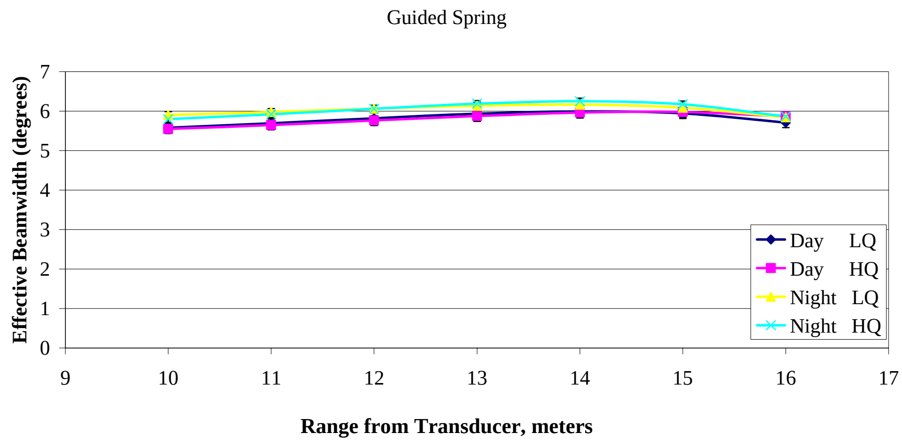

Figure C.3. Effective beamwidths for guided transducers in spring. Error bars denote 95% confidence intervals for the mean.

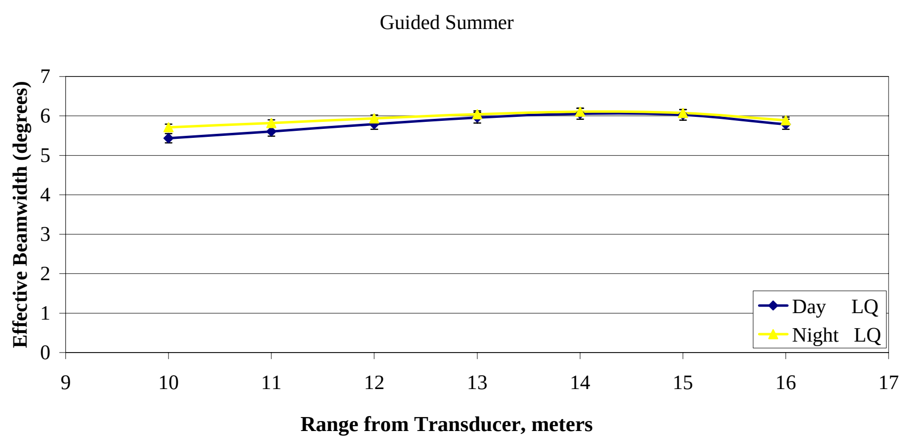

Figure C.4. Effective beamwidths for guided transducers in summer. Error bars denote 95% confidence intervals for the mean.

Appendix D

Raw Data –
Hourly Passage Estimates, Dam Operations, and Head Differentials

(provided on CD)