U.S. Army Corps of Engineers
Walla Walla District

Hydroacoustic Evaluation of Fish Passage and Behavior at Lower Granite Dam in Spring 1998

FINAL REPORT

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Summary

The U.S. Army Corps of Engineers, Walla Walla District (Corps) is working to improve juvenile fish protection systems at its four Lower Snake River projects by taking actions to: (1) monitor spill effectiveness, (2) evaluate effectiveness of extended-length submersible bar screens (ESBS), and (3) develop surface bypass. Results from evaluations of these actions will be included in the Lower Snake River Juvenile Salmon Migration Feasibility Study. The Feasibility Study was mandated by a 1995 National Marine Fisheries Service (NMFS) Biological Opinion (NMFS 1995) and is scheduled for completion in 2000. It will consider the benefits of three system alternatives to juvenile salmonids: existing system, major structural improvements, or natural river. The primary intent of our fish passage and behavior research at Lower Granite Dam is to provide information for the Feasibility Study on the biological performance of surface bypass, spill and screens.

To support this effort, Battelle conducted research at Lower Granite Dam in spring 1998. Our study emphasized performance monitoring of the Surface Bypass and Collector (SBC) and two new structures added in 1998: a Simulated Wells Intake (SWI) retrofitted to the powerhouse below the SBC, and a Behavioral Guidance Structure (BGS), attached to the south end of the SBC. The SWI was added to decrease smolt entrainment into turbines and increase their availability to the SBC by flattening flow lines in the forebay. The BGS was designed to divert smolts from Turbines 1-3 toward the SBC or spillway. We deployed different hydroacoustic systems (single-beam, multi-beam, and split-beam technologies) at many locations to monitor fish passage and fish behavior at the dam. The goal of the fish passage research was to measure the performance of spill, intake screens, and the prototype SBC. The goal of fish behavior studies was to investigate and characterize the behavior of juvenile salmonids as they approached the SBC and the BGS.

The single-beam research, which focused on fish passage, showed that spill, intake screens, and the SBC/SWI/BGS, together afforded a high level of smolt protection (fish passage efficiency = 92.6 ± 1.2 %) during spring 1998. While spill efficiency and effectiveness and overall fish guidance efficiency were somewhat lower in 1998 than in 1997, SBC performance improved noticeably in front of Turbines 4-6 in 1998 (50-54%) over performance in 1996 and 1997 (35-45%). This was not due to improved overall entrance conditions, as entrance efficiency was less than optimal (57.6 ± 0.2%), but rather to lower spill rates, lower load at Turbines 4-6, and lower total project discharge than in previous SBC test-years. SWI performance also contributed to improved SBC performance. Forebay entrainment into the turbines beneath the SBC was reduced in 1998, indicating that the SWI performed as expected by keeping fish higher in the water column and available to the SBC.

Fish tended to be more surface-oriented during the day than at night. This led to greater passage at the spillway during the day than at night and greater passage through turbine intakes at night than during the day.

The BGS diverted 78 ± 18% of fish intended for Turbines 1-3 toward the SBC, spillway, and Turbines 4-6. Total passage rates at Turbines 1-3 were generally lower than passage rates for the rest of the dam whether the BGS was attached to (IN) or detached from (OUT) the SBC. In large part, the presence of the BGS and turbine operations determined the horizontal distribution of fish passage at the powerhouse.

The multi-beam and split-beam technologies , which focused on fish behavior, showed that fish did not passively follow flow near the SBC/SWI and BGS structures. Instead, they exhibited very complex behaviors that may have depended on other environmental factors associated with the dam (e.g., sound, light).

Data collected in front of the SBC by the multi-beam transducers indicated that the presence of the BGS appeared to increase fish milling behavior in front of the SBC. Milling indicates fish had more opportunities to discover SBC entrances, but this may have also resulted in passage delay. The BGS also appeared to affect the depth distribution of fish near the SBC (within 13 meters). Fish were an average of 2 to 3 m higher in the water column when the BGS was IN and were therefore more likely to find an SBC entrance.

Data collected behind the BGS by the split-beam transducer indicated that large numbers of fish did not pass through the SBC/BGS junction. Thus, seals designed to keep fish from entering the area in front of Turbine Units 1-3 functioned as intended, or fish avoided this area.

Based on detailed analysis of our data, we recommend that SBC entrance conditions could be improved by reducing or eliminating the zone of slack water at the junction of the SBC and BGS and by making water acceleration into the SBC more gradual than is currently the case. Additional research to characterize basic biological responses of salmonid smolts to hydrodynamic characteristics (e.g., velocity, acceleration, turbulence) of the flow field in front of the SBC should be performed. Our data suggest fish may be reacting to sensory cues other than acceleration or flow long before they are in an area where they might be entrained by the SBC. Eliminating excess structure and other visual and auditory stimuli will serve to provide a more uniform approach environment.

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Contents

Summary iii

Acknowledgments v

Contents vii

Figures x

Tables xvi

Abbreviations, Acronyms, and Symbols xix

Section 1: Introduction 1.1
- 1.1 Background 1.1
- 1.2 Goals and Objectives 1.3
- 1.3 Report Contents 1.4

Section 2: Study Area Characterization 2.1
- 2.1 Fish Passage Structures 2.1
  - 2.1.1 Lower Granite Dam 2.1
  - 2.1.2 Surface Bypass and Collector Prototype (SBC) 2.2
  - 2.1.3 Simulated Wells Intake (SWI) ..... .23
  - 2.1.4 Behavioral Guidance Structure (BGS) 2.5
- 2.2 Hydraulic Conditions 2.6
- 2.3 Migration Characteristics 2.11

Section 3: Study Design and Methods 3.1
- 3.1 Study Design and SBC Configurations 3.1
- 3.2 Fish Passage Methods (Single-Beam) 3.5
  - 3.2.1 Single-Beam Transducer Locations and Orientations 3.5
  - 3.2.2 Fish-Trace Types from SBC Modified Squinted-Pairs 3.8
  - 3.2.3 Analysis Methods 3.9
  - 3.2.4 Estimation of Missing Data 3.10
- 3.3 Fish Behavior Methods (Multi-Beam) 3.11
  - 3.3.1 Multi-Beam Deployment and Data Collection 3.11
  - 3.3.2 Multi-Beam Data Processing and Analysis 3.14
- 3.4 Fish Behavior Methods (Split-Beam) 3.22
  - 3.4.1 Split-Beam Deployment and Data Collection 3.22
  - 3.4.2 Split-Beam Data Processing and Analysis 3.23

Section 4: Fish Passage Results 4.1
- 4.1 Single-Beam System Performance 4.1
- 4.2 Spill Passage 4.2
  - 4.2.1 Spill Efficiency 4.2
  - 4.2.2 Spill Effectiveness 4.2
  - 4.2.3 Fish Distributions 4.3
- 4.3 Turbine Intake Passage 4.5

4.3.1 Overall, Weekly, and Day/Night FGE 4.5
4.3.2 Fish Distributions at Intake Screens and Powerhouse Pier Noses 4.5
4.4 SBC/SWI and BGS Passage 4.8
4.4.1 BGS Performance 4.8
4.4.2 SBC/SWI Performance 4.12
4.4.3 Descriptive Relationships between SBC Variables 4.14
4.4.4 Statistical Relationships between SBC Variables 4.17
4.4.5 Fish Distributions at the SBC 4.18
4.4.6 Fish Trajectories at the SBC 4.21
4.5 Fish Passage Budgets and Efficiencies 4.22

Section 5: Fish Behavior Results 5.1
5.1 Fish Behavior in Front of the SBC (Multi-Beam) 5.1
5.1.1 Target Summary 5.1
5.1.2 Sonar Coverage 5.2
5.1.3 Target Depth Frequency Distribution 5.3
5.1.4 Direction of Movement 5.8
5.1.5 Kinematic Analysis 5.22
5.1.6 Track Characteristics 5.31
5.1.7 Multi-Beam Statistical Analysis 5.34
5.2 Fish Behavior in Front of Turbines 1-3 (Split-Beam) 5.45
5.2.1 Target Record Summary and Descriptive Statistics 5.46
5.2.2 Effective Spatial Coverage 5.48
5.2.3 Average Fish Speed and Direction 5.50
5.2.4 Target Depth Frequency Distribution 5.57
5.2.5 Split-Beam Statistical Analysis 5.58

Section 6: Discussion 6.1
6.1 Fish Passage (Single-beam) 6.1
6.1.1 Verification of Results 6.1
6.1.2 Spill Efficiency and Effectiveness 6.2
6.1.3 Fish Guidance Efficiency of Extended-Length Bar Screens 6.3
6.1.4 BGS Performance 6.4
6.1.5 SBC/SWI Performance 6.6
6.2 Fish Behavior 6.8
6.2.1 Fish Behavior in Front of the SBC (Multi-Beam) 6.8
6.2.2 Fish Behavior in Front of Turbine Units 1-3 (Split-Beam) 6.13
6.3 Applications and Comparisons to Other Dams 6.14

Section 7: Conclusions and Recommendations 7.1

Section 8: Literature Cited 8.1

Appendix A: Single-Beam Hydroacoustics A.1
A.1 Hydroacoustic Systems and Calibration A.1
A.2 Detectability A.5
A.3 Hydroacoustic Quality Control A.7

Appendix B: Daily Plots, ANOVA Tables, and Bivariate Plots B.1
B.1 Daily Plots B.1
B.2 Anova Tables B.5
B.3 Bivariate Plots B.9
Appendix C: Multi-Beam and Split-Beam Quality Control C.1
C.1 Multi-Beam Data Quality Analysis C.1
C.2 Split-Beam Data Quality Control C.2

Figures

Figure 2.1. Map of Pacific Northwest showing location of Lower Granite Dam on the Snake River. 2.1
Figure 2.2. Plan view of Lower Granite Dam and forebay showing location of powerhouse, spillway, navigation lock, earthen dam, bathymetry, and general current pattern (arrows). 2.2
Figure 2.3. Side view of Lower Granite Dam powerhouse showing locations of SBC, SWI, and ESBS. 2.3
Figure 2.4. Plan view of the SBC showing individual modules and location of SBC entrances (BGS, S, M, and N). 2.3
Figure 2.5. Profile of streamlines at the 1:40 sectional model for the 1996-97 SBC. 2.4
Figure 2.6. Profile of streamlines at the 1:40 sectional model for the 1998 SBC with SWI. 2.4
Figure 2.7. Plan view of forebay at Lower Granite Dam showing location of BGS in the IN position. 2.5
Figure 2.8. Daily total project, powerhouse, and spill discharge at Lower Granite Dam from April 13 to May 31, 1998. ..... 2.6
Figure 2.9. Percentage of total discharge at the SBC, Spill Bays 2-8 (S2-8), Turbines 1-3 (T1-3), and Turbines 4-6 (T4-6) from April 13 to May 31, 1998. ..... 2.8
Figure 2.10. Turbidity (NTU) and temperature (°C) at Lower Granite Dam in spring 1998. ..... 2.8
Figure 2.11. Plan view of total velocity for MAX configuration. 2.9
Figure 2.12. Side view of total velocity at the South and Middle entrances for the MAX configuration. 2.9
Figure 2.13. Plan view of total velocity for IHR configuration. Slice is at depth of second pair of doors. 2.10
Figure 2.14. Side view of total velocity at the South and Middle entrances for the IHR configuration. 2.10
Figure 2.15. Daily percentages of steelhead (ST) and spring/summer chinook salmon (CH) during the spring 1998 study at Lower Granite Dam. 2.11
Figure 2.16. Daily run timing data from the Smolt Monitoring Program at Lower Granite Dam during the spring 1998 study. 2.12
Figure 3.1. SBC entrance configurations tested in spring 1996, 1997, and 1998 at Lower Granite Dam. 3.2
Figure 3.2. Plan view showing location of single-beam transducers deployed at Lower Granite Dam in 1998. ..... 3.5
Figure 3.3. Front view of SBC showing squinted-pair transducers aimed up and down in front of SBC entrances. 3.6
Figure 3.4. Side view of SBC showing squinted-pair transducers in front of SBC entrances. 3.6
Figure 3.5. Side view showing guided, unguided, and pier nose single-beam transducers. 3.7
Figure 3.6. Side view showing a spill bay single-beam transducer. 3.8
Figure 3.7. Schematic of a squinted pair of single-beam transducers and the four possible trace types (termed Z-types). 3.9

Figure 3.8. Location of multi-beam and split-beam transducers in the forebay of Lower Granite Dam during the 1998 behavioral evaluation study. 3.11
Figure 3.9. Floating research platform anchored in front of the SBC at Lower Granite Dam in 1998. 3.12
Figure 3.10. Dual-Head Multi-Beam Sonar detail on floating research platform at Lower Granite Dam in 1998. 3.12
Figure 3.11. Total multi-beam spatial coverage and the seven beam rotation locations. 3.14
Figure 3.12. Lower Granite Dam side view showing the approximate spatial coverage of the multi-beam. 3.14
Figure 3.13. Data processing flow chart. 3.16
Figure 3.14. Plan and side views depicting bins used for data analysis. 3.17
Figure 3.15. Bin system used for depth frequency analysis. 3.17
Figure 3.16. Example of a side view polar histogram. 3.19
Figure 3.17. Example of vector plot components. 3.19
Figure 3.18. Examples of tortuosity values taken from the data set. T = tortuosity. 3.20
Figure 3.19. Images from the visualization tool. 3.21
Figure 3.20. Split-beam transducer and sensor package. 3.22
Figure 3.21. Location of split-beam transducer in the forebay of Lower Granite Dam during the 1998 fish behavior evaluation study. 3.23
Figure 3.22. Data processing and analysis flow chart. 3.25
Figure 4.1. Scatterplot of daily spill efficiency vs. the percentage of total discharge spilled from April 13 to May 31, 1998, for day and night separately. 4.2
Figure 4.2. Scatterplot of daily spill effectiveness vs. the percentage of total discharge that was spilled from April 13 to May 31, 1998, for day and night separately. 4.3
Figure 4.3. Horizontal distribution of fish passage through spill bays at Lower Granite Dam for day and night separately. 4.3
Figure 4.4. Horizontal distribution of total fish passage per total discharge (kcfs) for spill bays at Lower Granite Dam for day and night combined. 4.4
Figure 4.5. Vertical distribution of fish passage for Bays 2-8 combined. 4.4
Figure 4.6. Diel distribution of fish passage for Bays 2-8 combined. 4.4
Figure 4.7. Weekly FGE estimates at Lower Granite Dam from April 13 to May 31, 1998. 4.5
Figure 4.8. Horizontal distribution of FGE (%) for day and night separately. 4.6
Figure 4.9. Day and night horizontal distribution of total fish passage at pier nose sample locations. Turbine 2 was off-line during the entire study. 4.6
Figure 4.10. Vertical distribution of in-turbine passage for all guided and unguided locations combined. 4.7
Figure 4.11. Vertical distribution of pier nose passage presented separately for Turbines 1-3 without the SBC/SWI and Turbines 4-6 with the SBC/SWI. 4.7
Figure 4.12. Diel distribution of fish passage at in-turbine and pier nose sample locations. 4.8
Figure 4.13. BGS diversion efficiency (P_b-corrected) for day, night, and combined. 4.8

Figure 4.14. Day, night, and total (combined) BGS diversion efficiency (P_b-corrected) by block. 4.9
Figure 4.15. Comparison of fish passage percentages by structure for BGS IN and OUT conditions... 4.10
Figure 4.16. Comparison of mean daily passage by day and night for BGS IN and OUT conditions. .. 4.10
Figure 4.17. SBC efficiencies (R_{1-6} and R_{4-6}) for BGS IN and OUT conditions (%). 4.10
Figure 4.18. SBC efficiency estimates (R) for BGS IN and OUT conditions for IHR and MAX configurations combined (%). 4.11
Figure 4.19. SBC effectiveness estimates (E) for BGS IN and OUT conditions for IHR and MAX configurations combined (%). 4.11
Figure 4.20. FGE at Turbines 1-3 (FGE_{1-3}), Turbines 4-6 (FGE_{4-6}), and all turbines (FGE_{1-6}) for BGS IN and OUT conditions (%). 4.11
Figure 4.21. FPE for BGS IN and OUT conditions (%). 4.12
Figure 4.22. SBC efficiency estimates (R) for IHR and MAX configurations (%). 4.12
Figure 4.23. SBC effectiveness (E) estimates for IHR and MAX configurations (%). 4.13
Figure 4.24. SBC efficiency (R_{4-6}) in relation to water temperature (°C) and turbidity (NTU) in 1998. ..... 4.14
Figure 4.25. SBC efficiency (R_{4-6}) in relation to proportion SBC discharge (Q), proportion spill (Q), and lunar phase at Lower Granite Dam in 1998. ..... 4.15
Figure 4.26. Daily SBC efficiency (R_{all}) vs. percentage of SBC flow at Turbines 4-6 from April 13 to May 31, 1998. ..... 4.15
Figure 4.27. Daily SBC efficiency (R_{4-6}) vs. percentage of SBC flow at Turbines 4-6 from April 13 to May 31, 1998. ..... 4.16
Figure 4.28. Daily SBC efficiency (R_{all}) vs. percentage of spill out of total project discharge from April 13 to May 31, 1998. ..... 4.16
Figure 4.29. Daily SBC efficiency (R_{4-6}) vs. percentage of spill out of total project discharge from April 13 to May 31, 1998. ..... 4.16
Figure 4.30. Horizontal distribution of fish passage at the SBC for each configuration (%). 4.18
Figure 4.31. Horizontal distribution of SBC entrance efficiency (N) at the SBC for each configuration. 4.19
Figure 4.32. Vertical distribution of SBC fish passage for each entrance during IHR Configuration ... 4.19
Figure 4.33. Vertical distribution of fish passage into the BGS and Middle entrances of the SBC during MAX Configuration. 4.20
Figure 4.34. Diel distribution of fish passage into the SBC. 4.20
Figure 4.35a-d. Vertical distribution of fish trajectories into the SBC for MAX and IHR configurations and BGS IN and OUT conditions 4.21
Figure 4.36. Plan view of total project fish budget for the run-at-large in spring 1998. ..... 4.23
Figure 4.37. Side view of SBC/T4-6 fish budget for the run-at-large in spring 1998. ..... 4.24
Figure 4.38. Summary of fish passage efficiencies for day, night, and combined. 4.25
Figure 5.1. Scatter plot of tracked fish (top view). 5.2
Figure 5.2. Scatter plot of tracked fish (side view). 5.3

Figure 5.3. Scatter plot of tracked fish (front view as viewed from behind the SBC with the BGS opening on the right and the north opening on the left; not to scale). 5.3
Figure 5.4. Perspective view indicating near, mid, and far ranges from the SBC used to describe depth frequency distributions. 5.4
Figure 5.5. Median depth of fish targets in front of Turbines 4-6 during April-May 1998. 5.4
Figure 5.6. Depth distribution for fish targets in front of Turbines 4-6 in 1998. 5.6
Figure 5.7. Difference (BGS IN minus BGS OUT) in the proportion of the population at each depth 5.7
Figure 5.8. Difference (BGS IN minus BGS OUT) in the number of fish targets at each depth 5.7
Figure 5.9. Perspective view (xz plane) indicating spatial bins and data coverage for the top view. 5.8
Figure 5.10. Perspective view(yz plane) indicating spatial bins and data coverage for the side view. 5.9
Figure 5.11. Perspective view(xy plane) indicating spatial bins and data coverage for the front view. 5.9
Figure 5.12. Observed fish movement top view polar histograms for the IN condition. 5.11
Figure 5.13. Observed fish movement top view polar histograms for the OUT condition. 5.11
Figure 5.14. Observed fish movement side view polar histograms for the IN condition. 5.12
Figure 5.15. Observed fish movement side view polar histograms for the OUT condition. 5.12
Figure 5.16. Observed fish movement front view polar histograms for the IN condition. 5.13
Figure 5.17. Observed fish movement front view polar histograms for the OUT condition. 5.13
Figure 5.18. Swimming effort polar histogram (top view, IN, Ice Harbor configuration, high load). 5.16
Figure 5.19. Swimming effort vector plot (top view, IN, Ice Harbor configuration, high load). 5.16
Figure 5.20. Swimming effort polar histogram (top view, IN, maximum configuration, high load). 5.17
Figure 5.21. Swimming effort vector plot (top view, IN, maximum configuration, high load). 5.17
Figure 5.22. Swimming effort polar histogram (side view, IN, Ice Harbor configuration, high load). 5.18
Figure 5.23. Swimming effort vector plot (side view, IN, Ice Harbor configuration, high load). 5.18
Figure 5.24. Swimming effort polar histogram (side view, IN, maximum configuration, high load). 5.19
Figure 5.25. Swimming effort vector plot (side view, IN, maximum configuration, high load). 5.19
Figure 5.26. Swimming effort polar histogram (front view, IN, Ice Harbor configuration, high load). 5.20
Figure 5.27. Swimming effort vector plot (front view, IN, Ice Harbor configuration, high load). 5.20
Figure 5.28. Swimming effort polar histogram (front view, IN, maximum configuration, high load). 5.21
Figure 5.29. Swimming effort vector plot (front view, IN, maximum configuration, high load). 5.21
Figure 5.30. Speed frequency histograms showing observed fish speeds for the BGS IN and OUT conditions at three ranges (near, mid, far) from the SBC. 5.23
Figure 5.31. Speed frequency histograms showing fish effort for the BGS IN condition at three ranges (near, mid, far) from the dam. 5.24
Figure 5.32. Direction references for the xz plane (top) and the yz plane (bottom). 5.25
Figure 5.33. Observed X, Y, and Z axis speed components with range for the IN condition. 5.27
Figure 5.34. Observed X, Y, and Z axis speed components with range for the OUT condition. 5.28
Figure 5.35. Swimming Effort X, Y, and Z axis speed components with range for the IN condition. 5.30

Figure 5.36. Index of tortuosity with range for the IN and OUT conditions. 5.32
Figure 5.37. Median observed fish speed with range for the BGS IN and BGS OUT conditions. 5.33
Figure 5.38. Bin numbers used for statistical analysis in three layers (surface, middle, and bottom).... 5.34
Figure 5.39. Observed mean fish speed difference (m/s) between the BGS IN minus BGS OUT conditions for each block and the bins in the middle of the water column (i.e., between the SBC and the platform, bins 10, 11, 13, 14). 5.39
Figure 5.40. Observed mean fish speed difference (m/s) between the BGS IN minus BGS OUT conditions for each block and the bins nearest the SBC (bins 1, 2, 4, 5, 7). 5.40
Figure 5.41. Observed mean fish direction difference (angles) between the BGS IN minus BGS OUT conditions for each block and the bins in the middle of the water column (i.e., below the surface, bins 4, 5, 7, 13, 14). 5.43
Figure 5.42. Observed mean fish direction difference (angles) between the BGS IN minus BGS OUT conditions for each block and the bins at the top of the water column (bins 1, 2, 10, 11)..... 5.44
Figure 5.43 Direction references for the xy plane (top) and the xz plane (bottom)..... 5.45
Figure 5.44. Number of fish targets detected for each sample date by the split-beam transducer in front of Turbines 1-3 at Lower Granite Dam. 5.47
Figure 5.45. Number of fish targets/min of sampling time for each sample date in front of Turbines 1-3 at Lower Granite Dam. 5.47
Figure 5.46. Target strength for split-beam study period (April-May 1998) in front of Turbines 1-3 at Lower Granite Dam..... 5.48
Figure 5.47. Top view scatter plot of spatial coverage of the split-beam at Lower Granite Dam. 5.49
Figure 5.48. Side view scatter plot of spatial coverage for the first four horizontal split-beam positions at Lower Granite Dam. 5.49
Figure 5.49. Distribution of average observed fish speed for fish detected in front of Turbines 1-3 in April-May 1998 by the split-beam transducer. 5.50
Figure 5.50. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (day). 5.52
Figure 5.51. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (night)..... 5.53
Figure 5.52. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (side view, 0 to15 m from transducer). 5.54
Figure 5.53. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (side view, 15 to 30 m from transducer). 5.55
Figure 5.54. Average observed fish velocity vectors in front of Turbines1-3 at Lower Granite Dam in spring 1998 (side view, > 30 m from transducer). 5.56
Figure 5.55. Depth frequency distribution for fish targets from the split-beam in front of Turbines 1-3. ..... 5.58
Figure 6.1. Daily run timing data from hydroacoustic (HA) and the Fish Passage Centers SMP at LGR in spring 1998..... 6.1
Figure 6.2. Simple conceptual model of speed and noise exposure as outmigrant smolts move through the Snake and Columbia rivers. 6.9

Figure A.1. Typical single-beam hydroacoustic system used for data collection at Lower Granite Dam in 1998. ..... A.1
Figure A.2 Detectability results for the hydroacoustic systems in 1998. ..... A.6
Figure B.1. Daily spill efficiency (SY) from April 13 to May 31, 1998, not including passage into the SBC. B.1
Figure B.2. Daily spill efficiency (SY) from April 13 to May 31, 1998, including passage into the SBC. B.1
Figure B.3. Daily spill effectiveness (SS) from April 13 to May 31, 1998, not including passage into the SBC. B.2
Figure B.4. Daily spill effectiveness (SS) from April 13 to May 31, 1998, including passage into the SBC. B.2
Figure B.5. Daily SBC efficiency (R) metrics from April 13 to May 31, 1998. ..... B.3
Figure B.6. Daily total fish passage for the SBC (X) and Turbines 1-6 (T1-6), Turbines 4-6 (T4-6), and Turbines 4-5 (T4-5) from April 13 to May 31, 1998. ..... B.3
Figure B.7. Log plot of the HA and SMP run timing indices for spring 1998 at LGR. B.4
Figure B.8. Daily SBC entrance efficiency (N) from April 13 to May 31, 1998. ..... B.4
Figure B.9. Daily SBC effectiveness (E) metrics from April 13 to May 31, 1998. ..... B.4
Figure C.1. Number of targets selected by individual technicians vs. mean number of targets selected by the group of six technicians. C.2
Figure C.2. Quality control comparison for internal and external evaluations showing the number of traces selected in original and reprocessed files. C.4

Tables

Table 2.1. Average daily turbine discharge (kcfs) at Lower Granite Dam in spring 1998. ..... 2.7

Table 2.2. Species composition (percentages) from Smolt Monitoring Program data collected at Lower Granite Dam in spring 1998. ..... 2.11

Table 3.1. Summary of entrance conditions for the SBC configurations tested in 1996, 1997, and 1998. ..... 3.3

Table 3.2 Treatments for two factors with two levels each: SBC configuration (Maximum Area = MAX or Ice Harbor = IHR) and BGS condition (IN or OUT). 3.3

Table 3.3. Treatment schedule for the 1998 evaluation at Lower Granite Dam. 3.4

Table 3.4. Definitions for parameters in the fish passage analysis. 3.10

Table 4.1. Summary of available data for the single-beam systems at Lower Granite Dam during spring 1998. ..... 4.1

Table 4.2. Overall and highest SBC efficiencies and conditions. 4.13

Table 4.3. Summary of significant ANOVA results from the fish passage evaluation. 4.14

Table 4.4. Results from multiple regression analysis. 4.18

Table 4.5. Fish budget coefficients and SBC efficiency for the total project (R_{all}) and for the SBC/Turbines 4-6 ($R_{4\text{-}6}$) for 1997 and 1998 spring data from Lower Granite Dam. 4.22

Table 5.1. Summary of targets and records meeting acceptance criteria, including target maximum statistics for Lower Granite Dam multi-beam sampling in spring 1998. ..... 5.1

Table 5.2. Split-plot analysis of variance for observed fish speed (m/s). 5.35

Table 5.3. F test results from split-plot analysis of variance for observed fish speed (m/s) for all nine bins of water evaluated. 5.36

Table 5.4. Observed fish speed (m/s) means for BGS positions over all six blocks. 5.37

Table 5.5 Observed fish speed (m/s) means for SBC configuration over all six blocks. 5.37

Table 5.6. Observed mean fish speed (m/s) for each block and bin. 5.38

Table 5.7. Observed mean fish speed differences (m/s; BGS IN minus BGS OUT) for each block and bin. 5.38

Table 5.8. Split-plot analysis of variance for observed fish direction (side view, degrees). 5.40

Table 5.9. F test results from split-plot analysis of variance for observed fish direction (degrees) for all nine bins of water evaluated. 5.41

Table 5.10. Observed fish direction (degrees) means for BGS positions over all six blocks. 5.42

Table 5.11. Observed fish direction (degrees) means for SBC configuration over all six blocks. 5.42

Table 5.12. Average and maximum time observed, distance traveled along each axis, and number of pings for individual fish targets detected by the split-beam transducer at Lower Granite Dam in 1998. ..... 5.46

Table 5.13. Number of samples per bin for average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (day). 5.52

Table 5.14. Number of samples in each sampled bin for average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (night). 5.53

Table 5.15. Number of samples in each bin 0-15 m from the transducer for observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998. ..... 5.54
Table 5.16. Number of samples in each bin 15-30 m from the transducer for observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998. ..... 5.55
Table 5.17. Number of samples in each bin >30 m from the transducer for observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998. ..... 5.56
Table 5.18. Number of fish targets by distance from the transducer and depth. 5.57
Table 5.19. Number of fish detected by the split-beam transducer for the entire experimental period. 5.60
Table 5.20. Difference between the number of targets observed at positions 1+2 and 3+4 for four ranges (distance from split-beam transducer) and seven depths along the BGS..... 5.61
Table 5.21. Average observed fish speed (m/s) calculated from targets detected by the split-beam transducer for the entire experimental period 5.62
Table 6.1. Summary of composite fish passage results from hydroacoustics and radio telemetry. 6.2
Table 6.2. Spill efficiency and effectiveness (with 95% confidence intervals) without and with SBC passage in 1997 and 1998 at Lower Granite Dam. 6.3
Table 6.3. FGE estimates (%) from the literature for submerged traveling screens (STS) and extended-length submerged bar screens (ESBS) at Lower Granite and McNary dams. 6.4
Table 6.4. SBC efficiency relative to the entire project (R_{all}), the powerhouse (R_{1-6}), Turbines 4-6 (R_{4-6}), and Turbines 4 and 5 (R_{4-5})..... 6.6
Table A.1. Model and serial numbers for hydroacoustic systems used at Lower Granite Dam in 1998.....A.2
Table A.2. Hydroacoustic system parameters used at Lower Granite Dam in 1998. .....A.2
Table A.3. Echo signal processing parameters used during data collection at Lower Granite Dam in 1998.....A.2
Table A.4. Calibration and equalization data for single-beam hydroacoustic systems used at Lower Granite Dam in 1998. .....A.3
Table A.5. Acoustic detectability parameters and results for the five type of single-beam sample locations at Lower Granite Dam in 1998. .....A.5
Table A.6. Quality control actions in 1998 at Lower Granite Dam.....A.7
Table B.1. Analysis of Variance for R1-6 during the day only. B.5
Table B.2. Analysis of Variance for FGE1-6 during the day only. B.5
Table B.3. Analysis of Variance for SY during the day only. B.5
Table B.4. Analysis of Variance for FPE during the day only. B.6
Table B.5. Analysis of Variance for R1-6 during the night only.....B.6
Table B.6. Analysis of Variance for FGE1-6 during the night only. B.6
Table B.7. Analysis of Variance for SY during the night only. B.7
Table B.8. Analysis of Variance for FPE during the night only. B.7
Table B.9. Analysis of Variance for R1-6 day and night B.7
Table B.10. Analysis of Variance for FGE1-6 day and night.....B.8

Table B.11. Analysis of Variance for SY day and night. B.8
Table B.12. Analysis of Variance for FPE day and night.....B.8
Table C.1. Technician performance results compared to self, group average, and individual technicians.....C..1
Table C.2. Summary of quality control effort for 1998 split-beam hydroacoustic data. C.3
Table C.3. Results of quality control effort for 1998 split-beam hydroacoustic data.....C.3

Abbreviations, Acronyms, and Symbols

ANOVA	Analysis of Variance
BGS	Behavioral Guidance Structure
CBE	Combined bypass efficiency
cfs	Cubic feet per second
DART	Data Access in Real Time
E	SBC effectiveness
ESBS	Extended-length submersible bar screen
FGE	Fish guidance efficiency
FPE	Fish passage efficiency
fps	Feet per second
ft	Feet
IHR	Ice Harbor configuration
kcfs	1000 cubic feet per second
kHz	Kilohertz
LGR	Lower Granite Dam
m	Meters
m/s	Meters per second
m^3/s	Cubic meters per second
MW	Megawatts
MAX	Maximum area configuration
N	SBC entrance efficiency
NMFS	National Marine Fisheries Service
NTU	Nephelometric turbidity units
P_b	BGS diversion efficiency
P_b-corr	P_b corrected for gap passage
PIT	Passive Integrated Transponder
pps	Pings per second
PSC	Prototype Surface Collector
Q	Water discharge
R	SBC efficiency
S_{2-8}	Spill Bays 2, 3, 4, 5, 6, 7, and 8
SBC	Surface Bypass and Collector
SS	Spill effectiveness
SWI	Simulated Wells Intake
SY	Spill efficiency
T_{4-6}	Turbines 4, 5, and 6, etc.
Z1…Z4	Squinted-pair trace type, Z1, etc.

Section 1: Introduction

1.1 Background

The U.S. Army Corps of Engineers, Walla Walla District (Corps) is working to improve juvenile fish protection systems at its four Lower Snake River projects by taking actions to: (1) monitor spill effectiveness, (2) evaluate effectiveness of extended-length submersible bar screens, and (3) develop surface bypass. Results from evaluations of these actions will be included in the Lower Snake River Juvenile Salmon Migration Feasibility Study. The Feasibility Study was mandated by a 1995 National Marine Fisheries Service Biological Opinion (NMFS 1995) and is scheduled for completion in 2000. It will consider the benefits of three system alternatives to juvenile salmonids: existing system, major structural improvements, or natural river. The primary intent of our fish passage and behavior research at Lower Granite Dam was to provide information for the Feasibility Study on the biological performance of surface bypass, spill and screens.

Voluntary spill is widely used on the Columbia and Snake rivers as an interim measure to mitigate the effects of mainstem dams on juvenile salmonid migrations. Spill levels are set to maximum flows where dissolved gas levels do not exceed 120%. This strategy maximizes juvenile spill passage and minimizes harmful effects of gas bubble trauma on both juvenile and adult fish. In the Supplemental Biological Opinion (NMFS 1998), NMFS pointed out that further research on diel spillway passage, spill effectiveness, and spill efficiency are essential to maximize the incremental survival benefits of spill at mainstem dams. The spill effectiveness work at Lower Granite Dam in 1998 followed a similar evaluation conducted in 1997 (Johnson et al. 1998a). Basin-wide reviews of literature on spill passage may be found in Steig (1994) and Giorgi (1996).

Intake screens are used to divert fish from turbines into smolt bypass systems. The screen program began with development of the lower Snake River dams. In recent years, submersible traveling screens at some dams have been replaced with extended-length submersible bar screens, resulting in a 10-15% increase in overall fish guidance efficiency (FGE; Anglea et al. 1998). At Lower Granite Dam extended-length screens were installed in all 18 turbine intakes in early 1996. In 1997, FGE for the run-at-large was 87.4 ± 0.1% (Johnson et al. 1998a) and varied by species; subyearling chinook salmon had the lowest FGE at 42-53% (Adams et al. 1998a). Concerns about limited FGE and adverse effects of the screen bypass system on smolt condition led, in part, to development of surface bypass at mainstem Columbia and Snake river dams.

A surface bypass provides surface flows that juvenile fish, already distributed high in the water column, have an opportunity to discover and use to pass a dam safely (Johnson et al. 1997a). Surface bypass designs, while site-specific, rely heavily on concepts originally developed at Wells Dam (Johnson et al. 1992). At Wells Dam, 89% of all juvenile outmigrants pass in the surface bypass (Skalski et al. 1996). The Corps initiated planning and engineering design work on a prototype surface bypass and collector at Lower Granite Dam in 1995. Prototype surface bypasses are also currently being tested at Bonneville First Powerhouse (Ebberts 1998) and Rocky Reach dams (Peven 1998). In addition, the NMFS Biological Opinion calls for planning and development of surface bypass at John Day and The Dalles dams (NMFS 1995).

Our 1998 surface bypass research at Lower Granite Dam builds on previous studies. Johnson and Dauble (1995) reviewed available biological and hydraulic data and concluded that surface bypass at Lower Granite Dam might be successful because of the surface orientation of smolts and their concentration where the thalweg intersects the middle section of the dam. The prototype SBC was installed at Lower Granite Dam in 1996 and evaluated in 1996, 1997, and 1998. Normandeau et al. (1997) and Bjornn et al. (1997) documented safe passage at the SBC for juvenile and adult salmon, respectively. In 1996, overall efficiency of the SBC relative to Turbines 4-6 was about 40-45% (Adams et al. 1997; Johnson et al. 1997c). Relative to the dam as a whole, SBC efficiency in 1996 was about 10%, but this was because many fish were spilled (total discharge was 123% of normal) without having encountered the SBC. In 1997, another high flow year (154% of normal), the SBC was re-tested with similar results (Adams et al. 1998a; Johnson et al. 1998a). The 1996 and 1997 radio telemetry and hydroacoustic results, which were integrated by Johnson et al. (1997b), showed that the surface bypass concept is valid at Lower Granite Dam, but further improvement in SBC efficiency would be necessary for the SBC to be a viable, long-term smolt bypass. However, even at these performance levels, the SBC offered passage benefits at Lower Granite Dam when used in conjunction with the intake screens.

In 1998, two new major components were added to the prototype SBC. The first structure, called a Simulated Wells Intake was added to decrease smolt entrainment into turbines and increase their availability to the SBC by flattening flow lines in the forebay. The SWI was retrofitted to the powerhouse below the SBC from Intake 4A to Intake 6C. It extended into the intakes at Turbines 4-6 and formed a false intake ceiling. The SWI also effectively lowered the bottom of the SBC by about 6 m to a total depth of 23 m. The second modification, called a Behavioral Guidance Structure, was attached (and unattached for the purpose of evaluation) to the south end of the SBC. The purpose of the BGS was to divert smolts from Turbines 1-3 toward the SBC or spillway. The BGS was a steel wall 335 m long, extending from the SBC upstream to the south shoreline of the forebay. The upstream end of the BGS

was anchored about 30 m offshore to allow adult migrants to pass between the shoreline and the BGS. The BGS was 24 m deep where it intersected with the SBC and tapered to a depth of 16 m at its upstream end.

The focus of our research in 1998 was fish passage and fish behavior. Hydroacoustics was the method chosen for evaluation because it is non-intrusive and capable of a high sampling rate. Different hydroacoustic systems were matched to the specific type of information desired. Specifically, single-beam sonar was used to monitor fish passage and split-and multi-beam sonar were used to monitor fish behavior.

1.2 Goals and Objectives

The goal of the 1998 fish passage research was to measure the performance of spill, intake screens, and the prototype surface bypass structures. The emphasis of this study was on the prototype surface bypass. The main objectives of the fish passage[1] work were to:

- estimate spill efficiency and effectiveness and determine the relationship between these variables and the proportion of water spilled
- characterize spatial and temporal distributions of fish passage at the spillway, in-turbine locations, turbine entrances, and SBC[2]
- estimate overall and weekly fish guidance efficiency and compare to data from previous years
- estimate BGS diversion efficiency
- estimate SBC/SWI efficiency
- estimate trajectory of fish passage into the SBC for each of four treatments separately
- statistically compare performance metrics for the experimental treatments
- summarize fish passage budgets and passage efficiency data.

The aim of the behavioral research was to evaluate the fine-scale fish behavior in front of the prototype SBC. Fish behavior was remotely and non-intrusively assessed fish behavior in the vicinity of

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[1] All fish passage metrics used in this report are defined in Section 3.2.4.

[2] For the purpose of this report, the SBC term includes the SWI modification.

the SBCand BGS. We also reconciled observed fish movements with flow vectors to obtain the fish's swimming effort vector. Specific goals for this year of SBC evaluation were to:

- develop behavioral evaluation metrics based on speed, direction of travel, and fish track characteristics
- examine the potential fish behavioral differences based on SBC gate configuration and BGS condition
- monitor the area behind the BGS (in front of Turbines 1-3) to determine if fish pass through the junction between the SBC and BGS
- continue to build a basis of understanding about the approach dynamics of fish related to the SBC structure.

1.3 Report Contents

This document is the fifth in a series of reports that describe the results of the fixed-location hydroacoustic evaluation of the prototype SBC at Lower Granite Dam in the spring of 1998. Individual reports in this series were prepared according to the following schedule:

- July 1, 1998: Preliminary Draft Report
- August 3, 1998: Preliminary Draft Report
- November 17, 1998: Draft Final Report for Fish Passage
- December 18, 1998: Draft Final Report for Fish Behavior
- February 15, 1999: Final Report

This final report is organized into eight sections: Section 2 describes the study area. Methods for fish passage and behavior are described in Section 3. Fish passage results are presented in Section 4 and fish behavior results in Section 5. These results are discussed in Section 6. Conclusions and recommendations are provided in Section 7. Literature cited is included in Section 8. Appendices A, B, and C provide supplementary information.

Section 2: Study Area Characterization

This section describes the Lower Granite Dam study area, including fish passage structures (the dam, SBC, SWI, and BGS), hydraulic conditions, and migration characteristics in spring 1998.

2.1 Fish Passage Structures

2.1.1 Lower Granite Dam

Lower Granite Dam is located in the Snake River, Washington, at river kilometer 173 (river mile 107.5; Figure 2.1). It is a run-of-river project with an effective height of 47 m and a normal operating range of 1.5 m. The dam has four primary structures: powerhouse, spillway, lock, and earthen dam (Figure 2.2). The powerhouse is located on the south side of the river, the spillway on the south center, a navigation lock on the north center, and an earthen dam on the north side of the river. The powerhouse has six turbines with a total generating capacity of 810 MW. The total hydraulic capacity of the powerhouse is about 3,681 m^3/s (130 kcfs). The powerhouse is 200 m long. Each turbine intake (three per turbine) has an ESBS (Figure 2.3). During spring and summer, the juvenile salmonid migration seasons, the forebay is maintained near the minimum operating pool elevation of 223 m (733 ft) above mean sea level. The spillway is comprised of eight spill bays with Tainter gates and is approximately 156 m long. The crest of each spill bay is at elevation 208 m (681 ft) above mean sea level. The top deck of the dam is at elevation 229 m (751 ft) above mean sea level. A trash boom deflects debris away from the powerhouse toward the spillway (Figure 2.2).

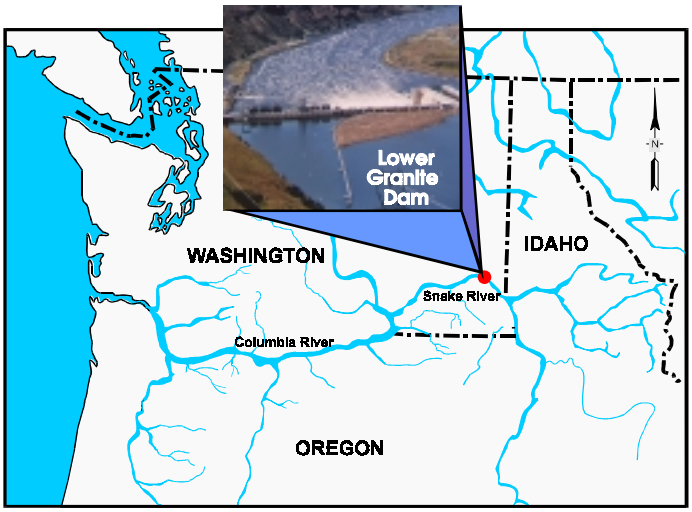


Figure 2.1. Map of Pacific Northwest showing location of Lower Granite Dam on the Snake River.

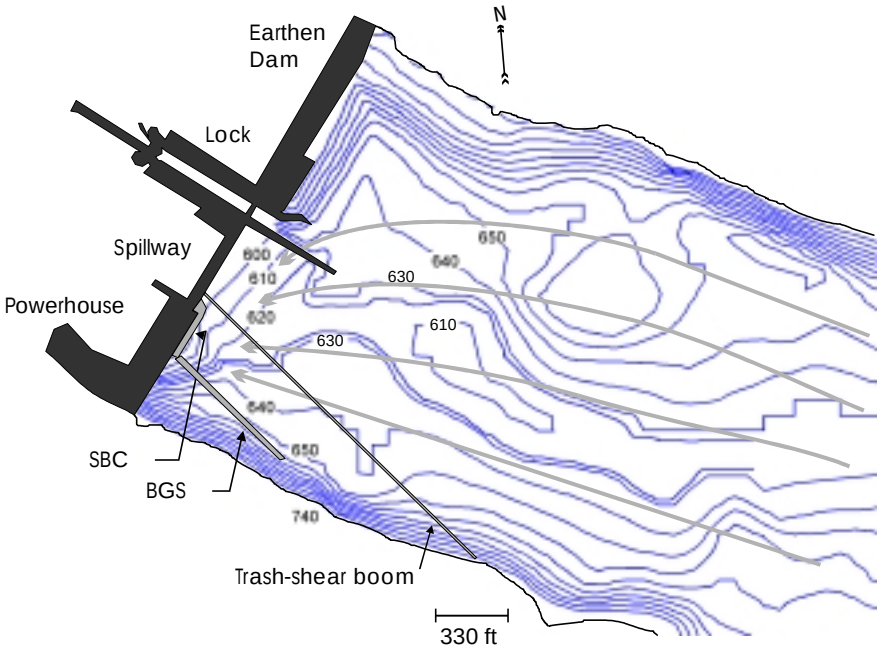


Figure 2.2. Plan view of Lower Granite Dam and forebay showing location of powerhouse, spillway, navigation lock, earthen dam, bathymetry, and general current pattern (arrows). The prototype SBC is located at the north half of the powerhouse. Bathymetry is shown in feet above mean sea level.

The river channel broadens and shifts from northwest to west at a point about 1.5 km upstream from the dam (Figure 2.2). The thalweg is at the north bank at this bend, and then it shifts toward the center of the forebay in this region. The reservoir is relatively wide and deep near the dam. Channel width is about 610 m at the dam, and maximum depths in the forebay are about 41 m at an operating level of 223 m (733 ft) above mean sea level. The thalweg intersects the dam at the junction of the powerhouse and spillway.

2.1.2 Surface Bypass and Collector Prototype (SBC)

The Lower Granite Dam SBC is a steel box 18 m high, 6 m deep, and 100 m long. It has large flotation chambers so that it can move vertically as forebay elevation changes. The four entrances to the SBC are designated BGS, South (S), Middle (M), and North (N) (Figure 2.4). The South, Middle, and North entrances each are six gates high and two gates wide. Gates are 2.3 x 2.3 m, and entrances are about 5 x 15 m. The BGS entrance is equipped with bulkhead channels to allow for modifications to entrance size. The BGS entrance is located over the junction of Turbine Intakes 4A and 4B, the South entrance is over Intake 4C, the Middle entrance is over Intake 5B, and the North entrance is over the junction between Intakes 5C and 6A (Figure 2.4). The BGS and Middle entrances are open to the surface (i.e., have overflow). The tops of the South and North entrances are 2.3 m under water. The gate at Spill

Bay 1, which is also the SBC outfall, regulates flow into the SBC. During the 1998 test, SBC discharge was 113 m^3/s (4,000 cfs). There is no de-watering in the prototype SBC.

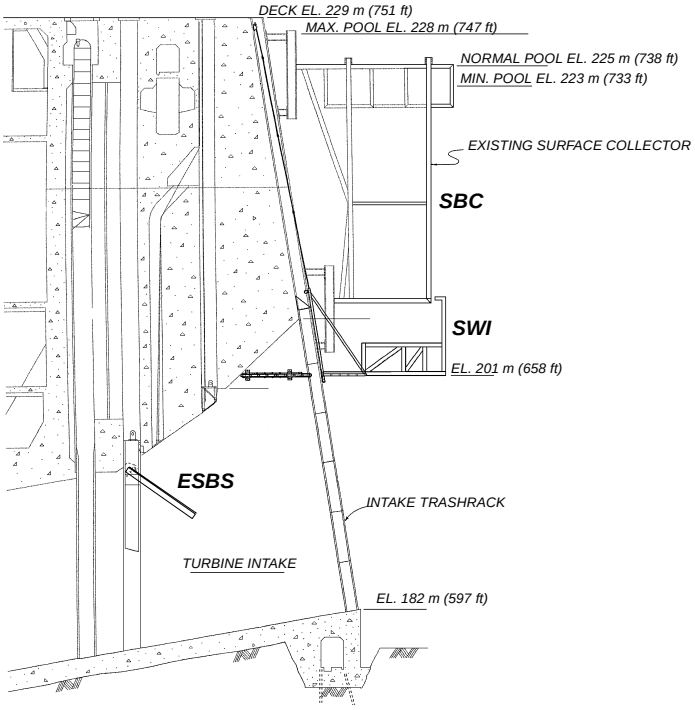


Figure 2.3. Side view of Lower Granite Dam powerhouse showing locations of SBC, SWI, and ESBS.

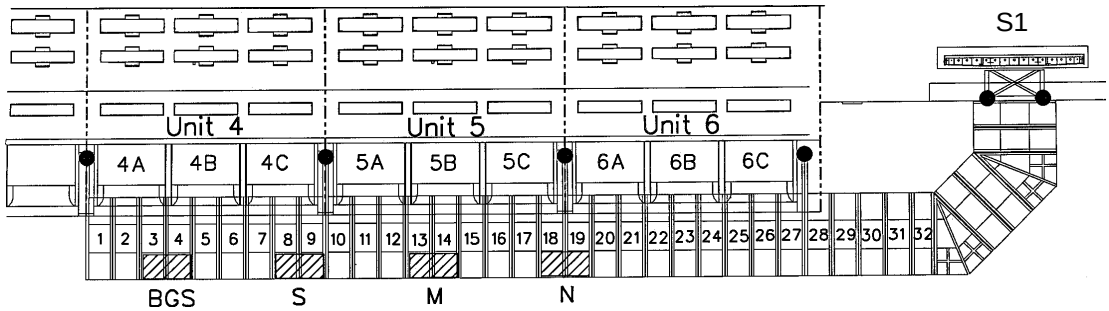


Figure 2.4. Plan view of the SBC showing individual modules and location of SBC entrances (BGS, S, M, and N). SBC discharges exit at Spill Bay 1 (S1), shown on the right part of the figure.

2.1.3 Simulated Wells Intake (SWI)

In 1998, the SWI (Figure 2.3) was retrofitted below the existing SBC. It spans the SBC from Intake 4A to Intake 6C and extends the bottom of the SBC about 6 m. The SWI is secured to the dam while the SBC floats. Thus, the SWI creates a false front and a false bottom for the SBC about 6 m below

the entrances. Because this false bottom to the SBC extends into the turbine intakes, it is, in effect, also a false ceiling for intakes at Turbines 4-6.

SWI hydraulics were studied extensively in 1:25 and 1:40 physical models of Lower Granite Dam at the Waterways Experiment Station in Vicksburg, Mississippi. Model results indicated that the SWI should flatten flow lines into the turbines beneath the SBC and increase the depth of the intermediate zone[1] in front of the SBC (Figure 2.5 and Figure 2.6). As stated earlier, the SWI reduced the downward component of flow in the intermediate zone, 3-30 m from the SBC/SWI. This effect was intended to reduce fish entrainment in turbine flow, and thus improve the opportunity for fish to discover the SBC entrances.

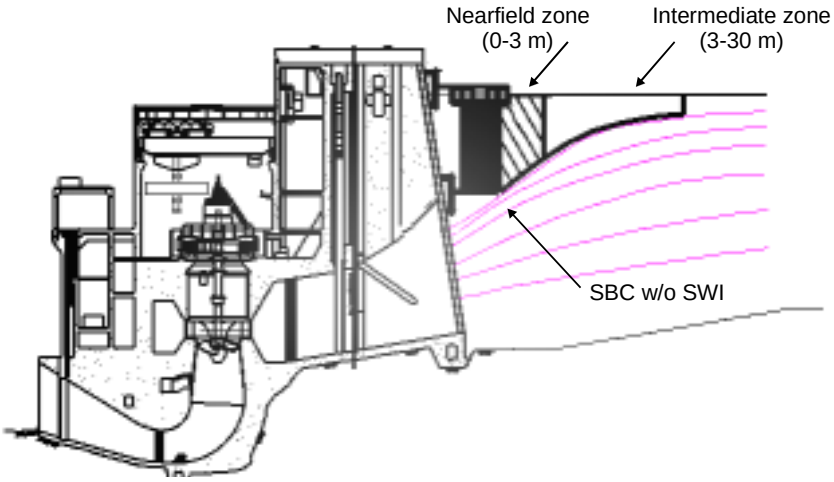


Figure 2.5. Profile of streamlines at the 1:40 sectional model for the 1996-97 SBC.

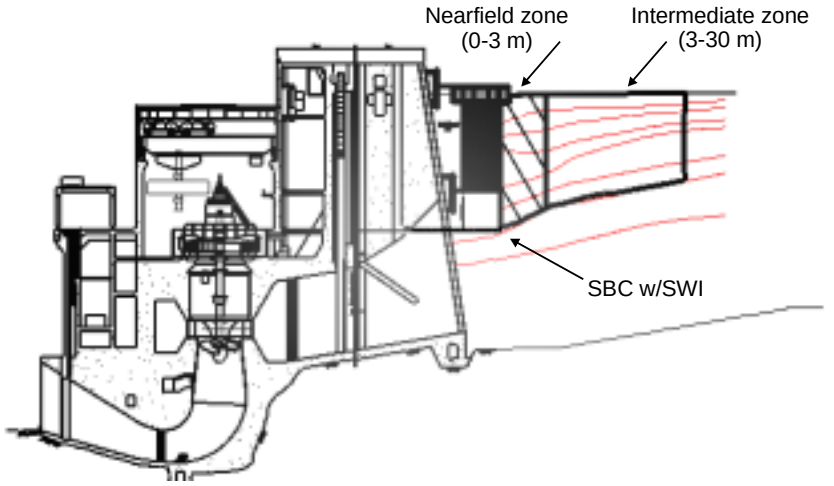


Figure 2.6. Profile of streamlines at the 1:40 sectional model for the 1998 SBC with SWI.

[1] The intermediate zone is defined as the region of the forebay 3-30 m upstream of the SBC.

2.1.4 Behavioral Guidance Structure (BGS)

The purpose of the BGS is to change the horizontal distribution of downstream migrating salmonids on approach to Turbines 1-3 and guide them toward the SBC. The BGS (Figure 2.7) is a steel wall, 335 m long, that comprises a series of 30-m wide steel plates that are supported by floats in a "catamaran" design. In its IN position, the BGS extended from the SBC upstream toward the south shoreline. Its upstream end was anchored approximately 30 m offshore to allow adult migrants to pass between the shoreline and the BGS. The BGS was 24 m deep where it met the SBC and tapered to a depth of 16 m at its upstream end, generally paralleling the incline of the river bottom. The SBC/BGS junction was fitted with a rubber seal and fixed brushes to prevent fish passage through gaps between the two structures.

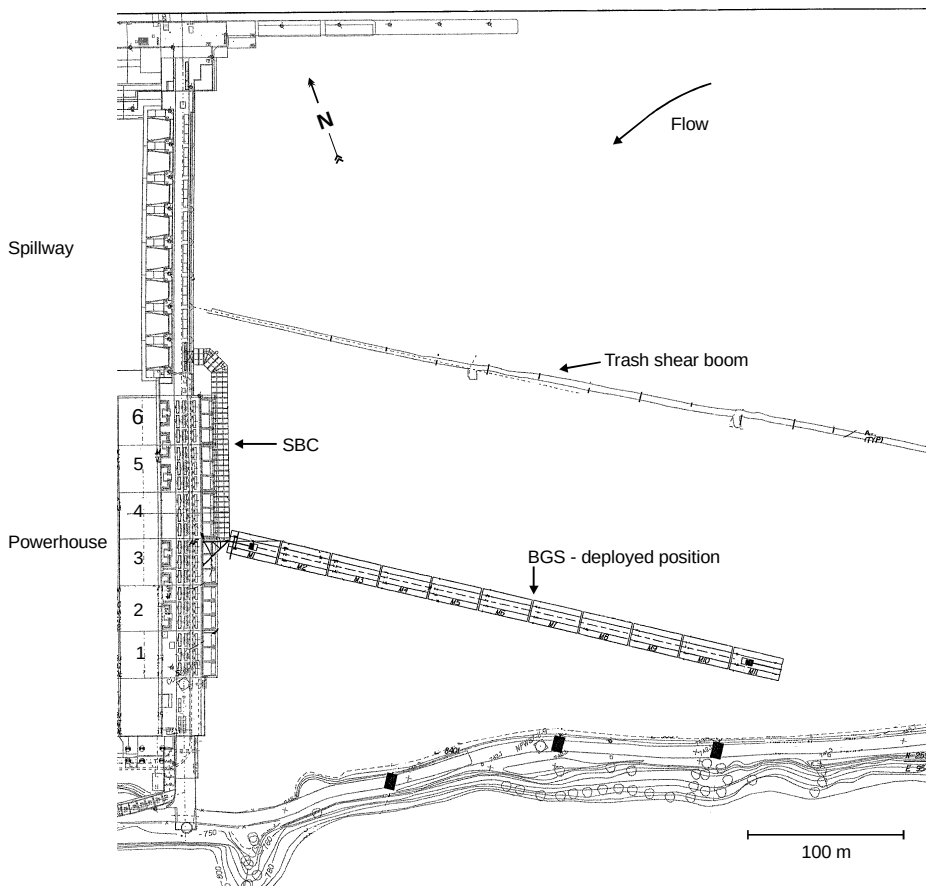


Figure 2.7. Plan view of forebay at Lower Granite Dam showing location of BGS in the IN position. In the OUT position the BGS was pulled about 300 m upstream along the south shore.

2.2 Hydraulic Conditions

River discharge at Lower Granite Dam in spring 1998 was 101% of normal. The "June Final" forecast was 29.9 million acre-feet at Lower Granite Dam for the April-July time period. Daily discharge was 1,557 m^3/s (55 kcfs) at the beginning of the study on April 13 (Figure 2.8). It peaked during the spring study at 6,060 m^3/s (214 kcfs) on May 27.

Turbine unit priority during spring, from first to last unit on, was: 1, 4, 5, 3, 6, 2. The powerhouse in spring 1998 was operated within the 1% peak efficiency guideline. The monitoring and evaluation plan (Walla Walla District 1998) called for Turbines 4-6 to be at the low end of 1% peak efficiency if conditions allowed. This was usually the case from April 13 to May 4 (Table 2.1). From May 5 to the end of the study, Turbines 4-6 were at the high end of 1% peak efficiency. Turbine 1 was usually at high-load, Turbine 2 was off-line throughout the study because of a broken head cover, and Turbine 3 was at low-load except for the last days of the study.

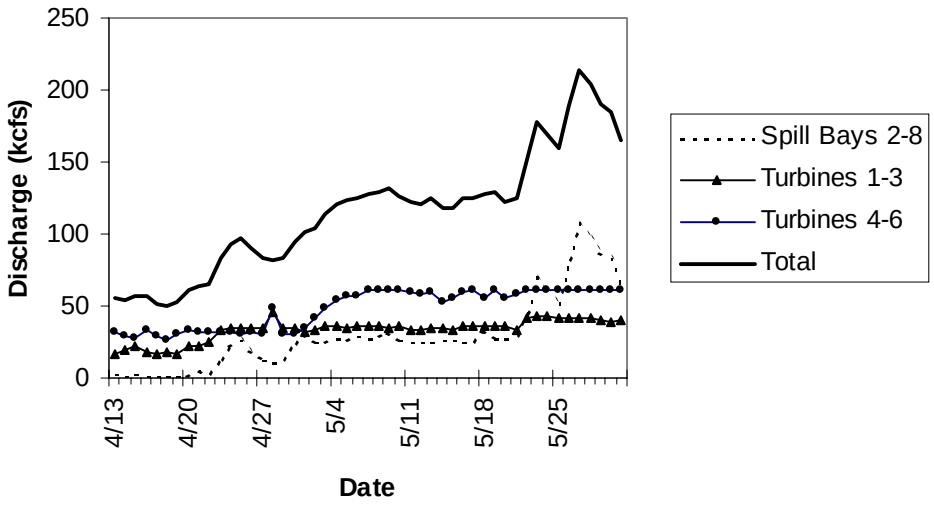


Figure 2.8. Daily total project, powerhouse, and spill discharge at Lower Granite Dam from April 13 to May 31, 1998. (Data from Lower Granite Spill Data Report via http://www.nww.usace.army.mil.)

Table 2.1. Average daily turbine discharge (kcfs) at Lower Granite Dam in spring 1998. Yellow represents low-load conditions, and gray represents high-load conditions. T=turbine. Turbine 2 was off-line.

Block	Date	T1	T3	T4	T5	T6
1	13-Apr	13.5	3.6	16.3	16.3	0.0
	14-Apr	16.3	2.9	16.3	12.9	0.0
	15-Apr	17.9	4.9	17.2	10.8	0.0
	16-Apr	18.5	0.0	16.3	16.3	0.0
	17-Apr	15.4	1.5	17.6	11.5	0.0
2	18-Apr	17.8	0.0	17.7	8.9	0.0
	19-Apr	16.3	0.0	16.5	14.2	0.0
	20-Apr	14.0	8.2	16.4	16.4	0.0
	21-Apr	15.6	6.6	16.3	16.2	0.0
	22-Apr	14.9	10.7	6.8	15.5	10.2
	23-Apr	19.3	14.7	11.5	16.0	4.5
3	24-Apr	19.5	15.4	12.4	15.8	3.4
	25-Apr	19.6	15.4	15.6	15.6	0.0
	26-Apr	19.8	15.5	15.7	15.6	0.0
	27-Apr	19.7	15.3	15.6	15.6	0.0
	28-Apr	19.7	15.3	15.5	15.6	0.0
	29-Apr	19.7	15.4	15.5	15.5	0.0
4	30-Apr	19.6	15.4	15.5	15.5	0.0
	1-May	19.8	12.3	15.6	15.6	2.9
	2-May	19.9	13.6	15.7	15.7	9.8
	3-May	20.0	15.5	15.7	16.8	16.8
	4-May	20.0	15.8	15.6	19.2	19.1
5	5-May	19.9	15.5	17.6	19.6	20.2
	6-May	20.2	15.6	18.0	18.6	20.3
	7-May	20.0	15.5	20.2	20.2	20.4
	8-May	19.8	15.6	20.2	20.2	20.3
	9-May	19.9	15.5	20.3	20.1	20.3
	10-May	19.9	15.6	20.3	20.2	20.4
6	11-May	19.8	13.8	18.7	20.2	20.3
	12-May	19.7	13.5	18.6	20.1	20.2
	13-May	19.8	15.6	19.9	19.9	20.1
	14-May	19.7	15.4	16.9	17.6	18.3
	15-May	19.8	15.5	17.1	20.1	20.3
	16-May	20.1	15.6	19.5	20.1	20.3
7	17-May	20.2	15.5	20.3	20.1	20.3
	18-May	20.1	15.4	20.1	18.4	16.7
	19-May	20.1	15.5	20.3	20.3	20.3
	20-May	19.9	15.5	17.3	18.4	20.2
	21-May	19.0	15.1	17.6	20.1	20.2
	22-May	21.0	21.0	20.2	20.2	20.3
	23-May	21.2	21.1	20.5	20.6	20.5
8	24-May	21.2	21.2	20.5	20.5	20.6
	25-May	21.2	21.2	20.5	20.5	20.5
	26-May	21.1	21.0	20.4	20.4	20.6
	27-May	21.0	20.9	20.3	20.2	20.6
	28-May	21.0	20.9	20.3	20.2	20.3

From April 13 to 20 there was no spill, except for SBC discharge at Bay 1 and additional spill at Bay 2. After this period, spill increased and was used to follow inflow so that discharge at the powerhouse could remain as constant as possible for the purposes of the SBC/BGS test. When there was spill besides that for the SBC, it was usually 24 h/d. Approximately 26% of mean daily flow was spilled at Bays 2-8 during this study (April 13-May 31). Including the SBC, 29% of total discharge was spill (Figure 2.9). The proportion of SBC discharge out of total SBC and turbine discharge was 4.8% and 7.8% at Turbines 1-6 and Turbines 4-6, respectively. SBC discharge was 3% of total project discharge.

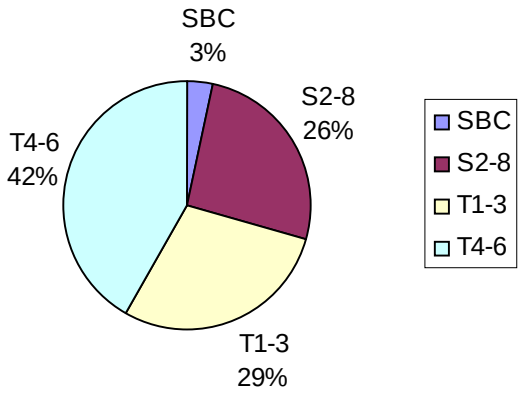


Figure 2.9. Percentage of total discharge at the SBC, Spill Bays 2-8 (S2-8), Turbines 1-3 (T1-3), and Turbines 4-6 (T4-6) from April 13 to May 31, 1998.

Turbidity measurements ranged from 2.4 to 3.3 Nephelometric Turbidity Units (NTU) during the spring study, and demonstrated no overall trend during the study period (Figure 2.10). Temperature increased slightly during the spring evaluation from around 9°C at the beginning of the study to a maximum of 13.3°C on May 21, 1998 (Figure 2.10).

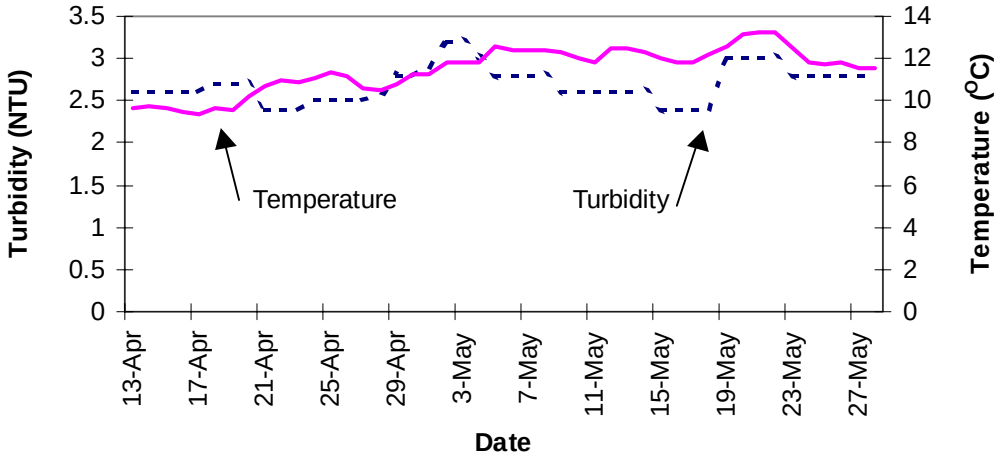


Figure 2.10. Turbidity (NTU) and temperature (°C) at Lower Granite Dam in spring 1998. (Temperature and turbidity measurements from DART http://www.cqs.washington.edu/dart/.)

Water velocity in the forebay of the prototype SBC were modeled by the University of Iowa. Plan and profile views of total velocity are presented for the MAX and IHR configurations. Profile perspectives are for the northern most column of gates in the Middle and South entrances for both SBC configurations. In general, velocity on approach to the SBC gradually decreased from about 1.9 fps at 150 ft from the SBC to 1 fps at 50 ft away (Figure 2.11 through Figure 2.14). For the MAX configuration, the decrease in velocity was most pronounced upstream of the South and BGS entrances

and culminated in "null zone" or localized region of reduced velocity ~0.5 fps at depths <30-40 ft and immediately upstream of the SBC (Figure 2.11). A deep body of water with gradually increasing velocity was present below this decelerating surface layer (Figure 2.12). There was also a "channel" of relatively high velocity into the Middle entrance. This phenomena resulted in flownet for the Middle entrance than that for the South and BGS entrances. At the entrances to the SBC, total velocity increased markedly (e.g., total velocity increased from 1.7 to 2.9 fps in 10 ft at the Middle entrance; Figure 2.11 and Figure 2.12).

The flownet for the Middle entrance in the MAX configuration was the most distinct of the four entrances; it extended upstream in the forebay about 20-30 ft. The entrance flownets were trumpet-shaped and did not appear to overlap even though the entrances were 25 ft apart. An important feature of the flownets were that they changed the natural deceleration of surface water approaching the SBC.

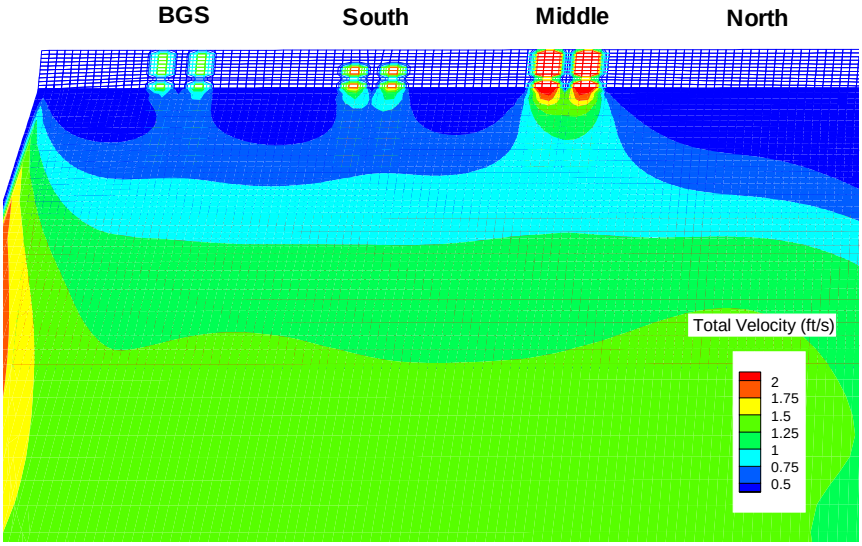


Figure 2.11. Plan view of total velocity for MAX configuration. Slice is at depth of second pair of doors. North entrance is closed. Grid represents front of SBC.

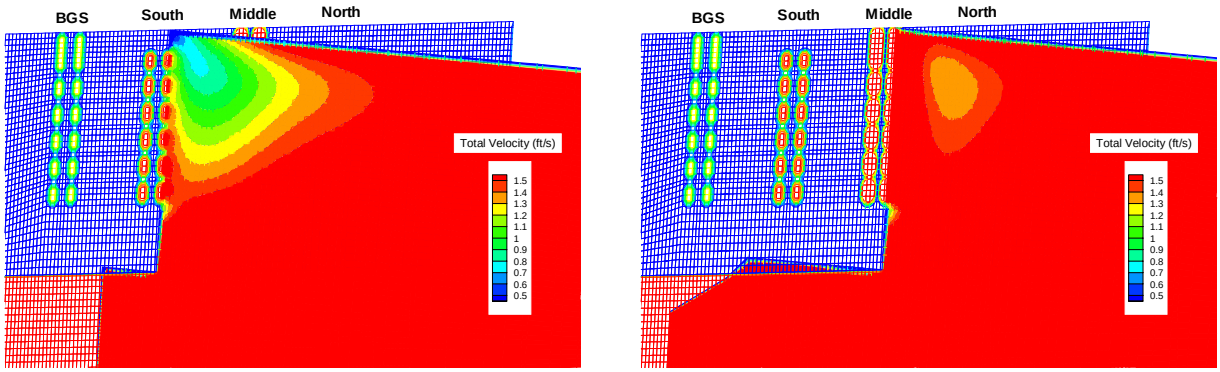


Figure 2.12. Side view of total velocity at the South and Middle entrances for the MAX configuration. Slice is through the middle of the northernmost column of doors. Grid represents front of SBC.

For the IHR configuration, the decrease in velocity was most pronounced at the North and South SBC entrances (Figure 2.13). Channels of relatively high velocity occurred at the BGS and Middle entrance, but the flownet at the Middle entrance extended further into the SBC forebay (Figure 2.13 and Figure 2.14). At the entrances to the SBC, total velocity increased markedly (e.g., total velocity increased from 1.2 to 2.9 fps in 10 ft at the Middle entrance; Figure 2.14). The flownet for the Middle entrance in the IHR configuration was the most distinct of the four entrances (Figure 2.13 and Figure 2.14).

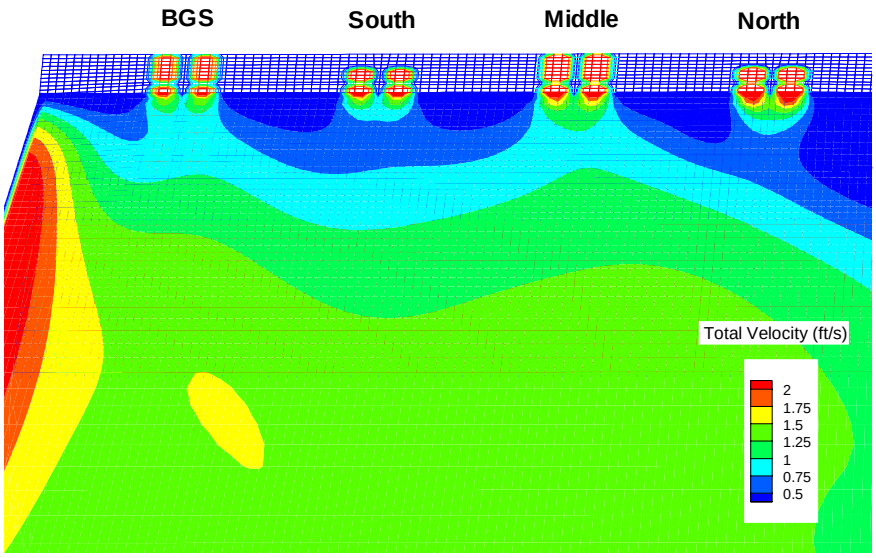


Figure 2.13. Plan view of total velocity for IHR configuration. Slice is at depth of second pair of doors. Grid represents front of SBC.

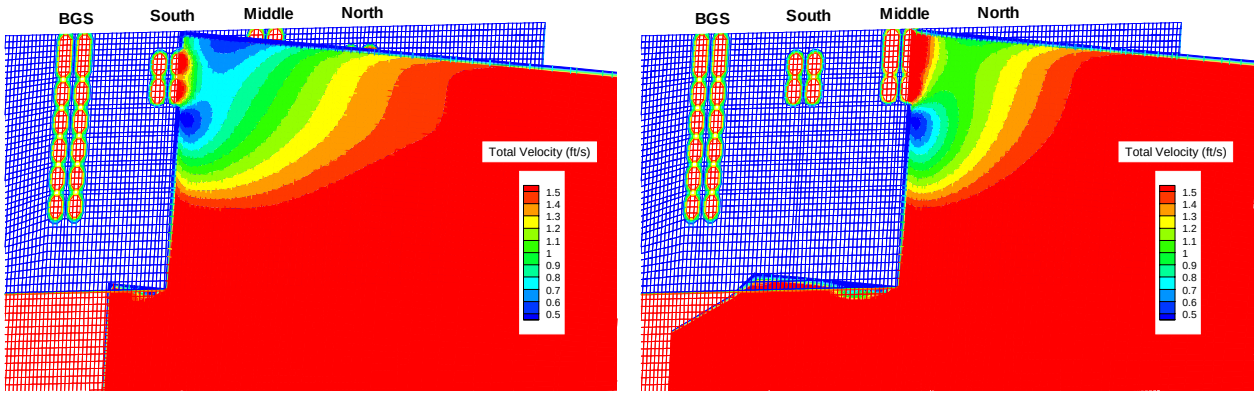


Figure 2.14. Side view of total velocity at the South and Middle entrances for the IHR configuration. Slice is through the middle of the northernmost column of doors. Grid represents front of SBC

2.3 Migration Characteristics

Species composition during the spring study period, as reported by the Fish Passage Center's Smolt Monitoring Program from screen bypass fish samples, was dominated by steelhead trout *(Oncorhynchus mykiss*) (Table 2.2 and Figure 2.15). Hatchery steelhead accounted for 67% of the total Smolt Monitoring Program index in spring. Wild and hatchery yearling chinook salmon *(O. tshawytscha)*, wild steelhead, coho salmon *(O. kisutch)*, and sockeye salmon *(O. nerka)* also migrated through Lower Granite Dam during the spring study. Total fish passage peaked on May 3 (Figure 2.16). Overall, the study period included most of the 1998 spring outmigration (Figure 2.16).

Table 2.2. Species composition (percentages) from Smolt Monitoring Program data collected at Lower Granite Dam in spring 1998.

	Wild	Hatchery	Total
Chinook 0	< 0.1	0	< 0.1
Chinook 1	3.5	18.7	22.1
Coho	0	2.3	2.3
Sockeye	< 0.1	0.7	0.7
Steelhead	8	66.9	74.9
Total	11.5	88.5	100

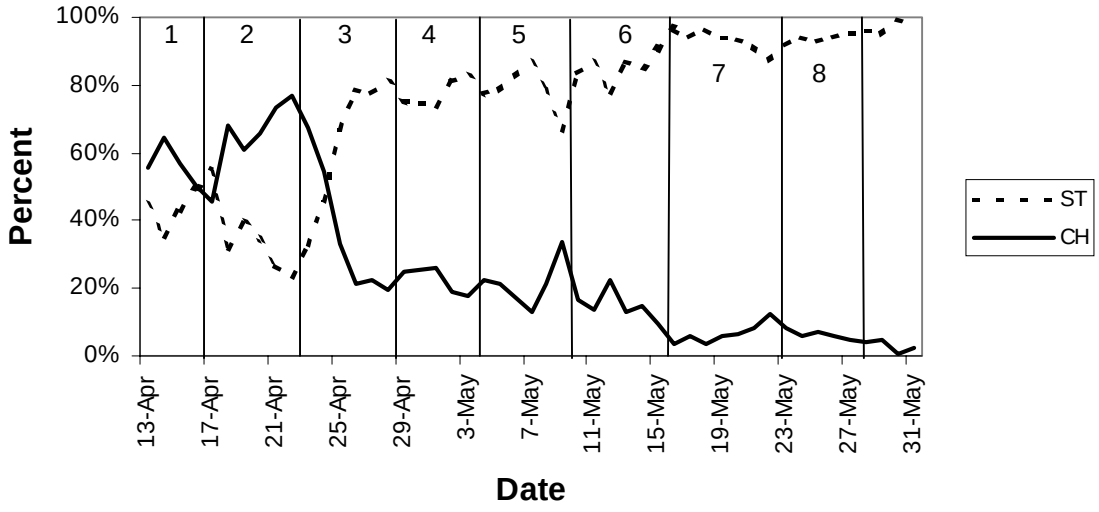


Figure 2.15. Daily percentages of steelhead (ST) and spring/summer chinook salmon (CH) during the spring 1998 study at Lower Granite Dam.

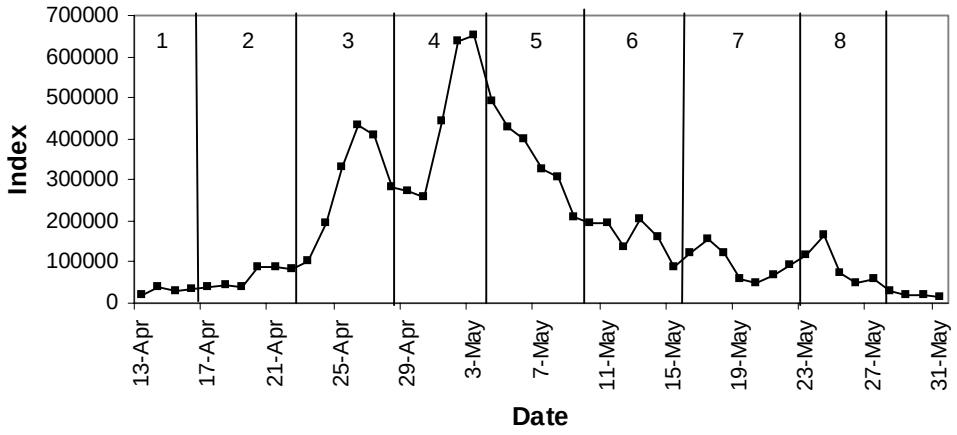


Figure 2.16. Daily run timing data from the Smolt Monitoring Program at Lower Granite Dam during the spring 1998 study. The eight study blocks are delineated. (Data from DART http://www.cqs.washington.edu/dart/.)

Section 3: Study Design and Methods

In this section, we briefly describe the experimental study design and SBC configurations evaluated in the spring 1998 study. A general description of the hydroacoustic methods for the fish passage and behavior evaluations are also presented.

3.1 Study Design and SBC Configurations

In 1998, two SBC configurations (Figure 3.1) were chosen to evaluate whether the efficiency of relatively low entrance velocities with maximum area (MAX) were better than relatively high entrance velocities oriented horizontally near the surface (IHR – Ice Harbor) for a long-term surface bypass design. The MAX and IHR configurations were selected as the most promising to investigate in 1998 based on results from 1996 and 1997 SBC tests at Lower Granite Dam (see Johnson et al. 1997b). Table 3.1 summarizes entrance conditions for each configuration tested in the 1996-1998 SBC evaluations.

The 1998 evaluation of the SBC/SWI and BGS at Lower Granite Dam consisted of a split-plot experimental design with a 2 x 2 factorial treatment design. We analyzed the data as a split-plot experiment and extracted information on SBC/SWI and BGS main effects and interactions. Specifically, the experimental design for 1998 focused on evaluation of two factors, SBC/SWI entrance configuration and BGS presence/absence, each with two levels, giving four treatments (Table 3.2).

We tested the four treatments using a six-day experimental block to accommodate the different test conditions along with two separate days to move the BGS IN or OUT. (The BGS did not always have to be moved between treatment blocks.) These six-day blocks were replicated eight times during the 1998 spring outmigration. The SBC configuration on a BGS-move day was the same as that for the next test day. Biological monitoring data continued to be collected on a BGS-move day. Table 3.3 shows the daily schedule of treatments.

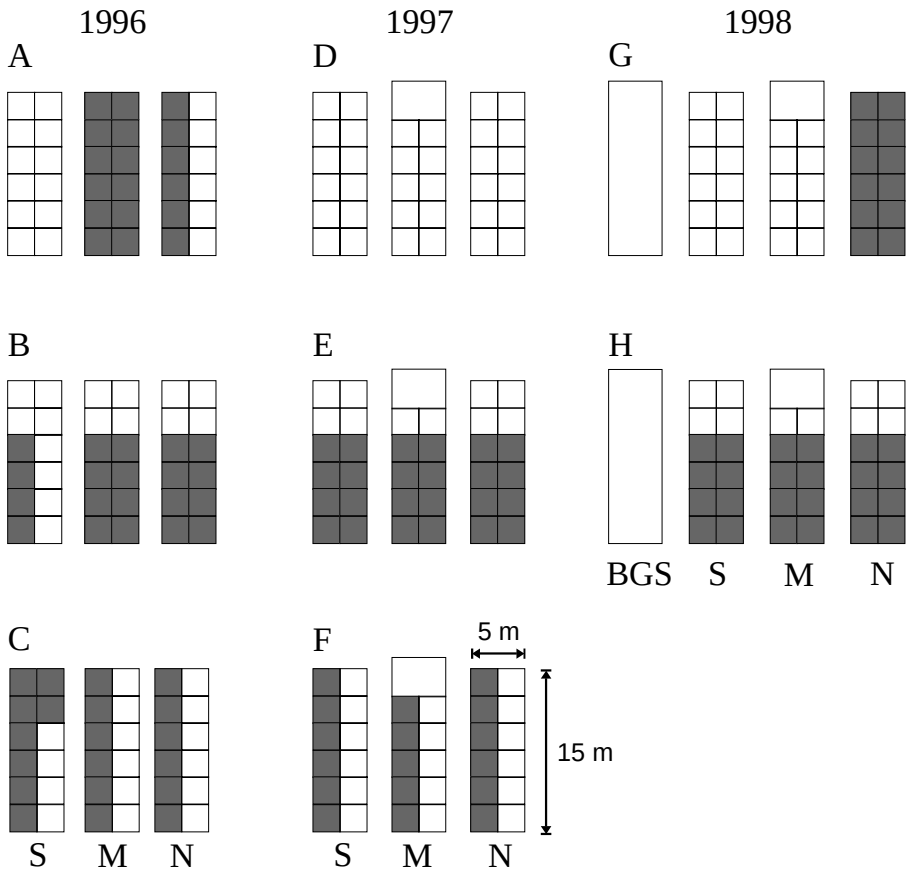


Figure 3.1. SBC entrance configurations tested in spring 1996, 1997, and 1998 at Lower Granite Dam. Shaded areas represent closed gates. The entrances are designated BGS for the SBC opening at the terminus of the BGS, S for South, M for Middle, and N for North. Note that the BGS and Middle entrances open to the surface, i.e., they have overflow into the SBC. Letters A-H correspond to entrance condition descriptions in Table 3.1. Note vertical and horizontal scales on Configuration F.

Table 3.1. Summary of entrance conditions for the SBC configurations tested in 1996, 1997, and 1998. See Figure 3.1 for entrance configurations. BGS = BGS entrance, S = South entrance, M = Middle entrance, N = North entrance, n/a indicates entrance was closed.

		Flow in m^3/s					Flow in cfs				
Code	Name	Total	BGS	S	M	N	Total	BGS	S	M	N
A	Low velocity vertical	60	n/a	39	n/a	21	2100	n/a	1359	n/a	741
B	Ice Harbor	110	n/a	53	28	30	3900	n/a	1856	971	1073
C	High velocity vertical	110	n/a	26	40	45	3900	n/a	906	1403	1591
D	Maximum area	113	n/a	22	36	55	4000	n/a	782	1272	1946
E	Ice Harbor	113	n/a	32	45	37	4000	n/a	1140	1572	1288
F	High velocity vertical	113	n/a	27	48	38	4000	n/a	958	1696	1346
G	Maximum area	113	23	30	60	n/a	4000	817	1051	2132	n/a
H	Ice Harbor	113	49	16	26	23	4000	1719	570	918	793

		Mean velocity in m/s				Mean velocity in fps			
Code	Name	BGS	S	M	N	BGS	S	M	N
A	Low velocity vertical	n/a	0.6	n/a	0.7	n/a	2.1	n/a	2.3
B	Ice Harbor	n/a	1.3	1.2	1.6	n/a	4.4	4	5.3
C	High velocity vertical	n/a	1.3	1.3	1.5	n/a	4.1	4.4	5
D	Maximum area	n/a	0.4	0.6	0.9	n/a	1.2	1.8	3
E	Ice Harbor	n/a	1.7	1.7	1.9	n/a	5.6	5.6	6.3
F	High velocity vertical	n/a	0.9	1	1.3	n/a	3	3.4	4.2
G	Maximum area	0.3	0.5	0.9	n/a	1.1	1.6	2.9	n/a
H	Ice Harbor	0.7	0.9	1	1.2	2.4	2.8	3.2	3.9

Table 3.2 Treatments for two factors with two levels each: SBC configuration (Maximum Area = MAX or Ice Harbor = IHR) and BGS condition (IN or OUT). Configurations are shown Figure 3.1.

	BGS IN	BGS OUT
SBC MAX	1	3
SBC IHR	2	4

Table 3.3. Treatment schedule for the 1998 evaluation at Lower Granite Dam. SBC configuration and BGS condition changes started at 0700 h on the calendar date shown. It took 20 min to change the SBC and 4 to 8 hrs to move the BGS. MAX = maximum area configuration and IHR = Ice Harbor configuration.

Month	Date	Block	BGS	SBC	Month	Date	Block	BGS	SBC
April	13	1	IN	MAX	May	11	6	Move	IHR
	14	1	IN	IHR		12	6	OUT	IHR
	15	1	Move	IHR		13	6	OUT	MAX
	16	1	OUT	IHR		14	6	Move	MAX
	17	1	OUT	MAX		15	6	IN	MAX
	18	2	Move	IHR		16	6	IN	IHR
	19	2	IN	IHR		17	Extra	IN	IHR
	20	2	IN	MAX		18	7	Move	IHR
	21	2	Move	IHR		19	7	OUT	IHR
	22	2	OUT	IHR		20	7	OUT	MAX
	23	2	OUT	MAX		21	7	Move	IHR
	24	3	Move	IHR		22	7	IN	IHR
	25	3	IN	IHR		23	7	IN	MAX
	26	3	IN	MAX		24	8	IN	IHR
	27	3	Move	MAX		25	8	IN	MAX
	28	3	OUT	MAX		26	8	Move	IHR
	29	3	OUT	IHR		27	8	OUT	IHR
	30	4	OUT	IHR		28	8	OUT	MAX
May	1	4	OUT	MAX		29	Extra	OUT	OFF
	2	4	Move	IHR		30	Extra	OUT	OFF
	3	4	IN	IHR		31	Extra	OUT	OFF
	4	4	IN	MAX					
	5	5	Move	MAX					
	6	5	OUT	IHR					
	7	5	OUT	MAX					
	8	5	Move	MAX					
	9	5	IN	MAX					
	10	5	IN	IHR					

3.2 Fish Passage Methods (Single-Beam)

In this section we describe single-beam transducer locations and orientations, system performance, fish trace types from squinted-pairs, and analysis methods. Critical parameters for the single-beam hydroacoustic technique are provided in Appendix A. Hydroacoustic techniques were "fixed-location" in that transducer mount locations and orientations were constant.

3.2.1 Single-Beam Transducer Locations and Orientations

Seven single-beam systems were used for fish passage research in 1998. A total of 54 single-beam transducers (nominal operating frequency of 420 kHz) were used to evaluate fish passage at 42 locations (Figure 3.2). Fish passage data were collected at all four SBC entrances, nine of 15 turbine intake screens[1], five of 18 powerhouse pier noses, and at all seven available spill bays. All systems were calibrated before and after the study. The following descriptions focus on the locations and orientations of the single-beam transducers.

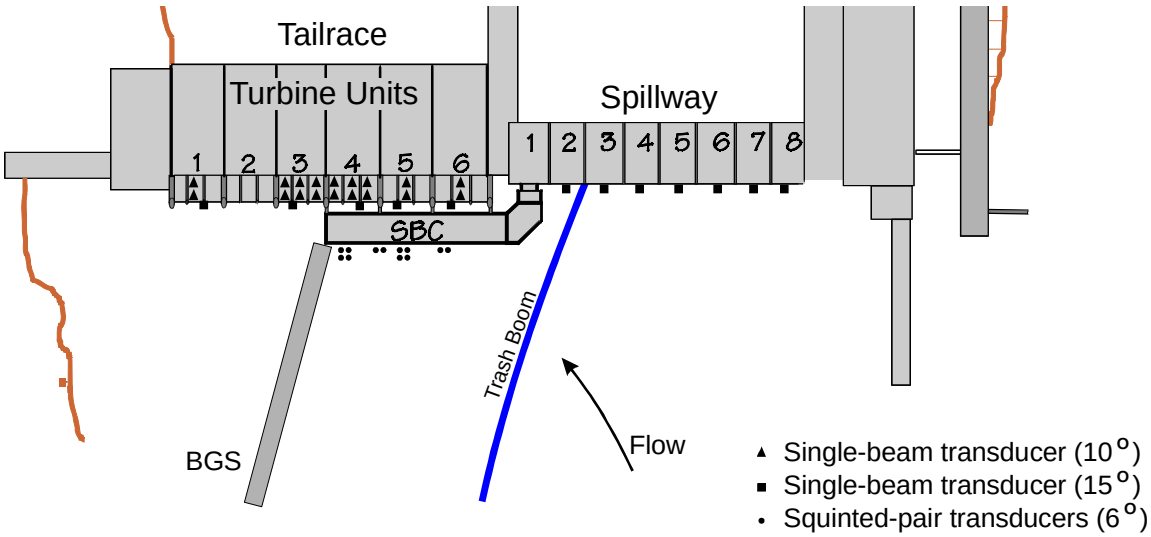


Figure 3.2. Plan view showing location of single-beam transducers deployed at Lower Granite Dam in 1998. The squinted-pair symbol represents two transducers.

<u>Systems 1 and 2 - SBC:</u> Twelve modified squinted-pairs of 6° transducers, pulsed at a rate of 20 pings per second (pps) and sampled fish passage at the SBC. Squinted-pairs were aimed up from the bottom of the BGS, South, Middle, and North entrances (Figure 3.3 and Figure 3.4). In addition,

squinted-pairs were aimed down from surface of the BGS and Middle entrances. The up- and down-looking transducer combinations provided complete vertical coverage at the BGS and Middle entrances. Single-axis rotators were used to aim the transducer beams as close to the SBC openings as was physically possible[2].

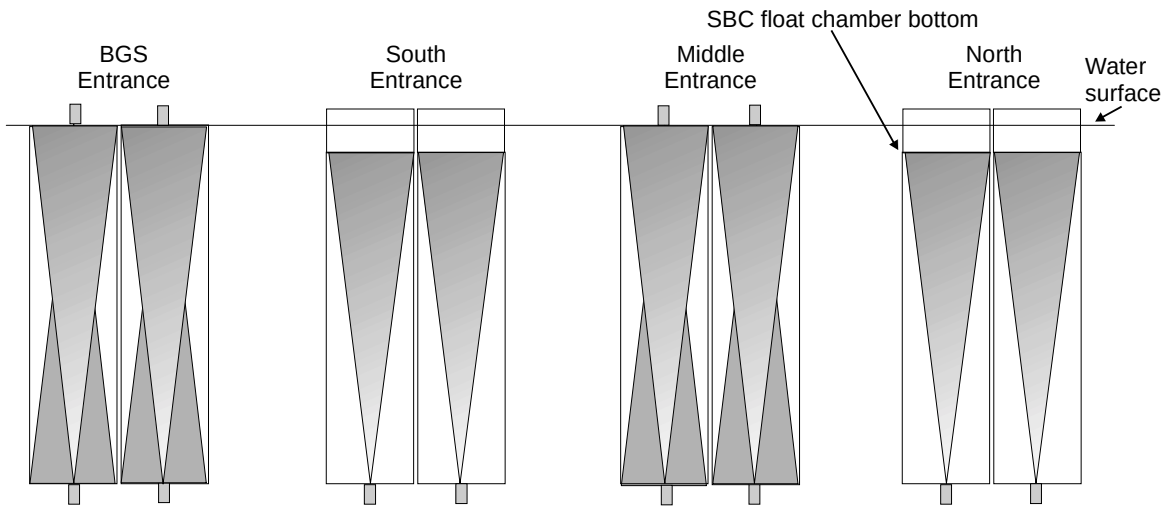
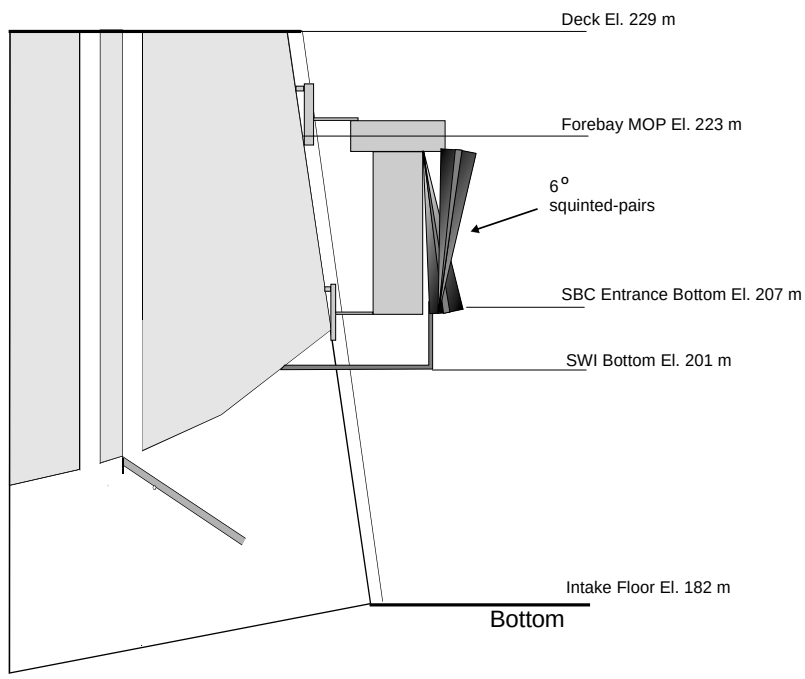


Figure 3.3. Front view of SBC showing squinted-pair transducers aimed up and down in front of SBC entrances.



[1] Turbine 2 was off-line the entire study.
[2] SBC squinted acoustic beams sampled from immediately in front of an entrance, out about 3 m into the SBC forebay at maximum range.

Figure 3.4. Side view of SBC showing squinted-pair transducers in front of SBC entrances.

Systems 3, 4, and 5 - FGE: Eighteen 10° transducers sampled guided and unguided fish separately at the ESBSs in nine intakes (1B, 3A, 3B, 3C, 4A, 4B, 4C, 5B, and 6B). As in past years, each operating "B" slot was sampled, and in 1998 all intakes in Turbines 3 and 4 were sampled due to their position behind the junction of the SBC/SWI and BGS. The transducers pulsed at 20 pps. Fish guided by the intake screen were enumerated with a transducer mounted on the tip of the screen and aimed up the face of the intake screen toward the intake ceiling (Figure 3.5). This transducer was aimed 25° off the face of the screen. Unguided fish were sampled with a transducer mounted to the top and back of the intake screen frame. This transducer was aimed down the back of the screen toward the intake floor. Fish were counted as they passed below the tip of the intake screen (Figure 3.5).

System 6 - Powerhouse Pier Noses: At pier noses of Turbines 1, 3, 4, 5, and 6, 15° transducers were mounted on sleds, aimed up approximately 10° from vertical, canted toward the center of an adjacent intake, and lowered to the bottom of the forebay (Figure 3.5). The transducers pulsed at 10 pps. One of three intakes from each operating turbine was evaluated. The intakes sampled were randomized for each half of the powerhouse separately with the constraint that an equal number of A, B, and C intakes be sampled. The intakes sampled were 1C, 3A, 4C, 5B, and 6A.

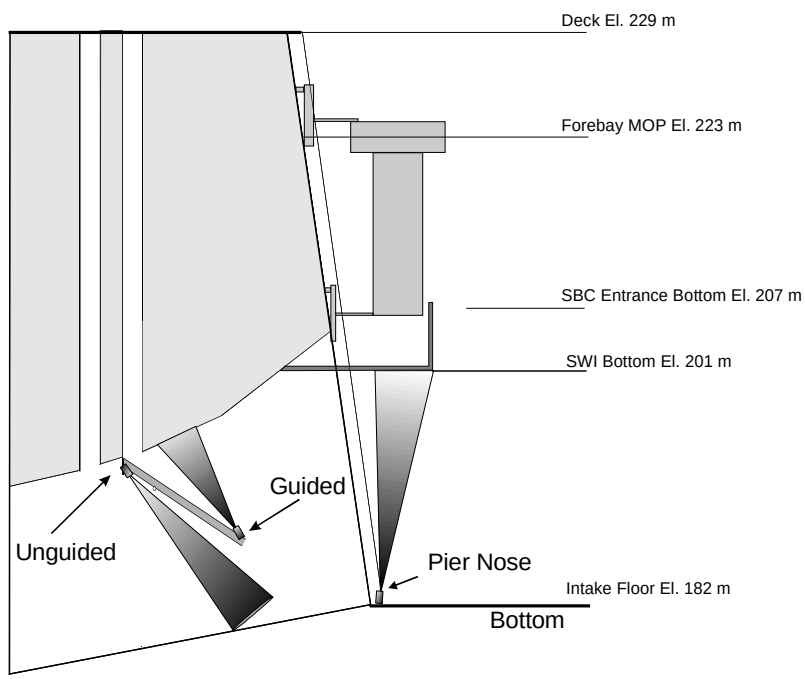


Figure 3.5. Side view showing guided, unguided, and pier nose single-beam transducers.

System 7 - Spillway: At Spill Bays 2, 3, 4, 5, 6, 7, and 8, we deployed 15° transducers just below the water surface in the center of the each bay. The transducers were aimed down and canted about 10° upstream (Figure 3.6) and pulsed at 10 pps.

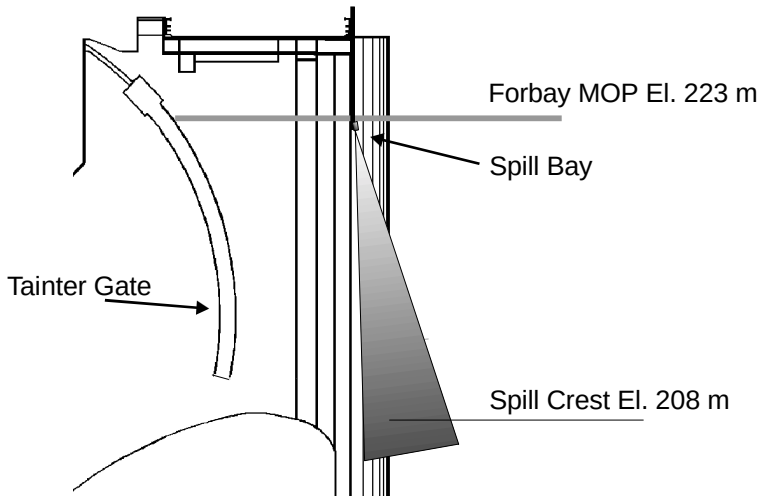


Figure 3.6. Side view showing a spill bay single-beam transducer.

3.2.2 Fish-Trace Types from SBC Modified Squinted-Pairs

In squinted-beam[1] data, there were four possible trace types, called Z-types. These trace types were used to determine total available fish at and fish passage into the SBC entrances (Figure 3.7). We detected fish on just the downstream transducer (Z1), just the upstream transducer (Z2), entering on the upstream and exiting on the downstream transducer (Z3), or entering on the downstream transducer and exiting on the upstream transducer (Z4). The classification of fish *entering the SBC* was critical in determining fish passage rates. We classified fish moving from upstream to downstream (Z3) as entering the SBC. We also classified fish detected on just the downstream transducer (Z1) as entrants because the acoustic beam was directly in front of the opening with entrance velocities of 0.3-1.2 m/s (1-4 fps). The squinted-beams were arranged so that we observed fish moving along the face of the SBC, or at least not exactly perpendicular to it. We assumed fish could enter the SBC without a Z3 trace type. This assumption was assessed with radio telemetry data. Adams and Rondorf (1998) determined the following percentages of radio-tagged fish within 2 m of each entrance that entered the SBC: BGS entrance 64%, South entrance 94%, Middle entrance 92%, and North entrance 91%. Thus, it was necessary to use these data to adjust the Z1 passage rate data. Passage rates for Z1 and Z3 were summed to get total passage

into the SBC. We estimated passage rates for each Z-type then summed all Z-types to determine total available fish at the SBC entrances. This process assumes that each fish is detected only once.

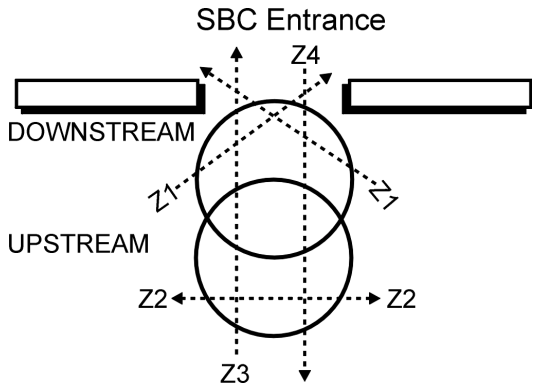


Figure 3.7. Schematic of a squinted pair of single-beam transducers and the four possible trace types (termed Z-types). Circles represent the cross-section of squinted-beam transducers.

3.2.3 Analysis Methods

Table 3.4 shows the analysis parameters used in the single-beam analysis. These parameters are similar to those used in 1997 (Johnson et al. 1998a). Results from BGS move days are not included in the BGS performance or statistical analysis sections. The estimates of variances for the single-beam data include temporal and some spatial variation associated with the way data were collected. Sources of error from seasonal and spatial variation across sample locations (e.g., a spill bay) are not included. Confidence intervals (brackets in bar graphs) are at the 95% level. Day is defined as 0600-2000 h and night as 2000-0600 h.

The primary of metrics of spillway performance are spill efficiency (SY) and spill effectiveness (SS). Spill efficiency is the number of fish passing over the spillway divided by the total project passage. Spill effectiveness is the proportion of fish spilled, divided by the proportion of water spilled. Transducers attached to the ESBS collect fish passage data used to determine FGE. FGE is defined as the number of fish guided by the ESBS divided by guided plus those fish not guided by the ESBS.

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[1] In a true squinted-beam approach, the transducers transmit simultaneously. We alternated transmit pulses between each transducer in a squinted-pair at 10 pps or 20 pps total.

Table 3.4. Definitions for parameters in the fish passage analysis.

Parameter	Descriptor	Estimator
CBE	Combined bypass efficiency shows non-turbine passage at the powerhouse, including the SBC	CBE = (X+G)/(X+G+U), where X = SBC passage, G = guided passage, and U = unguided passage
E	Effectiveness expresses SBC efficiency relative to discharge at turbines and the SBC	E = R/(f/(f+F)), where R = SBC efficiency, f = SBC discharge, and F = powerhouse discharge
FGE	Fish guidance efficiency depicts intake screen performance	FGE = G/(G+U)
FPE	Fish passage efficiency depicts non-turbine passage at the entire project	FPE = (X+G+S)/TOT, where S = spill passage and TOT = X+G+S+U
N	Entrance efficiency expresses SBC passage relative to available fish near open SBC entrances (within 3 m)	N = X/A, where A equals the total number of fish detected at the SBC entrances
Pb	BGS diversion efficiency shows fraction of fish intended for Turbines 1-3 that are diverted to the north	Pb = 1 – (PIN/POUT), where PIN = proportion at Turbines 1-3 with the BGS IN and POUT = proportion at Turbines 1-3 with the BGS OUT
Pb-corr	Pb corrected using radio telemetry data for passage through the upstream gap[1]	Pb-corr = Pb+(1–Pb)*(#gap/(#gap+#under)), # under = 3, # gap = 3
$\mathbf{R_{4\text{-}5}}$	SBC efficiency that expresses SBC passage relative to passage at Turbines 4-5	R4-5 = X/(X+T4-5), where T4-5 = Turbine 4-5 passage
$\mathbf{R_{4\text{-}6}}$	SBC efficiency that expresses SBC passage relative to passage at Turbines 4-6	R4-6 = X/(X+T4-6), where T4-6 = Turbine 4-6 passage
$\mathbf{R_{1\text{-}6}}$	SBC efficiency that expresses SBC passage relative to passage at Turbines 1-6	R1-6 = X/(X+T1-6), where T1-6 = Turbine 1-6 passage
$\mathbf{R_{all}}$	SBC efficiency that expresses SBC passage relative to total project passage	Rall = X/TOT
SS	Spill effectiveness shows the relationship between proportion of fish spilled and proportion of water spilled	SS = SY/(q/Q), where SY = spill efficiency, q = spill discharge, and Q = total project discharge
SY	Spill efficiency shows the proportion of fish spilled	SY = S/TOT

3.2.4 Estimation of Missing Data

Missing hourly passage and variance data, less than six hours in duration, were estimated by using adjacent hours of good data. The interpolation procedure determined estimates for the missing block by averaging a number of hourly measurements preceding and following the missing data block, equal to the number of missing hours (i.e., for a 4 hr missing data block, 4 hrs preceding and 4 hrs following were averaged). All hours within the missing data block received the same passage and variance estimates. For missing data blocks greater than 6 hrs, a regression estimator was used to estimate missing values on an hourly basis along with associated variances (Snedecor and Cochran 1989).

[1] This assumes that the upstream gap can be successfully modified to close-off juvenile passage while allowing adult passage.

3.3 Fish Behavior Methods (Multi-Beam)

The behavioral component of the 1998 study was comprised of two parts: a Dual Head Multi-Beam Sonar system for evaluating fish behavior in front of the SBC/SWI/BGS and a split-beam component for evaluating behavior behind the BGS, particularly at the junction of the SBC and BGS.

3.3.1 Multi-Beam Deployment and Data Collection

Multi-Beam Deployment: The location of the multi-beam hydroacoustic system used to collect fish behavior data is illustrated in (Figure 3.8).

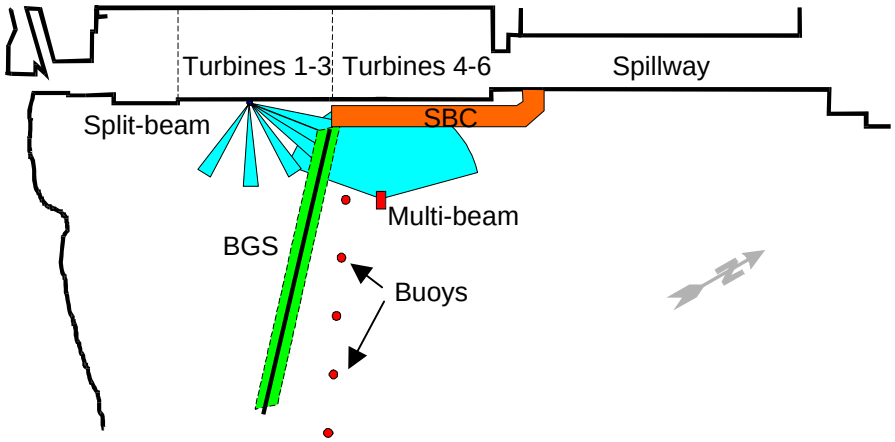


Figure 3.8. Location of multi-beam and split-beam transducers in the forebay of Lower Granite Dam during the 1998 behavioral evaluation study.

This system was deployed from an aluminum floating platform moored in the forebay of Lower Granite Dam (Figure 3.9 and Figure 3.10). The floating platform was initially secured with three 2,000-lb drop-anchors attached to buoys. Two Simrad SM2000™ sonar heads (multiple transducers and associated underwater electronics) were mounted near the end of a 4-m (3.4-m submerged) pole. The sonar heads were oriented at a 90° rotation to one another referenced to the primary axis of the two beams. The region of overlap of the horizontal and vertical beams was the volume sampled for fish tracking. The vertical aiming angle of the pole mount was controlled by rotating the transducers on their mounting plates. The orientation of the pole was monitored continuously by an Applied Micro Systems© fluxgate compass and dual-axis tilt sensor attached to the top of the transducer pole. The position of the floating platform relative to the dam was monitored at approximately 1-sec intervals using an MDL Laser Radar Fanbeam MKIII™ (Fanbeam). Prisms were placed at both the upstream and downstream ends of the floating platform for additional orientation data. Power and data telemetry were attached to a ¼-in.

steel cable umbilical belayed to the SBC structure at the middle SBC entrance. Cables were routed along the SBC and below the spillway deck to permit operation of the gantry cranes and allow for road traffic across the dam.

Figure 3.9. Floating research platform anchored in front of the SBC at Lower Granite Dam in 1998. (SBC structure shown in the foreground of the photo).

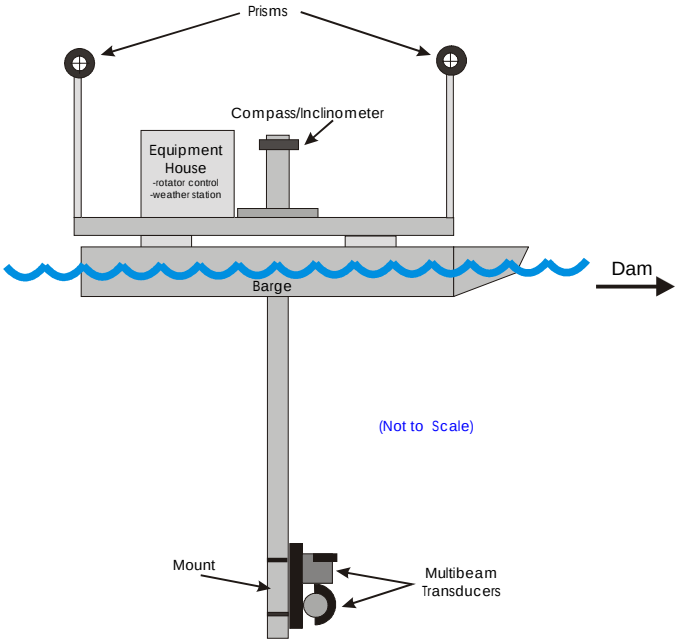


Figure 3.10. Dual-Head Multi-Beam Sonar detail on floating research platform at Lower Granite Dam in 1998.

Collecting precise fish track data from a floating platform in the forebay of a hydropower project is problematic under the best circumstances. In 1998, we dealt with additional adversities, including anchoring challenges related to the BGS operation, moving tie-off points, and a severed telemetry cable resulting from BGS operation. However, we were able make the necessary adjustments to the data.

Initial deployment of the floating platform was planned for a position approximately 50 m from the face of the SBC. However, due to the nature of the BGS deployment and ultimate anchoring scheme, the platform was moved to approximately 40 m from the face of the SBC. The anchors were removed and the platform was tied off to an upstream trash shear boom float and two points on the SBC. The modified position prevented us from interrogating the entire vertical extent of the water column. We rotated the transducers slightly downward to capture data closer to the bottom of the SWI. The system collected data 24 h/d from 1 m in front of the transducers (blanking range) to within approximately 6 m of the SBC. Both horizontal (Figure 3.11) and vertical (Figure 3.12) coverage was approximately 27 m at the maximum range for the beam location. The vertical coverage was extended by early-season adjustment of the aiming angle and by varying platform ranges.

Surface Equipment Configuration: The control and logging side of the system was housed in the equipment bunker provided by Lower Granite Dam operations, located on the deck of the dam between Turbine 6 and Spill Bay 1. The multi-beam system was comprised of two Simrad SM2000™ Sonar Surface Units, a control PC running Seismic Positioning System Software© for the Fanbeam, and a "3rdPC" running Battelle's Multi-Beam Data Acquisition Software© for logging data. Additionally, a Garmon global positioning system was mounted on a pole outside the bunker and the Fanbeam was positioned at the northernmost pier nose of Turbine 6. The global positioning system acquired Universal Coordinated Time (previously Greenwich Mean Time) only. The location of the Fanbeam was the reference point for distance measurements relative to the dam. An additional prism was attached to the railing of the upstream side of the SBC to provide a quality control reference point for platform positioning. Two additional prisms were attached to either end of the first module of the BGS. This provided location information on the BGS as it was installed and removed during subsequent sample blocks.

Calibration: The system was field calibrated. Calibration was performed using a 1.27-cm (0.5-in.) brass sphere attached to 8-lb-test monofilament line. The line was deployed from a "clothesline" type pulley arrangement attached between the barge and the SBC. The sphere could be deployed at different positions within the beam by moving the tie-off point on the SBC and moving the target in and out on the pulley system. The sphere gave consistent returns across at least three beams in both the

vertical and horizontal subsystems within the specified region of beam overlap. Calibration checks were performed at regular intervals throughout the study period and particularly when the system was repositioned for any reason.

Data Collection: Multi-beam data collection began April 18, 1998. The system operated continuously 24 h/d. The multi-beam transducers were rotated approximately every 8.5 min. and sampled seven locations each hour (Figure 3.11 and 3.12). The transducers were rotated clockwise for a series of seven rotations and then counterclockwise for seven rotations, like a windshield wiper. Fifty percent of the data collected on days when the BGS was not being moved were analyzed for inclusion in this report.

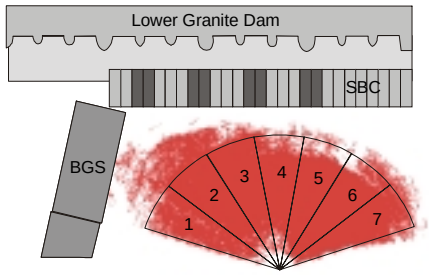


Figure 3.11. Total multi-beam spatial coverage and the seven beam rotation locations.

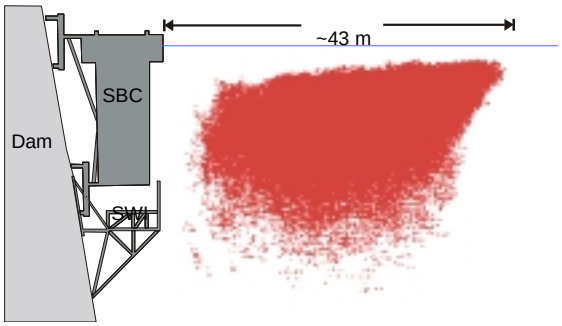


Figure 3.12. Lower Granite Dam side view showing the approximate spatial coverage of the multi-beam.

3.3.2 Multi-Beam Data Processing and Analysis

This section describes the methods used for multi-beam data processing and analysis associated with spring 1998 hydroacoustic sampling at Lower Granite Dam as part of the evaluation of fish behavior near the SBC and BGS.

3.3.2.1 Multi-Beam Data Processing

Data collected at the dam were sent daily via courier to Battelle's Pacific Northwest Division staff in Richland, Washington for processing. The binary files received from Lower Granite Dam were subdivided and processed by six data technicians. Data analysis consisted of the following steps: (1) group and select targets, (2) transfer to database, (3) query database, and (4) analyze and plot fish tracks. This data flow is illustrated in Figure 3.13.

MTrack software developed at Battelle was used to filter out permanent dam structures and group targets together based on their proximity in space, time, and angle units. Due to persistent wind-driven acoustic noise at this location and the occurrence of vortices emanating from the trash shear boom, nearly all the raw data files were manually post-processed. Manual post-processing permitted the selection or rejection of tracks to avoid noisy areas or to track fish through noise. MTrack applied further algorithms to retain only fish targets that overlapped in the horizontal and vertical transducer beams.

The output was a text, or "tracked fish," file (*.tff). Each file included approximately 4 min. of data recorded on a ping-by-ping basis. Data included with the file consisted of:

- number of targets associated with each ping-by-ping record
- date
- time to the nearest hundredth of a second
- compass bearing of the transducers
- tilt of platform (both pitch and roll)
- transducer rotator position
- laser radar angle from dam reference to prisms 1-6
- laser radar distance from dam reference to prisms 1-6.

Using range and angle information contained in these files, a Fortran program converted polar target positions to a Cartesian coordinate system. The programs corrected for fish location according to transducer location, tilt, and aspect. These and other data were then transferred to the database. As the data were loaded, the database calculated instantaneous velocities and accelerations for each target on a ping-by-ping basis and included them in the data set. More information was calculated and/or added to the data set to make querying more efficient. The additional data included:

- fish position in the x, y, and z planes
- instantaneous velocity in x, y, and z directions

- instantaneous acceleration in x, y, and z directions
- average fish position
- average fish speed
- block number
- day/night/sunrise/sunset designation
- BGS condition (IN or OUT)
- SBC configuration (eight distinct categories based on SBC gate position, BGS condition, and whether the BGS was stationary or moved during the day)
- number of pings associated with each track.

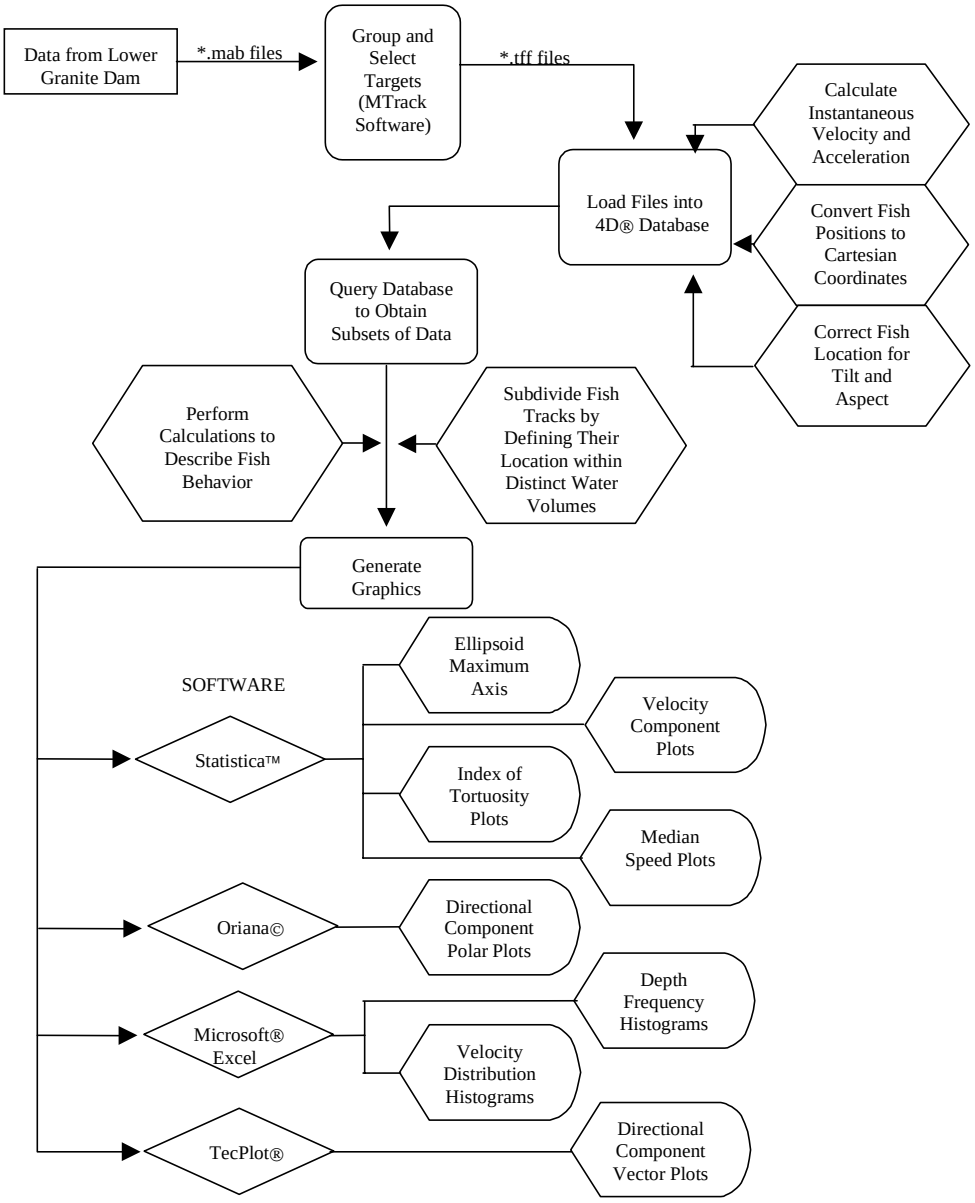


Figure 3.13. Data processing flow chart.

Data were then queried to obtain subsets of data used to generate the figures and tables for the Results section of this report. Before detailed graphing and analysis took place, the files were run through Fortran programs written to divide the data into cube-shaped volumes for general analysis and for depth frequency analysis (Figure 3.14 and Figure 3.15, respectively). Fortran programs also sub-sampled the data at 2-sec. intervals, determined the amount of time a fish track remained in a particular volume of water, and performed calculations that described track direction and speed. This was done to analyze the targets' depth and speed distribution, directional components, index of tortuosity, speed components, median speed, and spatial coverage.

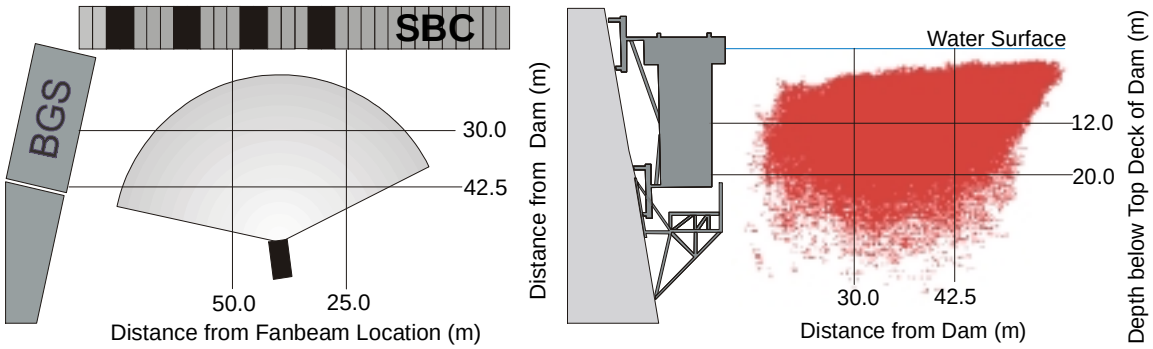


Figure 3.14. Plan and side views depicting bins used for data analysis.

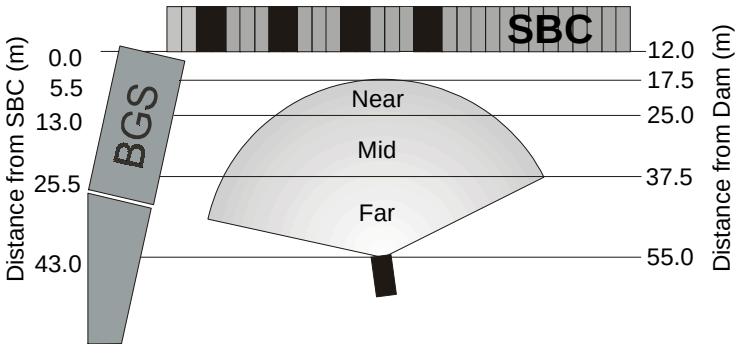


Figure 3.15. Bin system used for depth frequency analysis.

3.3.2.2 Multi-Beam Data Analysis

In past years, when analyzing behavior data from hydroacoustic tools at Lower Granite Dam, we mostly used vector graphics to display behavioral trends. This year we took a slightly different approach involving metrics to describe the behavioral characteristics of the fish population approaching the SBC at Lower Granite Dam. The analyses applied to the multi-beam data had various origins in such diverse areas as particle diffusion theory (Parrish and Hamner 1997; Bar-Shalom and Li 1995), spherical statistics (Zar 1984), geology (Davis 1986), and animal behavior (Parrish and Hamner 1997).

We began our analysis with fine-scale, bin-based vector plots in the Preliminary Draft Report (Johnson et al. 1998b) by including additional component analyses and breaking the vector structure into speed, component speeds, acceleration, and circular statistics. The analysis ultimately evolved to include various metrics including spatial coverage, depth distribution, directional components, kinematic analysis, cumulative flux box analysis, tortuosity, and ellipsoid component analysis (volume and maximum axis). All these analyses are included in this report, with the exception of the cumulative flux box analysis that is still under development and the ellipsoid component analysis that was ultimately considered redundant. We hope to apply the flux box analysis in future work to provide an alternate metric for SBC entrance efficiency. In addition, Appendix C presents details of an analysis performed to evaluate the quality of the multi-beam data.

Target Summary: Database queries were performed to determine numbers of individual fish identified in the early stages of the evaluation process. Fortran programs were also developed to count numbers of individual fish after the fish had been binned in specific volumes of water for more specific analyses.

Sonar Coverage: The sonar coverage was determined from perspective scattergrams of individual target ensonifications with positions corrected to a fixed reference point on the dam (the location of the Laser Radar Fanbeam).

Depth Distribution: The depth frequency distribution was based on the average track depth. The result of the analysis was a plot of the proportion of observations at a particular depth plotted against depth.

Direction: Polar histograms were used to show the distribution of directions within a specified volume of water or bin. These bins were artificially divided into discrete volumes and were Eulerian in nature. They illustrated not only the principal direction of the fish movement within the bin but also the

dispersion of the data. The histograms show only the instantaneous angular information within a spatial bin. The mean shown was an angular mean based on spherical statistics and should not be confused with a vector mean (Figure 3.16).

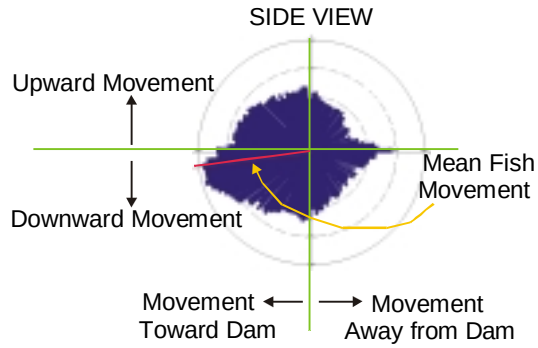


Figure 3.16. Example of a side view polar histogram.

Observed-flow-effort vector plots were binned on a finer spatial scale (1.5 m) than the polar histograms. These plots show the effect of subtracting the flow information supplied by University of Iowa's mathematical model (a computational fluid dynamics model) from the observed fish movements for mean vectors only. The resulting vector is the fish's swimming effort. Put another way, the flow and effort vectors are added to produce the observed vector. These plots contain both angle and magnitude information (Figure 3.17).

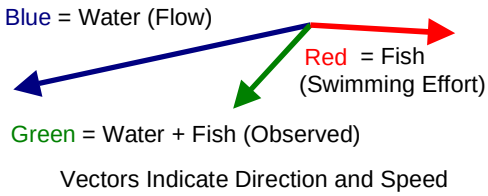


Figure 3.17. Example of vector plot components.

Kinematic Analysis: The kinematic, or motion, analysis was divided into two parts. First, descriptive statistics were developed to illustrate the overall distribution of fish speed for both BGS IN and BGS OUT conditions and for both the observed and effort (flow-corrected) data. Second, speed component ratios were plotted for each axis for each plane of the sample volume. Fish speed comprises movement in the x, y, and z planes. By calculating the ratio of each component to the overall speed it is possible to see which component(s) dominates the observed speed. Speed component ratios provide a compact form to display the relative contribution of the x, y, and z components of speed and another basis

for defining behavior regions. Speed component ratios are only shown for the BGS IN condition for the swimming effort data because flow data were not provided for the BGS OUT condition.

Track Characteristics: Several metrics were devised to represent individual fish behavior. These included an index of tortuosity, ellipsoid volume, and ellipsoid component analysis. Continued refinement of the metrics has shown that ellipsoid volume and component analysis contain the same information as the speed component analysis. Therefore, we present only tortuosity in this report.

The index of tortuosity is the inverse of linearity (linearity is an algorithm commonly used in single-beam hydroacoustic analysis), where:

$$\text{tortuosity} = \left(\frac{\text{distance traveled}}{\text{straight line distance}} \right)$$

Distance traveled is the sum of the small distances a target moved between each record along a track. The straight line distance is the difference between the target's first and last recorded positions. Using this equation, a fish traveling in a straight line will have a tortuosity equal to 1.0. Fish traveling more circuitous paths will have index values greater than 1.0. Sample tortuosity values and associated tracks (taken from the multi-beam data set) are shown in Figure 3.18. These tracks were chosen because they were comprised of a similar number of records (pings).

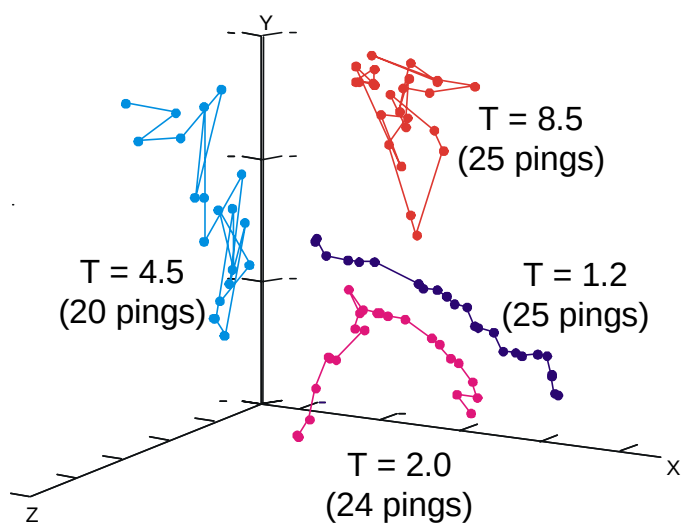


Figure 3.18. Examples of tortuosity values taken from the data set. T = tortuosity.

Visualization: An animated, three-dimensional, visualization tool was developed to view the fish movement in the context of the dam and SBC (Figure 3.19). The visualization includes user controls for manipulating the scene graphic, speed of data playback, and display of track histories. These visualizations were examined for trends and anomalies in the dataset. This flexibility permits the researcher and those interested in fine-scale "actual" fish movement as seen by the multi-beam sonar to view fish tracks and evaluate their characteristics. In practice this has served as a powerful quality assurance step and permitted fish observations that would otherwise be impossible. The authors may be contacted about availability of the visualization tool and the appropriate datasets for input to the software.

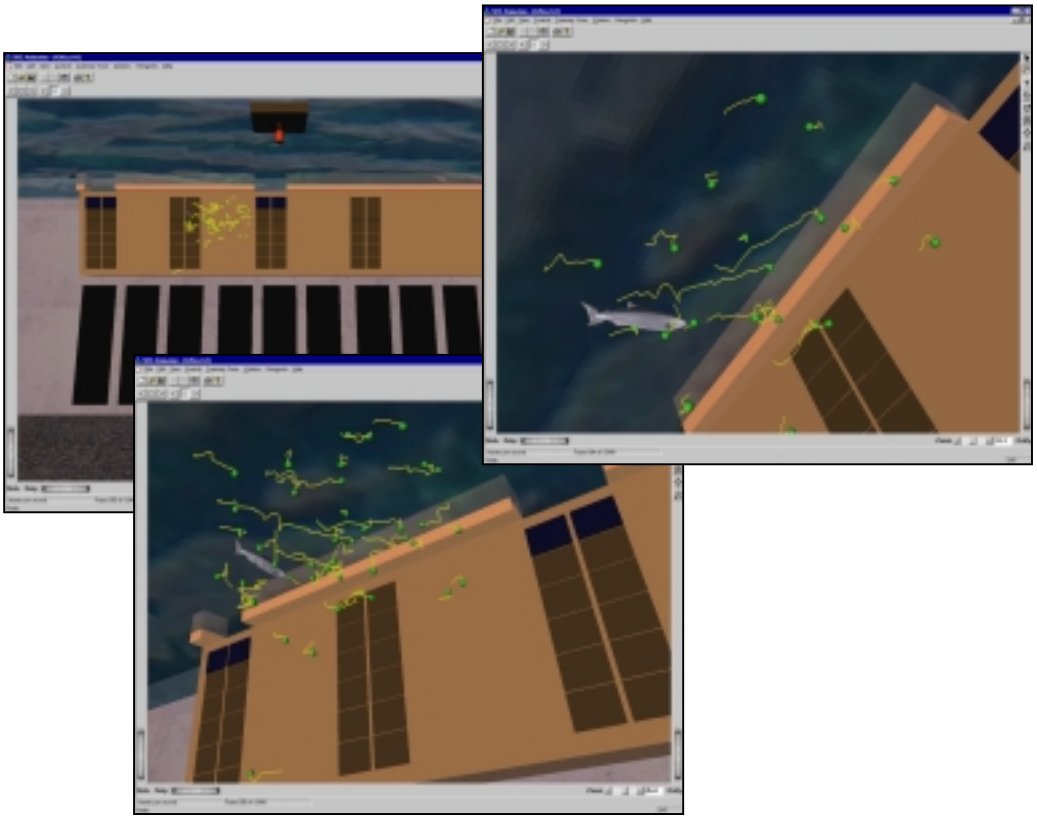


Figure 3.19. Images from the visualization tool.

3.4 Fish Behavior Methods (Split-Beam)

In this section we describe the deployment and methods used for split-beam processing and analysis as part of the evaluation of fish behavior in front of Turbines 1-3 and near the SBC/BGS junction.

3.4.1 Split-Beam Deployment and Data Collection

Split-Beam Deployment: A split-beam transducer (Figure 3.20) was deployed approximately 3 m below the forebay surface at the A/B pier nose of Turbine 2 and aimed upstream toward the BGS and in front of Turbines 1-3, including the SBC/BGS junction (Figure 3.21).

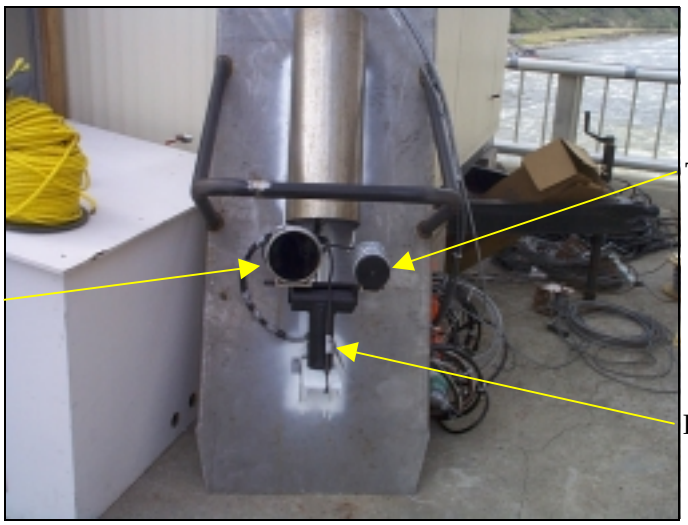


Figure 3.20. Split-beam transducer and sensor package.

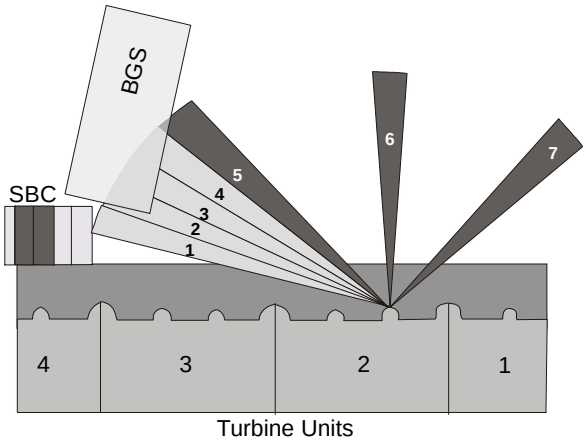


Figure 3.21. Location of split-beam transducer in the forebay of Lower Granite Dam during the 1998 fish behavior evaluation study. The transducer was mounted on the A/B pier nose of Turbine 2. Horizontal beam positions are labeled 1 through 7.

Data Collection: Split-beam data collection began April 18, 1998. The system operated continuously 24 h/d when the BGS was IN. The split-beam transducer was mounted on a rotator that, during 1 hour, moved through 27 positions. The rotator moved horizontally to seven positions (Figure 3.21). At the first four positions (labeled 1-4), the rotator also moved through six vertical positions. This allowed coverage of the junction of the BGS and SBC and areas upstream of this junction. The final three positions (labeled 5-7) looked out into the forebay and intersected fish moving toward Turbines 1-3. All data collected on days when the BGS was IN were analyzed for inclusion in this report.

Calibration: Factory calibration of the split-beam transducer system was performed before and after the data collection period. Calibration is critical to determining the acoustic size of aquatic targets and the amount of energy returned from the water column. System performance is based on three components of the calibration information: *noise* floor of the transducer, *source level* measured in decibels per micropascal, and *receiving sensitivity* measured in decibels per micropascal. This information is stored internally in the DT6000™ transducer at the time of calibration.

3.4.2 Split-Beam Data Processing and Analysis

3.4.2.1 Split-Beam Data Processing

Data processing required several steps, as described below and illustrated in the flow diagram in Figure 3.22. The original data files (*.dt4) were renamed to include month and day information for organizational purposes. Then the (*.dt4) files were processed by the Visual Analyzer© program (BioSonics) to remove structural features. The resulting files (*.txt) next were processed by an off-line

tracking program that examined the echoes and combined them into coherent trajectories. The program also calculated apparent velocities. The tracking program produced two types of output files: one (*.raw) containing all data and another (*.fsh) containing targets the program had identified as probable fish targets. The next step was to verify the tracked targets manually using a visual inspection program. The tracked fish files were graphically displayed using an S-Plus® program as an overlay with the raw echo file. One of two technicians next observed the differences in the targets that were tracked and those that were not, deciding to delete or add tracks. This manual step provided an opportunity to implement a quality control procedure to protect against inadvertently accepting ambiguous targets or deleting valid targets (see Appendix C for details). At the conclusion of the manual data exam procedure, the tracked fish file was saved as an import file (*.xls) to Microsoft Excel©. A final step before the data could be graphically plotted was to transform it from a conical coordinate system relative to the transducer to a Cartesian coordinate system relative to the dam.

A Fortran program performed the coordinate transformation. The output was an *.loc file that contained the following information:

- date
- time
- fish ID number
- number of pings associated with each fish track
- fish position in the x, y, and z planes
- fish speed in the x, y, and z directions
- mean target strength for each fish track.

Files were then combined and sorted into various subsets (day or night; early, mid, or late season) for plotting. The files were also run through a Fortran program that divided the data into distinct volumes of water (bins) for analysis.

3.4.2.2 Split-Beam Data Analysis

Directional component vector tables, created using Microsoft Excel© software, illustrate the sample size and average speed of targets per bin. Related figures, directional component vector plots, were created using Fortner's Transform© software. These plots show the mean direction and relative speed of targets. Target location plots, made using Excel and Fortner's Plot© software, enabled

visualization of fish target locations in both vertical and horizontal planes. Target strength distributions were visually compared across different depths, times of day, and season.

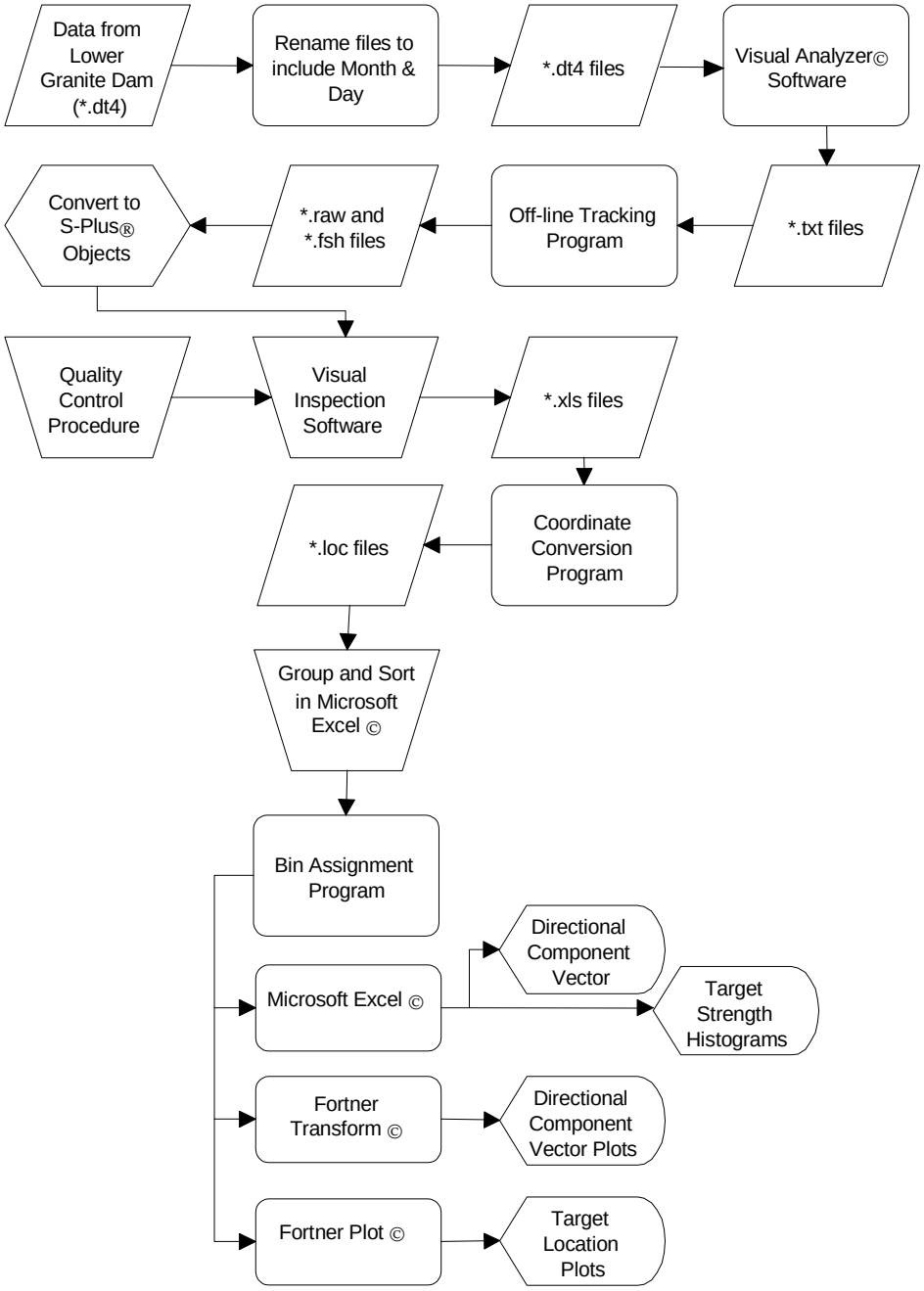


Figure 3.22. Data processing and analysis flow chart.

Section 4: Fish Passage Results

This section provides results of the 1998 fish passage evaluation. Results are organized into sections on system performance, spill passage, turbine intake passage, SBC/SWI and BGS passage, and fish passage budgets and efficiencies. Daily plots of fish passage data can be found in Appendix B. All confidence intervals are at the 95% level.

4.1 Single-Beam System Performance

The seven single-beam systems performed well during the 1998 evaluation period; we missed only 3% of the 48,000 total available transducer-hours of data (Table 4.1). Missing data was caused by severed cables at in-turbine guided locations and damaged cables at Module 9U. An error in the sampling sequence for pier nose transducers at Turbines 3 and 5 caused some acoustic cross-talk that obscured targets in part of the range for both locations from April 17 to May 8. Within the 15 m of total range, targets were obscured in the lower 11 m for Turbine 3 and in the lower 6 m for Turbine 5. Installation of a trash boom in the spillway forebay in 1998 and normal flows eliminated damage to hydroacoustic hardware at the spillway that occurred in 1996 and 1997.

Table 4.1. Summary of available data for the single-beam systems at Lower Granite Dam during spring 1998. Available data are expressed as the percentage of transducer-hours when usable data were collected during the total spring study period.

No.	System	Locations Where Some Data Were Missed	Missing Data Period (mm/dd hhmm)	Available Data (%)	# Transducer-hours of Missing Data
1	SBC1	Module 9U	05/16 0700 to 05/29 0600	95.3	312
2	SBC2	none		100	0
3	FGE1	none		100	0
4	FGE2	Intake 3B	04/20 0900 to 04/20 1900	99.8	11
5	FGE3	Intake 3C & 4B	04/13 0700 to 04/17 1100	98.5	107
6	Pier Nose	T3 & T5	04/17 0900 to 05/08 0900	85.7	1010
7	Spillway	none		100	0
	Total			97	1440

4.2 Spill Passage

This sub-section provides spring 1998 data on spill efficiency; spill effectiveness; and horizontal, vertical, and diel fish distributions at the spillway.

4.2.1 Spill Efficiency

In 1998, overall spill efficiency was 29.7 ± 0.4%. When SBC passage was included with spill passage, overall spill efficiency increased to 56.5 ± 0.4%. Spill efficiency was higher during day (34.7 ± 0.6%) than night (23.7 ± 0.5%) and was significantly related to percent spill (Figure 4.1). Spill efficiency increased as the percentage of spill increased up to about 20% spill for day and night (Figure 4.1), then it decreased slightly as the percentage of spill increased beyond 20%. This pattern was similar to what we observed in 1997.

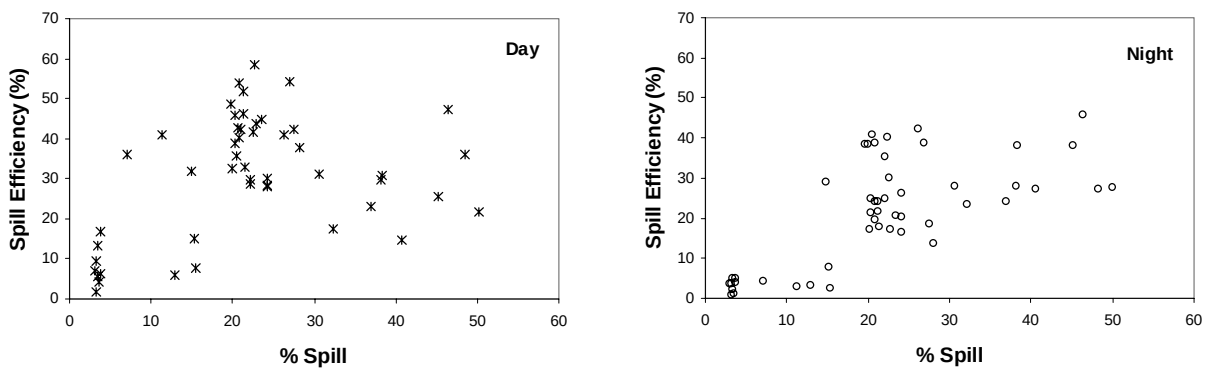


Figure 4.1. Scatterplot of daily spill efficiency vs. the percentage of total discharge spilled from April 13 to May 31, 1998, for day and night separately.

4.2.2 Spill Effectiveness

In spring 1998, spill effectiveness was 1.13 ± 0.02. When SBC passage was included with spill passage, spill effectiveness in spring 1998 increased to 1.90 ± 0.01. Spill effectiveness without SBC spill during the day (1.3 ± 0.02) was greater than that at night (0.9 ± 0.02). Spill effectiveness was significantly related to percent spill for day but not for night (Figure 4.2). During day, spill effectiveness was variable at spill levels below 20% and then decreased sharply as the percentage of spill increased above 20% (Figure 4.2).

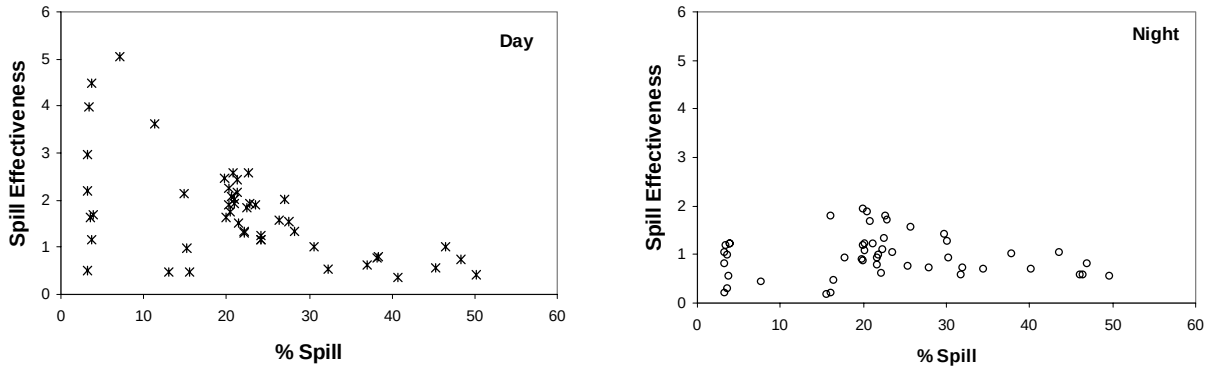
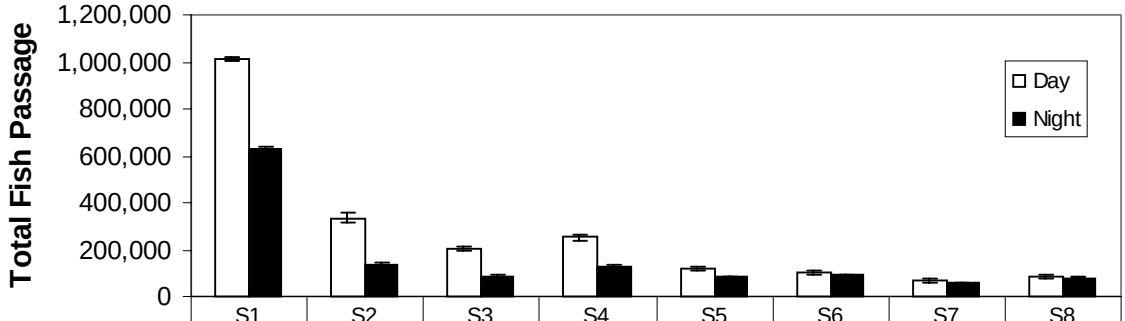


Figure 4.2. Scatterplot of daily spill effectiveness vs. the percentage of total discharge that was spilled from April 13 to May 31, 1998, for day and night separately.

4.2.3 Fish Distributions

We estimated horizontal, vertical, and diel fish distributions at the spillway. Nearly 47% of the fish passed via Spill Bay 1. Horizontally, total fish passage at non-SBC spill bays was highest at Bays 2 and 4 (Figure 4.3). Adjusting total spill bay passage by total discharge at each spill bay, demonstrated the same trend in horizontal distribution, with the majority of passage occurring at Spill Bays 1 (SBC passage) through 4 (Figure 4.4). Spill bay 8, on the northern end of the spillway, also demonstrated a high ratio of fish to total discharge. Vertically, fish passage was skewed toward the surface, with 79% of fish passage above 10 m, the upper two thirds of the water column above the ogee (Figure 4.5). On a diel basis, more fish passed through the spill bays during day (64%) than night (36%), and mean passage rates were higher during day (56%) than night (46%) (Figure 4.3 and Figure 4.6).



	S1	S2	S3	S4	S5	S6	S7	S8
Day	1,014,076	332,363	204,296	253,271	123,141	105,148	67,338	85,129
Night	632,531	135,822	86,155	127,028	82,037	91,156	57,162	80,047

Figure 4.3. Horizontal distribution of fish passage through spill bays at Lower Granite Dam for day and night separately. Spill bay 1 (S1) is the SBC outlet.

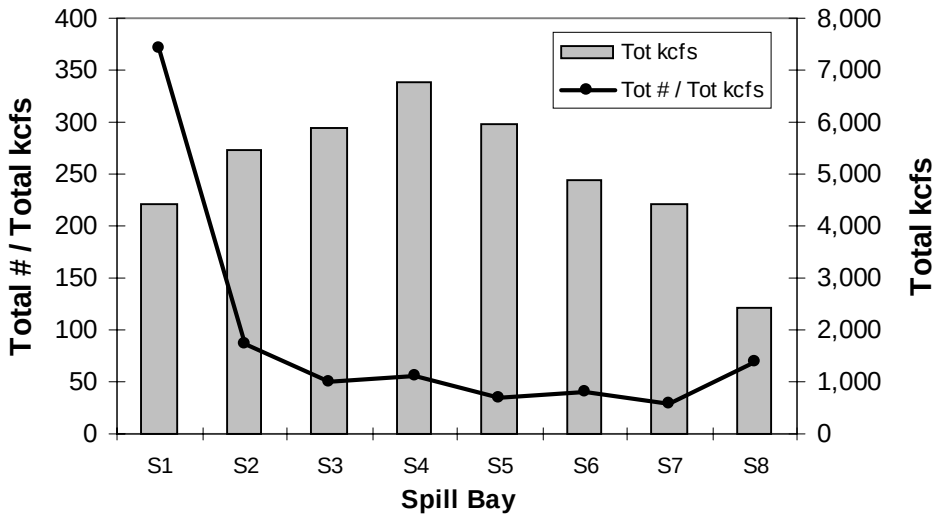


Figure 4.4. Horizontal distribution of total fish passage per total discharge (kcfs) for spill bays at Lower Granite Dam for day and night combined. Spill bay 1 (S1) is the SBC outlet.

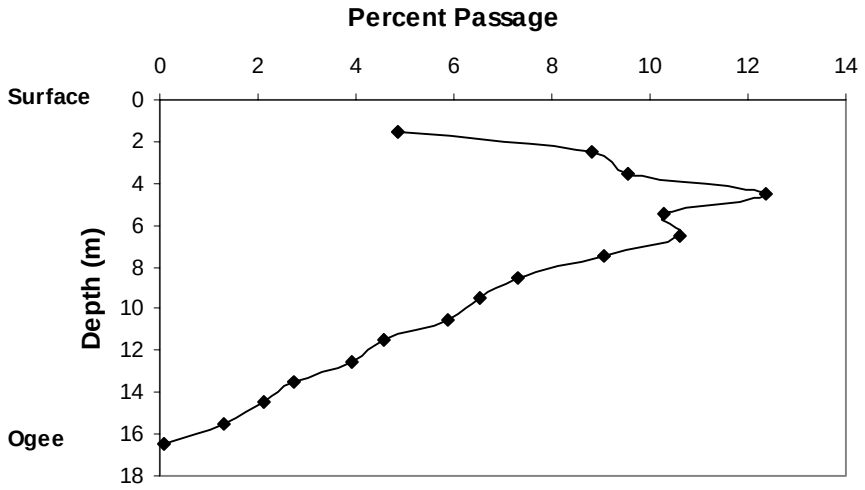


Figure 4.5. Vertical distribution of fish passage for Bays 2-8 combined.

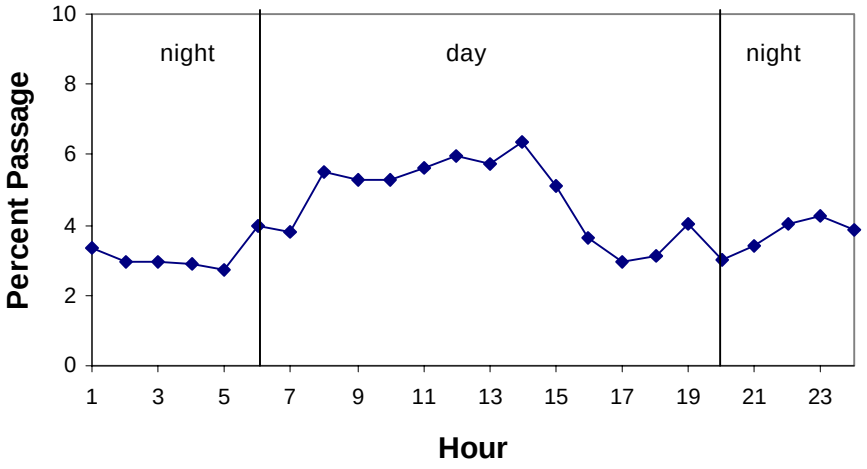


Figure 4.6. Diel distribution of fish passage for Bays 2-8 combined.

4.3 Turbine Intake Passage

This section includes overall, weekly, and day/night FGE estimates and fish distribution at the intake screen and powerhouse (pier nose) sample locations.

4.3.1 Overall, Weekly, and Day/Night FGE

Overall FGE for the run-at-large in spring 1998 was 83 ± 2.7%. Weekly FGE estimates (Monday-Sunday) were lowest during the first week of the study (<70%), increased in Weeks 2 and 3, dipped in Week 4, and increased again in Week 5 before decreasing in Weeks 6 and 7 (Figure 4.7). The decrease in FGE during Weeks 6 and 7 coincided with a dramatic increase in total river discharge (Figure 2.8). The trend observed in weekly FGE estimates in 1998 was similar to that observed in 1997. FGE for daytime was (81 ± 4.8%) was approximately 3% less than that for nighttime hours (84.3 ± 3.3%).

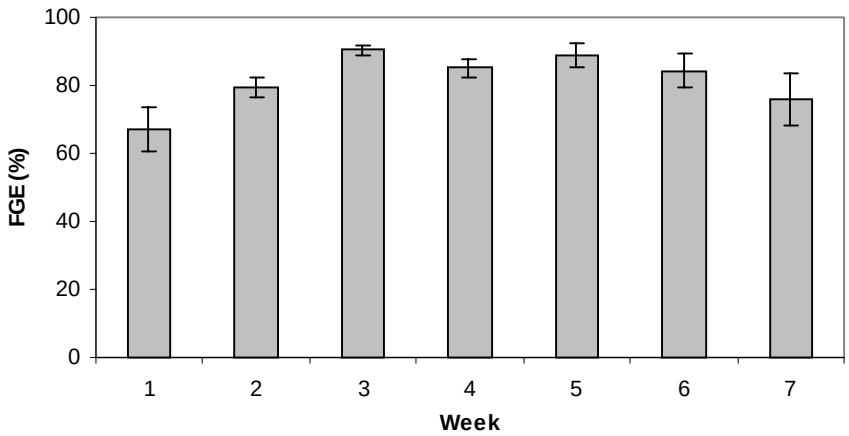
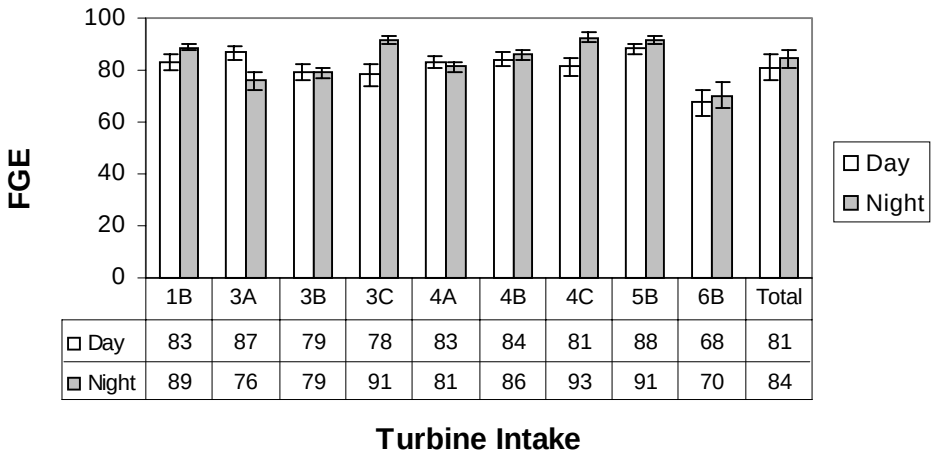


Figure 4.7. Weekly FGE estimates at Lower Granite Dam from April 13 to May 31, 1998.

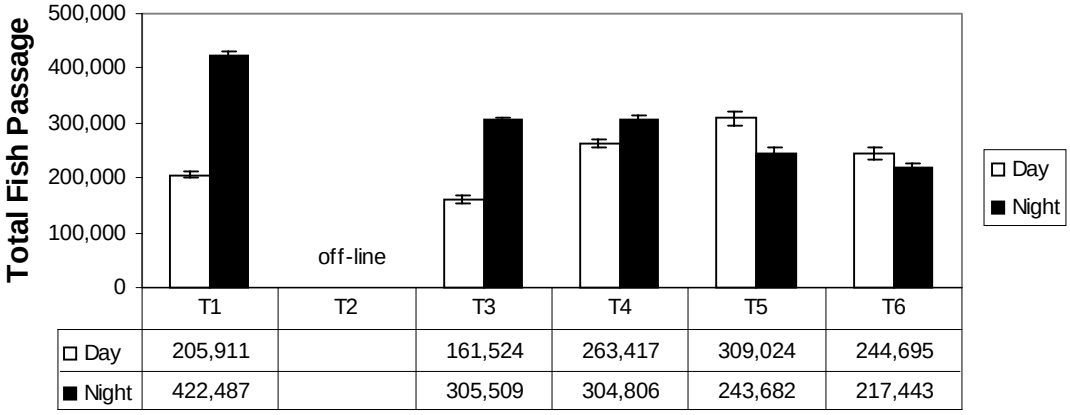
4.3.2 Fish Distributions at Intake Screens and Powerhouse Pier Noses

Fish guidance efficiency was fairly uniform across the sampled intakes, with the exception of Intake 6B where FGE was lowest (~ 70%) (Figure 4.8). Among intakes at Turbines 3 and 4, the only turbines where all three intakes were sampled, FGE was highest in C-intakes (Figure 4.8). Total fish passage was highest at Turbines 5 and 6 during day and Turbine 1,3, and 4 at night (Figure 4.9).



	1B	3A	3B	3C	4A	4B	4C	5B	6B	Total
Day	83	87	79	78	83	84	81	88	68	81
Night	89	76	79	91	81	86	93	91	70	84

Figure 4.8. Horizontal distribution of FGE (%) for day and night separately.



	T1	T2	T3	T4	T5	T6
Day	205,911		161,524	263,417	309,024	244,695
Night	422,487		305,509	304,806	243,682	217,443

Figure 4.9. Day and night horizontal distribution of total fish passage at pier nose sample locations. Turbine 2 was off-line during the entire study.

Vertically, passage of guided fish was highest toward the ceiling of the intakes (76% 2-4 m away; Figure 4.10). Passage of unguided fish was highest immediately below the tip of the ESBS (Figure 4.10). At powerhouse pier noses, fish passage was highest at depths just below the SWI (Figure 4.11)

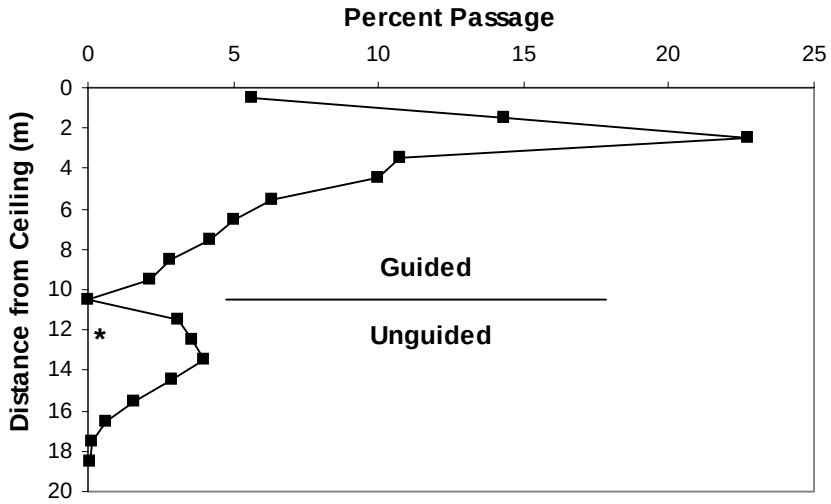


Figure 4.10. Vertical distribution of in-turbine passage for all guided and unguided locations combined. Note that guided transducers do not sample the lower 2 m of the screen and that the unguided transducers sample 1 m up from the tip behind the screen. The tip of the screen is designated by a star (*).

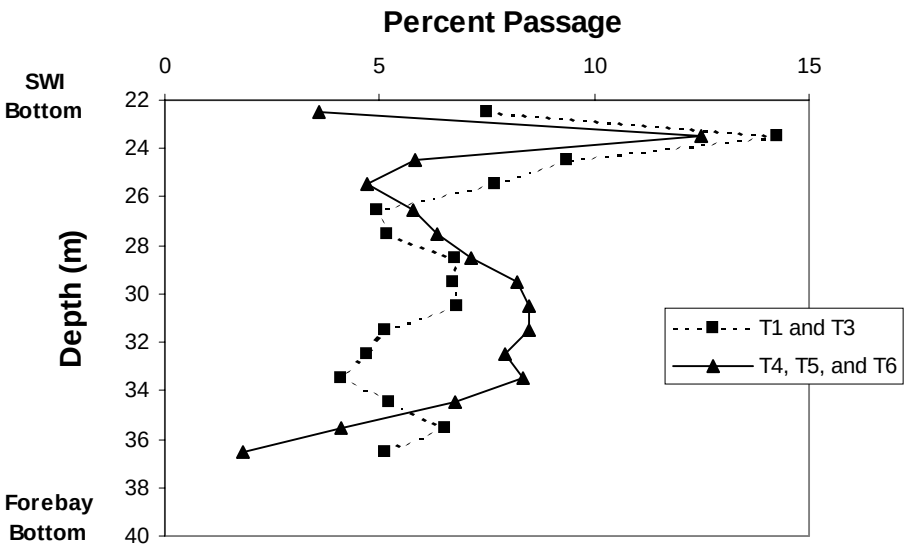


Figure 4.11. Vertical distribution of pier nose passage presented separately for Turbines 1-3 without the SBC/SWI and Turbines 4-6 with the SBC/SWI.

The diel trend of fish passage at in-turbine and pier nose sample locations was similar (Figure 4.12). Fish passage was highest for the period 2000-0100 h; in which 43% of in-turbine and 37% of pier nose fish passage occurred (Figure 4.12). This differs from passage at the spillway and SBC where a greater proportion of total passage occurred during daylight hours (see Section 4.1.3 and Section 4.3.5, respectively).

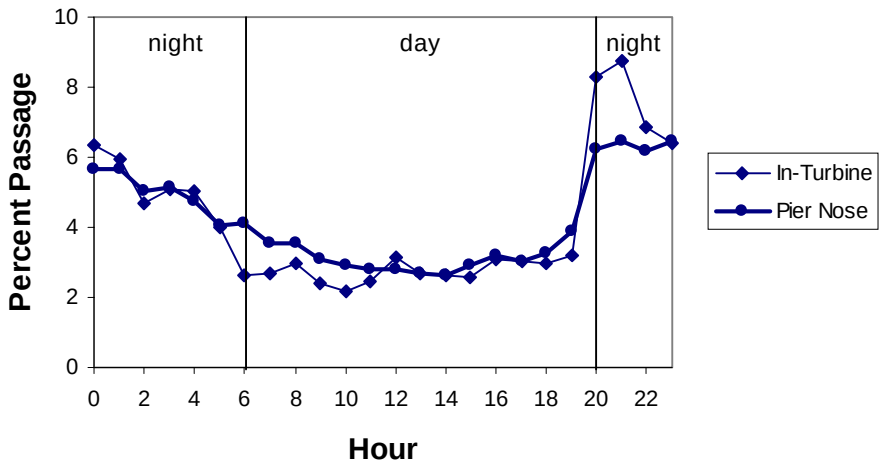


Figure 4.12. Diel distribution of fish passage at in-turbine and pier nose sample locations.

4.4 SBC/SWI and BGS Passage

This section provides results on BGS performance, SBC/SWI performance, descriptive and statistical relationships among SBC variables, fish distributions, and trajectories at the SBC.

4.4.1 BGS Performance

BGS diversion efficiency (P_b-corrected, see Table 3.5 for definition) for the study as a whole was 78 ± 18% (Figure 4.13). This means that for every 100 fish intended for Turbines 1-3, 78 fish were diverted to the north (i.e., either to the SBC, Turbines 4-6, or the spillway). BGS diversion efficiency was slightly higher (2.4%) at night than during day (Figure 4.13). On an experimental block basis, BGS diversion efficiency was greater than or equal to 73%, except for the last block (Figure 4.14).

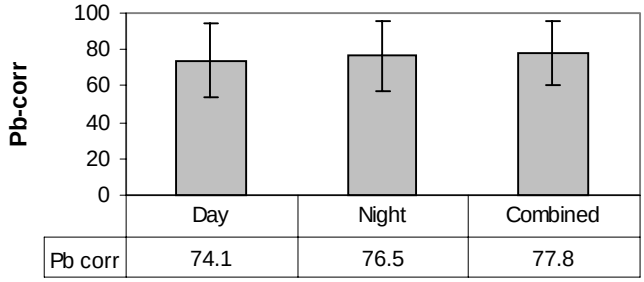
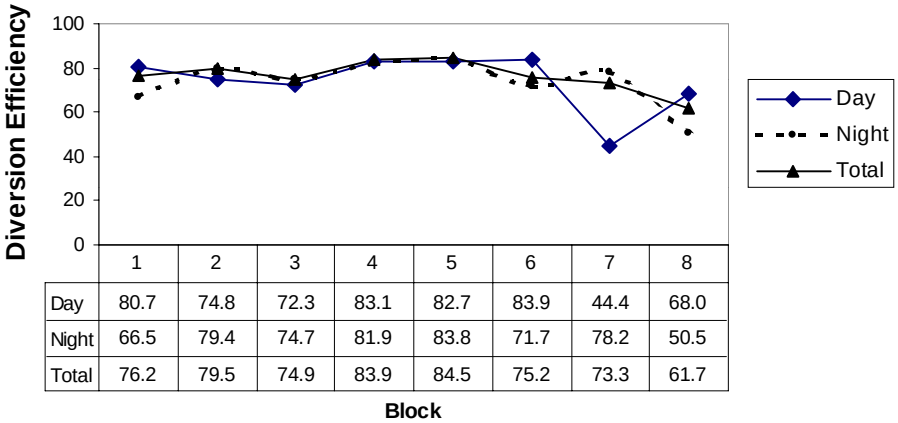


Figure 4.13. BGS diversion efficiency (P_b-corrected) for day, night, and combined.

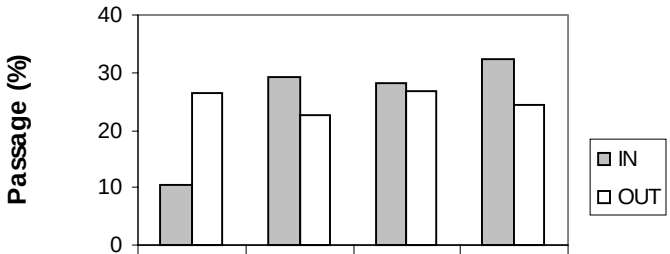


	1	2	3	4	5	6	7	8
Day	80.7	74.8	72.3	83.1	82.7	83.9	44.4	68.0
Night	66.5	79.4	74.7	81.9	83.8	71.7	78.2	50.5
Total	76.2	79.5	74.9	83.9	84.5	75.2	73.3	61.7

Figure 4.14. Day, night, and total (combined) BGS diversion efficiency (P_b-corrected) by block.

The proportion of total passage at Turbines 1-3 was 16% lower with the BGS IN than with it OUT for day and night combined (Figure 4.15). The proportion of fish passing through Turbines 4-6, the SBC, and spillway was higher with the BGS IN than when it was OUT (Figure 4.15). Data for daytime had the same pattern as the combined data except for the SBC, where mean daily passage was slightly higher during day with the BGS OUT (Figure 4.16). During the night, however, mean daily passage at Turbines 4-6, SBC, and spillway were all higher with BGS IN than OUT (Figure 4.16).

We compared SBC efficiency, FGE, and FPE for BGS IN and OUT conditions. R_{1-6} was higher with the BGS IN than OUT (Figure 4.17); this result was significant (P = 0.066) during night, but not during day or day/night combined. R_{4-6} was lower with the BGS IN than OUT (Figure 4.17), although this result was not statistically compared. SBC performance was lower with the BGS IN than with the BGS OUT when using passage at Turbines 4-6 (Figure 4.18). However, SBC performance was higher with the BGS IN than OUT when compared to Turbines 1-6 and total project passage (Figure 4.19). FGE at Turbines 1-3 was 4.9% lower with the BGS IN than OUT (Figure 4.20). But, FGE at Turbines 4-6 was 7.7% higher with the BGS IN than OUT (Figure 4.20). (We did not assess the statistical significance of these FGE estimates.) For all turbines combined, FGE was 2.1% higher with the BGS IN than OUT (Figure 4.20). FPE was 2.5% higher with the BGS IN than OUT (Figure 4.21); this result was statistically significant (P = 0.026).



	T1-3	T4-6	SBC	Spill2-8
IN	10.5	29.1	28.0	32.5
OUT	26.5	22.4	26.6	24.4

Figure 4.15. Comparison of fish passage percentages by structure for BGS IN and OUT conditions.

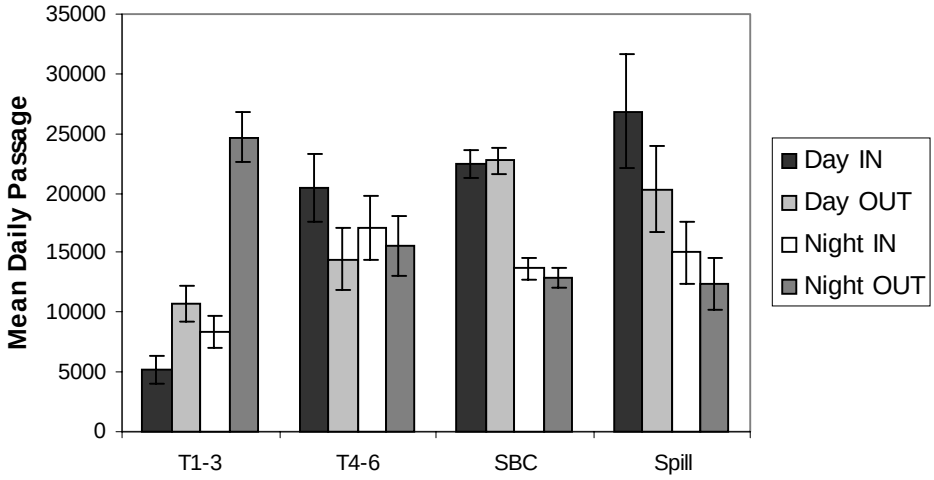
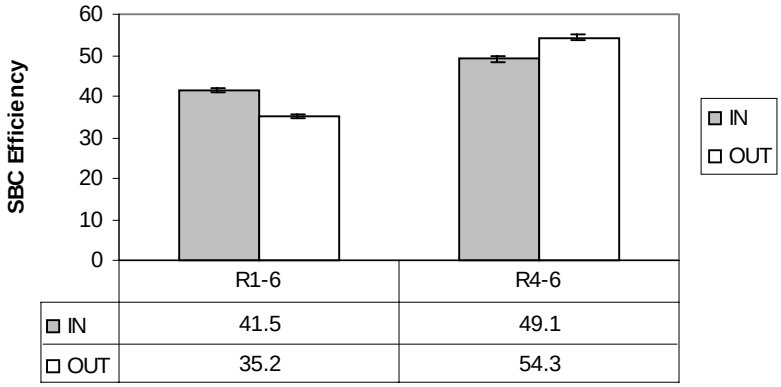
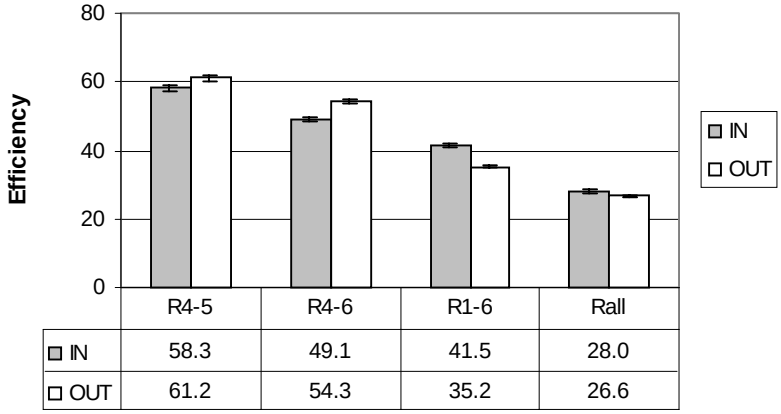


Figure 4.16. Comparison of mean daily passage by day and night for BGS IN and OUT conditions.



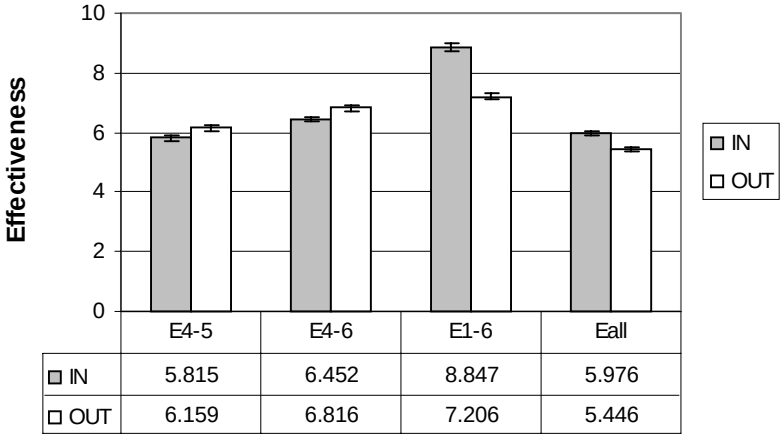
	R1-6	R4-6
IN	41.5	49.1
OUT	35.2	54.3

Figure 4.17. SBC efficiencies (R_{1-6} and R_{4-6}) for BGS IN and OUT conditions (%).



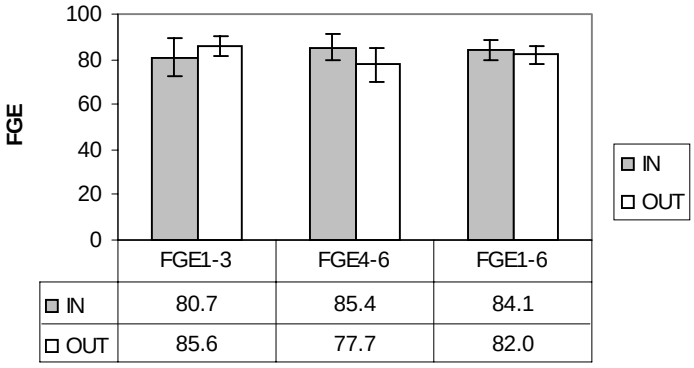
	R4-5	R4-6	R1-6	Rall
IN	58.3	49.1	41.5	28.0
OUT	61.2	54.3	35.2	26.6

Figure 4.18. SBC efficiency estimates (R) for BGS IN and OUT conditions for IHR and MAX configurations combined (%).



	E4-5	E4-6	E1-6	Eall
IN	5.815	6.452	8.847	5.976
OUT	6.159	6.816	7.206	5.446

Figure 4.19. SBC effectiveness estimates (E) for BGS IN and OUT conditions for IHR and MAX configurations combined.



	FGE1-3	FGE4-6	FGE1-6
IN	80.7	85.4	84.1
OUT	85.6	77.7	82.0

Figure 4.20. FGE at Turbines 1-3 (FGE_{1-3}), Turbines 4-6 (FGE_{4-6}), and all turbines (FGE_{1-6}) for BGS IN and OUT conditions (%).

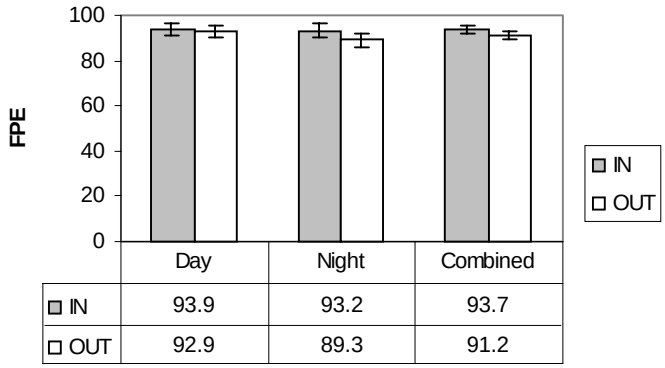


Figure 4.21. FPE for BGS IN and OUT conditions (%).

4.4.2 SBC/SWI Performance

For day and night combined, SBC efficiencies were slightly higher for the IHR than MAX configuration (e.g. R_{4-5} was 62.1% for IHR and 58.0% for MAX) (Figure 4.22). IHR and MAX also did not differ statistically for the SBC efficiencies used as response variables (R_{1-6} and R_{4-6}). Overall SBC efficiency and highest efficiency and conditions, considering both SBC configuration and BGS conditions, are presented in Table 4.2. Entrance efficiency (N) was 57.6 ± 0.2%. This was a decrease from the 60-70% observed in 1996 and 1997.

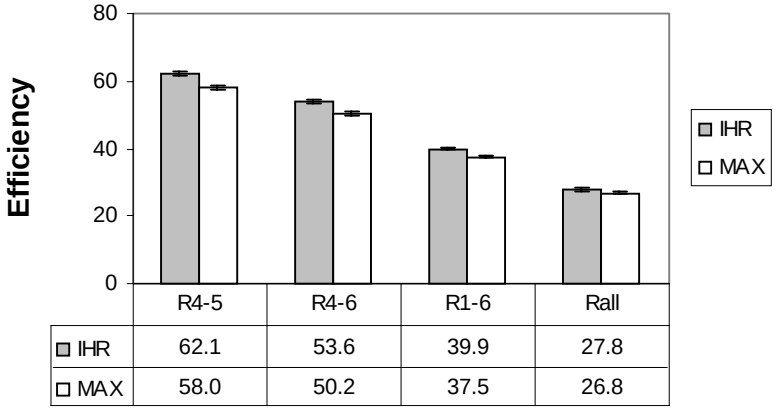


Figure 4.22. SBC efficiency estimates (R) for IHR and MAX configurations (%).

Table 4.2. Overall and highest SBC efficiencies and conditions.

Efficiency	Overall	Highest Value	Condition
R_{4-5}	59.5 ± 0.5%	61.5 ± 1.2%	IHR, BGS OUT
R_{4-6}	51.0 ± 0.4%	54.5 ± 1.1%	IHR, BGS OUT
R_{1-6}	38.1 ± 0.3%	42.9 ± 0.7%	IHR, BGS IN
R_{all}	27.4 ± 0.2%.	28.6 ± 0.6%.	IHR, BGS IN

SBC effectiveness (E) relative to Turbines 4-6 was 7.1 and relative to Turbines 1-6 was 8.6 %. Combined day and night SBC effectiveness was slightly higher for the IHR than MAX configuration (Figure 4.23).

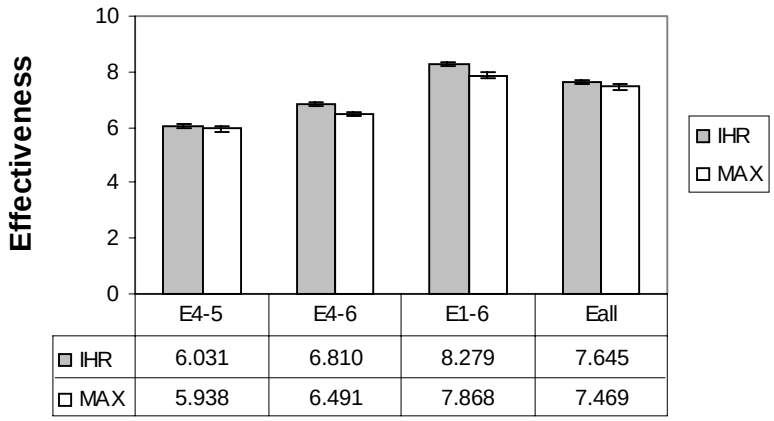


Figure 4.23. SBC effectiveness (E) estimates for IHR and MAX configurations (%).

Table 4.3 contains the significant ANOVA results ($P < 0.1$) from the 1998 single-beam hydroacoustic evaluation. (All ANOVA results are presented in Appendix B.) During day and day/night combined, fish passage efficiency was significantly higher for the IHR than the MAX configuration. FGE for the powerhouse as a whole was higher under the IHR than the MAX configuration. SBC efficiency R_{1-6} during night was significantly higher with the BGS IN than OUT. For night and day/night combined, fish passage efficiency was higher with the BGS IN than OUT. Note that SBC efficiency (R_{4-6}) was not significantly different ($P > 0.1$) between configurations.

Table 4.3. Summary of significant ANOVA results from the fish passage evaluation. (A complete set of the ANOVA results is presented in Appendix B.)

Factor	Variable/Condition	P	Conclusion
SBC Configuration	FPE day	0.074	IHR > MAX
SBC Configuration	FPE day and night	0.046	IHR > MAX
SBC Configuration	FGE1-6 day and night	0.050	IHR > MAX
BGS Condition	R1-6 night	0.066	IN > OUT
BGS Condition	FPE night	0.012	IN > OUT
BGS Condition	FPE day and night	0.026	IN > OUT

4.4.3 Descriptive Relationships between SBC Variables

The purpose of this descriptive analysis was to examine SBC/SWI performance relative to selected environmental factors. These factors included water temperature, turbidity, lunar phase, percentage of SBC discharge out of Turbine 4-6 discharge, and percentage of spill out of total project discharge. Relationships between SBC efficiency and these factors warranted a descriptive, post-season analysis, although this was not a formal part of the experimental design. A major caveat for this analysis, however, was that these factors were confounded with each other and other factors that vary seasonally, such as level of smoltification, species composition, and day-length. The next section contains a multiple regression analysis that addresses the situation with confounded independent variables.

Seasonal trends were evident in the SBC variables we examined (Figure 4.24 and Figure 4.25). As the season progressed, temperature and percent spill increased while percent SBC discharge and SBC efficiency declined. Turbidity did not vary much in the study period. The moon was full at the beginning of the study, and again on May 11.

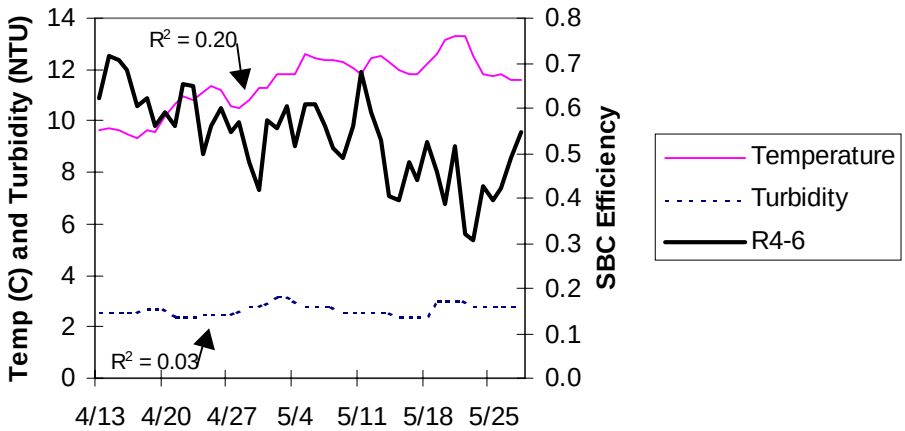


Figure 4.24. SBC efficiency ($R_{4\text{-}6}$) in relation to water temperature (°C) and turbidity (NTU) in 1998.

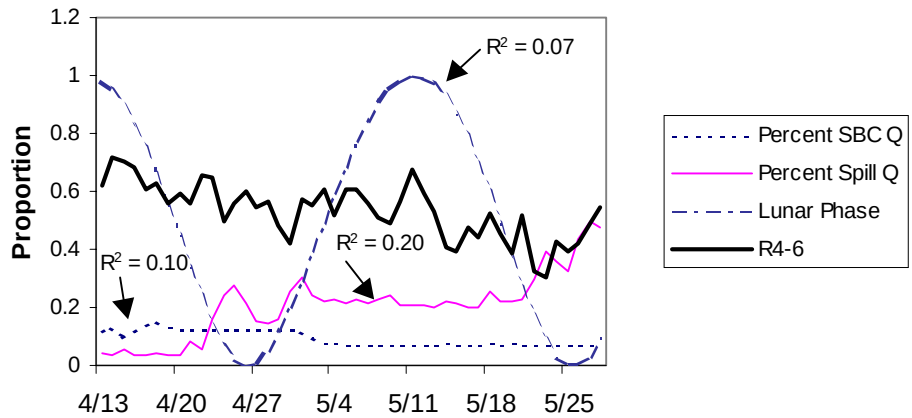


Figure 4.25. SBC efficiency ($R_{4\text{-}6}$) in relation to proportion SBC discharge (Q), proportion spill (Q), and lunar phase at Lower Granite Dam in 1998.

Percent SBC discharge reflected low- and high-load conditions at Turbines 4-6. Increased turbine load resulted in increased water velocity in the forebay, especially in the downward component. The SBC at Lower Granite Dam may perform better if the downward velocities were not as strong, thereby increasing fish availability to the SBC. This was the main reason for installing the SWI. SBC efficiencies (R_{all} and $R_{4\text{-}6}$) increased as the percentage of SBC flow increased (i.e., load decreased) (Figure 4.26 and Figure 4.27). These efficiencies decreased as the percentage of spill increased (Figure 4.28 and Figure 4.29).

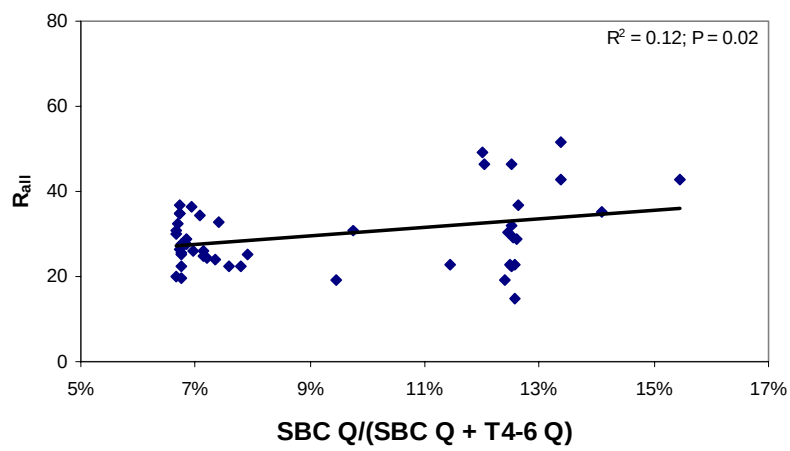


Figure 4.26. Daily SBC efficiency (R_{all}) vs. percentage of SBC flow at Turbines 4-6 from April 13 to May 31, 1998.

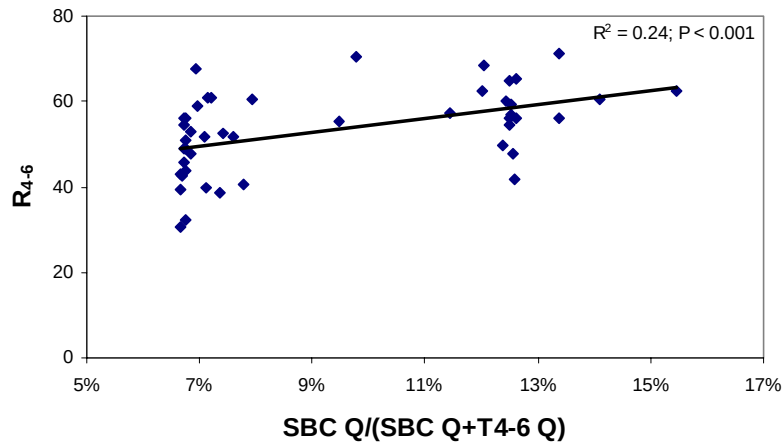


Figure 4.27. Daily SBC efficiency ($R_{4\text{-}6}$) vs. percentage of SBC flow at Turbines 4-6 from April 13 to May 31, 1998.

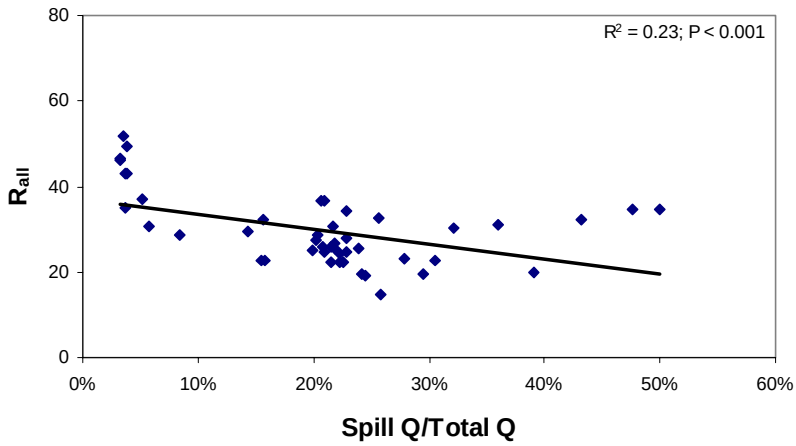


Figure 4.28. Daily SBC efficiency (R_{all}) vs. percentage of spill out of total project discharge from April 13 to May 31, 1998.

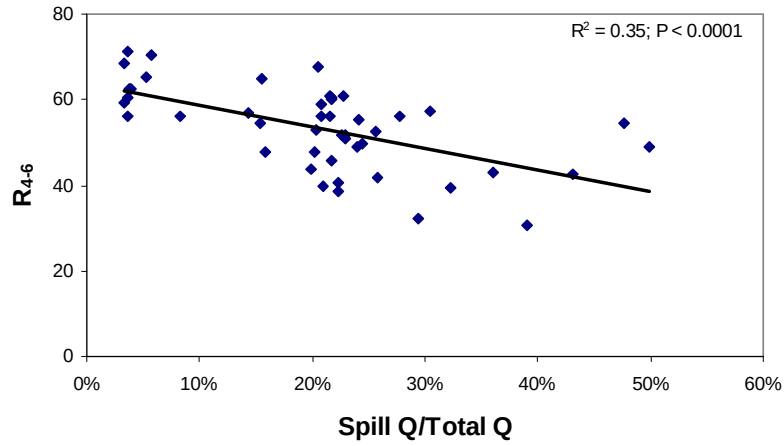


Figure 4.29. Daily SBC efficiency ($R_{4\text{-}6}$) vs. percentage of spill out of total project discharge from April 13 to May 31, 1998.

4.4.4 Statistical Relationships between SBC Variables

This section contains results using multiple regression techniques to analyze the statistical relationships between several dependent variables and various environmental factors. The dependent or response variables were daily data for SBC passage, T4-6 passage, and SBC efficiency ($R_{4\text{-}6}$). The independent variables were date, day/night, BGS condition, SBC configuration, water temperature, turbidity, percent SBC discharge (SBC Q/(SBC + T4-6 Q)), percent spill, lunar phase, and percent steelhead. The purpose of this analysis was to explore statistical relationships between variables. We cannot, however, identify the underlying causal mechanisms.

The regression coefficients represented the independent contribution of each independent variable to the prediction of the dependent variable (Neter and Wasserman 1974). To learn which variable contributed most to predicting, SBC passage for example, we examined the standardized regression coefficients (independent variables were standardized to have a mean of 0 and a variance of 1). The magnitude of the beta coefficients allowed us to compare the relative contribution of each independent variable in the prediction of the dependent variable. The partial correlation was the correlation between two variables after controlling for all other independent variables in the model. The partial correlation represented the unique contribution of the respective independent variable to prediction of the dependent variable. The semi-partial correlation was the correlation of the particular independent variable, adjusted by all other independent variables, with the raw, unadjusted dependent variable. The square of the semi-partial correlation was an indicator of the percentage of the total variance accounted for by that independent variable.

Bivariate plots showed the relationships between a dependent variable and various independent variables to be linear (Appendix B). Frequency histograms showed the dependent variables to be normally distributed. Therefore, it was not necessary to transform the data to meet the assumptions of a multiple linear regression model.

The most important variables to predict the dependent variable (SBC passage, T4-6 passage, or SBC efficiency) were date, temperature, and day/night (Table 4.4). Percent of SBC discharge and percent of spill discharge contributed marginally to the predictive power of the multiple regression models. The other variables contributed next to nothing to the predictive power of the model. Residual plots for observed and predicted values showed the aptness of the models.

Table 4.4. Results from multiple regression analysis.

Dependent Variable	Independent Variables	Beta	SE of Beta	Partial Corr.	Semi-Partial Corr. Squared	P-level
SBC passage	Date	-0.88	0.24	-0.38	0.08	0.0004
	Temperature	0.54	0.15	0.38	0.08	0.0005
	Day/night	0.48	0.08	0.57	0.22	0.0000
	%SBC Q	-0.43	0.21	-0.22	0.03	0.0398
T4-6 passage	Temperature	0.58	0.14	0.42	0.09	0.0001
	%spill	-0.30	0.16	-0.21	0.02	0.0586
SBC eff. (R_{4-6})	Date	-0.90	0.22	-0.42	0.08	0.0001
	Day/night	0.47	0.07	0.60	0.22	0.0000
	%SBC Q	-0.43	0.19	-0.25	0.03	0.0254

4.4.5 Fish Distributions at the SBC

For the IHR configuration, the highest proportions of fish passed through the Middle and North entrances of the SBC (Figure 4.30). For the MAX configuration, the proportion of fish passage was highest for the Middle entrance. The South entrance had the lowest proportion of passage for both configurations.

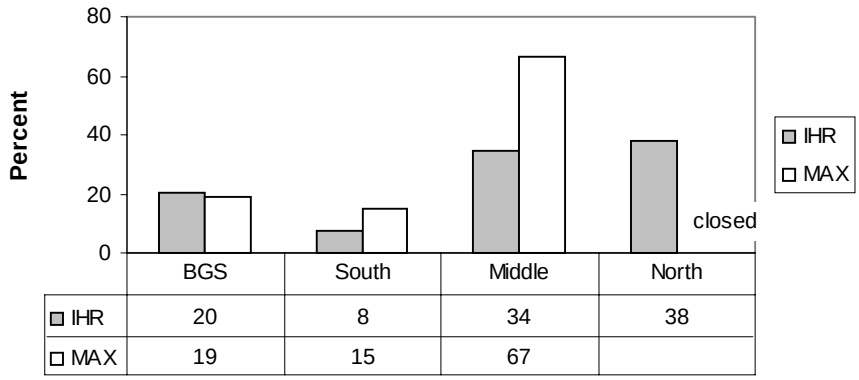


Figure 4.30. Horizontal distribution of fish passage at the SBC for each configuration (%).

The horizontal distribution of SBC entrance efficiency (N) was similar to the distribution of passage. Highest entrance efficiencies were observed at the Middle and North entrances while in the IHR

configuration and at the Middle entrance while in the MAX configuration (Figure 4.31). Lowest entrance efficiencies were observed at the South entrance for both configurations.

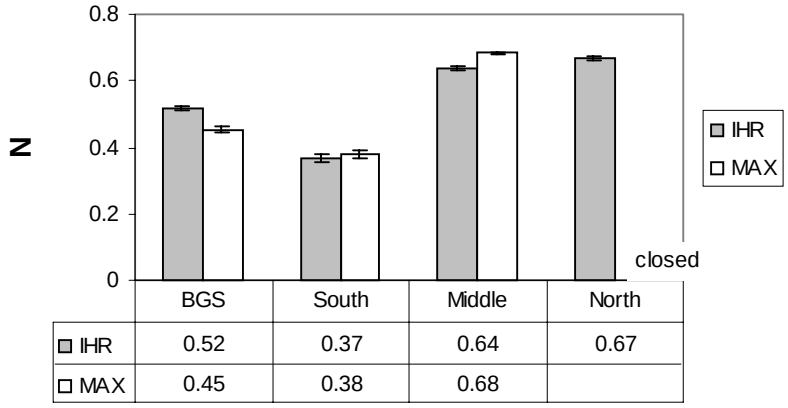


Figure 4.31. Horizontal distribution of SBC entrance efficiency (N) at the SBC for each configuration.

Vertically, the distribution of fish passage at all four SBC entrances during the IHR configuration was oriented toward the surface, with most fish passage occurring from 4 to 8 m deep (Figure 4.32). Passage at the South, Middle, and North entrances had a more pronounced peak in passage from 4 to 8 m (67% of total passage) compared to the BGS (49% of total passage) entrance. Passage at the BGS entrance was distributed lower in the water column with highest passage occurring from 5 to 11 m.

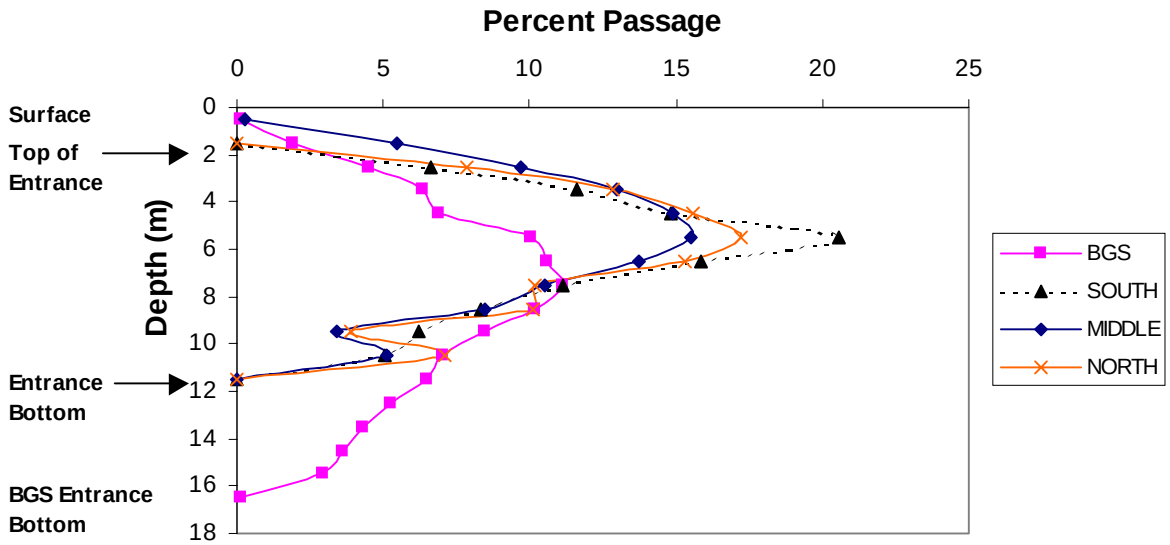


Figure 4.32. Vertical distribution of SBC fish passage for each entrance during IHR Configuration. The lower doors at the South, Middle, and North entrances are closed in the IHR Configuration.

Vertical distribution data at the SBC for the MAX configuration are presented for only the BGS and Middle entrances because only these locations had the full complement of up and down-looking squinted-pairs. Passage into the SBC at the BGS and Middle entrances was similar during the MAX configuration with highest passage occurring from 4 to 10 m deep (Figure 4.33).

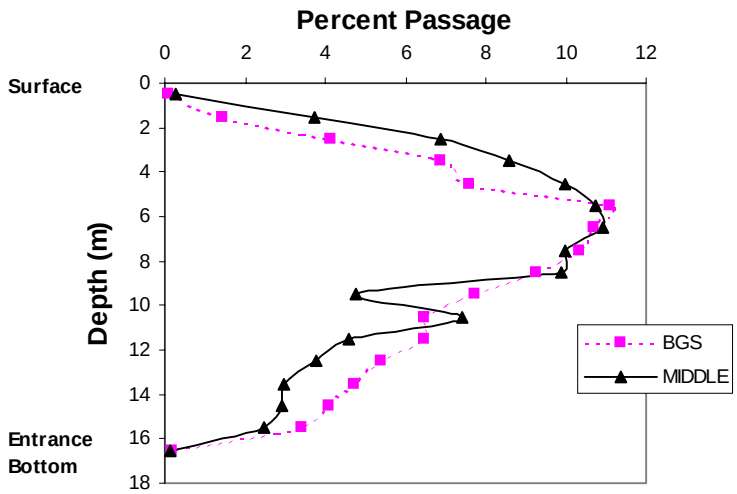


Figure 4.33. Vertical distribution of fish passage into the BGS and Middle entrances of the SBC during MAX Configuration.

The diel distribution of SBC fish passage was similar to that observed for spill passage. The proportion of total passage during daylight hours (63%) was higher than passage at night (37%) and mean passage rates were higher during day (55%) than night (45%) (Figure 4.34).

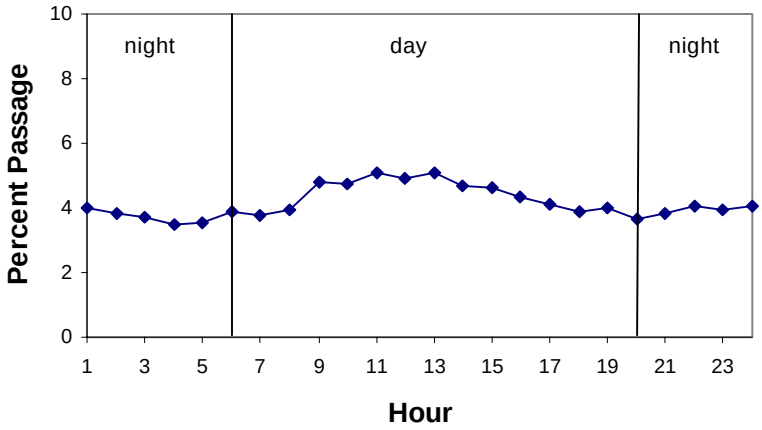
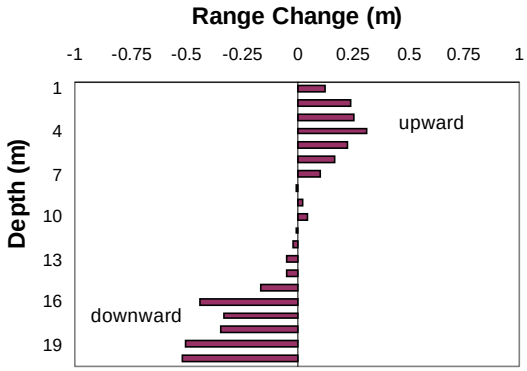


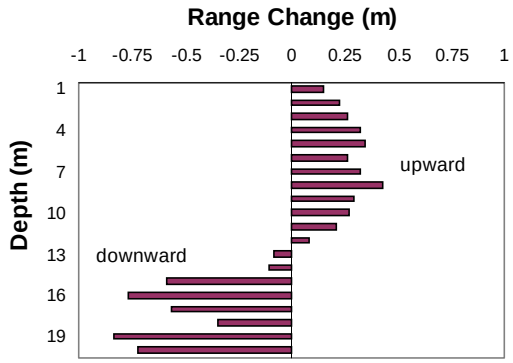
Figure 4.34. Diel distribution of fish passage into the SBC.

4.4.6 Fish Trajectories at the SBC

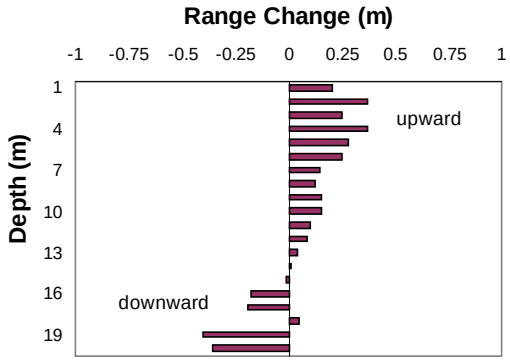
For each SBC configuration and BGS condition, fish entering the SBC were generally moving upward in the upper half of the water column in front of the SBC and downward in the lower region (Figure 4.35). While in the MAX configuration, fish trajectories were angled more steeply downward and the transition zone was shallower with the BGS IN than OUT (Figure 4.35a, b). Fish trajectories also demonstrated a stronger downward component while in the IHR configuration with the BGS IN than OUT (Figure 4.35c, d). The IHR configuration had the greatest range of fish moving up in the water column and most pronounced trajectories, but the demarcation depth (~13 m) was the same whether the BGS was IN or OUT (Figure 4.35c,d).



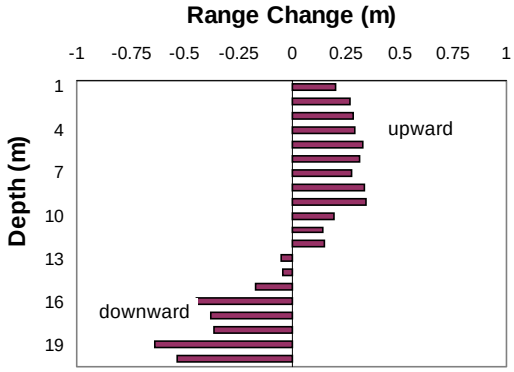
a. BGS IN, MAX Configuration.



c. BGS IN, IHR Configuration.



b. BGS OUT, MAX Configuration.



d. BGS OUT, IHR Configuration.

Figure 4.35a-d. Vertical distribution of fish trajectories into the SBC for MAX and IHR configurations and BGS IN and OUT conditions. Trajectories are expressed as change in range (m) from entrance to exit of the squinted-pairs.

4.5 Fish Passage Budgets and Efficiencies

In this section, we present fish passage budgets and summarize passage efficiency data. We derived fish budgets at two measurement scales, one for the total project (estimator for R_{all}) and one for just the SBC and Turbines 4-6 (estimator for R_{4-6}). The coefficients used in the fish budgets are presented in Table 4.5. Spill efficiency was lower in 1998 than 1997. Horizontal distribution at the powerhouse (i.e., proportion of fish at the SBC and Turbines 4-6 out of total powerhouse and SBC passage) was skewed more to Turbines 4-6/SBC in 1998 than 1997. Vertical distribution relative to the SBC structures was higher because of the SWI. The entrainment parameter and entrance efficiency were less in 1998 than 1997 (Table 4.5).

Table 4.5. Fish budget coefficients and SBC efficiency for the total project (R_{all}) and for the SBC/Turbines 4-6 (R_{4-6}) for 1997 and 1998 spring data from Lower Granite Dam.

Parameter	1997	1998
Spill Efficiency	0.48	0.30
Horizontal distribution	0.65	0.75
Vertical distribution	0.79	0.90
Entrainment parameter	0.33	0.05
Entrance efficiency	0.69	0.59
R_{all}	0.12	0.27
R_{4-6}	0.37	0.51

For the total project fish budget (Figure 4.36), we started with 100 fish entering the forebay and then partitioned these fish into various routes of passage based on hydroacoustic index data from spring 1998. We knew from spill efficiency data that 30 of the 100 fish were spilled. Of the remaining 70 fish, horizontal distribution data showed that 53 entered the forebay (0-30 m) of the SBC and 17 passed into Turbines 1-3. Of the 53 fish that entered the SBC forebay, 5 fish were below the bottom of the SBC/SWI and 48 fish (90%) were distributed vertically above the bottom of the SBC/SWI. On approach to the SBC, 5% or 2 of the 48 fish became entrained in turbine flow before becoming available (within 3 m) to the SBC. This leaves 46 fish that got within 3 m of the SBC entrances. Entrance efficiency data showed that 27 (59%) of these 46 fish went into the SBC, but 19 fish went under or around the SBC. The equation that described the total project fish budget is:

R_{all} = (1 – spill efficiency) x (horizontal distribution) x (vertical distribution) x (1 – entrainment rate) x (entrance efficiency)

= 0.70 x 0.75 x 0.91 x 0.95 x 0.59 = 0.27

In summary, the total project fish budget (Figure 4.36) showed that given 100 fish entering the entire forebay, 30 were spilled, 36 were guided by the ESBS in turbine intakes, 7 were unguided passing in turbine flow, and 27 went through the SBC.

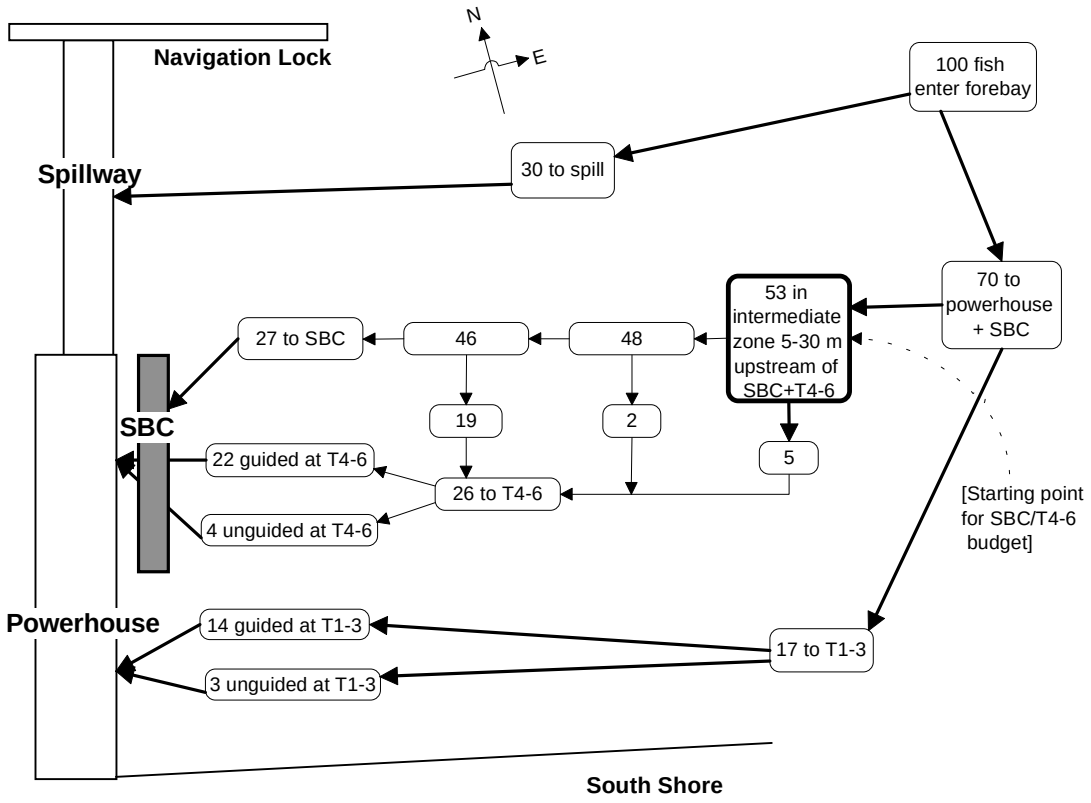


Figure 4.36. Plan view of total project fish budget for the run-at-large in spring 1998.

The second fish budget was for the forebay 0-30 m upstream of the SBC and Turbines 4-6 (Figure 4.37). This region includes the intermediate zone (3-30 m) as described by Johnson et al. (1997a), and is where the SBC and turbine flownets begin to separate. The inner region (0-3 m), called the nearfield, is where the SBC's zone of influence is presumed to occur. (We do not know where smolts first sense the SBC flownet in the forebay.) Fish in the nearfield are assumed to be available to the SBC. To develop the SBC/T4-6 fish budget, we started with 100 fish entering the intermediate zone. Vertical distribution data showed that 91% of the fish were above the bottom of the SBC and thus potentially available. We assumed the other 9% of the fish passed into the turbine intakes simply because of their vertical distribution. Five percent or 5 fish of these 91 fish were entrained in turbine flow before having the opportunity to discover and become available to the SBC. (We call this phenomenon entrainment, although these fish also could have actively sounded to pass the dam.) This leaves 86 fish available to the

SBC. Of these, 51 went into the SBC, and 35 went under or around the SBC and likely passed through the turbines or spillway. The equation that described the SBC/T4-6 fish budget as it related to SBC performance is:

$R_{4\text{-}6}$ = (vertical distribution) x (1 – entrainment rate) x (entrance efficiency)

= 0.91 x 0.95 x 0.59 = 0.51.

In summary, the SBC/T4-6 fish budget (Figure 4.37) shows that for every 100 fish that entered the intermediate zone of the SBC, 41 were guided by the extended-length screens, 8 were unguided passing in turbine flow, and 51 went through the SBC.

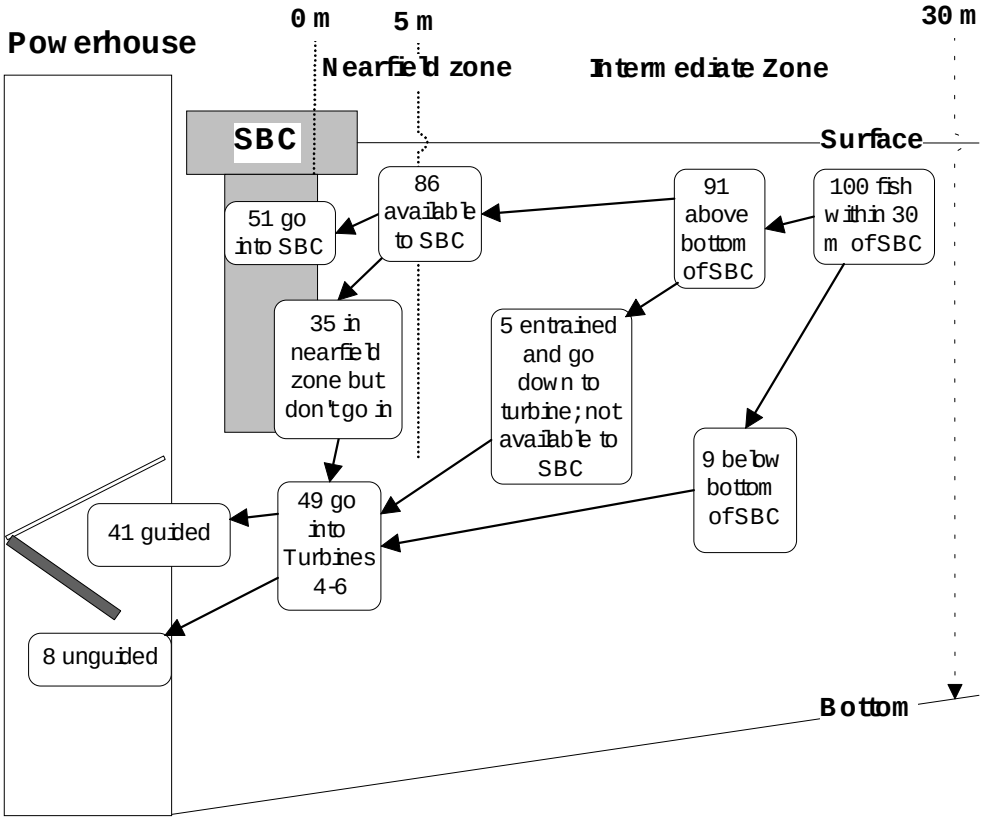
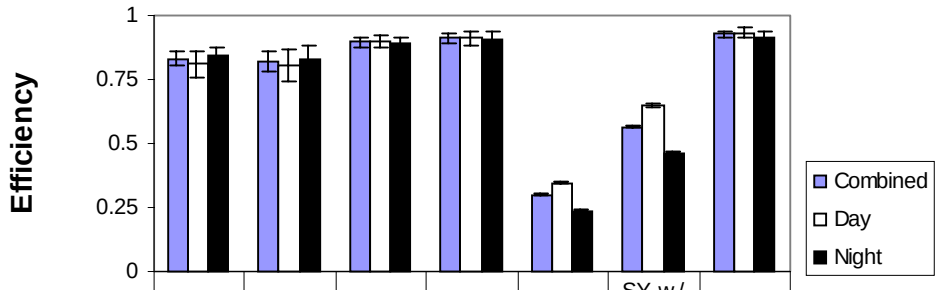


Figure 4.37. Side view of SBC/T4-6 fish budget for the run-at-large in spring 1998.

Passage efficiency estimates (Figure 4.38) showed the performance of spill, the intake screens, and the SBC at diverting fish from turbines. Spill efficiency was 29.7 ± 0.4% and was lower at night than during the day, with and without SBC passage included (Figure 4.38). Overall, FGE was 83.0 ± 2.7%,

which was lower than the 87.4 ± 0.1% we estimated in 1997. For the powerhouse as a whole, combined bypass efficiency (CBE) was 89.5 ± 1.7%, down slightly from 90.9 ± 0.2% in 1997. CBE and fish passage efficiency (FPE) were slightly higher during the day than at night (Figure 4.38). Overall, FPE was 92.6 ± 1.2%, compared to 95.0 ± 0.4% in 1997.



	FGE1-6	FGE4-6	CBE1-6	CBE4-6	SY	SY w/ S1	FPE
Combined	0.830	0.817	0.895	0.910	0.297	0.565	0.926
Day	0.809	0.804	0.897	0.912	0.347	0.648	0.933
Night	0.843	0.829	0.890	0.906	0.237	0.464	0.916

Figure 4.38. Summary of fish passage efficiencies for day, night, and combined.

Section 5: Fish Behavior Results

5.1 Fish Behavior in Front of the SBC (Multi-Beam)

5.1.1 Target Summary

A summary of the targets acquired by the multi-beam is provided in Table 5.1. This represents the sample sizes used in our analyses. The number of targets detected in the sonar beams during the season was much greater than was used in our data analyses (105,000 tracked targets). The processing methods used, primarily visual inspection of each acceptable target, resulted in stringent criteria for target acceptance. To be accepted for analysis, targets had to meet minimum acceptance criteria (a 4-hit minimum) and conform to various tracking and filtering algorithms developed for the purpose of target discrimination. During binning-based analyses, fish tracks were assigned to bins based on their starting location. Individual fish may have left a sample region and returned at a later time or been re-acquired in an adjacent rotational sector of the total sampled volume as the transducer was rotated from sector to sector. Because there was no way to determine if a target was sampled more than once, those fish were assumed to be unique fish targets for the purpose of analysis.

Table 5.1. Summary of targets and records meeting acceptance criteria, including target maximum statistics for Lower Granite Dam multi-beam sampling in spring 1998.

BGS	Day/Night	Number of targets	Number of records	Maximum time (s)	Maximum x-distance (m)	Maximum y-distance (m)	Maximum z-distance (m)
IN	Day	4000	19,938	23.7	9.7	10.1	10.9
IN	Night	3009	14,600	20.0	7.8	12.3	9.3
OUT	Day	4727	23,779	22.0	11.6	9.7	9.9
OUT	Night	4702	22,556	20.0	11.3	13.9	12.0
Total		16,438	80,873				

5.1.2 Sonar Coverage

The effective beam width of the multi-beam was approximately 30°. Due to the horizontal rotation capability and movement of the floating platform, the beam actually sampled a much larger area. Wind and wave action expanded the sample volume in a more or less random fashion. However, we continued to have difficulty sampling the region inside the poles that were deployed for underwater radio tracking. This was partly due to their motion and size, and partly due to an inherent limitation of multi-beam acoustics to "see" beyond such obstacles.

Fish positions were plotted from three perspectives (side, top, and front) following the dam-referenced coordinate system used for analysis. The total coverage was nearly 80 m horizontal (parallel to the SBC), 35 m vertical (well below the SWI), and extended approximately 55 m into the forebay from the face of the dam[1] (Figure 5.1, through Figure 5.3). Please note that the frontal view (Figure 5.3) is oriented as though viewed from behind the SBC looking upstream toward the forebay.

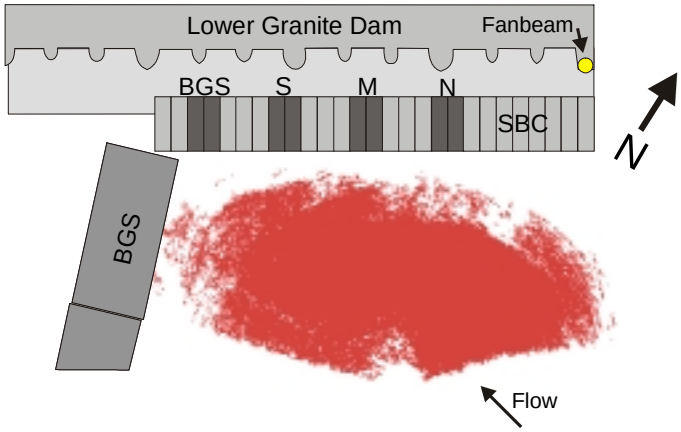


Figure 5.1. Scatter plot of tracked fish (top view).

[1] The face of the SBC extended approximately 12 m beyond the dam reference line at the deck level.

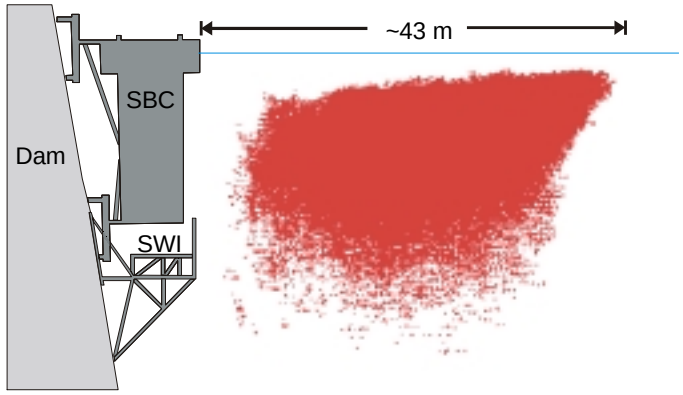


Figure 5.2. Scatter plot of tracked fish (side view).

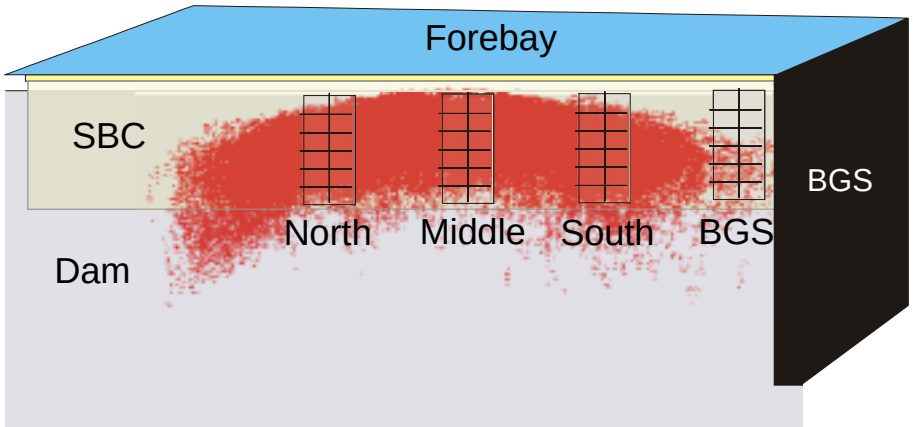


Figure 5.3. Scatter plot of tracked fish (front view as viewed from behind the SBC with the BGS opening on the right and the north opening on the left; not to scale).

5.1.3 Target Depth Frequency Distribution

Fish target depth distribution was evaluated based on three regions in front of the SBC and Turbines 4-6. The three regions (near, 5.5 to 13 m; mid, 13 to 25.5 m; and far, 25.5 to 43 m) are illustrated in Figure 5.4.

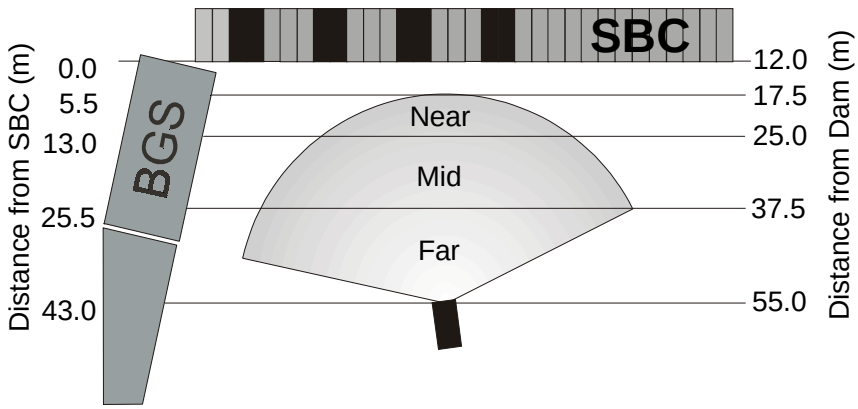


Figure 5.4. Perspective view indicating near, mid, and far ranges from the SBC used to describe depth frequency distributions.

The depth distribution of fish targets (Figure 5.5) suggest that, as fish approached the SBC, they were distributed slightly deeper when the BGS was OUT. Between 27 and 50 m from the dam there was no apparent difference in median fish depth between BGS conditions. Closer to the SBC (21 to 27 m from the dam), fish detected with the BGS IN maintained their depth, while the median depth for BGS OUT fish dropped approximately 2-3 m. At the extent of the area examined by the multi-beam (approximately 21 m from the dam and 9 m from the SBC), the median depth for fish targets was 13 m for the BGS OUT condition compared to 11.4 m for the BGS IN condition.

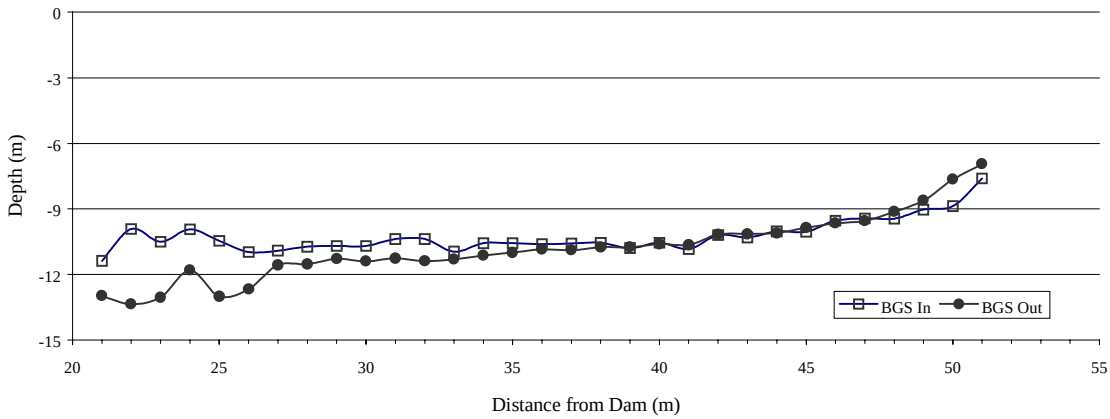


Figure 5.5. Median depth of fish targets in front of Turbines 4-6 during April-May 1998.

Comparing the distribution of targets between BGS IN and OUT for 3 regions in front of the SBC (Figure 5.6), we noted that near the SBC with the BGS IN, the distribution of targets was higher in the water column than when the BGS was OUT. Smaller differences in the distributions were evident when we looked at targets in the mid and far ranges. These differences were made more evident when we looked at the differences (BGS IN minus BGS OUT) in the distributions plotted against depth (Figure 5.7). For targets in the near region, there were more fish targets below 12 m when the BGS was OUT than when the BGS was IN. The greatest difference was at 13 m, where there were 7% more fish when the BGS was OUT compared to when it was IN. At mid range, a greater proportion of the population was found deeper, between 10-15 m when the BGS was OUT. This trend was reversed for the fish targets farthest from the SBC, with fish targets deeper when the BGS was IN.

The differences in distribution described above are based on the proportion of the population in each range category by depth. When we look at total fish numbers instead of proportions, the differences between BGS IN and OUT are not as obvious (Figure 5.8). This is due to our tracking a much larger number of fish in the far region compared to the near. However, the trends are still present. Thus, for the area of concern near the SBC, fish targets were higher in the water column when the BGS was IN compared to when it was OUT.

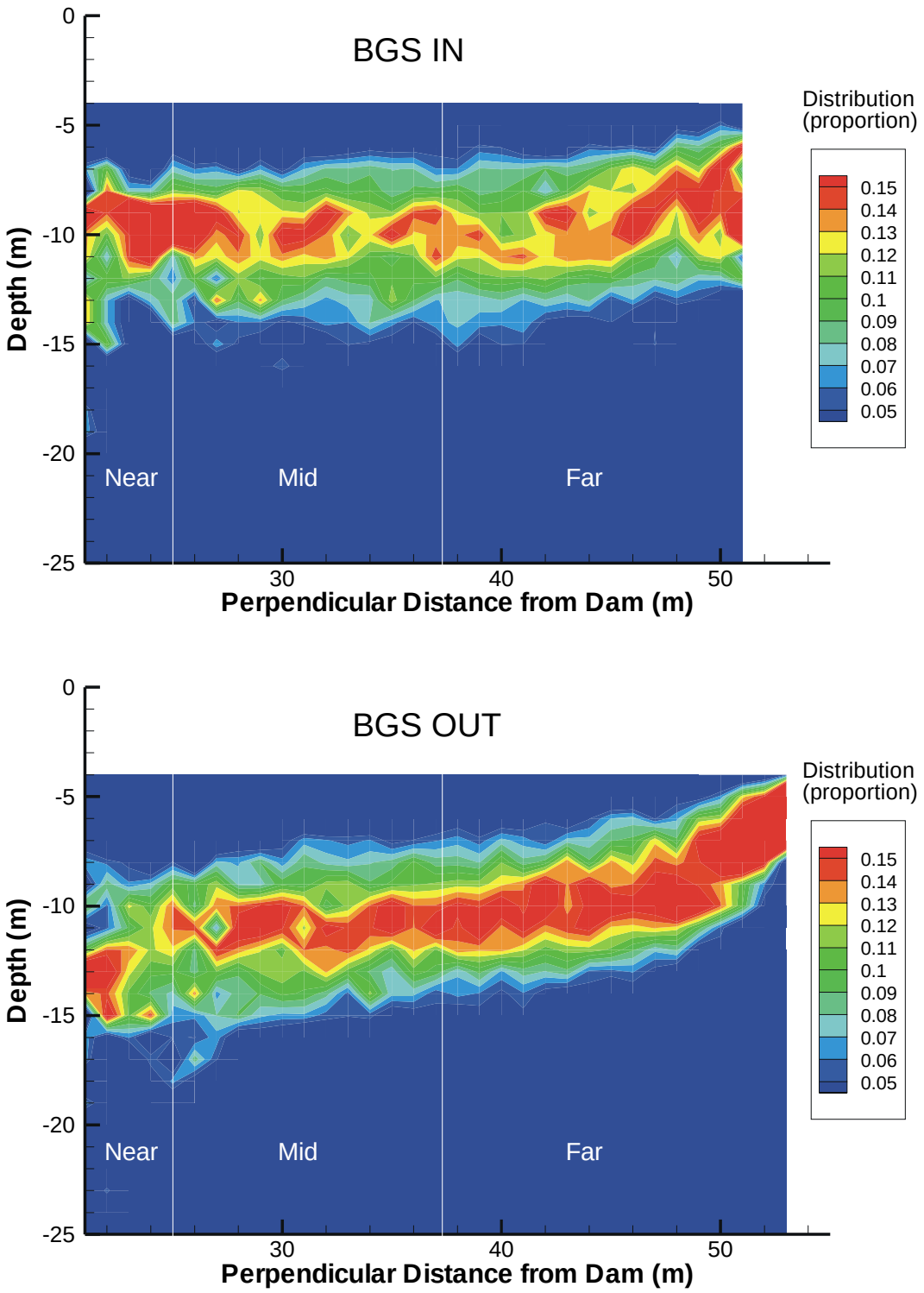


Figure 5.6. Depth distribution for fish targets in front of Turbines 4-6 in 1998.

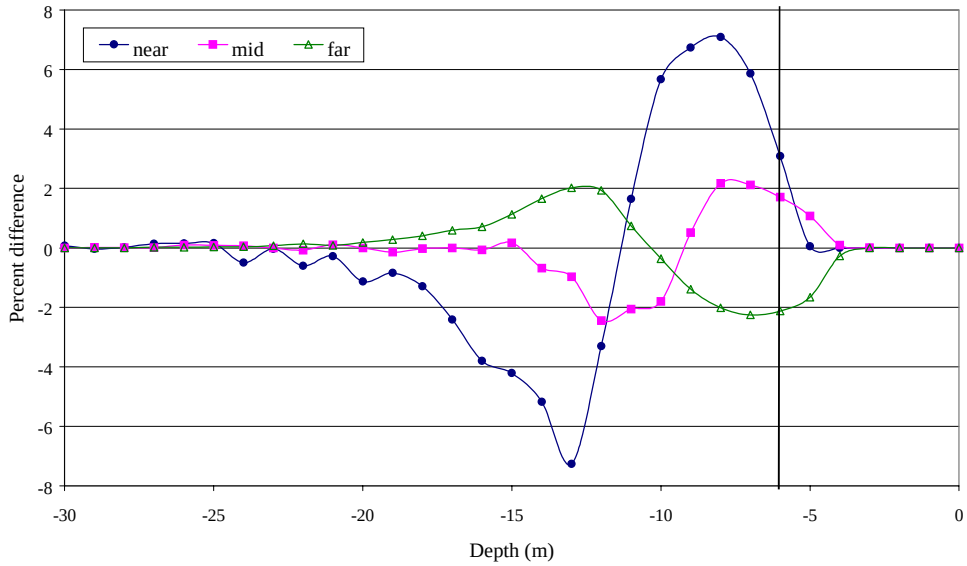


Figure 5.7. Difference (BGS IN minus BGS OUT) in the proportion of the population at each depth. Black vertical line indicates limit of detectability. Points above zero on vertical axis represent depths where there are proportionally more fish targets when the BGS is IN than when it is OUT; points below zero are depths where there are fewer fish targets when the BGS was IN than OUT.

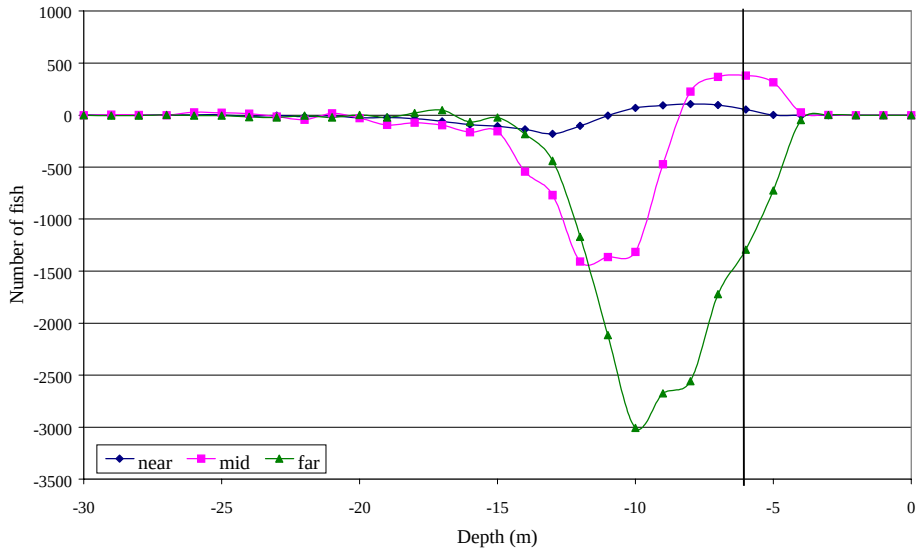


Figure 5.8. Difference (BGS IN minus BGS OUT) in the number of fish targets at each depth. Black vertical line indicates limit of detectability. Points above zero on vertical axis represent depths where there are more fish targets when the BGS is IN than when it is OUT; points below zero are depths where there are fewer fish targets when the BGS was IN than OUT.

5.1.4 Direction of Movement

The direction of movement is plotted with polar histograms of instantaneous direction within spatial regions. The extent of each wedge (3°) in the polar plot is the number of observations in that direction. The red line is the angular mean. We only present observed fish direction of movement (fish + water) for BGS IN and OUT, and fish swimming effort direction of movement (fish only) for BGS IN, high turbine load.

A series of perspective views follow to aid in visualization of the data. The top view (Figure 5.9) is looking down on top of the sample region with the dam at the top. The side view looks from the BGS position out into the forebay in front of the SBC (Figure 5.10). The front view (Figure 5.11) is looking from the dam upstream toward the sample region. The lines indicate the approximate sample region divisions.

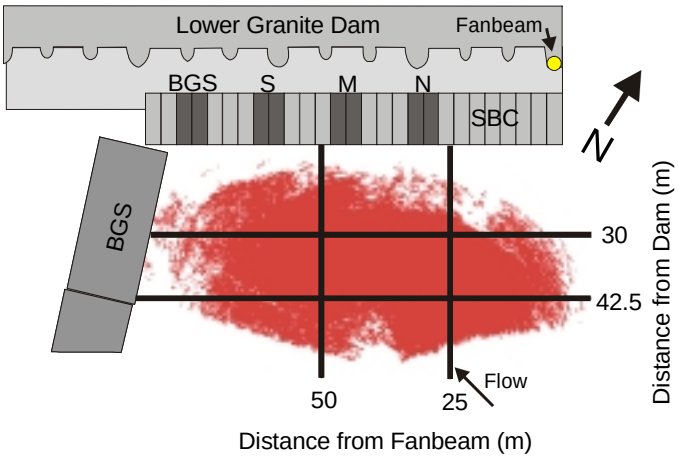


Figure 5.9. Perspective view (xz plane) indicating spatial bins and data coverage for the top view.

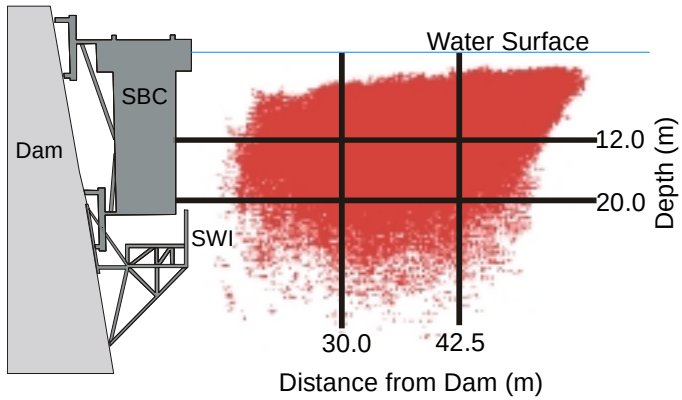


Figure 5.10. Perspective view(yz plane) indicating spatial bins and data coverage for the side view.

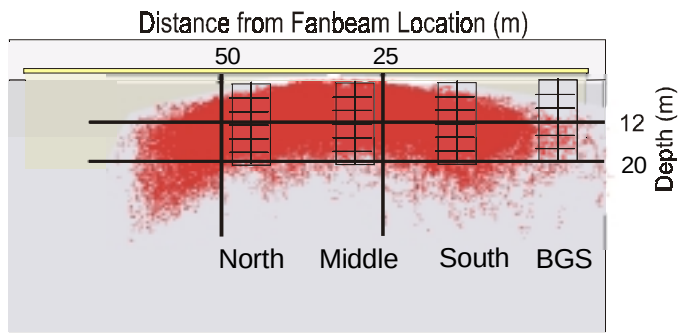


Figure 5.11. Perspective view(xy plane) indicating spatial bins and data coverage for the front view. (Note that the BGS is to the right in this perspective).

5.1.4.1 Observed Fish Movement

5.1.4.1.1 Observed Top View (xz plane)

In general, fish appeared to move in the direction water flowed in the sample region. However, three distinct patterns emerged from the top view polar histograms (Figure 5.12 and Figure 5.13). First, fish approaching from the northeast corner of the sampled region were highly directed downstream. Second, as they moved in front of the floating platform and toward the SBC, their movement patterns became more variable. Fish even closer to the SBC exhibited a strong tendency to move toward and/or parallel to the SBC. These patterns were similar for BGS IN and OUT. Third, as fish passed by the barge toward the BGS, they appeared to become bimodal in their direction. Fish

appeared to either move along the BGS or toward the BGS and slightly upstream. This bimodality was less apparent when the BGS was not present.

The computational fluid dynamics model indicated that there were complex flow patterns near the BGS structure. When the BGS was in place, water pushed against it so that the bottom was forced slightly toward the south shore. Most water flowed under the BGS, but some welled up along the curtain and created a backward flow, especially notable in the corner where the BGS met the SBC and near the water surface. This complex flow pattern may have contributed to the IN vs. OUT difference in observed behavior at the BGS/SBC corner.

5.1.4.1.2 Observed Side View (yz plane)

The side view perspective (Figure 5.14 and Figure 5.15) did not result in any clear directional trends. There were subtle differences in mean direction as a function of depth. Fish near the surface were oriented slightly downward on average, fish in the mid region moved fairly level, and fish in the deepest layer were moving slightly upward in the water column. This was true for both BGS IN and OUT conditions. In all regions, except for the top layer closest to the floating platform, fish were moved toward the SBC. In the top layer closest to the platform, fish movements were highly variable.

5.1.4.1.3 Observed Front View (xy plane)

The front view (Figure 5.16 and Figure 5.17) was typified by two patterns: strong lateral movement (north and south parallel to the SBC) and highly variable patterns. The strong lateral movements were in the top layer in front of the South and BGS entrances. Fish in the southernmost bin were headed north, and fish in the middle bin were headed south in this perspective.

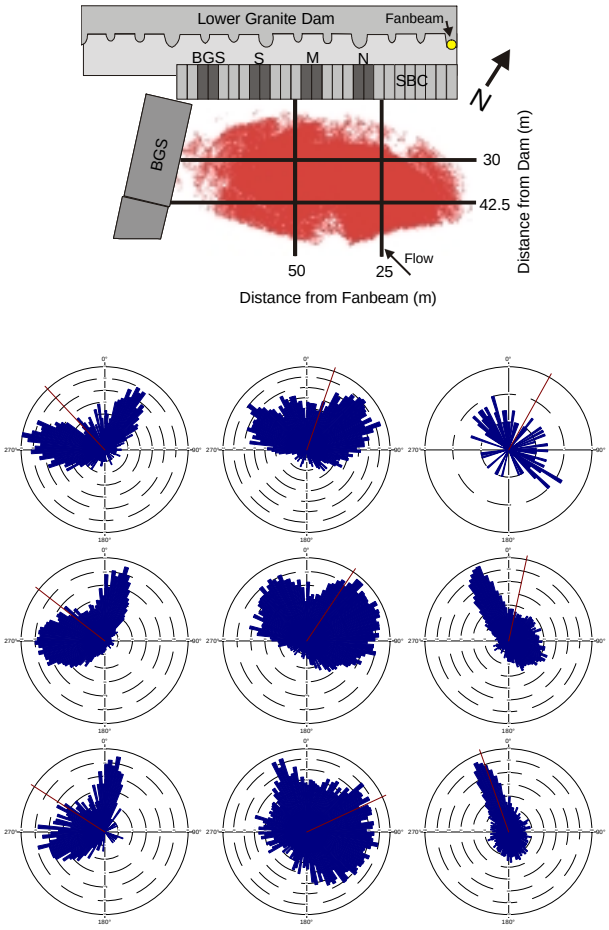


Figure 5.12. Observed fish movement top view polar histograms for the IN condition.

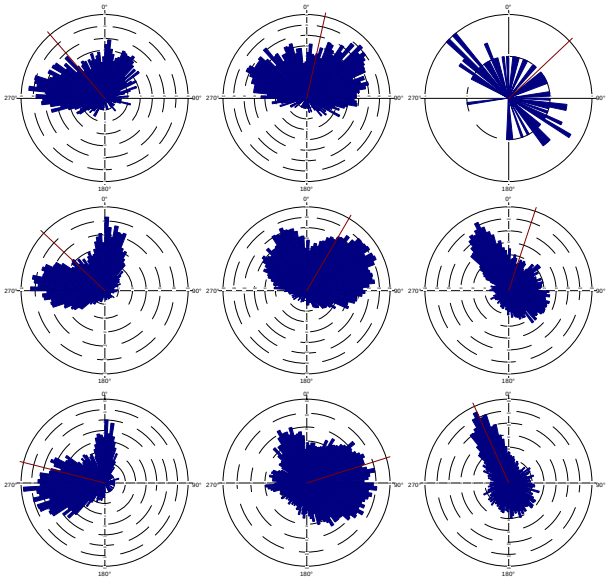
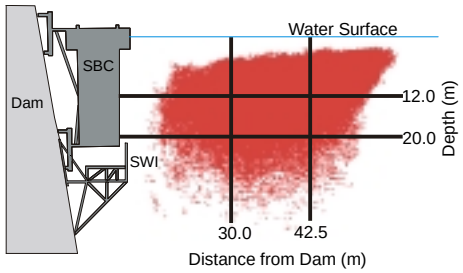


Figure 5.13. Observed fish movement top view polar histograms for the OUT condition.



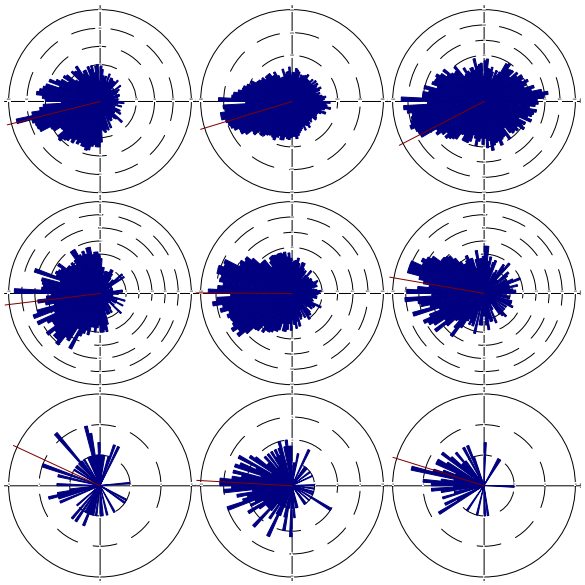


Figure 5.14. Observed fish movement side view polar histograms for the IN condition.

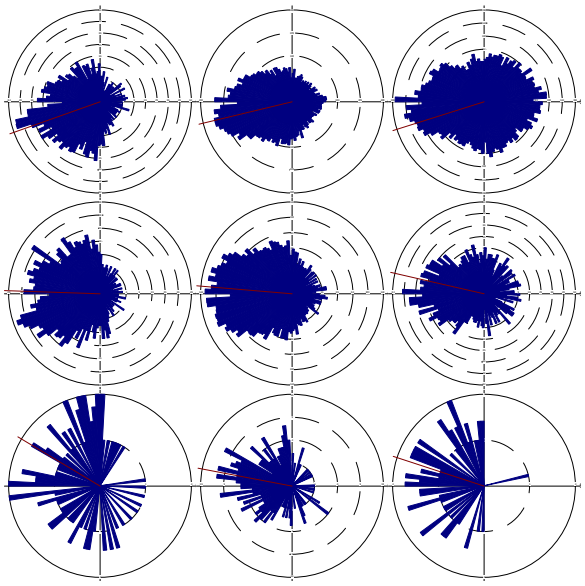
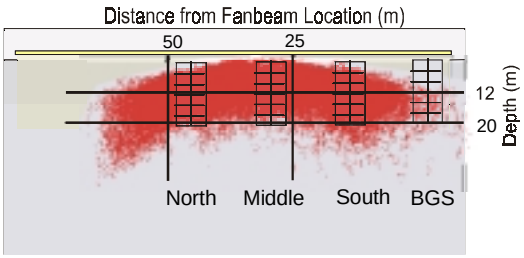


Figure 5.15. Observed fish movement side view polar histograms for the OUT condition.



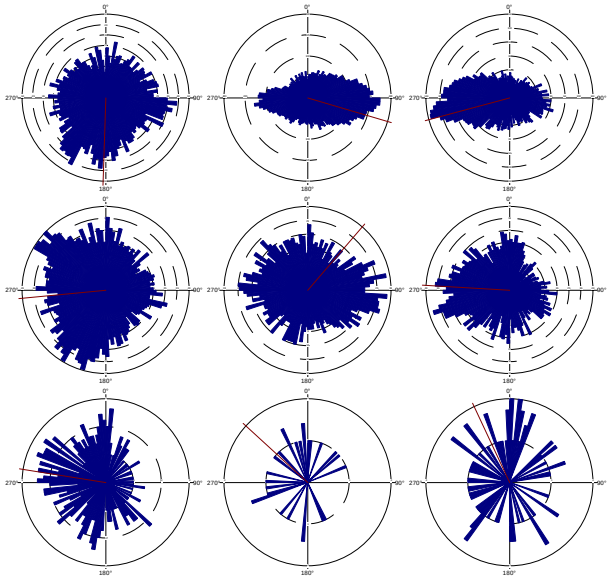


Figure 5.16. Observed fish movement front view polar histograms for the IN condition.

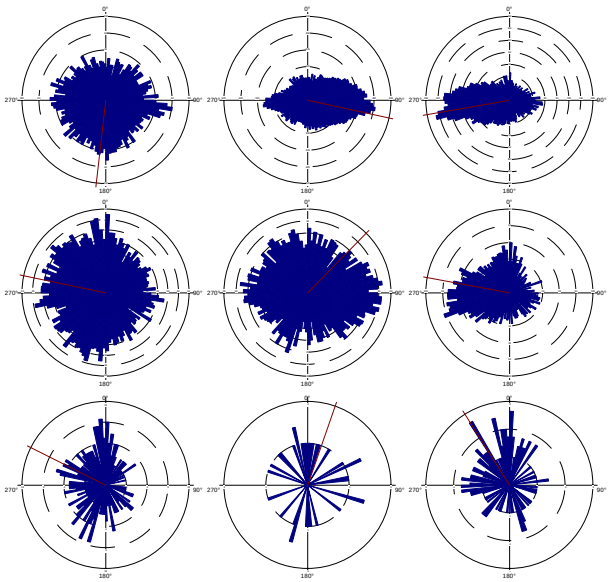


Figure 5.17. Observed fish movement front view polar histograms for the OUT condition.

5.1.4.2 Fish Swimming Effort

Only the BGS IN condition was evaluated for fish swimming effort because flow data were not provided for the BGS OUT condition. Although the direction of fish swimming effort was evaluated based on high and low turbine loading and IHR and MAX configurations, we will only report the high turbine loading data for IHR and MAX configurations as results from these configurations were very similar (Johnson et al. 1998b). We also present a tri-vector plot with each polar histogram as described in the methods section. Note that the resolution of the vector plots is on a finer scale than the polar histograms. This is visually more appealing for interpreting general trends in the data.

5.1.4.2.1 Swimming Effort Top View (xz plane)

Fish behavior in response to the IHR configuration was typified by strong swimming effort in an upstream direction (Figure 5.18 and Figure 5.19). The flow approaches the SBC from an oblique angle. As fish moved closer to the BGS, their movement was more complex. The same general trends can be noted for the MAX configuration (Figure 5.20 and Figure 5.21). The greatest area of variability appeared to be at the BGS/SBC junction area. This region was typified by relatively slack water compared to other regions, particularly at the depth where the majority of the fish were detected (Figure 2.11).

5.1.4.2.2 Swimming Effort Side View (yz plane)

The side view data show the direction of fish swimming effort was more variable than the top view data for the majority of the water column (Figure 5.22 and Figure 5.23). The notable exception was the surface layers, particularly in the two bins farthest from the SBC. There, the majority of the fish were oriented upstream. The orientation of fish targets in the surface bin nearest the SBC, while still generally upward and upstream, was more variable. Again, the data for the MAX and IHR configurations were very similar (Figure 5.24 and Figure 5.25). Some of the dispersion at the maximum range from the sonar transducer may have been attributed to small sample sizes as indicated by the polar histograms. In nearly all instances, however, the data show fish generally swimming upward in the water column and upstream. The steepness of the angle of upward swimming effort appeared to increase as fish moved closer to the SBC. These phenomena, as in past years' data, suggest that the fish do not appear to want to dive at the face of the structure. While their swimming effort was generally upstream and upward in the water column, their ultimate fate was in a downstream direction as indicated by the green observed portion of the tri-vector plots.

5.1.4.2.3 Swimming Effort Front View (xy plane)

The front view data are presented as viewed from behind the SBC looking upstream. The BGS would, therefore, be on the right side of the picture and north is to the left. This perspective shows the fish's swimming effort mostly toward the north or away from the BGS for both conditions (Figure 5.26 through Figure 5.29). Again, fish are oriented upstream and upward in the water column. The vectors on the northern half of the region (left) appeared to be flatter than those near the BGS (right). The fish closer to the BGS appeared more vertically oriented, probably reacting to the downward flow field near the BGS structure. Also, the data are more variable near the BGS, suggesting a more complex environment for the fish. The majority of the fish were holding with a number of bins registering an upstream average observed movement away from the BGS in the region closest to the BGS structure.

The data presented in this section underline the complexity with which fish move in proximity to the SBC/BGS structure. Many of the shifts in behavior are apparently beyond regions of high acceleration (depicted in Figures 2.11 through 2.14), suggesting that stimuli other than flow may affect fish behavior in the forebay.

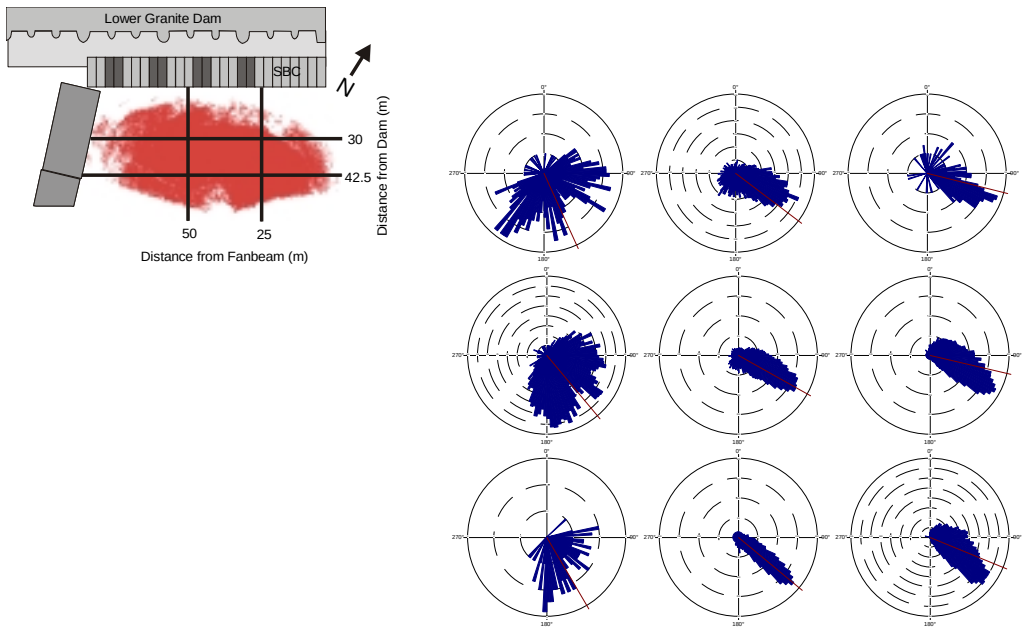


Figure 5.18. Swimming effort polar histogram (top view, IN, Ice Harbor configuration, high load).

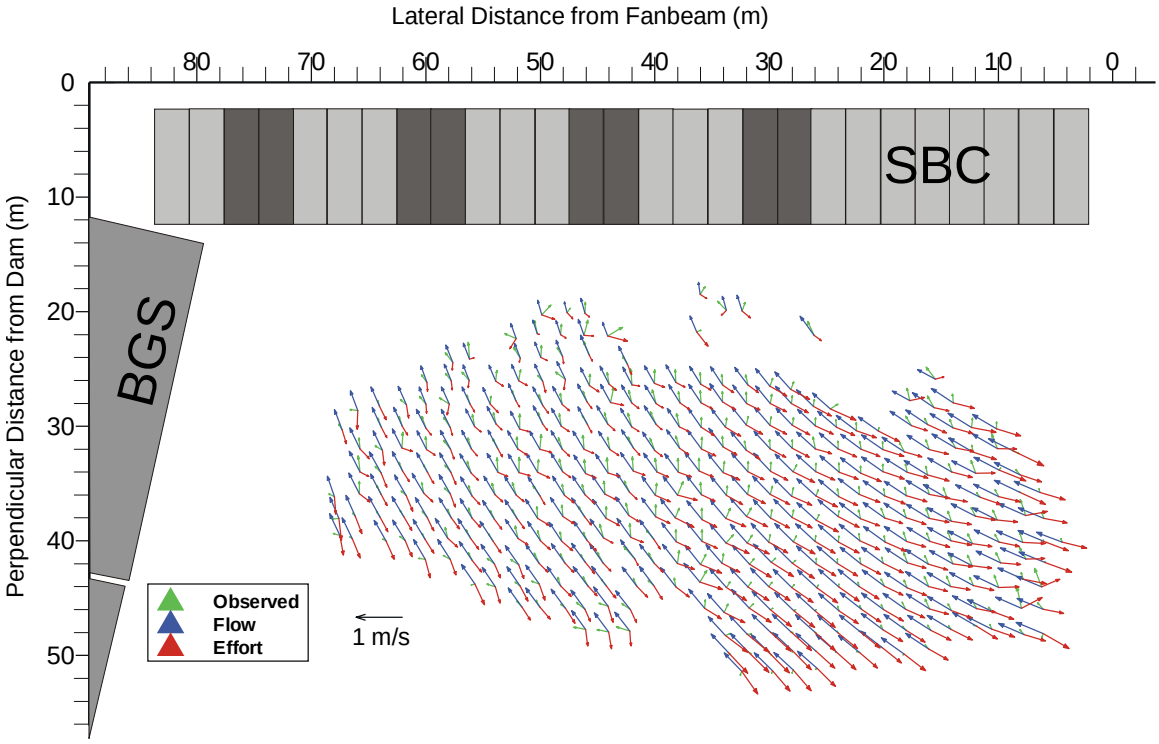


Figure 5.19. Swimming effort vector plot (top view, IN, Ice Harbor configuration, high load).

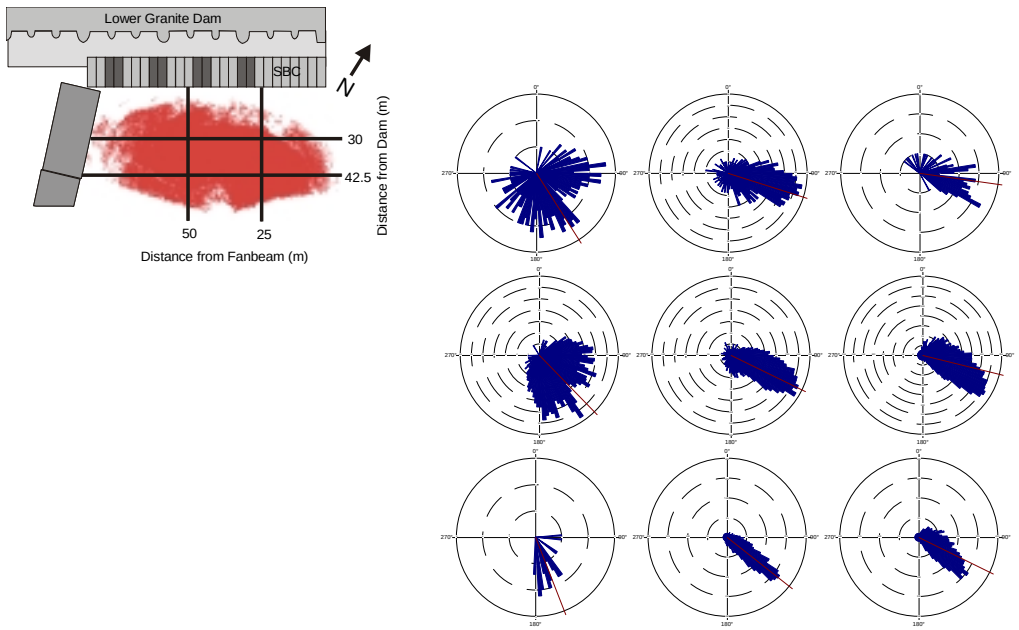


Figure 5.20. Swimming effort polar histogram (top view, IN, maximum configuration, high load).

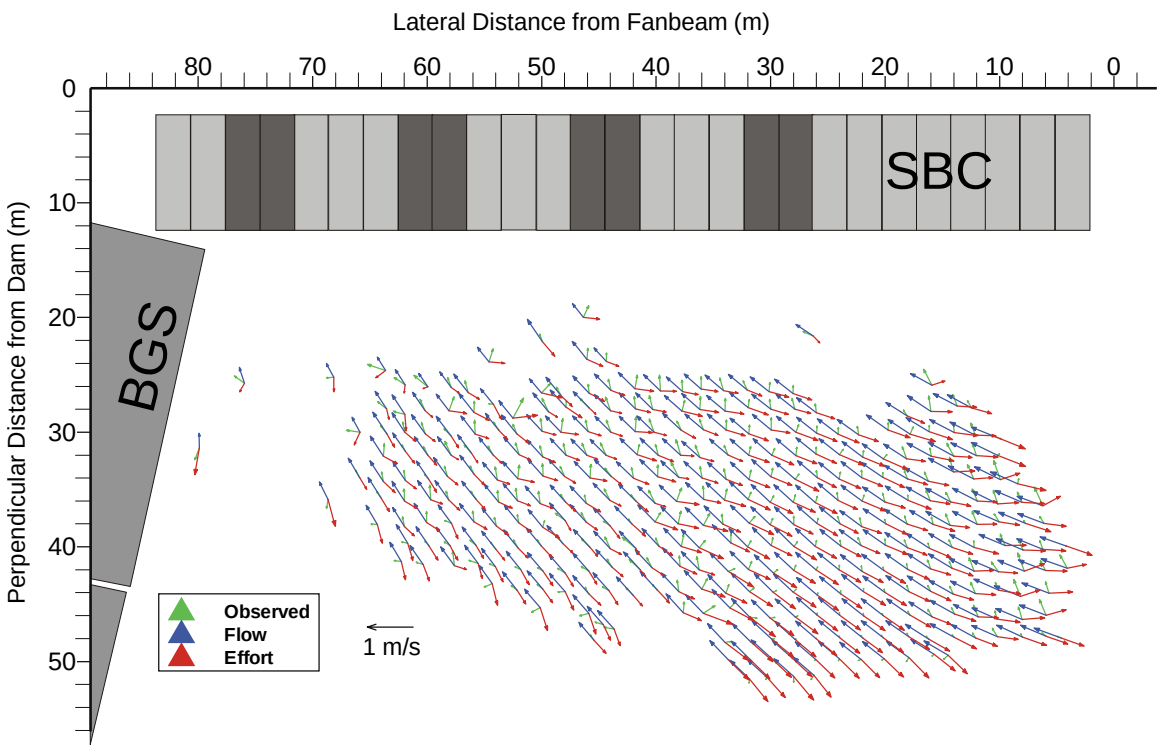


Figure 5.21. Swimming effort vector plot (top view, IN, maximum configuration, high load).

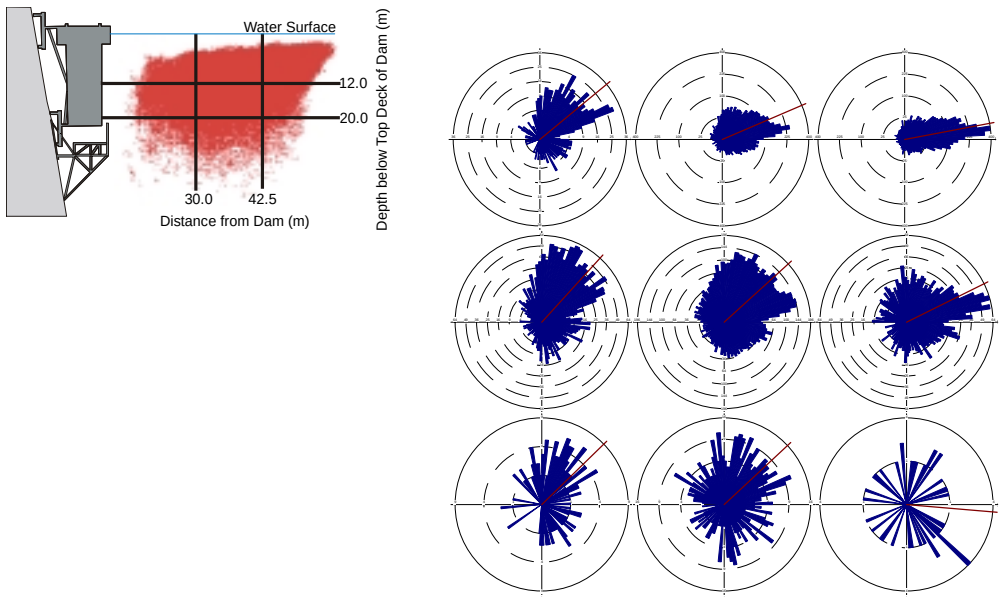


Figure 5.22. Swimming effort polar histogram (side view, IN, Ice Harbor configuration, high load).

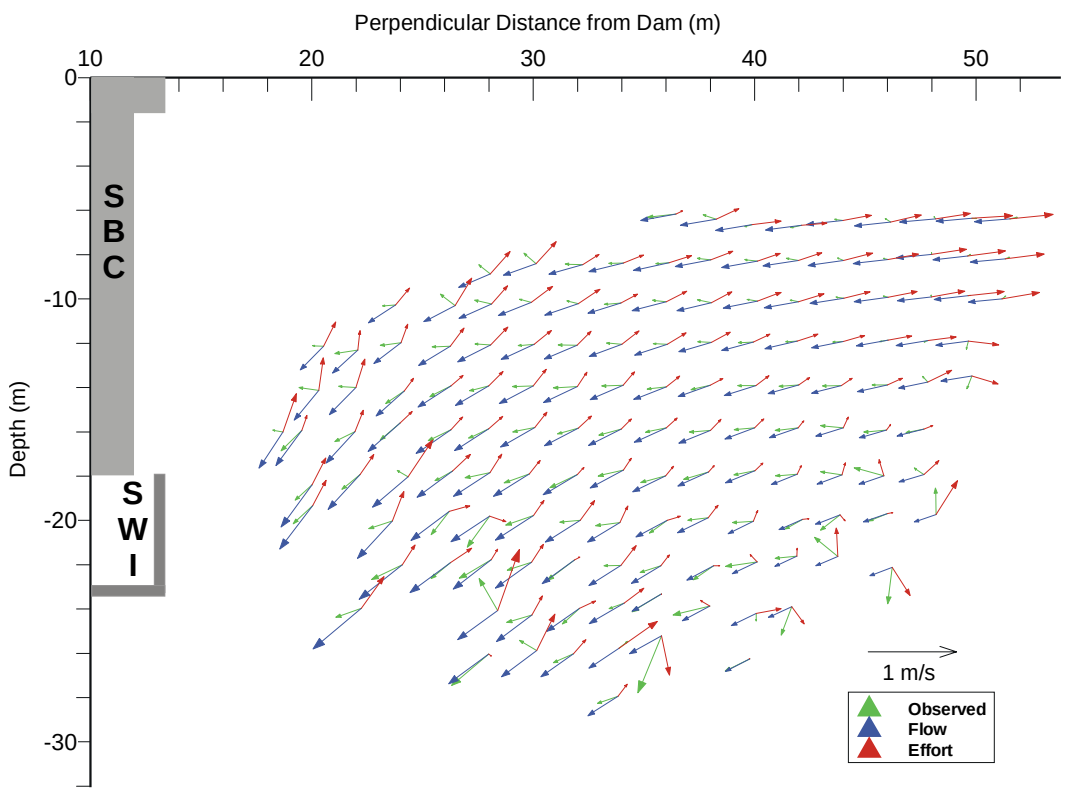


Figure 5.23. Swimming effort vector plot (side view, IN, Ice Harbor configuration, high load).

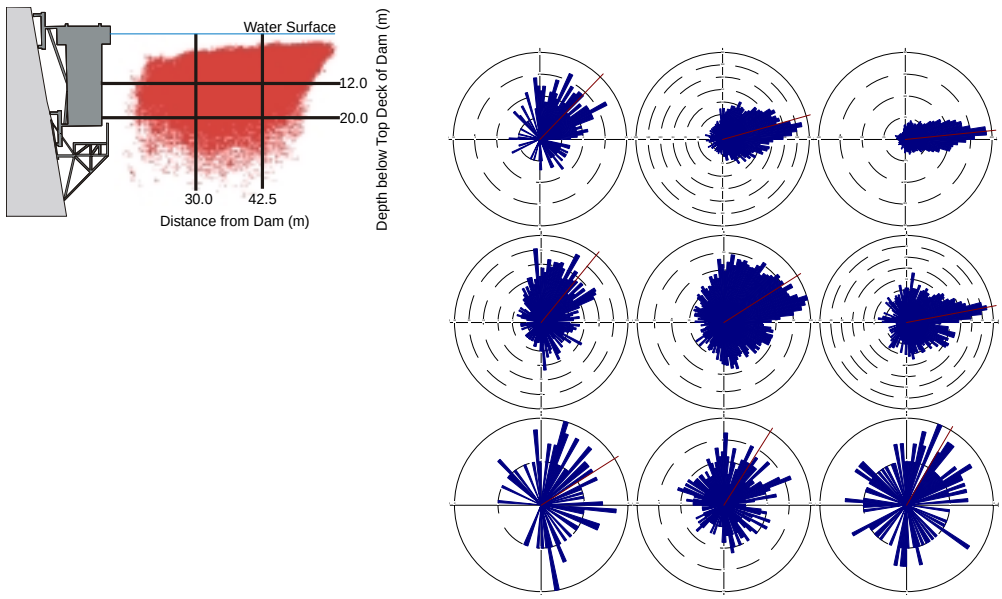


Figure 5.24. Swimming effort polar histogram (side view, IN, maximum configuration, high load).

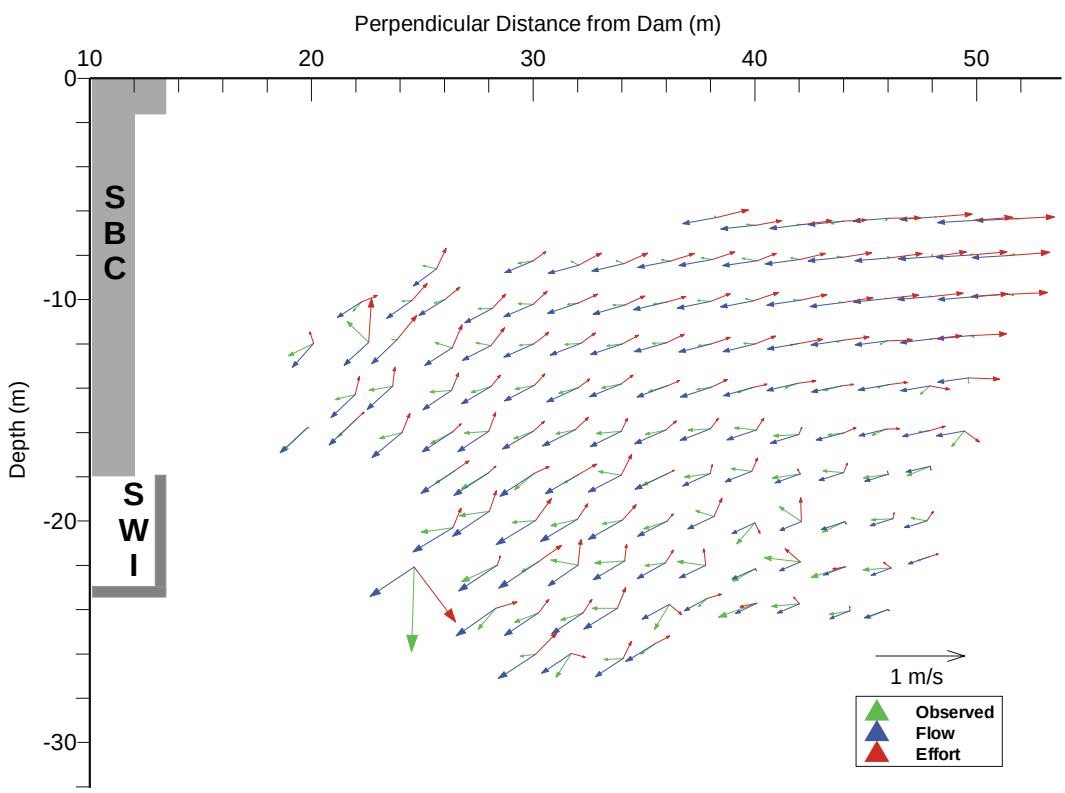


Figure 5.25. Swimming effort vector plot (side view, IN, maximum configuration, high load).

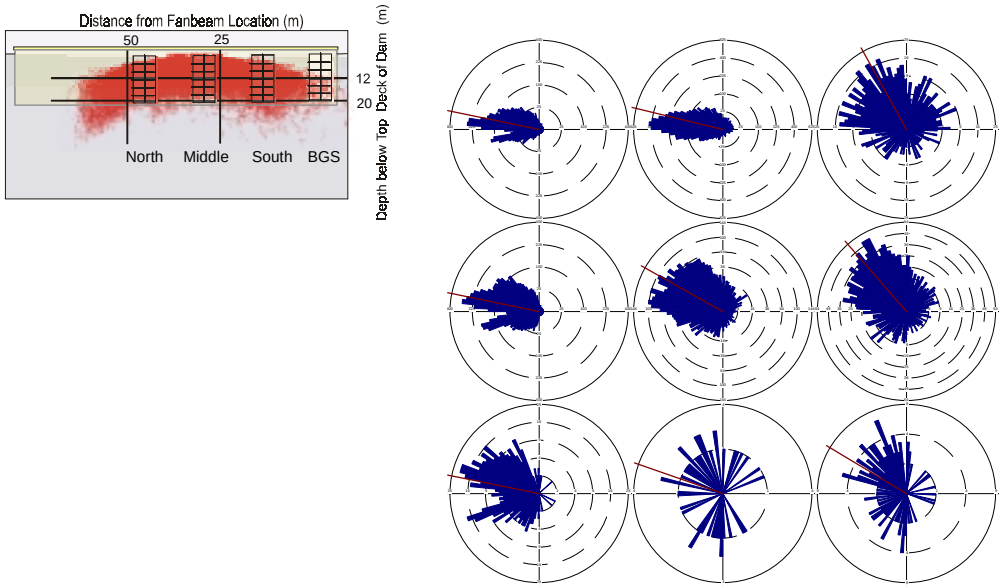


Figure 5.26. Swimming effort polar histogram (front view, IN, Ice Harbor configuration, high load).

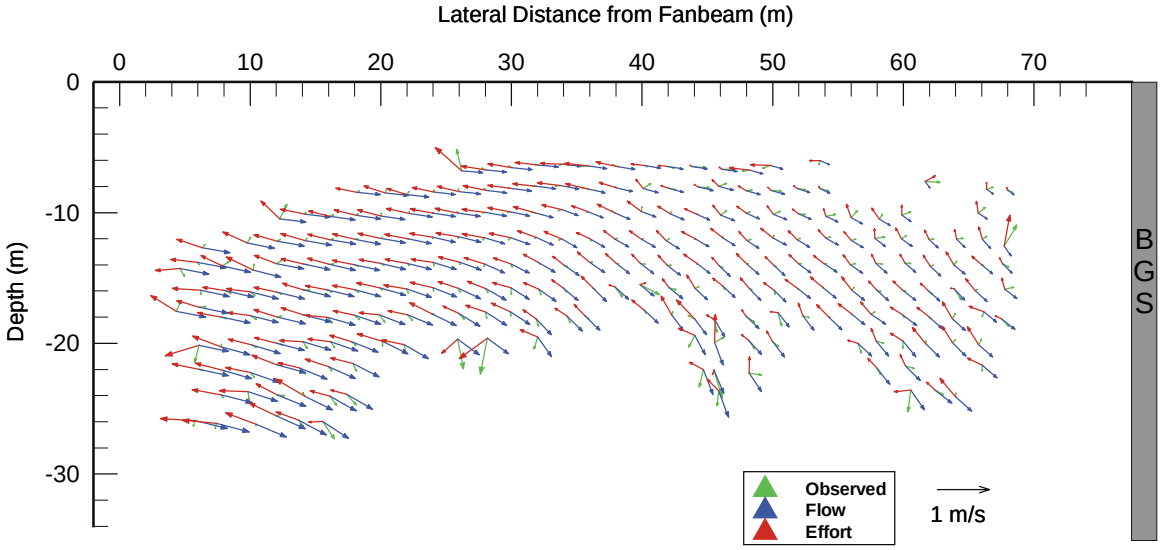


Figure 5.27. Swimming effort vector plot (front view, IN, Ice Harbor configuration, high load).

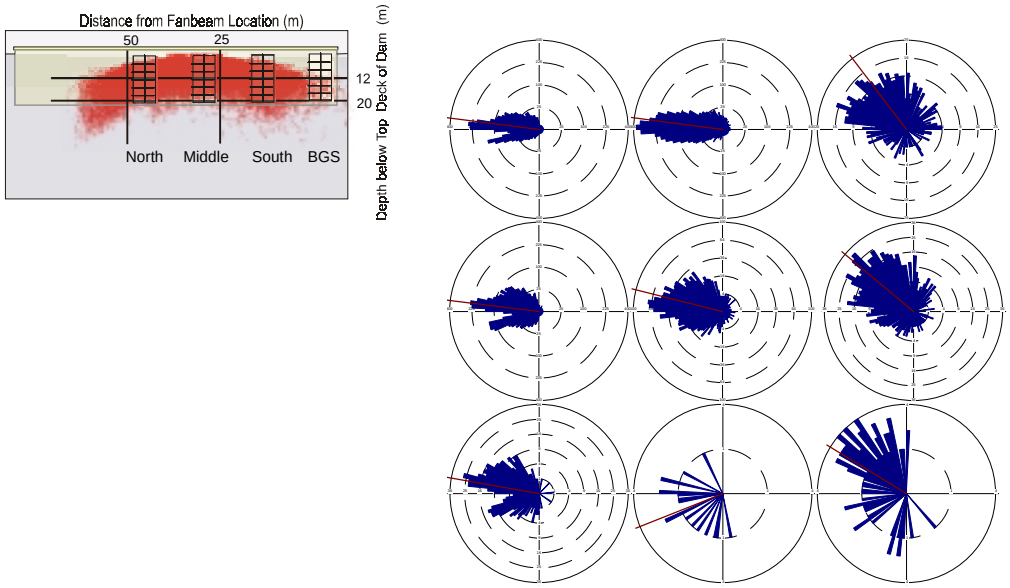


Figure 5.28. Swimming effort polar histogram (front view, IN, maximum configuration, high load).

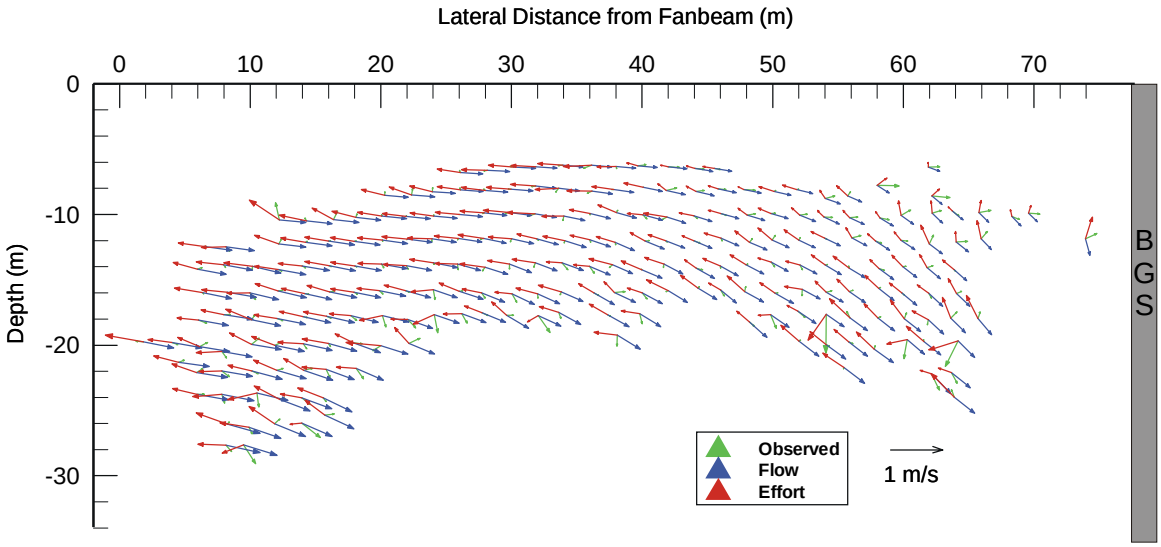


Figure 5.29. Swimming effort vector plot (front view, IN, maximum configuration, high load).

5.1.5 Kinematic Analysis

5.1.5.1 Speed Frequency Distribution

The figures in this section illustrate the distribution of fish speeds detected with the multi-beam sonar in 1998. The speeds compare favorably to those measured with split-beam hydroacoustics in past studies (Johnson et al. 1998a; Johnson et al. 1997c). Speed histograms are presented for the observed fish targets (BGS IN and BGS OUT), and for swimming effort (BGS IN only). The observed speeds are plotted in Figure 5.30 for the BGS IN (blue) and BGS OUT (red) at three ranges from the SBC, near (5.5-13 m), mid (13-25.5 m), and far (25.5-43 m). Observed fish speed distributions are nearly identical at all three ranges for BGS IN and OUT. Observed fish speeds appear to decrease with range from the SBC and except for the mid range, there appears to be little difference in observed fish speed related to BGS condition.

Fish swimming effort speeds increase slightly with distance from the SBC (Figure 5.31). This is opposite to the trend described for observed fish targets but compares favorably to the velocity vector data presented earlier in this section. The average direction of swimming effort movement was mostly against the flow throughout the sampled region as demonstrated in the previous section.

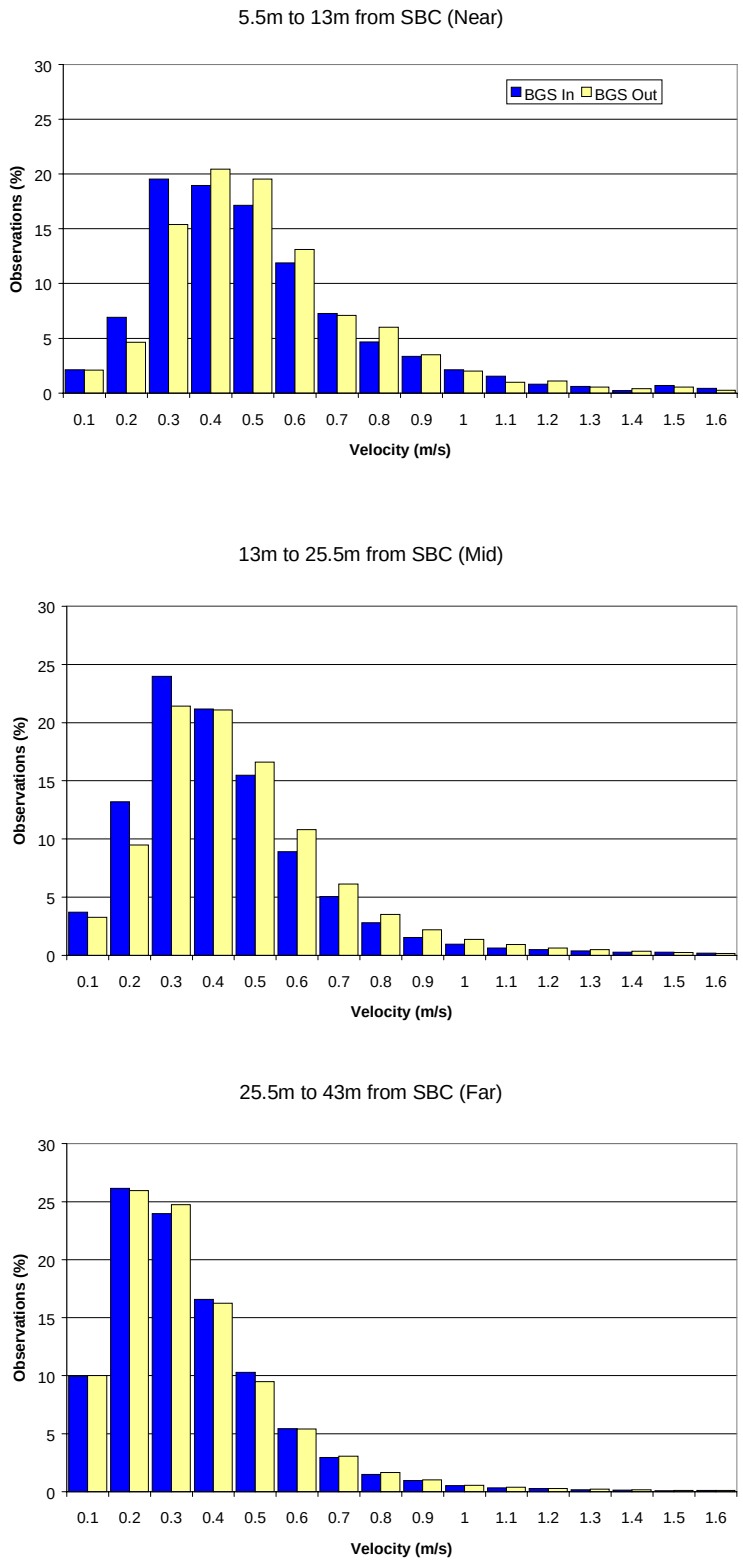


Figure 5.30. Speed frequency histograms showing observed fish speeds for the BGS IN and OUT conditions at three ranges (near, mid, far) from the SBC.

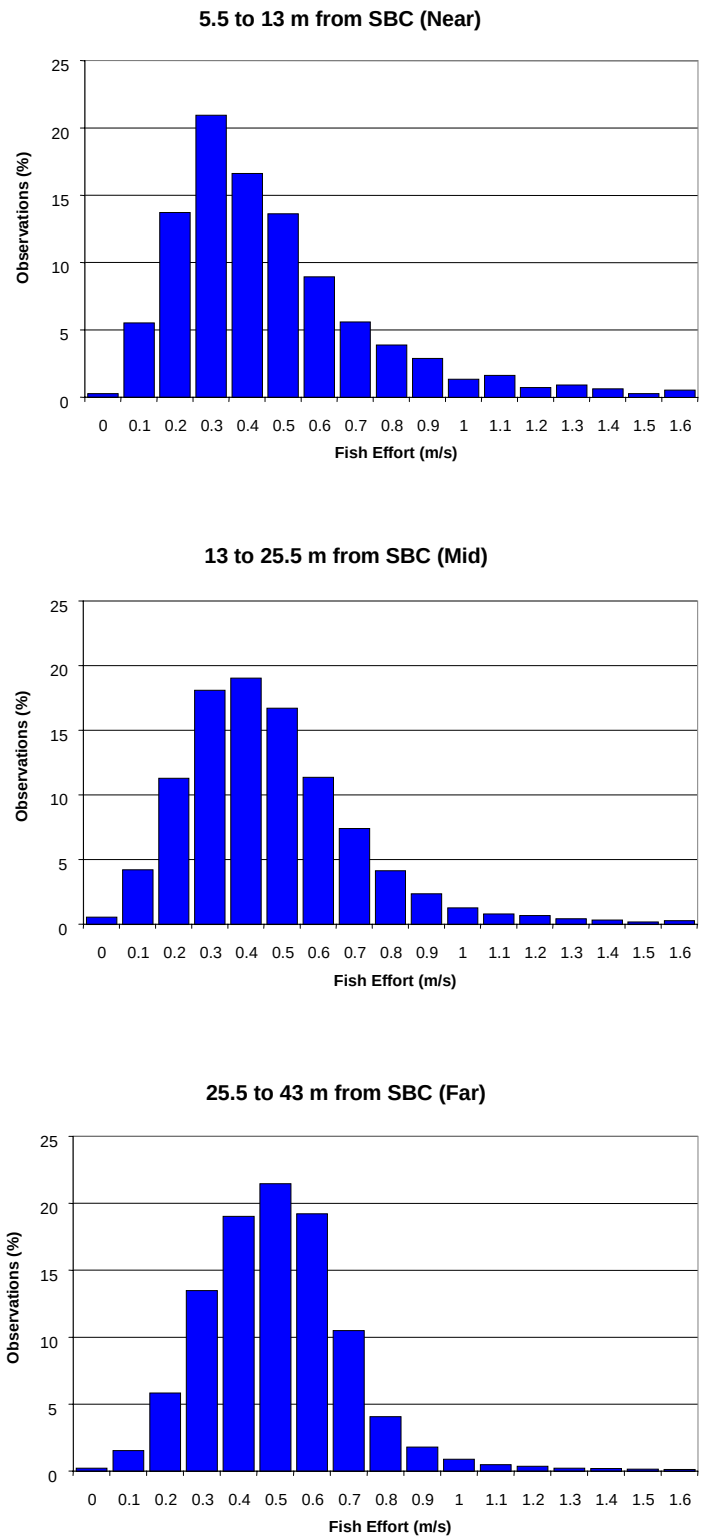


Figure 5.31. Speed frequency histograms showing fish effort for the BGS IN condition at three ranges (near, mid, far) from the dam. Note that the face of the SBC is at approximately 12 m from the dam.

5.1.5.2 Speed Components

The x, y, z components of fish target speed were plotted relative to the three axes, i.e., the distance across (parallel to) the SBC, vertical (depth), and by range from (perpendicular to) the SBC (Figure 5.32). This was done for all observed fish tracks as seen by the multi-beam sonar for BGS IN and BGS OUT, and for all fish swimming efforts for BGS IN.

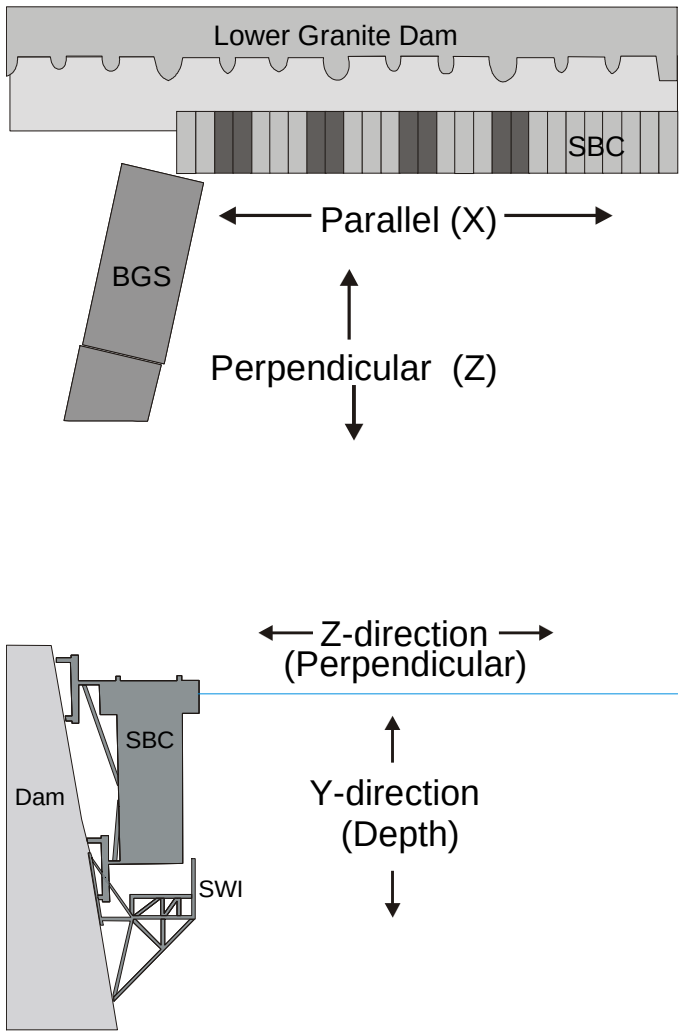


Figure 5.32. Direction references for the xz plane (top) and the yz plane (bottom).

In evaluating the x,y,z components of speed (and other metrics), we looked for relationships between the components. Examples of such relationships are when one component always dominates the other two components or when one component decreases in dominance as another increases. The term we used to describe data exhibiting these relationships is “structured. “Unstructured” data

showed no apparent relationship among the components. When depicted graphically, unstructured components criss-cross a great deal or overlap and cannot be easily distinguished.

5.1.5.2.1 Observed Speed Components

For the BGS IN condition, the observed speed components plotted against the parallel axis were somewhat structured 15 m on either side of the middle opening of the SBC, with the speed components parallel and perpendicular to the SBC dominating (Figure 5.33a). The dominant movement in this area was parallel to the SBC. Closer to the BGS entrance, the speed components became unstructured with no one component dominating. Toward the north end of the SBC, the speed was dominated by the perpendicular and depth components.

The speed components plotted against depth were highly structured throughout the water column (Figure 5.33b). Near the surface, speed was characterized primarily by the parallel component. At increasing depths, this parallel component was replaced by the increasing influence of the perpendicular component (at about 10 m) and by the depth component (at about 13 m). Below 18 m the relationship between components was unchanged except that the depth component began to dominate below the SWI.

As fish moved from the floating platform to the dam, the perpendicular component was replaced by the parallel component near the SBC and dam. The depth component remained relatively constant and was generally the least dominant in this direction.

Figure 5.34 illustrates the observed speed components for the BGS OUT condition. The relative patterns of the components were very similar to those for the BGS IN condition.

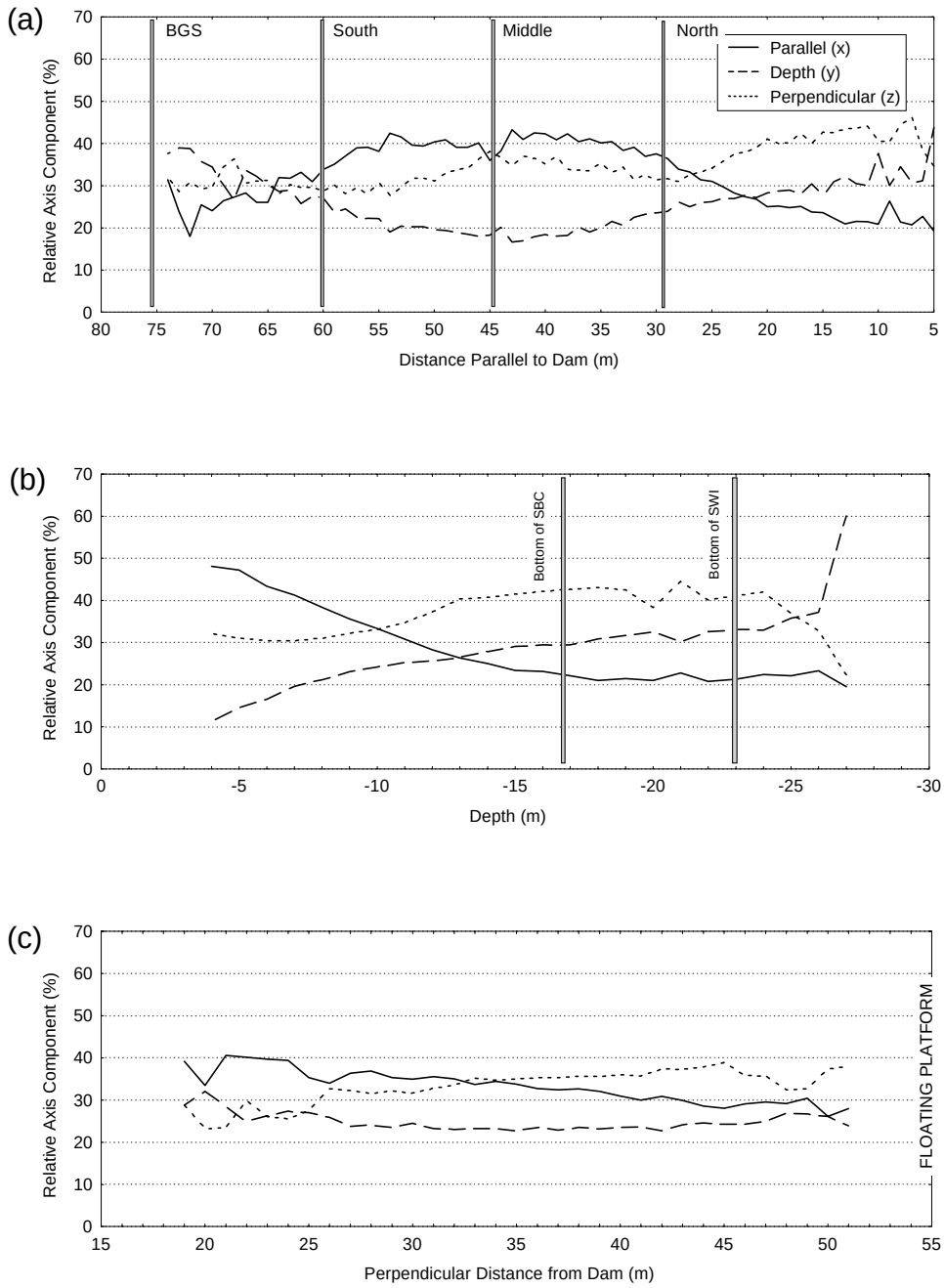


Figure 5.33. Observed X, Y, and Z axis speed components with range for the IN condition.

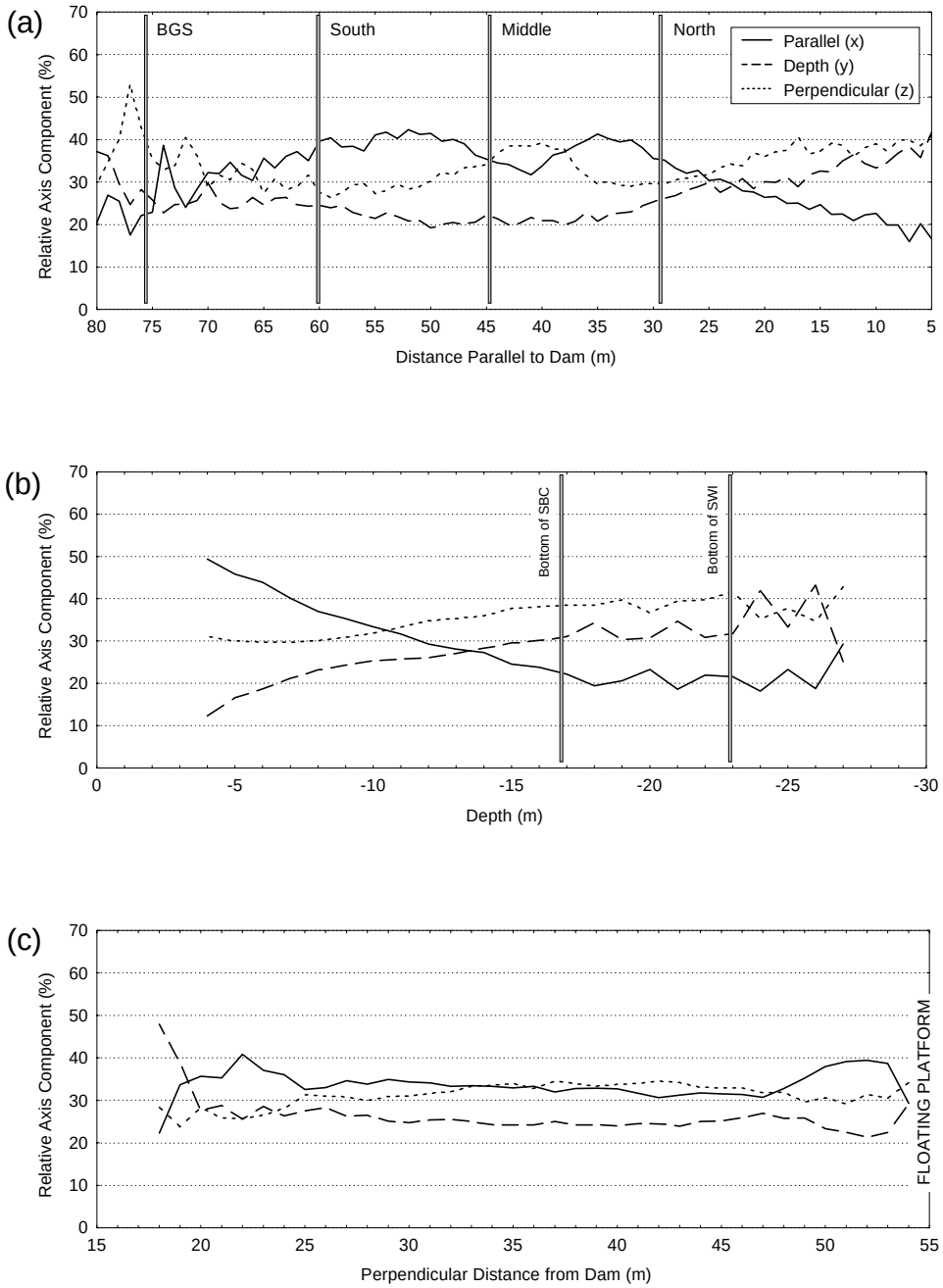


Figure 5.34. Observed X, Y, and Z axis speed components with range for the OUT condition.

5.1.5.2.2 Fish Swimming Effort Speed Components

Fish swimming effort speed components were plotted only for the BGS IN condition (Figure 5.35). However, all aspects of these swimming effort speeds were highly structured. This difference between observed and swimming effort results suggests that data corrected for flow conditions realistically interprets true fish behavior. Looking across the SBC from north end toward the south (Figure 5.35a), the parallel speed component was the dominant component to the Middle entrance. Between the Middle and South entrances, the perpendicular component became dominant, and the parallel component receded sharply. Between the South and BGS entrances, the perpendicular component dominated the speed structure. The orientation in this area was directed away from the SBC (Figure 5.18 through Figure 5.21).

Over depth, fish target speeds (Figure 5.35b) were dominated by the parallel component with a secondary perpendicular component that declined around 13 m. The depth component was minimal near the surface and increased at a depth of 13 m; then slightly dominated the perpendicular component, while the parallel component continued to dominate to maximum depth of detection. The orientation of the swimming effort in these areas was directed upward in the water column (Figure 5.23 through Figure 5.25).

For fish approaching the SBC from the floating platform, the parallel speed component was dominant throughout most of the sampled range (Figure 5.35c). The perpendicular component steadily decreased toward the SBC, and the depth component steadily increased toward the SBC. Again, the majority of the swimming effort was upward and parallel to the SBC as fish approached the structure (Figure 5.18 through Figure 5.25).

In sum, Figure 5.35 shows that the parallel component was dominant over much of the survey area. Fish that moved parallel to the SBC were most likely milling or searching for a safe route past the dam. Only in those areas between the BGS and the Middle entrance did the relationship of the components change. Near the BGS the perpendicular component often dominated. This indicates that fish were guiding along the BGS structure.

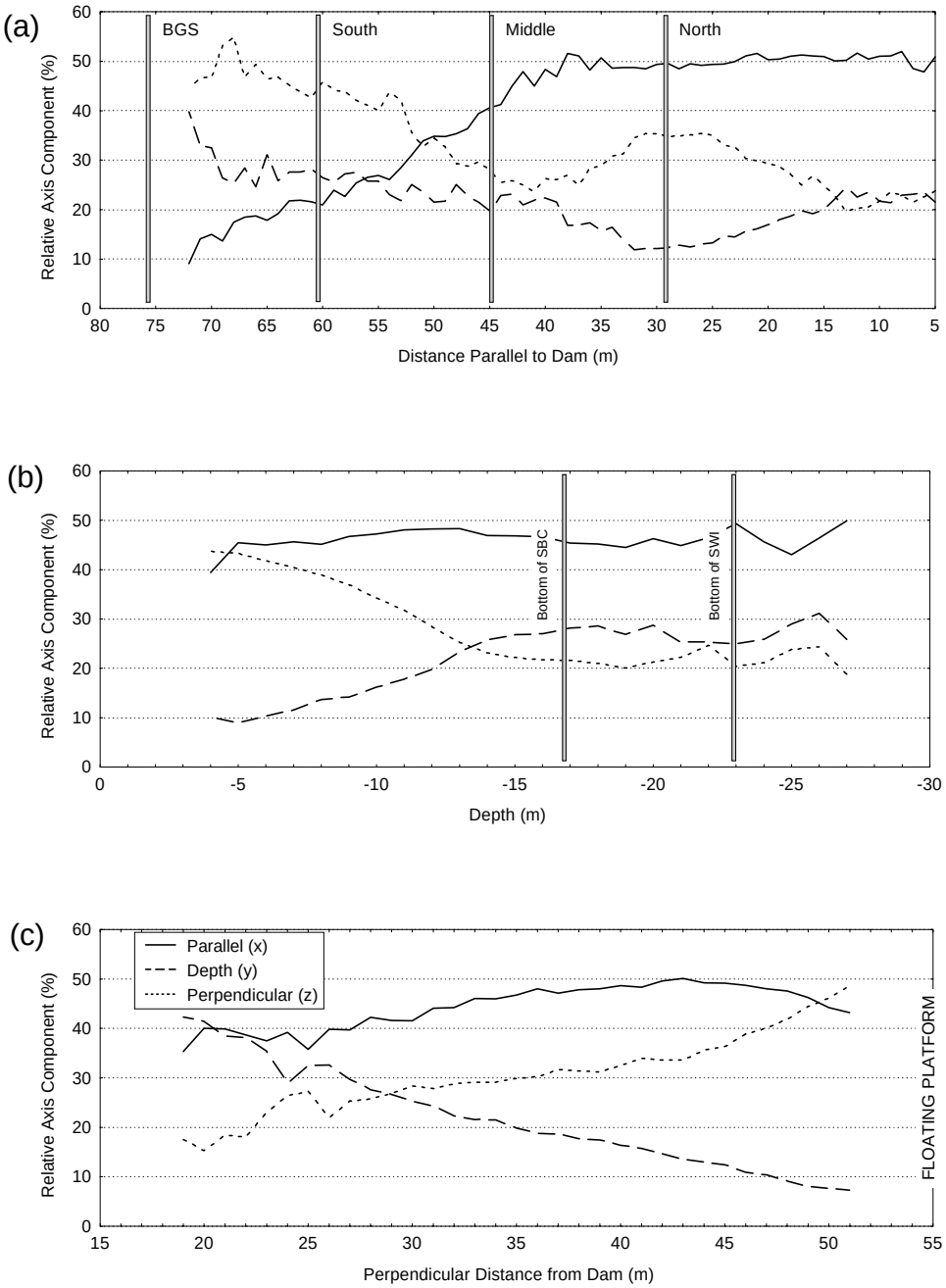


Figure 5.35. Swimming Effort X, Y, and Z axis speed components with range for the IN condition.

5.1.6 Track Characteristics

One of the more difficult aspects of the analysis has been track characterization, or behavioral classification. Several metrics were devised to represent individual fish behavior. Tortuosity, or tortuous behavior, has proved to be the most useful that we have explored thus far. A high degree of tortuosity indicates fish holding stationary (if tracks are tightly bounded) or milling (if tracks are widely ranging). Median speed also provides an indication of track characteristics.

5.1.6.1 Tortuosity with Range

Tortuosity was calculated at 1-m intervals perpendicular from the dam. The face of the SBC was approximately 12 m from the face of the dam. Values for tortuosity begin at approximately 21 m from the face of the dam, or about 9 m from the face of the SBC.

A box and whisker plot of tortuosity values was used to show the median, the range of 50% of the data, and the range of 90% of the data (Figure 5.36). The median values were relatively constant between the floating platform and the SBC, generally ranging between 1.0 and 1.5. The range of the values also remained relatively constant. This suggests that the fish track characteristics did not change with range from the SBC to any great extent. This is in sharp contrast to the observation at Bonneville Dam First Powerhouse Prototype Surface Collector, where the range of tortuosity values increased sharply very near the structure (within approximately 5 m; Johnson et al. 1999, in print). It is thought the increased range indicates that there was more diverse behavior near the Bonneville collector. This was likely due to the fish using their swimming ability to maintain control and a reluctance to enter the Bonneville collector immediately. This same type of observation might be possible if we were able to sonically "see" closer to the SBC structure.

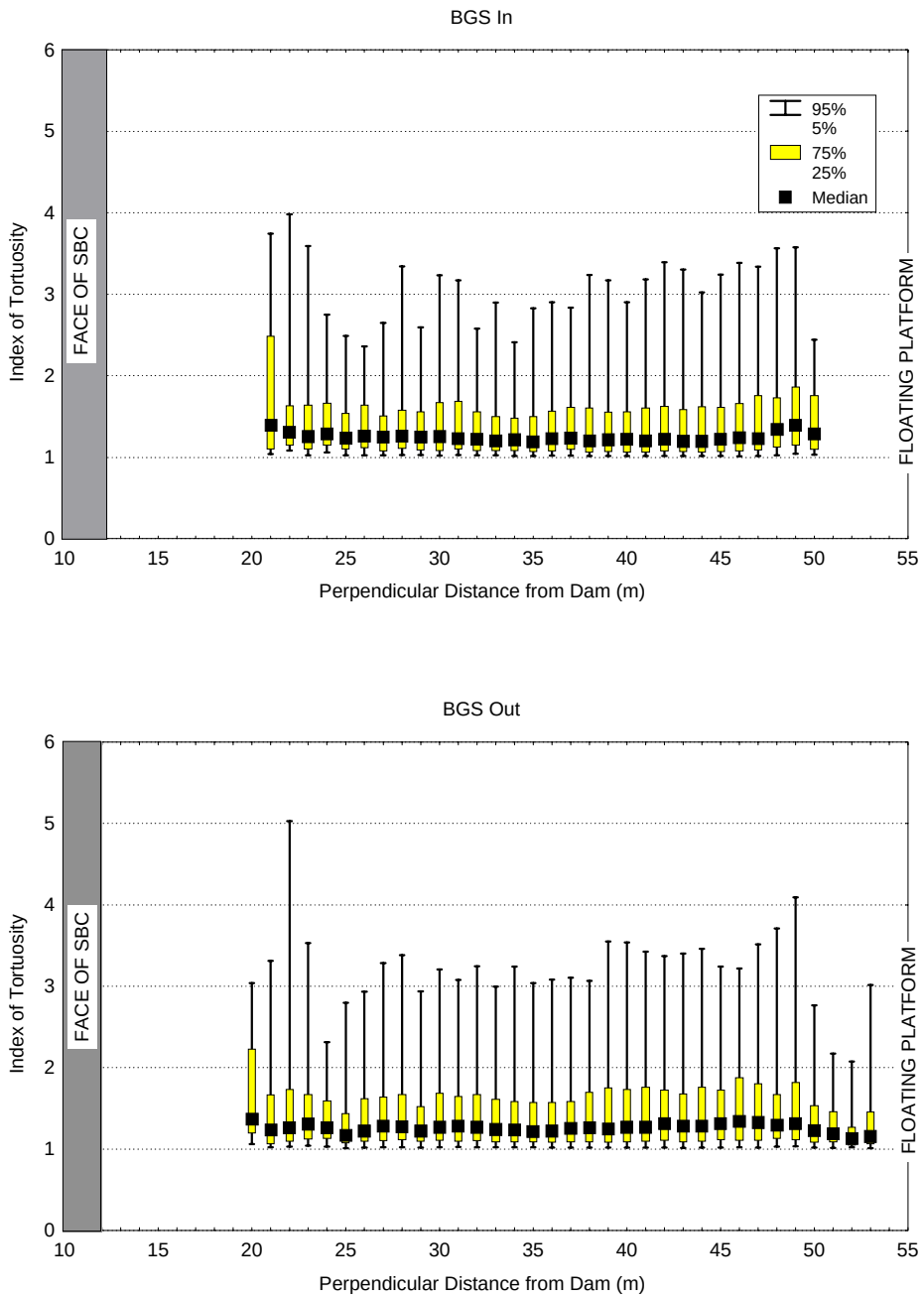


Figure 5.36. Index of tortuosity with range for the IN and OUT conditions.

5.1.6.2 Median Speed

Median observed fish speeds were generally the same or slightly lower when the BGS was IN than when the BGS was OUT (Figure 5.37). For both conditions, median observed fish speed increased as fish approached the SBC. As fish approached the SBC when the BGS was OUT, variability in median observed speed increased to a slightly greater extent than when the BGS was IN.

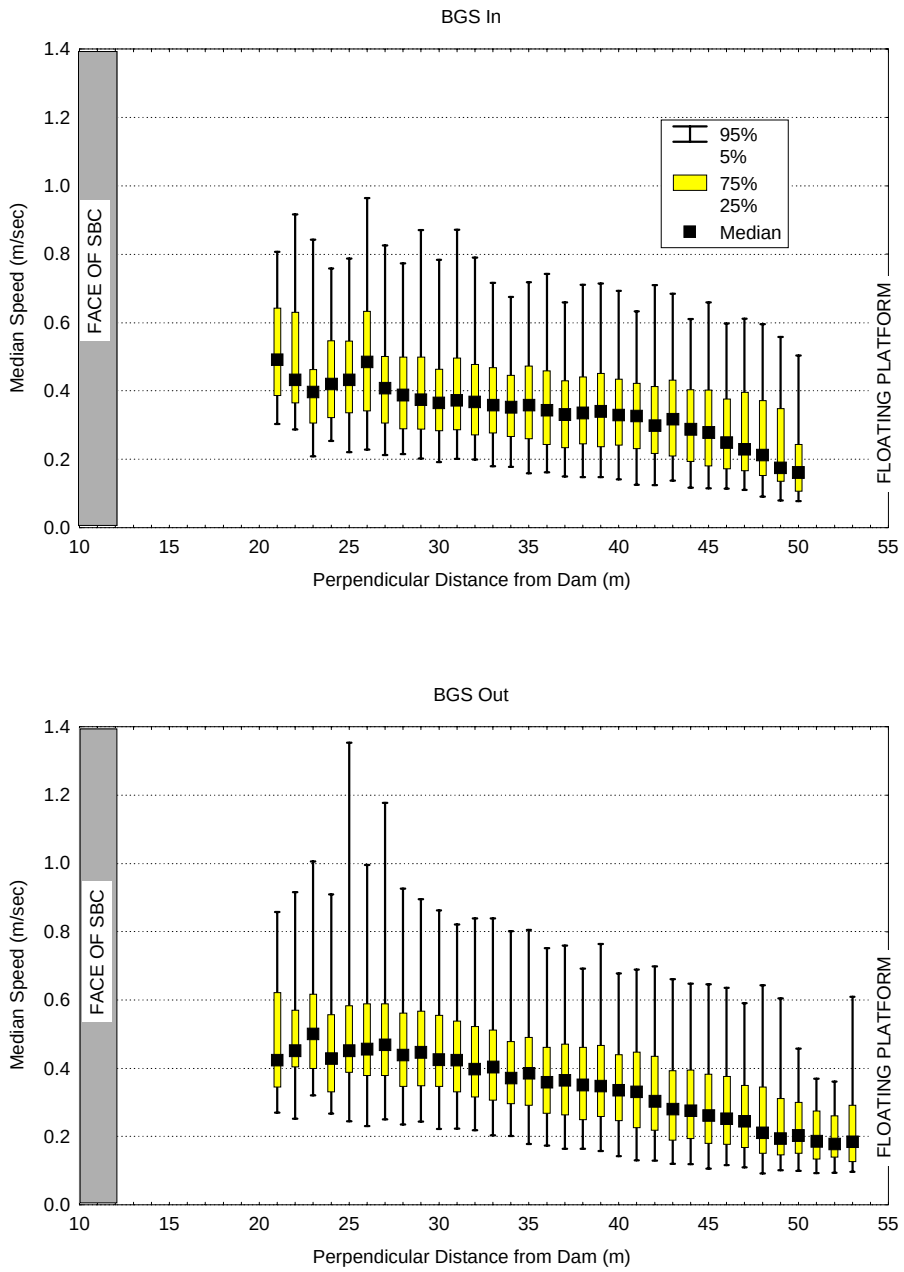


Figure 5.37. Median observed fish speed with range for the BGS IN and BGS OUT conditions.

5.1.7 Multi-Beam Statistical Analysis

The forebay was divided into 27 bins that were approximately 25 m wide by 12.5 m long and 8 m deep (Figure 5.38). Only 9 of the 27 bins had 6 complete blocks of data that could be used for the analysis of variance. All other bins had at least one or more blocks that were incomplete (in addition to block eight, which had a paucity of data, and block one, which for technical reasons was not collected). Blocks were incomplete when there were not enough fish targets within a specific bin for the four SBC/BGS treatments (Table 2.4) across all the time blocks. Generally, incomplete blocks were the result of platform movement that meant water volumes covered by the beams were not consistent during the entire study. Platform movement affected the position of the multibeam and thus the number of targets recorded in particular bins of water over time. Because of this effect and several instances where data were not collected due to broken cables or equipment malfunction, data for the day and night periods were combined, rather than considered separately, for the following statistical analyses. This reduced the number of variables required for a "complete" block of data and increased the likelihood that there were enough fish tracks in each bin of water for all SBC configurations, BGS conditions, and blocks of time to perform the ANOVA's. Approximately 16,000 fish tracks were processed for use in these analyses. It was difficult to assess the effects of early, middle, and late seasons because they were confounded by a change in the tilt of the transducer after the first two blocks (to achieve greater depth penetration) and by our movement of the sonar platform during the late blocks (6-8). The platform was moved because we attempted to "see" past some of the forebay obstructions close to the SBC and BGS. Figure 5.38 shows the plan view location of the numbered sample bins from three vertical layers referred to in the following analysis.

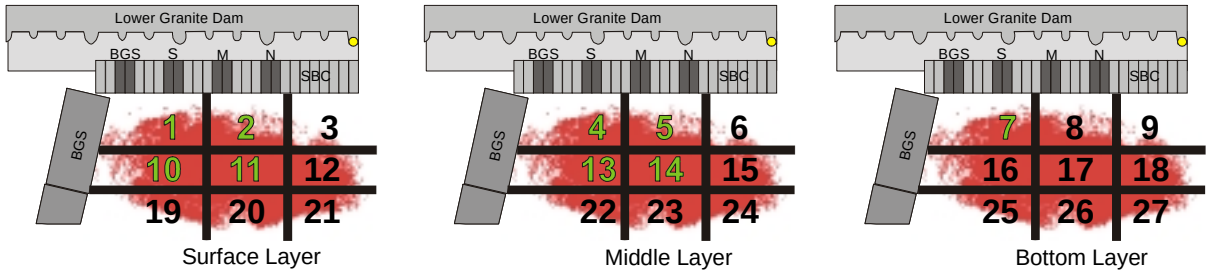


Figure 5.38. Bin numbers used for statistical analysis in three layers (surface, middle, and bottom). Green numbers indicate bins of water used for the analysis of variance.

5.1.7.1 Analysis of Variance

The split-plot experimental design with a 2 x 2 factorial treatment design was evaluated using ANOVA. Observed fish speed and direction were evaluated using this technique. Table 5.2 shows the complete ANOVA for observed average fish speed for bin 2 (from Figure 5.38).

Table 5.2. Split-plot analysis of variance for observed fish speed (m/s). The bin position was at the middle of the river, nearest the SBC, and at the top of the water column (Bin 2).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-Ratio	P-value
Whole Plots					
Blocks	5	1.836	0.367	3.117	0.13
BGS	1	0.001	0.001	0.007	0.94
Whole plot error	5	0.589	0.118		
Sub Plots					
SBC	1	0.125	0.125	4.012	0.08
SBC x BGS	1	0.003	0.003	0.099	0.76
Sub plot error	10	0.312	0.031		
Total	23	2.866			

The results of this analysis indicate that there were no statistically significant effects of the BGS or the SBC. An F ratio of 5.05 and 4.96 for blocks and SBC would be needed for statistical significance at the $P < 0.05$ level.

The results of the F tests from the split-plot ANOVA for nine bins of water are in Table 5.3. These results indicate that there were no statistically significant differences attributable to the BGS IN or OUT, the two SBC configurations, or the interaction of SBC and BGS. However blocks were statistically significant in bin 14 in the middle of the water column. The conclusions are provisional because the fish speeds were not corrected for water flow direction (shown to be very important in previous studies).

Table 5.3. F test results from split-plot analysis of variance for observed fish speed (m/s) for all nine bins of water evaluated. F-ratios for statistical significance (P < 0.05) of blocks, BGS, SBC, and SBC x BGS are 5.1, 6.5, 5.0, and 5.0, respectively.

Bin Number	Bin Location Across SBC	Position Relative to SBC and Barge	Position in Water Column	F Ratios			
				Blocks	BGS	SBC	SBC x BGS
2	Middle	Near	Top	3.1	0.01	4.0	0.1
5	Middle	Near	Middle	3.6	1.2	0.1	0.5
11	Middle	Middle	Top	2.4	0.4	0.8	1.4
14	Middle	Middle	Middle	6.6**	0.4	0.7	3.8
1	South	Near	Top	0.5	0.3	0.8	1.2
4	South	Near	Middle	1.7	2.3	2.3	0.9
7	South	Near	Bottom	1.5	1.2	1.5	0.9
10	South	Middle	Top	1.5	0.4	0.1	0.1
13	South	Middle	Middle	3.0	5.1	0.02	2.2

** P < 0.05

The means for BGS and SBC configurations over all six blocks are given in Table 5.4 and Table 5.5. Bin 11 showed reduced speed for both BGS and SBC configurations when compared to all other bins where data were available. Confidence intervals (95%) overlapped, but water speed correction to determine fish swimming effort could result in narrower intervals. We note that results from bin 10 also showed a similar tendency for reduced speed (Table 5.4 and Table 5.5). Bin 7 showed increased fish speeds for both BGS and SBC configurations, possibly a reflection of increased flow. In all but two bins (2 and 11), it appeared that the speeds were higher for the BGS IN condition (see the column BGS OUT minus BGS IN; Table 5.4). This result could indicate an overall increase in fish speed for the BGS IN condition, even though it was not detected in the bin-by-bin ANOVA. A similar evaluation of the difference in SBC configurations (Table 5.5) indicates a slight decrease in fish speed for the MAX configuration. These treatment effects on speed may or may not indicate beneficial effects of either the SBC or the BGS.

Table 5.4. Observed fish speed (m/s) means for BGS positions over all six blocks.

Bin Number	Position of Bin: Across SBC	Position of Bin: Relative to SBC and Platform	Position of Bin: In Water Column	BGS Condition: OUT	BGS Condition: IN	Difference BGS OUT minus BGS IN
2	Middle	Near	Top	1.4	1.4	0
5	Middle	Near	Middle	1.5	1.8	-0.3
11	Middle	Middle	Top	1.0	0.9	0.1
14	Middle	Middle	Middle	1.2	1.3	-0.1
1	South	Near	Top	1.4	1.5	-0.1
4	South	Near	Middle	1.5	1.9	-0.4
7	South	Near	Bottom	2.3	2.7	-0.4
10	South	Middle	Top	1.0	1.1	-0.1
13	South	Middle	Middle	1.3	1.5	-0.2

Table 5.5 Observed fish speed (m/s) means for SBC configuration over all six blocks.

Bin Number	Position of Bin: Across SBC	Position of Bin: Relative to SBC and Platform	Position of Bin: In Water Column	SBC Configuration: IHR	SBC Configuration: MAX	Difference IHR minus MAX
2	Middle	Near	Top	1.5	1.3	0.2
5	Middle	Near	Middle	1.7	1.7	0
11	Middle	Middle	Top	1.0	0.9	0.1
14	Middle	Middle	Middle	1.2	1.3	-0.1
1	South	Near	Top	1.5	1.4	0.1
4	South	Near	Middle	1.8	1.7	0.1
7	South	Near	Bottom	2.6	2.4	0.2
10	South	Middle	Top	1.1	1.0	0.1
13	South	Middle	Middle	1.4	1.4	0

Tables 5.6 and 5.7 further examine the BGS effect on fish speed and its consistency over blocks and bins. Table 5.6 contains the mean observed fish speed as a function of block and bin location. Table 5.7 presents the mean difference of BGS IN minus BGS OUT for each block and bin. It is evident from Table 5.6 that fish speeds differ, depending on the bin or block (marginal means in Table 5.6) as well as within bins and within blocks. Overall least significant difference statistics for each bin show the size of difference that could have been detected. Bin 7 exhibits the highest speed over all blocks, and block 7 contains the highest speeds compared to other blocks most of the time. The higher speeds near the bottom were noted earlier, while the different speed in block 7 could be due to the movement of the floating platform in an attempt to circumvent the effects of man-made objects obstructing the multi-beam equipment. When the mean fish speeds by bin are rearranged by location relative to the platform, the means nearest the structure are higher (2.5, 1.7, 1.7, 1.5, and 1.4 m/s) compared to those in the middle

relative to the SBC and platform (1.4, 1.2, 1.0, and 0.9 m/s). Even discounting the effect of bin 7 (2.5 m/s), faster fish speeds occurred closer to the SBC. Rearrangement of the block means from earlier to later in the season and ignoring block 7, shows that earlier speeds (1.6, 1.5, and 1.3 m/s) were higher than those in the later blocks (1.3 and 1.2 m/s), indicating some effect of season (probably strongly correlated with flow).

Table 5.6. Observed mean fish speed (m/s) for each block and bin.

	Position of Bin			Block Number						
Bin Number	Across SBC	Relative to SBC and Platform	In Water Column	2	3	4	5	6	7	Bin Mean
2	Middle	Near	Top	1.2	1.2	1.6	1.3	1.2	1.7	1.4
5	Middle	Near	Middle	1.6	1.5	1.7	1.4	1.2	2.3	1.7
11	Middle	Middle	Top	0.9	0.9	1.1	0.8	0.8	1.3	0.9
14	Middle	Middle	Middle	1.2	1.2	1.3	0.9	0.9	1.9	1.2
1	South	Near	Top	1.3	1.1	1.5	1.5	1.4	1.4	1.5
4	South	Near	Middle	1.8	1.5	1.8	1.4	1.3	1.8	1.7
7	South	Near	Bottom	3.0	2.4	2.5	1.9	1.6	3.6	2.5
10	South	Middle	Top	1.1	0.9	1.3	0.9	0.9	1.1	1.0
13	South	Middle	Middle	1.6	1.3	1.6	1.2	1.1	1.5	1.4
Block Mean				1.5	1.3	1.6	1.3	1.2	1.9	

Table 5.7. Observed mean fish speed differences (m/s; BGS IN minus BGS OUT) for each block and bin.

	Position of Bin			Block Number							
Bin Number	Across SBC	Relative to SBC and Platform	In Water Column	2	3	4	5	6	7	Bin Mean	LSD[1]
2	Middle	Near	Top	0.5	-0.5	-0.1	-0.2	0.1	0.4	0.0	0.51
5	Middle	Near	Middle	0.5	-0.2	0.0	-0.2	0.1	1.3	0.2	0.84
11	Middle	Middle	Top	0.3	-0.4	-0.1	-0.1	0.0	-0.2	-0.1	0.35
14	Middle	Middle	Middle	0.6	-0.2	-0.1	-0.1	0.0	0.4	0.1	0.43
1	South	Near	Top	0.7	-0.3	-0.2	0.4	0.0	0.3	0.1	0.55
4	South	Near	Middle	0.8	-0.2	0.0	0.1	0.0	1.4	0.4	0.92
7	South	Near	Bottom	1.8	-1.1	-0.4	0.3	0.4	1.7	0.5	1.62
10	South	Middle	Top	0.5	-0.2	-0.1	0.1	0.1	0.0	0.1	0.35
13	South	Middle	Middle	0.7	0.0	0.1	0.1	0.1	0.5	0.3	0.43
Number +				9	0	1	5	5	7	7	
Number -				0	8	6	4	0	1	1	
Number 0				0	1	2	0	4	1	1	

[1] Least significant difference ($P < 0.05$). The bin mean difference must be larger than the LSD value to be statistically significant.

The effect of BGS IN and OUT is not consistent over bins and blocks (Table 5.7). The mean difference and the sign for fish speed difference for the two conditions showed that the increased overall speed for the BGS IN condition observed above (and shown in the last column of Table 5.7) is due especially to the results for blocks 2 and 7. Both of these blocks contained predominate-plus values for the difference in fish speed (distribution of signs of the differences in each block at the bottom of Table 5.7). Again, bin 7 generally exhibited larger mean negative and positive differences compared to those found in the other bins. These differences are shown in Figure 5.39 and Figure 5.40. In addition, the effects of being in the middle of the water column relative to the SBC and the platform (Figure 5.39) and being near the SBC (Figure 5.40) are illustrated. The effect of the BGS on fish speed is not the same from block to block in most bins. This that the estimated BGS effect was not consistent from block to block, resulting in a large whole plot error and difficulty in detecting differences using ANOVA (Table 5.2 and Table 5.3). The large LSD values in Table 5.7 are also a reflection of this fact.

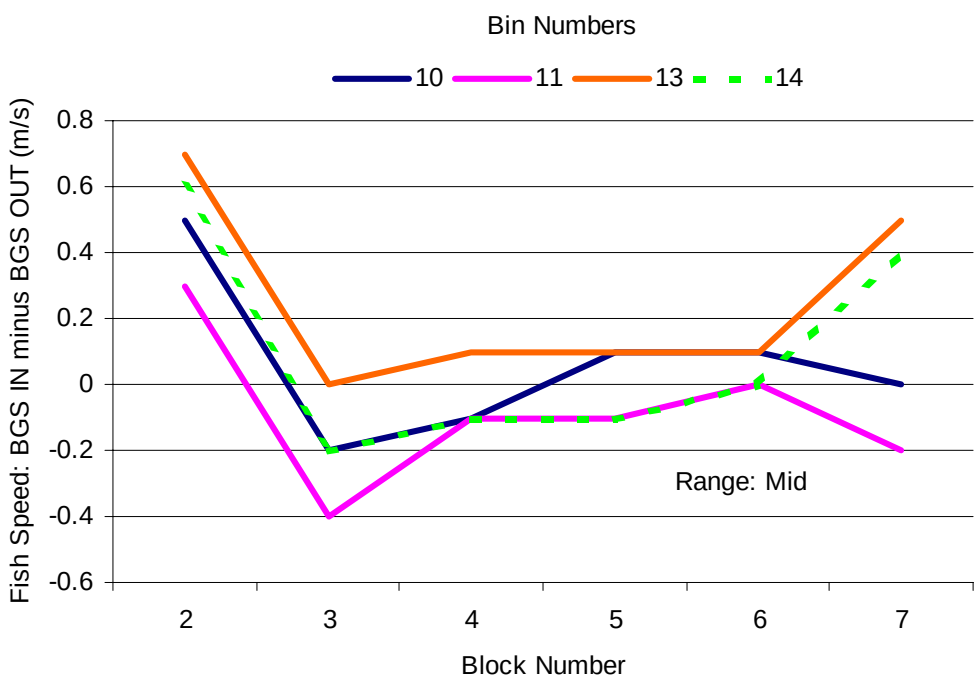


Figure 5.39. Observed mean fish speed difference (m/s) between the BGS IN minus BGS OUT conditions for each block and the bins in the middle of the water column (i.e., between the SBC and the platform, bins 10, 11, 13, 14).

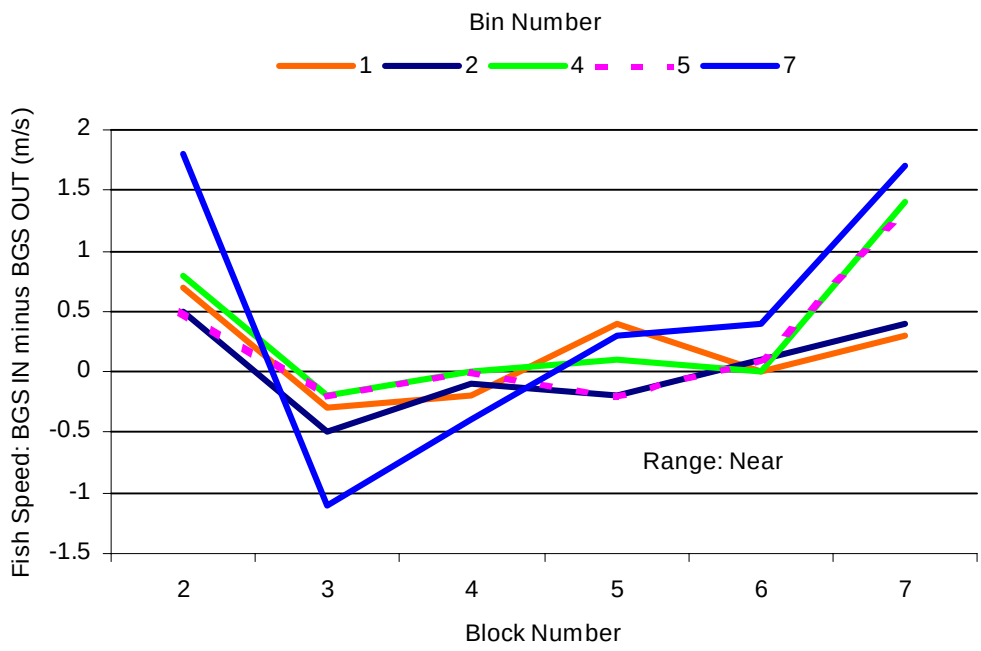


Figure 5.40. Observed mean fish speed difference (m/s) between the BGS IN minus BGS OUT conditions for each block and the bins nearest the SBC (bins 1, 2, 4, 5, 7).

Table 5.8 shows the complete ANOVA for observed fish direction (degrees) for the middle bin (across the SBC), nearest the SBC (between the SBC and the platform, bin 2), and the top of the water column (similar to Table 5.2). The results of the analysis indicate that there were no statistically significant effects of the BGS, the SBC, or their interaction. F-values of 5.05, 6.61, 4.96, and 4.96 for blocks, BGS, SBC, and BGS x SBC, respectively, would be needed for statistical significance at the $P < 0.05$ level.

Table 5.8. Split-plot analysis of variance for observed fish direction (side view, degrees). The bin position was at the middle of the river, nearest the SBC, and at the top of the water column (bin 2).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F tests	P value
Whole Plots					
Blocks	5	354,501	70,900	3.68	0.09
BGS	1	89,594	89,594	4.64	0.09
Whole plot error	5	96,446	19,289		
Sub Plots					
SBC	1	249	249	0.02	0.90
SBC x BGS	1	23,675	23,675	2.38	0.18
Sub plot error	10	99,582	9,958		
Total	23	664,046			

The results of the F tests from all of the split-plot ANOVA (nine bins of water) for direction are in Table 5.9. These results indicate that there were no statistically significant differences in the BGS IN or OUT, SBC configurations, or interaction of SBC and BGS. However, blocks were statistically significant ($P < 0.01$) at the south, middle, top location (bin 10). The blocking in bin 14 for fish speed was also statistically significant (Table 5.3). Thus, the overall results for fish speed and direction indicate that blocking was not very effective. However, we elected not to eliminate blocks and increase the error degrees of freedom. These conclusions relative to direction are preliminary (similar to fish speed) because corrections for water flow direction were not available.

Table 5.9. F test results from split-plot analysis of variance for observed fish direction (degrees) for all nine bins of water evaluated.

				F Ratios			
Bin Number	Bin Location Across SBC	Position Relative to SBC and Platform	Position in Water Column	Blocks	BGS	SBC	SBC x BGS
2	Middle	Near	Top	3.68	4.64	0.02	2.38
5	Middle	Near	Middle	2.95	4.95	1.63	0.51
11	Middle	Middle	Top	2.51	0.90	1.58	1.10
14	Middle	Middle	Middle	0.75	1.33	0.04	.001
1	South	Near	Top	1.40	3.11	0.03	1.11
4	South	Near	Middle	3.32	0.40	1.46	0.22
7	South	Near	Bottom	1.16	0.03	0.52	1.33
10	South	Middle	Top	9.1**	1.06	1.14	1.33
13	South	Middle	Middle	0.66	1.34	0.39	0.02

**$P < 0.01$

The observed fish direction means for BGS and SBC configurations over all eight blocks are included in Table 5.10 and Table 5.11. The orientation for target direction is 0° at the SBC and 180° at the floating platform. For the side view, the predominant direction appears to be downward toward the SBC (270-360°). The direction for fish in bins 1 and 2, located in the top region nearest the SBC, showed angles either away from the SBC (180-270°) or up and away for both BGS and SBC configurations when compared to all other bins where data were available (Table 5.10 and Table 5.11). We evaluated the effect of BGS position (BGS OUT minus BGS IN; Table 5.10) by location in the water column (top, -122, -41, -97, and -30) versus middle (4, 16, -2 and 11). Thus, fish exhibited a change in direction for the BGS IN condition near the water surface but showed no change in direction in the middle of the water column. The differences caused by SBC configuration are not large and do not seem to exhibit any

pattern (Table 5.11). The large LSD values compared to the treatment differences in Table 5.10 and Table 5.11 indicate that the power to detect treatment differences was low.

Table 5.10. Observed fish direction (degrees) means for BGS positions over all six blocks.

	Position of Bin			BGS Condition			
Bin Number	Across SBC	Relative to SBC and Platform	In Water Column	OUT	IN	BGS OUT minus BGS IN	LSD[1]
2	Middle	Near	Top	149	271	-122	206
5	Middle	Near	Middle	335	331	4	7
11	Middle	Middle	Top	291	332	-41	160
14	Middle	Middle	Middle	331	315	16	51
1	South	Near	Top	156	253	-97	199
4	South	Near	Middle	336	338	-2	12
7	South	Near	Bottom	298	301	-3	71
10	South	Middle	Top	287	317	-30	103
13	South	Middle	Middle	330	319	11	34

[1] Least significant difference ($P < 0.05$). The bin mean difference must be larger than the LSD value to be statistically significant.

Table 5.11. Observed fish direction (degrees) means for SBC configuration over all six blocks.

	Position of Bin			SBC Configuration		Difference	
Bin Number	Across SBC	Relative to SBC and Platform	In Water Column	IHR	MAX	IHR minus MAX	LSD[1]
2	Middle	Near	Top	214	207	7	128
5	Middle	Near	Middle	335	331	4	8
11	Middle	Middle	Top	314	310	4	10
14	Middle	Middle	Middle	324	323	1	17
1	South	Near	Top	198	210	-12	229
4	South	Near	Middle	336	339	-3	9
7	South	Near	Bottom	302	297	5	22
10	South	Middle	Top	317	287	30	90
13	South	Middle	Middle	323	325	-2	11

[1] Least significant difference ($P < 0.05$). The bin mean difference must be larger than the LSD value to be statistically significant.

The differences because of the BGS condition and position in the water column (bins) are illustrated as a function of blocks in Figure 5.41 and Figure 5.42. Except for bin 1 in block 2 (Figure 5.40), there appears to be a BGS effect because the differences are nonzero and appear to be reasonably consistent in a bin over all blocks. Similarly, the directional differences in mid and bottom bins (Figure 5.42) seem mostly consistent and either negative or near zero. Thus, there does not seem to be a pronounced interaction for blocks and BGS. The figures showed a directional difference at the top of the water column (see the All position in Figure 5.41) and little if any difference in the area of bins beneath the surface (Figure 5.42).

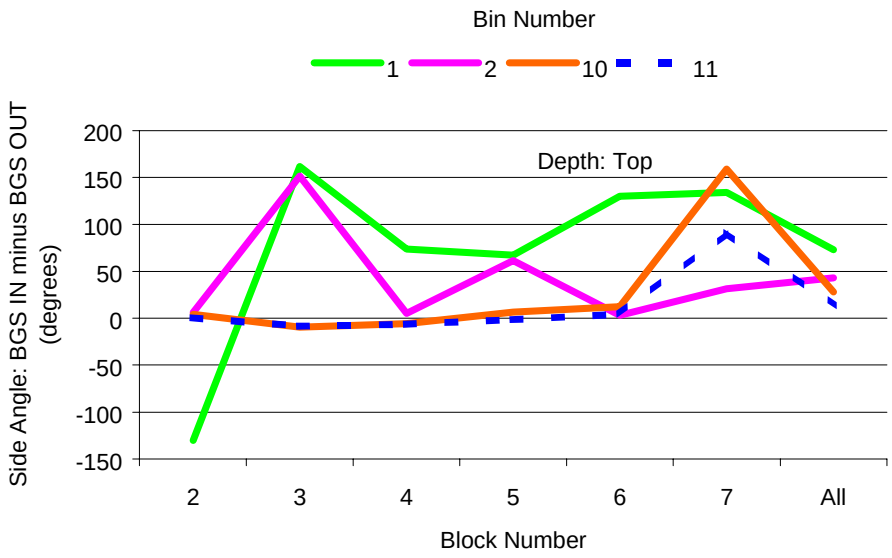


Figure 5.41. Observed mean fish direction difference (angles) between the BGS IN minus BGS OUT conditions for each block and the bins in the middle of the water column (i.e., below the surface, bins 4, 5, 7, 13, 14).

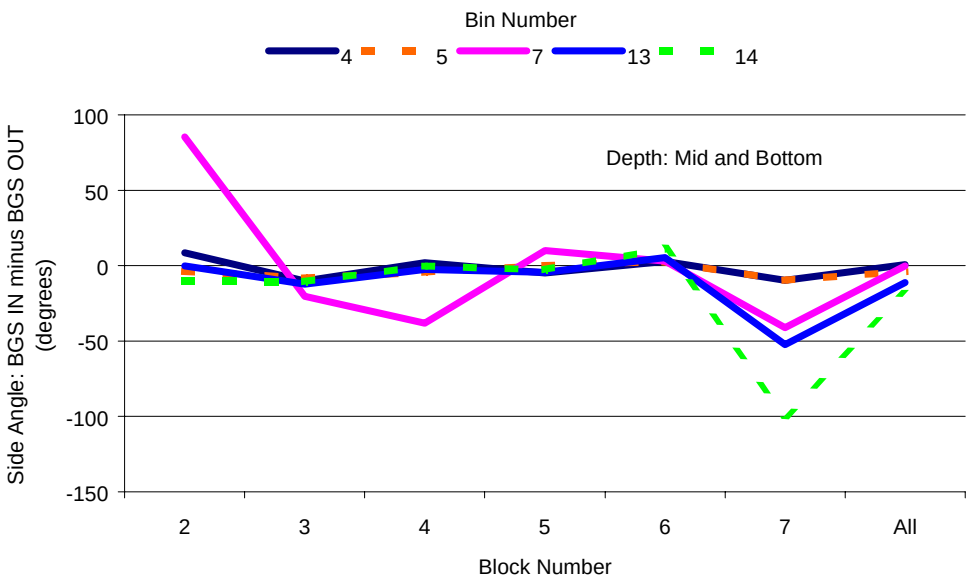


Figure 5.42. Observed mean fish direction difference (angles) between the BGS IN minus BGS OUT conditions for each block and the bins at the top of the water column (bins 1, 2, 10, 11).

5.2 Fish Behavior in Front of Turbines 1-3 (Split-Beam)

The split-beam data collected in front of Turbines 1-3 are presented in vector graphs, both in plan view and in side view relative to the respective beam transects (vertical transects of the water column accomplished by rotating the split-beam transducer over six consecutive vertical locations). A complete set of plan and vertical vector plots are available for evaluation in Appendix D of the Preliminary Draft Report (Johnson et al. 1998b). **Figure 5.43** depicts the x,y,z axes as they relate to the dam, prototype structures, and split-beam deployment. Recall that the split-beam system at Pier Nose 2 A/B (Figure 3.14) was only operated when the BGS was IN.

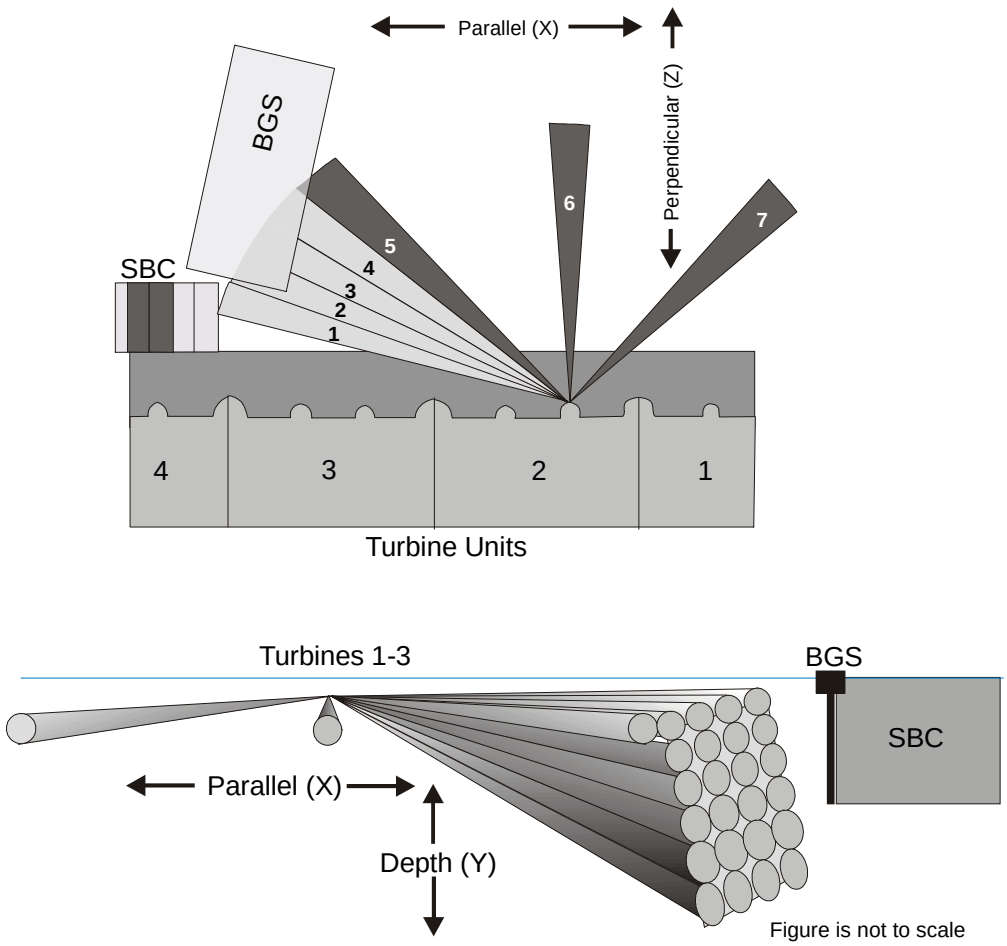


Figure 5.43 Direction references for the xy plane (top) and the xz plane (bottom).

5.2.1 Target Record Summary and Descriptive Statistics

During the 1998 split-beam sampling period, 26,695 fish targets were identified in front of Turbines 1-3. These do not necessarily represent unique fish because, as the split-beam transducer was rotated, the same fish could have been seen more than once. A summary of target characteristics acquired by the split-beam transducer at Lower Granite Dam is provided in Table 5.12, Figure 5.44, and Figure 5.45.

Table 5.12. Average and maximum time observed, distance traveled along each axis, and number of pings for individual fish targets detected by the split-beam transducer at Lower Granite Dam in 1998.

	Time Observed (s)	Parallel Distance Traveled (m)	Vertical Distance Traveled (m)	Perpendicular Distance Traveled (m)	Number of Pings
Average	12	0.15	0.07	0.3	8.1
Maximum	24	5.6	5.5	8.9	69

The split-beam sampled at three pings/s. Selection criteria eliminated any target with fewer than four pings. The largest number of fish targets detected by the split-beam transducer occurred on May 4, 1998 (Figure 5.44). However, because sample time varied by date (Table 3.1) as a result of movement of the BGS, the number of targets detected per minute provides a better indication of the size of the population in front of Turbines 1-3. In Figure 5.45, the maximum number of targets/min (3.3) occurred on April 27.

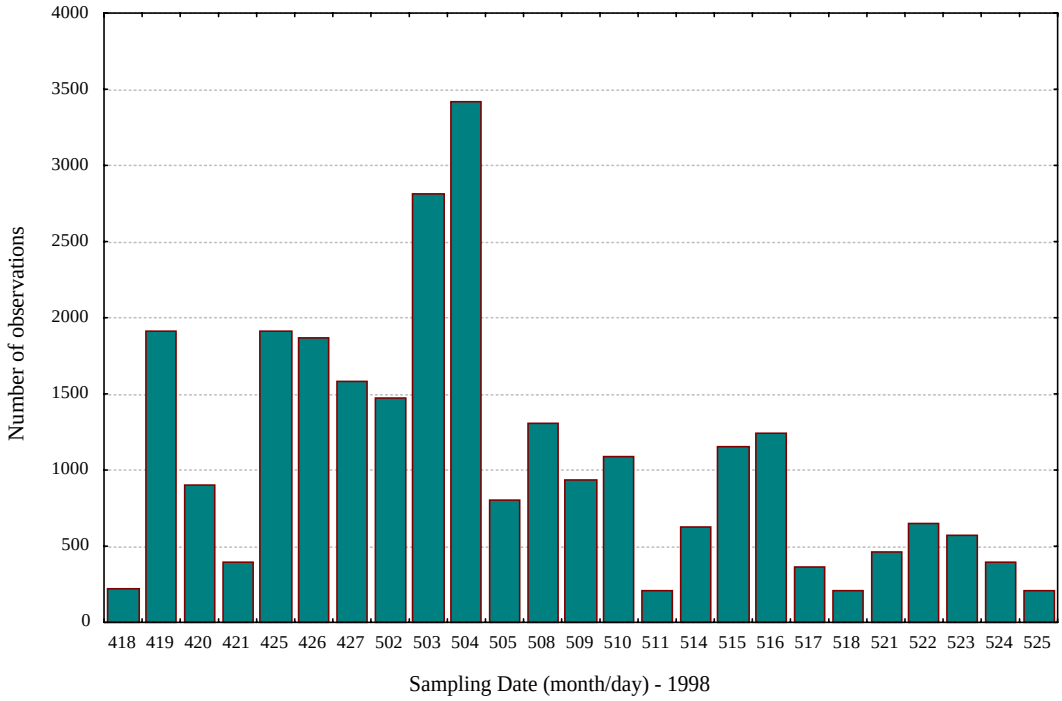


Figure 5.44. Number of fish targets detected for each sample date by the split-beam transducer in front of Turbines 1-3 at Lower Granite Dam.

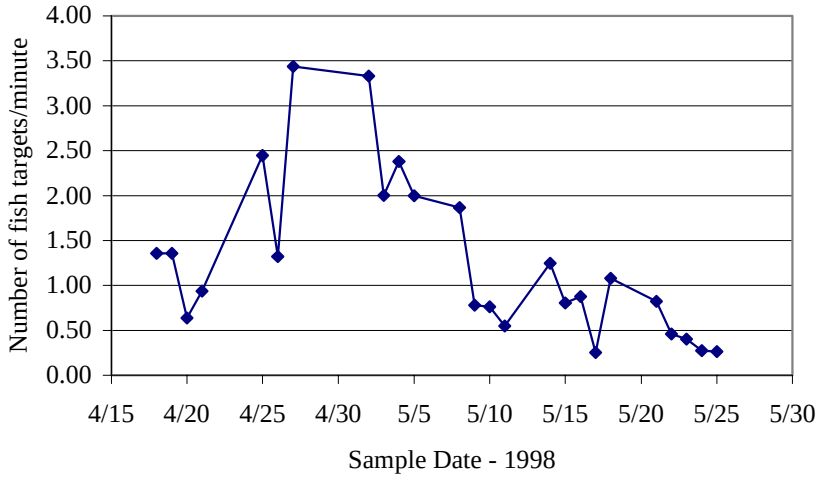


Figure 5.45. Number of fish targets/min of sampling time for each sample date in front of Turbines 1-3 at Lower Granite Dam.

The distribution of all target strengths for the April-May sampling period is presented in Figure 5.46. From a visual comparison, there were no apparent differences in target strength between day and night, over the range of depths or between early, mid, and late season.

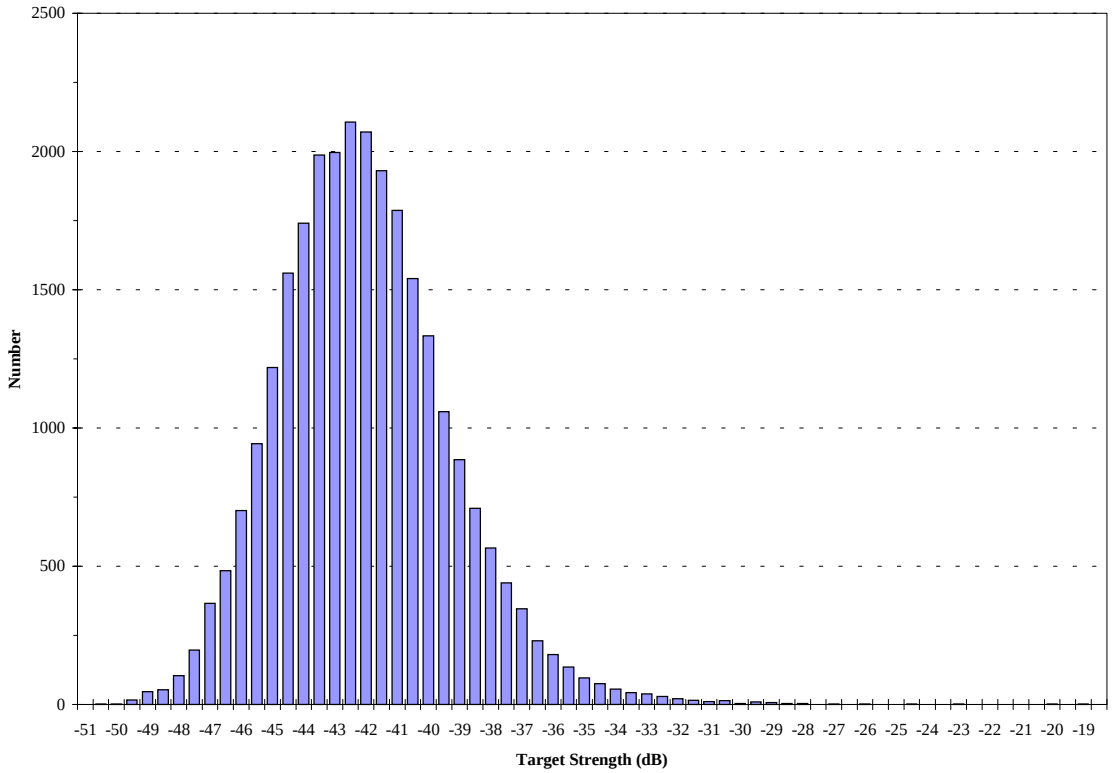


Figure 5.46. Target strength for split-beam study period (April-May 1998) in front of Turbines 1-3 at Lower Granite Dam.

5.2.2 Effective Spatial Coverage

Figure 5.47 and Figure 5.48 show the top and side view of the spatial coverage of the split-beam for the April-May 1998 sampling period.

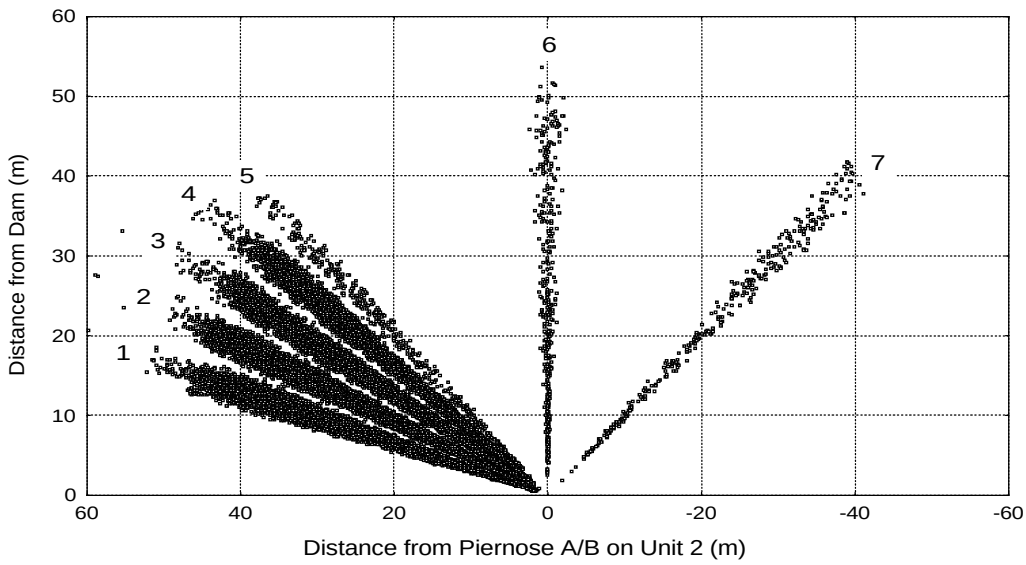


Figure 5.47. Top view scatter plot of spatial coverage of the split-beam at Lower Granite Dam. Numbers indicate the seven horizontal positions. Origin is on pier nose A/B of Turbine 2. The BGS is located along the left side of the plot. Data are from the entire April-May 1998 split-beam sampling period.

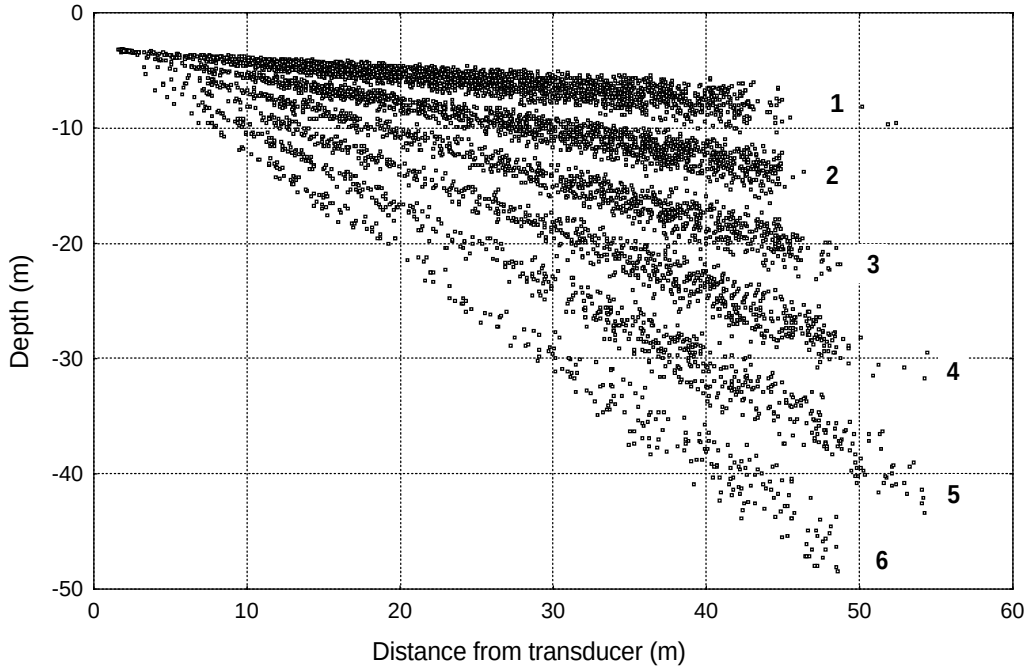


Figure 5.48. Side view scatter plot of spatial coverage for the first four horizontal split-beam positions at Lower Granite Dam. Origin is on pier nose A/B of Turbine 2. Numbers indicate the six vertical positions for horizontal positions 1-4. The BGS is located along the right side of the plot. Data are from the entire April-May 1998 split-beam sampling period.

5.2.3 Average Fish Speed and Direction

The average observed fish direction and speed provide information on fish population behavioral dynamics behind the BGS and in front of Turbines 1-3.

5.2.3.1 Average Fish Speed

Figure Figure 5.49 represents the observed fish target speed distribution for fish detected in front of Turbines 1-3 and behind the BGS. The higher speeds are presumably a result of darting behavior. The majority of the fish were moving at less than 1 m/s which is comparable to data collected in 1996 and 1997 in front of Turbines 1-3 (Johnson et al. 1997a and 1998a).

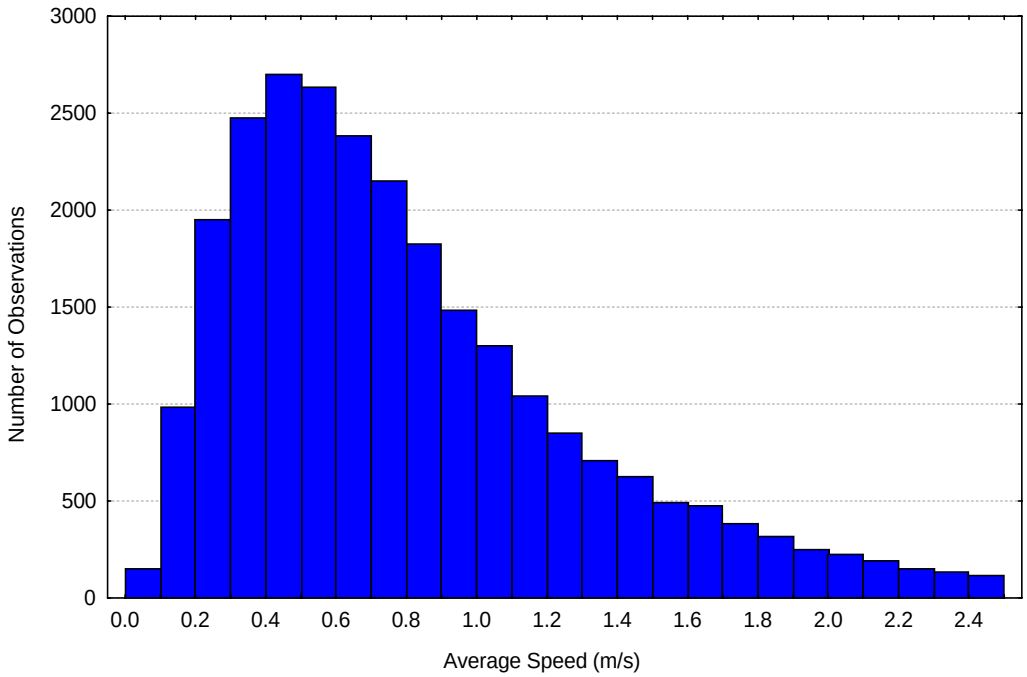


Figure 5.49. Distribution of average observed fish speed for fish detected in front of Turbines 1-3 in April-May 1998 by the split-beam transducer.

5.2.3.2 Direction

Direction and speed are best displayed as bin-based velocity vectors with average observed fish direction indicated by the direction the arrow is pointing and speed by the length of the arrow. The plan view of the split-beam fish vector data in Figure 5.50 and Figure 5.51 show the pattern of movement for all data throughout the water column for day and night. From these vector plots there is no apparent difference in the behavior of the fish between day and night. Companion tables of fish numbers (Table 5.13 and Table 5.14) are provided to illustrate the sample sizes in Figure 5.50 and Figure 5.51, respectively.

Side-view slices in Figure 5.52 and Table 5.15 (0-15-m from transducer), Figure 5.53 and Table 5.16 (15-30-m from transducer), and Figure 5.54 and Table 5.17 (>30-m from transducer) provide insight into the vertical component of the data set. Near the transducer (Figure 5.52), fish were found to be moving up the face of the dam above the intake at Unit 2, pier nose B/C (unit off) and then moving outward toward the forebay. This, combined with the plan view, suggests that the fish were actually moving up and toward the backside of the BGS.

The mid-range slice (Figure 5.53) also showed fish moving upward toward the surface and then away from the dam. This slice would have been within the influence of Unit 3 that was in operation during the study. Again, combined with the plan-view data, the fish were actually moving toward the backside of the BGS.

The far-range slice (Figure 5.54) provided the most unique perspective of fish movement. In this slice, which was in front of Unit 3 and directly behind the BGS, fish were exhibiting the same upward and away motion above the unit but below and near the ceiling of the unit, fish were observed being drawn downward toward the unit at relatively high speeds. Vectors farther out toward the forebay (right side of figure) suggested that some fish were successfully moving away from the unit. The size of these fish is not known.

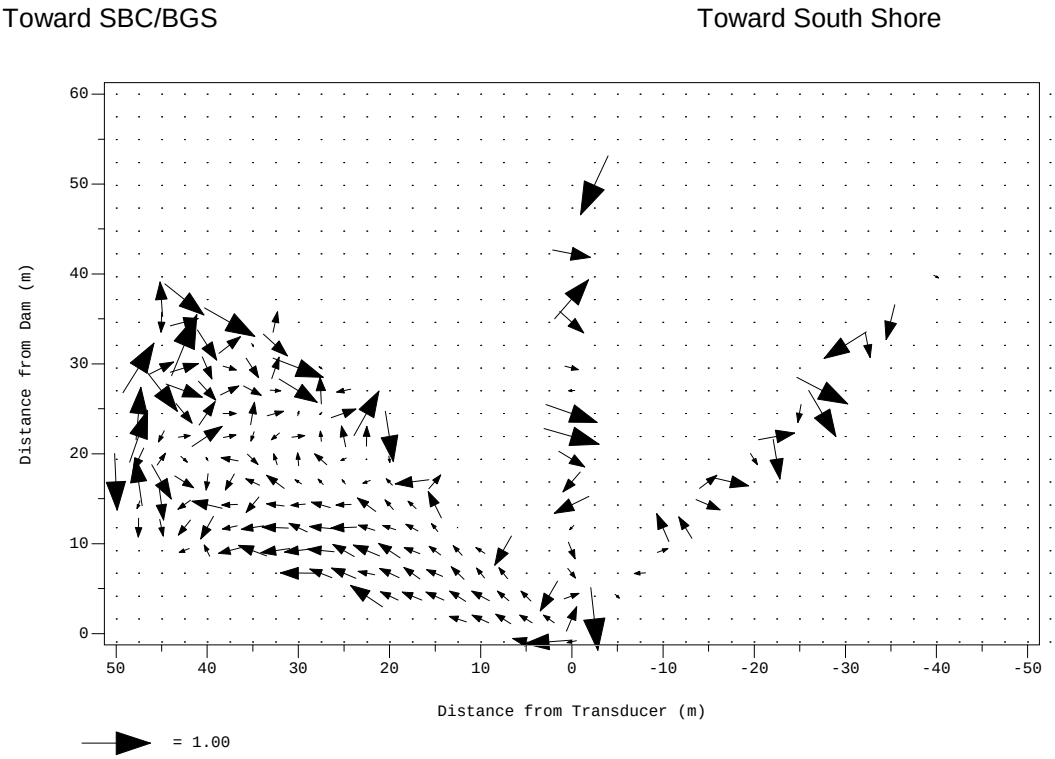


Figure 5.50. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (day). The scale of the arrow is 1 m/s.

Table 5.13. Number of samples per bin for average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (day). Empty spaces were not sampled or did not fall into a bin.

N Targets	Distance from Transducer (m)																																						
Distance from Dam (m)	47.5	45	42.5	40	37.5	35	32.5	30	27.5	25	22.5	20	17.5	15	12.5	10	7.5	5	2.5	0	-2.5	-5	-7.5	-10	-12.5	-15	-17.5	-20	-22.5	-25	-27.5	-30	-32.5	-35	-37.5	-40	Grand Total
52.5																				4																	4
50																					1																1
45																				2																	2
42.5																				3																1	4
40																			1																1	1	3
37.5		1	1		2	2														1														1	1		9
35		5	5	1	1	2	2													8													1	9	2		36
32.5			3	9	14	2	5	2												3												1	5				44
30	2	3	1	9	50	49	11	14	2											4											1	7	1				154
27.5	1	7	14	25	18	55	81	8	7	2										3										1	5						227
25	2		8	67	73	9	72	90	27	9	3									3										3	3						389
22.5	8	16	12	17	60	82	27	42	137	31	14	2								7									3	1							459
20	6	38	109	67	22	23	83	67	25	116	44	3	1							8							1	3	1								617
17.5	2	3	33	68	101	102	29	83	108	34	99	59	7	1			1			12						3	6										751
15	11	29	50	40	23	81	165	122	36	93	73	85	96	8						3						6											921
12.5	4	18	51	108	113	100	47	57	136	114	68	127	113	173	24					9				2	3												1267
10			1	4	24	92	117	127	92	68	152	173	132	254	293	59	2			22				11													1623
7.5								13	51	103	164	154	267	338	337	478	171			22			13	1													2112
5											1	57	204	345	597	547	562	256	1	19		11															2600
2.5															66	198	293	368	125	6	2																1058
0																		6	78	1																	85
Grand Total	36	120	288	415	501	599	639	625	621	570	618	660	820	1119	1317	1282	1029	630	205	140	3	11	13	14	3	9	7	3	4	5	9	8	7	10	4	2	12346

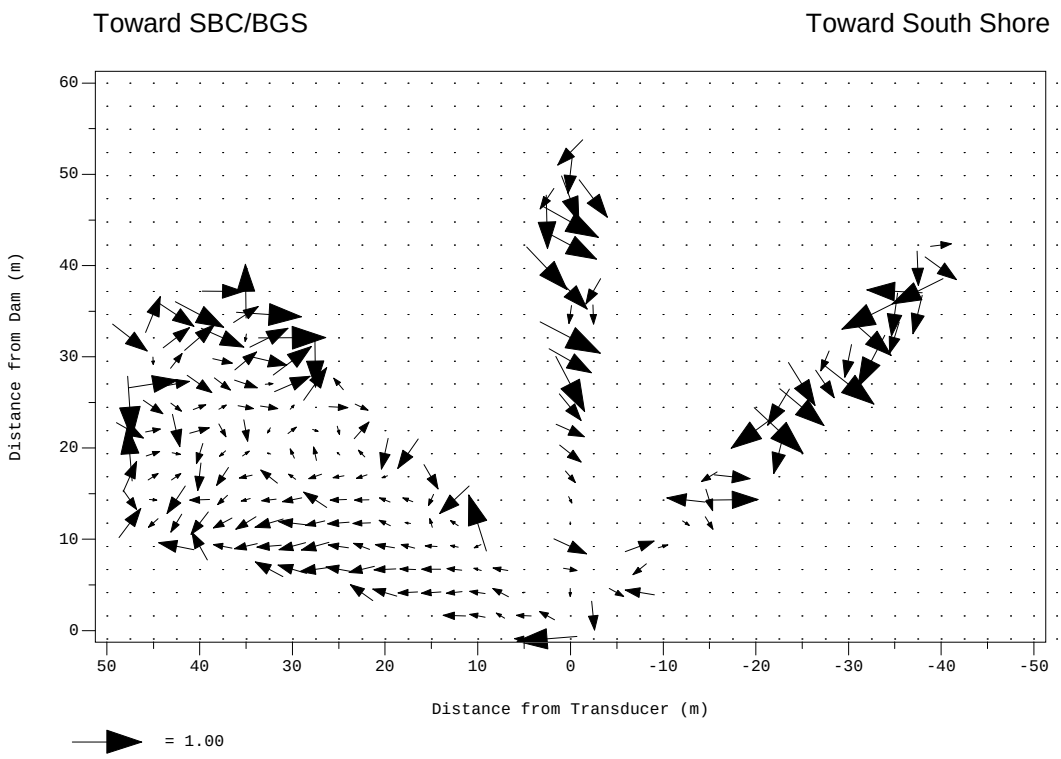


Figure 5.51. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (night). The scale of the arrow is 1 m/s.

Table 5.14. Number of samples in each sampled bin for average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (night). Empty spaces were not sampled or did not fall into a bin.

N Targets	Distance from Transducer (m)																																								
Distance from Dam (m)	47.5	45	42.5	40	37.5	35	32.5	30	27.5	25	22.5	20	17.5	15	12.5	10	7.5	5	2.5	0	-2.5	-5	-7.5	-10	-12.5	-15	-17.5	-20	-22.5	-25	-27.5	-30	-32.5	-35	-37.5	-40	Grand Total
57.5																				1																	1
52.5																				1																	1
50																			1	6																	7
47.5																			1	13	5																19
45																			3	11	4																18
42.5																				17																2	19
40																			2	10	1														6	6	25
37.5					5	3													1	12	2													4	4	4	35
35		2	6	1		9	5												2	7	1												2	12	2		49
32.5	1		6	20	8	2	14	2	1											11												3	9	6			83
30	3	4	2	10	68	55	12	13	3											9											5	7	5				196
27.5	4	9	19	14	15	117	120	18	19	4										10										9	11	6					375
25	2	1	19	91	83	16	99	168	40	19	6									21									2	13	3						583
22.5	8	8	14	26	118	173	51	85	203	68	25	7								20								1	8	1							816
20	3	43	112	116	43	66	200	160	80	192	97	21	1						1	13							1	13	3								1165
17.5	5	8	30	112	217	165	76	149	266	95	204	112	20	2						11						3	9	1									1485
15	20	72	91	62	52	135	327	225	92	231	199	155	186	23	1					20					1	4	3										1899
12.5	4	20	82	215	265	209	106	154	297	254	139	296	167	224	34	1				10					10	2											2489
10			1	8	55	168	289	296	183	146	278	262	216	210	179	48				7			1	14													2361
7.5							3	26	129	228	211	173	238	199	198	162	51			5			9														1632
5											7	63	158	172	199	137	91	28		2		2	1														860
2.5															24	58	45	38	7		1																173
0																		1	52																		53
Grand Total	50	167	382	675	929	1118	1302	1296	1313	1237	1166	1089	986	830	635	406	187	67	70	217	14	2	11	14	11	9	13	15	13	23	19	16	16	22	12	12	14344

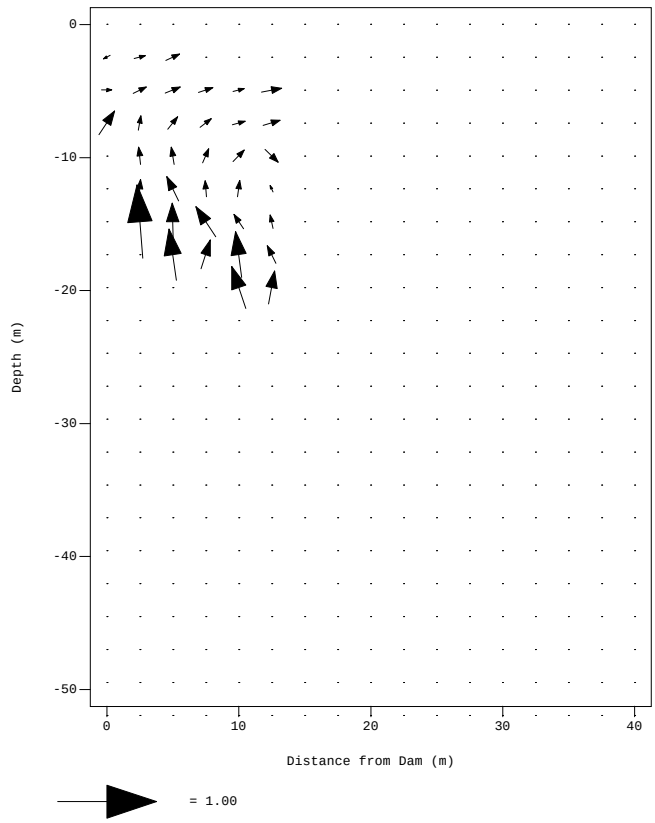


Figure 5.52. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (side view, 0 to15 m from transducer). The scale of the arrow is 1 m/s.

Table 5.15. Number of samples in each bin 0-15 m from the transducer for observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998. Empty spaces were not covered by the beam.

N Targets	Distance from Dam (m)						
Depth (m)	0	2.5	5	7.5	10	12.5	Grand Total
-2.5	127	190	56				373
-5	10	774	1747	1009	403	114	4057
-7.5	1	161	481	299	165	41	1148
-10		67	214	155	65	18	519
-12.5		16	113	98	49	12	288
-15		4	41	68	43	9	165
-17.5			11	34	41	8	94
-20					8	8	16

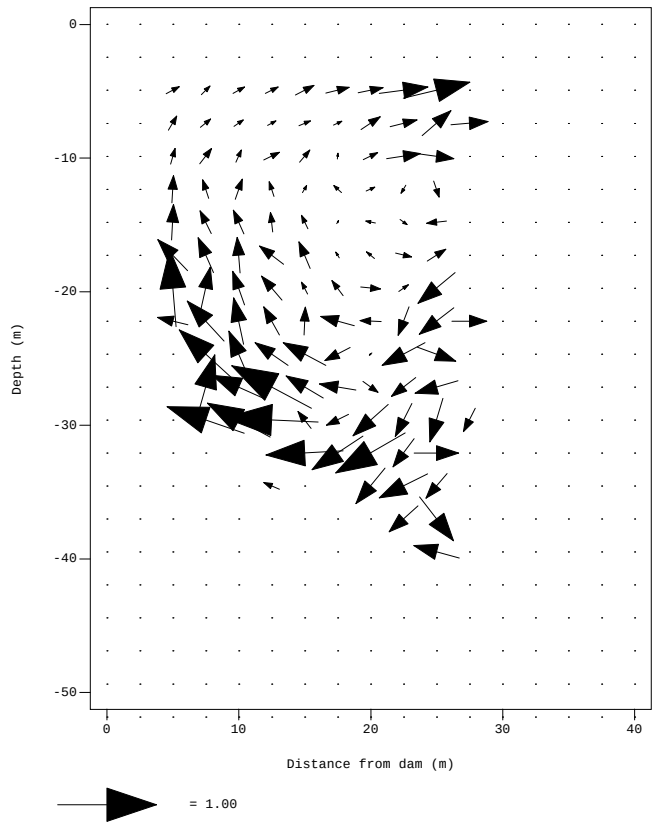


Figure 5.53. Average observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998 (side view, 15 to 30 m from transducer). The scale of the arrow is 1 m/s.

Table 5.16. Number of samples in each bin 15-30 m from the transducer for observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998. Empty spaces were not covered by the beam.

N Targets	Distance from Dam (m)										
Depth (m)	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	Grand Total
-5	357	867	923	749	375	162	53	24	4		3514
-7.5	163	429	408	359	265	204	118	85	24	1	2056
-10	72	263	281	293	201	207	110	73	12		1512
-12.5	54	153	147	158	132	97	53	88	37		919
-15	39	89	135	151	136	123	85	38	7		803
-17.5	31	74	93	111	66	70	27	54	13		539
-20	9	51	52	110	92	81	49	28	7		479
-22.5	2	32	43	54	48	46	33	36	23	1	318
-25		14	22	37	38	42	41	23	8		225
-27.5		7	13	11	19	45	29	26	11		161
-30		5	13	23	10	24	10	21	12	1	119
-32.5			2	5	9	17	17	12	2		64
-35				1		5	6	16	5		33
-37.5								3	10		13
-40									1		1

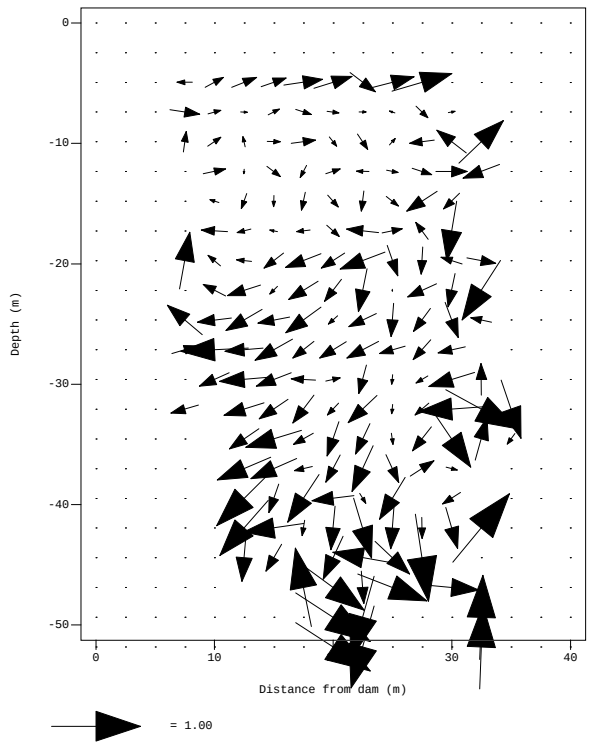


Figure 5.54. Average observed fish velocity vectors in front of Turbines1-3 at Lower Granite Dam in spring 1998 (side view, > 30 m from transducer). The scale of the arrow is 1 m/s.

Table 5.17. Number of samples in each bin >30 m from the transducer for observed fish velocity vectors in front of Turbines 1-3 at Lower Granite Dam in spring 1998. Empty spaces were not covered by the beam.

N Targets	Distance from Dam (m)													
Depth (m)	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	Grand Total
-5	1	72	34	58	23	29	7	6	6					236
-7.5	5	253	228	216	155	136	114	82	54	22	1			1266
-10	4	122	102	98	64	51	40	47	28	27	3			586
-12.5		129	247	198	168	153	99	83	72	21	1			1171
-15		95	69	90	59	64	48	69	38	51	5			588
-17.5		73	139	106	99	62	46	33	22	3	1			584
-20	1	59	97	118	67	63	45	56	47	28	5			586
-22.5		45	106	105	65	65	20	35	22	27	14			504
-25	1	43	76	62	68	41	43	32	37	9	1			413
-27.5	1	40	99	89	53	76	35	41	33	13	2			482
-30		19	65	39	39	106	37	48	57	9	14	2		435
-32.5	1	19	50	44	51	68	29	60	32	12	7	13	1	387
-35		7	37	44	48	71	27	33	23	14	1	5		310
-37.5		8	27	41	24	34	22	17	13	9	4			199
-40		1	24	28	24	14	19	12	4	7	2			135
-42.5			12	10	22	20	11	12	16	7	2			112
-45			4	11	4	11	3	14	8	8			1	64
-47.5			3	8	1	7	7	3	2	6				37
-50						2	1				1			4

5.2.4 Target Depth Frequency Distribution

The area sampled by the split-beam transducer was cone shaped with the broad edge of the cone nearest the BGS (Figure 5.47). The overall depth distribution of fish targets, Figure 5.55, indicated a majority of fish between 4 and 6-m depth; however, this distribution is somewhat biased because of the shape of the beam. In Table 5.18, the depth distribution of fish targets is separated by distance from the transducer. At distances less than 20 m from the transducer (not shown), fish were concentrated in the upper 10 m. For the 20- 30-m range, the majority of targets were still within 10 m of the surface, but at greater ranges (30–50 m from the transducer), more targets were found in the 10- 20-m depth range.

Table 5.18. Number of fish targets by distance from the transducer and depth. Horizontal beam refers to the rotation of the transducer, beam 1 was aimed at the junction of the BGS and SBC, with beams 2 to 4 aimed upstream. Beams 5 to 7 were aimed into the forebay at a single vertical position.

	Horizontal Beam (Range 20-30m)							
Depth (m)	1	2	3	4	5	6	7	Total N
0 to -10	1,031	1,252	963	705				3,951
-10 to -20	394	454	382	390	75	71	42	1,808
-20 to -30	88	113	97	161	18	8	12	497
-30 to -40		4	8	3				15
	Horizontal Beam (Range 30-40 m)							
Depth (m)	1	2	3	4	5	6	7	Total N
0 to -10	633	586	473	325				2,017
-10 to -20	826	826	633	618	3			2,906
-20 to -30	353	369	249	299	126	55	62	1,513
-30 to -40	107	114	80	101				402
-40 to -50			3					3
	Horizontal Beam (Range 40-50 m)							
Depth (m)	1	2	3	4	5	6	7	Total N
0 to -10	129	124	198	173				624
-10 to -20	337	334	300	332				1,303
-20 to -30	294	327	226	207	50	43	40	1,187
-30 to -40	175	311	183	112	31	34	34	880
-40 to -50	66	79	49	54				248
	Horizontal Beam (Range 50-60 m)							
Depth (m)	1	2	3	4	5	6	7	Total N
0 to -10	4			4				8
-10 to -20				5				5
-20 to -30	2	5	18	21				46
-30 to -40	16	25	42	35	19	7	39	183
-40 to -50	13	10		6				29
-50 to -60		5						5

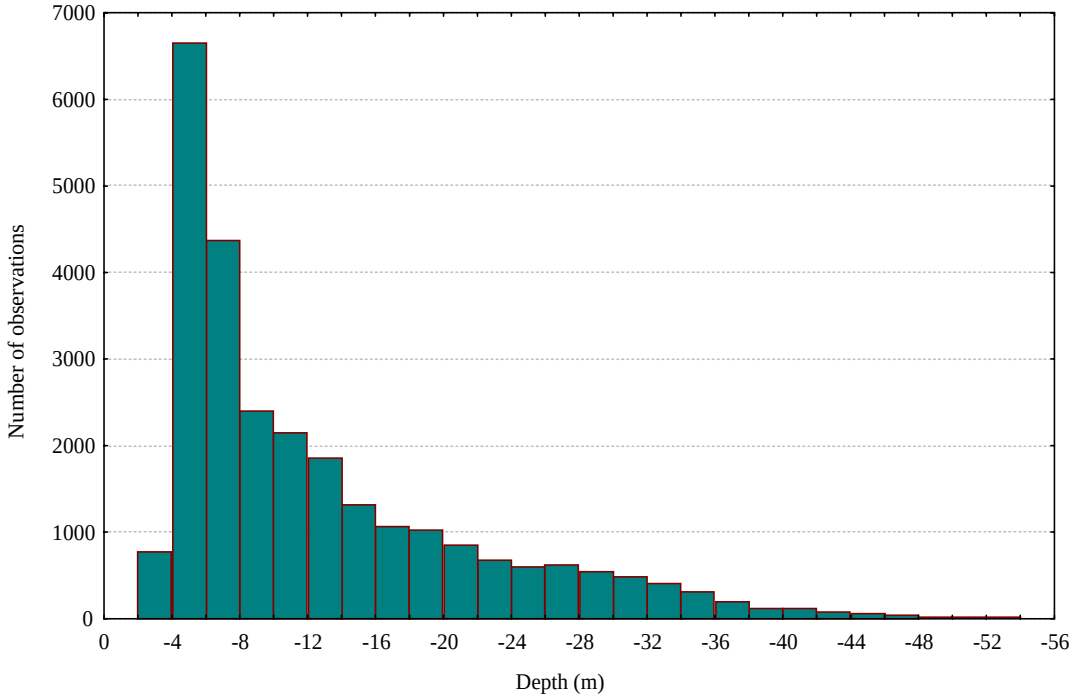


Figure 5.55. Depth frequency distribution for fish targets from the split-beam in front of Turbines 1-3.

5.2.5 Split-Beam Statistical Analysis

The purpose of the split-beam hydroacoustic study was to evaluate behavior in front of Turbines 1-3 and behind the downstream end of the BGS and the south end of the SBC. In particular, one goal was to detect fish passing through any possible openings between the SBC and the BGS. Split-beam data were only collected when the BGS was in place (BGS IN). A confounding problem with the detection of fish targets passing through the SBC/BGS junction was that fish could arrive at the junction by entering on the south side of the BGS and following it down to the juncture with the SBC. In addition, it was possible that fish could swim under the BGS. However, fish arriving by either of these routes would probably exhibit different speeds and directions from those at other locations in the water column.

To investigate the question of passage through the junction of the SBC and the BGS and under the BGS, the number of fish sightings (and their speeds) in relevant areas of water were ascertained and compared to those in areas not near the proposed passage areas. Increased fish numbers or different observed speeds at the BGS/SBC junction location were considered to be evidence for passage. In addition, we compared the numbers of fish in bins of water contained in the sweep of the junction (up and down) to the numbers in similar bins in the sweeps upstream of the junction. There were four sweeps: one at the junction (horizontal position 1) and three upstream of the junction (horizontal positions 2-4).

According to radio telemetry studies, a few fish arrived along the south side of the BGS (Adams and Rondorf 1998).

Table 5.19 shows the observed number of targets when the BGS was IN for the entire experimental period. The beams covered more area at greater distances from the transducer. The distance from the transducer on Lower Granite Dam to the BGS was around 50 m. At 50-60 m from the split-beam transducer (near the BGS-SBC junction) few fish were observed at any depth. At this range, the targets were generally detected below the BGS at depths greater than 30 m. This was true for horizontal positions 1-4, indicating that few fish were coming through the junction or from the BGS area immediately upstream. At the 40- to 50-m range from the transducer, substantially more fish were observed than at 50- to 60-m range. Also at the 40- to 50-m distance, slightly more fish were in the -10 to -20-m-depth profile than at other depths. Again there were apparently no more fish at the junction than at the three upstream locations at this distance from the transducer. These results at the 50- to 60-m and 40- to 50-m distances from the transducer indicate that few fish were coming through the junction. Fish could be coming in under the BGS at a constant rate and/or around the upstream end of the structure. However, that does not seem likely. At the two distances farthest from the junction and closest to the transducer (20-30 and 30-40 m), far more fish were observed, but, again, there did not seem to be any relationship between the number of fish closest to the interface and those farther upstream. However, these areas are 20 m away from the junction. The observed increase in numbers could be from fish traveling down the BGS from the east and/or those coming in beneath the BGS. Even if the latter were the case, only between 100-200 fish per day were observed in the two maximum areas. This is not likely to be a major source of fish loss compared to the numbers observed on the other side of the BGS (when it was in place).

Table 5.19. Number of fish detected by the split-beam transducer for the entire experimental period.

Distance from Split-Beam Transducer								
	20-30 m				30-40 m			
	Position*				Position			
Depth (m)	1	2	3	4	1	2	3	4
0 to -10	1,031	1,252	963	705	633	586	473	325
-10 to -20	394	454	382	390	826	826	633	618
-20 to -30	88	113	97	161	353	369	249	299
-30 to -40		4	8	3	107	114	80	101
-40 to -50							3	
-50 to -60								
Total	1,513	1,823	1,450	1,259	1,919	1,895	1,438	1,343
	40-50 m				50-60 m			
	Position				Position			
Depth (m)	1	2	3	4	1	2	3	4
0 to -10	129	124	198	173	4			4
-10 to -20	337	334	300	332				4
-20 to -30	294	327	226	207	2	5	18	21
-30 to -40	175	311	183	112	16	25	42	35
-40 to -50	66	79	49	54	13	10		6
-50 to -60						5		
Total	1,001	1,175	956	878	35	45	60	70

* Position refers to horizontal beam position, with 1 being at junction of BGS/SBC and 2-4 being upstream of the junction.

Additional support for the above is shown in Table 5.20. The difference between the number of targets observed at positions 1 + 2 are compared to those in positions 3 + 4 for the four distances from the transducer and six depths. With the exception of a large positive number (+615) at the 0- to -10-m depth and the 20- to 30-m range, there is no evidence indicating there were vastly more fish nearer the junction at any depth or range. Even though +615 is at the junction of the SBC and BGS, it is not excessive because it is a sum over the entire study period. We evaluated the effect of time (early, mid, and late seasons) on the overall results. There were a few changes in the magnitude of the differences for the 30-40-m distance from the junction and at the 0 to –10-m and –10 to –20-m depths in the early vs. late

seasons. However, these had no effect on the overall conclusions. Table 5.21 shows that observed fish speed is generally higher at the 40- to 50-m distance from the transducer at all depths compared to the other distances. The 50- to 60-m distance as well as the -30 to -50-m depths at 20 to 40 m from the transducer should be excluded because of few targets (Table 5.19). These speeds could be a reflection of greater current nearer the SBC-BGS junction or an effort by these fish to move away from this area.

Table 5.20. Difference between the number of targets observed at positions 1+2 and 3+4 for four ranges (distance from split-beam transducer) and seven depths along the BGS.

	Positions (1+2) - (3+4) Range (m)				Mean number of targets (1 to 4) Range (m)			
Depth	20-30	30-40	40-50	50-60	20-30	30-40	40-50	50-60
0 to -10	+615	+44	-118		988	504	156	2
-10 to -20	+76	+401	+39		452	727	326	1
-20 to -30	-57	+174	+188	-32	124	378	297	11
-30 to -40		+40	+191	-35	4	100	220	47
-40 to -50			+42			1	24	27
-50 to -60								1
Total Fish Observed					6,271	6,841	4,242	276

Table 5.21. Average observed fish speed (m/s) calculated from targets detected by the split-beam transducer for the entire experimental period

Distance from Split-Beam Transducer								
	20-30 m				30-40 m			
	Position				Position			
Depth (m)	1	2	3	4	1	2	3	4
0 to -10	0.60	0.58	0.57	0.58	0.74	0.67	0.77	0.82
-10 to -20	0.83	0.78	0.80	0.80	0.87	0.86	0.89	0.94
-20 to -30	0.98	0.96	0.85	0.84	0.94	0.86	0.83	0.88
-30 to -40		1.32	1.18	1.00	1.13	1.00	1.00	1.04
-40 to -50							1.30	
-50 to -60								
	40-50 m				50-60 m			
	Position				Position			
Depth (m)	1	2	3	4	1	2	3	4
0 to -10	1.04	0.88	1.04	1.00	1.36			2.43
-10 to -20	1.01	1.04	1.11	1.14				2.89
-20 to -30	1.04	1.00	1.00	1.18	0.44	1.12	1.08	1.66
-30 to -40	1.05	0.87	0.81	0.94	2.05	1.62	1.65	2.08
-40 to -50	1.29	1.37	1.15	1.34	2.09	1.89		1.18
-50 to -60						1.96		

Section 6: Discussion

6.1 Fish Passage (Single-beam)

In this section we discuss the following aspects of the single-beam fixed-location hydroacoustic study at Lower Granite Dam during spring 1998: verification of results, spill efficiency and effectiveness, FGE of extended-length bar screens, BGS performance, SBC/SWI performance, and applications and comparisons to other dams.

6.1.1 Verification of Results

We verified the hydroacoustic data by comparing it to similar data from the Smolt Monitoring Program and the radio telemetry study (Adams and Rondorf 1998). The Smolt Monitoring Program and hydroacoustic indices of total project passage correlated well ($R^2 = 0.66$, $P < 0.001$). During the peak of the outmigration, however, the Smolt Monitoring Program index was about twice as high as the hydroacoustic index (Figure 6.1). The reason for this discrepancy is unknown. But, since the performance metrics in the evaluation are ratios, the hydroacoustic data are valid because there was equivalent detectability among locations (see Appendix A). We are also confident in the passage indices obtained via hydroacoustics because they comport well with results obtained by radio telemetry (Table 6.1).

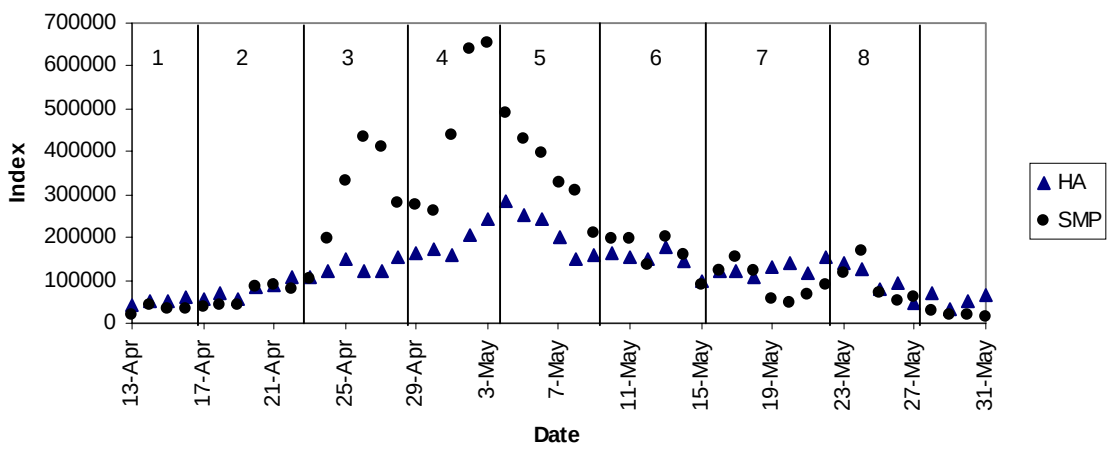


Figure 6.1. Daily run timing data from hydroacoustic (HA) and the Fish Passage Centers SMP at LGR in spring 1998. SMP data from DART http://www.cqs.washington.edu/dart/.

Table 6.1. Summary of composite fish passage results from hydroacoustics and radio telemetry. Radio telemetry data are from Adams and Rondorf (1998; updated in a letter from Evans to Wik dated October 13, 1998) and were weighted by species-composition. Parameters are defined in Table 3.5.

Parameter	Hydroacoustic	Radio Telemetry
FPE	0.926 ± 0.012	0.945
CBE_{4-6}	0.910 ± 0.019	0.944
FGE_{1-6}	0.830 ± 0.027	0.906
R_{all}	0.268 ± 0.002	0.265
R_{1-6}	0.381 ± 0.003	0.317
R_{4-6}	0.510 ± 0.004	0.427
SY	0.297 ± 0.004	0.235
P_{b-corr}	0.778 ± 0.180	0.804

6.1.2 Spill Efficiency and Effectiveness

Spill efficiency and effectiveness were lower in 1998 than in 1997 at Lower Granite Dam (Table 6.2). These differences may be attributed to the fact that the volume of spill during the study period was lower in 1998 (3,597 hm^3 or 2,916 kaf) than in 1997 (4,850 hm^3 or 3,932 kaf). Spill effectiveness declined because the percentage of fish spilled (spill efficiency) declined relative to the percentage of water spilled. This could reflect a difference in forebay hydraulic and fish approach patterns between average flow conditions (101% of normal) in 1998 and high flow conditions (154% of normal) in 1997.

Because spill was 24 h/d during most of the spring study at Lower Granite Dam in 1998, we can assess the diel distribution of fish passage at the spillway. Spill passage was higher during the 14-h day period (65% total spill passage) than the 10-h night period (35% total spill passage). This shows that downstream migrants will pass the spillway at Lower Granite Dam during daylight, if given the opportunity. Any spill program for fish protection at Lower Granite Dam should consider 24 h/d spill. This should reduce forebay delay and enhance migration conditions at the project.

Spill passage was augmented by the SBC. For example, when SBC passage was combined with spill passage in 1998, spill efficiency and effectiveness almost doubled in 1998 (Table 6.2). A similar, though smaller trend was observed in 1997. SBC discharge (113 m^3/s or 4,000 cfs) diverted a relatively large quantity of fish from the powerhouse to the spillway. This suggests that the SBC could be used in lieu of or to supplement much larger spillway flows to pass a similar number of fish. This would result in the benefit of reduced dissolved gas levels for voluntary spill.

Table 6.2. Spill efficiency and effectiveness (with 95% confidence intervals) without and with SBC passage in 1997 and 1998 at Lower Granite Dam.

Spill Parameter	SBC	1997	1998
Efficiency	without	0.48 ± 0.01	0.30 ± 0.004
Efficiency	with	0.60 ± 0.01	0.57 ± 0.004
Effectiveness	without	1.45 ± 0.02	1.13 ± 0.02
Effectiveness	with	1.70 ± 0.002	1.90 ± 0.0001

6.1.3 Fish Guidance Efficiency of Extended-Length Bar Screens

The 1998 study was the second year with ESBSs in all 18 intakes at Lower Granite Dam. Total project FGE for the run-at-large declined somewhat from 87.4 ± 0.1% in 1997 to 83 ± 2.7% in 1998. Other than year-to-year variability, a possible reason for the difference in FGE between 1997 and 1998 was species composition. The run-at-large was composed of more chinook salmon in 1998 (22%) than in 1997 (6%). Fyke net and radio telemetry studies have shown that chinook salmon do not guide as well as steelhead (Table 6.3). Another possible reason is that the SBC passed proportionately more fish that otherwise would have been guided by the screens.

FGE was an important metric in 1998 because the new structures (BGS and SWI) could have forced fish deeper in the forebay and thus reduced the probability of them being intercepted by the intake screens. We found that FGE was lower at Turbines 1-3 when the BGS was IN compared to when it was OUT. But, this effect was offset by FGE at Turbines 4-6, which was higher with the BGS IN than OUT. In addition, Turbines 4-6 passed about 40% more fish than Turbines 1-3. Thus, the BGS and SWI did not appear to adversely affect overall FGE in 1998.

The seasonal trend for FGE followed the same pattern observed by numerous researchers over the years (e.g., Giorgi et al. 1988; Johnson et al. 1998a). Early in the study period in mid-April, FGE was relatively low when spring/summer chinook salmon yearlings were prevalent. FGE increased as steelhead dominated the run in early May. FGE peaked in mid-May, then declined toward the end of the study period on May 31, 1998, when river discharge peaked. Williams et al. (1996) noted that species composition, water temperature, level of smoltification, and other variables can influence FGE. They concluded that FGE will always vary.

We also observed differences in FGE among intakes. Variability in FGE among intakes is an important consideration in estimating FGE, whether one uses hydroacoustic or other methods. There was

a high degree of intake-to-intake variability in FGE at Lower Granite Dam in 1998. For example, FGE at the nine intakes sampled ranged from 69% at Intake 6B to 90% at Intake 5B. At Turbines 3 and 4, where all three intakes at each unit were sampled, the C-intakes each had the highest FGE. These data demonstrate that it is important to randomize sample locations or increase the number of intakes sampled when estimating total project FGE.

The FGE values of 83-87% for the run-at-large we observed in 1997 and 1998 are similar to those obtained using radio telemetry. Adams and Rondorf (1998) reported an FGE of 97% for hatchery steelhead, 86% for wild steelhead, and 73% for spring/summer chinook salmon yearlings. The run-at-large FGE estimates also compare well with FGE estimated from fyke net data (Table 6.3). The extended-length submersible bar screens have improved FGE by about 10-15% over submersible travelling screens. Even with the new extend-length screen technology, however, we may be approaching the upper limit of FGE (ISAB 1998). Other bypass methods, such as surface bypass, may be necessary to more completely protect downstream migrating salmonids.

Table 6.3. FGE estimates (%) from the literature for submerged traveling screens (STS) and extended-length submerged bar screens (ESBS) at Lower Granite and McNary dams. F = fyke net data, RT = radio telemetry data, and HA = hydroacoustic data.

Study	Gear Type	Screen Type	Project	Steelhead	Yearling Chinook	Sub-yearling Chinook	Run-at-Large
Swan et al. 1990	F	STS	Lower Granite	77	57	--	--
McComas et al. 1993	F	STS	McNary	65	61	30	--
Swan et al. 1990	F	ESBS	Lower Granite	82	66	--	--
McComas et al. 1993	F	ESBS	McNary	83	80	53	--
Adams et al. 1997	RT	ESBS	Lower Granite	74-90	63-71	--	--
Adams et al. 1998a	RT	ESBS	Lower Granite	85	56-62	42-53	--
Johnson et al. 1998a	HA	ESBS	Lower Granite	--	--	--	87
Johnson et al. 1998c	HA	ESBS	Lower Granite	--	--	--	83
Adams and Rondorf 1998	RT	ESBS	Lower Granite	86, 97	73	72	--

6.1.4 BGS Performance

As a component of the surface bypass at Lower Granite Dam, the BGS diverted 78 ± 18% of the fish intended for Turbines 1-3 to the north. Mean daily passage rates and proportions were generally lower at Turbines 1-3 and higher at Turbines 4-6, the SBC, and the spillway with the BGS IN compared

to OUT. Thus, the BGS apparently influenced fish migration through much of the forebay. Fish were exposed to many different conditions at the dam besides those at their ultimate passage route. Although the BGS successfully diverted fish, not all diverted fish entered the SBC, as demonstrated by lower SBC efficiency (R_{4-6}) with the BGS IN than OUT. Passage at Turbines 1-3 was lower with the BGS IN, which in turn improved overall efficiency (R_{1-6} and R_{all}) and effectiveness (E_{1-6} and E_{all}) of the SBC. However, a proportion of the fish that were diverted from Turbines 1-3 may have passed through Turbines 4-6 thereby decreasing SBC performance for this section of the powerhouse. These data indicate that entrance conditions at the SBC might have been less than optimal (see discussion section 6.1.5). However, with the BGS IN, enhanced passage at the spillway improved FPE such that there was a significant ($P = 0.026$) difference in FPE between BGS IN and OUT conditions.

The BGS performed especially well at night when downstream migrants will sound if necessary to pass a dam (J. Williams, pers. comm.). At night, mean daily passage rates at Turbines 1-3 were about one-third lower with the BGS IN than OUT. Most importantly, SBC efficiency (R_{1-6}) was significantly ($P = 0.066$) higher at night with the BGS IN than OUT. Even though fish migrate deeper during night than day (Thorne and Johnson 1993), day and night BGS diversion probabilities were comparable. Thus, the BGS was deep enough to intercept most fish headed toward Turbines 1-3 during both day and night.

In general, the BGS concept seems valid, although the first-year test in 1998 was not sufficient for long-term decision-making. A major caveat to the 1998 test was that Turbine 2 was off-line the entire study. This means there was one-third less flow under the BGS than there would have been with Turbines 1-3 at full load. This is an appreciable amount of water (~566 m^3/s or ~20 kcfs) that could influence the number of fish moving under the BGS. The BGS should be studied with Turbines 1-3 at full load (~1,699 m^3/s or ~60 kcfs) to examine how well it diverts fish with maximum discharge at the turbines behind it.

Besides the prototype BGS at Lower Granite Dam, other walls have shown a propensity to divert juvenile salmonids. Powerhouses at Rocky Reach and The Dalles dams are oriented parallel to the main river flow. Juvenile fish have been observed guiding along the concrete face of these dams above the trashracks (Stevenson et al. 1997 for Rocky Reach and Sheer et al. 1997 for The Dalles). The only other flat-wall diversion structure for downstream migrant anadromous fish that we are aware of is at Bellows Falls Dam on the Connecticut River in Vermont. The flows (~283 m^3/s or ~10 kcfs) there are relatively low. The structure diverted 94% of radio-tagged juvenile Atlantic salmon (*Salmo salar*) smolts (CH2M-Hill 1998). Walls in rivers can efficiently divert fish as long as the migrants are surface oriented, flows

under the wall are reasonable (< 0.6 m/s or 2 fps at Lower Granite Dam), and safe structures can be reliably deployed.

6.1.5 SBC/SWI Performance

The SBC performed better in 1998 than it did in 1996 or 1997 (Table 6.4). This may be largely attributed to the addition of the SWI and lower flows in 1998. Improved SBC performance was not due to the BGS because SBC efficiency (R_{4-6}) was actually lower with the BGS IN than OUT. In 1998, more fish had an opportunity to discover SBC entrances than in previous years (i.e., more fish were available [within 3 m] in 1998 than before).

Table 6.4. SBC efficiency relative to the entire project (R_{all}), the powerhouse (R_{1-6}), Turbines 4-6 (R_{4-6}), and Turbines 4 and 5 (R_{4-5}).

Efficiency	1996	1997	1998
R_{all}	n/a	0.136 ± 0.003	0.268 ± 0.002
R_{1-6}	0.349 ± 0.003	0.293 ± 0.006	0.381 ± 0.003
R_{4-6}	0.427 ± 0.003	0.379 ± 0.010	0.510 ± 0.004
R_{4-5}	0.505 ± 0.004	0.462 ± 0.012	0.595 ± 0.005

Entrance efficiency within 3 m of the SBC was less in 1998 (57.6 ± 0.2%) compared to both 1996 (65.6%) and 1997 (69.0%). However, entrance efficiencies at the Middle and North entrances were comparable to previous years. At the BGS and South entrances, fish were apparently getting close but were not going in, as indicated by relatively low entrance efficiencies. Thus, conditions at the BGS and South entrances in 1998 were less than optimal. The BGS entrance had the lowest entrance velocity of all entrances (0.34 m/s or 1.10 fps for MAX and 0.72 m/s or 2.37 fps for IHR). In retrospect, the 0.3 m/s (1 fps) condition was possibly too slow. The South entrance continued to perform the poorest. Conditions there may have been affected by the “null zone” of slow moving water in front of the BGS and South entrances (described in Section 2.2 for the MAX configuration with the BGS in). The Middle and North entrances consistently passed the most fish and appear to be prime entrance locations.

The flow regime in the SBC forebay may have affected SBC performance. Water velocity gradually decreased on approach to the SBC, then abruptly increased within a few meters of the SBC. A smoother transition in flow into the SBC may improve SBC performance. The “null zone,” with very slow water velocity, was especially noticeable in front of the South and BGS entrances, which may have influenced fish passage there. “Null zones” of velocity need to be eliminated.

Of the two SBC entrance configurations we studied in 1998, the IHR (R_{4-6} = 53.6 ± 0.6%) slightly out-performed the MAX (50.2 ± 0.7%). With the IHR configuration, we observed fish moving rapidly upward in the water column into the surface entrances. There was a pronounced demarcation in direction of fish movement at a depth of 10-13 m as observed with both single- and multi-beam acoustics; fish above 10-13 m tended to move upward, while those below 10-13 m moved downward. Thus, the results of SBC configuration tests in 1996-1998 show the potential for horizontal, surface overflow entrances with hydraulically smooth entrance walls and consistent water acceleration to an entrance velocity of 0.91-2.13 m/s (3-7 fps). These conditions should improve entrance efficiency.

The data on descriptive relationships between SBC variables showed that increasing the percentage of SBC discharge should result in increased SBC efficiency. Since discharge at the current SBC is already maximized at 113 m^3/s (4,000 cfs), we suggest the Corps operate Turbines 4-6 at low load (~425 m^3/s or 15,000 cfs each) to increase the proportion of water going into the SBC during the downstream migration. Furthermore, thought should be given to turning Turbine 6 off completely to enhance SBC performance.

SBC efficiency relative to Turbines 4-5 (R_{4-5}) was the best metric to estimate performance of a stand-alone SBC because it represented SBC performance for the part of the powerhouse directly below the hydraulic influence of the SBC. Turbine 6 was not included because its flows came largely from the north across the spillway forebay and went under the end of the SBC where there was no SWI component. SBC efficiency (R_{4-5}) for the run-at-large was 59.5% ± 0.5%. These data mean that a two-unit SBC was about 60% efficient at diverting fish from turbines into the surface bypass in 1998. R_{4-5} for the IHR configuration, the best performer, was 62.1% ± 0.1%, which represents the best performance of a stand-alone SBC given 1998 conditions.

SBC efficiency (R_{1-6}) with the BGS in represented the performance of a total powerhouse surface bypass comprised of a SBC/SWI and a BGS. Composite R_{1-6} with the BGS in was 41.5% ± 0.6%. These data showed the potential for a surface bypass system that would be a combination of diversion wall (i.e., the BGS) and a powerhouse surface bypass (i.e., the SBC). Both components take advantage of smolt behavior to be surface-oriented. As it stands now, however, SBC efficiency will have to be increased to attain a stand-alone surface bypass system for the entire powerhouse.

6.2 Fish Behavior

In this section we discuss the fish behavior results from the multi-beam sonar in front of the SBC and split-beam sonar in front of Turbines 1-3 at Lower Granite Dam in spring 1998.

6.2.1 Fish Behavior in Front of the SBC (Multi-Beam)

It is helpful to put the behavioral data in the context of a conceptual model that describes a salmonid smolt's experience during its ocean bound voyage. Smolts arriving at the forebay of Lower Granite Dam have just begun their trek to the ocean through an altered pathway of reservoirs and dams. Before dams were constructed, smolts leaving their natal stream or hatchery would encounter pools, riffles, runs, eddies, and slack water habitats. These conditions provided opportunities for both rest and transport. The construction of dams on the Snake and Columbia rivers have, however, created a much different environment. In a sense, they have simplified the natural environment, resulting in long stretches of calm reservoir interrupted by turbulent waters at dam spillways and tailraces; complex collection facilities; and the dark, noisy holes called turbine intakes. Fish that successfully pass each dam find themselves back in a quiet reservoir, actively swimming to the next dam. This cycle repeats eight times for fish beginning their journey upstream of Lower Granite Dam. With each project they encounter, they are exposed to rapid changes in both their hydraulic and auditory environment. The simple conceptual model in Figure 6.2 represents this migration scenario. It is possible that a smolt negotiating several dams might learn what to expect and develop a behavior consistent with their experience. This learning could be manifested by either a submission to their fate or an avoidance reaction coupled with search for an alternate route. In other words, fish encountering this migration scenario could exhibit various behavioral responses near dam structures.

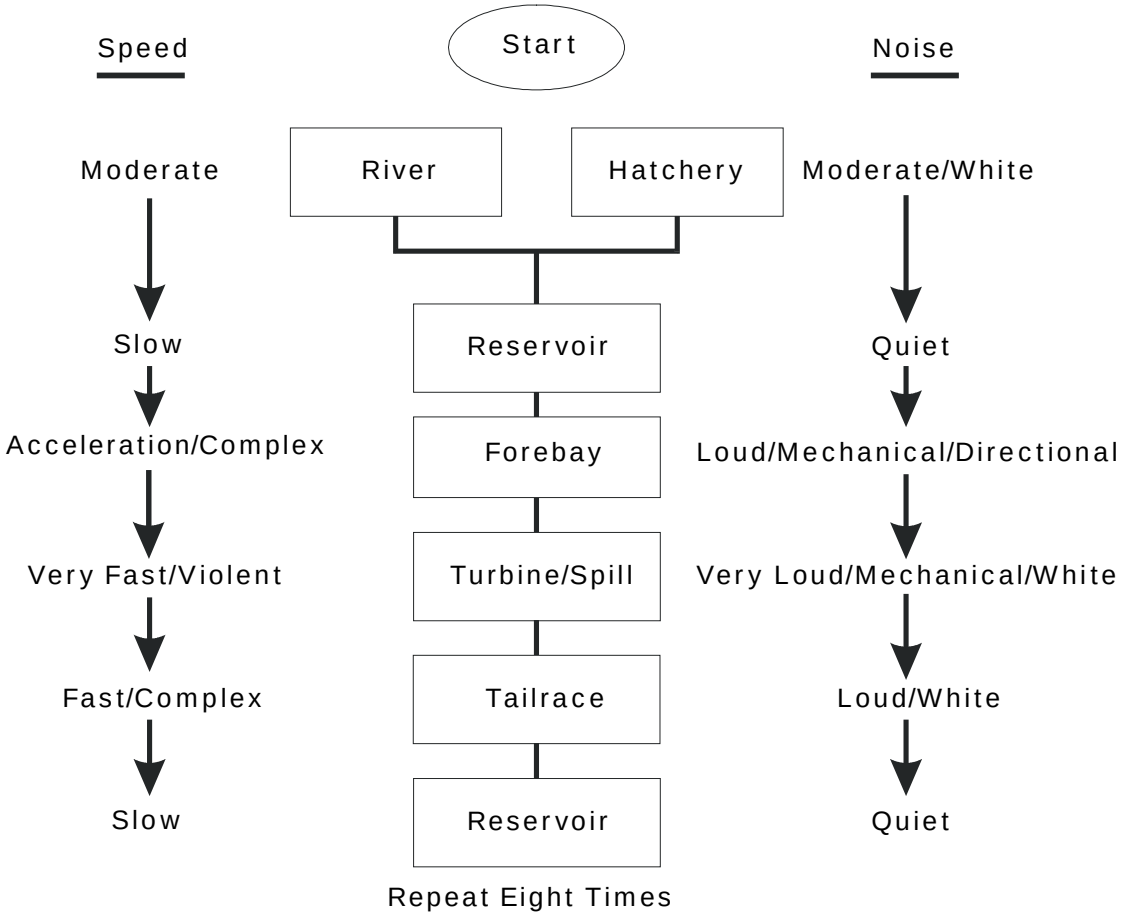


Figure 6.2. Simple conceptual model of speed and noise exposure as outmigrant smolts move through the Snake and Columbia rivers.

The goal of this study was to investigate and characterize the behavior of juvenile salmonids as they approached the SBC and BGS at Lower Granite Dam. This information is significant for two reasons. First, this is the first of eight dams that smolts approach under the scenario described above. They have emerged from their natal stream, entered the long, quiet Lower Granite reservoir and actively traveled downstream to arrive at a concrete wall comprised of several passage routes: turbines, spill, and SBC. The critical uncertainty is how the fish will react to this obstacle. Will they search for and take the nearest exit or will they loiter and search for the path that offers the least sense of danger? Second, Lower Granite Dam, because it is the first project encountered by smolts, should provide a baseline for comparison with smolt behavior farther downstream. The critical uncertainty here is whether smolts "learn" to navigate past dams as they move downstream. For instance, what is the behavioral difference

between a smolt approaching Lower Granite Dam and a smolt approaching Bonneville Dam? Are these differences, if detectable, a result of "learned" response or of some other attribute such as the degree of smoltification? Both uncertainties lead to the question, what can be done with the flow and/or the structure to provide for the highest possible efficiency while providing a benign passageway or collection facility for the smolt at a hydropower project?

In an attempt to understand the fundamental behavior of fish in a hydropower forebay and particularly in relation to the SBC/BGS evaluations at Lower Granite Dam, we chose to use hydroacoustics, a benign and non-intrusive sampling technique. This was highly significant from a behavioral study standpoint. Because characterizing natural fish behavior was the point of the study, it would have been counterproductive to alter the fish's behavior and still expect to understand how the individuals and the population behave. This is one drawback of baseline tagging studies for behavioral evaluations. On the other hand, hydroacoustics does not carry adequate information to permit species discrimination. We relied on run timing to provide us with high assurance that we interrogated salmonid smolts and not other fish species that might be present in the water column.

6.2.1.1. Target Summary

During the time period of this study, we collected over a million track records with the multi-beam system. After initial filtering for analysis, we had identified approximately 105,000 individual fish tracks. Subsequent filtering and careful target scrutiny yielded approximately 16,000 tracks for final analysis. Based on run timing data and the low numbers of non-salmonid species present in the Lower Granite forebay, we are certain that the majority of multi-beam-tracked fish targets were salmonid smolts.

6.2.1.2. Sonar Coverage

The multi-beam sonar coverage was better than that of any previous sampling strategy undertaken to evaluate fish movement in the forebay of a hydropower project. Even so, this coverage was perturbed from time to time because of broken cables and purposeful movement of the sonar platform. Because we monitored the location of the platform and the orientation of the sonar head in great detail, this actually resulted in an extension of our coverage. However, it also decreased the consistency of our spatial coverage.

The forebay nearfield zone (within 3 m of the SBC) was not covered due to the presence of large radio antenna poles suspended from floats in front of the North, Middle, and South SBC entrances. Acoustic noise from these sources also extended to the BGS entrance. One purposeful sonar platform

move was designed to try to acoustically "see" inside the radio antenna poles deployed in front of the SBC. This met with only limited success, so we returned the platform to its original position. The placement of poles in view of our sonar was the only major impediment to our coverage.

6.2.1.3. Depth Distribution

The depth of approaching fish provides an indication of availability to the SBC (Figure 5.5 and Figure 5.6). Fish sounded from 6-7 m depth to 10-12 m depth as they swam from the transducer to a range approximately 27 m from the dam (15 m from the SBC) for both BGS IN and OUT conditions. They then remained at a relatively constant depth of between 10 and 12 m to within 27 m of the dam. Inside 27 m, the BGS IN group remained at a relatively constant depth while the BGS OUT group sounded several meters. Thus, the BGS may have had a role in keeping fish higher in the water column and available to the SBC. This was based on the proportion of fish detected at various ranges and not actual numbers of fish. While proportions showed a marked difference in depth distribution (Figure 5.7), actual numbers only represented a small difference (Figure 5.8). However, the consistency in the trend is important to note. At Bonneville Dam in 1998, where we could “see” to within 3 m of the Prototype Surface Collector (PSC), a drastic increase in depth distribution of fish targets was noted at the face of the PSC for both slot widths tested (Johnson et al. 1999, in press). Because we were unable to "see" very near the SBC structure with multi-beam sonar at Lower Granite Dam, we can only speculate whether this trend to move downward near the dam continued in front of the SBC.

6.2.1.4. Direction of Movement

Consistent patterns emerged from the direction of movement analysis for both the observed and swimming effort analyses. First, the variability in the observed data was much greater than that of the swimming effort data (Figure 5.12 vs. Figure 5.18). This suggests that the swimming effort data might be a better indicator for decision points in fish behavior than the observed movement patterns. The observed direction of movement did, however, underline the complexity of fish movement and underscore the need to improve our understanding of why fish behavior is so complex near these structures. Overall, observed data showed that fish moved toward the SBC and that there was no difference in the variability in their direction between the BGS IN and OUT conditions. However, fish did not appear to be passively following flow, but responding to some other stimuli as they approached the powerhouse. Fish appeared to show behavioral responses well beyond their ability to see the structures or feel changes in flow near the SBC and BGS.

On average, fish swimming effort data indicated that fish were positively rheotactic, i.e., swimming into the current, and swam in an upward direction (Figures 5.22 through 5.25). However, it should be noted that an individual's directional behavior within this entire region was highly complex, as observed in our 3-D visualization (see Section 3.3.2.2). The complexity of the direction of movement appeared to be greatest near the BGS and SBC, as well as deeper in the water column. One observation of interest was that fish exhibited different swimming effort behaviors associated with their position along the SBC (Figure 5.35). Fish north of the middle entrance tended to swim parallel to the structure toward the spillway. Fish south of the middle entrance (closer to the BGS) were characterized by vertical and perpendicular (mostly upstream) swimming effort. This suggests that fish exhibited more milling behavior near the BGS/SBC junction. When examining the University of Iowa's computational fluid dynamics model of flow, we also noted complexity in the flow field in the area south of the middle entrance. In some cases, flow was almost non-existent, while in others the water appeared to rebound off the BGS curtain and create a backward flow, particularly near the water surface.

In 1997, a change in orientation was noted near the surface and approximately 10 m from the SBC. This change was not as evident in this year's data. It should be noted, however, that flow data for 1998 came from the computational fluid dynamics model developed at the University of Iowa, while 1997 flow data came from physical model data collected at the Waterways Experiment Station in Vicksburg, Mississippi. Also, we were not able to collect a large amount of data within 10 m of the SBC in 1998 due to several sources of interference.

6.2.1.5. Kinematics

Analysis of the observed component speed ratios show that no one component dominated except in the depth perspective (Figure 5.33 and 5.34). In the depth perspective, the predominant movement was parallel, or across, the face of the SBC near the surface. The prominence of the parallel component, while not a sure indication of rejection of the structure, may account for the lower-than-expected efficiency of the SBC entrances (Section 4.3.2). Below the bottom of the SBC, fish swam mostly up and down and perpendicular to the dam.

The vertical component was least significant near the surface and also least significant in the region in front of the middle and south entrances to the SBC. Overall, there was little detectable difference in the observed speed components between the BGS IN and BGS OUT conditions.

Again, fish swimming effort refers to the actual speed of the fish without the water flow component. When we analyzed the components of this speed (Figure 5.35), we noted that over much of

the sampled area, the primary component was along the north-south axis, i.e., parallel to the SBC. This was true to the north of the Middle entrance, at most depths, and for most of the distance between the multi-beam transducer and the SBC. Directional histograms (e.g., Figure 5.20) indicated that this movement was toward the spillway. Thus, fish were oriented toward the spillway and were actively swimming in that direction. The main area showing a different pattern was near the junction of the SBC and BGS. In that region, fish speed was dominated by movement either along the BGS or up and down in the water column. The directional histograms indicated there was no preference in direction in that area. These results were similar to those noted for the Prototype Surface Collector at Bonneville Dam (Johnson et al. 1999, in print) and are one on the principle reasons we suspect that fish are either reacting to the complexity of the flow field (acceleration/deceleration) or other stimuli such as low frequency noise or lighting conditions.

Overall swimming effort was greatest farther from the structure than near it (Figure 5.31). Fish may have had to swim harder upstream where water speeds were faster than near the structures, especially when the BGS was IN (Figures 2.11 and 2.13).

6.2.1.6. Track Characterization

The analysis of tortuosity revealed no obvious trends in behavior associated with BGS condition or with range from the SBC (Figure 5.36). This lack of trends contrasts to what was observed using multi-beam sonar at Bonneville Dam in 1998 (Johnson et al. 1999, in print). There we were able to acoustically "see" very close to the PSC. Thus, we may have missed changes in tortuosity that occurred within that range at Lower Granite Dam. Median tortuosity values derived from the Lower Granite Dam data were consistent with the values found at similar ranges from the structure at Bonneville Dam.

6.2.2 Fish Behavior in Front of Turbine Units 1-3 (Split-Beam)

While we collected a large number of targets (more than 26,000) during a limited sample time frame (the split-beam system was only operated during the BGS IN condition), we believe that many fish were repeat detections. Our analysis of movement patterns suggested that fish milled in the slack water behind the BGS and in front of Turbine 2 (Figure 5.52; Turbine 2 was shut down during the entire study). Fish milling probably inflated the number of fish tracks collected on the south side of the BGS. The relatively low numbers of fish detected entering Turbines 1 and 3 with BGS IN substantiated this observation (Figure 4.15).

Our main reason for monitoring the region behind the BGS was to determine if fish detected in the forebay in front of Turbines 1-3 had entered the area through the junction of the SBC and the BGS and to monitor for large accumulations of fish in that area. Our monitoring indicated that there were not substantial numbers of fish moving into the region through the SBC/BGS juncture. The majority of fish ensonifications indicated that fish were milling near the face of the dam and were located near the water surface (in the top 20 m; Table 5.18). We did not find large accumulations of fish in the region behind the BGS (Table 5.19). Those fish present probably entered the backside of the BGS from the upstream gap along the shoreline or came under the BGS upstream of our sample location.

The target strength distribution behind the BGS was uni-modal with a mean of –42.3 dB and a range of –50.6 to –19.0 dB (Figure 5.46). This suggests that there were some large fish, presumably returning adults, detected in this relatively slack water. Large fish were observed throughout the study behind the BGS and jumping in the forebay.

6.3 Applications and Comparisons to Other Dams

The results from research on the SBC/SWI and BGS at Lower Granite Dam may be applicable to other dams where surface bypasses are being developed. Site-specific features and a prototype structure will always be necessary in the development process. And, there is no guarantee that what we have learned at Lower Granite Dam will work when applied at other sites. Lower Granite results will probably be more applicable to other lower Snake River dams than the lower Columbia River dams because the lower Snake River projects have similar geometry. Certain general principles and lessons learned at Lower Granite Dam, however, should be considered for application at other sites. These include the following:

- Smolts follow the bulk flow in the forebay upstream of a dam, tend to concentrate in the thalweg, and are surface-oriented.
- During daytime, smolts prefer not to sound to pass a dam. They will use a surface route if given the opportunity. If a surface route is not available, they will delay during the day and sound at night to pass through turbines.
- Forebay currents with a strong downward component will decrease surface bypass performance by entraining fish into turbines before they can discover a surface bypass.
- A wall in a forebay can divert downstream migrants horizontally.

- Surface bypass flows should accelerate uniformly so as to not cause an avoidance response by the fish. A "null zone" of velocity should be avoided. Mean entrance velocity of 0.9-2.1 m/s (3-7 fps) seems appropriate based on our experience with the SBC.
- Surface bypass discharge should be at least 10% of total turbine discharge beneath the bypass based on the desire to eliminate the “null zone.”
- For a given entrance velocity, multiple entrances with a relatively large amount of surface area and flow near the water surface are better than entrances with small surface area and flow.
- An overflow or weir condition at the entrance seems to help surface bypass passage based on the relatively high performance of the Middle entrance at the SBC. (The BGS entrance also had overflow, but the velocities were apparently too slow.)
- A powerhouse surface bypass with a high volume channel connected to a spillway can quickly and safely deposit smolts at a spill bay outfall.
- Any prototype surface bypass test should include a formal, pre-season monitoring and evaluation plan with experimental design, in-season reporting of preliminary data, analytical and statistical scrutiny, preliminary post-season reports to feed the engineering and regional review processes, and peer review.

It is useful to compare performance of the SBC at Lower Granite Dam with other prototype surface bypasses in the region. At Rocky Reach Dam on the mid-Columbia River, a “corner collector” surface bypass has been under development since 1995 when proof-of-concept was demonstrated. In 1996, the evaluation showed that about 10% of the PIT-tagged smolts released for the evaluation used the collector (Peven et al. 1996). In 1997, internal and external hydraulic conditions at the collector were improved and water was diverted off the gatewell of a prototype intake screen. About 35% of PIT-tagged fish used the corner collector during the 1997 test (Peven and Mosey 1997), although there was some concern about the release location of PIT-tagged fish. In 1998, a second surface bypass entrance was added, but fish seemed to avoid it perhaps because of unforeseen hydraulic conditions (C. Peven, pers. comm.). The corner collector surface bypass in conjunction with intake diversion screens at some turbines is the preferred long-term solution for juvenile bypass at Rocky Reach Dam.

At Bonneville Dam on the lower Columbia River, prototype surface bypasses were tested at both powerhouses in 1998. A prototype surface collector (PSC) was installed on the upstream face of Bonneville First Powerhouse at Turbine Units 3-6. It extended 15.2 m deep and had entrances above

Intakes 3B and 5B. Two entrance configurations were tested, 6.0 m (110 m^3/s at 1.4 m/s or 3,900 cfs at 4.6 fps) and 1.5 m wide (48 m^3/s at 2.4 m/s or 1,700 cfs at 7.8 fps). PSC flow out of both turbines 3 and 5 (Turbines 4 and 6 were off-line) was 10% for 1.5 m openings and 30% for 6 m openings. Water exited the PSC through the trashracks into the turbines behind it (i.e., the PSC had a floor, sides, and a front, but no back). PSC efficiencies [PSC / (PSC + turbine 3 + turbine 5)] from hydroacoustic and radio telemetry samples were greater than 90% for the 6-m configuration, but less than 90% for the 1.5-m slot (Ploskey et al. 1998; Shively et al. 1998). The sluice chute at Bonneville Second Powerhouse is also being investigated as a possible surface bypass. In 1998, hydroacoustic estimates of efficiency relative to turbines 11-13 were about 87% during spring and summer tests. In addition, about half of the radio-tagged fish used this route, which had only about 85 m^3/s or 3,000 cfs (Shively et al. 1998). Clearly, surface bypass has solid potential at both powerhouses at Bonneville Dam.

SBC performance can also be assessed relative to the only agency-accepted, long-term surface flow bypass in the region, the one at Wells Dam. When compared to Wells, performance to date for the stand-alone SBC system at Lower Granite Dam was satisfactory ($R_{4\text{-}5}$ = 60%), but not outstanding. At Wells Dam, surface bypass efficiency was 89% during the 1990-1992 total project evaluation (Skalski et al. 1996). Wells' surface bypass uses about 311 m^3/s (11,000 cfs), which is about 5-7% of total project discharge. This is comparable to the SBC's 113 m^3/s (4,000 cfs), which is about 6% of one-half powerhouse hydraulic capacity at Lower Granite Dam. One reason the surface bypass at Wells Dam works so well could be the way fish are concentrated horizontally and vertically with access to attractive bypass entrances. At this stage of development at Lower Granite Dam, the SBC probably can not be used to replace the intake screens. However, performance ($CBE_{1\text{-}6}$ = 89.5 ± 1.7%) of the SBC and screens combined, the "hybrid" bypass system, is comparable to total project bypass efficiency at Wells Dam.

Section 7: Conclusions and Recommendations

Fish did not passively follow flow in the Lower Granite forebay into the SBC entrances. Instead, they exhibited complex movements near the Lower Granite prototype structures that may have depended on other environmental factors associated with the dam. Overall, spill, intake screens, and the SBC/SWI/BGS together afforded a high level of smolt protection (FPE = 92.6 ± 1.2%) during spring 1998 at Lower Granite Dam. This section contains conclusions and associated recommendations from the fish passage and behavior evaluations of spill passage, fish guidance at intake screens, powerhouse passage, BGS performance, and SBC/SWI performance. Suggestions for additional investigations are also included.

Spill Passage

Spill efficiency (29.7 ± 0.4%) and effectiveness (1.13 ± 0.02) were not as high as in previous years, perhaps because less water was spilled in 1998 than 1997 (26% less by volume). The spill openings were more effective during the day than at night, in large part because fish that passed through the spillway were surface-oriented and had higher passage rates during day than night.

Recommendation: Spill program for fish protection at Lower Granite Dam should consider 24 h/d spill.

Intake Screen and Powerhouse Passage

Overall fish guidance efficiency was 83 ± 2.7%, or approximately 3.5% lower than we observed in 1997, probably because there was an increase in chinook salmon species composition from 6% in 1997 to 22% in 1998. In general, chinook salmon inside turbine intakes do not guide as well as steelhead. Fish may have held in the forebay during the day and sounded to pass (> 18 m or 60 ft) through turbine intakes at night. Turbine operations and the presence of the BGS, in large part, determined the horizontal distribution of fish passage at the powerhouse.

Recommendations: In general, operate the turbines behind the BGS (Turbines 1-3) at full load and the turbines beneath the SBC (Turbines 4-6) at low load. Operate turbines, from first to last on, as follows 1-5-2-4-3-6.

BGS Performance

The BGS performed as intended and diverted 78 ± 18% away from Turbines 1-3. Fish found passage routes to the north of the BGS through the SBC, spillway, or Turbines 4-6. Total passage rates at Turbines 1-3, in general, were low compared to those for the rest of the dam, whether the BGS was IN or OUT. The BGS did not adversely affect fish guidance efficiency or fish passage efficiency. Fish guidance efficiency was 2.1% higher with the BGS IN than OUT, although this difference was not statistically significant (P = 0.33). Fish passage efficiency was significantly (P = 0.03) higher (+2.5%) with the BGS IN. Also, when fish approached to within 13 m of the SBC, they remained higher in the water column when the BGS was in position. They are, therefore, more likely to encounter an SBC entrance when the BGS is IN.

Recommendation: Operate with the BGS IN and assess BGS performance (i.e., horizontal distribution of fish at the powerhouse) with all turbines behind it at full load, including Turbine 2, which did not operate in 1998.

SBC/SWI Performance

1. SBC performance improved noticeably in 1998 (R_{4-6}, 50-54%) over that observed in 1996 and 1997 (R_{4-6}, 35-45%). Possible reasons for this improvement include the addition of the SWI, lower load at Turbines 4-6, less spill, and lower total project discharge in 1998 than previous SBC test-years. A better indication of performance for a stand-alone SBC is SBC efficiency relative only to Turbines 4 and 5 (59.5 ± 0.5%). This is because water entering Turbine 6 did not allow fish to encounter the SBC entrances as currently positioned and there was no SWI on the end of the SBC near Turbine 6.

   Recommendation: Extend SWI to the end of the SBC and operate Turbine 6 at low load.

2. SBC gate configuration did not affect SBC performance. Differences in performance estimates based on the low velocity maximum area (MAX) or relatively high velocity horizontal surface flow (IHR) were not statistically significant (P = 0.27 for R_{1-6}, day/night combined), although the overall performance estimates for IHR were 4% higher than those for MAX.

   Recommendation: Utilize the weir condition at the Middle and BGS entrances. Identify gate configuration, through hydraulic modeling, that provides a channel of relatively high velocity water into bypass entrances.

3. Forebay entrainment into the turbines beneath the SBC was reduced in 1998 (the entrainment parameter in the fish budget was 0.33 in 1997 and 0.05 in 1998). Fish availability to the SBC increased, probably because the SWI reduced the downward component of flow in the SBC forebay and the BGS guided fish toward the SBC. However, the entrance conditions at the SBC were less than optimal as shown by an overall entrance efficiency of 57.6 ± 0.2%. Thus, the increase in SBC efficiency in 1998 was caused by increased fish availability, not improved entrance conditions. This relatively poor entrance efficiency may have been caused by the velocity/acceleration regime in the SBC forebay. Velocity gradually decreased on approach to the SBC then abruptly increased within a few meters of the entrances.

   However, our data also indicated that fish react to sensory cues other than acceleration or flow long before they can see structures or are close enough to be entrained by the SBC. Increased noise in the forebay from turbine operation or changes in lighting conditions may cause the fish to change their approach patterns. Smolts may be more likely to explore along the structures for safe passage routes if provided an approach environment that more closely resembles the upstream reservoir.

   Recommendations: SBC entrance conditions could be improved by reducing or eliminating the “null zone” in the SBC forebay and making water acceleration into the SBC more gradual than is presently the case. Further fine-scale behavioral evaluations, particularly near the SBC would help characterize how fish behave in front of the SBC entrances under different flow conditions and would result in improved entrance efficiency estimates.

4. Smolts exhibited erratic behavior near the BGS entrance, probably due to the large region of relatively slack water or "null" zone at the junction. Fish moving along the BGS appeared to become more varied in their movements at the junction and orient toward the spillway.

   Recommendation: Providing a stronger surface component to the attraction flow field, may counter the effect of the null zone at that corner. In particular, a stronger flow at the BGS entrance may provide the "corner collector" type condition that was so effective at Bonneville Powerhouse 2.

5. The SBC improved the efficiency (+ 26.8%) of water spilled for fish protection. Lower spill rates and higher SBC discharge proportions were related to improved SBC efficiency. This indicated that the SBC may be an important operational tool in low flow years. Overall, data on descriptive relationships between the SBC variables showed that increasing the percentage of SBC discharge should result in increased SBC efficiency.

Recommendation: Since SBC discharge in 1998 was already maximized at 113 m^3/s (4,000 cfs), we suggest that, besides continuing to maximize SBC discharge, Turbines 4-6 be operated at low load (~425m^3/s or 15,000 cfs each) to increase the proportion of water going into the SBC during the downstream migration. Spill Bay 2 should operate at a minimum of 57 m^3/s (2,000 cfs). The Middle and North SBC entrances should be opened accordingly to have about 1.2-1.8 m/s (4-6 fps) mean velocity at each entrance. Final decisions on entrance velocities should be confirmed with numerical modeling.

Additional Investigations

1. Construction of untested surface bypass structures is time-consuming and cost-prohibitive. Models that integrate data sets of environmental conditions at particular points in the forebay of a hydroelectric project could be used to perform preliminary analyses and evaluations of fish passage in advance of costly construction.

   Recommendation: Develop a probabilistic/simulation forebay fish behavior model from historical and future behavior data. Use available data on environmental conditions (flow, light, noise, etc.) at specific forebay location to predict the direction fish are expected to swim, their speed, and their orientation.

2. Fine-scale computational fluid dynamics models provide the opportunity to perform pre-construction evaluations of forebay attraction flows. This coupled with a fish behavior model would be a powerful tool for pre-construction evaluations at Lower Granite Dam as well as other dams on the Snake and Columbia rivers.

   Recommendation: Continue development of a fine-scale computational fluid dynamics model of the forebay and cross-calibrate with the physical model and field measurements.

3. Turbulence occurs naturally in front of the SBC. Characterizing this phenomena will provide better insight into fish behavior in turbulent flow near the SBC vs. non-turbulent flow in other regions of the forebay.

   Recommendation: Characterize the naturally occurring turbulence in front of the SBC.

4. Understanding the acoustic noise levels fish are exposed to may help us understand fish behavior in the presence of dam-related sound sources. Infra-sound and low-frequency sound have been successfully used to modify fish behavior. Broadband noise sources may also affect fish behavior

and influence researchers to choose a particular hydroacoustic technique to collect fish behavior data.

Recommendation: Measure background acoustic levels in-season during actual SBC operation to characterize the forebay noise environment.

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Appendix A

Single-Beam Hydroacoustic Methods

Appendix A: Single-Beam Hydroacoustics

A.1 Hydroacoustic Systems and Calibration

The typical single-beam system (420 kHz) used at Lower Granite Dam in 1998 was comprised of an echo sounder, unarmored and armored coaxial cables, transducers (6°, 10°, and 15°), a multiplexer/equalizer, an echo signal processor, and a computer (Figure A.1). The systems operated as follows. The sounder generated a transmit pulse that was directed by the multiplexer/equalizer to a particular transducer via electrical cables. The piezo-electric transducer converted electrical energy to mechanical energy of acoustic pressure waves. Acoustic waves emanated out from the transducer and were reflected from objects in the water, such as fish with swim bladders, back to the transducer. The transducer reconverted the mechanical energy to electrical energy and sent the echo signal back through the cables to the sounder via the multiplexer. The sounder amplified the signal with a 40logR time-varied-gain to compensate for spreading loss. The signal next went to the multiplexer/equalizer where differences in source level and receiving sensitivity among different transducers were accounted for. Then the signal went to the echo signal processor installed on a personal computer. Here the electrical signals that exceeded a certain magnitude and satisfied certain shape criteria were digitized. Finally, the digital data on each echo was written to computer files. See Table A.1 for model and serial numbers of equipment, Table A.2 for hydroacoustic system parameters, and Table A.3 for echo signal processing parameters.

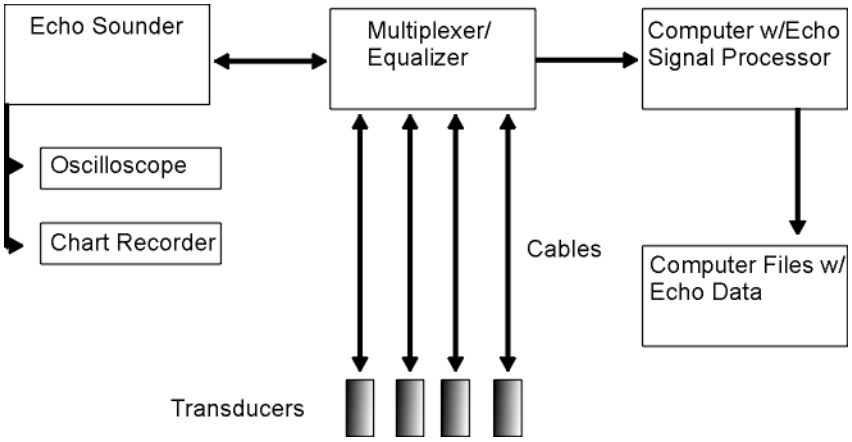


Figure A.1. Typical single-beam hydroacoustic system used for data collection at Lower Granite Dam in 1998.

Table A.1. Model and serial numbers for hydroacoustic systems used at Lower Granite Dam in 1998. See Table A.4 for transducer serial numbers.

System	Echo Sounder	Echo signal processor	Multiplexer/equalizer	Oscilloscope
System 1 SBC	ES2000-96-023	127	n/a	TEK-MY15014
System 2 SBC	ES2000-96-024	134	n/a	TEK-MY15013
System 3 FGE	101-82-017	133	151-88-022	TEK-B263710
System 4 FGE	102-86-004	80	151-88-027	TEK-B017625
System 5 FGE	101-82-016	131	151-84-12	TEK-B018667
System 6 Pier Nose	101-81-013	126	151-84-011	GOLDSTAR-5080558
System 7 Spill	101-83-028	128	151-85-019	TEK-MY15012

Table A.2. Hydroacoustic system parameters used at Lower Granite Dam in 1998. Receiver gain for Systems 1 and 2 depended on the transducers because receiver gain and equalization are added at the same time in these systems.

Parameter	System 1 SBC 1	System 2 SBC	System 3 FGE	System 4 FGE	System 5 FGE	System 6 Pier Nose	System 7 Spill
Transmit Power (dB)	0	0	0	0	0	0	0
Pulse Width (msec)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Pulse Rate (pps)	20	20	20	20	20	10	10
Receiver gain (dB)	depends	depends	-18	-12	-18	-12	-6
Time-varied gain	40 log R	40 log R	40 log R	40 log R	40 log R	40 log R	40 log R
Absorption coefficient	0	0	0	0	0	0	0
Bandwidth (kHz)	5	5	5	5	5	5	5
TVG Range (m)	50	50	n/a	n/a	n/a	n/a	n/a

Table A.3. Echo signal processing parameters used during data collection at Lower Granite Dam in 1998.

Parameter	System 1 SBC	System 2 SBC	System 3 FGE	System 4 FGE	System 5 FGE	System 6 Pier Nose	System 7 Spill
Threshold (mV)	100	100	100	100	100	100	100
Pulse search window	100%	100%	100%	100%	100%	100%	100%
Wide peak search window	50%	50%	50%	50%	50%	50%	50%
1/2 amplitude pulse width	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6
1/4 amplitude pulse width	0.4-0.72	0.4-0.72	0.4-0.72	0.4-0.72	0.4-0.72	0.4-0.72	0.4-0.72
Auto track	disabled	disabled	disabled	disabled	disabled	disabled	disabled

Scientific hydroacoustic systems must be calibrated before and after a study. For each sounder/transducer set, calibration provided data on the source level, receiving sensitivity, and beam-pattern. These data were used to calculate the equalizations (Equations 1 and 2). Table A.4 contains

calibration and equalization data for the single-beam hydroacoustic systems used at Lower Granite Dam in 1998. The systems were set up to detect a -52 dB target on-axis, which corresponds to fish about 90 mm long (Love 1977) in the nominal sample volume (-3 dB off-axis).

$$Vo = SL + G1 + TS + RG + EQ \qquad \text{Eq. 1}$$

where,

Vo = voltage out of the system (dB)

SL = source level (dBuPa@1m)

G1 = receiving sensitivity (dBv/uPa)

TS = target strength (dB)

RG = receiver gain (dB)

EQ = equalization (dB)

Thus,

$$EQ = Vo - SL - G1 - TS - RG \qquad \text{Eq. 2}$$

Table A.4. Calibration and equalization data for single-beam hydroacoustic systems used at Lower Granite Dam in 1998. We assumed TS = -52 dB, Rg = +0 dB, Vo = threshold = 100 mV, and 40 log R TVG. Location is the sampling location (for SBC locations, extension 1 is the downstream transducer for up- and down-looking squinted-pairs). Mount depth is expressed as elevation from mean sea level in feet with the water surface at 733 ft MSL. Cable length is the total length (ft.) of cable deployed for each location. Port is the multiplexer port. Lobe is the highest height of the first side lobe (dB). Width is the -3 dB beam width. G1 is the receiving sensitivity at 1 m (dB). SL is the source level (dB). And EQ is the equalization (dB). See Table A.1 for sounder serial numbers.

System	Transducer	Location	Mount Depth	Cable Length	Port	Lobe	Width	G1	SL	EQ
1	06-095	M3U1	678	675	X1	-31	6.6	-169.8	217.93	-16.2
	06-096	M3U2	678	675	X2	-31	6.1	-170	217.7	-15.71
	06-103	M3D1	730	500	X3	-29	6.2	-169.2	219.4	-18.9
	06-105	M3D2	730	500	X4	-28	6.1	-170.2	217.8	-15.5
	06-097	M4U1	678	675	X5	-27	5.8	-169.2	217.8	-15.5
	06-100	M4U2	678	675	X6	-29	5.8	-169.2	218.2	-17
	06-102	M4D1	730	500	X7	-28	6.1	-169.5	219.2	-18.4
	06-104	M4D2	730	500	X8	-29	6.2	-169	219.6	-19.2
	06-027B	M8U1	678	675	X9	-35	6.2	-169.8	217.8	-16
	06-57	M8U2	678	675	X10	-33	6.3	-169.6	218.3	-16.7
	06-110	M9U1	678	675	X11	-29	6.2	-170.1	217.9	-15.9
	06-114	M9U2	678	675	X12	-27	6.3	-170	218.1	-16.1
2	06-129	M13U1	678	675	X1	-26	6.3	-169	217.6	-16.7
	06-130	M13U2	678	675	X2	-27	6.1	-168.3	218.1	-17.8

System	Transducer	Location	Mount Depth	Cable Length	Port	Lobe	Width	G1	SL	EQ
	06-115	M13D1	730	500	X3	-27	6.3	-168.5	218.4	-18.4
	06-116	M13D2	730	500	X4	-28	6	-168	218.4	-18.9
	06-201	M14U1	678	675	X5	-29	5.8	-166.2	219.5	-21.3
	06-202	M14U2	678	675	X6	-27	5.9	-166.3	219.4	-21.1
	06-203	M14D1	730	500	X7	-30	6	-166.1	219.5	-22.5
	06-204	M14D2	730	500	X8	-30	6	-166.1	219.4	-22.4
	06-205	M18U1	678	675	X9	-30	6	-166	219.6	-21.6
	06-206	M18U2	678	675	X10	-30	5.9	-165.8	219.7	-21.8
	06-207	M19U1	678	675	X11	-28	5.9	-165.9	219.6	-21.6
	06-208	M19U2	678	675	X12	-28	5.9	-166.3	219.3	-21
3	10-023	1BG	617	1175	X1	-30	9.5	-176.5	215.5	5
	10-024	1BU	635	1175	X2	-30	9.7	-176.4	215.6	4.7
	10-025	6BG	617	675	X3	-30	9.4	-174.2	217.3	0.9
	10-026	6BU	635	675	X4	-26	9.2	-174	217.1	1
	10-027	3AG	617	675	X5	-26	9.1	-173.9	217.5	0.4
	10-028	3AU	635	675	X6	-27	9.1	-174.4	216.8	1.6
4	10-021	3BG	617	675	X1	-30	9.6	-166	213.2	2.9
	10-022	3BU	635	675	X2	-31	9.1	-166	213.2	2.8
	10-017	5BG	617	1175	X3	-27	9.1	-166	213.4	2.2
4	10-020	5BU	635	1175	X4	-26	9.2	-166.5	213.2	3.3
	10-018	4AG	617	675	X5	-28	9.5	-165.6	213.5	2.1
	10-019	4AU	635	675	X6	-29	9.5	-166.3	213.2	3.1
5	10-029	4BG	617	675	X1	-27	9.1	-165.2	213.3	4.9
	10-031	4BU	635	675	X2	-30	9	-171	217.3	3.7
	10-034	4CG	617	675	X3	-29	9.1	-171.4	217.1	4.3
	10-032	4CU	635	675	X4	-27	9.1	-170.8	217.3	3.6
	10-039	3CG	617	675	X5	-29	9.4	-170.6	217.6	3
	10-037	3CU	635	675	X6	-26	9.3	-170.9	217.6	3.3
6	15-214	T1	601	1175	X1	-17	15.2	-172.5	208.3	8.3
	15-212	T3	603	675	X3	-20	14.6	-171	209.3	5.7
	15-215	T4	606	675	X4	-18	14.1	-170.3	210.2	4.1
	15-216	T5	602	675	X5	-18	14.1	-170.2	210.2	4
	15-217	T6	601	675	X6	-20	13.7	-171.4	209	6.4
7	15-186	S2	730	500	X2	-17	14.5	-172.7	209.7	1.1
	15-179-2	S3	730	500	X3	-17	14.3	-172.9	210.8	0.1
	15-218	S4	730	500	X4	-18	14.6	-172.5	210.4	0.1
	15-157	S5	730	500	X5	-17	13.9	-172.6	209.3	1.4
	15-004	S6	730	500	X6	-17	14.1	-172.4	209.5	0.9
	15-131	S7	730	1000	X7	-19	13.9	-175.7	205.5	8.2
	15-183	S8	730	1000	X8	-15	14.2	-175.3	205.7	7.6

A.2 Detectability

A detectability model was used to confirm our ability to sample fish at the various sampling locations. The following table (Table A.5) shows the transducer parameters and detectability results for each of the main sampling locations in the 1998 hydroacoustic evaluation at Lower Granite Dam. Detectability was excellent, except within 3.7 m (12 ft) of the guided and unguided transducers (Figure A.2). Entrance velocities for the MAX configuration ranged from 0.3 to 0.9 mps (1.1 to 2.9 fps) and from 0.7 to 1.2 m/s (2.3 to 3.9 fps) for the IHR configuration. Fish velocities at pier nose locations were 0.3 m/s (1 fps) for Turbines 1 and 3, and 1.1 m/s (3.5 fps) for Turbines 4-6, immediately below the SWI.

Table A.5. Acoustic detectability parameters and results for the five type of single-beam sample locations at Lower Granite Dam in 1998.

Parameter	SBC	FGE (unguided)	FGE (guided)	Pier Nose	Spill
Fish velocity (mps)	0.3, 1.2	3.6	1.8	0.3, 1.1	2
Ping rate (#/sec)	20	20	20	10	10
Min. echoes	4	3	3	4	4
Beam angle	6	10	10	15	15
Transducer aiming direction	Up/Down	Down	Up	Up	Down
Angle off vertical	0	40	25	10	10
Angle of fish trajectory	0	0	0	-45	0
Max. model range	60	60	60	125, 105	60
Results	Excellent	Good	Good	Excellent	Excellent

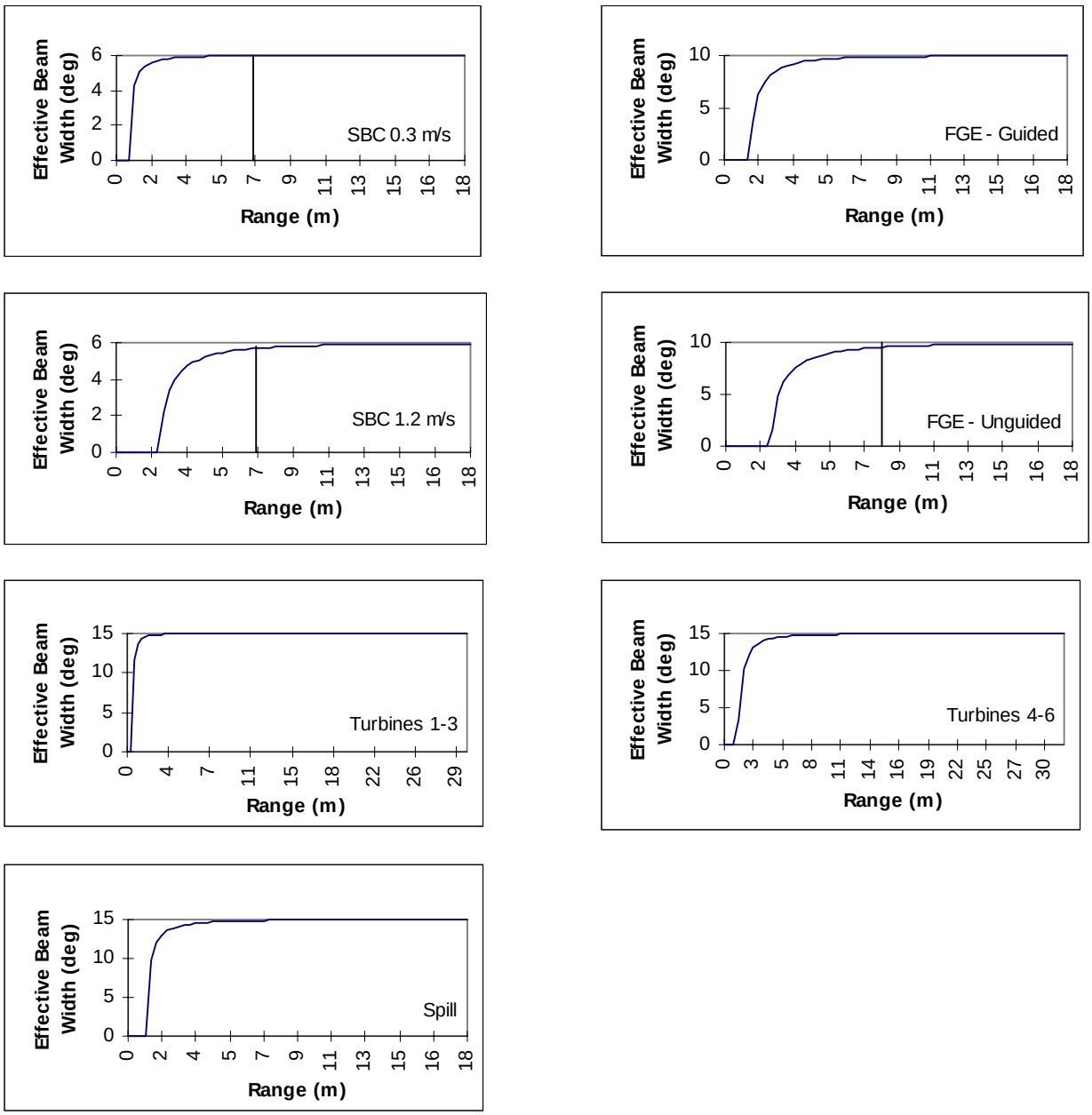


Figure A.2 Detectability results for the hydroacoustic systems in 1998. Vertical lines in SBC and FGE (unguided) plots indicate minimum range of interest.

A.3 Hydroacoustic Quality Control

Several steps were taken before, during, and after the 1998 evaluation period to ensure the quality of the single-beam hydroacoustic data (Table A.6). Quality control was conducted through evaluation of output files and review of hydroacoustic system logbooks. To ensure selection of trace types consistent with previous years efforts, routine evaluation of hydroacoustic technician/vidpadder output files and visual observations of trace type selection were conducted throughout the entire processing period. Output files were evaluated on a weekly basis by generating hardcopies of two output files from each vidpadder. Files from each of the seven systems were evaluated. The On-Site Manager and Data Analyst processed the selected data files and compared the output files to those generated by the technicians. Feedback was provided to individual technicians indicating both instances of appropriate trace selection and identifying the need for modification. Logbook entries and data file tracking sheets indicated occurrences of duplicate trace selection, missing data blocks, stuck transducers, and transducer samples that were too noisy to process. Editing of output files was conducted by the Data Analyst prior to execution of weekly analyses programs.

Table A.6. Quality control actions in 1998 at Lower Granite Dam.

Phase	Action
Preparation	Calibrate systems
	Calculate equalizations and verify
	Check equalization adjustments for cable length
	Cross-check expected ranges to actual
	Train vidpadders
	Set fish selection criteria and modify if needed
Collection	Confirm actual ping rates
	Confirm sample interval length
	Confirm number samples/hr
Processing	Vidpad data and compare results with original vidpad number
	Check number of fish in vidpad files compared to visual counts from sample echograms
	Remove errors from output files
	Provide regular feedback to vidpadders
Analysis	Select data based on range and echo criteria
	Check ½ power beam widths in INIT files
	Check number of sample intervals and sample time in INIT file
	Check time weighting from GR98
	Check spatial weighting from GR98
	Check variances from GR98
	Check extrapolation widths in INIT file
	Cross-check HA run timing with SMP index
	Cross-check HA daily estimates with SMP index
	Cross-check HA passage rate estimates with previous work
	Cross-check HA passage rates among locations
	Cross-check HA data with radio telemetry data
	Cross-check diel distributions with previous data

Appendix B

Daily Plots, ANOVA Tables, and Bivariate Plots

Appendix B: Daily Plots, ANOVA Tables, and Bivariate Plots

Appendix B contains daily plots of spill efficiency and effectiveness, SBC efficiency, SBC and powerhouse passage, SBC entrance efficiency, and SBC effectiveness. Experimental blocks are numbered and delineated. Summary ANOVA tables, and bivariate plots are also presented.

B.1 Daily Plots

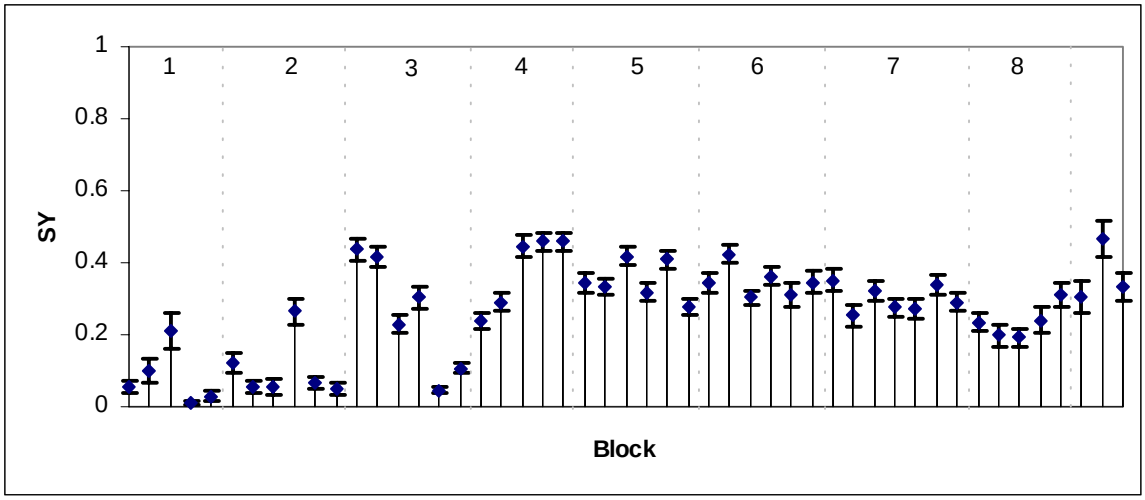


Figure B.1. Daily spill efficiency (SY) from April 13 to May 31, 1998, not including passage into the SBC.

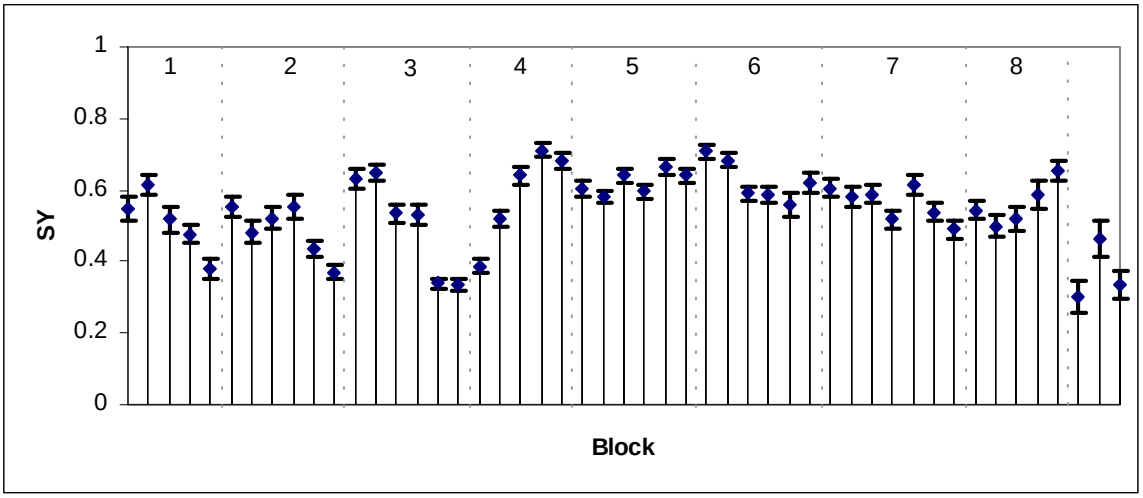


Figure B.2. Daily spill efficiency (SY) from April 13 to May 31, 1998, including passage into the SBC.

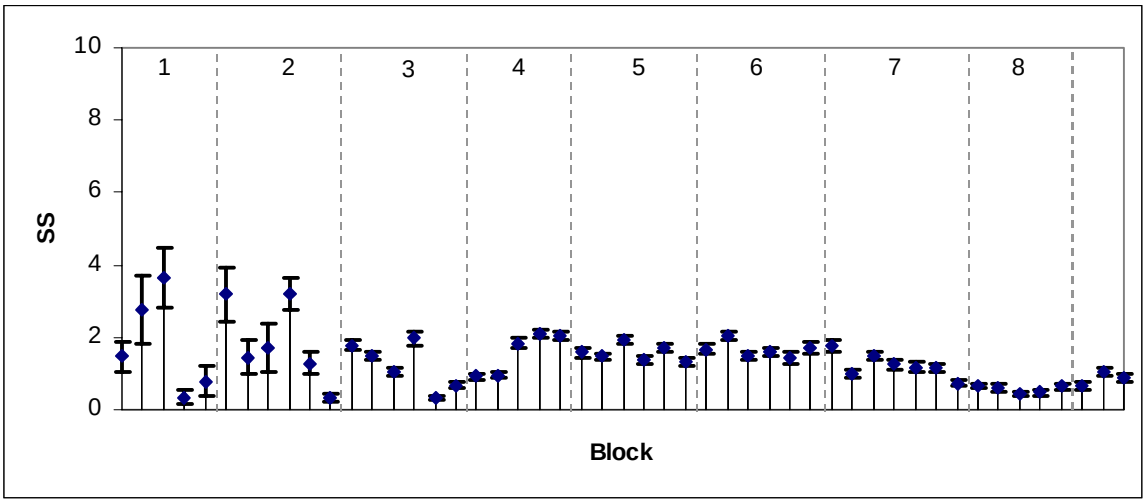


Figure B.3. Daily spill effectiveness (SS) from April 13 to May 31, 1998, not including passage into the SBC.

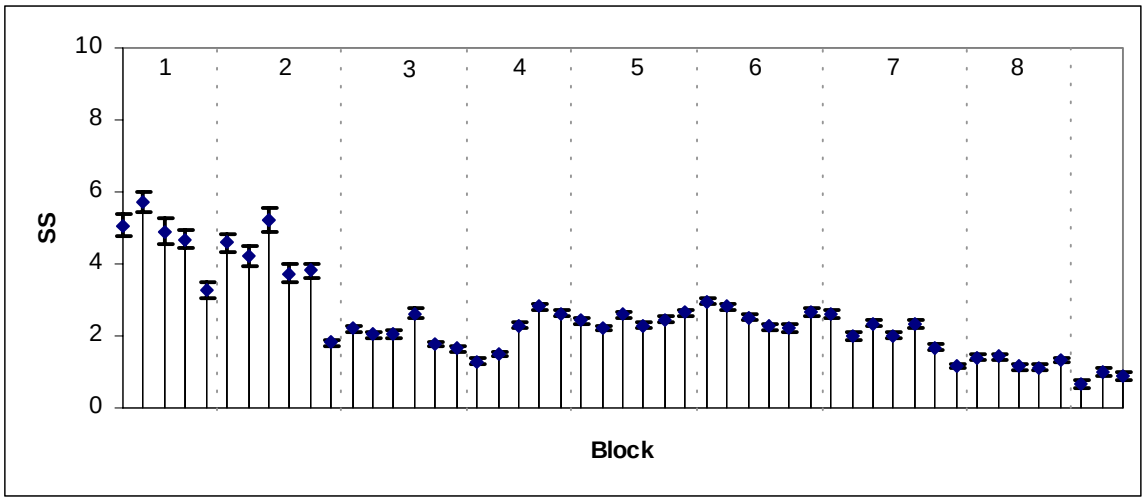


Figure B.4. Daily spill effectiveness (SS) from April 13 to May 31, 1998, including passage into the SBC.

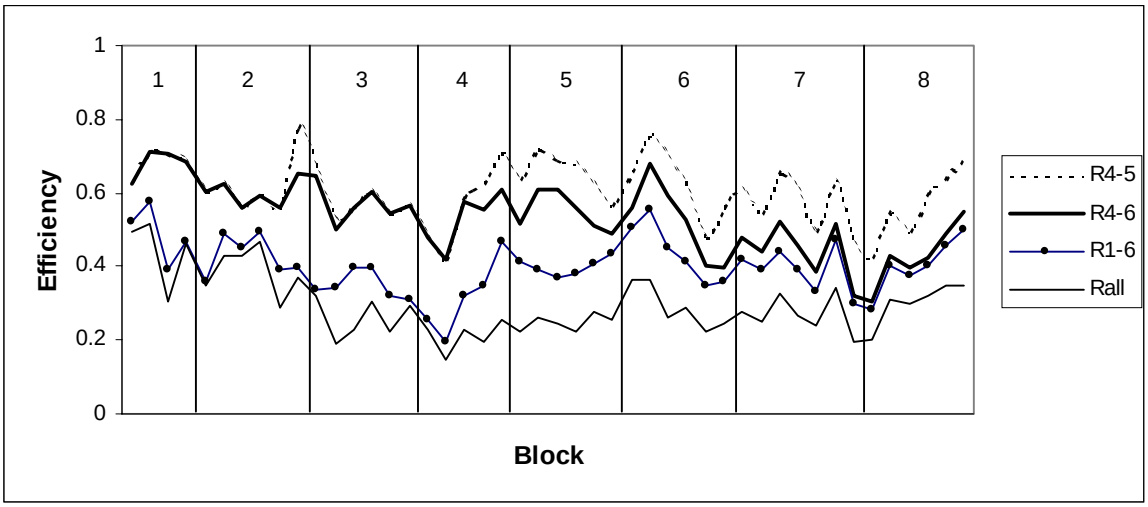


Figure B.5. Daily SBC efficiency (R) metrics from April 13 to May 31, 1998. See Table 3.5 for definitions of R-values.

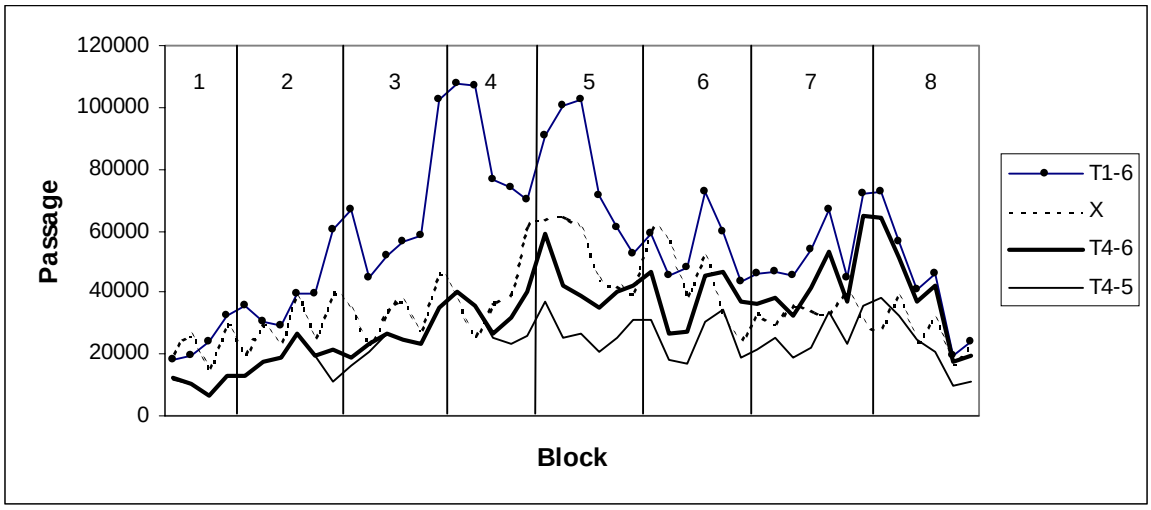


Figure B.6. Daily total fish passage for the SBC (X) and Turbines 1-6 (T1-6), Turbines 4-6 (T4-6), and Turbines 4-5 (T4-5) from April 13 to May 31, 1998.

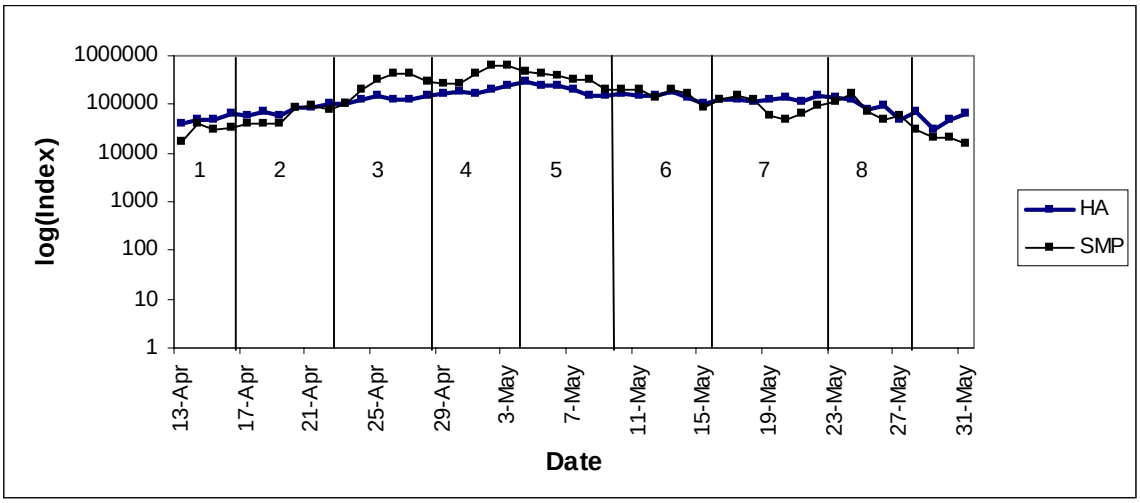


Figure B.7. Log plot of the HA and SMP run timing indices for spring 1998 at LGR.

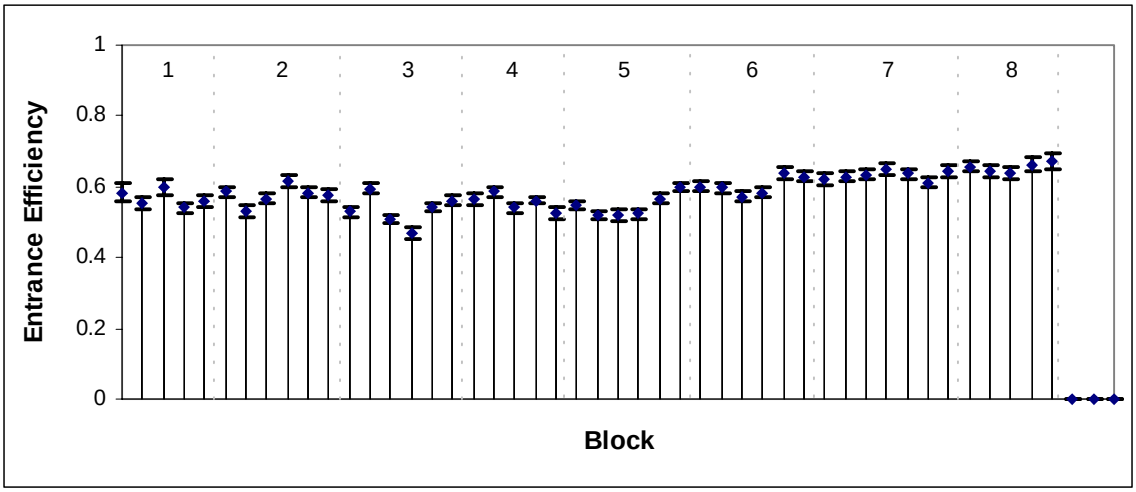


Figure B.8. Daily SBC entrance efficiency (N) from April 13 to May 31, 1998.

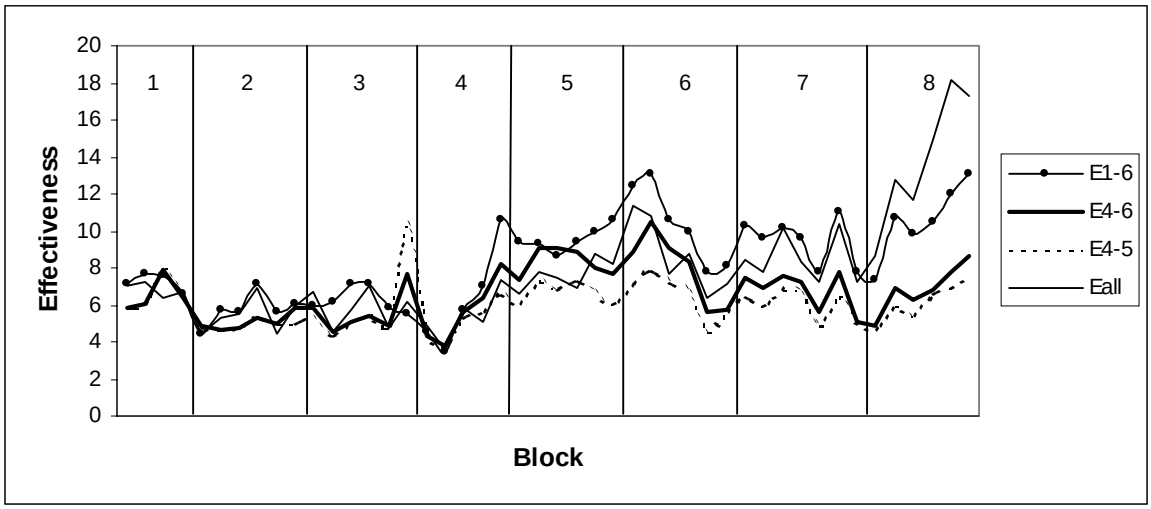


Figure B.9. Daily SBC effectiveness (E) metrics from April 13 to May 31, 1998.

B.2 Anova Tables

Table B.1. Analysis of Variance for R1-6 during the day only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.2639			
Whole Plots					
Blocks	7	0.1337	0.0191	2.3167	0.1450
BGS	1	0.0000	0.0000	0.0007	0.9796
Error	7	0.0577	0.0082		
Subplots					
Configuration	1	0.0091	0.0091	2.0123	0.1779
Configuration x BGS	1	0.0000	0.0000	0.0000	0.9975
Error	14	0.0634	0.0091		
Configuration x Block	(7)	(0.0537)	(0.0077)		
Config x Block x BGS	(7)	(0.0097)	(0.0014)		

Table B.2. Analysis of Variance for FGE1-6 during the day only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.3468			
Whole Plots					
Blocks	7	0.2238	0.0320	3.9574	0.0450
BGS	1	0.0002	0.0002	0.0281	0.8716
Error	7	0.0565	0.0081		
Subplots					
Configuration	1	0.0040	0.0040	1.0078	0.3325
Configuration x BGS	1	0.0068	0.0068	1.7083	0.2123
Error	14	0.0555	0.0079		
Configuration x Block	(7)	(0.0484)	(0.0069)		
Config x Block x BGS	(7)	(0.0071)	(0.0010)		

Table B.3. Analysis of Variance for SY during the day only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.8305			
Whole Plots					
Blocks	7	0.6123	0.0875	4.6969	0.0293
BGS	1	0.0152	0.0152	0.8175	0.3960
Error	7	0.1304	0.0186		
Subplots					
Configuration	1	0.0117	0.0117	2.7573	0.1190
Configuration x BGS	1	0.0013	0.0013	0.2942	0.5961
Error	14	0.0596	0.0085		
Configuration x Block	(7)	(0.0443)	(0.0063)		
Config x Block x BGS	(7)	(0.0153)	(0.0022)		

Table B.4. Analysis of Variance for FPE during the day only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.0460			
Whole Plots					
Blocks	7	0.0345	0.0049	11.7744	0.0021
BGS	1	0.0004	0.0004	0.9504	0.3621
Error	7	0.0029	0.0004		
Subplots					
Configuration	1	0.0015	0.0015	3.7245	0.0741
Configuration x BGS	1	0.0009	0.0009	2.2740	0.1538
Error	14	0.0058	0.0009		
Configuration x Block	(7)	(0.0047)	(0.0007)		
Config x Block x BGS	(7)	(0.0011)	(0.0002)		

Table B.5. Analysis of Variance for R1-6 during the night only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.2599			
Whole Plots					
Blocks	7	0.0832	0.0119	1.1647	0.4229
BGS	1	0.0485	0.0485	4.7580	0.0655
Error	7	0.0714	0.0102		
Subplots					
Configuration	1	0.0000	0.0000	0.0006	0.9802
Configuration x BGS	1	0.0032	0.0032	0.8466	0.3731
Error	14	0.0536	0.0076		
Configuration x Block	(7)	(0.0281)	(0.0040)		
Config x Block x BGS	(7)	(0.0255)	(0.0036)		

Table B.6. Analysis of Variance for FGE1-6 during the night only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.3651			
Whole Plots					
Blocks	7	0.1575	0.0225	1.5821	0.2799
BGS	1	0.0377	0.0377	2.6493	0.1476
Error	7	0.0996	0.0142		
Subplots					
Configuration	1	0.0107	0.0107	2.8888	0.1113
Configuration x BGS	1	0.0076	0.0076	2.0323	0.1759
Error	14	0.0520	0.0074		
Configuration x Block	(7)	(0.0230)	(0.0033)		
Config x Block x BGS	(7)	(0.0290)	(0.0041)		

Table B.7. Analysis of Variance for SY during the night only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.5165			
Whole Plots					
Blocks	7	0.3373	0.0482	5.9402	0.0157
BGS	1	0.0144	0.0144	1.7698	0.2251
Error	7	0.0568	0.0081		
Subplots					
Configuration	1	0.0036	0.0036	0.4882	0.4962
Configuration x BGS	1	0.0001	0.0001	0.0127	0.9120
Error	14	0.1043	0.0149		
Configuration x Block	(7)	(0.0729)	(0.0104)		
Config x Block x BGS	(7)	(0.0314)	(0.0045)		

Table B.8. Analysis of Variance for FPE during the night only.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.1545			
Whole Plots					
Blocks	7	0.0945	0.0135	8.2149	0.0063
BGS	1	0.0186	0.0186	11.2960	0.0121
Error	7	0.0115	0.0016		
Subplots					
Configuration	1	0.0021	0.0021	1.1050	0.3110
Configuration x BGS	1	0.0015	0.0015	0.7952	0.3876
Error	14	0.0263	0.0037		
Configuration x Block	(7)	(0.0094)	(0.0013)		
Config x Block x BGS	(7)	(0.0169)	(0.0024)		

Table B.9. Analysis of Variance for R1-6 day and night

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.2104			
Whole Plots					
Blocks	7	0.0828	0.0118	1.0860	0.4581
BGS	1	0.0225	0.0225	2.0689	0.1935
Error	7	0.0762	0.0109		
Subplots					
Configuration	1	0.0023	0.0023	1.3046	0.2725
Configuration x BGS	1	0.0015	0.0015	0.8527	0.3714
Error	14	0.0251	0.0035		
Configuration x Block	(7)	(0.0108)	(0.0015)		
Config x Block x BGS	(7)	(0.0143)	(0.0020)		

Table B.10. Analysis of Variance for FGE1-6 day and night.

Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.2667			
Whole Plots					
Blocks	7	0.1597	0.0228	2.5753	0.1176
BGS	1	0.0096	0.0096	1.0846	0.3323
Error	7	0.0620	0.0089		
Subplots					
Configuration	1	0.0087	0.0087	4.5870	0.0503
Configuration x BGS	1	0.0000	0.0000	0.0074	0.9328
Error	14	0.0267	0.0039		
Configuration x Block	(7)	(0.0095)	(0.0014)		
Config x Block x BGS	(7)	(0.0172)	(0.0025)		

Table B.11. Analysis of Variance for SY day and night.

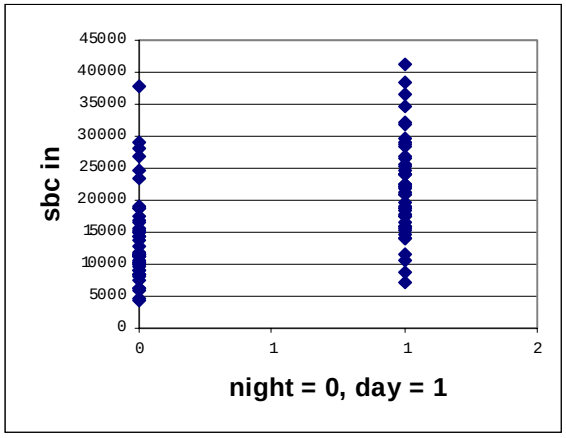
Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.6234			
Whole Plots					
Blocks	7	0.4676	0.0668	5.1854	0.0227
BGS	1	0.0182	0.0182	1.4159	0.2729
Error	7	0.0902	0.0129		
Subplots					
Configuration	1	0.0018	0.0018	0.5537	0.4691
Configuration x BGS	1	0.0011	0.0011	0.3523	0.5623
Error	14	0.0445	0.0064		
Configuration x Block	(7)	(0.0349)	(0.0050)		
Config x Block x BGS	(7)	(0.0096)	(0.0014)		

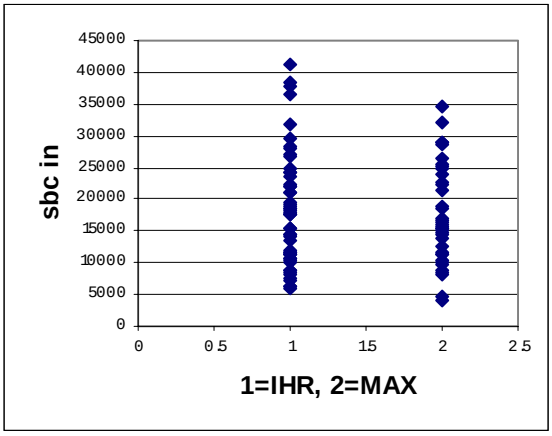
Table B.12. Analysis of Variance for FPE day and night.

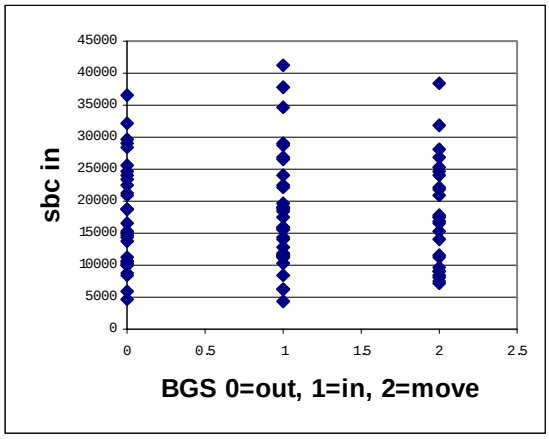
Source	df	Sum of squares	Mean Squares	F	P
Total corrected	31	0.0709			
Whole Plots					
Blocks	7	0.0503	0.0072	9.2784	0.0044
BGS	1	0.0061	0.0061	7.9169	0.0260
Error	7	0.0054	0.0008		
Subplots					
Configuration	1	0.0023	0.0023	4.7948	0.0460
Configuration x BGS	1	0.0000	0.0000	0.0235	0.8804
Error	14	0.0068	0.0009		
Configuration x Block	(7)	(0.0031)	(0.0004)		
Config x Block x BGS	(7)	(0.0037)	(0.0005)		

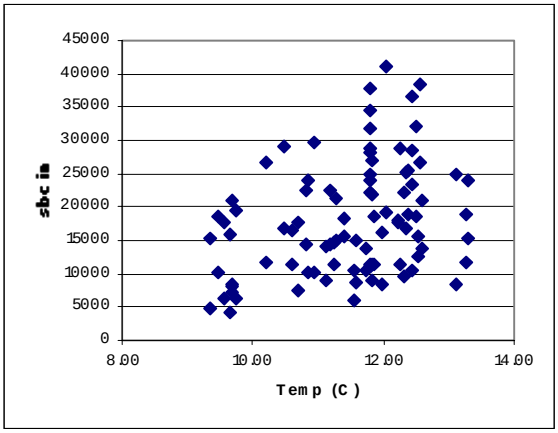
B.3 Bivariate Plots

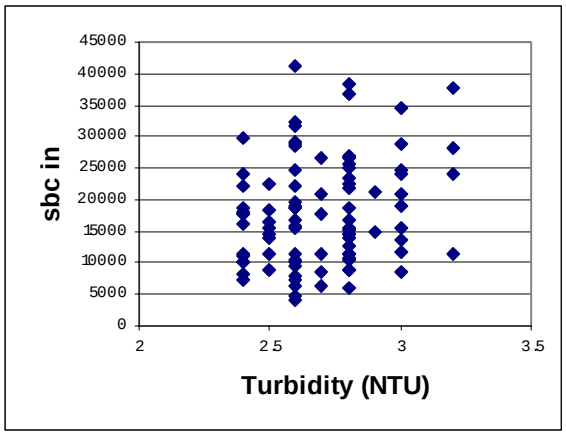
Bivariate plots are presented for three dependent variables: passage into the SBC (sbc in), passage into Turbines 4-6 (T4-6), and SBC efficiency ($R_{4\text{-}6}$). Each of these variables is plotted with the independent variables day/night, BGS in/out, SBC configuration, temperature, turbidity, percent SBC flow, percent spill, and lunar phase.

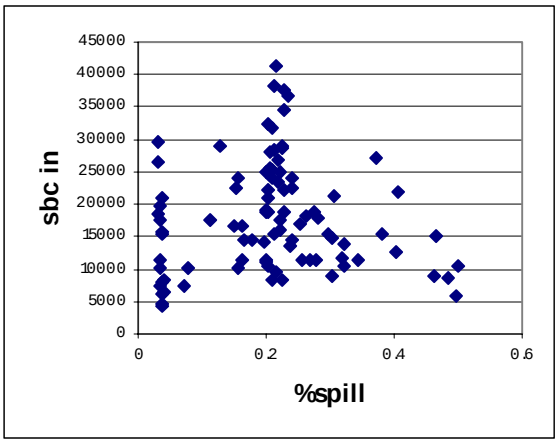


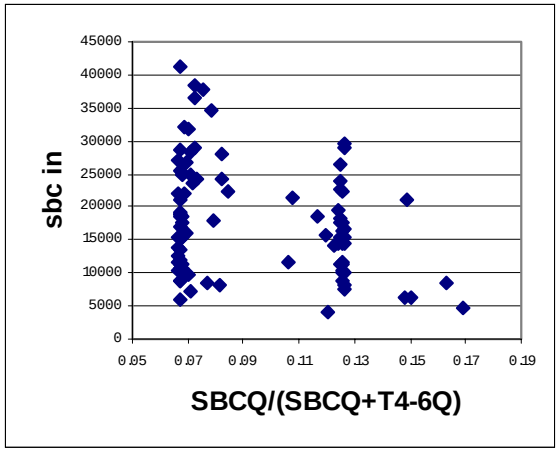


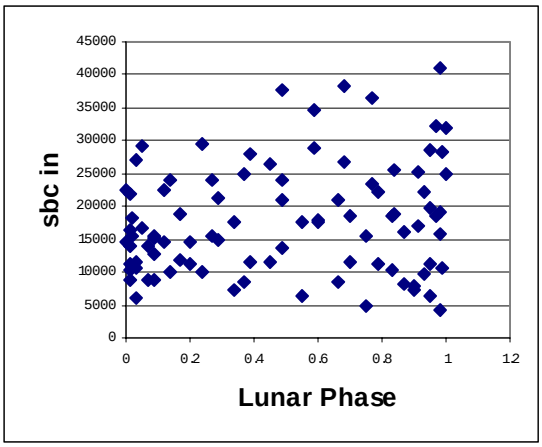


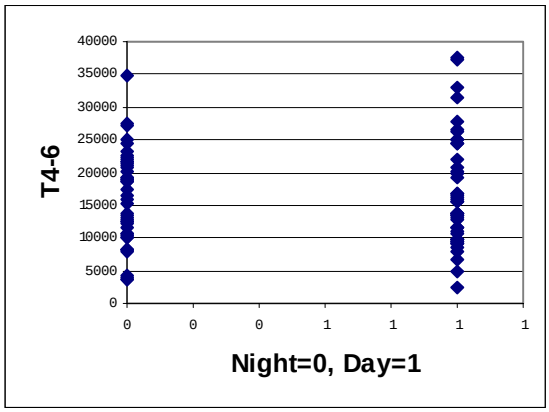


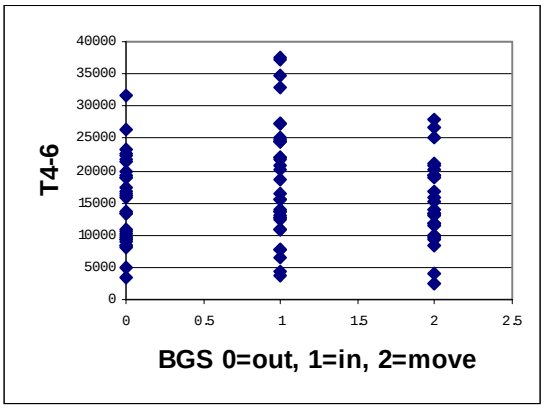

sbc in
Turbidity (NTU)

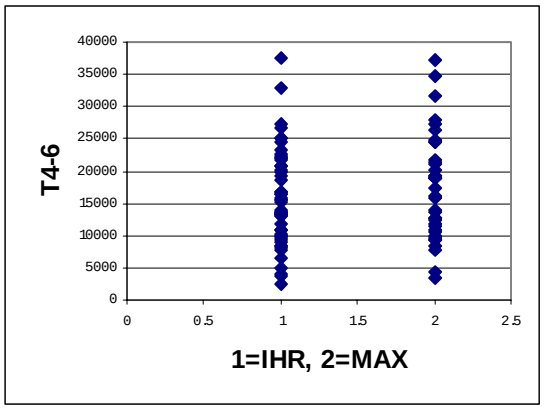

sbc in
%spill

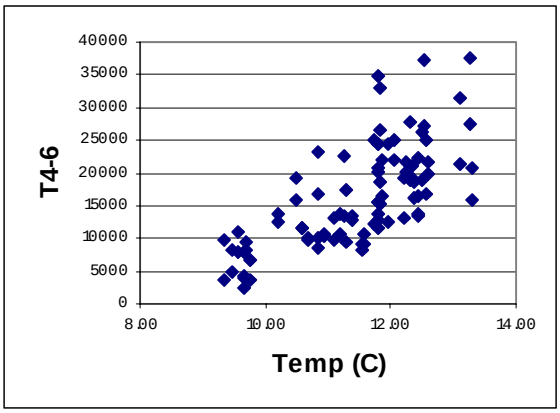

sbc in
SBCQ/(SBCQ+T4-6Q)

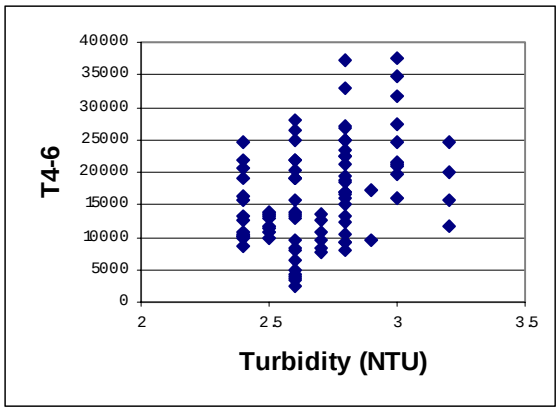

sbc in
Lunar Phase

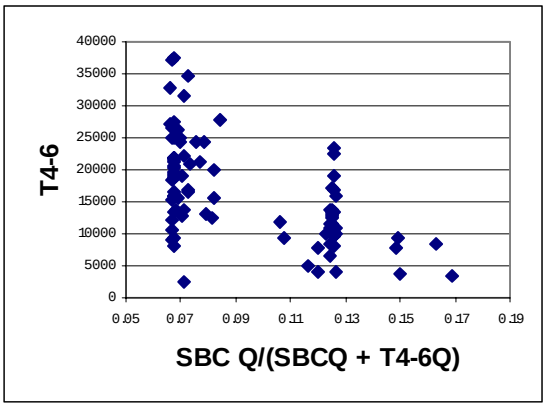

T4-6
Night=0, Day=1

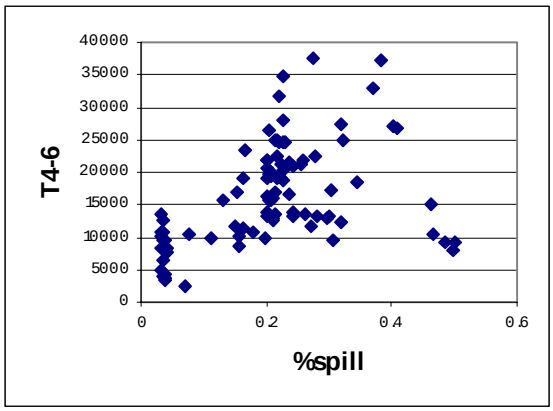

T4-6
BGS 0=out, 1=in, 2=move

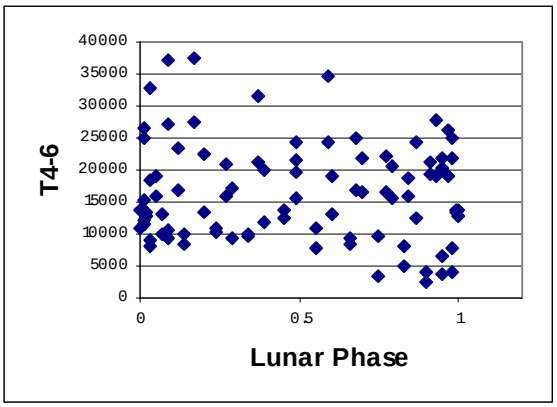

T4-6
1=IHR, 2=MAX

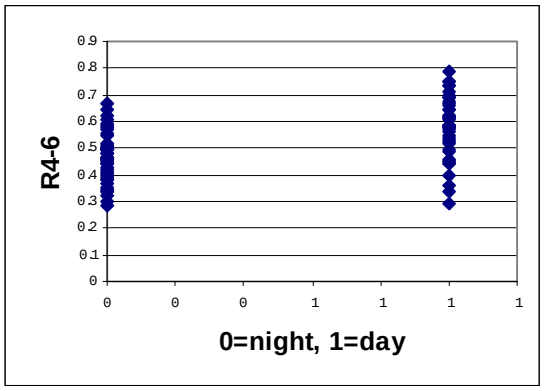

T4-6
Temp (C)

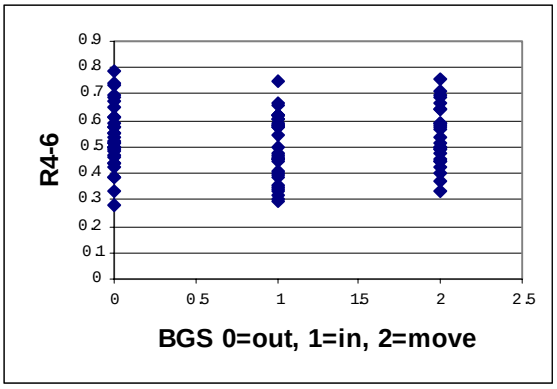

T4-6
Turbidity (NTU)

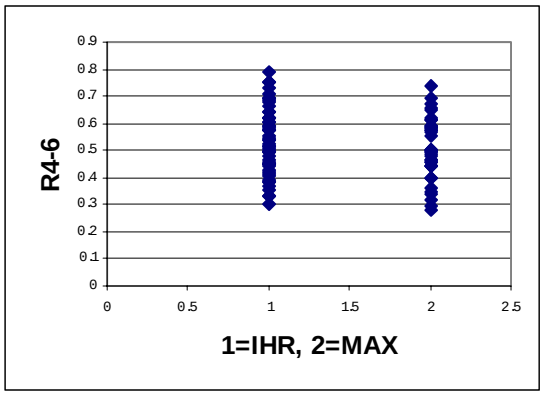

T4-6
SBC Q/(SBCQ + T4-6Q)

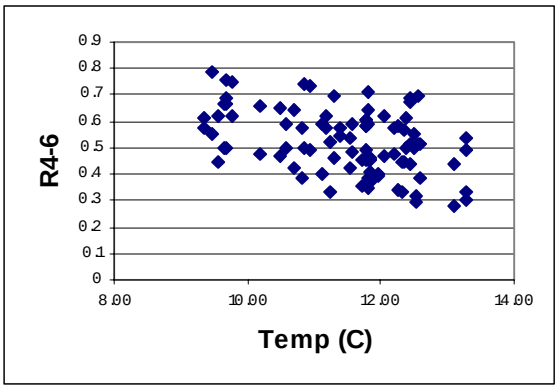

T4-6
%spill

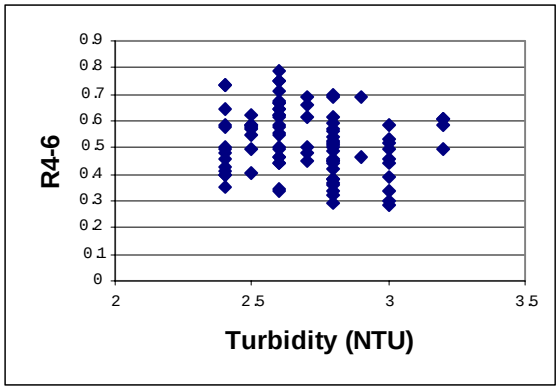

T4-6
Lunar Phase

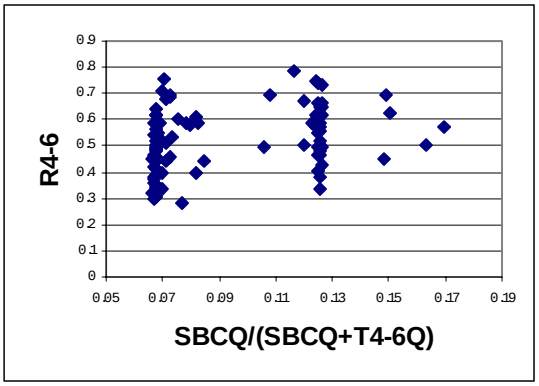

R4-6
0=night, 1=day

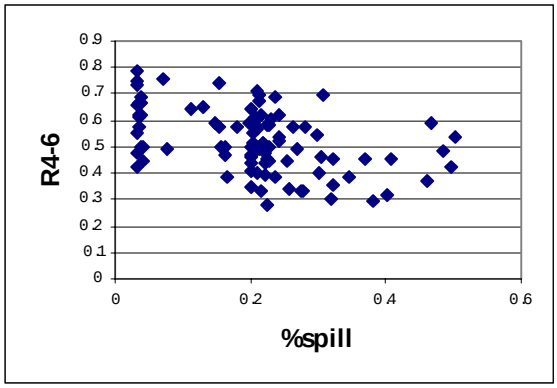

R4-6
BGS 0=out, 1=in, 2=move

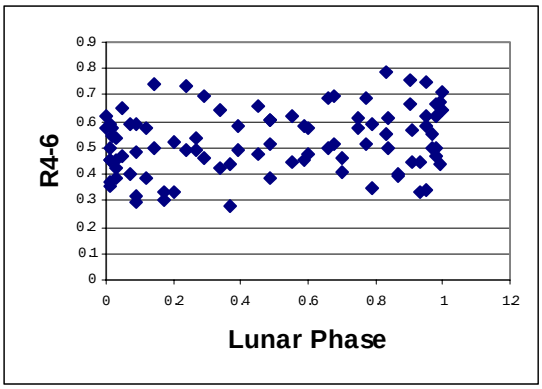

R4-6
1=IHR, 2=MAX


R4-6
Temp (C)


R4-6
Turbidity (NTU)


R4-6
SBCQ/(SBCQ+T4-6Q)


R4-6
%spill


R4-6
Lunar Phase

Appendix C

Multi-Beam and Split-Beam Quality Control

Appendix C: Multi-Beam and Split-Beam Quality Control

C.1 Multi-Beam Data Quality Analysis

To determine the quality of the multi-beam data, a two-part quality analysis procedure was implemented after the 1998 data collection period. An "internal" examination checked for consistent track selection by each technician. Files processed by each technician were selected and reprocessed by the original processing technician. The number of tracks selected in the original processing was compared to the number selected during reprocessing. An "external" examination checked for consistent track selection between pairs of technicians and between a technician and the group mean. The number of tracks selected by one technician was compared to the number of tracks selected by each of the other five technicians and to the mean number of tracks selected by all six technicians.

The criterion for acceptable data selection by a technician for large files (☛ 25 tracks on average) was set at a difference of within 20% of the mean; for small files (< 25 tracks on average), a difference of 5 tracks or less. Overall, the quality analysis procedure demonstrated consistent track selection between technicians and the group mean. However, it also showed a dichotomy in track selection by the technicians. The six technicians can be divided into two distinct groups of three according to how many targets they selected for each file. Group 1 technicians met acceptance criteria with themselves at a higher percent than did Group 2 technicians. However, Group 2 technicians were closer to the group mean than were Group 1 (Table C.1).

Table C.1. Technician performance results compared to self, group average, and individual technicians.

Technician	% Meets Acceptance Criteria with Self	%Meets Acceptance Criteria with Group Average	% Compliant with Tech.2	% Compliant with Tech.3	% Compliant with Tech.4	% Compliant with Tech.5	% Compliant with Tech.6
1	66.7	73.9	64.4	62.7	80.4	87.2	46.7
2	50.0	86.7		73.3	53.3	54.5	76.9
3	100.0	78.3			50.0	56.4	80.0
4	71.4	80.4				79.5	42.2
5	100.0	76.9					59.0
6	60.0	79.5					
Group 1:	Technicians 1,4,5	77.1					
Group 2:	Technicians 2,3,6	81.5					

The mean number of tracks selected compared to the tracks selected by individual technicians is shown in Figure C.1. The two groups' data are highlighted. Group 1 technicians consistently selected more targets per file than Group 2.

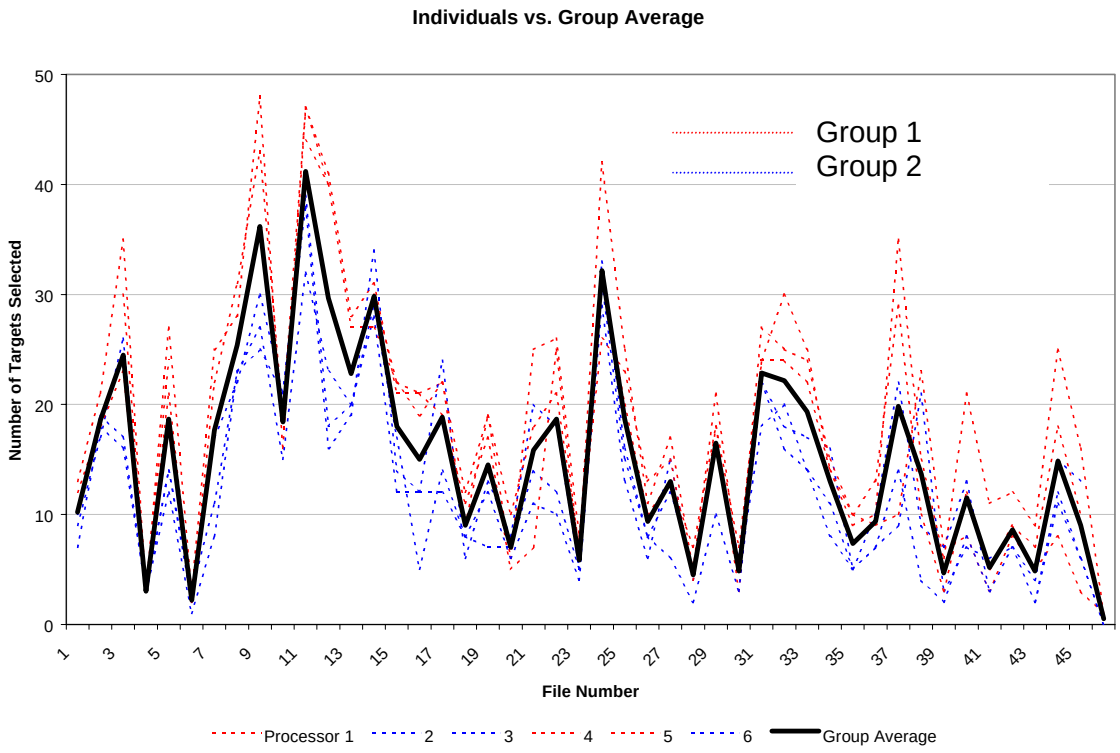


Figure C.1. Number of targets selected by individual technicians vs. mean number of targets selected by the group of six technicians.

C.2 Split-Beam Data Quality Control

To ensure the quality of split-beam hydroacoustic data, a two-part quality control procedure was implemented during the 1998 data collection period (Table C.2). "Internal" quality control checked for consistent trace selection by each of the two processing technicians. "External" quality control checked for consistent trace selection between the two technicians. On a weekly basis, files processed by each technician were randomly selected and reprocessed by either the original technician (internal) or the other technician (external). The number of traces selected in the original processing was compared to the number selected during (Table C.3).

Criteria for meeting quality control for large files (>=25 average traces) was set at a difference of within 20% of the mean; for small files (<25 average traces), a difference of 5 traces or less. Discrepancies in trace selection for both internal and external quality control were evaluated, and appropriate changes in selection criteria were made as needed. A benefit of in-season quality control

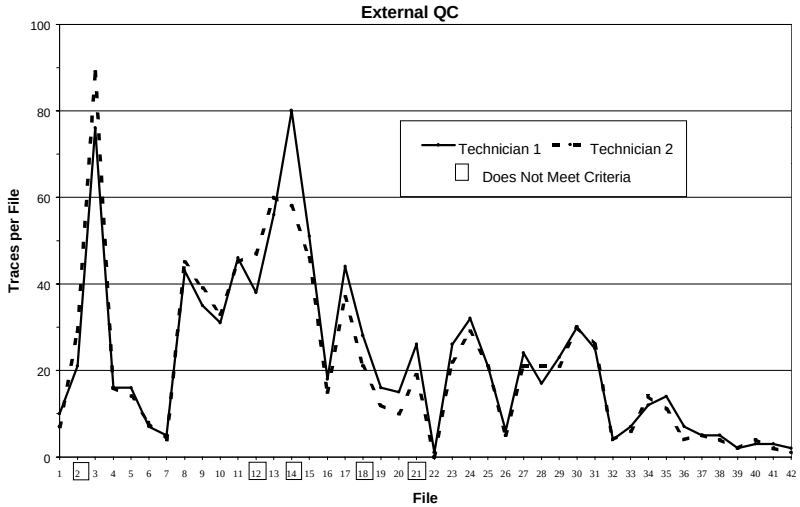
evaluation was the ability to modify trace selection criteria and each technician's effort as data were collected and processed. Overall, the procedure demonstrated consistent trace selection, both internally and externally (Figure C.2).

Table C.2. Summary of quality control effort for 1998 split-beam hydroacoustic data.

	Internal		External
	Technician 1	Technician 2	Total
Number of Files Processed	901	172	1073
Number QC'd	28	6	42
Percent QC'd	3.11	3.49	3.91

Table C.3. Results of quality control effort for 1998 split-beam hydroacoustic data.

	Small Files (<25)		Large Files (>=25)		Combined		
	Number Meet	Number Fail	Number Meet	Number Fail	Number Meet	Number Fail	Percent Meet Criteria
Internal-T1	16	0	8	4	24	4	85.71
Internal-T2	3	0	3	0	6	0	100.00
External	26	2	11	3	37	5	88.10



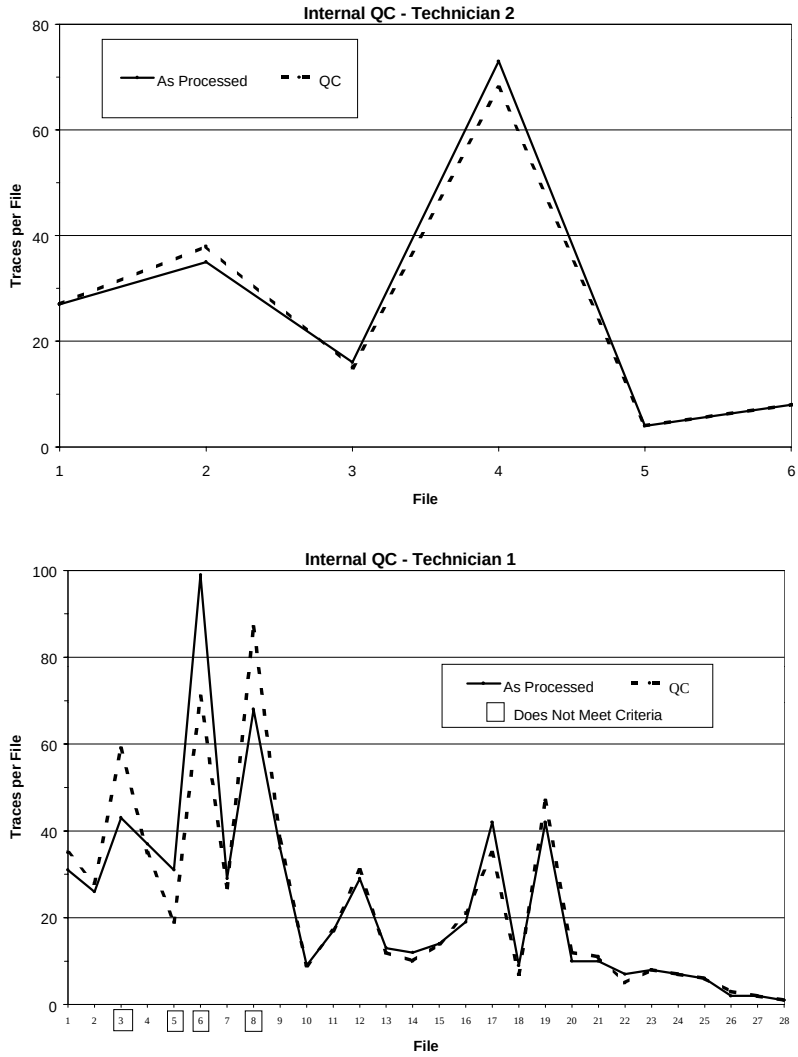


Figure C.2. Quality control comparison for internal and external evaluations showing the number of traces selected in original and reprocessed files.