ADCP Velocity Profiling and Feasibility Hydroacoustics at Grand Coulee Dam in 2000

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Abstract

Acoustic Doppler current profiler (ADCP) transects were performed in the forebay of Grand Coulee Dam to determine the water velocities approaching the 'cul-de-sac' near the third powerhouse during the spring of 2000. Velocity data were needed to determine whether the site selection for a behavioral deterrent system intended to decrease entrainment of kokanee and rainbow trout would be appropriate. ADCP water velocity data were collected during late afternoon and early morning periods on 12 dates between May 4 and June 29, 2000. A feasibility multibeam hydroacoustics survey was conducted on June 28 and 29, 2000. Water velocities across the entrance to the 'cul-de-sac' near the third powerhouse were influenced by project discharge. Not surprisingly, higher discharges resulted in higher velocities in the forebay. Water velocities typically were less than 1.0 m/s across the 'cul-de-sac' opening. Higher velocities were associated with an eddy/shear zone adjacent to the apex between the right and third powerhouses. The highest velocities (> 2.0 m/s) were in excess of what juvenile salmonids would be expected to maintain position in, however, even during high discharge periods, there were points along the 'cul-de-sac' opening where water velocities were lower. A computer animation of various aspects of the ADCP data is given on a CD included with this report and is linked within the electronic version of the report. Multibeam hydroacoustics equipment was capable of detecting fish in the forebay environment of Grand Coulee Dam. Fish were detected within close proximity of the trash racks on turbine intakes 19 and 23 on the third powerhouse. Fish position and movement data in those areas indicated fish were capable of swimming toward and away from the intakes without being entrained.

Introduction

Background

The draft subbasin summary for Lake Roosevelt identifies hydro-operations as the most significant limiting factor to fish populations in that system (Underwood 2000). LeCaire (1999) reported that a substantial amount of fish entrainment occurs through Grand Coulee Dam. LeCaire (1999) found that the majority of the fish that are entrained through Grand Coulee Dam pass through the third powerhouse. Underwood (2000) stated that the entrainment of kokanee and rainbow trout through Grand Coulee Dam severely limits the fishery in Lake Roosevelt.

To address the entrainment problem, fish managers (Colville Tribe, Spokane Tribe, and the Washington Department of Fish and Wildlife) and U.S. Bureau of Reclamation researchers have proposed the use of a behavioral deterrent system to reduce entrainment through the third powerhouse. A large strobe light system has been selected as the preferred alternative to be tested as a behavioral deterrent to reduce the passage of kokanee and rainbow trout into the 'cul-de-sac' area of the forebay which leads into the third powerhouse. The strobe system was selected for testing due to recent successes in using strobe light systems to alter fish movement and distribution (Johnson et al. 2000; Maiolie et al. unpublished report). Pacific Northwest National Laboratory (PNNL) measured the water velocities across the entrance to the 'cul-de-sac' to facilitate the design of the deterrent system and to reduce uncertainties about the hydraulic characteristics of the area where the system would be deployed.

In conjunction with the Colville Confederated Tribe's Fisheries program, the fisheries and hydroacoustic staff in the Ecology Group at Pacific Northwest National Laboratory (PNNL) in Richland, used an Acoustic Doppler Current Profiler (ADCP) to collect velocity data required to evaluate the efficacy of a behavioral deterrent system that would preclude fish from entrainment through the third powerhouse at Grand Coulee Dam. In addition, PNNL worked with Colville Tribe staff to develop an experimental design for evaluating the effects of strobe lights on the behavior of kokanee and rainbow trout in the forebay of Grand Coulee Dam. Further, PNNL provided training to two Colville Tribe staff members in the deployment and operation of split-beam and multibeam hydroacoustics and 3D sonic tracking (this activity is not detailed in this report). Finally, PNNL staff deployed a mobile multibeam hydroacoustics system in the 'cul-de-sac' adjacent to the third powerhouse to determine whether the equipment would be capable of detecting fish in the 'near-dam' environment (to examine the acoustic environment for sources of possible interference). Additional information on fish distribution and behavior were also collected as a part of that effort. The objectives of PNNL activities on this project in 2000 were to:

- Train Colville Fisheries staff in hydroacoustics use/data processing.
- Characterize hydraulic conditions in the entrance to the 'cul-de-sac' near the third powerhouse at Grand Coulee Dam .

- Test the feasibility of using multibeam hydroacoustics in the Grand Coulee Dam forebay.

Velocity and hydroacoustics data will be summarized in this report and will be supported by 3D graphical animations provided on a CD. In addition, complete data files from the ADCP and hydroacoustics surveys will be provided on the CD.

Methods

ADCP Surveys

We used an RD Instruments Broadband ADCP (model BB-DR-600), using a frequency of 600 kHz. The ADCP records depth from the surface at which data were collected, so each velocity reading is associated with an XY coordinate and a depth (Z). Velocity readings for each given transect were averaged at depth bands representing 0.2, 0.4, 0.6, and 0.8 of the total depth, however all data collected is included in Appendix A on the associated CD. The azimuth of the velocity vector for each reading by the ADCP was determined using the internal compass aboard the ADCP. After the data were downloaded from the ADCP their azimuths were corrected for the local magnetic declination (19.5° determined from the USGS 7.5' Grand Coulee Dam Quadrangle).

The ADCP settings used are listed below:

Depth of sensor (below surface): 30 cm for Seastar; 60 cm for Colville Tribe boat
Compass correction: 0°
Magnetic variation: 0° (this was accounted for by correcting azimuth data for 19.5^o declination after download)

Firmware: 5.50	Beam Angle: 20°	Frequency: 600 kHz
Orientation: Down	Pattern: Convex	Depth cell length: 0.5 m
Mode: 4	No. of cells: 100	Pings/cell: 5 water:5 bottom
Sound Adsorption: 0.084 dB/m		Intensity scaling factor: 0.43 dB/cfs
Salinity: 0.00 ppm		

The ADCP data were collected on transects across the entrance to the 'cul-de-sac' (Figure 1) and were located in real world coordinates using a Trimble Pathfinder™ Pro XR global positioning system (GPS). The GPS was located on board the survey vessel with the ADCP and continually collected real time differentially corrected data every 3 seconds. These data, collected at sub meter accuracy (~0.5 m), were viewed concurrently during data collection using Trimble Aspen software. The software allowed for previously defined waypoints to be displayed on the screen while collecting position data, thus we were able to reproduce the boat track of a given transect at a later time under different operating conditions or forebay stages. The ADCP clock is adjustable and was synchronized with the GPS clock manually by ensuring clocks were synchronized before initiating data collection simultaneously on both devices. Both the GPS and the ADCP data outputs were time-stamped, thus ADCP velocity data were correlated with horizontal GPS position using time.

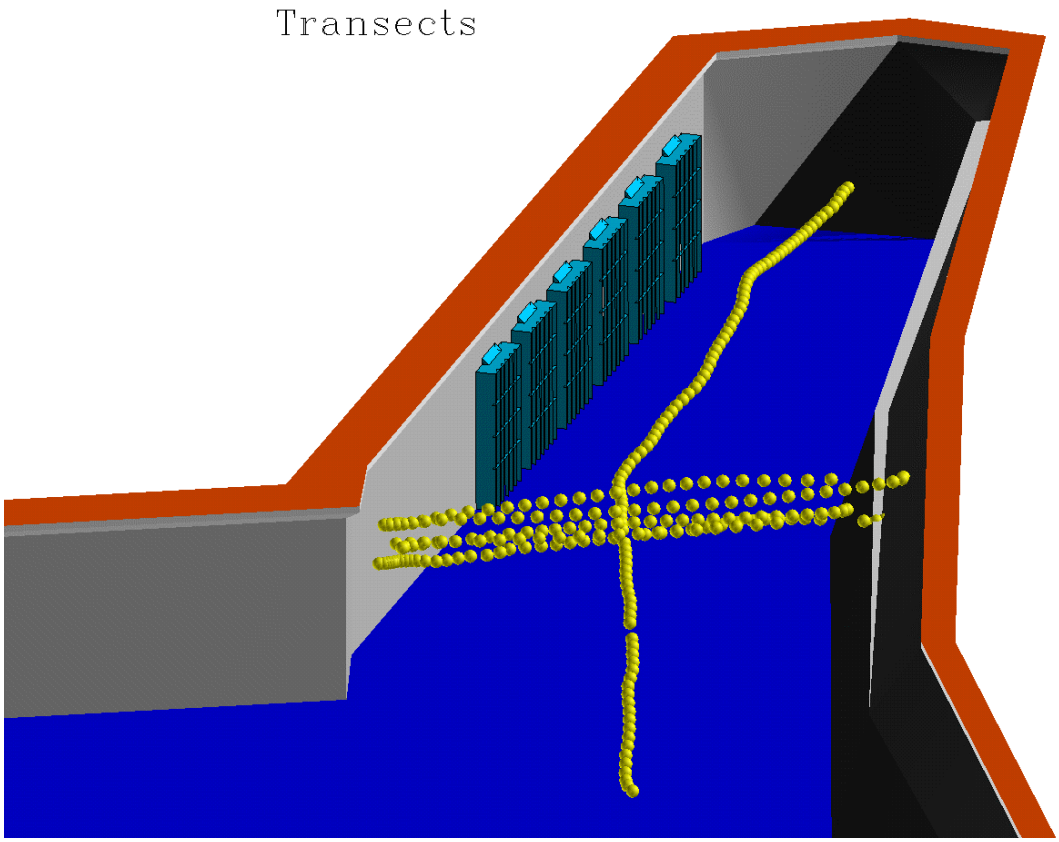

Figure 1. Diagram of transect locations for the collection of ADCP water velocity data in the forebay of Grand Coulee Dam in May and June, 2000. The dam is located on the left side of the figure, and the trash racks for turbine intakes on units 19-24 on the third powerhouse are shown.

Several software packages were used in the production of ADCP data animation and associated still figures to create the final product. Raw ADCP data was processed in a database application and exported to a visualization package. Images and animation sequences were generated using the visualization software and the movie was created using digital video editing and sequencing software.

The raw ADCP data set, consisting of coordinates and velocity components for each measurement location, was first loaded into a Microsoft Access97 application designed by PNNL for managing three-dimensional vector field data. The application has data processing capabilities for transforming and reselecting data sets. The Grand Coulee data sets were processed to obtain vertically averaged velocities at 5-meter intervals, making visualization of the large ADCP data sets more meaningful. The processed data sets were then exported into a format acceptable to the data visualization software.

Data visualization was performed using the FieldView package from Intelligent Light, running on a Silicon Graphics platform. To place the ADCP data into context, Grand Coulee dam geometry files were built using satellite images and construction drawings. Scripts were written for FieldView to create sequences of images, which were output in tagged image file format (TIFF). A total of 4,959 individual TIFF frames were generated (15 frames/sec) to create the animation sequences.

Finally, the MainActor Sequencer package from MainConcept, was used to assemble the TIFF files into proper sequence as well as add titles and video effects, such as fading. The image sequence was exported into a movie file in Microsoft's Audio Video Interleave (AVI) format with Cinepak Radius compression.

Data analyses were concentrated on the transect data that were collected across the 'cul-de-sac' opening because that is the proposed location for the behavioral deterrent system.

Hydroacoustics

Deployment and Data Acquisition

The multibeam system used in this study was a SIMRAD SM2000 operating at 200 kHz with a sonar head including an array of 80 elements producing 128 beams over 120° (1.7° beams on 0.94° centers). The system was operated under software control from a Windows based interface loaded in an industrial PC surface unit. Sonar images were displayed in real time at resolutions of 800 x 600 pixels. Sonar transmission rates for the system are rated up to 20 pings per second over the entire array but we operated at a much slower rate (2-5 pings/s) due to the large coverage to conserve data storage space. Both profiled data (pre-processed with target selection parameters) and raw data were written to on-board Jaz media.

The sonar head was mounted on a pole mount attached to the bow of a small boat (17.5 feet) and aimed downward approximately 46°. The surface unit and other peripheral equipment was placed inside the boat cabin and powered by a gasoline driven generator.

Data was collected from moving transects, and from fixed stations located over turbine units 19 and 23. Tables 1 and 2 list the data collection event log entries during the sample period. The first day of the survey (June 28th) was devoted to exploration as noted in the data collection logs. We located significant numbers of targets in the vicinity of the 3rd powerhouse and decided to concentrate our efforts at units 19 and 23. On the second day, we ran regular transects and again devoted time to stationary locations at units 19 and 23. The transects and stationary locations are mapped in Figure 2.

Table 1. Hydroacoustics data collection log for June 28, 2000 at Grand Coulee Dam, Washington.

Start Time	Stop Time	File Name	Comments
1549	1550	GF281549	Stationary @ bottom end of 3rd PH forebay
1550	1600	GF281550	Slow transect upstream near rock wall (heading south)
1603	1608	GF281603	Slow transect downstream near rock wall (heading north). Entered debris and whirlpool at the narrow end of the forebay.
1609	1614	GF281609	Holding in narrow end of forebay. Lots of targets toward the end of the file but some may be debris
1620	1627	GF281620	Tied boat at BioSonics cable at Unit 19 with bow looking out approximately 90° from dam. We used a 10m range setting and saw lots of fish milling over the entrance.
1632	1641	GF281632	Tied boat to BioSonics rope at Unit 23 – as above we noted lots of targets milling over the unit entrance.
1647	1654	GF281647	Running up the ;middle of the 3rd PH forebay toward the south. Auto pinging at 3.21/s
1654	1701	GF281654	Range changed to 20m while transecting across PH2 to PH1.

Table 2. Hydroacoustics data collection log for June 29, 2000 at Grand Coulee Dam, Washington.

Start Time	Stop Time	File Name	Comments
0700	0711	GF290700	Transect 1 across face of PH1, spill, and PH2 (Range 30m, ping rate 2.04, gain=50)(#1). Stopped transect short of the rock wall due to a long rope in the path.
0715	0722	GF290715	Transect along rock wall (#2). Stopped at wall at north end of cul-de-sac.
0729	0734	GF290729	Stationary at Unit 23 (#5) (range 15m, ping rate 4.25, gain=50). Very few fish but lots of bubbles.
0736	0740	GF290736	Transect along 3rd PH (#3). Stopped @ corner of PH. Very few fish – no turbines operating.
0746	0755	GF290746	Stationary at Unit 19 (#4) (range 15m, ping rate 4.16, gain=50).
0757	0804	GF290757	Transect up the middle of the cul-de-sac (#6).
0807	0817	GF290807	Transect across front of PH2, spill, PH1 (#7). Stopped short of buoys due to noise.

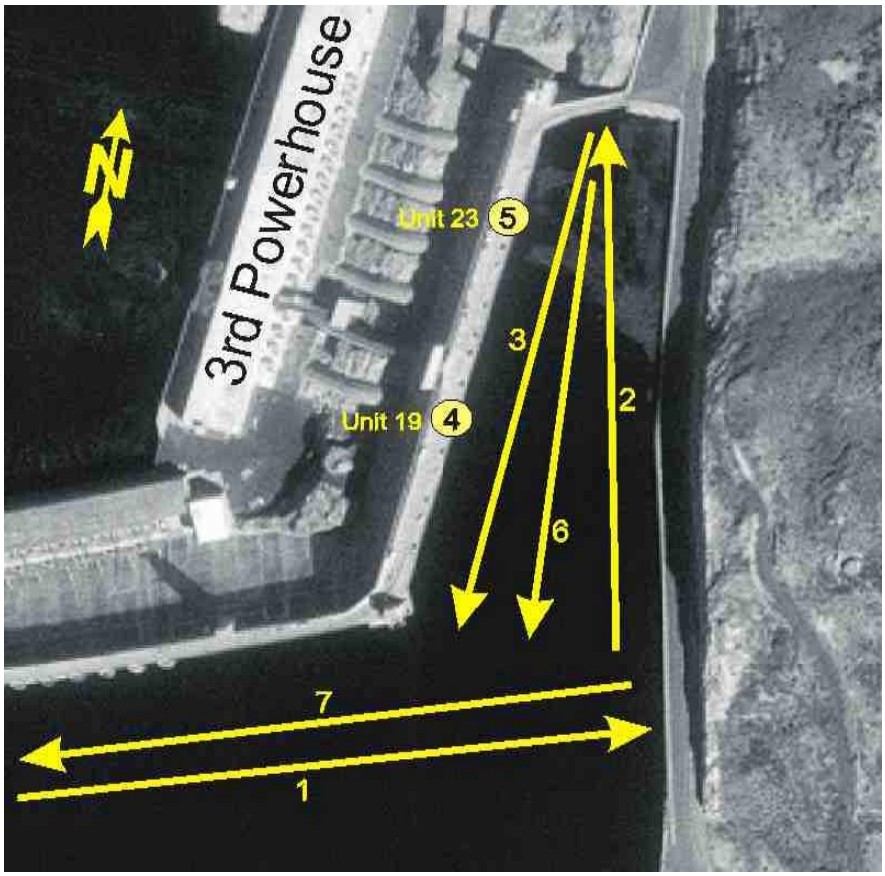

Figure 2. Approximate location of multibeam transects and stations in the forebay of Grand Coulee Dam, Third Powerhouse, June 29, 2000.

Data Processing and Analysis

Since the dataset was small for this feasibility test, we chose to process the data manually from the raw data records using the playback features of the sonar. The playback features of the sonar operate similar to a tape recorder allowing the user to start, stop, and pause the data stream. Each raw data file was played back to display fish tracks, then paused periodically to record the location of each target on the display. The location of a target was recorded relative to the transducer location (range and azimuth). A series of such measurements constituted a fish track. Each fish track was assigned a unique ID. When multiple targets were being tracked, it was necessary to mark each one on the screen to avoid confusing tracks that occurred in close proximity to one another. The final step of the data processing procedure was to convert the data to Cartesian coordinates by trigonometry.

Data analysis focused on the two stationary locations at turbine units 19 and 23. We examined the location of sequential echoes and performed a component analysis of movement. The component analysis of movement involved breaking the point to point movement of a fish (ping to ping) into its x-y-z components, referred to as displacement fractions. If a fish was moving in a positive direction on the x-axis, that component

would be assigned a value of 1. If the directions was negative, it would be assigned a value of 0. By tallying the 1's and 0's, we were able to compute the proportion of fish movement in a direction for each of the axes. Since all measurements were made relative to the location of the transducer, we termed the lateral movement as Off-set from the direction the transducer was pointing. Off-set relative to the face of the third powerhouse was either north or south. Range was the distance from the transducer. And depth was 'presumed depth' of the target based on a transducer tilt angle of 46°. The depth metric should be used with caution as it is strongly correlated to range since we only used one of two sonar heads typically used for this type of study. The single sonar head satisfied the primary study objective to verify target detectability in the third powerhouse forebay. With the future addition of the second sonar head oriented at 90° to the first, true 3-D tracking is possible. The complexity of processing 3D data is much higher and was considered outside the scope of this test.

Results

ADCP Surveys

Water velocities across the opening of the 'cul-de-sac' were typically less than 1 m/s at all depths (Figure 3, Table 3), however some higher velocities were associated with the apex of the dam between the right and third powerhouses (Figures 4 and 5). Water velocities were generally lower across the 'cul-de-sac' opening when the discharge through the dam was lower. Water velocities at all depths were greatly affected by discharge through the third powerhouse. For example, on the afternoon of June 28, 2000, when project discharge was 179,320 cfs 80.5 % of the velocities measured across the 'cul-de-sac' opening exceeded 0.8 m/s and only 0.4% of the velocities measured in that area the following morning, when project discharge was 72,800 cfs exceeded 0.8 m/s.

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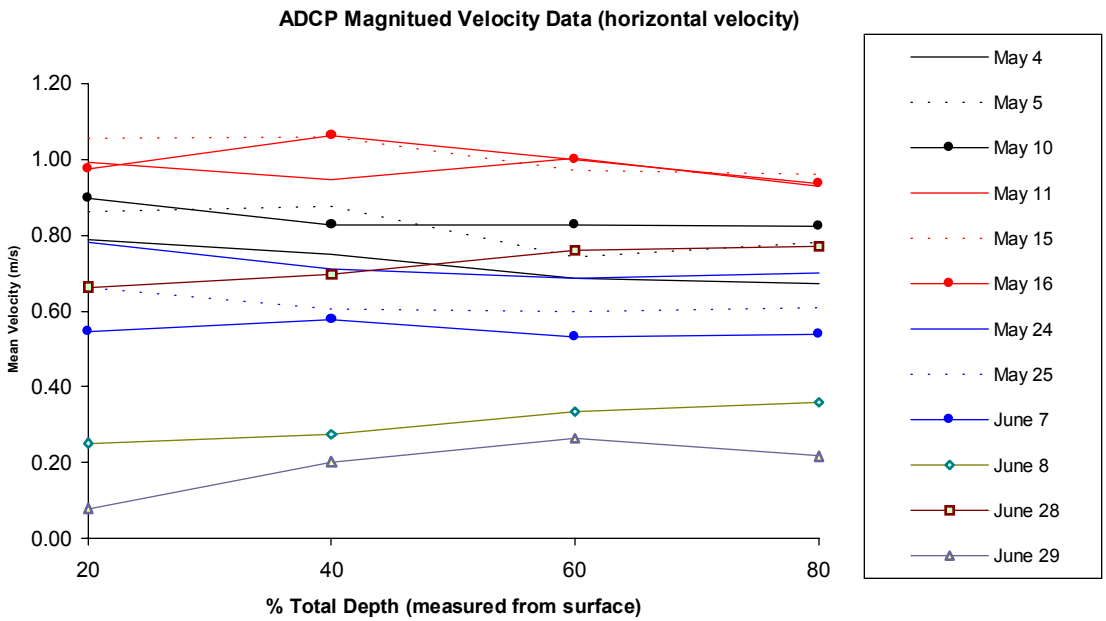

Figure 3. Mean horizontal water velocities (m/s) across the 'cul-de-sac' opening in the Grand Coulee Dam forebay at 20, 40, 60 , and 80% of depth. Legend shows the dates of the 12 separate surveys. Symbols are shown on some lines to allow for better visualization of the data.

Table 3. Mean vertical and horizontal water velocity data at four different depths on 12 different dates. Operational conditions are also summarized.

Vertical velocity

% Total Depth	May 4	May 5	May 10	May 11	May 15	May 16	May 24	May 25	June 7	June 8	June 28	June 29
20	-0.06	-0.05	-0.05	-0.11	-0.06	-0.06	-0.04	-0.04	-0.01	-0.01	-0.02	0.00
40	-0.06	-0.08	-0.07	-0.20	-0.11	-0.11	-0.06	-0.06	-0.03	-0.01	-0.07	-0.01
60	-0.08	-0.09	-0.10	-0.20	-0.16	-0.14	-0.07	-0.07	-0.03	-0.02	-0.07	-0.01
80	-0.05	-0.07	-0.06	-0.13	-0.08	-0.08	-0.04	-0.04	-0.03	0.01	-0.03	0.00

Horizontal Magnitude velocity

% Total Depth	May 4	May 5	May 10	May 11	May 15	May 16	May 24	May 25	June 7	June 8	June 28	June 29
20	0.79	0.86	0.90	0.99	1.06	0.97	0.78	0.66	0.55	0.25	0.66	0.08
40	0.75	0.88	0.83	0.95	1.06	1.06	0.71	0.60	0.58	0.28	0.70	0.20
60	0.69	0.74	0.83	1.00	0.97	1.00	0.68	0.60	0.53	0.33	0.76	0.26
80	0.67	0.78	0.82	0.93	0.96	0.93	0.70	0.61	0.54	0.36	0.77	0.22

Operational Conditions

	May 4	May 5	May 10	May 11	May 15	May 16	May 24	May 25	June 7	June 8	June 28	June 29
Pool Elevation (ft)	1241	1242	1241	1241	1238	1237	1237	1239	1255	1257	1279	1279
No. Units	5	5	5	5	5	5	6	6	5	5	6	6
AVG. Q (KCFS)	181	169	187	197	208	182	147	117	132	84	179	73

Figures 4 and 5 show the magnitude and direction of water velocities across the 'cul-de-sac' entrance under low and high discharge conditions, respectively. These figures illustrate the high velocity shears and eddies surrounding the apex between the right and third powerhouses.

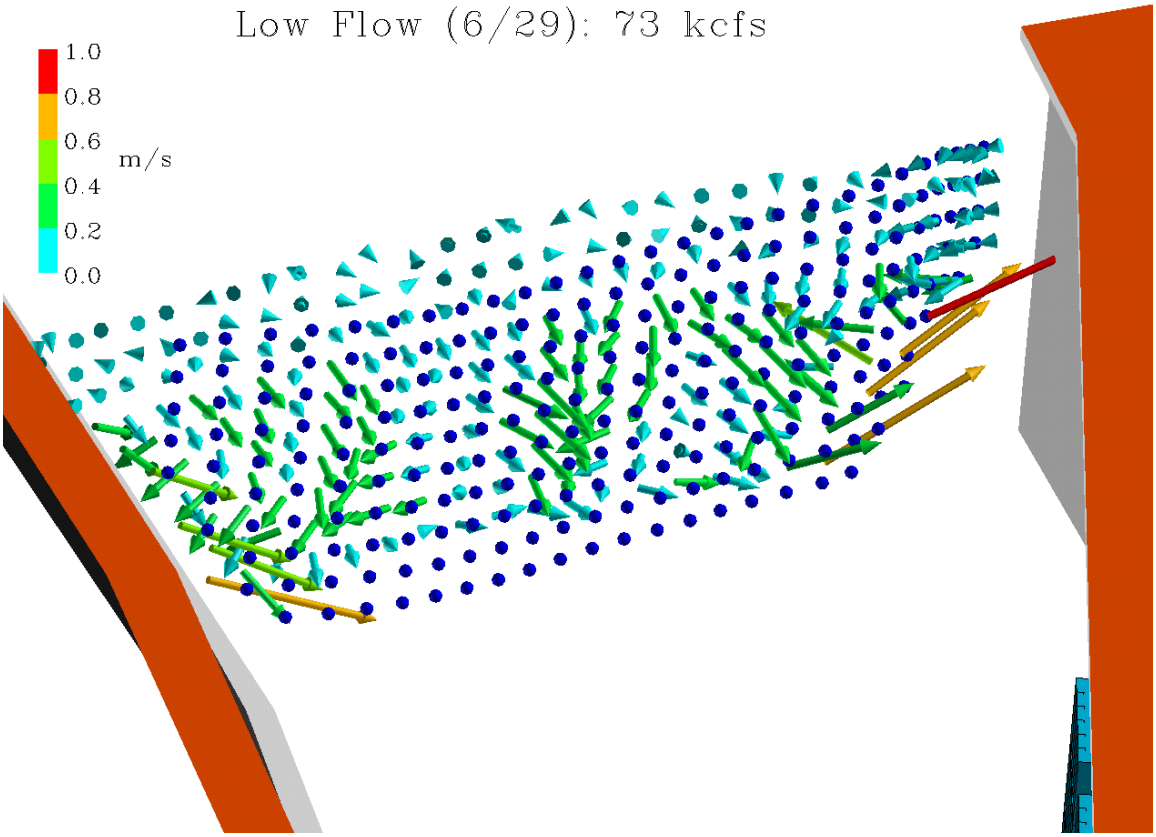

Figure 4. ADCP velocity data across the opening of the 'cul-de-sac' near the third powerhouse at Grand Coulee Dam collected under relatively low discharge conditions (73 kcfs) on the morning of June 29, 2000. The view is looking down and toward the forebay. Vectors represent water velocity magnitude (arrow color and length) and direction. Unit 19 of the third powerhouse is depicted in the lower right corner of the figure.

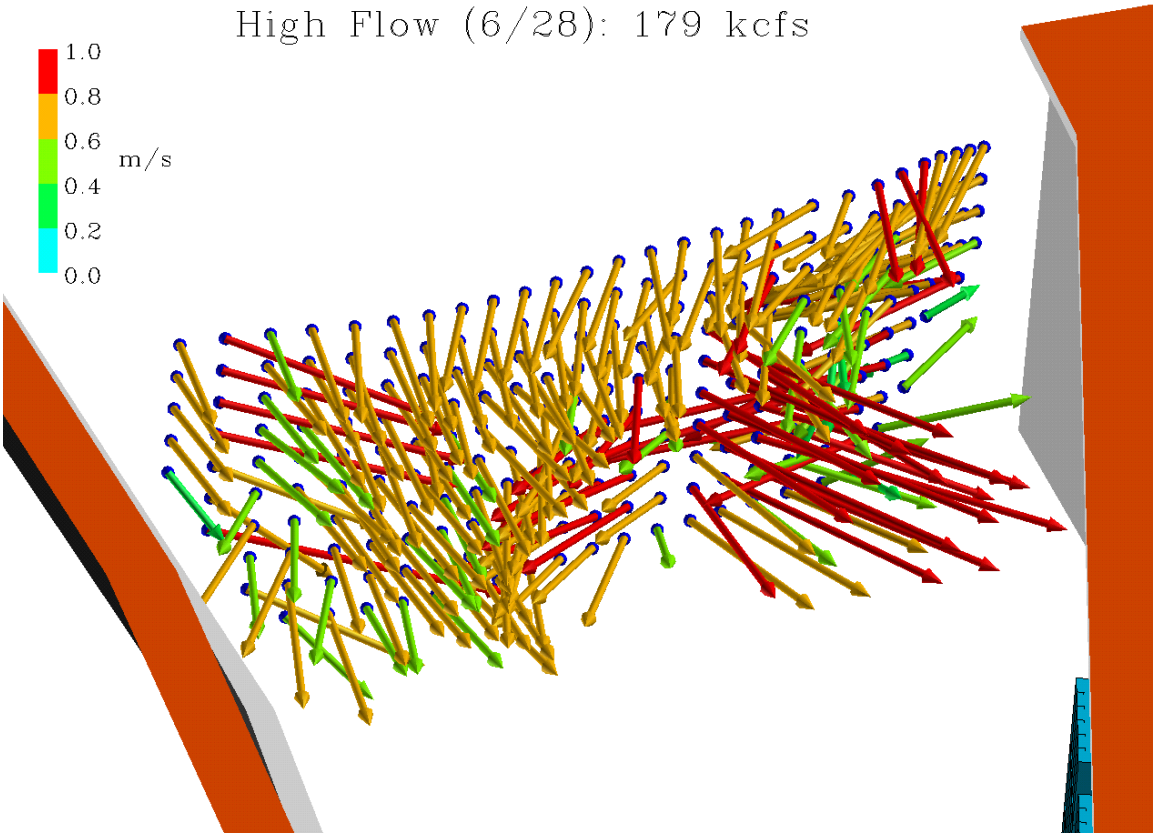

Figure 5. ADCP velocity data across the opening of the 'cul-de-sac' near the third powerhouse at Grand Coulee Dam collected under relatively high discharge conditions (179 kcfs) on the afternoon of June 28, 2000. The view is looking down and toward the forebay. Vectors represent water velocity magnitude (arrow color and length) and direction. Unit 19 of the third powerhouse is depicted in the lower right corner of the figure.

Figure 6 shows comparisons of high and low discharge at 20, 40, 60, and 80% of total depth on June 28 and 29, 2000.

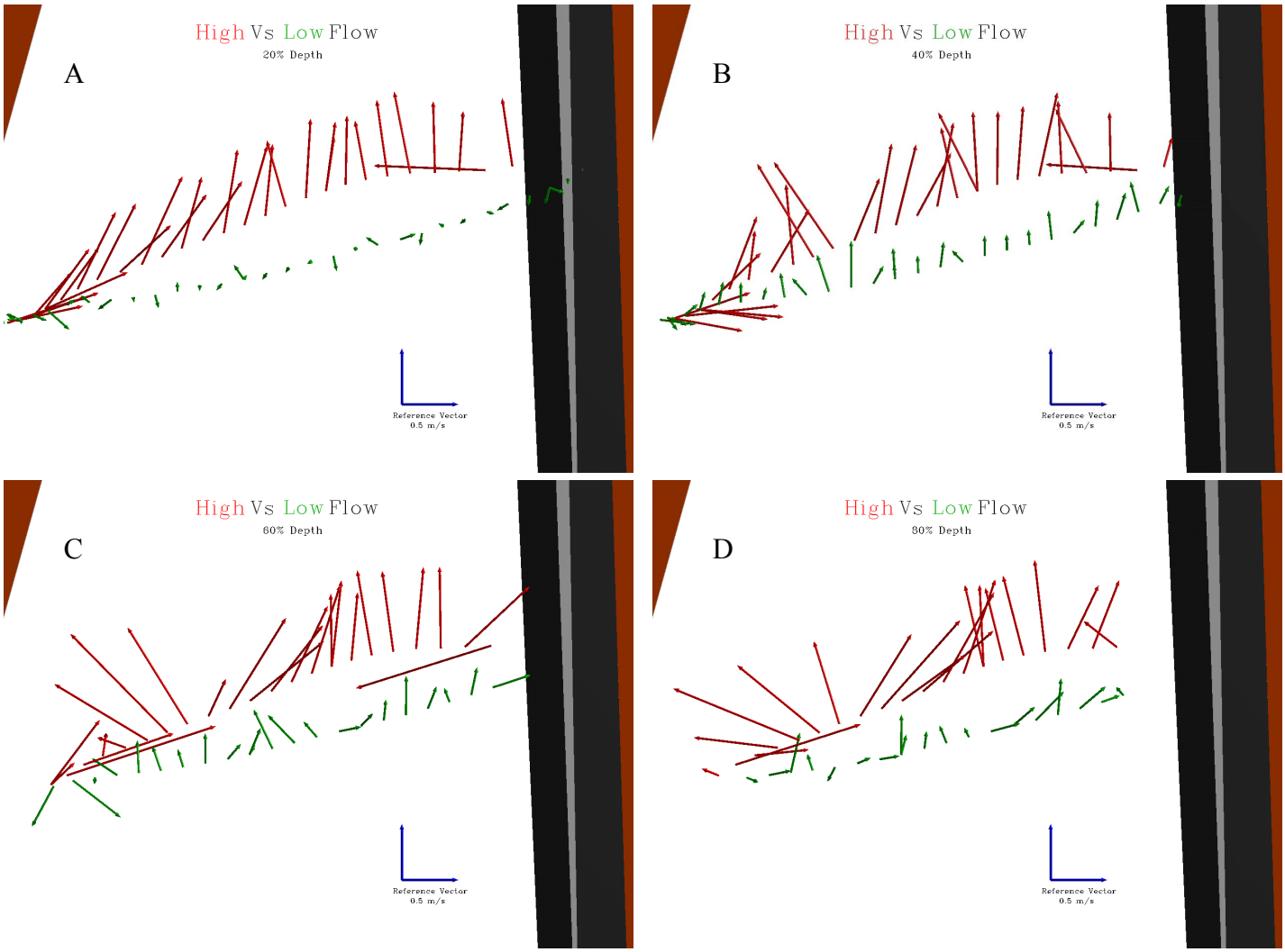

Figure 6. Plan view of water velocities at the 'cul-de-sac' opening at Grand Coulee Dam at high (179 kcfs, June 28) and low (73 kcfs; June 29) discharges. Magnitude velocities and directions are shown at 20 (A), 40 (B), 60 (C), and 80% (D) of total depth. Reference line showing 0.5 m/s are shown on each panel.

Detailed animations of the ADCP data are available by contacting the authors. Complete data files are appended to this document (Appendix A, Appendix B).

Hydroacoustics

Multibeam hydroacoustics equipment was successfully used to detect fish targets in the forebay of Grand Coulee Dam. Feasibility surveys on June 28 and 29, 2000, succeeded in detecting fish in the area of the forebay near the third powerhouse and adjacent to the trash racks at turbine units 19 and 23. Fish were detected in all areas of

the forebay and were relatively more abundant in the north end of the 'cul-de-sac' on the afternoon of June 28 (‘high flow’) and were more abundant outside the 'cul-de-sac' on the early morning of June 29 (‘low flow’). Similarly, fish were detected at a higher rate adjacent to the trash racks at units 19 and 23 on the afternoon of June 28 than they were on the early morning of June 29. Figures 7 through 12 illustrate the spatial distribution of fish targets detected near these turbine intakes as viewed from the side, top, and front of the intakes. The upper edge of the turbine intake opening was approximately 100 feet below the transducer when the data was collected.

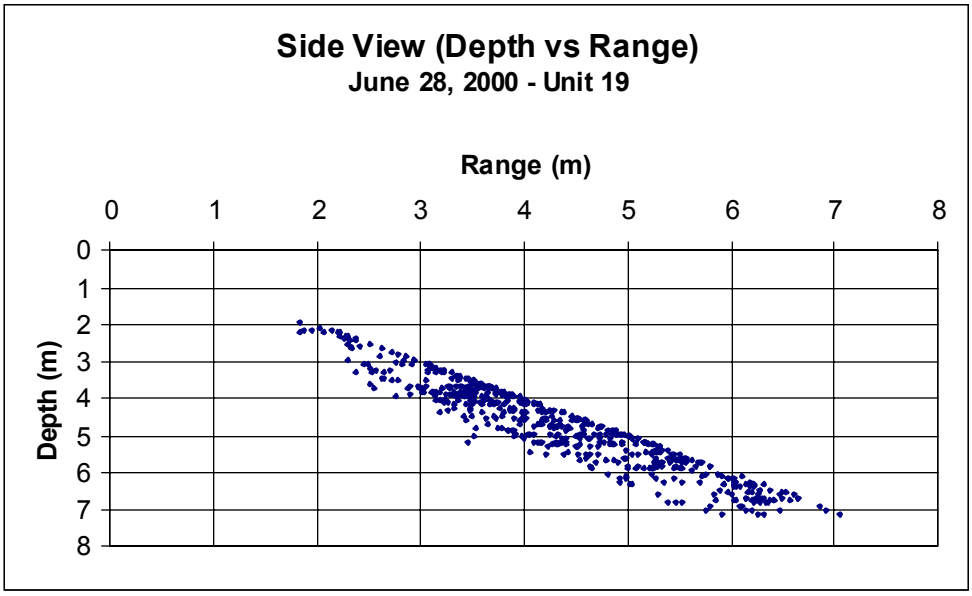

Figure 7. Side view of fish targets detected by multibeam hydroacoustics from a stationary boat located over the trash rack at unit 19 of the third powerhouse at Grand Coulee Dam. The transducer would be located in the upper left of the graph. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

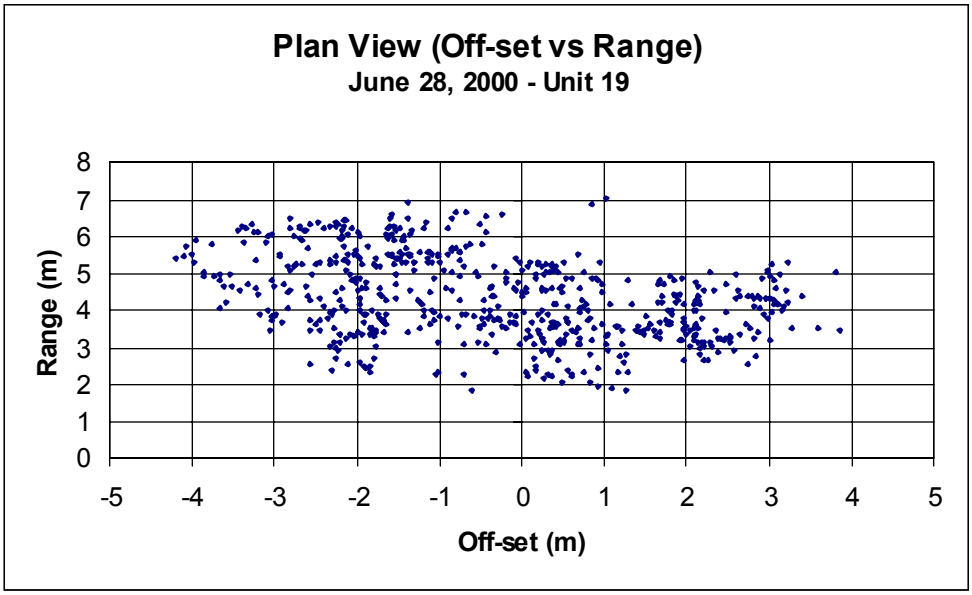

Figure 8. Plan view of fish targets detected by multibeam hydroacoustics from a stationary boat located over the trash rack at unit 19 of the third powerhouse at Grand Coulee Dam. The transducer would be located in the bottom center of the graph. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

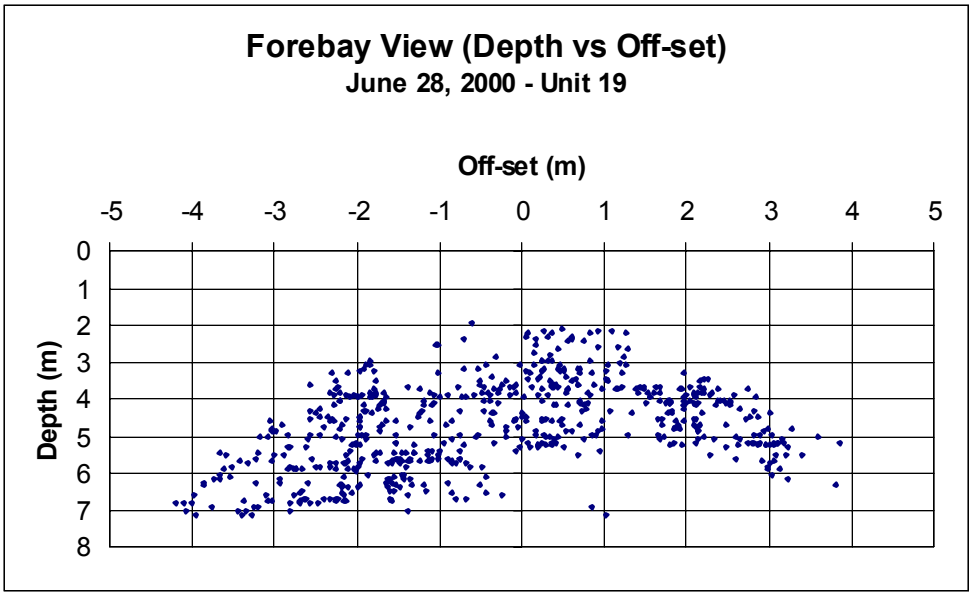

Figure 9. Forebay view of fish targets detected by multibeam hydroacoustics from a stationary boat located over the trash rack at unit 19 of the third powerhouse at Grand Coulee Dam. The transducer would be located in the top center of the graph. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

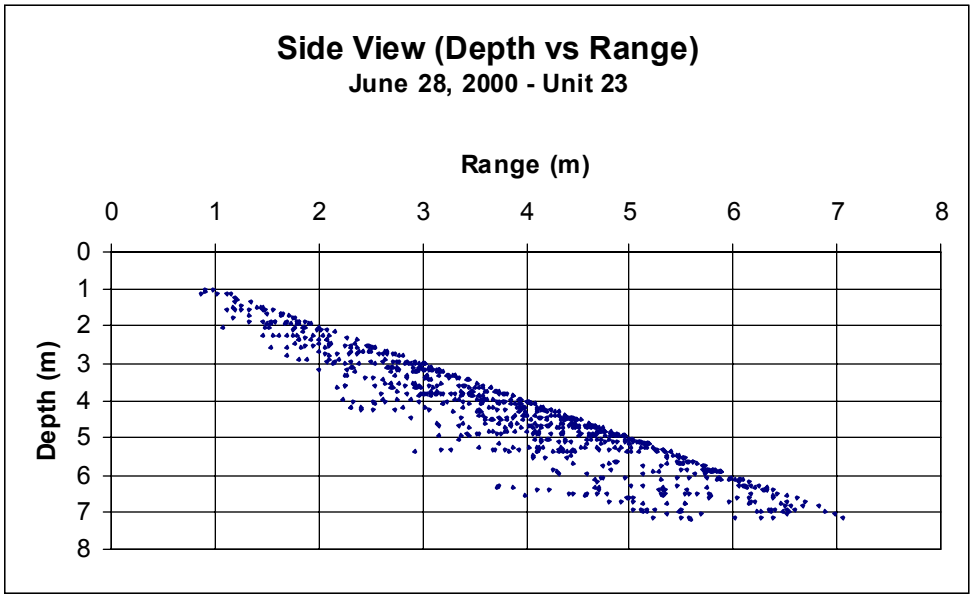

Figure 10. Side view of fish targets detected by multibeam hydroacoustics from a stationary boat located over the trash rack at unit 23 of the third powerhouse at Grand Coulee Dam. The transducer would be located in the upper left of the graph. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

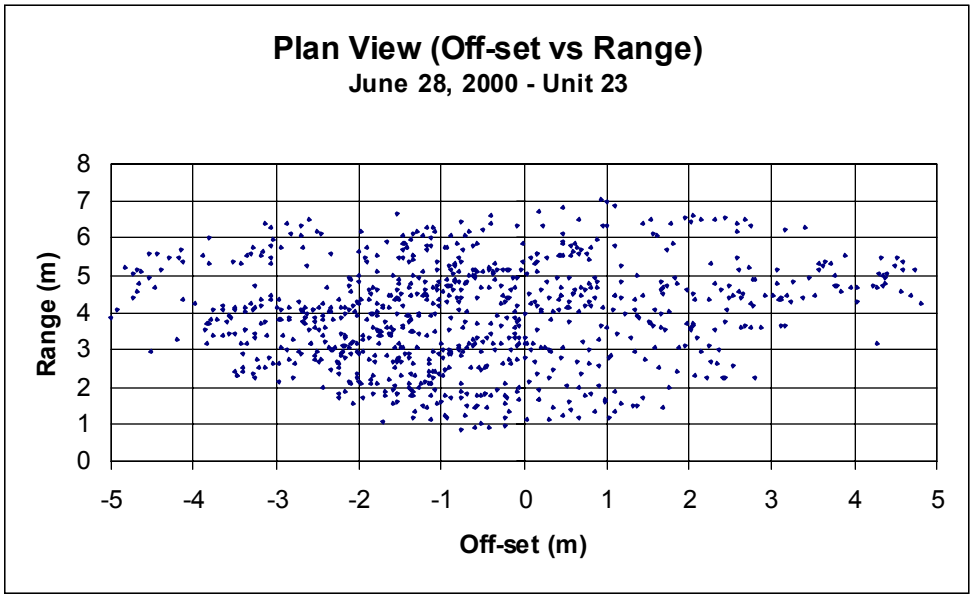

Figure 11. Plan view of fish targets detected by multibeam hydroacoustics from a stationary boat located over the trash rack at unit 23 of the third powerhouse at Grand Coulee Dam. The transducer would be located in the bottom center of the graph. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

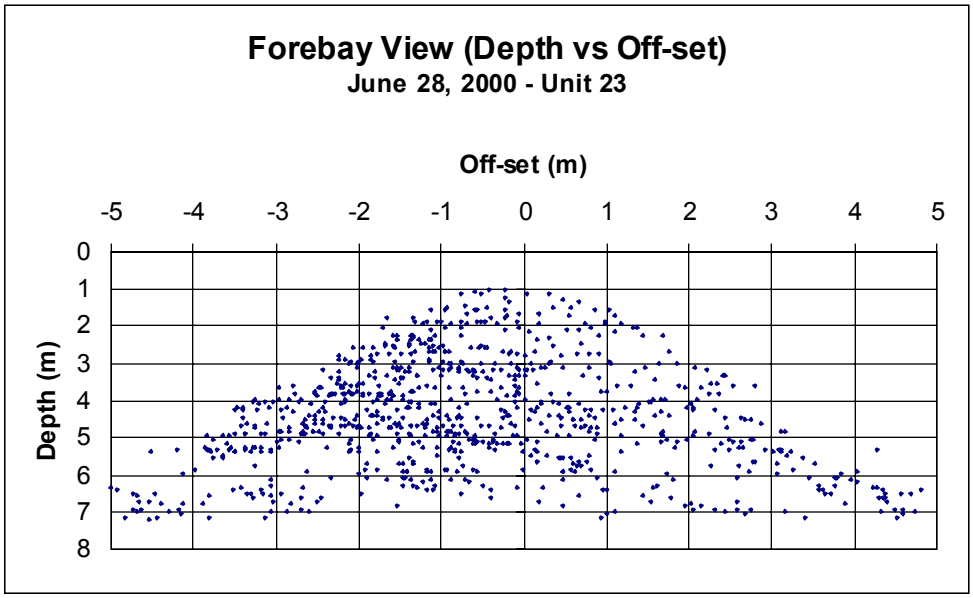

Figure 12. Forebay view of fish targets detected by multibeam hydroacoustics from a stationary boat located over the trash rack at unit 23 of the third powerhouse at Grand Coulee Dam. The transducer would be located in the top center of the graph. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

It appeared that fish were capable of moving against the direction of the current in close proximity to the trash racks under the high flow conditions on June 28 (Figures 13 and 14). Fish behavior was inferred from the direction of motion of the fish tracks (e.g., a fish moving ‘up’ and ‘away’ was moving against the current that was moving ‘down’ and ‘toward’ the turbine intake opening beneath the boat. The 3D animations of fish tracks in these locations, provided on the accompanying CD (animation of fish distribution and movement tracks from multibeam hydroacoustics data), illustrate the movement patterns of fish detected near the trash racks of units 19 and 23 and distribution on one transect through the 'cul-de-sac'. The echograms of fish track at units 19 (Figure 15) and 23 (Figure 16) also show the movement of fish in and away from the trash racks. Note that the tracks of several targets at both units moved in toward the transducer and then turned and moved away from the transducer.

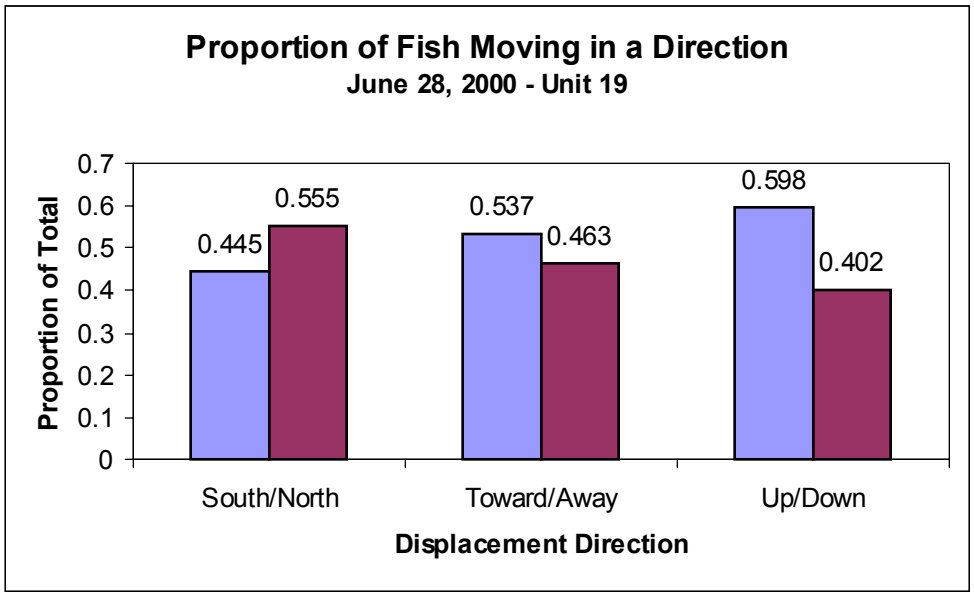

Figure 13. Proportion of fish (targets interpreted to be fish) moving in a direction as detected by multibeam hydroacoustics at unit 19 of the third powerhouse at Grand Coulee Dam. The transducer was aimed out into the forebay perpendicular to the axis of the dam. Example: fish moving 'toward' were moving from the forebay toward the dam.

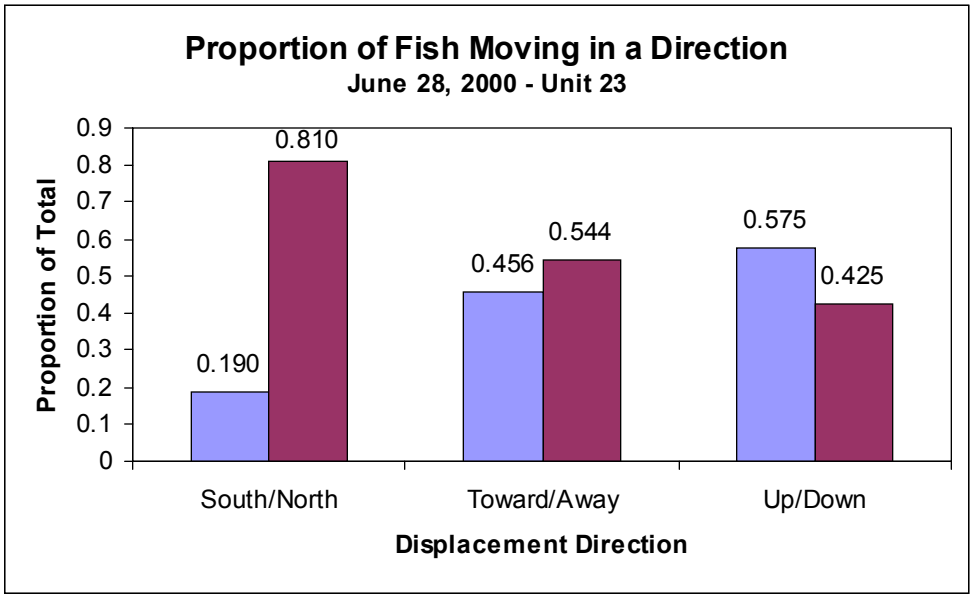

Figure 14. Proportion of fish (targets interpreted to be fish) moving in a direction as detected by multibeam hydroacoustics at unit 23 of the third powerhouse at Grand Coulee Dam. The transducer was aimed out into the forebay perpendicular to the axis of the dam. Example: fish moving 'toward' were moving from the forebay toward the dam.

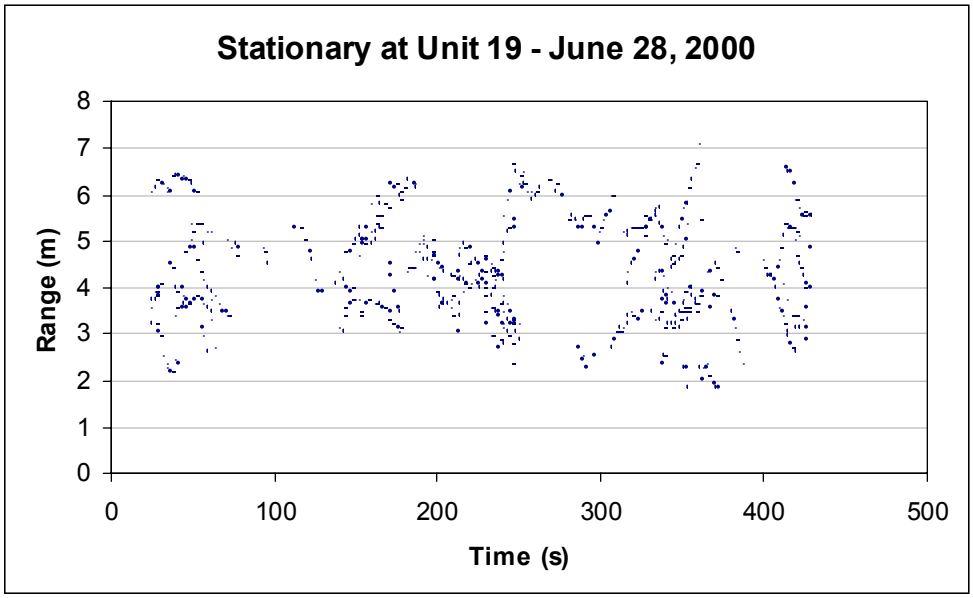

Figure 15. Echograms (range vs. time) of fish tracks for fish detected by multibeam hydroacoustics at unit 19 of the third powerhouse at Grand Coulee Dam. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

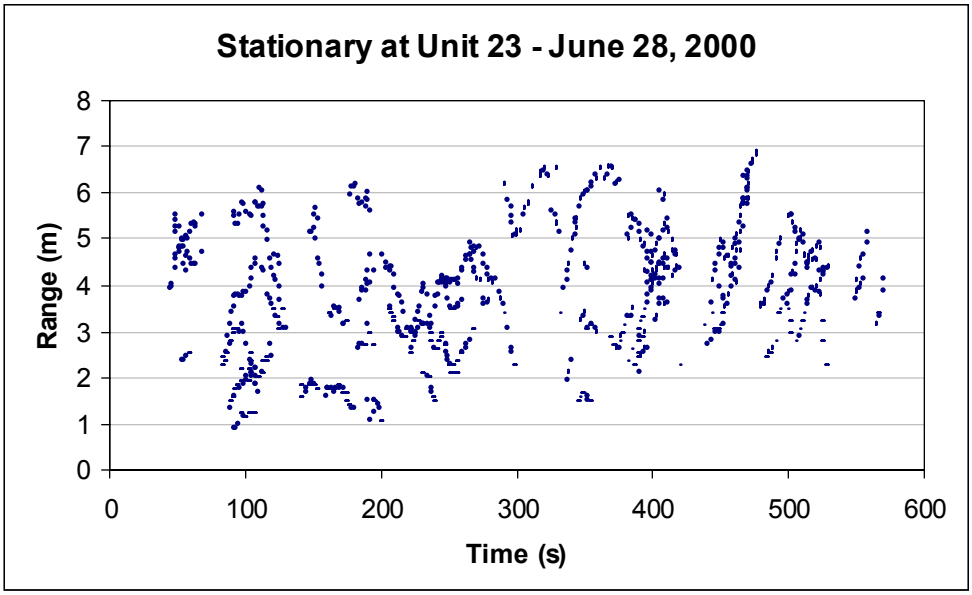

Figure 16. Echograms (range vs. time) of fish tracks for fish detected by multibeam hydroacoustics at unit 23 of the third powerhouse at Grand Coulee Dam. The transducer was aimed out into the forebay perpendicular to the axis of the dam.

Discussion

The maximum single cell (0.5 m^2) velocity recorded during the high discharge period on the 'high-flow' survey on June 28 was 2.04 m/s. A 150 mm-long kokanee or rainbow trout would have to swim 13.6 body lengths per second to maintain position in that velocity. Juvenile salmonids typically have a burst speed of about 9 body lengths/second (Puckett and Dill 1984). The mean velocities across the 'cul-de-sac' opening were typically less than 1.0 m/s, which would equate to a swimming speed of 6.7 body lengths/sec for a 150 mm-long fish. It is likely that fish are capable of passing into and out of much of the 'cul-de-sac' area without being involuntarily entrained. When we conducted a feasibility multibeam hydroacoustics survey in the forebay area, we observed fish moving with and against the velocity within a few meters of the trash racks over units 19 and 23 on the third powerhouse. Their behavior was consistent with that which might be exhibited by milling/feeding fishes. It is possible that the concentrations of zooplankton in the 'cul-de-sac', especially near its terminus, attract planktivorous fishes. Proximity of large numbers of fish to the turbine intakes on the third powerhouse would be expected to result in high entrainment of fish that encounter extreme vertical and horizontal water velocities adjacent to the turbine intakes.

If a behavioral deterrent system were deployed that was capable of reducing passage of fishes into the 'cul-de-sac' area, it would very likely reduce the amount of entrainment through Grand Coulee Dam. The water velocities measured in the 'cul-de-sac' opening across a wide range of dates and operational conditions revealed that, under most conditions, fish could swim against the current to areas of lower velocity (further away from the dam).

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