PRELIMINARY RESEARCH PROPOSAL
SUBMITTED TO THE U.S. ARMY CORPS OF ENGINEERS UNDER THE ANADROMOUS FISH EVALUATION PROGRAM
2007 PROJECT YEAR

I. BASIC INFORMATION

A. TITLE OF PROJECT

Hydroacoustic Evaluation of Juvenile Salmonid Passage at The Dalles Dam in 2007 with Emphasis on a Spillway Vortex Suppression Device

B. PROJECT LEADERS

Mr. Gary E. Johnson, Pacific Northwest National Laboratory, 620 SW 5th Avenue, Portland, OR 97204, Tel: 503/ 417-7567

Mr. Fenton Khan, Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Tel: 509/372-0426

C. STUDY CODE

SPE-P-00-08

D. ANTICIPATED DURATION

January 2007 – December 2007

E. DATE OF SUBMISSION

July 28, 2006

II. PROJECT SUMMARY

The problem being addressed in this study is the skewed distribution of juvenile salmonid passage toward Bay 5+6 at The Dalles Dam spillway. Passage at Bay 5+6 results in lower survival rates and longer egress times than passage at Bays 1-4. The skewed distribution problem is important to resolve because the outcome is likely to lead to improved project survival rates for juvenile salmonids at the dam. Accordingly, this proposal concerns a hydroacoustic evaluation of the effect of the spillway vortex suppression device (VSD) on fish passage conditions, distributions, and efficiencies at The Dalles Dam. The objectives will be to: 1) estimate passage efficiencies for the total project, sluiceway, and spillway; 2) estimate vertical and horizontal distributions and passage rates at the spillway with and without the VSD in Bays 5+6 to determine if the VSD redistributes fish at the spillway; and 3) assess the effect of the VSD on passage conditions and juvenile salmonid behavior by examining the following hypotheses: a) juvenile salmonids are entrained by the vortex at Bay 6 and b) once in the vortex, the fish do not escape. To meet these objectives, we propose to apply fixed-location hydroacoustic and acoustic imaging techniques in conjunction with hydraulic data from an acoustic Doppler current profiler

and a computational fluid dynamics model. For Objective 1, we will produce data for the run-at-large on daily and seasonal total project fish passage efficiency, sluiceway passage efficiency and spillway passage efficiency and as a function of date, spill volume, and spill proportion. For Objective 2, we will compare VSD IN vs. OUT data for spillway horizontal distributions and passage rates, with emphasis on Bays 5+6, assuming it is logistically feasible to install and remove the VSD according to a randomized block experimental design. For Objective 3, we will describe fish movements relative to the Bay 6 vortex, as well as integrate fish movement data from the acoustic camera with water velocity measurements and hydraulic conditions. Execution of Objective 3 is contingent upon river conditions; i.e., flows as high as spring and early summer 2006 will not allow for this objective. In conclusion, this study will provide a detailed evaluation of the effects of the spillway vortex suppression device on juvenile salmonid passage rates, distributions, and conditions at The Dalles Dam in 2007.

This project is relevant to the Implementation Plan for the Federal Updated Proposed Action (USACE et al. 2005) for the Endangered Species Act consultation process for operation of the FCRPS -- *Hydro substrategy 1.4; ESU Actions-The Dalles Dam*.

III. PROJECT DESCRIPTION

A. BACKGROUND

Development of long-term measures to protect juvenile salmon at The Dalles Dam (Figure 1) is a high priority in the endeavor to increase salmon smolt survival through the Federal Columbia River Power System (FCRPS) (National Marine Fisheries Service 2004). The multi-faceted strategy to improve smolt survival at TDA involves all three passage routes: turbine, spillway, and sluiceway. At the turbines, intake occlusions were tested in 2001 and 2002 to determine if blocking the upper half of the turbine intakes at the trash racks might significantly reduce turbine entrainment. Results from this research indicated that the occlusions were generally not effective at reducing turbine passage (Johnson et al. 2003; Hausmann et al. 2004). At the sluiceway, an alternate means of operating the entrance gates was investigated as a means to provide additional protection for juvenile salmonids at the TDA powerhouse (Johnson et al. 2005; Hansel et al. 2005). Passage efficiencies for the three main routes have commonly been estimated (e.g., Beeman et al. 2005). An engineering study was conducted select a site for a floating wall in the forebay to divert juvenile salmonids from the powerhouse to the spillway (USACE 2006). This effort applied results from forebay distribution and migration pathway studies by Cash et al. (2005) and Faber et al. (2005).

Figure 1. Aerial Photograph of The Dalles Dam. Flow is from right to left.

At the spillway, survival of downstream migrants is typically lower than at other projects on the lower Columbia River (Counihan at al. 2002, Ploskey et al. 2001). In an effort to improve survival of spilled fish, a wall dividing the spillway between Bays 6 and 7 was installed prior to the 2004 juvenile salmonid migration season and a bulk spill pattern at Bays 1-6 was adopted. Results from spill-wall post-construction evaluations in 2004-05 indicate that under the revised spill pattern (Bays 1-6) and at current spill levels, most migrant juvenile salmonids pass The Dalles Dam through the spillway (Johnson et al. 2005). For example, in 2005, nearly two thirds of radio-tagged fish passing TDA via the spillway passed through Bays 5and 6 (J. Beeman, USGS). However, studies continue to show that spillway passage survival is lower than desired (<98%). This combined with approximately 80% spill passage efficiency results in total project-passage survival that is lower than the NMFS BiOp performance standard of ~96% per FCRPS project.

Two years of data indicate that survival through Bay 5 and 6 is lower compared to survival through Bays 1-4. It has been hypothesized that this is due to the formation of a large vortex[1] that forms in Bay 6. The large vortex creates a strong surface flow for fish migrating into Bay 6. Fish could become entrained in this vortex on the south side of Bay 6. Direct survival tests in 2004 resulted in survival estimates of 85% for fish that were hand-tossed into the vortex in Bay 6 compared to >98% in Bays 2 and 4. Furthermore, model studies show that a proportion of dye released through Bay 6 is distributed across the stilling-basin shelf south of the spill wall. This indicates that fish passing through Bay 6 may also be guided in this direction, perhaps making them to be more vulnerable to predation than if passing elsewhere in spill. As stated by the Corps in the research summary for this study (May 2006), "*This information has led to the hypothesis*

[1] According to Vischer and Hager (1998, p. 221), "a vortex is a coherent structure of rotational flow. It is mainly caused by eccentricity of the approach flow to a hydraulic sink, but asymmetric approach flow conditions and obstruction effects among other reasons can also set up vortices."

that re-distributing fish across the spillway by reducing passage through bays 5&6 will lead to increases in spillway survival and ultimately dam-passage survival."

Potential ways to achieve re-distribution of fish at the spillway include: 1) suppress the vortex in Bay 6, and 2) guide fish toward the center of the spillway using a strategically placed guidance structure. Results from CFD model runs of the vortex and a VSD show complex interactions between spillway structures and hydraulic conditions (M. Richmond, pers. comm., PNNL). A pilot study using the sensor fish to characterize hydraulic conditions at the Bay 6 vortex in spring 2006 showed that fish released at the surface experienced larger pressure changes and more rapid angular velocities than sensor fish released in the middle of Bay 6 (Deng et al. 2006). Observations in the general 1:80 scale physical model at ERDC and field tests at the project (July 11, 2006) showed that placing a stop log to a depth of 3-4 ft can help suppress the vortex. Further model tests at ERDC were performed during July 17-20, 2006. Here is a photograph of the vortex at Bay 6 for a gate height of 6.7 ft, courtesy of Z. Deng (p. 3.2, Deng et al. 2006):

In summary, the problem being addressed in this study is the skewed distribution of fish passage toward Bay 6 at the TDA spillway. This problem is important to resolve because the outcome might lead to improved project survival rates for juvenile salmonids at the dam. Accordingly, this proposal concerns a hydroacoustic evaluation of the effect of the spillway vortex suppression device on fish passage conditions, distributions, and efficiencies at The Dalles Dam.

B. GOALS AND OBJECTIVES

The goal of this study is to evaluate the effect of the spillway vortex suppression device (VSD) on juvenile salmonid passage efficiencies, distributions, and conditions at The Dalles Dam.

The objectives of the 2007 study are to:

1. Estimate passage efficiencies[2] (total project FPE, sluice passage efficiency and spillway passage efficiency).
2. Estimate vertical and horizontal distributions and passage rates at the spillway with and without the VSD in Bays 5+6 to determine if the VSD redistributes fish at the spillway.

[2] By definition, "efficiency" is the proportion of fish passing at a given route out of total project passage.

3. Assess the effect of the VSD on passage conditions and juvenile salmonid behavior by examining the following hypotheses:
    a. Juvenile salmonids are entrained by the vortex at Bay 6.
    b. Once in the vortex, the fish do not escape.
    c.

C. METHODS

Fixed-location hydroacoustic techniques (explained in general by Thorne and Johnson 1993 and in detail by Ploskey et al. 2003) will be used to estimate fish passage efficiencies and distributions at the spillway, sluiceway, and turbines. Acoustic imaging techniques will be used to study fish behavior near the vortex in Bay 6. Computational fluid dynamics model results will be used to interpret the fish behavior data. We plan to conduct hydroacoustic sampling 24 h/d during 48-day spring (April 17 to June 3) and 40-day summer (June 4 to July 13) study periods. Methods are presented below for each objective.

Objective 1: Estimate passage efficiencies (total project FPE, sluice passage efficiency and spillway passage efficiency).

<u>General</u>

To estimate fish passage rates and distributions, we propose to use a combination of single- and split-beam transducer deployments. This approach uses the acoustic screen model to determine passage rates. Split-beams will be used to provide data to determine weighting factors, assess assumptions of the model, and determine the magnitude of any biases. Single- and split-beam transducers will be deployed to sample fish passage at the spillway, ice and trash sluiceway, and turbines. All transducers will be randomly placed horizontally within a passage route (e.g., west, middle, or east at the powerhouse and north, middle, south at the spillway.) Transducer sampling volumes will be strategically placed to minimize ambiguity in ultimate fish passage routes and potential for multiple detections.

In general, a hydroacoustic system consists of an echosounder, cables, transducers, an oscilloscope, and a computer system. An echosounder generates electric signals of specific frequency and amplitude and at the required pulse durations and repetition rates, and cables conduct those transmit signals from the echosounder to transducers and return data signals from the transducers to the echosounder. Transducers convert voltages into sound on transmission and sound into voltages after echoes return to the transducer. The oscilloscopes will be used to display echo voltages. The computer system will control echosounder activity and record data to a hard disk. The 420 kHz, circular, single- or split-beam Precision Acoustic Systems (PAS) transducers will be controlled by PAS 103 echosounders and Hydroacoustic Assessments' HARP software running on Pentium-class computers.

<u>Sampling Intensity</u>

The proposed sampling intensity minimizes the duration per sample and maximizes the number of samples, as recommended by Skalski et al. (1993). We do not propose to "fast-multiplex" (sample two locations simultaneously) on the same system at the spillway, because it is more important to maximize the pulse repetition rate and, hence, detectability (Table 1).

Table 1. Hydroacoustic Sampling Intensity for Fish Passage Estimation

Route	Sample Intervals per Hour	Minutes Sampled per Hour
Turbine Intakes	8	8
Spillway	15	15
Sluiceway	12	12

Sampling Locations and Orientations

Turbine Intakes. One randomly selected intake (intakes 1, 2, or 3) within each of the 22 main turbine units and the two fish turbine units (slots 1 or 2) will be monitored. We will use 6° circular single-beam transducers (first side lobe about -30 dB) for sampling the powerhouse. In addition, one 6° circular split-beam transducer will be used for sampling at one of the powerhouse locations. The split beam data are used in the detectability calculations and will replace the single beam at that particular location. Trash rack J-mounts will be used with transducers aimed upward 23° and downstream so that the beam is perpendicular to the intake ceiling (Figure 2). The pulse repetition rate for all turbine transducers will be 15 pings/s.

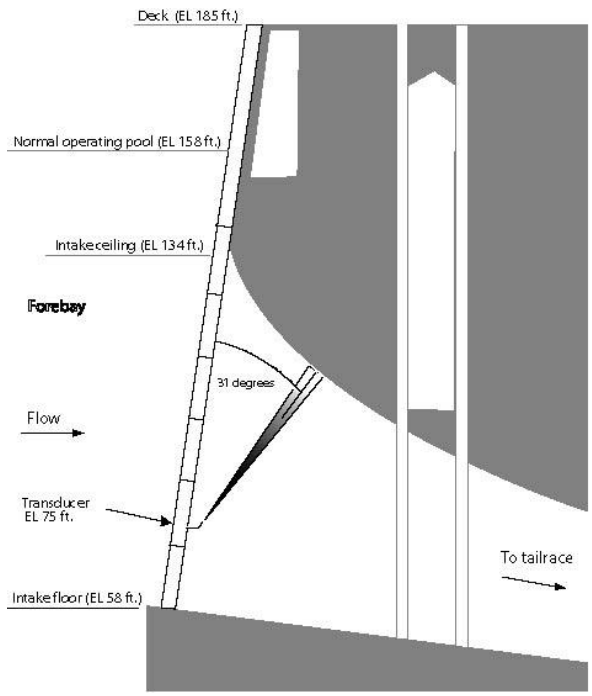


Figure 1. Turbine Intake Sampling Orientation

Sluiceway. To sample fish passage into the sluiceway, we plan to deploy one 6° circular, split-beam transducer at each of the six open sluice gates (based on 2006 operations, SL 1-1, 1-2. 1-3, 5-3, 18-1, and 18-2). These transducers will be aimed horizontally across the sill from mount locations on adjacent pier noses (Figure 3). This deployment, which was successfully used in the 2004 and 2005 hydroacoustic studies at TDA, is a distinct improvement over previous hydroacoustic sampling because the sampled fish are entrained in sluice flow. The pulse repetition rate at the sluiceway will be 33 ping/s.

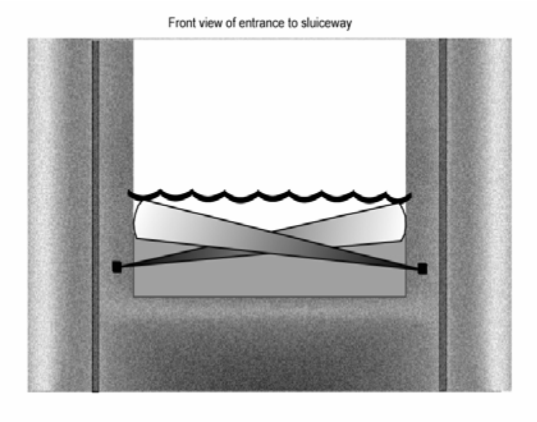


Figure 2. Front View of an Intake Showing a Pair of 6-Degree Transducers Angled Across and Back Toward the Surface of the Water (only one transducer of the pair will be used in 2007)

Spillway. We propose to deploy 6° circular, split-beam transducers in 10 of 23 spill bays. All transducers will be mounted on the bottom of poles (approximate El. 46.9 m or 154 ft) aimed downward about 8° downstream (Figure 4). The repetition rate at the spillway will be 33 pings/s.

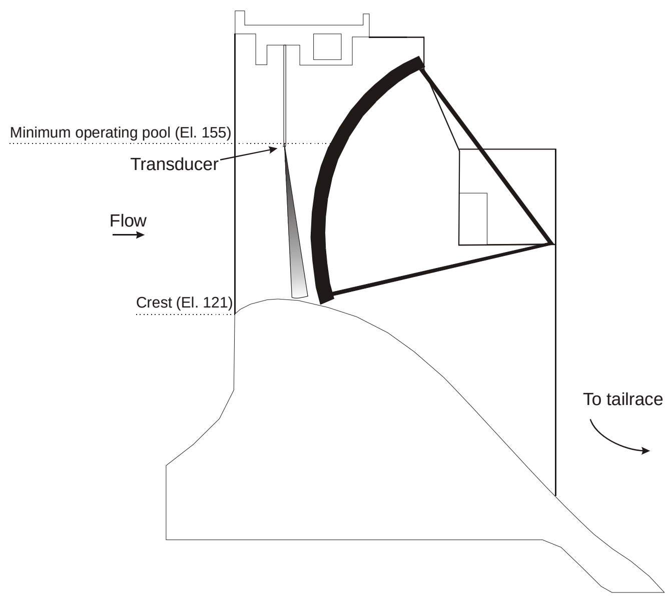


Figure 3. Transverse section of a Spill Bay Showing Spill Transducer

Hydroacoustic Systems

Before deployment, all hydroacoustic equipment will be transported to Seattle, Washington, where Precision Acoustic Systems (PAS) will electronically check the echosounders and transducers and calibrate the transducers using a standard transducer. After calibration, we will calculate receiver gains to equalize the output voltages among transducers for on-axis targets ranging in hydroacoustic size from –56 to –36 dB || 1μPa at 1 m. Lengths of fish corresponding to that acoustic size range would be about 1.3 and 15 inches, respectively, for fish ensonified within 21° of dorsal aspect.

Data Processing

All data files acquired during the study will be processed with automated tracking software after the software has been carefully calibrated for every transducer. The autotracker tracks almost all linear traces of echoes meeting liberal tracking criteria and then tracked traces are filtered to exclude non-fish using filters derived for every transducer during the calibration process. Acoustic counts of juvenile salmon acquired at spill bays, and turbine intakes will be expanded based upon the ratio of intake width to beam diameter at the range of detection:

$$\text{Expanded Numbers} = OW / (MID\_R \times TAN(EBA/2) \times 2) \quad (1)$$

where, OW is opening width in m, MID_R is the mid-point range of a trace in m, TAN is the tangent, and EBA is effective beam angle in degrees. For sluiceways, opening height (OH) will be substituted for OW in Equation 1, and it will be calculated as forebay elevation minus weir crest elevation.

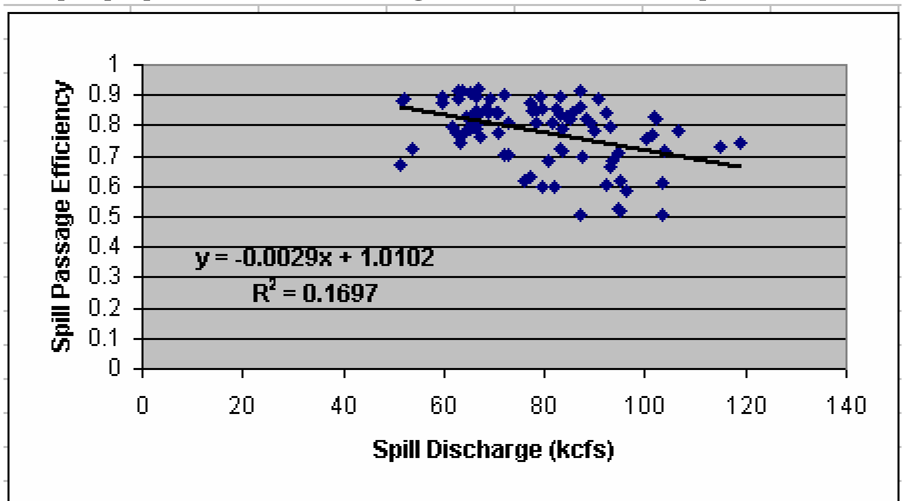
Effective beam angle depends upon the detectability of fish of different sizes in the acoustic beam and is a function of nominal beam width and ping rate (pings/s) as well as fish size, aspect, trajectory, velocity, and range. We will model detectability to determine effective beam widths using fish velocity data by 1-m strata and target strength data from the split-beam transducers, as well as flow velocity data by 1- m strata from the computational fluid dynamics (CFD) model. These data and other hydroacoustic-acquisition data (e.g., beam tilt, ping rate, target-strength threshold, number of echoes, and maximum ping gaps) will be entered into a stochastic detectability model. Effective beam angles for every 1-m range strata (EBA in Equation 1) will be used to expand every tracked fish at its range of detection to the width of the turbine intake. Within-hour counts of fish will be expanded spatially to the width of every passage route and temporally to estimate hourly passage and its variance. Counts and variances also will be expanded to estimate passage for spill bays and turbine intakes that were not sampled.

Data Analysis

We will calculate fish-passage metrics, including passage proportions relative to passage at other routes (efficiencies). Secondary estimates will include passage proportions relative to flow proportions (effectiveness), and seasonal, diel, and vertical distributions. Fish passage sums and variances will be combined to estimate the spring and summer fish-passage efficiency for the entire project and its 95 % confidence interval using the methods of Skalski et al. (1996). Seasonal, diel, and distribution trends in fish passage and major will be plotted graphically, examined, and discussed. Regression analyses will be used to describe relations between major metrics and percentage spill and spill volume. Analyses will be based on daily values of the passage metrics. Separate regression analyses will be performed during spring and summer seasons.

Example Data

Figure 5 shows example data on the relationship between spill passage efficiency and spill discharge and spill proportion of total discharge. Similar data will be produced in 2007.



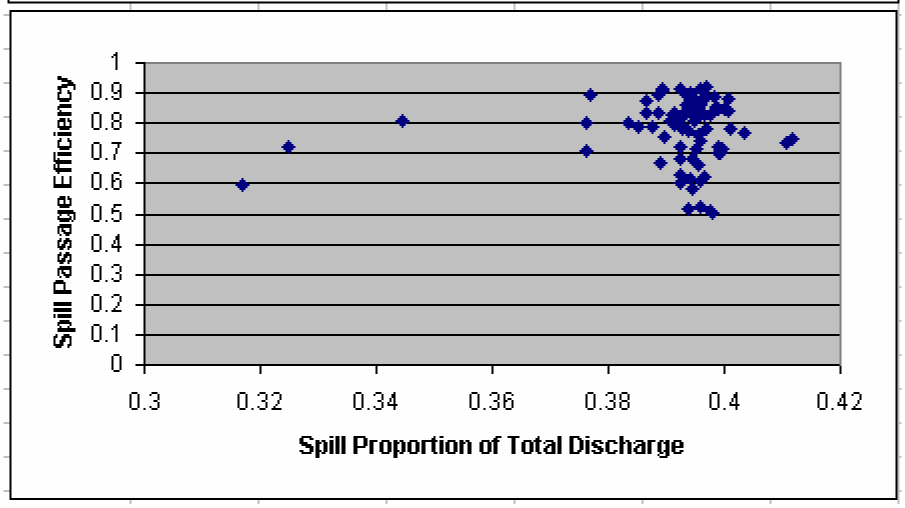
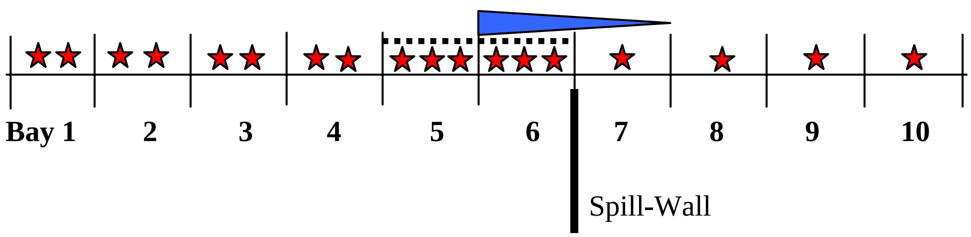


Figure 5. Example Daily Spill Passage Efficiency Data for the Run-at-Large at The Dalles Dam. These unpublished data are from the hydroacoustic evaluation at The Dalles Dam in 2004 (Johnson et al. 2005).

Objective 2: Estimate vertical and horizontal distributions and passage rates at the spillway with and without the VSD in Bays 5+6 to determine if the VSD redistributes fish at the spillway.

Sampling Locations

Objective 2, Spillway Distributions with and without the VSD, will involve intensive sampling at Spill Bays 1-6. Each down-looking split beam transducer deployed for Objective 1 will be augmented by 1 or 2 additional split-beam transducers, and a side-looking split-beam transducer in front of Bay 6, for a total deployment as follows (the dashed lines represent the VSD; the stars represent transducers):



In July 2006, we deployed a side-looking transducer about 5 m deep off the pier nose between Bays 7 and 8. We aimed it to sample fish trajectories in front of the vortex at Bay 6. Although the data are still being analyzed, the echograms reveal long, unambiguous fish tracks immediately upstream of the vortex. This deployment will show differences in fish trajectories upstream of the Bay 6 vortex with and without the VSD in place.

Experimental Design

Assuming the Corps can deploy and remove the VSD during the study, a randomized block experimental design will be implemented to compare spillway passage distributions and efficiencies with and without the VSD.

Treatment 1 – VSD deployed at Bays 5+6 (IN)
Treatment 2 – VSD removed (OUT)

A given treatment will be in place for two days for logistical reasons. Thus, blocks will be four days long. Over the course of the 48-day spring and 40-day summer study periods, there will be 12 blocks in during spring and 10 blocks during summer.

Power Analysis

The increase in intensity of sampling at the spillway above and beyond Objective 1 for the purpose of Objective 2 will improve the likelihood of determining whether the VSD redistributes juvenile salmonids at the TDA spillway. We plan to perform an a priori power analysis for the final proposal.

Statistical Analysis

The primary response variable will be the passage rate at Bays 5+6. The test of the effect of VSD treatments will be performed using a two-way ANOVA for a randomized block experimental design. The ANOVA table will be as follows:

Source	df	SS	MS	F
Total	2B			
Mean	1			
$Total_{Cor}$	2B-1	SSTOT		
Blocks	B-1	SSB		
Treatment	1	SST	MST	$F_{B-1} = \frac{MST}{MSE}$
Error	B-1	SSE	MSE	

Example Data

Detailed vertical and horizontal distribution and trajectory data will be produced and integrated with hydraulic data from a computational fluid dynamics model. Example horizontal distribution data are shown in Figure 6. At Bays 5 and 6 where three transducers each will be deployed, contour plots combine vertical and horizontal distribution of passage in the plane of the transducers (centerline of the roadway deck covers, angled 8 deg downstream) will be produced (example in Figure 7).

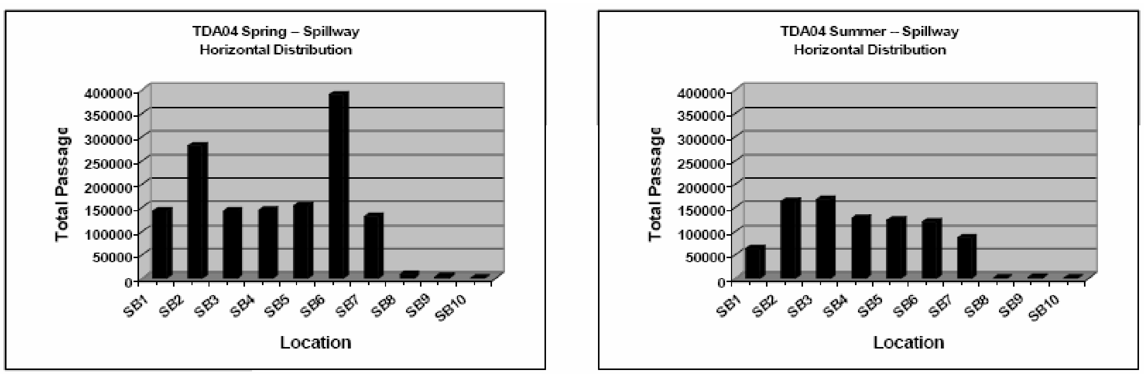


Figure 6. Example Data on the Horizontal Distribution of Fish Passage at The Dalles Dam Spillway. These data are from the hydroacoustic evaluation at The Dalles Dam in 2004 (Johnson et al. 2005; p. 4.24).

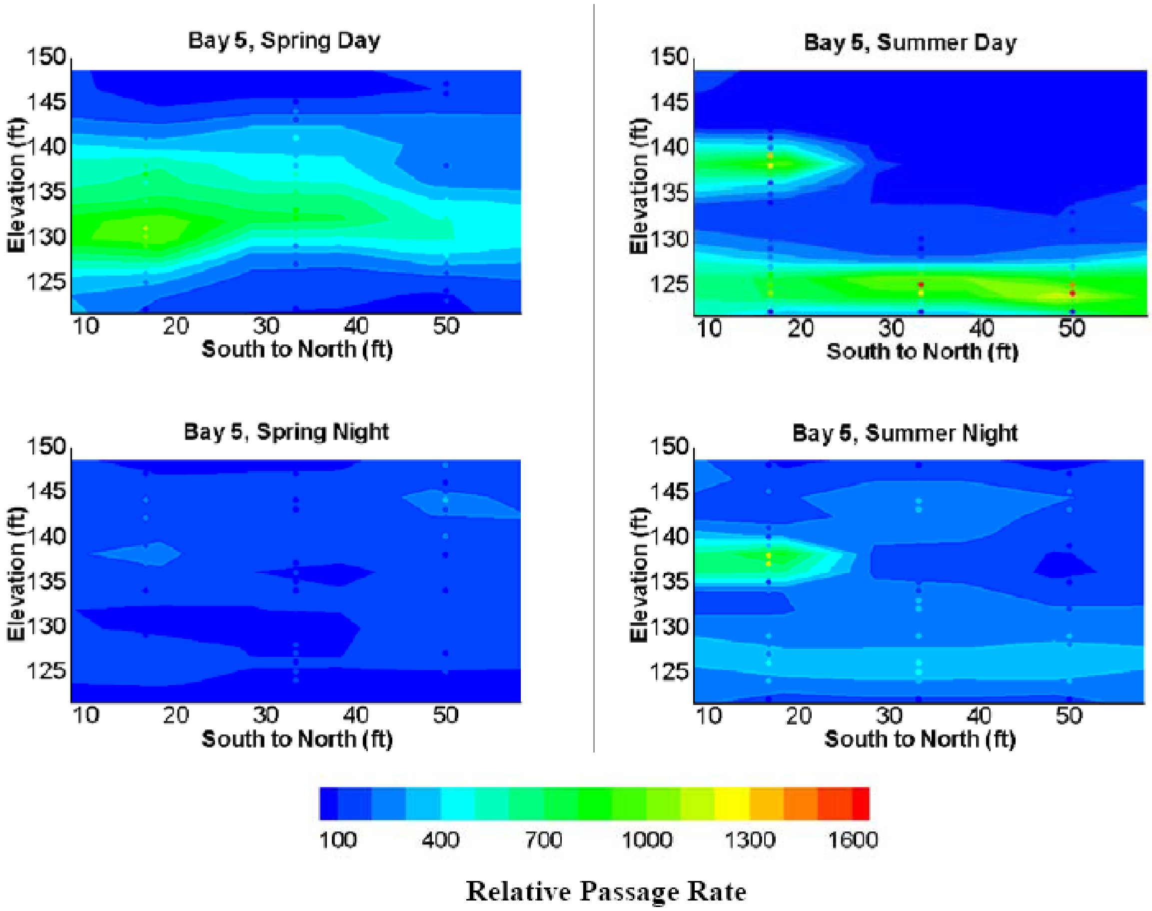


Figure 7. Example Data on the Vertical and Horizontal Distribution of Fish Passage within a Spill Bay at The Dalles Dam. These data are from the hydroacoustic evaluation at The Dalles Dam in 2004 (Johnson et al. 2005; p. 4.26).

Objective 3: Assess the effect of the VSD on passage conditions and juvenile salmonid behavior by examining the following hypotheses: a) juvenile salmonids are entrained by the vortex at Bay 6, and b) once in the vortex, the fish do not escape.

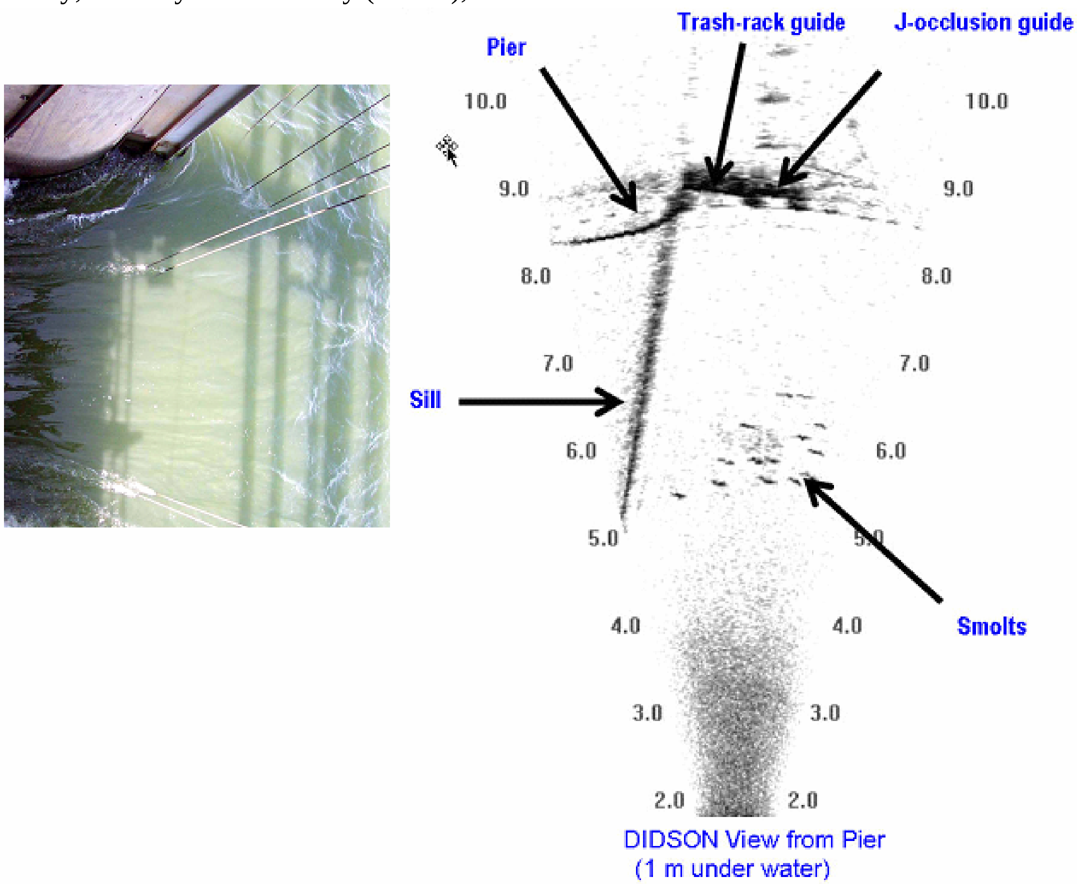
Note, execution of Objective 3 is contingent upon river conditions; i.e., flows as high as spring and early summer 2006 will not allow for this objective because of the equipment necessarily deployed underwater at Bay 6. Also, the deployment for Objective 3 will need to be coordinated with the deployments for Objectives 1 and 2 as we do not want the split-beam transducers to disrupt the DIDSON or ADCP data streams.

<u>General</u>

The general approach for Objective 3, VSD Effects on Passage Conditions and Fish Behavior, will involve a Dual Frequency Identification Sonar (DIDSON), an acoustic Doppler current profiler (ADCP), and a computational fluid dynamics (CFD) model. At Bay 6, we propose to simultaneously use the DIDSON to record 2D movements of approaching fish and the ADCP to measure water velocity. The CFD model will provide data on water velocity and acceleration, including the vortex itself, to help interpret the biological data from the DIDSON.

<u>DIDSON</u>

The DIDSON bridges the gap between conventional fisheries sonar, which can detect acoustic targets at various ranges but cannot record the shapes or sizes of targets, and optical systems, which can videotape fish in clear water but are limited at low light levels or when turbidity is high. The DIDSON has a high resolution and fast frame rate designed to allow it to substitute for optical systems in turbid or dark water, as shown in the following image from The Dalles Dam sluiceway, courtesy of G. Ploskey (PNNL),:



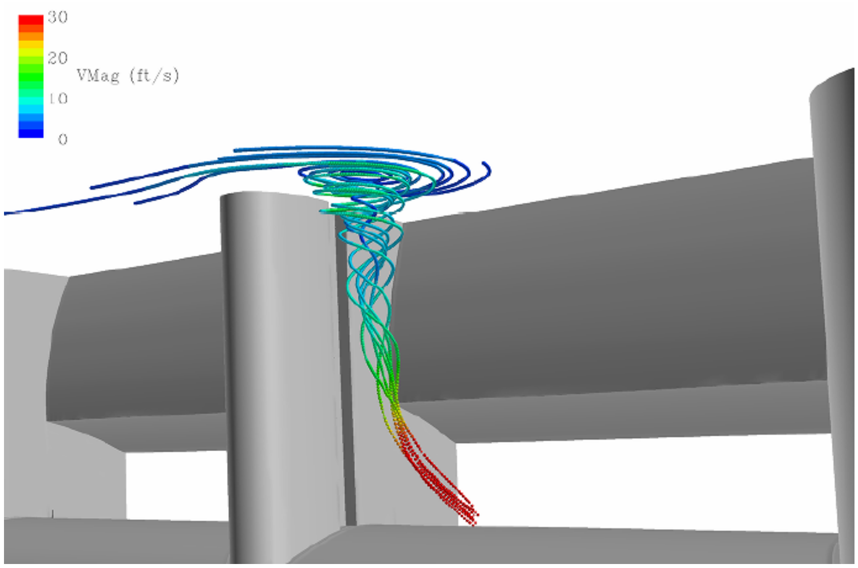
We have an automated system for identifying and tracking fish movements in DIDSON images so that track statistics can be rapidly extracted and saved. Fish positions through time will be converted to 3-dimensional coordinates from frame-by-frame integration of dual-axis rotator coordinates, time, and fish position in the DIDSON field of view. The DIDSON will operate at the highest frame rate attainable (projected at 6-7 frames per second).

<u>ADCP</u>

A standard foot-print (28°) ADCP (RDI, Inc. 600 kHz) will be used to obtain water velocity data while we collect DIDSON data. The ADCP will sample average water velocity within 0.5-m strata from the instrument. Note that the ADCP provides an averaged velocity over the area of the foot print and thus is much larger area than occupied by a fish. The ADCP will be mounted on the same plate as the DIDSON and will sample the same zone as the DIDSON at the same time. Standard processing techniques will be used to estimate water velocity by range through time and a common GPS clock of time will ensure that time lines for fish tracks and water velocities are synchronized. Note, the ADCP will not be able to sample the vortex itself because the water is too chaotic. The ADCP looks like the following, courtesy of C. Cook (PNNL),:

<u>CFD</u>

We also will characterize flow using a CFD model for the average dam operations during the two 2-week DIDSON sampling periods. The model runs will be integrated with biological studies of the effect of the VSD on the behavior of juvenile salmonids. The computational mesh that will be used for these simulations was created for the Corps, Portland District PNNL (Rakowski, et al 2005). For this study, the mesh will be rotated and translated onto the State Plane feet, Oregon North geographic coordinate system. The TDA forebay CFD model includes three intakes for each of the turbine units, individual spill bays, sluiceway inflows, and the station service flows. In May 2006, the mesh was modified to increase the number of mesh cells in spill bays 1-8 and with even further increased resolution in Bay 6 in order to resolve the vortex. All simulations will use STAR-CD, a commercial CFD solver. The CFD model will be applied to a total of eight runs: spring and summer, two flow operations, VSD IN and OUT treatments. We will select the time periods, obtain mean total discharges for the spillway and turbines, and then make a spreadsheet and allocate the discharges by location according to the patterns determined from the dam operations analysis. The CFD data will be useful to describe passage conditions, especially with respect to the Bay 6 vortex. An example CFD model image of the simulated Bay 6 vortex, courtesy of J. Serkowski (PNNL), is shown here:



<u>Sampling Design</u>

Both the DIDSON and the ADCP will be mounted on the same plate, which will be moved by a programmable stepper motor. The stepper motor will be programmed to aim the instruments to sample each of six 30° wide, 12° deep zones for 10 minutes every hour. All zones will be upstream of the entrainment zone so we do not expect structure to interfere with ADCP sampling. Three of the adjacent horizontal zones will be as close to the water's surface as possible and the other three zones will be immediately below the near-surface zones. We propose sampling zones because previous attempts at actively tracking individual or schools of fish did not result in a large pool of long complete tracks for analysis because most fish were lost even by the most diligent tracker. The DIDSON/ADCP will sample for 24 h/d for 2 weeks during spring and 2 weeks during summer 2007.

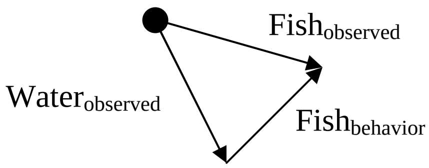
<u>Merging of Biological and Physical Data</u>

The ADCP data on water velocity and associated hydrodynamic characteristics such as acceleration and rate of strain will be merged with the fish data for specific times and three-dimensional positions. The universal coordinate system for this study will be Oregon south for TDA referenced to the NAD27 horizontal datum and the NGVD vertical datum. This is the same as for previous studies at Bonneville and The Dalles dams (Ploskey et al. 2005; Johnson et al. 2005). A reference position at each study site will be established. The measured fish position data and the measured ADCP data will be transformed to the universal coordinate system. Once the master biological and environmental data sets are ready, they will be merged. Merging allows the sequential positions and associated behaviors of ensonified fish obtained by the acoustic camera to be related to hydraulic data for each sequential fish location.

Observed fish movements are a combination of passive advection and active swimming. The active swimming component reflects fish behavior and is fundamental to the understanding of fish response to hydrodynamic conditions. To extract the active swimming component from the observed fish movement data, we will assume passive advection is represented by the ambient water velocity vector and subtract this vector from the observed fish movement vector. Johnson et al. (1998) used this approach, conceptualized as follows:

$$\overrightarrow{Fish}_{behavior} = \overrightarrow{Fish}_{observed} - \overrightarrow{Water}_{observed}$$

That is, for a given time increment, the vector difference between the displacements of fish and water is the active swimming or fish behavior component as follows:



For the analysis of fish/hydrodynamic relationships, the fish behavior vector will be the basic dependent variable and hydrodynamic and other environmental conditions will be the independent variables. Water acceleration and related variables (e.g., strain) are thought to influence fish behavior (Goodwin 2004), along with other environmental conditions such as the presence of predators, water temperature, and pressure. Thus, independent variables will likely include:

1. Total water velocity
2. Total water acceleration
3. Longitudinal component of water acceleration
4. Transverse vertical component of water acceleration
5. Transverse horizontal component of water acceleration
6. Water temperature
7. Hydrostatic pressure

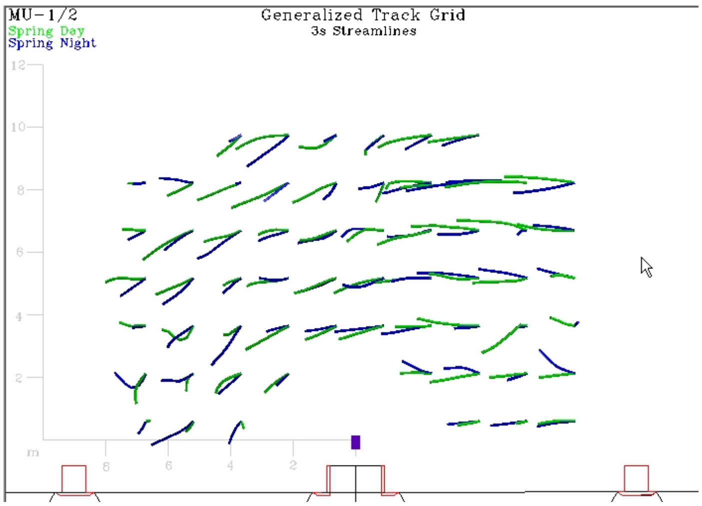
We will explore the data initially using frequency histograms, bivariate scatterplots, and correlation analyses. Because of the non-linear and complex nature of these types of data sets, we propose to apply multivariate statistical methods (Sokal and Rohlf 1981) to examine relationships between the dependent and independent variables. For example, a Principle Components Analysis will reveal any variables or combinations of variables that explain a majority of the variability (> 50%) in the dependent variable being analyzed.

<u>Assessment of Hypotheses about Fish Behavior at Vortices</u>

We will use fish track data relative to the position of the Bay 6 vortex to determine if a) juvenile salmonids are entrained by the vortex at Bay 6, and b) once in the vortex, the fish do not escape. This assessment will entail observing fish in the vicinity (1-2 m) of the vortex and then categorizing whether they became entrained in the vortex. Subsequently, we will sample the water column in the near the core of the vortex to observe whether fish swim out of the vortex once they are in it. The data will be presented as proportions of the total observed fish showing each behavior.

Example Data

Descriptive results from the DIDSON data sets will be useful to characterize fish movements in general and to foster comparison among sites. Typical descriptive data include the mean and standard deviations of observed fish velocities and computed fish swimming velocities. These data will be partitioned by time season, period within season, and day/night and, if appropriate, region of the forebay. The sampling volume will also be divided into cells to describe fish movements, as shown in the following example from Johnson et al. 2005:



Schedule

The draft final report will be submitted in December 2007. Response to review comments and submission of a final report will be completed by spring 2008.

Limitations of Proposed Methodology and Expected Difficulties

None.

D. FACILITIES AND EQUIPMENT - REQUIREMENTS

Required facilities include software and hardware to develop databases and tools to analyze the datasets. In addition, the following list of equipment will be necessary for this study.

- PAS hydroacoustic systems (owned by the Corps)
- DIDSON (owned by the Corps)
- ADCP: 600 kHz, standard footprint (owned by the Corps)
- Programmable stepper motor and cables (owned by the Corps)
- Vehicle (2 leased from GSA)
- Crane support (commercial for transducer mounts and Corps for VSD deployment)
- Commercial diving services to install turbine intake transducers (provided by the Corps under separate contract)
- Apparatus to deploy of DIDSON and ADCP (subcontractor)

E. IMPACTS

No unusual impacts on ongoing or proposed research or system operation are anticipated.

F. COLLABORATIVE ARRANGEMENTS AND/OR SUBCONTRACTS

This project will be a collaborative effort with staff from PNNL Ecology and Hydrology Groups. We will work closely with Drs. Marshall Richmond and Thomas Carlson and their CFD modeling and sensor fish research, respectively, at the TDA spillway. Authorship of the final report will reflect the contributions of all collaborating parties.

IV. KEY PERSONNEL AND PROJECT DUTIES

Principal Investigator: Gary Johnson (PNNL) will be responsible for overall conduct of the study, including design, data collection and analysis, and reporting.

Project Leader: Fenton Khan (PNNL) will be responsible for on-site coordination and execution of the study. He will collect and manage the data, develop databases, and analyze data.

DIDSON/ADCP Leaders: Bob Mueller and Bob Johnson (PNNL) will be responsible for data collection and processing for Objective 3.

CFD Modelers: Cindy Rakowski, Bill Perkins, and John Serkowski (PNNL) model spillway forebay flows.

V. TECHNOLOGY TRANSFER

Information acquired during the proposed work will be transferred in the form of written and oral research reports and scientific publications. In addition, a presentation will be made at the Corps' annual Anadromous Fish Evaluation Program Review for 2007. Technology transfer activities may also include presentation of results at regional or national fisheries symposia.

VI. LITERATURE CITED

Beeman, J., H. Hansel, P. Haner, and K. Daniel. 2005. *Estimates of fish, spill, and sluiceway passage efficiencies of radio-tagged juvenile steelhead and yearling Chinook salmon at The Dalles Dam, 2001.* Final report of research by the USGS Biological Resources Division submitted to the U.S. Army Corps of Engineers – Portland District.

Cash, K. and 13 co-authors. 2005. *Three-dimensional behavior and passage of juvenile salmonids at The Dalles Dam, 2004.* Draft final report by the USGS Biological Resources Division and PNNL submitted to the U.S. Army Corps of Engineers – Portland District. February 2005.

Counihan, T.D., G.S. Holmberg, C.E. Walker, and J.M. Hardiman. 2002. *Survival estimates of migrant juvenile salmonids in the Columbia River through The Dalles Dam using radio-telemetry, 2002.* Submitted to the U.S. Army Corps of Engineers, Portland District, September 2003, Contract No. W66QKZ10382025

Deng, Z., M. C. Richmond, and T. J. Carlson. 2006. *Characterization of The Dalles Dam spillbay 6 vortex using surface entrained sensor fish device.* Preliminary report submitted by PNNL to the U.S. Army Corps of Engineers, Portland District, PNNL-15883.

Faber, D. M,. M. E. Hanks, S. A. Zimmerman, J. R. Skalski, and P. W. Dillingham. 2005. *The distribution and flux of fish in the forebay of The Dalles Dam in 2003*. Final report by PNNL submitted to the U.S. Army Corps of Engineers – Portland District. PNNL-14628.

Goodwin R.A. 2004. *Hydrodynamics and juvenile salmon movement behavior at Lower Granite Dam: decoding the relationship using 3-D space-time (CEL Agent IBM) simulation.* Ph. D. Dissertation, Cornell University.

Hansel, H. C., S. D. Juhnke, P. V. Haner , L. Dingmon, and J. W. Beeman. 2005. *Estimates of fish, spill, and sluiceway passage efficiencies of radio- Chinook salmon during spring and summer at The Dalles Dam in 2004.* Draft final report of research by the USGS Biological Resources Division submitted to the U.S. Army Corps of Engineers – Portland District, April 21, 2005

Hausmann, B., J. Beeman, H. Hansel, S. Juhnke, and P. Haner. 2004. *Estimates of fish, spill, and sluiceway passage efficiencies of radio-tagged juvenile salmonids relative to the Sluiceway Guidance Improvement Device at The Dalles Dam in 2002.* Final report of research prepared by the USGS Biological Resources Division for the U.S. Army Corps of Engineers -- Portland District.

Johnson, G. E. M. E. Hanks F. Khan J. B. Hedgepeth R. P. Mueller C. L. Rakowski M. C. Richmond S. L. Sargeant J. A. Serkowski J. R. Skalski. 2005. *Hydroacoustic evaluation of juvenile salmonid passage at The Dalles Dam in 2004.* Final report by Battelle submitted to the U.S. Army Corps of Engineers – Portland District. PNNL-15180.

Johnson, G.E., M.E. Hanks, J.B. Hedgepeth, B.D. McFadden, R.A. Moursund, R.P. Mueller, and J.R. Skalski. 2003. *Hydroacoustic evaluation of turbine intake J-occlusions at The Dalles Dam in 2002.* Final report by Battelle submitted to the U.S. Army Corps of Engineers – Portland District. PNWD-3226.

Johnson, R. D. Daly and G. Johnson. 1998. *Combining hydroacoustics, flow models to study fish behavior.* Hydro Review 18:42-56.

National Marine Fisheries Service (NMFS). 2004. *Federal Columbia River Power System Biological Opinion: Operation of the Federal Columbia River Power System, Including 19 Bureau of Reclamation Projects in the Columbia Basin.* NMFS-NWR, Seattle, Washington. September 2004.

Ploskey G., T. Poe, A. Giorgi, and G. Johnson. 2001. *Synthesis of Radio Telemetry, Hydroacoustic, and Survival Studies of Juvenile Salmon at The Dalles Dam (1982-2000).* Final report submitted by Battelle to the U.S. Army Corps of Engineers – Portland District. PNWD-3131.

Ploskey, G. R. C. R. Schilt J. Kim C. W. Escher and J. R. Skalski. 2003. *Hydroacoustic evaluation of fish passage through Bonneville Dam in 2002.* Final report submitted by Battelle to the U.S. Army Corps of Engineers, Portland District, PNNL-14356.

Rakowski, C. L.. M. C. Richmond, J. A. Serkowski, and G. E. Johnson. 2006. *Forebay computational fluid dynamics modeling for The Dalles Dam to support behavior guidance system siting studies.* Final report submitted by PNNL to the U.S. Army Corps of Engineers, Portland District, PNNL-15689.

Skalski J. R., A. Hoffman, B. H. Ransom, and T. W. Steig. 1993. *Fixed-location hydroacoustic monitoring designs for estimating fish passage using stratified random and systematic sampling*. Canadian Journal of Fisheries and Aquatic Sciences 50:1208-1221.

Skalski, J. R., G. E. Johnson, C. M. Sullivan, E. Kudera, and M. W. Erho. 1996. *Statistical evaluation of turbine bypass efficiency at Wells Dam on the Columbia River, Washington*. Canadian Journal of Fisheries and Aquatic Sciences 53:2188-2198.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Company, San Francisco, CA.

Thorne, R. and G. Johnson. 1993. *A Review of Hydroacoustic Studies for Estimation of Salmonid Downriver Migration Past Hydroelectric Facilities on the Columbia and Snake Rivers in the 1980s.* Reviews in Fisheries Science 1:27-56.

U.S. Army Corps of Engineers (USACE), Bureau of Reclamation and Bonneville Power Administration. 2005. *2005-2007 Implementation Plan for the Federal Columbia River Power System Endangered Species Act Updated Proposed Action*. Portland, OR, May 2005.

Vischer, D.L. and W. H. Hager. 1998. Dam Hydraulics. John Wiley and Sons, New York.

VII. BUDGET

PNNL will provide a budget to the Portland District under separate cover.