Northwest Power and Conservation Council

February 8, 2006

MEMORANDUM

TO: Council Members

FROM: Doug Marker, Director
Fish and Wildlife Division

SUBJECT: Briefing on issues for evaluating load following effects on fish passage at mainstem dams

We will discuss a proposed evaluation of effects of load following on fish passage at mainstem dams. Steve Oliver, Bonneville's Vice President of Generation Analysis, will participate to present concerns about the context of such a study. I would appreciate Council discussion and guidance on further development of a proposed study and Bonneville's concerns.

Last year the ISRP urged the Council, NMFS and CRITFC to support a study on the effects of load following on outmigrating smolts in the Snake River. Load following is the operation of the hydrosystem to match energy consumption demand. The ISAB said that there is an important question of whether flow interruptions that occur from load following affect fish survival, particularly in low-flow years. They urged the region to initiate a study in 2005 anticipating a low-flow year and no spill operations in the summer (ISAB document 2005-3).

In response, the Implementation Team of the Regional Forum discussed the request and determined that it was not feasible to initiate such a test. Further, the subsequent injunction in the Biological Opinion mandated summer spill at the Snake River dams. Council staff asked for the development of a study proposal in the Scientific Review Work Group of the Regional Forum. A proposal has been prepared by the USGS and the Pacific Northwest National Laboratory (attached).

Following the ISAB's letter, Greg Delwiche; Bonneville's Vice President for Environment, Fish and Wildlife; urged the Council to obtain broader analysis of power system impacts and alternative generation needs for system capacity before recommending funding for the research proposal (attached). Steve Oliver will address those concerns.

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Independent Scientific Advisory Board
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April 29, 2005

To: Melinda Eden, Chair, Northwest Power and Conservation Council
Olney Patt, Jr., Executive Director, Columbia River Inter-Tribal Fish Commission
Usha Varanasi, Director, NOAA-Fisheries Northwest Fisheries Science Center
D. Robert Lohn, Regional Administrator, NOAA Fisheries

From: Eric J. Loudenslager, Chair, Independent Scientific Advisory Board

Re: Recommendation to Study Effects of Load Following on Juvenile Salmon Migratory Behavior and Survival

The ISAB recommends to the Council, NOAA Fisheries, and CRITFC that during 2005 there be a study of the effects of load following (flow interruption) on survival of outmigrant smolts in the Snake River and perhaps the lower Columbia River. We understand that there is a new Biological Opinion (BiOp) that bears on flow management, that this new BiOp is being challenged in court, and that there is a specific legal challenge seeking an injunction to increase flow in the Lower Snake River. Any or all of these may constrain the ability to manage flow during the period of outmigration of salmonid smolts this year. Nevertheless, 2005 presents an opportunity to answer critical questions concerning the effects of *flow interruption*, brought about by load following by the hydrosystem, on survival of migrating juvenile chinook and steelhead during extreme low flow conditions. This critical question is not explicitly discussed in the BiOp or the present challenges to it. The prospects for “no spill” this summer would simplify the design of the experiment. We are sorry that our recommendation comes so late in the season. The timeliness of inspiration cannot always be regulated. Although it is probably too late to include spring chinook and steelhead in the study, and estimating survival of fall chinook with sufficient precision to detect an effect of load flow interruption may be problematic, nevertheless the study should proceed, at least as a pilot study. At the very least it will provide useful information on whether flow fluctuations do or do not affect migratory behavior.

The ISAB views the question of fish survival during exceptionally low flow years as an important one. Although managers tend to think of extreme drought years as climatic anomalies that occur infrequently, recent evidence suggests that drought years tend to be somewhat clustered and that multiple low-flow years can occur over a short time period. Gedalof et al. (2004), using tree ring data to model Columbia River flows, concluded that low flow episodes have happened a number of times since 1750. The following figure from their paper illustrates the distribution of drought years.

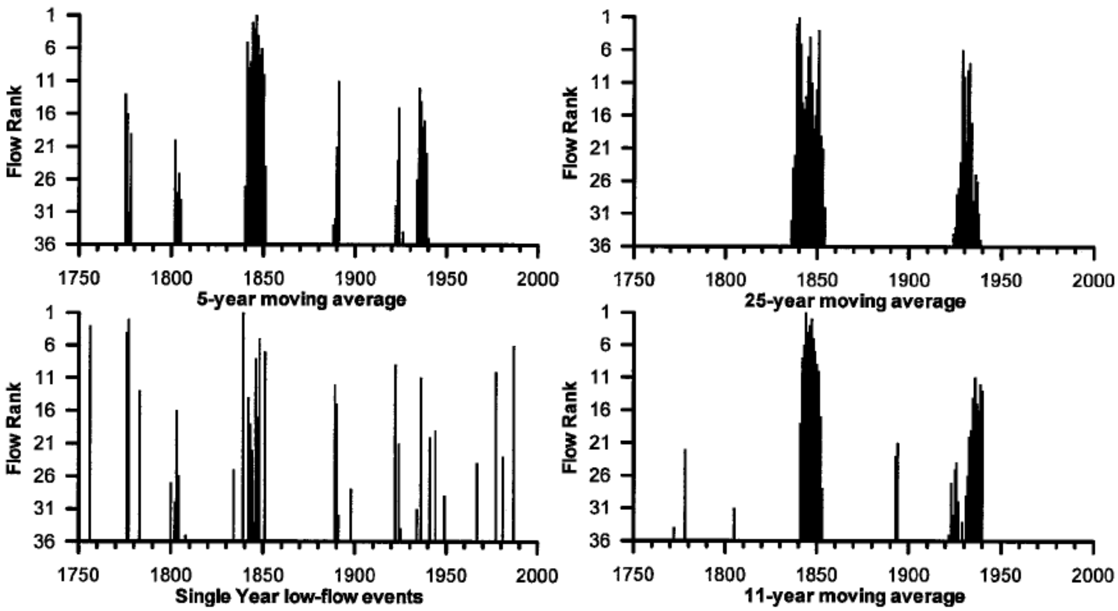

Figure 5. The Distribution of n-Year Moving Average Mean Flow for the Lowest 15th Percentile Over the Period of Reconstruction. Low rankings are indicated by longer bars, and represent lower flow events.

As these authors point out, the period 1950-1987 is unusual in the context of this flow record in having no multi-year drought events. Yet the Columbia River experienced a severe drought in 2001 and is apparently experiencing another in 2005. If we are entering a period of drought-prone years (especially one as severe as in 1835-1850), the issue of migrant survival during exceptionally low flows, with and without load following, becomes particularly important.

The neglected question, which could be addressed in this experiment, is whether low in-river survival rates and migration speeds often observed during extreme low flow conditions are in large part a consequence of abnormal cycles of flow interruption (and possible within-pool flow reversal) induced by load following at the dams, or a consequence of low flow itself (other effects such as temperature and season aside). The essential hypothesis justifying the experiment is that a pattern of relatively constant low flow would prove less damaging to in-river survival rate and migration speed than would the pattern of load following imposed on the same average flow. This issue was most recently discussed in the ISAB's report, *Review of Flow Augmentation: Update and Clarification* (ISAB 2003-1), which was an examination of flow augmentation. More detailed information is given there. The essential design of the experiment would involve temporal switching from "treatment" flow management (load following) to "control" flow management (constant flow with the same average flow), and back, at intervals of time that are long enough to satisfy the requirements of the fish marking method identified as being most likely to produce the "best" survival estimates. PIT tags and radio tags are the two marking technologies that we know are available. The choice of method for the existing circumstances would best be selected by agreement among the contractors presently engaged in studies in the Snake and Columbia rivers that could be modified to collect the relevant data. Information we have available at this time suggests that radio tagging would be most likely to produce the desired results this year. We discuss this suggestion further below.

The essential design issues are:

1. Obtaining a good enough match between "treatment" time blocks and "control" time blocks so that extraneous environmental factors (other than the treatment with load following or the control with stable flows) that might operate differently at those times do not confound the results. Possible confounding factors include temperature, turbidity, average flow, smoltification status, and condition of the released fish. The match (and the effects of mismatch) will be affected by the choice of the time period for the experiment and the number of treatment/control pairs that can be established.
2. Providing a large enough sample size of releases to allow survival rates and migration speed estimates to be made with sufficient precision from the recoveries so that the treatment effect can be resolved against the noise of sampling variation and the possible effects of confounding factors (time block effects).

Existing information about survival rates, migration rates, detection rates, and the variation in these rates should be adequate for arriving at a design with useful anticipated statistical performance (power). It would not be worthwhile to proceed with an expensive experiment bearing on a possibly controversial management issue, unless the design shows prospects for delivering reasonably conclusive results.

The goal of the experiment is to obtain data that would inform the region whether flow interruption substantially affects survival or migration behavior of tagged smolts migrating in the river(s). The study objectives would include description of behavior and if feasible estimation of relative survival of tagged groups of hatchery chinook and/or steelhead: 1) with flow interruption and 2) without flow interruption. We assume that hatchery fall chinook during summer would be the best test fish and time period for the study this year. Prediction of the effects on wild populations would only require the assumption that the relative rates estimated for the two tagged groups are approximately the same. If the hypothesis is correct, the experiment would benefit all in-river migrants, including any wild fish migrating in-river. The design we outline does not specifically attempt to generate estimates for unmarked fish migrating in river. Carrying out the experiment should not raise any ESA issues.

We suggest the design use fixed alternating periods (e.g., with a length of one week), following a random start to avoid the possibility of clumping of particular test or control groups at the beginning or end of the study. This would take into account, insofar as possible the known fact that survival shows a trend with time due to temperature and other factors, including degree of smoltification, turbidity, and volume of flow.

Although PIT tagged fish might be used to estimate survival, there is a possible complication in that as a batch of test fish moves through the hydrosystem they tend to migrate at different rates. This is particularly true for fall chinook. Thus, the PIT tagged fish in a batch may not all be subject to the same treatment or control. We suggest using radio tags for the survival estimates, because their use would make it possible to regroup the fish into treatment and control groups based upon their known locations through the study period. In any case, the information provided on their migration routes will indicate whether there is an effect of the different flow conditions.

We understand that NOAA Fisheries, the USFWS and NPT will be conducting a transportation study in the Snake River and will be making weekly survival estimates through the period of outmigration, using recoveries of PIT tagged fish at detectors located at the dams. These estimates may be useful as is, but NOAA Fisheries scientists should be consulted. In addition, we understand that other agency employees will be conducting radiotracking studies of juvenile salmonids during the migration period. It would be necessary to bring key agency scientists together to formulate and approve an appropriate study design. We foresee little additional costs associated with this study beyond existing budgets, except in two areas: 1. Responsibility for submitting to the Council a written study design, and a completion report providing an analysis of results should be assigned to one or more of the participating agencies; 2. Monitoring of flows between the dams included within the study reach should be done with the objective of detecting any unusual effects of flow interruption on downstream movement of the river, such as the seiches observed in the ISAB 2003-1 report. We know of no existing study that might add this to their list of tasks, so a new project might need to be established.

We have thought of the Lower Snake River as a logical location for this test. The four lower Snake River hydropower projects are operated more or less as a unit because of their limited storage capacity combined with limitations of fluctuations in reservoir elevations specified in the BiOp. That being the case, to accomplish the study objectives in that reach would require close cooperation of Idaho Power Company in the operations of the Hells Canyon complex to provide storage and release of water according to the schedule in the study design.

Action Steps:

1. Assign agency personnel currently involved in survival or behavior studies of juvenile salmonids the task of developing a detailed study plan to accomplish the objective of measuring the effect of flow fluctuations associated with hydrosystem load following.
2. Commence discussions with the hydrosystem operators to develop a schedule for load following alternating with no load following to fit the study design.
3. Fund a project to monitor hydraulic conditions in the reservoirs for the purpose of detecting any unusual patterns of flow that might result from flow fluctuations due to load following.
4. Fund, if necessary, a project specifically designed to coordinate the collection of necessary data and to provide a summary report focused upon the question whether flow fluctuations affect survival, and if so to what degree.

References Cited

Gedalof, Z., D. L. Peterson, and N. J. Mantua. 2004. Columbia River flow and drought since 1750. Journal of the American Water Resources Association, December 2004:1-14.

ISAB 2003. Independent Scientific Advisory Board. (11 members). Review of Flow Augmentation: Update and Clarification. Report to the Northwest Power Planning Council, Portland, OR. ISAB 2003-1, February 10, 2003. 69 pp. www.nwcouncil.org/library/isab/isab2003-1.htm

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Department of Energy

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ENVIRONMENT, FISH AND WILDLIFE

July 12, 2005

In reply refer to: KEW

Mr. Doug Marker and Mr. Bruce Suzumoto
Northwest Power and Conservation Council
851 SW Sixth Avenue Suite 1100
Portland, Oregon 97204-1348

Subject: ISAB Proposed 2005 study on load-following, Council response letter

Dear Mr. Marker and Mr. Suzumoto:

This letter is in response to the draft copy of your memo to the Council explaining the issues with implementing the ISAB-proposed study of the effects of load following on fish behavior and survival this summer in the lower Snake River. We also have a copy of the research summary that you developed for inclusion into the Corps of Engineers' Anadromous Fish Evaluation Program's (AFEP) process for identifying, refining, and coordinating research needs and proposals for 2006. The purpose of this letter is to request that the Council address the broad policy issue raised by this research. I believe it is important to address both the policy and technical issues before a decision is made to recommend funding a load-following study.

The idea of a load following study raises substantial policy issues, as pointed out in your memo. The fundamental question is whether it is feasible for the proposed operation to be implemented for the long-term. This question goes beyond the load following at the lower Snake River dams, as load following occurs at all of the mainstem Snake River and Columbia River Dams where fish passage is of utmost concern. Taken together, these dams generate a significant portion of the energy consumed in the Pacific Northwest. So far, there has been no plan or discussion of how to address the policy issue raised by this research proposal. We believe it is important for the Council's Power Division to address the broad policy issues in preparation for determining the priority of funding this proposed research next year. More specifically, we request that the Council staff analyze the potential impacts of discontinuing load-following operations at the mainstem Snake River and Columbia River dams, including federal and non-federal dams (i.e. mid-Columbia and Hells Canyon). We would also like the Council staff to prepare an analysis of potential alternatives to meet the end-use power loads that these dams currently shape their output to meet. Generation and transmission infrastructure ramifications, as well as economic and rate effects, would need to be evaluated. This analysis will be critical to us in determining the priority of funding the proposed load following research.

Finally, we understand that the intent is to work within the Corps of Engineers' AFEP process to address technical issues and challenges to developing a statistically valid load following research proposal. Then, after adequate technical development, if a study is feasible, the proposal will be submitted as an FY06 within-year request for BPA funding consideration under the Northwest Power and Conservation Council's Program. However, we ask that the Council address the policy issues of power peaking before we receive a research proposal.

Please contact either me, or Kim Fodrea of my staff, to discuss this request further. We look forward to continuing discussion of this research proposal in the near future.

Sincerely,

/s/

Gregory K. Delwiche, Vice President
Environment, Fish & Wildlife

RESEARCH PROPOSAL

TITLE: Determining the effects of load following on reservoir hydraulics and migration behavior of juvenile salmonids.

CO-PROJECT LEADERS:

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PERFORMANCE PERIOD: January 1, 2006 through December 31, 2006.

DATE SUBMITTED: December 14, 2005

PROJECT SUMMARY

RESEARCH GOALS

The goal of this project is to measure the behavioral response of juvenile salmonids to load following operations in the reservoir upstream of Little Goose Dam (i.e., Lake Bryan). To fully understand this response, both hydraulic conditions in the reservoir and fish movements will be measured concurrently. In addition, the project will utilize previously developed hydrodynamic and water quality models of the reservoir to link behavioral response to hydraulic conditions.

STUDY OBJECTIVES

Objective 1: Quantify the effects of load following operations on the migrational behavior of juvenile salmonids.

Objective 2: Quantify transient hydraulic conditions in the reservoir that result from load following and other phenomena via direct measurements (ADCPs, temperature loggers, etc.).

Objective 3: Relate transient hydraulic conditions to migrational behavior of juvenile salmonids using collected field data and numerical modeling.

METHODOLOGY

To meet the first study objective, we propose the use of radio telemetry techniques to examine the behavior juvenile salmonids migrating through the reservoir upstream of Little Goose Dam. This reservoir was selected because the USGS is planning to measure passage behavior and survival at Lower Granite Dam (Study Code: SBE-W-05-2) and Little Goose Dam (Study Code: SPE-W-04-2) concurrent with this proposed study. The incremental costs to examine fish behavior relative to load following operations in the reservoir would therefore be relatively low.

Since the objective is to quantify the response of juvenile salmonids to load following operations, migration behavior must be measured on smaller temporal and spatial scales than typically implemented in a typical radio-telemetry study. We propose to use a series of closely-spaced telemetry arrays (about 1.5 – 3 km apart) that will result in travel times of 1-3 h between arrays. This approach will allow us to examine migration behavior as a function of time of day, which is important both biologically and for capturing diurnal fluctuations in discharge through the reservoir which are a direct result of load following operations. In addition, we propose conducting mobile tracking of juvenile salmonids within the study reaches. Mobile tracking data will help identify specific locations where fish travel in the channel cross-section and identify behavioral patterns occurring at scales less than the distance between telemetry arrays.

To meet the second study objective, we propose collecting vertical profiles of water velocity and water temperature throughout the reservoir. Water velocity measurements will be collected using self-contained bottom-mounted acoustic Doppler current profilers (ADCPs) to obtain time-series velocity fluctuations. In addition to the bottom-mounted ADCPs, boat-mounted ADCPs will be used to understand velocity gradients between bottom-mounted ADCP locations, and will be collected in conjunction with the mobile tracking of fish movements. Time-series profiles of water temperature will be collected by suspending self-contained temperature loggers on wire rope at several locations throughout the reservoir. Several of these temperature loggers contain pressure sensors and dynamic variations in water surface elevation will also be collected. During summer periods when the reservoir is stratified, additional temperature profiles will be collected using a conductivity-temperature-depth (CTD) probe. These measurements will be made in conjunction with the mobile ADCP and fish tracking.

The third study objective will link observed patterns in diel behavior of juvenile salmonids with hydraulic variables. This will be accomplished using the datasets collected under the first two objectives and through the use of numerical models. PNNL has previously developed 2D and 3D models of the reservoir, and these models will be used to better understand hydraulic transients induced by reservoir operations (e.g., load following) and meteorological conditions. Numerical modeling results will also be used by the Lagrangian particle tracking model FINS to develop integrated metrics (e.g., integrated travel times and temperature exposures for a generic streamline versus particle with 5 m depth preference) that can be compared over the passage season. The numerical models will also be used before the field data is collected to aid prediction of various hydraulic phenomena in the reservoir and where best to locate fixed telemetry arrays and bottom-mounted ADCPs.

RELEVANCE TO THE BIOLOGICAL OPINION

Although the status of the 2004 BiOp UPAs is currently in flux (see rulings by the U.S. District Court [Oregon, June 2005] and Ninth Circuit Court of Appeals [July 2005]), the following sections are germane to this project:

- **UPA, Section IV. RM&E Substrategy 1.3: Hydrosystem Corridor Monitoring, pg 90** "Monitor smolt condition relative to biological and environmental conditions" and "Effectiveness research that quantifies the effect of hydrosystem fish passage improvement actions on the survival of juvenile and adult anadromous fish."
- **UPA Section IV. RM&E Substrategy 2.1: Hydrosystem, pg 91** "Study the effect of summer flow augmentation on water temperature velocity, and juvenile fall Chinook salmon migratory behavior and survival in Lower Granite Reservoir."
- **UPA, Section III.E. ESP Specific Actions, Key Alternatives Under Development, Measures that address TDG and Temperature, Temperature Measures, pg 43** "Action Agencies have been working…to develop a plan to model water temperature effects of alternative Snake River Operations. Action Agencies will continue to refine the water temperature model [CE-QUAL-W2] and its use as a river operations management tool."
- **2000 BiOp RPA 141** The Action Agencies shall evaluate juvenile fish condition due to disease in relation to high temperature impacts during critical migration periods. It is essential to acquire a better base of information to understand the sources of fish disease and mortality at the lower Columbia and lower Snake River dams during critical fish migration periods and high temperature events. This information could be used to better understand the effect of high water temperature on juvenile fish survival
- **2000 BiOp RPA 143**. The Action Agencies shall develop and coordinate with NOAA Fisheries and EPA on a plan to model the water temperature effects of alternative Snake River operations. The modeling plan shall include a temperature data collection strategy developed in consultation with EPA, NOAA Fisheries and state and tribal water-quality agencies. The data collection strategy

shall be sufficient to develop and operate the model and to document the effects of project operations.

PROJECT DESCRIPTION

BACKGROUND

Reservoir drawdown, flow augmentation, and spill have been identified as potential means of improving the survival of migratory salmon smolts, thereby assisting the recovery of threatened and endangered salmon stocks. The U.S. Army Corps of Engineers (COE) has worked with regional, state, and federal resource agencies to design and implement experiments to determine which management alternatives would provide significant biological benefits to out-migrating smolts. Recently, the Independent Scientific Advisory Board (ISAB 2003) reviewed and clarified the effects of flow augmentation on survival of juvenile salmonids. In this review, the ISAB hypothesized that load following operations at hydroelectric projects may compound the negative effects of low discharge on migration timing and survival of juvenile salmonids. They also suggest that stable hourly flows may increase survival.

Load following occurs when dams vary power generation throughout the day to increase generation during peak power demand periods and reduce generation when demand is low. These operations result in hourly fluctuations of discharge that can be large relative to mean daily flows. At Little Goose Dam for example, total discharge can vary by up to 40 kcfs within a day, representing fluctuations from the mean discharge of up to 30% during the spring and 60% during the summer (Figure 1). Hourly discharge generally follows a consistent daily pattern, with discharge being lowest at night, increasing in the morning, and peaking in the early evening hours (Figure 2). Fluctuating discharge also causes hourly changes in reservoir elevations that follow similar patterns to hourly discharge, except with maximum elevations occurring during mid-day and minimum elevations occurring in the early evening. The ISRP raised concerns that large fluctuations in both discharge and reservoir elevation could interact to produce seiches (i.e., the sloshing bathtub effect) that result in widely fluctuating hydraulic conditions in the reservoir. These changes in discharge and reservoir hydraulics may disrupt or change the hydraulic cues used by juvenile salmonids for directed downstream movement.

The ISAB hypothesized that load following operations could be an important factor contributing to poor survival during low discharge (ISAB 2003). The prevailing hypothesis driving flow augmentation is that increases in discharge will increase water velocity and smolt migration rates through reservoirs, reducing the time that fish are exposed to factors causing mortality (ISAB 2003). Recently, discharge thresholds have been identified, only below which are discharge and survival linked (Smith et al. 2002). Plumb et al. (2003; In press) identified behavioral mechanisms that help explain poor survival during low flow. They found 1) that travel times of juvenile salmonids are non-linearly related to discharge, with a threshold at about 100 kcfs below which travel times increased considerably with further decreases in discharge, 2) upstream travel increased substantially (both the proportion of fish and the number of upstream trips per fish) below the discharge threshold, and 3) that upstream travel was largely responsible for the observed increases in travel time (Plumb et al. 2003; In press).

During the summer flow augmentation periods of 2003 and 2004, a mid-pool temperature anomaly was noted in LGS and LMN reservoirs, when temperature logger data at similar depths were compared between mid-pool and downstream in the forebay BRZ (Cook et al. 2005). This anomaly consisted of mid-pool epilimnetic (typically the top 5 to 10 m) temperatures 1°C to 3°C warmer than downstream at the forebay BRZ (see Figure 3; note: phenomenon occurs whenever the red line is above the green and blue BRZ lines). PNNL, under contract with BPA, performed a synoptic ADCP and CTD survey to collect water velocity and temperature profiles in LMN and LGS reservoirs to unravel this anomaly on July 24, 2005 (see Figure 4). On this day, the reservoir was stratified at mid-pool, with a vertical temperature difference of approximately 2.5°C. BRZ epilimnetic temperatures were also less than mid-pool by approximately 1.3°C, indicating presence of the anomaly. ADCP data, such as the water direction contour plot shown in Figure 4, suggests that wind setup may be the most likely cause. In the upper ~5m portion of the water column, water magnitudes were generally small although moving slowly (0 to 10 cm/s) upstream. Beneath the thermocline, water velocities were moving relatively quickly in the downstream direction.

Although juvenile salmonid migrational behavior observed during periods of low discharge may be associated with poor survival, what remains unclear is the underlying mechanisms leading to the observed thresholds in travel time, upriver travel, and ultimately, survival. Are slow migration times, increased upriver travel, and poor survival during low discharge periods due simply to low mean discharge? Could these patterns be due to the large diel fluctuations in discharge relative to the mean flows? Could these patterns be due to wind setup? Most likely all factors contribute, however the interaction between load following, low total river discharge, onset of reservoir stratification, and wind setup are poorly understood. This proposal aims to clarify and answer questions raised by the ISAB about the effects of load following operations and surface wind setup on the behavior of juvenile salmonids in the reservoir.

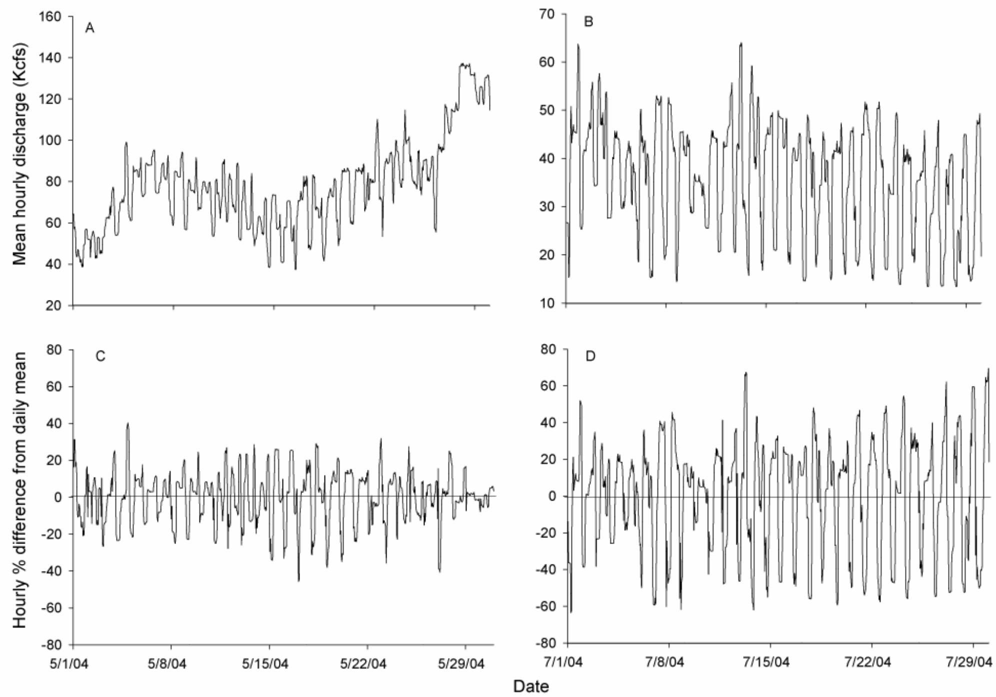

Figure 1 Mean hourly discharge during A) May and B) July and percent deviation of hourly discharge from the mean daily discharge during C) May and D) July at Little Goose Dam during 2004. Note: y-axis scales are different for plots A and B.

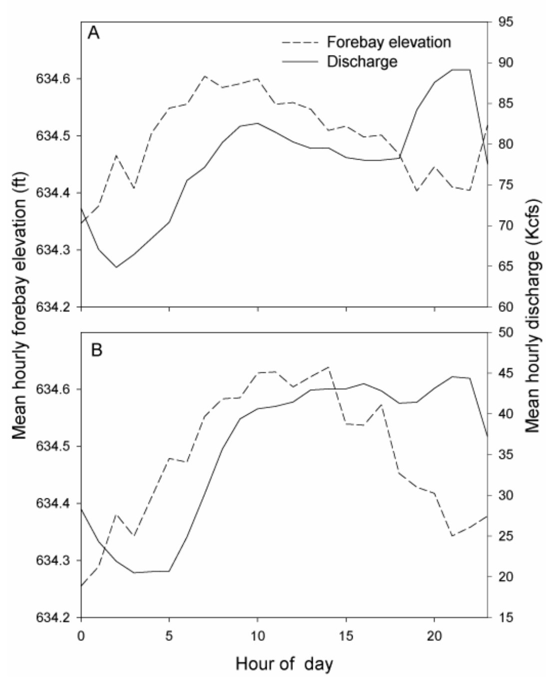

Figure 2 Mean hourly discharge and forebay elevation averaged by hour of the day for the months of A) May and B) July at Little Goose Dam during 2004.

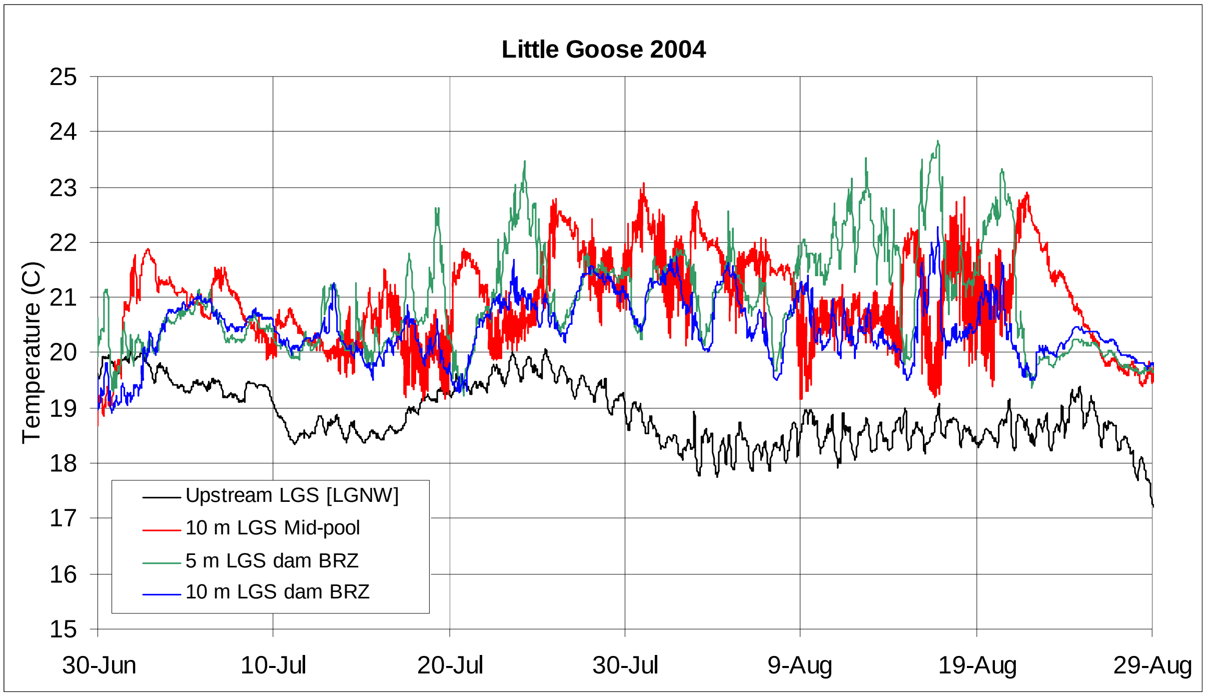

Figure 3 Time series of water temperatures in the Little Goose Reservoir during 2004. Mid-pool loggers were collected at approximately the same location as the ADCP transect in Figure 4, and forebay BRZ loggers were located at approximately the dot closest LGS dam in Figure 4. Raw data from Joe Carroll, USACE contractor, OA Systems Inc.

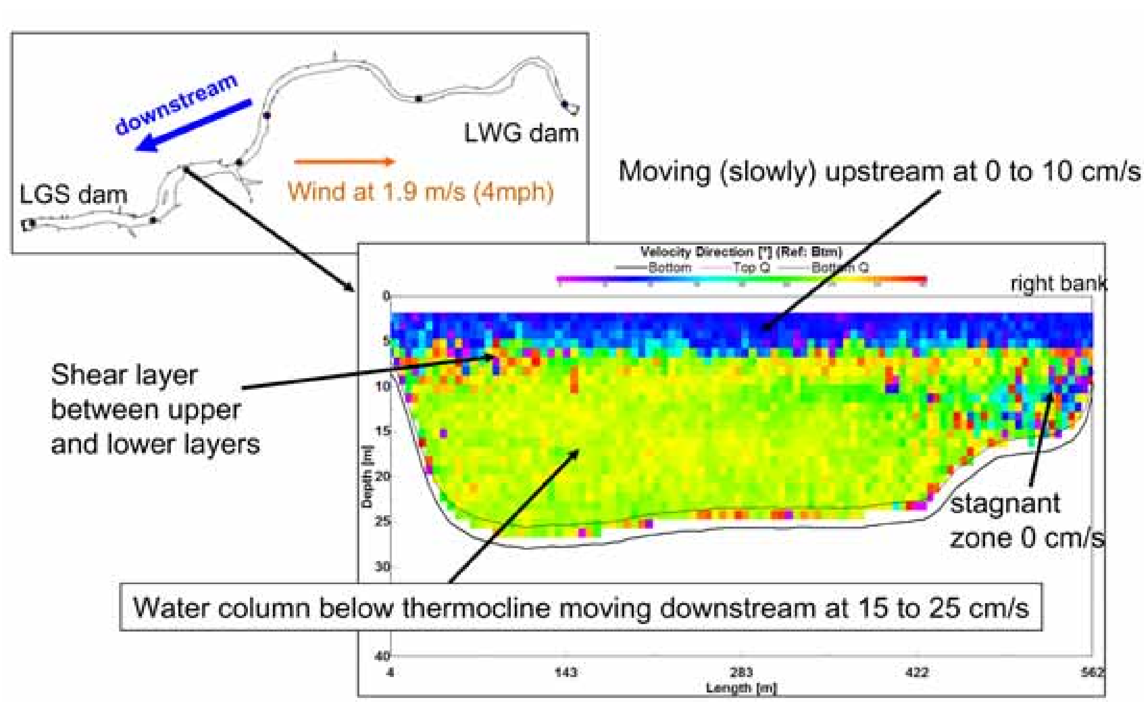

Figure 4 Lateral transect of water velocity directions collected on July 24, 2005 at mid-pool. Reservoir was stratified, and a 1.2°C temperature difference existed between mid-pool and the forebay BRZ at a depths smaller than 4 m. Data collected by PNNL.

CURRENT STATUS

The USGS has conducted research at Lower Granite Dam since 1994 and at Little Goose Dam, from 1995 to 1997 and in 2005. Detailed results from this research can be found in the annual reports to the U.S. Army Corps of Engineers. The primary objective of this research has been to evaluate passage structures such as the Surface Bypass Collector (SBC), the Behavioral Guidance Structure (BGS), and the Removable Spillway Weir (RSW). In addition, multiple years of data over a range of environmental conditions have helped quantify thresholds in the relations between travel time, upriver travel, and discharge that are important for understanding the effects of low discharge on survival of juvenile salmonids (Plumb et al. 2003; In press).

PNNL has collected ADCP and water temperature time-series data in Lower Granite Reservoir since 2002 under BPA Project 2002-027-00, which ends in January 2006. This research has focused on stratification and the influence of cold hypolimnetic releases from Dworshak Dam on the cascade of lower Snake River reservoirs (Cook et al 2005). As part of a collaborate arrangement organized through the 2000 Bi-Op RPA 143 group, USACE contractors collected water temperature time-series data at mid-pool and forebay BRZ upstream of Ice Harbor, Lower Monumental, and Little Goose dams. PNNL's contribution to the group was to develop real-time capable 2D models (CE-QUAL-W2) of the lower Snake River using these data as calibration and validation sets. PNNL has also developed 3D models (EFDC) for each lower Snake River reservoir and the Lagrangian particle tracking model FINS (Scheibe and Richmond 2002) for the Walla Walla District, US Army Corps of Engineers. FINS has been linked for use with both the 2D and 3D models. Researchers at PNNL also have proven experience measuring seiche and wind driven circulation in lakes using temperature loggers and ADCPs, and simulating these transients using numerical models (Cook 2000 and Cook et al. 2002).

Other studies are currently proposed by USGS for 2006 at Lower Granite and Little Goose dams, which would substantially reduce the cost of conducting the research proposed here. For 2006, the USGS has submitted proposals to estimate survival and migration behavior of juvenile salmonids at Lower Granite Dam (Study Code: SBE-W-05-2) and Little Goose Dam (Study Code: SPE-W-04-2). At Lower Granite Dam, we proposed to release up to 2,000 radio-tagged fish of each population (yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon) to estimate survival and passage behavior in response to the operation of the Behavioral Guidance Structure. For Little Goose Dam, additional fish may be released into the tailrace of Lower Granite Dam. Fish tagged for these studies could be used to quantify the effects of load following on behavior of juvenile salmonids, eliminating the need to tag additional fish for objectives outlined in this proposal.

PROJECT OVERVIEW

We propose the use radio telemetry to quantify the effects of load following operations on the migration behavior of juvenile salmonids in the reservoir upstream of Little Goose Dam. To quantify the response of juvenile salmonids to load following operations, it will be necessary to measure variation in migration behavior on smaller temporal and spatial scales than typically implemented in a radio-telemetry study. Typically, telemetry arrays within the reservoir are separated by 10-25 km and median travel times through these reaches can range from 18 h to 36 h (unpublished data for subyearling Chinook salmon in Little Goose Reservoir, 2005). Because discharge changes on an hourly time scale throughout the day, travel times through reaches of this length are averaged over the diel cycle, masking possible effects of load following operations on migration behavior of juvenile salmonids.

We propose to use a series of closely-spaced telemetry arrays (about 1.5 – 3 km apart) that will result in travel times of 1-3 h between arrays (Figure 5). This approach will allow us to examine migration behavior as a function of the time of day as discharge varies due to load following operations. Specifically, we will examine migration rates, travel times, and upriver travel (proportion of population exhibiting upriver travel and frequency of upriver trips per fish).

The distance that fish travel upriver and the frequency of upriver trips is also likely driven by the spatial scale of observation. For example, fish probably make numerous short forays upstream and fewer long distance forays. Therefore, we expect our study design will be able to capture substantial upriver travel at the scale of 1.5-3 km since upriver travel has been observed at much larger spatial scales (Plumb et al. 2003, In Press). To understand of potential wind setup and stratification, the study will divide the reservoir into upper, middle, and lower sections. We propose to use 5 telemetry arrays each in the upper and lower reservoir and 3 arrays in middle (Figure 5).

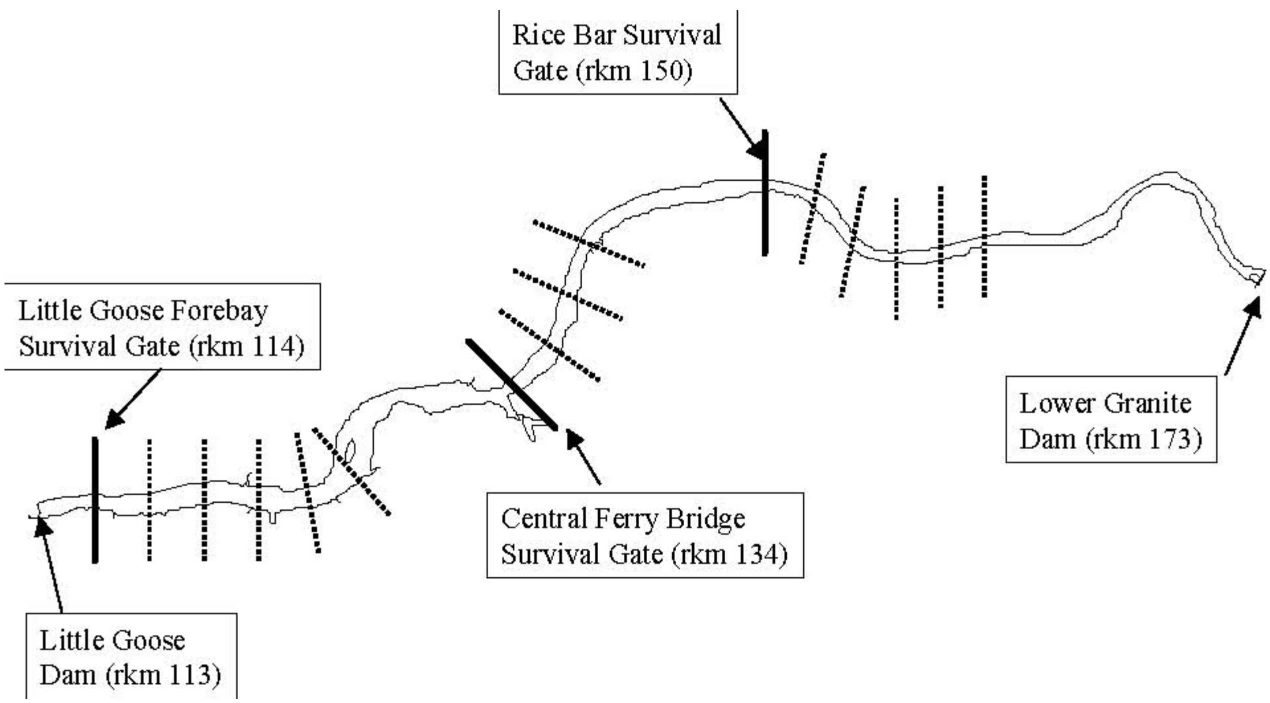

Figure 5 Little Goose Reservoir showing Lower Granite and Little Goose dams, telemetry arrays currently deployed for estimating survival of juvenile salmonids (solid lines), and dashed lines showing approximate locations of proposed telemetry arrays spaced 1.5-3 km

To obtain yet finer-scale data to support water velocity and fixed-station telemetry data, we propose to conduct mobile tracking of juvenile salmonids within the study reaches. The location of individual fish will be recorded with GPS every 0.5 h within a study reach. This data will quantify spatial patterns of fish migration to determine if fish tend to migrate in certain areas of the channel cross-section (e.g., the thalweg). This data can help focus analysis of water velocity data to better understand the patterns of water velocity (e.g, wind setup and stratification) where fish are migrating in the river channel. Mobile tracking data will also help identify whether upriver travel occurs at scales smaller than the distance between telemetry arrays. Upriver travel at smaller scales than the distance between telemetry arrays would not be captured by fixed telemetry arrays.

We propose collecting vertical profiles of water velocity and water temperature throughout the reservoir. Water velocity measurements will be collected using self-contained bottom-mounted acoustic Doppler current profilers (ADCPs) to obtain time-series velocity fluctuations. The project will deploy at two bottom-mounted ADCPs. One will be located just upstream of the forebay BRZ and the second will be located near mid-pool (near Central Ferry). Data will be collected at a frequency of (at least) every 15 minutes throughout the migration season. In addition to the bottom-mounted ADCPs, boat-mounted ADCPs will be used to understand velocity gradients between bottom-mounted ADCP locations, and will be collected in conjunction with the mobile tracking of fish movements.

Time-series profiles of water temperature will be collected by suspending self-contained temperature loggers on wire rope (i.e., a thermistor sting) at six locations throughout the reservoir. These locations correspond to the start and end of the three telemetry arrays shown in Figure 5. Data will be collected at intervals of approximately every 10 minutes. Each thermistor string will contain at least one temperature logger with an integrated pressure sensor to record variations in water surface elevation throughout the reservoir. These loggers, made by SeaBird (SBE39), will collect data at the much higher rate of one sample per minute. During summer periods when the reservoir is stratified, additional temperature profiles will be collected using a conductivity-temperature-depth (CTD) probe. These measurements will be made in conjunction with the mobile ADCP and fish tracking.

Meteorological conditions are automatically recorded by the Agri-Met Meteorological Station at Rice Bar. This site will collects information on incoming solar radiation, air temperature, and relative humidity, wind speed and wind direction, which are necessary for computing surface heat exchange in the numerical models.

This study will also link observed patterns in diel behavior of juvenile salmonids with hydraulic variables. This will be accomplished using the datasets collected under the first two objectives and through the use of numerical models. PNNL has previously developed 2D and 3D models of the reservoir, and these models will be used to better understand hydraulic transients induced by reservoir operations (e.g., load following) and meteorological conditions. Numerical modeling results will also be used by the Lagrangian particle tracking model FINS to develop integrated metrics (e.g., integrated travel times and temperature exposures for a generic streamline versus particle with 5 m depth preference) that can be compared over the passage season. The numerical models will also be used before the field data is collected to aid prediction of various hydraulic phenomena in the reservoir and where best to locate fixed telemetry arrays and bottom-mounted ADCPs.

OBJECTIVES AND METHODOLOGY

Objective 1: Quantify the effects of load following operations on the migrational behavior of juvenile salmonids.

To quantify the effect of load following operations on juvenile salmonids, we will release radio-tagged juvenile salmonids during the spring (mid-April through May) and summer (June through July) migration periods. Fish will be tagged and released as part of other ongoing studies and their migration behavior will be measured through a series of 1.5-3 km reaches (see Figure 5). Expected travel time of actively downstream migrating fish is 1-3 h. Mobile tracking over the diel cycle will also be used to identify fine-scale behavior of individual fish.

Schedule of tasks

Task 1.1: Install closely-spaced (1.5-3km) fixed monitoring sites at 5 sites in the upper part of the reservoir, 3 sites in the middle, and 5 sites in lower part of Little Goose Reservoir (see Figure 5).

Activity 1.1.1 Install, calibrate, and test aerial antenna arrays in Little Goose Reservoir.
Collaborator Lead: USGS

Task 1.2: Conduct releases of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon in Lower Granite Reservoir during 2006.

Activity 1.2.1 Continue to develop analytical procedures for examining radio-telemetry data. We will consult with statisticians as the Region reaches consensus on a design for the 2006 test.
Collaborator Lead: USGS

Activity 1.2.2 Determine the release site, the number of fish per release, and the time interval between releases. We propose that the release site be located at Blyton Landing for treatment releases and the tailrace of Lower Granite Dam for control releases. Blyton Landing has been the primary release site used since 1996. This site appeared to be far enough upriver of the dam to allow fish to recover from the stress associated with the tagging procedure, but still allowed us to have some control over fish arrival time at the dam.
Collaborator Lead: USGS

Activity 1.2.3 Complete the necessary Endangered Species Act and documentation and obtain the necessary permits and approval to work in the Snake River.
Collaborator Lead: USGS and PNNL

Activity 1.2.4 Coordinate with appropriate agencies to sequester, implant tags, and release smolts April and August 2006.
Collaborator Lead: USGS

Activity 1.2.5 Monitor the movements of radio-tagged fish as they migrate through Little Goose Reservoir. This will be done in conjunction with the mobile ADCP and water temperature profile data collection described in Activity 2.2.1.
Collaborator Lead: USGS

<u>Objective 2</u>: Quantify transient hydraulic conditions in the reservoir that result from load following and other phenomena via direct measurements (ADCPs, temperature loggers, etc.).

To quantify the transient effects of load following, onset of thermal stratification, and wind setup in the reservoir, detailed hydraulic measurements will be conducted. These include the deployment of self-contained ADCPs, temperature loggers, and pressure sensors. In addition, synoptic 'snapshots' of hydraulic conditions will be collected throughout the reservoir to understand how conditions vary between the fixed monitors.

Schedule of tasks

Task 2.1: Deploy and maintain fixed hydraulic equipment.

Activity 2.1.1 Install and maintain two bottom-mounted ADCPs. Two RD Instuments WorkHorse Sentinel ADCPs will be deployed in the reservoir during the field season. Near the forebay BRZ where water depths are deepest, a 600 kHz unit with pressure sensor and 'waves' will be deployed. Near the mid-pool, a 1200kHz unit will be deployed. Data will be collected at a frequency of (at least) every 15 minutes. The ADCPs run on battery packs and will be downloaded/maintained once per month.
Collaborator Lead: PNNL.

Activity 2.1.2 Install and maintain six thermistor strings. Strings will be located at the upstream and downstream ends of the three radio-telemetry arrays shown in Figure 5. Self-contained temperature loggers will be connected together using wire rope and deployed using bottom weights, a sub-surface buoy, and a surface buoys (see Cook et al 2002). Loggers will be spaced at a 2 to 3 m vertical interval in the hypolimnion and an increased vertical resolution of 1 to 2 m in the expected epilimnion and thermocline region. These locations will be based upon observed 2003 and 2004 mid-pool and forebay BRZ data. Data will be collect at a frequency of (at least) every 10 minutes. The temperature loggers will be downloaded/maintained once per month.
Collaborator Lead: PNNL.

Activity 2.1.3 Install and maintain pressure sensors. On each of the six thermistor strings, pressure sensors (SeaBird SBE 39s) will be deployed to record changes in water surface elevation. These loggers will be programmed to collected data at a frequency of once per minute to record the occurrence of surface elevation changes due to load following. The pressure sensors will be downloaded/maintained once per month.
Collaborator Lead: PNNL.

Task 2.2: Collect mobile ADCP and water temperature profile data

Activity 2.2.1 Mobile ADCP and water temperature profile data will be collected to understand how hydraulic conditions vary between the fixed monitors. Data will be collected in conjunction with the mobile radio tracking described in Activity 1.2.5. ADCP data will

be collected with either a 1200 kHz or 600 kHz RDI ADCP. Real-time differentially corrected GPS data will be collected concurrently with the ADCP measurements.
Collaborator Lead: USGS with setup and processing assistance by PNNL.

Objective 3: Relate transient hydraulic conditions to migrational behavior of juvenile salmonids using collected field data and numerical modeling

This objective will relate the hydraulic data and radio-tagged fish information to the larger hydraulic circulation pattern. The numerical models developed by PNNL include calibrated and validated 2D (Cook et al 2005) and 3D (Rakowski et al. 2003) hydrodynamic and water quality models. These model are capable of examining load following, wind setup, and onset/erosion of thermal stratification in the reservoir. These models are also capable of predicting reservoir conditions, and will be used to help deploy the radio-telemetry arrays, temperature loggers, and bottom-mounted ADCPs.

Task 3.1: Apply the 2D model before the field season to optimize deployment.

Activity 3.1.1 The calibrated and validated model CE-QUAL-W2 will be used to predict the range of hydraulic conditions in the reservoir based upon predicted water supply, system operation requests (SORs), and summer spill schedulte before the field data is collected. This information will help target location of fixed instruments. It will also be used to determine the expected magnitude and duration of seiche induced by load following operations.
Collaborator Lead: PNNL

Task 3.2: Combine and visualize tagged fish information, hydraulic datasets, and numerical model results.

Activity 3.2.1 Mobile and fixed array data will be distilled and visualized to enhance synthesis with other datasets.
Collaborator Lead: USGS

Activity 3.2.2 Mobile and fixed ADCP and water temperature data will be distilled and visualized to enhance synthesis with other datasets.
Collaborator Lead: PNNL

Activity 3.2.3 PNNL numerical models will be programmed to simulate the field study period. Models will be validated against the observed dataset.
Collaborator Lead: PNNL

Activity 3.2.4 Products from Activities 3.2.1 through 3.2.3 will be combined to produce synthesized results that link observed fish migration behaviors (travel rate, travel time, upriver travel) with observed and simulated hydraulic phenomenon. These data will be related through time, and is expected to vary over both diurnal and seasonal time scales.
Collaborator Lead: PNNL and USGS

Management and Reporting: These tasks cover collaboration meetings, dissemination of data, monthly/quarterly Pisces reporting, and final project reporting.

Task 4.1: Collaborator meetings

Activity 4.1.1 A series of (at least) three meetings will occur to present data collection plans, work schedules, data distillation progress, and findings. These meetings are expected to occur (at least) before, during, and after the field season.

Collaborator Lead: USGS and PNNL

Task 4.2: Monthly/Quarterly Reporting

Activity 4.2.1 Each collaborator will independently submit cost sheets and complete required PISCES reporting work elements.

Collaborator Lead: USGS and PNNL

Task 4.3: Produce Project Report

Activity 4.3.1 Both a draft and final project report will be produced. This report will follow PNNL reporting requirements, and a PNNL technical editor will be involved in report development. Report cover sheets will be appropriately modified to reflect the collaborative nature of this project.

Collaborator Lead: PNNL (note: this is not an indication of author order, which will be determined once field data has been collected and report writing is underway)

Task 4.4: Data reduction, storage, analysis, and transfer procedures.

Activity 4.4.1 The transfer and dissemination of collected field data is vital for the Action Agencies to make informed management decisions regarding the operation of the Columbia River hydropower system. In response to these needs, all collected field data will be released to the public once it has been checked for quality control.

Collaborator Lead: USGS and PNNL

WORKING SCHEDULE: 2006

February 1: Funding has been received and work is initiated.

March 15: Collaborators meeting. PNNL model simulations for upcoming summer will be presented. These will be based on current water supply predictions, SOR requests, and summer spill decisions are presented. Telemetry array locations will be finalized.

April 1: Radio telemetry array deployed. Bottom mounted ADCPs deployed. Temperature logger string deployed.

April 15: Collection and tagging of fish begins.

April 15: Mobile ADCP and radio tracking surveys begin with a frequency of… Continues until July 20

May 1: ADCP and temperature logger data maintained.

May 15: Collaborators meeting. Update on progress and refine schedule as needed.

June 1: ADCP and temperature logger data maintained.

July 1: ADCP and temperature logger data maintained.

July 20: Mobile ADCP and radio tracking surveys stopped.

July 25: Numerical modeling of field season begins.

Aug 1: Radio telemetry array retrieved. ADCP and temperature logger data retrieved.

Aug 15: Collaborators meeting. Discuss collected data, rate and anticipated dates of completion, integration of field and numerical model datasets.

Nov 1: Draft report released

Dec 1: Final comments received back.

Dec 20: Report finalized and distributed.

FACILITIES AND EQUIPMENT

PNNL has long experience monitoring the hydrodynamic flow field, water quality parameters, and atmospheric boundary layer. Specific equipment that is germane to this project include high (~10 with accuracy of <0.01°C) and medium (~100 with accuracy of 0.2°C) accuracy self-contained water temperature loggers, self-contained conductivity-temperature-depth (CTD) probes, three RD Instruments acoustic Doppler current profilers (600 kHz broadband, 600 kHz workhorse sentinel with waves, 1200 kHz 'zed-head' sentinel workhorse), two 25+ft floating rafts platforms, six 25+ft motorized research vessels, five 50-ft crank-up towers on trailers, ten 10-m towers, numerous 2-D and 3-D sonic anemometers, precision radiometers and data loggers. PNNL also has a full suite of mathematical modeling tools and computational facilities. We use industry standard data analysis/imaging software, such as FieldView and MATLAB, hydrodynamic/water quality CFD software, such as Flow-3D and Star-CD, geospatial tools, such as ARC-Info and the open-source GIS Grass, as well as specialized research software developed at PNNL, such as FINS. The co-principal investigators have access to numerous computers, ranging from desktop WindowsXP and Linux PCs, to Linux clusters and onsite supercomputers.

The USGS operates the Columbia River Research Laboratory that includes research boats, vehicles, office space, and laboratory facilities to conduct this study. Boats will be operated at cost with no additional lease cost to the project. Only department of Interior certified boat operators trained in CPR and First Aid will operate boats. In order to meet U.S. Coast Guard standards boats will be inspected by a third party. Furthermore, USGS will provide a quality control system consistent with the Good Laboratory Practices Act. Other resources include: A selection of 30 boats up to 30 feet in length for work on the river; two 2700 square foot storage facilities with a shop; 4000 square foot wet lab facility; a local computer network integrating state-of-the-art GIS capabilities; a technical staff of 60-100 fishery biologists, ecologists, and GIS specialists; an office and analytical laboratory in a 15,000 square foot facility.

IMPACTS

Impacts to other researchers

Because we will be using radio-telemetry technology to study the movements of the test fish, there is a great potential for interference with other studies that use the same technology. Other studies using radio tags with the same frequencies may cause interference and could cause the loss of data that would otherwise be collected. During 1994, 1995, and 1996 our ability to collect data was compromised due to radio interference caused by other researchers. An extensive coordination effort throughout the basin allowed us to minimize this problem during 1997-1998. In conjunction with coded tag manufacturers we were able to incorporate radio tags that operated on a unique frequency used only by USGS scientists. During the 2000-2001 study periods we used these modified radio tag frequencies to reduce multiple signal collisions and eliminate unwanted detections (of fish released by other researchers), and therefore increased overall data integrity. This unique tag frequency will be used during the 2006 evaluation.

Impacts to the Lower Granite Project

Pre-season installation of equipment will start in February 2006 and continue through May 2006. The equipment will be in use through the end August 2006. We are capable of installing most of the necessary equipment for the aerial arrays, and the impact to the Lower Granite project should be minimal.

COLLABORATIVE ARRANGEMENTS

This project is submitted as a collaborative agreement between the Pacific Northwest National Laboratory and the US Geological Survey. Some of the labor needed to complete the activities outlined in this proposal, however, may be furnished through a sub-contract with a labor service provider.

KEY PERSONNEL AND DUTIES

BRD, USGS

Russell Perry:	Biological Component Co-Project Leader
Noah Adams:	Biological Component Co-Project Leader
Kenneth Tiffan:	Biological Component
Dennis Rondorf:	Section Leader
Amy Braaaz:	Biological Technical Lead, implementation and coordination

PNNL

Christopher Cook:	Hydraulic Component Co-Project Leader
Marshall Richmond:	Hydraulic Component
Dennis Dauble:	Division Leader
Scott Titzler:	Hydraulic implementation and coordination
Berhon Dibrani:	Hydraulic implementation and modeling

TECHNOLOGY TRANSFER

We plan to transfer information obtained from our analysis in the manners listed below. In addition, the information will be used by other federal and state agencies, Indian Tribes, and the public to make management decisions to aid in the recovery of threatened and endangered populations of salmon in the Columbia Basin.

REFERENCES

Cook C.B., B. Dibrani, M.C. Richmond, M.D. Bleich, S.P. Titzler, T. Fu 2005. "Hydraulic Characteristics of the Lower Snake River during Periods of Juvenile Fall Chinook Migration" PNNL-15532, Final Project Report for BPA Project 2002-027-00, Pacific Northwest National Laboratory, Richland, WA.

Cook C.B., C.L. Rakowski, M.C. Richmond, S.P. Titzler, A.M. Coleman, M.D. Bleich 2003. "Numerically Simulating the Hydrodynamic and Water Quality Environment for Migrating Salmon in the Lower Snake River." PNNL-14297, Annual Report for BPA Project 2002-027-00, Pacific Northwest National Laboratory, Richland, WA.

Cook C.B., G.T. Orlob, and D.W. Huston (2002). *Simulation of Wind-Driven Circulation in the Salton Sea: Implications for Indigenous Ecosystems*, Hydrobiologia, **473**: 59-75.

Cook C.B. 2000. *Internal Dynamics of a Terminal Basin Lake: A Numerical Model for Management of the Salton Sea*, Ph.D. dissertation, Department of Civil and Environmental Engineering, University of California, Davis.

Independent Scientific Advisory Board. 2003. "Review of flow augmentation: Update and clarification." Report by the ISAB to the Northwest Power Planning Council, Portland, Oregon.

Plumb, J.M., M.S. Novick, A.C. Braatz, J.N. Lucchesi, J..M. Sprando, N.S. Adams, and D.W. Rondorf. 2003. Behavior and Migratory Delay of Radio-Tagged Juvenile Spring Chinook Salmon and Steelhead Through Lower Granite Dam and Reservoir During a Drought Year, 2001. Annual report by the U. S. Geological Survey to the U.S. Army Corps of Engineers, contract W68SBV00104592, Walla Walla, Washington.

Plumb, J.M., R.W. Perry, N.S. Adams, and D.W. Rondorf. In press. The effects of river impoundment and hatchery rearing on the migration behavior of juvenile steelhead in the Lower Snake River, Washington. North American Journal of Fisheries Management.

Rakowski, C.L., M.C. Richmond, and W.A. Perkins 2003. "Characterizing the Physical Environment Encountered by Mobile-Tracked Salmon in the Columbia and Snake Rivers", PNWD-3354, Report to the US Army Corps of Engineers Walla Wall District, Pacific Northwest National Laboratory, Richland, WA.

Scheibe, T.D. and M.C. Richmond, 2002. "Fish individual-based numerical simulator (FINS): a particle-based model of juvenile salmonid movement and dissolved gas exposure history in the Columbia River basin", *Ecological Modelling*, 147:233-252.

Smith, S. S., W. D. Muir, and J. G. Williams. 2002. Factors associated with travel time and survival of migrant yearling chinook salmon and steelhead in the lower Snake River. North American Journal of Fisheries Management. 22:385-405.