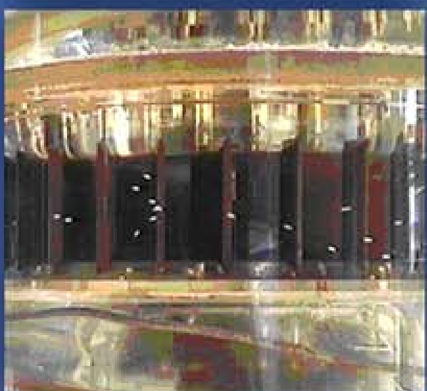

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Optimizing Dam Operations for Power and for Fish:

An Overview of Advanced Turbine Development R&D Conducted by the US Army Corps of Engineers and the US Department of Energy

HydroVision 2006

A Pre-Conference Workshop
at HydroVision 2006
Oregon Convention Center,
Portland, Oregon, July 31, 2006

Pacific Northwest
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Optimizing Dam Operations for Power and for Fish

Monday, July 31, 2006, 1:00 - 5:00 p.m.

Session 1 - Current Programs and Research Tools	
1:00 p.m. - 1:20 p.m.	USACE's Turbine Survival Program *Dan Feil, USACE Walla Walla District*
1:20 p.m. - 1:40 p.m.	History of the USDOE Hydropower Program *Mike Sale, ORNL*
1:40 p.m. - 2:00 p.m.	Physical Hydraulic Model Investigations *Bob Davidson, USACE ERDC*
2:00 p.m. - 2:20 p.m.	Developing Biocriteria to Ensure Safe Fish Passage *Glenn Čada, ORNL*
2:20 p.m. - 2:40 p.m.	Pressure Investigations using Sensor Fish and Hyperbaric Testing *Tom Carlson, PNNL*
2:40 p.m. - 3:00 p.m.	Evaluation of Blade Strike Models as a Means to Estimate the Biological Performance of Kaplan Turbines *Daniel Deng, PNNL*
3:00 p.m. - 3:20 p.m.	Break
Session 2 - Monitoring Turbine Performance	
3:20 p.m. - 3:40 p.m.	Optimizing Power Plant Operations *Rod Wittinger, USACE*
3:40 p.m. - 4:00 p.m.	Application of BioIndex Testing to Evaluate Turbine Performance and Improve Fish Survival *Blaine Ebberts and Dan Feil, USACE*
4:00 p.m. - 4:20 p.m.	Estimating Turbine Survival *Mike Langeslay, USACE*
4:20 p.m. - 4:40 p.m.	Improvements in the Turbine Hydraulic Passageways for Fish Passage and Turbine Performance *Ryan Sollars, USACE*
4:40 p.m. - 5:00 p.m.	The TSP Design Approach: Bringing it all Together *Martin Ahmann, USACE*

HydroVision 2006

July 31 - August 4, 2006

Oregon Convention Center
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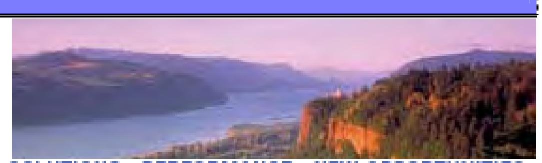

SOLUTIONS. PERFORMANCE. NEW OPPORTUNITIES.

US Army Corps of Engineers Northwestern Division Turbine Survival Program

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The Northwestern Division of the US Army Corps of Engineers (USACE) owns and operates eight hydroelectric dams on the Lower Columbia and Snake rivers. These dams provide flood control, navigation, and electricity to residents and industry of the Pacific Northwest region of the United States. Both the Columbia and Snake rivers also provide residence to several threatened and/or endangered anadromous salmon species. In 1995, the National Marine Fisheries Service issued its initial Biological Opinion, which provided guidance for operation of the Federal Columbia River Power System (FCRPS) to ensure the safe passage of anadromous salmon through the hydrosystem. Subsequently, the USACE Turbine Survival Program (TSP) was formed and federally funded under the Columbia River Fish Mitigation (CRFM) Program to examine the design and operation of existing turbines and to help formulate design criteria guidelines to rehabilitate aging turbines throughout the FCRPS with designs that minimize injury to juvenile salmonids. Since the TSP's inception, efforts have focused on collecting biological and physical field data and constructing and interrogating 1:25 scale physical observational models at the USACE Engineer Research and Development Center (ERDC) to gain a better understanding of the hydraulic and physical in-turbine environment and how it may affect fish survival.

Current areas of focus for defining safe operation and design of hydroturbines to improve juvenile salmonid survival include optimizing powerhouse operations, defining the effects of pressure change on juvenile salmonids, and developing design criteria for advanced turbine runners that minimize fish injury and mortality.

History of the US Department of Energy's Hydropower Program

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The U.S. Department of Energy has been conducting unique research and development focused on the domestic hydropower industry since 1977. In the 1970s and early 1980s, DOE's Hydropower Program started with work on technology assessment and a Small Hydropower Demonstration Program. After a period of zero funding in the late 1980s, the Program restarted with the goal of developing new technology that would improve the environmental performance of hydropower projects.

A unique partnership of industry and federal cost-sharing allowed DOE's Advanced Hydropower Turbine Systems activity to be established in 1994 – this led to new fish-friendly turbine designs and testing. Interagency cooperation with organizations like the U.S. Army Corps of Engineers has been a consistent part of the Program. Three of DOE's national laboratories, Idaho National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory, have been an integral part of this innovative research.

Program accomplishments include several new turbine designs, biological design criteria, computational and physical modeling, and environmental sensors. Along with the Corps, the DOE-sponsored research has concentrated on making the path through the turbine safer for fish, so that the dual goals of clean energy production and environmental quality can be achieved.

Physical Hydraulic Model Investigations

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The US Army Corps of Engineers (USACE) owns and operates eight hydroelectric projects located within the lower Columbia River drainage basin in the Pacific Northwest region of the United States. Downstream migration and survival of juvenile salmon is a major concern. At each of the USACE projects, juvenile salmon are bypassed around the turbines by passing fish over the project spillways or through juvenile bypass systems located in the intake structure of the powerhouse. However, a significant number of fish still pass through turbines at these projects. The turbine type at these projects is Kaplan.

USACE has constructed 1:25-scale section turbine models of several of its projects at the Engineer Research Development Center (ERDC) in Vicksburg, Mississippi, USA. The passageways of these models are fabricated of acrylic to allow for observation of flow conditions approaching the turbine, through the turbine, in the draft tube, and in the area downstream of the draft tube exit. These models, which have operational turbines and wicket gates, are used to investigate areas of the water passageways for their potential to injure fish. The models are also used to investigate turbine operations and designs that may increase the survival of juvenile fish passing through them. In particular, potential injury due to blade strike or high-velocity shear can be assessed. These models have also been used to design and evaluate modifications to the turbine environment to improve fish survival while increasing the efficiency of the turbine.

Results have been obtained from bead experiments through the McNary turbine runner model over a varying operating range. In addition, results obtained from laser measurements near the draft tube exit indicate draft tubes perform better at higher discharges.

Developing Biocriteria to Ensure Safe Fish Passage

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Improvement of the survival of turbine-passed fish requires knowledge of both the physical conditions (injury mechanisms) that affect entrained fish and the fish's tolerance to those conditions. Possible causes of turbine passage mortality were identified in a U.S. Army Corps of Engineers workshop in 1995. Potential injury mechanisms are many and varied; injury and mortality can result from rapid and extreme water pressure changes, cavitation, shear stress, turbulence, strike, and grinding. A subsequent DOE report concluded that available information on fish response to turbine-passage injury mechanisms was not sufficient to support the design of "fish-friendly" turbines. Consequently, since 1997 the DOE Hydropower Program has supported laboratory and field studies to quantify the responses of fish to turbine passage stresses. The goal of these studies is to develop biological criteria for advanced turbine designs, i.e., to specify the hydraulic conditions, probabilities of strike, and water pressure change rates and magnitudes within which survival of entrained fish is expected to be high.

Examples of information from these experiments that can be used to develop biocriteria include the following: (1) injuries and mortalities are likely to occur above a shear threshold of 500 cm/s/cm; (2) the pressure increases found inside most turbines are not damaging to fish; (3) rapid pressure decreases to 0.1 atm are not damaging to salmonids, but are lethal to bluegills; (4) depth acclimation and dissolved gas supersaturation increase the adverse effects of pressure decreases; and (5) sublethal stresses may not result in visible injury to the fish, but can increase their susceptibility to predators (indirect mortality). These laboratory studies are being used by turbine designers to improve the environmental performance of a new generation of turbines. In addition, innovative laboratory and field techniques are being developed to refine our understanding of both the nature of injury mechanisms within a turbine system and the fishes' responses to them.

Biocriteria and other environmental reports produced by the DOE Hydropower Program can be downloaded from http://hydropower.inel.gov/

Pressure Investigations Using Sensor Fish and Hyperbaric Testing

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The pressure environment fish experience during passage through large Kaplan hydroturbines is very complex. Hyperbaric testing in laboratory studies is being used to assess pressure related injuries such as barotrauma that may be experienced by turbine-passed fish. Through field and laboratory studies, the Sensor Fish, a device for measuring pressure and angular motion in turbine environments, developed by PNNL with support from DOE and COE, is also contributing to our understanding of the conditions fish experience during turbine passage. In 2005 and 2006, Sensor Fish devices were used to obtain pressure time history data from passage through large Kaplan turbines at three mainstem Columbia River dams. Samples were obtained over a range of turbine operating conditions and turbine intake elevations.

The obtained pressure time history data show a relatively low frequency of occurrence of pressure nadirs typical of those used in previous laboratory studies of barotrauma. The data also show a wide range in pressure rate of change during runner passage indicating the possible importance of this parameter in barotrauma and turbine passage risk assessment research. Barotrauma research using computer-controlled hyperbaric chambers that permitted simulation of a turbine passage time history has shown significantly increased susceptibility of turbine-passed test fish bearing implanted telemetry devices to barotrauma injury and mortality relative to that of test fish without such devices.

Evaluation of Blade Strike Models as a Means to Estimate the Biological Performance of Kaplan Turbines

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Bio-indexing of hydroturbines has been identified as an important means to optimize passage conditions for fish through hydroturbines by identifying operations for existing and new design turbines that minimize the probability of injury to fish. Cost-effective implementation of bio-indexing requires the use of tools such as numerical and physical turbine models to generate hypotheses for turbine operations that can be tested at prototype scales using live fish. Blade strike has been proposed as an index variable for the biological performance of turbines. Here we report on an evaluation of the use of numerical blade strike models to predict the probability of blade strike and injury to juvenile salmon smolts passing through large Kaplan turbines on the mainstem Columbia River.

Deterministic and stochastic blade strike models were developed for a 1:25-scale physical turbine model built by the U.S. Army Corps of Engineers for the original design turbine at McNary Dam and for prototype-scale original design and replacement minimum gap runner (MGR) design turbines at Bonneville Dam's first powerhouse. The stochastic model was implemented by randomizing the input variables such as discharge, fish length, and orientation using the Monte Carlo method. The performance of the numerical blade-strike models was then evaluated by comparing the prediction of the numerical blade strike models with 1) observations from the McNary physical turbine model using neutrally buoyant beads and 2) prototype-scale live fish tests of turbine biological performance at Bonneville Dam's first powerhouse.

We concluded that the numerical blade strike models are valuable and cost-effective tools for assessing the biological performance of large Kaplan hydro turbines as it relates to blade strike. However, the numerical models did not show the variability between operating conditions present in physical model bead strike data or the trend in differences in fish injury and mortality estimates between Bonneville Dam original and MGR design runners. In addition, we found that fish orientation at the time of entry into the plane of the leading edges of turbine runner blades is one of the most significant factors and uncertainties in blade strike modeling. Based on our results, we recommend the use of stochastic blade-strike models that consider the aspect of fish approaching the leading edges of a turbine runner's blades. Randomization of fish aspect appears to provide a more comparable prediction with experimental results and should be the preferred method for prediction of blade strike and injury probability for juvenile salmon and steelhead using numerical blade-strike models. Future models of blade strike should incorporate three-dimensional computational fluid dynamics simulations of the turbulent flow environment that are coupled with computing the motion of fish-sized objects interacting with the turbine system components.

Optimizing Power Plant Operations

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The operation of individual hydro-turbines, groups of hydro-turbines, or entire hydro-power sites can be improved to benefit both fish passage and power production. The combination of emerging biological information, turbine operational parameters resulting from modeling, and the advancements in instrumentation and control technologies is providing the opportunity to optimize both existing and rehabilitated turbines. An overview of the current status and the potential vision of measurement improvements, automated Index testing, control improvements, individual unit optimization, powerhouse optimization, and site optimization will be discussed.

Application of Biological Index Testing to Evaluate Turbine Performance and Improve Fish Survival

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The mechanisms that cause injury or mortality to juvenile salmonids as they pass through Kaplan hydroelectric turbines are poorly understood. The Northwestern Division of the US Army Corps of Engineers (USACE) is currently working to identify potential mechanisms of injury and mortality under the Turbine Survival Program (TSP). The USACE currently classifies turbine passage-related injury and mortality of juvenile salmonids as either 1) direct mechanical injury and/or mortality caused by impacts with structure, strike by turbine runner blades, or injury from shear or turbulence; 2) indirect mortality, such as predation by birds or other fishes that occurs post-passage; and 3) pressure-related injury and/or mortality that occurs during turbine passage.

Presently, the concept of Biological Index Testing (BIT) of existing turbines is being examined to determine if injury and mortality of juvenile salmonids can be minimized at USACE-operated dams on the Columbia and Snake rivers by optimizing the operation of single turbine units, the powerhouse, and the project as a whole. Current turbine operating guidelines for turbine units at Snake and Columbia River dams call for operating turbines within ±1.0% of peak efficiency during the juvenile fish passage season. While juvenile salmonid survival is assumed to be greatest within this peak efficiency range, additional survival benefits may be realized by operating turbines at an optimal, more open geometry. An “open geometry” is described as the best possible alignment of stay vanes and wicket gates combined with optimum runner blade angle to produce the best quality of flow (lower turbulence and shear) through the turbine environment. By optimizing the quality of flow (reducing turbulence and shear) through the turbine environment, direct mechanical injuries and egress time out of the draft tube may be minimized to improve the overall survival of juvenile salmonids passing through the turbines.

During spring 2006, a direct injury and 48-hour survival study was conducted at John Day Dam to test the hypothesis that gains in fish survival can be achieved by optimizing turbine operation. Preliminary results from this study will be discussed, along with future plans for BIT at USACE projects.

Estimating Turbine Survival

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Fisheries managers have long regarded turbines as the least preferable route to pass juvenile salmonids through hydroelectric facilities. Fish passage studies often confirm that juvenile fish survival through turbines is lower than survival through spillways and juvenile bypass systems. As a result, the Northwestern Division of the US Army Corps of Engineers, the US Department of Energy, and other groups have been working to improve fish passage conditions through turbines. The metric used to evaluate these efforts is almost always fish survival. However, estimating fish survival is not as simple as it sounds. There are a variety of methods and tools that can be used to measure fish survival. Biologists and engineers working on turbine improvement programs have a multitude of decisions to make regarding survival study design: what size and species of fish to use, where and how to release them, what turbine operating conditions to use, what comparisons to make, what statistical model to use, etc. The challenge for fisheries managers is to understand how survival estimates are generated, the strengths and weaknesses of those estimates, and what can and cannot be inferred from them.

The biological relevance of data obtained from turbine survival studies is often limited by the study methods used. For example, balloon-tag mark-recapture methods provide useful information on the immediate effects of turbine passage, fish injury, and mortality. However, longer term chronic effects resulting from turbine passage are not necessarily captured by this methodology. In addition, fish must be released directly into the turbine units, which may influence the injury mechanisms that individual test specimens are exposed to and can result in biased estimates. Survival estimation using active tag technologies (e.g., radio and acoustic telemetries) captures direct and indirect effects of turbine passage on fish survival. Active tags also allow for the upstream release of test fish, which then pass turbine units in a more representative distribution than fish released into turbines via hoses or other mechanisms. However, the weight of the tags may influence the buoyancy compensation of the fish, biasing survival estimates. Additionally, releasing fish upstream of hydro-plants with multiple turbines and other downstream passage routes may require very large sample sizes to obtain statistically precise turbine survival estimates. Fish size is also an issue with active tags. Currently, the smallest salmonids that can be tagged with active tags, without affecting behavior and survival, are approximately 90 mm. However, for some species and stocks, length frequency distributions of active migrants start well below 90 mm. Passive technologies such as coded wire tags (CWT) and passive integrated transponder (PIT) tags are much smaller, thereby allowing incorporation of smaller fish into the study design. In addition, these tags persist for the entire life cycle of the individual fish, allowing for smolt-to-adult return estimates. However, passive tags do have some limitations, including 1) having to release fish through hoses or other direct release mechanisms to ensure passage through a turbine, and 2) low post-release detection and recapture probabilities, which require handling and tagging of a large number of a species that are often listed under the US Endangered Species Act of 1972.

Improvements in the Turbine Hydraulic Passageways for Fish Passage and Turbine Performance

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Studies conducted by the US Army Corps of Engineers have shown potential fish passage improvements and Kaplan turbine performance increases from stay vane, wicket gate, and draft tube modifications. Items investigated on the stay vanes and wicket gates include changes to the alignment of the stay vanes and wickets gates, profile of the stay vanes and wicket gates, and modifications to the gap between the stay vanes and wicket gates. Items investigated on the draft tube include changes to the geometry of the draft tube and draft tube extensions.

Study results estimate efficiency increases ranging from 0.5 to 0.7 percent for wicket gate modifications and from 0.1 to over 1 percent for changes to the draft-tube geometry. These results show that fish passage improvements and turbine performance increases can be gained at the same time. The studies are based primarily on observational and performance model tests of Lower Granite Dam on the Snake River, Washington, and McNary Dam on the Columbia River near Umatilla, Oregon.

This research is part of the Turbine Survival Program, a multi-discipline program established by the US Army Corps of Engineers to examine improvements in the design and operation of hydro turbines to minimize injury to juvenile salmonids.

The TSP Design Approach: Bringing it all Together

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The US Army Corps of Engineers has developed a new design approach for replacement of turbine runners and other possible turbine modifications that optimize turbine performance for both fish and power. This recommended process combines results of fish survival studies with a thorough understanding of the physical hydraulic conditions through the turbine to identify areas to improve and to develop appropriate design objectives and criteria.

This new approach relies on the interactive use of physical hydraulic models at the Corps of Engineers' Engineering Research and Development Center (ERDC), the turbine industry's standard performance test models, and computational fluid dynamic (CFD) models to identify, develop, and test possible design alternatives.

The Corps has prepared a plan to test the process as a "proof of concept" by replacing failing Kaplan turbine units at the Ice Harbor Lock and Dam on the lower Snake River. This 6-year plan includes baseline testing, development and evaluation of alternatives, design of selected modifications, installation of the prototype runner, and water passage way improvements and prototype testing. If approved, this project will begin in FY 2007 and will be completed with the installation and testing of a new turbine unit in FY 2012. The tools and methods used to establish baseline conditions, to develop and evaluate design alternatives, and to test the prototype turbine will be presented.