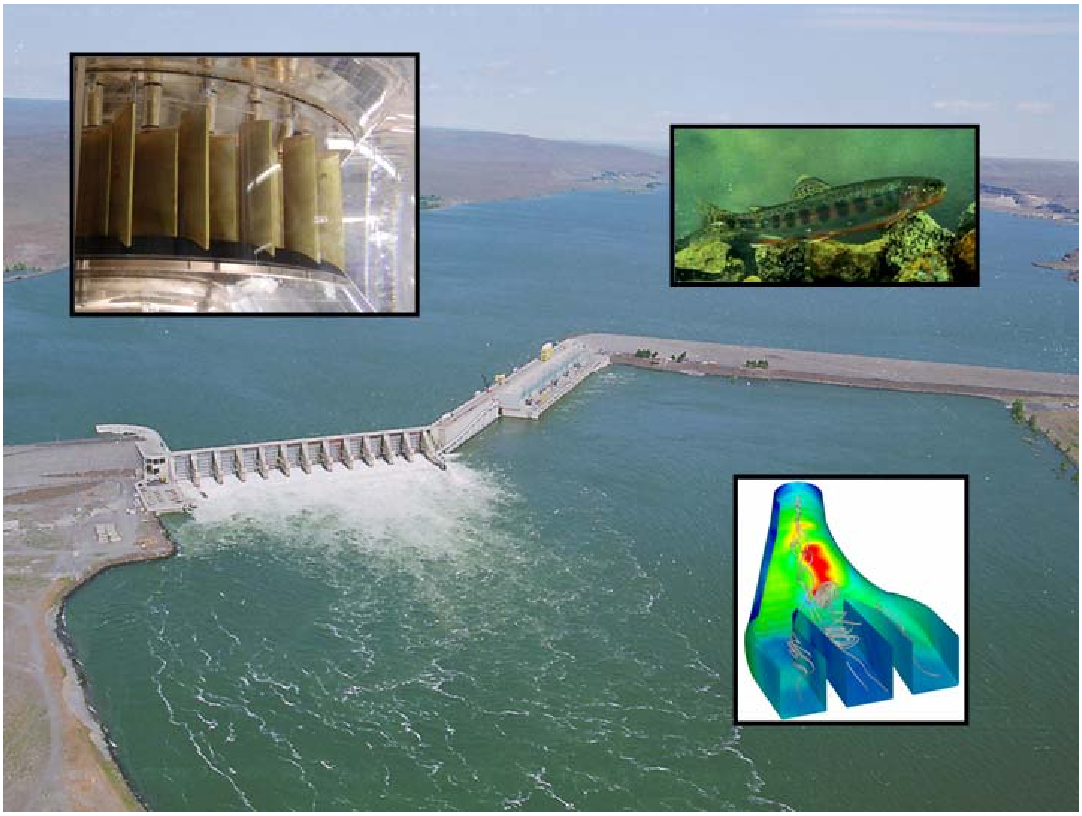
DOE/NE-ID-11136

DOE Hydropower Program Annual Report for FY 2003



U.S. Department of Energy
Energy Efficiency and Renewable Energy

Wind and Hydropower Technologies

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable.

DOE/NE-ID-11136

DOE Hydropower Program
Annual Report for FY 2003

(October 2002 - September 2003)

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SUMMARY

The U.S. Department of Energy (DOE) Hydropower Program is a part of the Office of Wind and Hydropower Technologies, Office of Energy Efficiency and Renewable Energy. The Program's mission is to conduct research and development (R&D) that will increase the technical, societal, and environmental benefits of hydropower. DOE Hydropower Program activities are carried out by its national laboratories: Idaho National Engineering and Environmental Laboratory (INEEL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and National Renewable Energy Laboratory (NREL), as well as a number of industry, university, and federal research facilities.

DOE Hydropower Program activities are conducted in 2 key areas, Technology Viability and Technology Application. R&D is organized into two subkey activities within the Technology Viability area: (1) Advanced Hydropower Technology (Large Turbine Field Testing, Testing of the Alden/NREC pilot scale runner, and Improved Mitigation Practices); and (2) Supporting Research and Testing (Biological Design Criteria, Computer and Physical Modeling, Instrumentation and Controls, and Environmental Analysis). Similarly, the Technology Application area is comprised of two subkey activities: (1) Systems Integration and Technology Acceptance (Wind/Hydro Integration Studies and Technical Support and Outreach); and (2) Engineering and Analysis (Innovative Technology Characterization). This report describes the progress of the R&D conducted in FY2003 under all four subkey activity areas.

Major accomplishments in FY2003 include:

- Field testing was carried out of the Retrofit Aeration System that is designed to increase the dissolved oxygen content of water discharged from the turbines of the Osage Project in Missouri (MEC Water Resources, Inc. 2003).
- Proof-of-concept tests of the Alden/NREC pilot scale runner were completed (Cook et al. 2003).
- A series of laboratory studies of the effects on fish of turbine-induced pressure changes and dissolved gas supersaturation were completed (Abernethy et al. 2003).
- Effects of sublethal stresses characteristic of turbine and spillway passage on the escape behavior of fish were reported (Cada et al. 2003).
- The distribution within a Kaplan turbine of potentially lethal shear stresses was estimated by means of computational modeling (Garrison et al. 2003).
- The sensor fish measuring device was further developed and tested at hydropower plants in the Columbia River (Carlson and Duncan 2003). Data from the sensor fish are coupled with a computational model to yield a more detailed assessment of hydraulic environments at dams.
- Low Head/Low Power Resource Assessments for conventional turbines, unconventional systems, and micro hydropower systems were completed for the conterminous United States (Hall et al. 2003c).
- Laboratory and DOE staff participated in numerous workshops, conferences, coordination meetings, and reviews. The Hydropower Program web site is continually updated to make its publications available for downloading.

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FIGURES

FIGURES (continued)

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DOE Hydropower Program Annual Report for FY 2003

1. INTRODUCTION

This report describes hydropower activities supported by the U.S. Department of Energy (DOE) Wind and Hydropower Program during Fiscal Year 2003 (October 1, 2002 to September 30, 2003). Background on the program, FY03 accomplishments, and future plans are presented in the following sections.

1.1 Technology Description

Hydropower is one of the nation's most important renewable energy resources, because it represents about 10% of the country's electrical generating capability and provides more than 75% of the electricity generated from renewable sources (EIA 2003a). Technology for producing hydroelectricity from falling water has existed for more than a century. Hydropower has significant advantages over other energy sources: it is a reliable, domestic, renewable resource with large undeveloped potential, and it emits essentially none of the atmospheric emissions that are of growing concern, such as nitrogen and sulfur oxides and greenhouse gases. Hydropower projects can provide substantial non-power benefits as well, including water supply, flood control, navigation, and recreation.

Hydropower poses unique challenges in energy development, because it combines great benefits with some difficult environmental challenges. The benefits of hydropower can sometimes be offset by environmental impacts. The environmental issues that most frequently confront the hydropower industry are blockage of upstream fish passage, fish injury and mortality from passage through turbines, and changes in the quality and quantity of water released below dams and diversions.

The current installed capacity of hydropower in the U.S. is approximately 80,000 MW (EIA 2003a). Hydroelectricity is produced at about 180 federal projects and more than 2,000 non-federal projects that are regulated by the Federal Energy Regulatory Commission (FERC) in all 50 states and Puerto Rico. Although there are substantial undeveloped resources in the U.S. (Section 2.4.1), hydropower's share of the nation's generation is predicted to decline through 2020 to about 6%, due to a combination of environmental issues, regulatory complexity and pressures, and changes in energy economics. Only 560 MW of conventional hydropower capacity is expected to be added by 2025 (EIA 2003b).

1.2 Background

The U. S. Department of Energy (DOE) initiated the Hydropower Program in 1976 to support research and development that would provide technical and environmental guidance to improve the operation and development of hydropower facilities in the United States. DOE National Laboratories provide support to the program: INEEL (engineering), ORNL (biological and environmental), PNNL (technology development / biological testing), and NREL (integration of hydropower and other renewable energy sources). Over the years, the Program has supported a Low-Head Hydropower Feasibility Program, research on environmental issues and mitigation practices, the development of advanced, environmentally friendly hydropower turbines, and hydropower resource assessments.

The Hydropower Program maintains close working relationships with private industry, national hydropower organizations, regulatory agencies, and other federal agencies (U. S. Army Corps of Engineers, Bonneville Power Administration, Tennessee Valley Authority, U. S. Bureau of Reclamation, U. S. Geological Survey, and NOAA Fisheries). These relationships allow DOE to 1) better understand the needs of the hydropower industry; 2) complement research being conducted by others; and 3) leverage research and development funds through cooperative or cost shared agreements.

The program's contributions have been summarized in regular biennial and annual reports (e.g., Sale et al. 2003). A description of the DOE Wind and Hydropower Technologies Program can be found at http://www.eere.energy.gov/windandhydro/ Annual and topical research reports are available on the DOE Hydropower Program website: http://hydropower.id.doe.gov/

1.3 Mission and Goals

The program mission is to conduct research and development (R&D) that will increase the technical, societal, and environmental benefits of hydropower and provide cost-competitive technologies that enable the development of new and incremental hydropower capacity, adding diversity to the nation's energy supply.

The Hydropower Program has two parallel goals and a completion target date of 2010. The program goals are to:

- Develop and demonstrate new technologies that will enable 10% growth in hydropower generation at existing plants with enhanced environmental performance; and
- Conduct analyses and studies that will enable undeveloped hydropower capacity to be harnessed without constructing new dams or causing unacceptable environmental damage.

1.4 Program Organization and Management

The Office of Wind and Hydropower Technologies (DOE-HQ) is responsible for planning and organizing the DOE Hydropower Program. Principal functions of DOE-HQ are program and policy development, budget formulation and justification, and overall program guidance and direction. DOE-HQ has the authority and responsibility for technical project direction and contracting the research and development activities (through DOE-Golden Field Office) that support the program.

A concerted effort is made to coordinate the DOE R&D with that of other federal agencies and industry, including both private and public entities involved with hydropower development. An open peer-review process involving industry and environmental resource agencies ensures that stakeholders are involved and that high-priority research needs are being addressed. A Technical Committee is maintained to review progress, evaluate results, and ensure coordination with related R&D activities of other agencies and industry. This Technical Committee consists of experts from the hydropower industry and state and Federal agencies. In addition, the reviews of specialists who are not members of the Technical Committee are obtained, when appropriate. Active coordination provides "situational awareness," avoids duplication of research efforts, and creates a synergy among related research effects.

DOE National Laboratories with experience in hydropower issues provide technical support to the Program: Idaho National Engineering and Environmental Laboratory (INEEL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and National Renewable Energy Laboratory (NREL). The laboratory for engineering and program management support is INEEL. ORNL is the laboratory for environmental and computational support. PNNL provides biological and other studies, taking advantage of their experience and facilities for conducting tests on fish. NREL provides support in the area of integration of hydropower with other renewables. A combination of industry, universities, and federal facilities conduct research activities for the hydropower program. Where federal facilities have the equipment and personnel to reduce the overall cost to DOE, they are used for conducting R&D.

2. FY 2003 ACTIVITIES

The Hydropower Program is subdivided into two key activity areas, ***Technology Viability*** and ***Technology Application***. Each of these key activity areas has two subkey activities and each of the subkey activities is comprised of several project areas, each of which has numerous project activities. Figure 2-1 shows the program structure down to the project areas and includes the program goals for each key activity.

The overall purpose of the **Technology Viability** part of the program is to develop new, cost-effective technologies that will enhance environmental performance and achieve greater energy efficiencies. More specifically, this program component consists of the following:

- Testing new turbine technology, analyzing test results, and reporting the test results and conclusions;
- Identifying new technology efficiencies, effectiveness of water use, and opportunities for optimal plant operations;
- Providing basic data and developing computer models that help define conditions of the water column inside an operational turbine; and
- Correlating plant operations with environmental and ecological conditions in the vicinity of hydro projects.

The intended goal of this work is to provide sufficient data for industry to recognize the value of identified new technologies and select these new technologies for installation at existing projects such that the overall hydroelectricity generation growth in the U. S. will be 10% by the year 2010.

The two subkey activities within Technology Viability include Advanced Hydropower Technology (Section 2.1) and Supporting Research and Testing (Section 2.2).

Technology Application is the second major Hydropower Program activity. Its purpose is to conduct research and analyses that identify barriers to development and strategies to reduce those barriers. Specifically, this program component consists of the following:

- Quantifying technical issues, economic costs, environmental constraints, and benefits of integrating hydropower and wind operations;
- Pursuing the establishment of a National Hydropower Collaborative with representatives from all stakeholders and interest groups to provide input concerning program issues and direction;
- Providing outreach and information transfer concerning program activities and R&D results to other agencies, industry, non-governmental organizations, and the public;
- Quantifying the varied benefits of hydropower to help the public and policymakers properly position hydropower in future competitive energy development considerations; and
- Evaluating unconventional turbine designs to address the undeveloped low head / low power potential identified in every region of the country.

The intended goal of this work is to provide sufficient data by 2010 to enable industry to begin developing the untapped low head / low power potential in the U. S. without constructing new dams.

The two subkey activities within Technology Viability include Systems Integration and Technology Acceptance (Section 2.3) and Engineering and Analysis (Section 2.4).

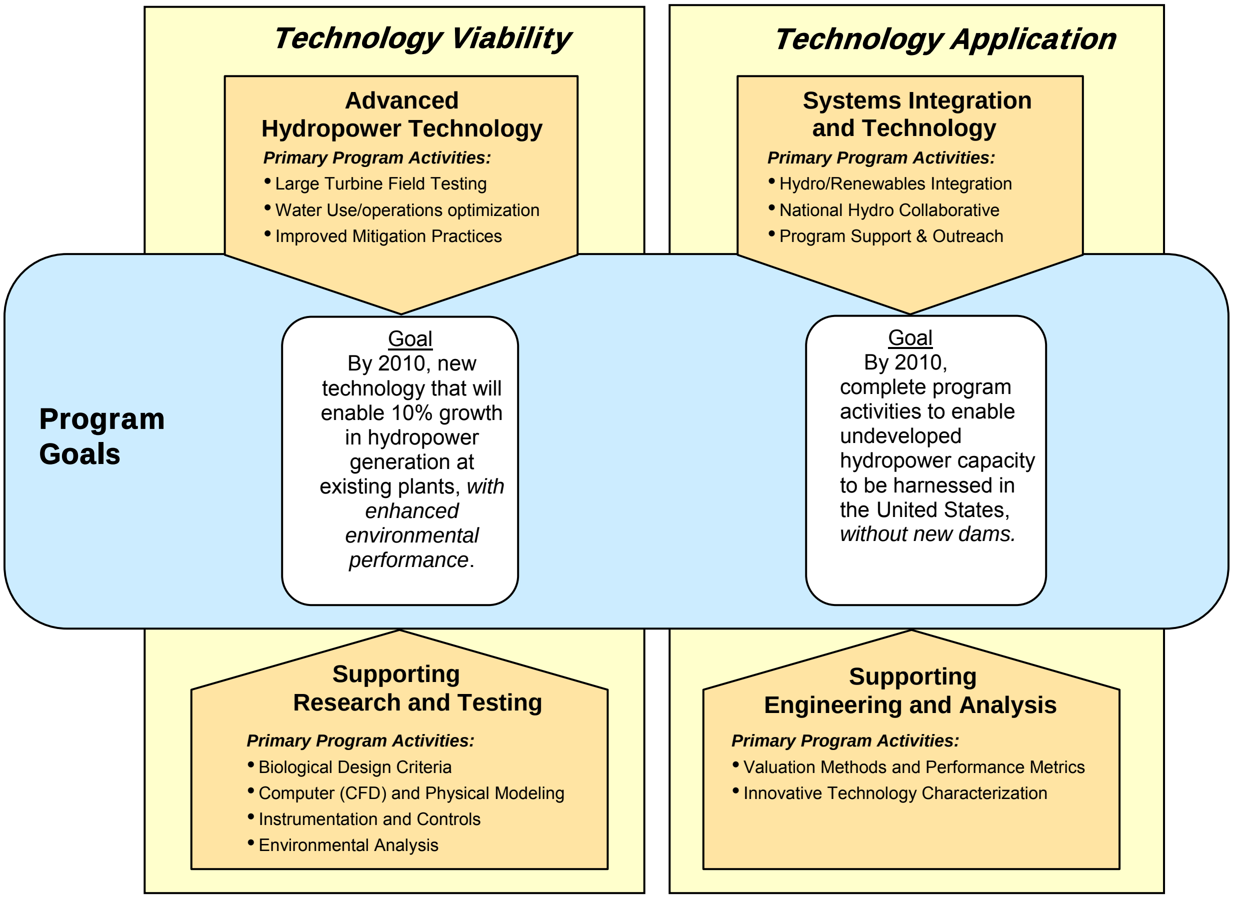

Figure 2-1. Organization of the activities in the U.S. Department of Energy Hydropower Program.

The accomplishments of particular projects in these areas during FY03 are summarized in the following sections.

2.1 Technology Viability – Advanced Hydropower Technology

Project areas associated with this subkey activity included Large Turbine Field Testing (Section 2.1.1), testing of the Alden/NREC pilot scale turbine runner (Section 2.1.2), and Improved Mitigation Practices (Section 2.1.3).

2.1.1 Large Turbine Field Testing

This project area involves testing new generation turbines for efficiency (compared with older machine efficiencies), compatibility with environmental requirements (i.e., dissolved oxygen concentrations and fish passage survival), and commercial viability. The methodology involves designing field test protocols, performing baseline field tests on existing plant equipment and operation, installing new technology, conducting repeat field tests on the new technology equipment, and analyzing and comparing test data related to performance objectives.

Osage Project (AmerenUE) Turbine Testing. A Retrofit Aeration System (RAS) has been installed at the Osage project in Missouri. The RAS was selected for testing as one of the new technical approaches available to enhance dissolved oxygen (DO) and improve water quality at hydropower facilities. The R&D effort for this project involves cost-sharing the following tasks with the site owner and operator (AmerenUE):

- Designing the RAS system;
- Developing the engineering and biological test protocol;
- Conducting baseline engineering and biological field tests for present conditions;
- Conducting engineering and biological field tests of the RAS system;
- Developing an O&M monitoring protocol; and
- Reporting on field test results and O&M issues and costs.

The final design report, all baseline and post-RAS system installation field tests have been conducted, and the O&M monitoring protocol document is under preparation. The final report on field tests completed to date is expected in FY2004. A supplemental DO enhancement methodologies report is anticipated in FY2005 and a final report on additional testing and O&M data is expected in FY2006.

This total cost of this project (including RAS system installation) is about $ 1,300,000. DOE contracted to fund about 50% (or about $ 658,000). DOE allocated $ 271,000 in FY2002 and no funds in FY2003 to AmerenUE for this project.

Wanapum Dam (Grant County PUD) Turbine Testing. A Minimum Gap Runner (MGR) turbine will be installed at the Wanapum Dam (Priest Rapids Project) on the Columbia River in Washington. The MGR was selected for testing as one of the new turbines available to the hydropower industry that is capable of meeting the above goals and reducing fish mortality at hydropower projects. The R&D effort for this project will involve cost-sharing the following tasks with the site owner and operator (Grant County Public Utility District No. 2):

- Designing the new turbine;
- Developing the engineering and biological test protocol;
- Conducting baseline engineering and biological field tests for present conditions with the original turbine in place;
- Conducting engineering and biological field tests after the new turbine is installed;
- Developing an O&M monitoring protocol; and
- Reporting on field test results and O&M issues and costs.

Presently, the engineering effort is about 50% complete, the design of imbedded and rotating parts is about 90% complete, and manufacturing about 35% complete. If the project stays on schedule, the final report of all baseline and post-turbine installation field tests should be in August 2005 and the final O&M report for the initial 10 months of operation should be July 2006.

This total cost of this project (including the new turbine, ancillary equipment, and installation labor) is about $ 18,200,000. DOE is contracted to fund about 13% (or about $ 2,352,000). DOE allocated $ 300,000 in FY2002 and $ 250,000 in FY2003 to Grant County for this project.

Box Canyon Hydroelectric Project (Pend Oreille County PUD) Turbine Testing. A Minimum Gap Runner (MGR) turbine will be installed at the Box Canyon project in northeastern Washington State. The MGR was selected for testing as one of the new turbines available to the hydropower industry that is capable of meeting the above goals and reducing fish mortality at hydropower projects. The R&D effort for this project will involve cost-sharing the following tasks with the site owner and operator (Public Utility District No. 1 of Pend Oreille County):

- Selecting the turbine manufacturer and designing the new turbine;
- Developing the engineering and biological test protocol;
- Conducting baseline engineering and biological field tests for present conditions with the original turbine in place;
- Conducting engineering and biological field tests after the new turbine is installed;
- Developing an O&M monitoring protocol; and
- Reporting on field test results and O&M issues and costs.

A final schedule for the above tasks cannot be established until the new operating license for the project is issued by the Federal Energy Regulatory Commission (FERC). The date of issuance has recently been fluid, but the FERC now indicates that a late summer 2004 issuance date is likely. Major tasks will be scheduled and implemented at that time. Based on a late summer license issuance, the final report of all baseline and post-turbine installation field tests should be in September 2007 and the final O&M report for the initial six months of operation should be March 2008.

This total cost of this project (including the new turbine, ancillary equipment, and installation labor) is about $ 9,800,000. DOE is contracted to fund about 25% (or about $ 2,478,000). DOE allocated $ 200,000 in FY2002 and $ 100,000 in FY2003 to Pend Oreille for this project.

Bonneville Project Turbine Model. This project involved constructing a 1:25 Bonneville First Powerhouse model, fabricating two turbine runner models to fit the Bonneville powerhouse model, conducting biological simulation tests of fish passage travel paths using neutrally buoyant beads, and analyzing the test data. The two turbine runner models, one a standard Kaplan runner and the other a Minimum Gap Runner (MGR) were constructed by Voith-Siemens Hydro. Biological conditions encountered during 1999-2000 tests at Bonneville were emulated during the model tests. The purpose of the tests was to identify the most likely path traveled by fish through the turbine from three different test release points. The experiments consisted of releasing neutrally buoyant beads at the stay vanes and documenting their path through the turbine environment utilizing high-speed photography. Model studies were conducted in 2002.

The Bonneville Turbine model tests were able to clearly demonstrate the need for physical models in setting up expensive biological field tests. The field tests conducted in 1999-2000 were set up without the benefit a model test. These model test data are proving invaluable in evaluating fish passage through the prototype MGR runner.

Second Year McNary Turbine Fish Survival Test. This project involved the planning, design, and implementation of a 2nd year of biological turbine testing at McNary Dam on the Columbia River in Washington. The first year test was conducted at a single operating point, which happened to be at a moderate blade opening with a moderate gap at the hub and blade tip. The 2nd year test included four operating points, two of which represented almost wide open and almost closed blade opening configurations. The other two test points were with the turbine / generator unit operating at more than 1% above peak efficiency. A pilot study of passage of adult salmonids was also performed successfully during these tests. The tests were performed in the spring of 2002. The final report (*Survival / Condition of Chinook Salmon Smolts Under Different Turbine Operations at McNary Dam, Columbia River*) was released in March 2003.

The test results did not detect a relationship between discharge volume and fish survival, as was previously believed. Current COE hydropower project operations are within plus or minus 1% of peak unit efficiency based on a belief that maximum fish survival is achieved within this operating range. This study showed that maximum fish survival actually occurred at an operating point well above the normal 1% limitation. This study should help resolve some unknowns about fish survival and aid in convincing regulators and others that increased fish survival is possible at hydropower plants while allowing greater flexibility in power operations.

Lower Granite Project Stay Vane and Wicket Gate Study. This project involves a hydraulic model study to assess the potential relationship between stay vane and wicket gate locations/configurations and their effects on fish passing through these devices. A new stay vane and wicket gate design prepared by VATech was incorporated into the Lower Granite project model at the U. S. Army Corps of Engineers (COE) Engineering Research and Design Center (ERDC or the old Waterways Experiment Station) in Vicksburg, MS where the studies were conducted. Two new stay vane and wicket gate arrangements were fabricated for the model, neutrally buoyant beads were passed through the model for these two arrangements, and the collected data were analyzed. The hydraulic effects in "backroll" areas immediately downstream from the turbine were also investigated. The results of the study using new configurations were compared with the results of studies for the original configuration. Model studies were conducted from September 2000 through April 2003.

The study identified areas of significant shear when wicket-gates are not hydraulically aligned with stay vanes. For these unaligned conditions, fish would be subjected high shear forces as well as the potential for striking the trailing edge of wicket gates that protrude over the turbine intake lip. Although this study did not include biological assessments of these conditions, it is clear that aligning stay vanes with wicket gates will reduce shear and strike potential for fish passing through these devices.

Ice Harbor Project Turbine Testing. Turbine Unit #2 at Ice Harbor Dam on the Columbia River in Washington is in need of replacement. A design with potential fish benefits is being considered for this replacement. This design will be evaluated at ERDC. Project steps include:

- Performing baseline biological fields tests of Ice Harbor Units #1 and #3;
- Performing turbine performance model tests of the first-generation design of a new turbine at the facility of the manufacturer selected for fabrication of the replacement turbine;
- Constructing a 1:25 scale model representing Ice Harbor Units #1 and #3 at ERDC;

- Fabricating a runner model of a second-generation turbine design based on the results of the manufacturers model tests on the first-generation model, and supplying the second-generation model to ERDC for independent testing;
- Performing hydraulic testing of the second-generation runner model at the ERDC; and
- Performing a post-biological field test of the second-generation turbine design.

Presently the turbine hydraulic model at ERDC is about 75% complete. The second-generation turbine runner model will be completed after award of the prototype contract.

The ERDC turbine hydraulic model is expected to yield results that are valuable to all involved with the design and operation of Kaplan turbines elsewhere. The results of the modeling should identify any potential biological concerns with the new design prior to installation. In addition, these results should aid in the effective design of post-construction biological tests to maximize the value of the test results.

ALSTOM Turbine Runner Proposal. ALSTOM will provide a next generation MGR turbine runner model of their design to ERDC for testing in the Lower Granite physical model. The results from the ALSTOM runner tests will be compared to test results from a standard Kaplan runner conducted in the same Lower Granite physical model. Each runner will undergo tests at three different flow rates. Two of the selected flows relate to flow conditions under which biological testing was performed at the Lower Granite project in 1995. The third flow point corresponds to the upper limit of the 1% efficiency range for the ALSTOM MGR. Testing will consist of observing neutrally buoyant beads passing through the turbine runner using high-speed video. Velocity distribution in the draft tube will also be measured.

It is anticipated that higher efficiency and greater fish survival will be indicated for the ALSTOM MGR design compared to the standard Kaplan turbine runner. Lessons learned from this should be applicable to most new Kaplan turbine designs. Testing is scheduled to begin in March 2004 and a Draft Report is expected in December 2004.

2.1.2 Alden/NREC Pilot Scale Turbine Runner Testing

In the initial phase of the AHTS research, the Alden Research Laboratory, Inc. (Alden) and its partner, Northern Research and Engineering Corporation (NREC) developed a conceptual design for a new turbine runner that would minimize both the sources of injury to fish and the penalty on turbine efficiency (Cook et al. 1997; Hecker et al. 1997). The new runner, which is based on the shape of a pump impeller (Figure 2.1.2-1), minimizes the number of blade leading edges, reduces the pressure versus time and the velocity versus distance gradients within the runner, minimizes clearance between the runner and runner housing, and maximizes the size of flow passages, all with minimal penalty on turbine efficiency. The flow characteristics of the new runner were analyzed using two-dimensional and three-dimensional Computational Fluid Dynamics (CFD) models.

Due to the uniqueness of this new runner and the biological assumptions with which it was designed, DOE decided to build a prototype model and facility where it could be tested (Cook et al. 2000). Construction of the test facility at Alden Research Laboratory (ARL) in Holden, Massachusetts, was completed in FY 2001, and testing operations began in September 2001. The test facility is centered on a 1/3-scale, 4-foot diameter prototype runner set in a closed-loop system that is large enough to pass fish (Figure 2.1.2-2). Injection ports for control fish (not subject to turbine passage) are built into the test loop, along with a fish screen and recovery chamber.

Figure 2.1.2-1. Alden/Concepts NREC runner.

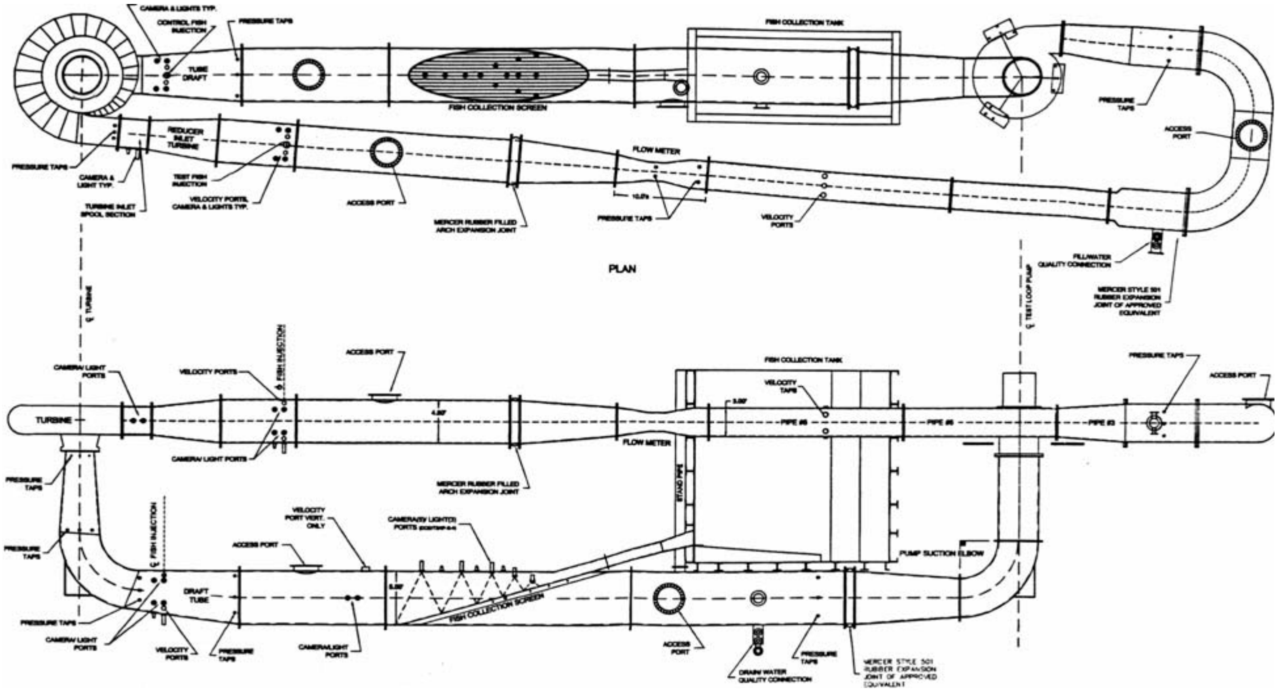

Figure 2.1.2-2. Test loop at Alden Research Laboratory, Holden, Massachusetts.

The first phase of biological and hydraulic testing was completed in October 2001. The report of the Fall 2001 engineering and biological tests was issued March 2002. Review of the Fall 2001 tests resulted in several revisions to the planned Spring 2002 and Fall 2002 tests. The Spring tests began in April 2002 and were completed in early June 2002. The report for the Spring 2002 tests was issued in July 2002. The Fall 2002 tests began in September. During the spring and fall tests several visits to Alden were conducted by various members of the technical committee to review both the biological and engineering tests.

Additional testing refinements were made and the final biological and engineering tests were completed in January 2003. The pilot scale test results were presented to the members of the Technical Committee in March 2003. A draft of the final report was issued for review in June 2003, and the final report (Cook et al. 2003) was published in September 2003.

Most tests with juvenile rainbow trout at the best efficiency point setting showed immediate and 96-hr survivals over 90%. Smaller trout (3.7 inch) had higher survival rates than larger trout (6.9 inch). All sizes of trout had higher survivals at lower runner rotation speeds and hydraulic heads. Smallmouth bass also exhibited an inverse relationship between fish size and turbine passage survival. Turbine-passed smallmouth bass, white sturgeon, eels, alewives, and coho salmon all had 96-hr. survivals at or above 90%. American eels (9.8 and 17 inches long) had immediate survivals of 100%; 96-hr. survivals exceeded 98%. Compared to a prototype (full-sized) runner, the pilot scale runner used in these tests is 1/3 as large and rotates faster. Owing to the lower rotation speed and larger fish passage areas in a prototype, fish passage survival is predicted to be greater at field sites employing the full-sized turbine.

The pilot scale test results indicated the Alden/Concepts NREC turbine has the potential to pass fish at hydroelectric projects with minimal injury and mortality. The next step in the development of the Alden/Concepts NREC turbine would be to redesign the turbine runner using the verified CFD model. Refinements to the design should further improve the high survival rates measured in the pilot scale turbine. Increasing the thickness of the leading edge on the runner blade would further minimize fish mortality due to strike. Reshaping the leading and trailing edges of the runner blade geometry would eliminate pressure reversal and excess residual swirl, and thus, improve power efficiency. Increasing the radial height at the runner inlet would increase the power density for a given runner diameter. The viability of this technology has been demonstrated at the pilot scale, and DOE does not plan to sponsor any further testing of the turbine.

2.1.3 Improved Mitigation Practices

This project area involves developing a scientific basis and economic baseline for mitigation practices typically required for hydro projects. Approaches for mitigating low dissolved oxygen in reservoir discharges and reduced instream flows were addressed in FY03.

Dissolved Oxygen Mitigation. Low dissolved oxygen (DO) concentrations are a common water quality problem downstream of hydropower facilities. At some power plants, structural improvements (e.g., installation of weir dams or aerating turbines) or operational changes (spilling water over the dam) can be made to improve downstream DO levels. In other cases, structural and operational approaches are too costly for the project to implement.

Peterson et al. (2003) examined the value of regulatory approaches to addressing DO issues, including negotiation of site-specific water quality criteria, use of biological monitoring, watershed-based strategies for the management of water quality, and watershed-based trading.

The possible value of innovative regulatory approaches for hydropower plants was considered by reviewing their use in other contexts (e.g., for other types of facilities or effluent dischargers, or for other water quality issues), by reviewing recent regulatory policy, and by the application of hypothetical examples. Cada et al. (2003a) compared these approaches to the regulation of water quality in the European Union under their recently enacted Water Framework Directive. This project activity was completed in FY 2003.

Instream Flow Mitigation. Reduced flow and extreme daily fluctuations in flow have been recognized for many years as consequences of hydropower production which have the potential to negatively impact fish communities below hydropower dams. Common mitigation to address these concerns includes minimum instream flow requirements and changing the operation mode from peaking to run-of-river. The purpose of this project is to evaluate the costs (both operational and lost power) and environmental benefits of flow modifications at a variety of projects where recent modifications have affected instream flow. In FY 2003 we identified projects with recent changes in project operations resulting in modified flows. We analyzed stream gage data to evaluate whether stream flow was modified as intended. We used flow evaluation software to compare daily and seasonal flow characteristics from pre- and post-modification years. We discovered that monitoring studies following flow modifications to assess environmental response are rare. Mitigation costs were evaluated from surveys completed by project owners. This project continues into FY 2004.

Effects of Hyporheic Discharge on Redd Temperatures/Emergence Timing. Research conducted under this project (cost-shared in FY03 by Idaho Power Company and Bonneville Power Administration) evaluated the relationships among river discharge, hyporheic zone characteristics, and egg pocket water temperature in Snake River fall Chinook salmon spawning areas. The overall objective was to evaluate relationships between riverbed hydrologic exchange processes and the survival and emergence timing of incubating fall Chinook salmon. We hypothesized that flows could be manipulated to accelerate egg incubation and fry emergence, thereby shifting the smolt emigration from the Hells Canyon Reach to a period when downstream reservoir water temperatures are more conducive to survival.

The hydrologic regime during the 2002–2003 sampling period exhibited the lowest, most stable daily discharge than any of the previous 11 water years. Hydraulic gradients between the river and the riverbed (hyporheic zone) suggested that the dominant exchange process was river water downwelling into the riverbed. The use of temperature as a conservative tracer resulted in similar findings of river water downwelling into the hyporheic zone at all sites during the spawning and incubation periods. Using site M4 as an example, the daily minimum and maximum temperatures within the riverbed (egg pocket and hyporheic zone) lagged by 1–6 h behind the minimum and maximum temperature of the river water. Initial results from a mechanistic model of riverbed temperature suggest that conduction of thermal energy (resulting from temperature gradients between the river and the bed) is more important than advection (i.e., via changing stage and hydraulic gradients). The range of fall Chinook salmon emergence timing within a site was greater based on egg differences (5-8 days) than based on egg pocket and river temperatures (1-3 days). The 2002-2003 water year was one of the driest on record, which in turn affected total river discharge, water temperature, and hydroelectric dam operations at the Hells Canyon Complex. Additional empirical data from different water year types will be required to fully describe the hydrologic exchange between the river and riverbed.

2.2 Technology Viability – Supporting Research and Testing

Project areas associated with this subkey activity included Biological Design Criteria (Section 2.2.1), Computer (CFD) and Physical Modeling (Section 2.2.2), Instrumentation and Controls (Section 2.2.3), and Environmental Analysis (Section 2.2.4).

2.2.1 Biological Design Criteria

This project area involves assessing the stresses associated with downstream fish passage (i.e., within turbines or spillways) that kill or injure fish so that new designs and modes of operation can be developed with improved environmental performance.

Protocols for Biocriteria Development. It has long been recognized that there are significant gaps in our knowledge of fish responses to the physical stresses experienced during passage through a turbine or spillway (Wittinger et al. 1995; Cada et al. 1997). Hence, a major focus of the Advanced Hydropower Turbine Systems Program (and now the Advanced Hydropower Technology effort) has been the quantification of fish injury and mortality associated with these potential fish injury mechanisms. Laboratory experiments are carried out to quantify the fish responses, based on experimental protocols that encompass the magnitude and qualitative nature of the stresses that are experienced. Subsequently, the information is used to define biocriteria for turbine design and operation, i.e., the conditions within which the likelihood of safe fish passage is expected to be high.

Studies of shear, pressure and gas supersaturation have been completed, and have led to a greatly improved understanding of safe passage conditions. In FY 2003 we began work on developing the experimental protocols that will help define fish response to two other potential injury mechanisms – turbulence and strike. A Workshop on Turbulence at Hydroelectric Power Plants was help in Atlanta on June 12, 2003. Its purpose was to bring together investigators performing turbulence research to assist in the formulation of experimental protocols for turbulence experiments. Presentations were made by 10 participants from ORNL, PNNL, Corps of Engineers, Tennessee Valley Authority, and Georgia Tech. The workshop participants discussed all aspects of turbulence at hydropower plants, from measurements to modeling to biological responses. Similarly, development of protocols for strike began in FY 2003, including investigations of the potential usefulness of pressure sensitive film for quantifying strike exposures (Section 2.2.3).

Bioindex Testing. The overall objective of this project is to develop a relationship between fish size, turbine operations, and risk of injury for salmonids passing through turbines. The probability of blade strike is a predominant factor resulting in fish injury. Information on blade strike is needed to develop biological tests for establishing biological criteria for operation of turbines. Survival gains for turbine-passed fish on the order of 10% above current levels may be achievable with optimized conditions.

In FY03, we integrated historical and recent test results for turbine passage in conjunction with published theory for turbine runner blade strike to examine the relationship among fish size, turbine operation, and injury to fish during turbine passage. Use of Monte Carlo techniques allowed consideration of factors such as fish orientation at entry to the runner, distribution of fish along runner blades, and important sources of error and variability in strike-probability estimation. Blade strike was considered for analysis because it is an obvious source of injury and injury mechanisms have been mathematically and empirically studied. Additionally, blade strike has been studied using beads in a physical model. The first phase of analysis included a sensitivity analysis to consider the effects of differences in geometry and operations between families of turbines on the strike probability response surface. Blade-strike models predicted that injury increases with decreasing discharge and with increasing fish-passage radius. Over a range of discharges, the average prediction of injury from blade strike

was 2 to 5 times higher than average empirical estimates of visible injury from shear and mechanical means. The orientation of fish relative to the leading edge of a runner blade and the location that fish pass along the blade between the hub and blade tip are critical uncertainties in blade strike models.

We will continue with analysis in FY04 addressing the vertical distribution of fish at the wicket gates relative to distributions inside intake trash racks as well as characterizing the orientation of fish passing runner blades. Field tests are planned for subsequent years and results will help provide guidelines for operations that optimize the safe passage of fish through turbines.

Laboratory Studies of Pressure Effects. Pressure change has been identified as a potential source of injury and mortality for fish during turbine passage and has been extensively studied over the past 3 years. Previous studies emphasized exposures of juvenile salmon, trout, and bluegill sunfish to pressure regimes expected during passage through a vertical Kaplan turbine, including tests where fish were simultaneously exposed to high levels of total dissolved gas. A final series of studies involved pressure changes modified to simulate passage through a horizontal bulb turbine, commonly installed at low-head dams. Laboratory tests indicated that pressure changes occurring during passage through most of the cross-sectional area of a horizontal bulb turbine are not harmful to juvenile Chinook salmon and only minimally harmful to bluegill. Some areas within a horizontal bulb turbine may have more extreme pressure conditions but the potential risk of injury is reduced because of small cross-sectional area. A final report (Abernethy et al. 2003) and a summary article (Becker et al. 2003) were published in FY03.

Quantification of Hydraulic Forces. The goal of this project is to quantify the response threshold of juvenile fish to hydraulic forces. It has strong linkages to other programmatic components, including sensor fish data and development of CFD-based biomechanics model. Quantifying the dynamic parameters associated with the biological response of fish requires characterization of the fine-scale hydraulics in the boundary region of the fish as well as detailed information on the dynamic motion of test objects.

In FY03, studies focused on the use of advanced high-speed video and 3-D motion analysis techniques to better quantify dynamic parameters associated with the exposure of free-swimming fish and the sensor fish device to turbulent shear flow (Figure 2.2.1-1). A Particle Image Velocimetry (PIV) system was purchased to allow high-frequency, high-resolution mapping of experimental flow fields. Injury type and severity was related to the size (length and mass) of the fish, strain rate, turbulence, and measures of dynamic parameters computed from video-derived 3-D trajectory paths.

Additional studies involved the testing of damage caused to the vestibular system of fish exposed to varying levels of acceleration. The influence of gravitational forces on fish is sensed by the vestibular system, while the influence of light is sensed by visual input. An automated testing apparatus was constructed to examine the influence of accelerations between 3.1 and 10 g on the dorsal light reflex (DLR). The DLR was used as a behavioral measurement of vestibular function. Other responses included determining the length of time that it takes fish to regain a normal DLR, and the amount of time it takes fish to orient to the flow. The primary activities for FY04 will include conducting turbulence and strike experiments on fish and sensor fish using the PIV system for flow characterization and motion tracking.

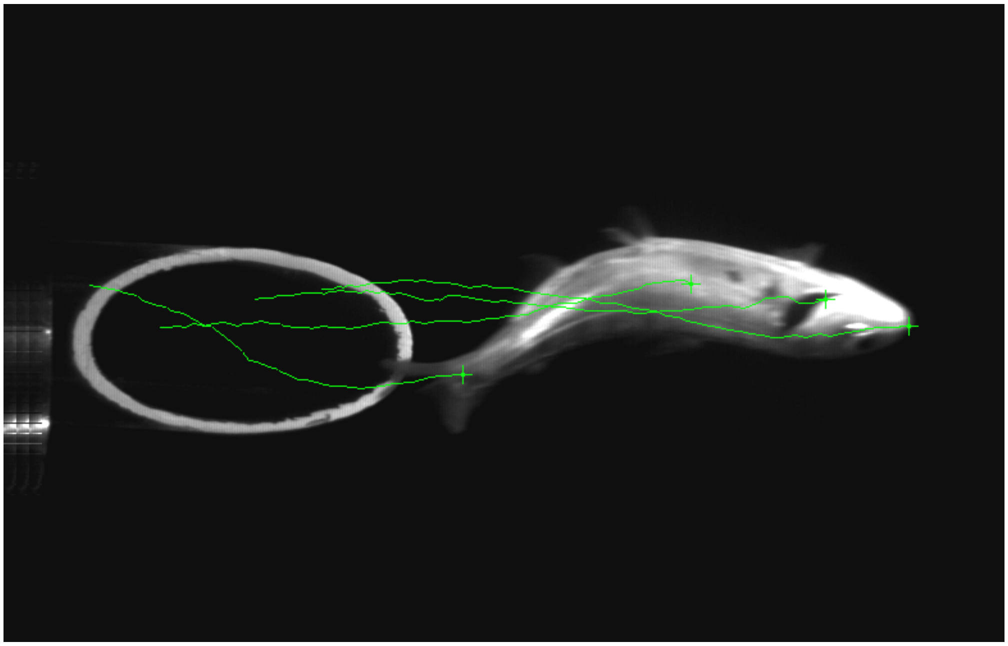

Figure 2.2.1-1. Image of juvenile Chinook salmon trajectory path showing its response to a high velocity environment.

Effects of Sublethal Stresses on Escape Behavior. High-speed video studies were used to explore changes in fish escape behavior as possible indicators of the effects of sublethal stresses associated with downstream passage at hydropower plants (Figure 2.2.1-2). Minnows that were subjected to turbulence in laboratory test tanks subsequently exhibited impaired escape behavior (Cada et al. 2003b). The behavioral changes were temporary and often short-lived, becoming non-significant at 5 minutes after exposure to the stress. However, these results suggest that there may be a period of increased vulnerability to predators in the first minutes after turbine or spillway passage. These effects were comparable to standard predator preference tests that were conducted concurrently (which showed increased vulnerability to predation of sublethally stressed fish).

Changes in escape behavior were assessed among rainbow trout that passed uninjured through the Alden pilot scale turbine runner. Behavior was analyzed for three groups of trout: control fish, fish that passed through the circulating loop and collection system (but not the runner), and fish that passed through the circulating loop, and collection system, and runner. Temporary, short-term impairments of escape behavior were observed among rainbow trout that had passed uninjured through the test system. The behavior of fish that passed through the entire system (test loop, collection, and advanced runner) was not significantly different from those that passed only through the test loop and collection system, i.e., the additional factor of runner passage did not further alter escape behavior. Studies of changes in escape behavior are continuing in FY2004 under the Response of Fish to Turbulence activity.

Figure 2.2.1-2. Turbulence test tank used to measure changes in C-shape (escape) behavior in fish.

2.2.2 Computer (CFD) and Physical Modeling

Investigations in this project area develop new methods to predict both the physical conditions inside operating turbines and the biological effects of those conditions.

Biomechanics CFD. Identification of conditions that cause injuries to fish in severe hydraulic environments (Cada et al. 1997) has been aided by recent studies conducted as elements of the Department of Energy's Advanced Hydropower Turbine Systems program (DOE-AHTS). Studies conducted at PNNL (Neitzel et al. 2000) have shown that fish can be directly injured or killed by exposure to shear and turbulence and that temporary disability, such as stunning, increases indirect mortality by predation. These studies showed that the majority of serious injuries were located in the frontal area of the fish. Torn, bent, and bruised isthmus, gill covers and gills were the prevalent injuries.

These experiments related fish injuries to the fluid environment in a general manner; missing are detailed measurements of the bending and torsion of the parts of the fish body, total force acting on the fish, and how these are related to the observed injuries. Detailed measurements and computations are necessary to gain an improved understanding of the biomechanics of injury mechanisms and injury thresholds. In FY2003 we continued work to develop and validate a coupled computational fluid dynamics (CFD) and a computational analog of the sensor fish device. Parallel to the computational work we conducted a set of experiments (see Section 2.2.1 Quantification of Hydraulic Forces) using high-speed imaging to provide key data that will be used to correlate sensor fish acceleration histories to the biological response of live fish. Using these laboratory correlations, CFD, and the computational sensor fish analog will provide a method to estimate biological response in turbulent flows. This computational method is currently being used at The Dalles Dam in conjunction with releases of sensor fish and balloon-tagged fish. Metrics such as collision intensity (see Figure 2.2.2-1) are then used to identify locations and events that present a high-probability for injury to fish and make recommendations for changes in the spillway configuration and operation that could lower fish injury rates. The computations and experiments will be in progress during FY2004.

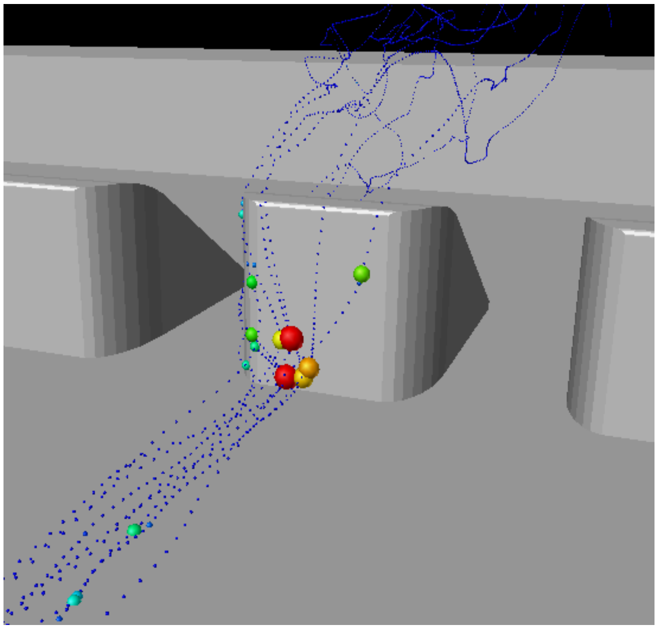

Figure 2.2.2-1. Relative collision intensities at a baffle block experienced by computational sensor fish analogs in an unsteady CFD model of The Dalles Dam stilling basin. A larger diameter sphere and red color indicates a more severe collision. The dotted blue lines show the simulated trajectories of the sensor fish analogs.

Measurement of Turbulence in COE Turbine Physical Model. Turbulence occurs at all scales in a hydropower turbine and is a suspected source of mortality for fish passing through the hydropower turbines of the Columbia River federal hydropower system. However, it is difficult to obtain measurements of turbulence at prototype scales primarily because of the extreme difficulty and cost of deploying instrumentation in the turbine environment. Because of this difficulty, physical hydraulic models are being used to investigate the biological performance of existing structures as well as to examine the features of structures being designed. This information helps identify locations of potential hazard for fish and improves understanding of potential injury mechanisms.

The goal of this project is to characterize the large-scale turbulence that occurs in turbine draft tubes by tracking neutrally buoyant beads through sections of the Corps of Engineers 1:25-scale physical turbine model for Bonneville Dam Powerhouse 1 at the Environmental Research and Development Center (ERDC) using high-speed digital video cameras to produce 3-D bead trajectories. Near neutrally buoyant beads have been used to map the path of flow and probable path of fish through turbines and to estimate probability of strike and make general observations of hydraulic conditions. Previously, these observations have been made in 2-dimensions at mainly a qualitative level.

Data were collected with the minimum gap runner (MGR) model at two operating conditions, lower 1% efficiency and maximum operation level. Paired high speed digital video cameras (1000 frames/sec) acquired bead images in four regions of the draft tube in the model at both operating conditions. Approximately 5000 beads were released into the model for these tests. Initial analysis of data has provided good bead trajectory paths and realistic velocity estimates. Averaging of points to smooth the data was required to improve estimates of acceleration. Preliminary observations show greater turbulence at the lower operating condition and in the region below the runner (Figure 2.2.2-2). High-speed digital cameras with better pixel resolution will be tested in FY04 to determine if greater resolution will improve estimates of acceleration.

Unsteady CFD Modeling. We have developed a state-of-the-art CFD method for simulating the dynamics of large-scale unsteady vortices in hydroelectric power plants using unsteady statistical turbulence models. The numerical model employs domain decomposition with Chimera overset grids to accurately discretize arbitrarily complex three-dimensional geometries and solves the governing equations with a finite-volume scheme which is second order accurate in space and time. Various unsteady turbulence modeling strategies have been incorporated into the model, ranging from the Large-Eddy Simulation (LES) approach to the more practical, for engineering, high Reynolds number flow simulations, unsteady Reynolds-averaged Navier-Stokes (URANS) and hybrid URANS/LES turbulence models. The CFD model has undergone extensive validation for various internal and external flows for which experimental data have been reported. Specific validation cases include flow past a strongly curved, 90 deg, rectangular bend and flows in open channels with multiple bottom-mounted obstacles. For all simulated cases the agreement between experimental data and numerical results was very good. The promise of the model as a powerful tool for simulating real-life hydro turbine flows was demonstrated by applying it to simulate unsteady flow in a complex hydro-turbine draft-tube (Figure 2.2.2-3). The computed results showed that the model can capture well known large-scale vortex phenomena such as the formation of a precessing, highly unsteady rope vortex downstream of the runner. Comparisons of the simulated flowfields with the limited amount of available experimental data showed great promise and underscored the need for detailed high-resolution mean flow and turbulence statistics measurements to facilitate further model development and validation.

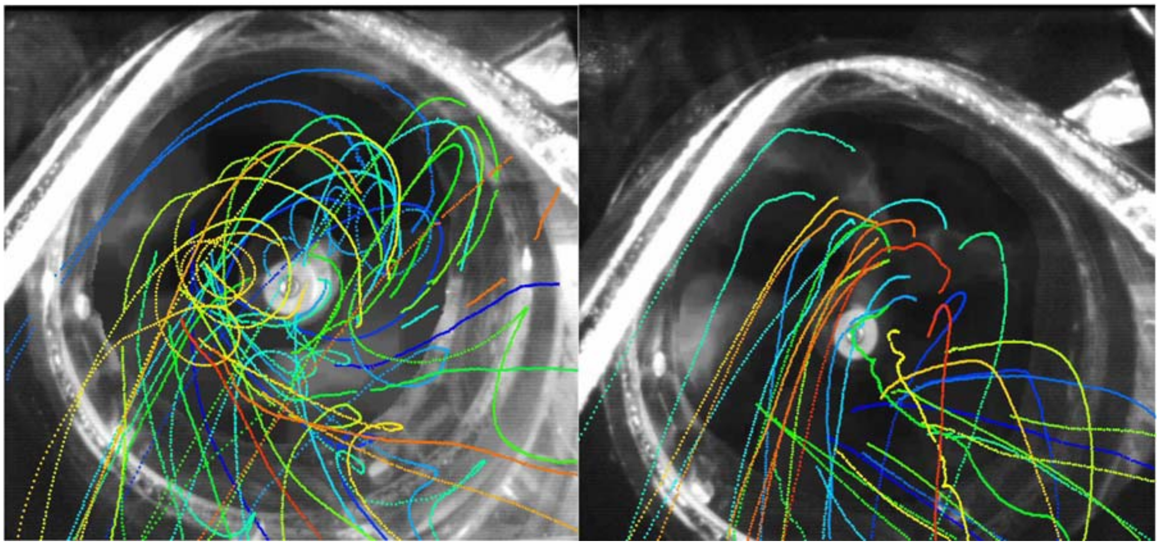

Figure 2.2.2-2. Trajectory of beads below the MGR runner, released mid-depth in the gatewell of the B intake, in the Bonneville PH1 1:25 scale model at lower 1% operating efficiency (left) and maximum operation level (right).

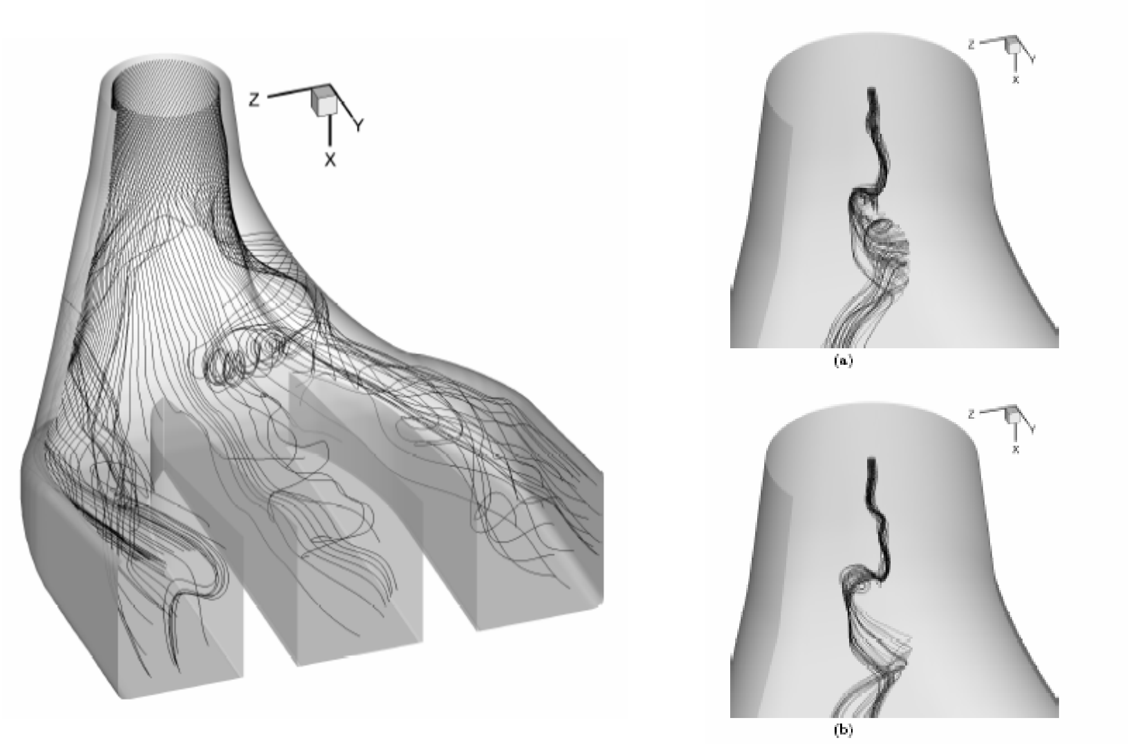

Figure 2.2.2-3. Instantaneous particle paths depicting large-scale unsteady vortex formation in TVA's Norris Dam draft tube. Left: Large-scale vortices upstream of the piers; Right: Rope vortex downstream of the runner.

Modeling Fish Inside Turbines. We have completed the development of a significant part of the numerical infrastructure for a powerful, strongly-coupled numerical model for simulating the motion of three-dimensional, flexible, fish-like bodies in turbulent hydro turbine flows. The model can simulate flows in domains containing arbitrarily complex, flexible immersed boundaries using a hybrid Cartesian/immersed boundary, sharp interface approach with direct forcing. We have carried out extensive validation of the method by applying it to a variety of benchmark three-dimensional flows and have established its excellent spatial and temporal accuracy. The method has been applied to simulate the flow past a swimming mackerel in order to investigate the effects of body kinematics and Reynolds number on hydrodynamic drag reduction and the production of propulsive thrust. These studies were undertaken in order to validate the model by comparing its predictions with the findings of recent experiments with live fish. The simulations reproduced with remarkable accuracy most experimental observations, including the well documented fact that thrust production is linked to the formation of a reverse Karman street in the wake of the fish (Figure 2.2.2-4). Future work will focus on extending the model to turbulent flows.

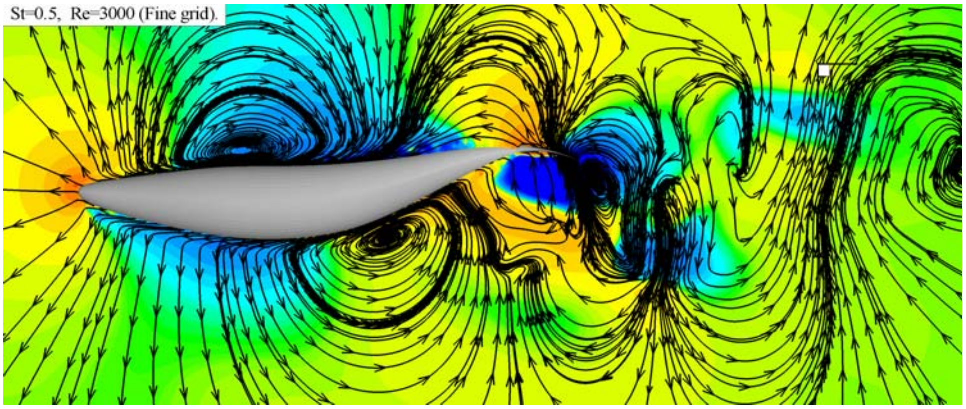

Figure 2.2.2-4. Simulated reverse Karman street (thrust wake) for flow past a swimming fish-like body.

Inventory of Damaging Shear in Kaplan Turbines. In cooperation with ORNL, Voith Siemens developed methods for predicting the location and magnitude of damaging shear to fish passing through hydropower turbines. Experimental data and CFD modeling were used to quantify shear areas within a Kaplan turbine operated at optimum (11,000 cfs) and high (17,000 cfs) flow conditions at Wanapum Dam on the Columbia River. Many shear zones that would be damaging to fish were identified in this initial feasibility study.

The same CFD methods were applied to a wider range of operating flows (9,000 and 15,000 cfs in addition to the previous two flows) in a subsequent study (Garrison et al. 2003), and the modeling results were compared to data on fish mortality obtained from field studies of turbine passage at the Wanapum Dam. Tagged coho salmon smolts were released at two depths (10 ft and 30 ft from the intake ceiling), corresponding to passage near the hub and in the middle of the turbine runner blade, respectively. The highest observed survival for both release depths occurred at 15,000 cfs, which exceeded the flow for peak turbine operating efficiency of 11,000 cfs and was not consistent with the CFD modeling results that predicted an increase in shear-related mortality with flow. The Wanapum field studies also indicated that survival was lower in the hub-passed than the mid-runner-passed fish, but this trend was not consistent with the CFD predictions of shear for these regions (Figure 2.2.2-5).

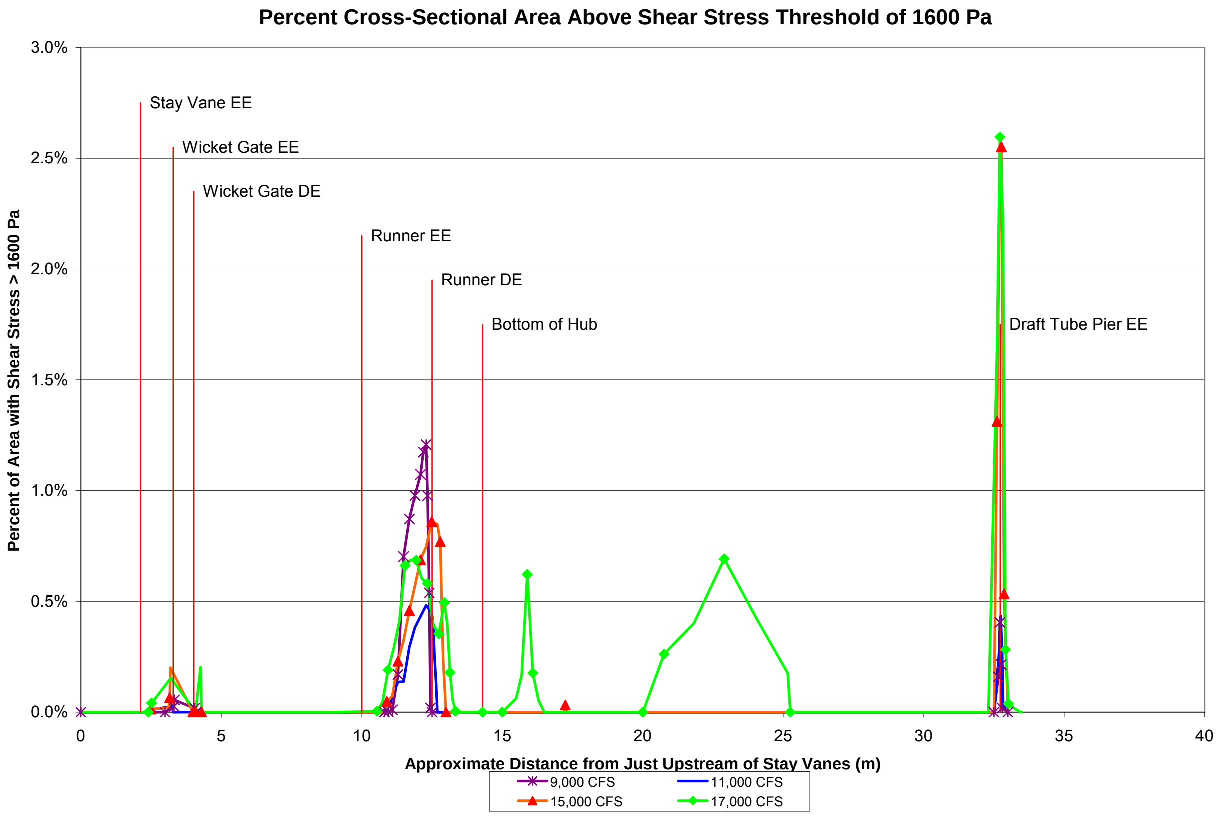

Figure 2.2.2-5. Predicted high shear regions in the Wanapum turbine, expressed as percentages of cross-sectional area through the water passage. The percentages were calculated by cutting planes across the water passage and calculating the area within the planes that is above the threshold, then dividing by the total area of the planes within the flow. EE stands for Entrance Edge and DE stands for Discharge Edge. From Garrison et al. (2003).

Several factors may account for these differences between observed and predicted survival during turbine passage. The field studies estimated total mortality from all sources of mortality to fish that pass through hydropower turbines (e.g, shear, pressure, turbulence, strike), yet the CFD model estimated only shear. Also, CFD modeling assumes that the distribution of the fish passing through the turbine is due only to flow, but the field studies suggest that the assumption is too simplistic and more information is needed on the trajectories taken by fish during turbine passage. This modeling approach represents an important tool for evaluating alternative turbine designs and identifying those that minimize fish mortality.

2.2.3 Instrumentation and Controls

The intent of this project area is to develop new technologies to measure physical conditions inside turbines. These measurements will increase understanding of conditions affecting fish inside turbines and provide knowledge of needed design modifications that will reduce impacts to the fish passing through turbines.

Sensor Fish Development. The sensor fish has evolved to be an essential part of fish passage studies where it is used to identify structural features and operating conditions deleterious to fish. In FY03 sensor fish were used extensively to investigate spill as a bypass alternative at mainstem Columbia River dams. As an element of studies conducted for the US Army Corps of Engineers to characterize conditions fish experience during turbine and spill passage, PNNL developed a particle tracker to be used with CFD simulations that emulates features of our current 3 DOF (three degree of freedom) sensor fish. This effort permitted identification of “signatures” in sensor fish pressure and acceleration time histories characteristic of passage by structural features such as baffle blocks in spill stilling basins. This technical breakthrough permits a complex environment like a turbine or spill stilling basin to be separated into discrete zones based on significant structural elements.

One example of “signature” identification (Figure 2.2.3-1) shows the pressure time history for passage of a numerically simulated sensor fish compared to output generated using a fully transient CFD model of The Dalles Dam stilling basin. Location signatures identified events such as contact with structures (e.g., stilling basin baffle blocks and end sill) or exposure to shear. Successful development of a prototype numerical surrogate for the sensor fish is an significant achievement. Close coupling of numerical capability such as CFD and numerical surrogates of sensor fish allows for investigations of the biological and physical performance of fish passage facilities during both the design stage and after project completion. Identification of additional signatures will lead to more detailed assessment of turbine environments and operating conditions.

Activities planned for FY04 include continued improvements to the current 3 DOF sensor fish and to complete design specifications and initial testing for a 6 DOF + pressure sensor fish devise. The goal is to have the next generation device ready for testing the new turbine at Wanapum Dam in the spring 2005.

Pressure Sensitive Film Applications. In many areas of fisheries management there is a need to quantify the interactions between fish and mechanical or hydraulic structures that might lead to physical trauma. For example, fish may be injured by contact with solid structures (e.g., water intake screens; passage through pumps, pipes, and hydroelectric turbines and spillways) or fluid structures (submerged jets; shear stresses and turbulence associated with turbine discharges, spillways, and the wakes from vessel hulls and propellers). All of these potential fish injury mechanisms can be expressed as force per unit area (pressure). If the magnitude and likelihood of these mechanisms can be measured with suitable instruments and related to known effects of pressure on fish, efforts can be made to reduce their effects.

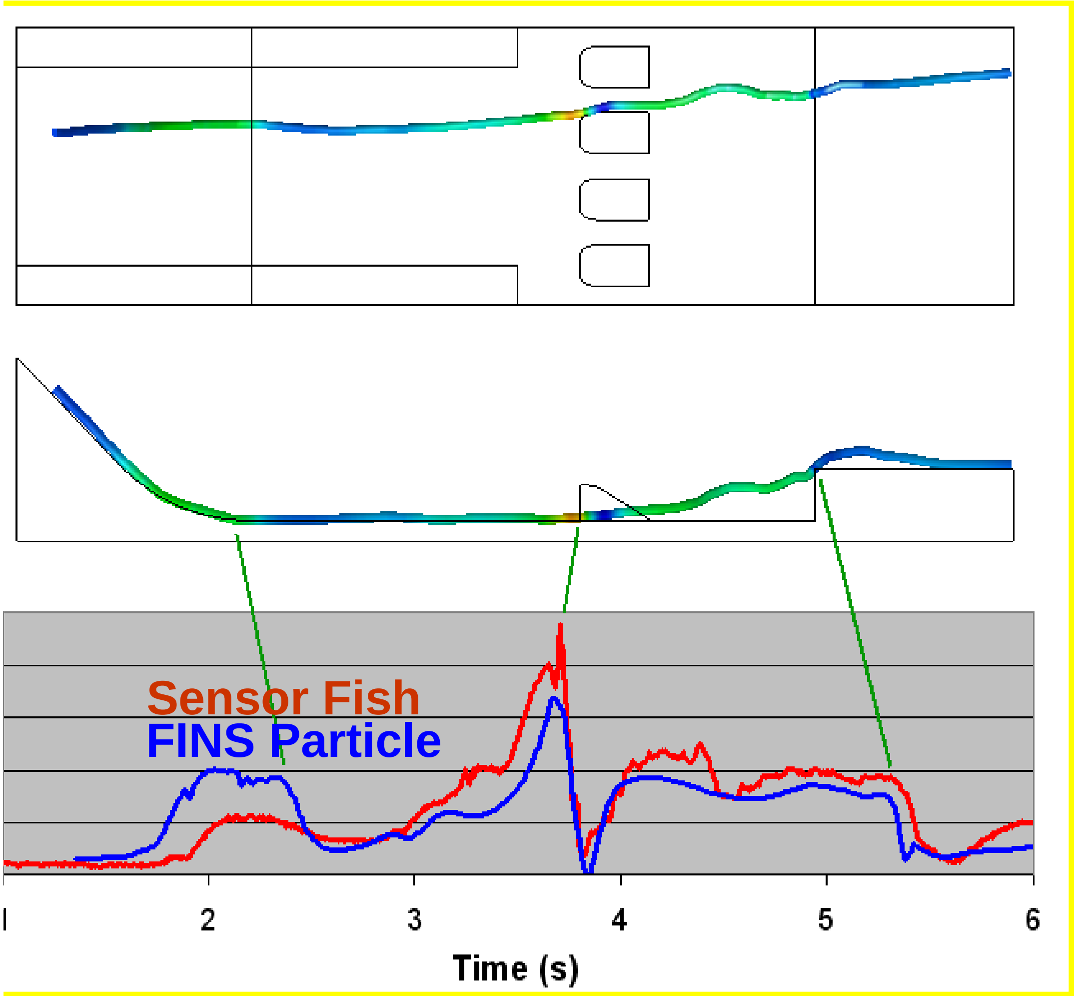

Figure 2.2.3-1. The top portion of this graph shows the pressure time history for passage of a numerically simulated sensor fish using a fully transient CFD model of The Dalles Dam stilling basin. The lower part is the pressure time history of a sensor fish through the actual stilling basin under the same operating conditions. Time history section 1 represents the characteristic pressure signature for entry of the sensor numerical surrogate and the actual sensor into the stilling basin from the spill conveyance chute. Sections 2 and 3 show the characteristic pressure signatures for passage past baffle blocks and the endsill, respectively.

The value of pressure sensitive film (PSF) for quantifying impacts caused by the contact of fish with mechanical and hydraulic structures was explored. The films responded well to a wide range of applied pressures (0.5 to 50 MPa; 363 to 7,252 psi). PSF provided reliable estimates of pressures even when contained within waterproof plastic packaging, stacked under other films, and exposed at low water temperatures or low and high relative humidities. Waterproof packages of PSF were field tested by wrapping them around polycarbonate plastic cylinders (sensor fish) and passing them down spillways of hydroelectric dams. Most of the spillway-passed PSF samples had marks indicating impacts with mechanical or fluid structures (Figure 2.2.3-2). Many of the marks revealed high values of pressure (e.g., > 40 MPa) that are likely to injure fish. This project activity was completed in FY 2003.

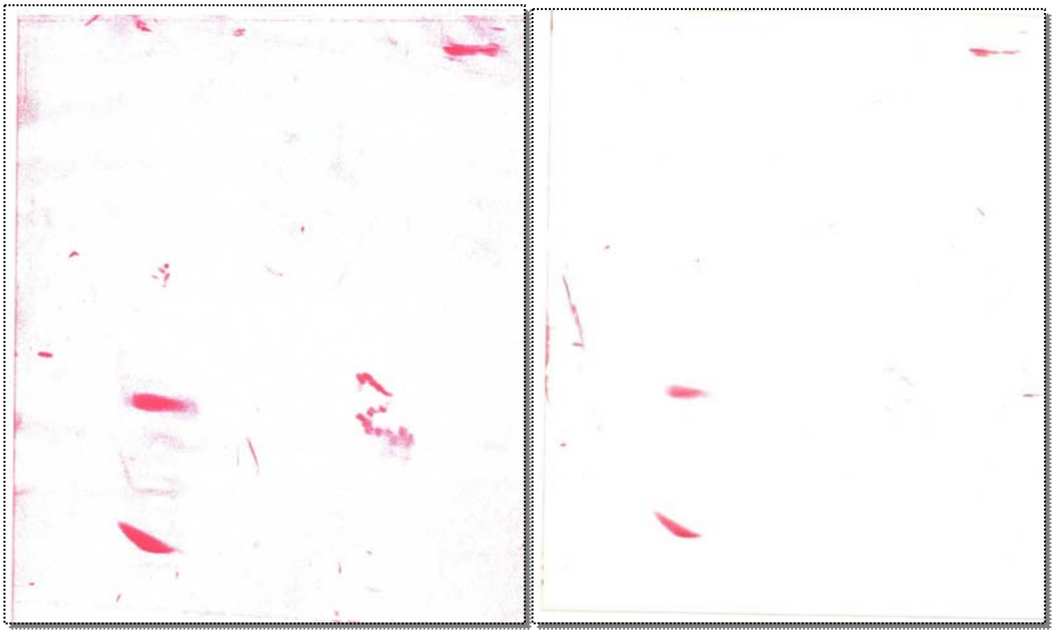

Figure 2.2.3-2. Examples of marks on LW PSF (left) and MW PSF (right) that were wrapped around a sensor fish and passed down the spillway of Bonneville Dam on August 28, 2002. The LW PSF registers pressures of 2.5 to 10.0 MPa, which makes it more sensitive to impacts than the MW PSF (10.0 to 50.0 MPa).

Measurement of Turbulent Flows in Turbine Systems. Analyses of data measured during FY 2002 field tests at Melton Hill Dam were completed in FY 2003. These analyses identified needed improvements to the signal processing configuration and interpretation of the Acoustic Doppler velocimeters (ADV) used to measure velocity time series in the high-speed turbulent flows of the draft tube. Velocity range limitations of standard ADVs used in FY 2002 limit the usefulness of the Melton Hill data for computation of non-linear statistics of the flow such as Reynolds stress components or proper orthogonal decomposition. However, follow-up flume testing with ADVs in the core and shear layer regions of high speed jets indicate that this limitation can be overcome with the application of a Doppler ambiguity resolution algorithm to ADV data collected with a modified acoustic pulsing scheme. This new arrangement has yielded accurate time series data from laboratory flume flows with time-average velocities of up to 20 feet per second. The modified acoustic pulsing scheme was implemented in the turbulence data acquisition system along with real-time monitoring of velocity histograms that allow for detection and resolution of Doppler ambiguity.

The improved turbulence data acquisition system was deployed in the intake gate slot of Unit 6 at the Tennessee Valley Authority's (TVA) Pickwick Landing Project in conjunction with absolute flow rate measurement with conventional propeller current meters, conducted as part of TVA's ongoing program of hydro unit characteristics assessment and hydro unit optimization. Three propeller current meters were replaced with ADVs to provide information on the temporal and spatial variations of the intake flow field in the vicinity of non-streamlined geometry at the top of the intake gate slot. The turbulence data acquisition system performed well in this converging flow field, capturing the entire range of turbulent velocity fluctuations present and providing useful information about the time-averaged direction of flow at the measurement section. Analyses of these data will continue in FY 2004, focusing on the suitability of the data for computation of non-linear turbulent statistics. The Pickwick intake data are valuable in the context of draft tube turbulence because they serve as a full-scale, high-speed, low-turbulence reference to which data from intensely turbulent draft tube flows may be compared.

The next step will be to return to the Melton Hill draft tube with the improved turbulence data acquisition system. Four ADVs will be deployed to yield synchronized three-dimensional velocity time series from an array of locations in the upper half of the draft tube gate slot cross section. Data will be collected at three turbine settings: (1) below peak efficiency, (2) peak efficiency, and (3) maximum sustainable load.

Advanced Imaging. A major challenge towards evaluating the biological performance of operating turbines is to determine the approach and interaction of fish with turbine structural elements because these regions have high velocities, are highly turbid, and difficult to access. This project addressed these issues with a goal to identify and evaluate imaging alternatives for observing details of fish behavior within an operating Kaplan turbine unit.

The approach for this project in FY03 was to specify technological approaches for quantifying causal mechanism(s) of injury to juvenile fish during turbine passage. The physical environment was specified as that area immediately upstream of the turbine wicket gates and the turbine runner, respectively. Potential sources of injury and desired data from an imaging system were also considered to define possible technologies and implementation approaches for imaging. Imaging alternatives were identified and evaluated both theoretically and in limited laboratory settings for observing details of the behavior of juvenile fish within an operating Kaplan turbine unit.

High-speed optical imaging solutions were determined to be the only feasible technology to image fish fast enough and at high enough resolution to detect operculum and eye injuries at the runner tip. Further, only a laser light source would produce enough light in the extremely short exposure required to prevent image blur from the fish (or runner) moving at 32 m/s or so through the tip region (Figure 2.2.3-3). Absorption would be minimized through water in the 500 to 530 nm (green) range. Both argon ion (514.5 nm) and Nd:YAG diode (532 nm) lasers are readily available from industrial sources. Optical wavelength scattering due to turbid river conditions will limit the range of detection and image resolution to very short ranges depending on the time of year and the particular river. Future activities will involve the use of balloon- and light-emitting tagged fish and data acquisition from two or more high-speed digital cameras placed within the immediate runner environment.

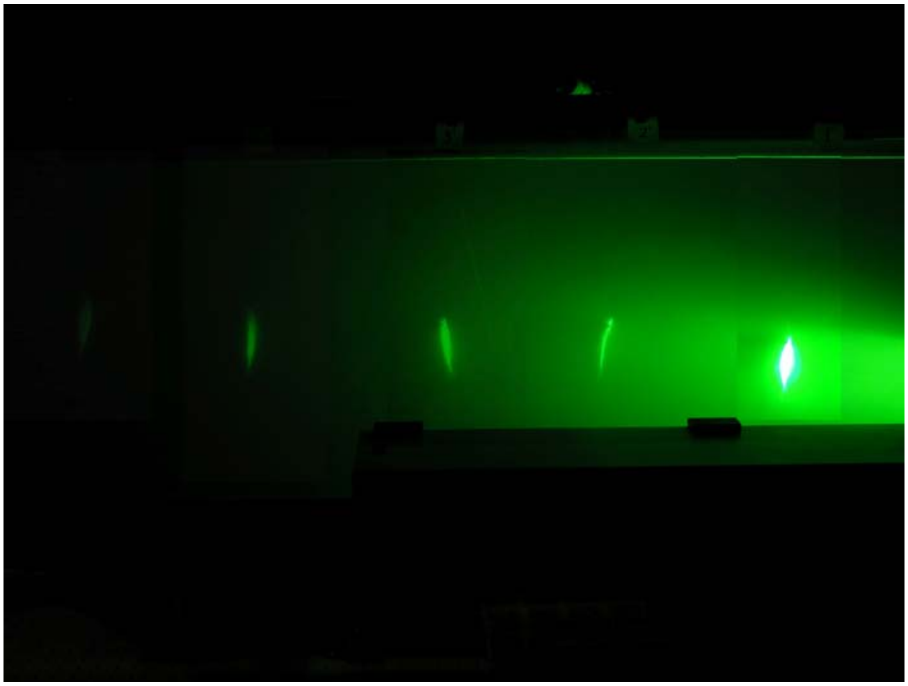

Figure 2.2.3-3. Image of subyearling Chinook salmon in 0.3 m intervals from a Nd:YAG laser light source to 1.5 m in highly turbid river water (0.8 ft. Secchi visibility).

Light-Emitting and 3-D Ultrasonic Methods. This study evaluated the feasibility of light-emitting and ultrasonic technologies to observe fish and near neutrally buoyant drogues as they move through hydropower turbines. The information can be used to assess the biological benefits of turbine design features such as reductions in gaps at the tips and hub of turbine runner blades, reshaping wicket gates and stay vanes, modifications to draft tube splitter piers, and design changes that enhance egress through the powerhouse and tailrace.

The light-emitting technologies evaluated were standard frame rate cameras and high-speed digital cameras capable of sample rates of up to 1000 frames/s. The high-speed digital camera provided a spatial resolution of about 3.8 cm at 250 frames/s in flow rates of 9.1 m/s. Two ultrasonic tracking arrays and an acoustic camera were evaluated. One tracking array, a line-of-sight short-baseline system, used the phase of received transmissions from a transmitter to estimate the direction of the incoming transmission. The second tracking array, typically used in situations where the baseline array extends over a larger volume, used a variation of hyperbolic tracking based on differences in the time-of-arrival of a transmitted signal at a minimum of four omnidirectional hydrophones. The line-of-sight array and the acoustic camera have a range of over 30.5 m, and the detection range of the time-of-arrival array is limited only by the number of hydrophones used and the design of the receiving array. Spatial resolution of these technologies is low (Figure 2.2.3-4) and resolution is affected by noise within the turbine environment. The acoustic camera though not constrained by the ping rate of an acoustic tag is limited by its frame rate that is currently less than 21 image/s at very short ranges and is typically limited to 8 to 10 image/s at ranges likely to be necessary in turbine environments. A project completion report “Technologies for Evaluating Fish Passage through Turbines” will be issued in FY04.

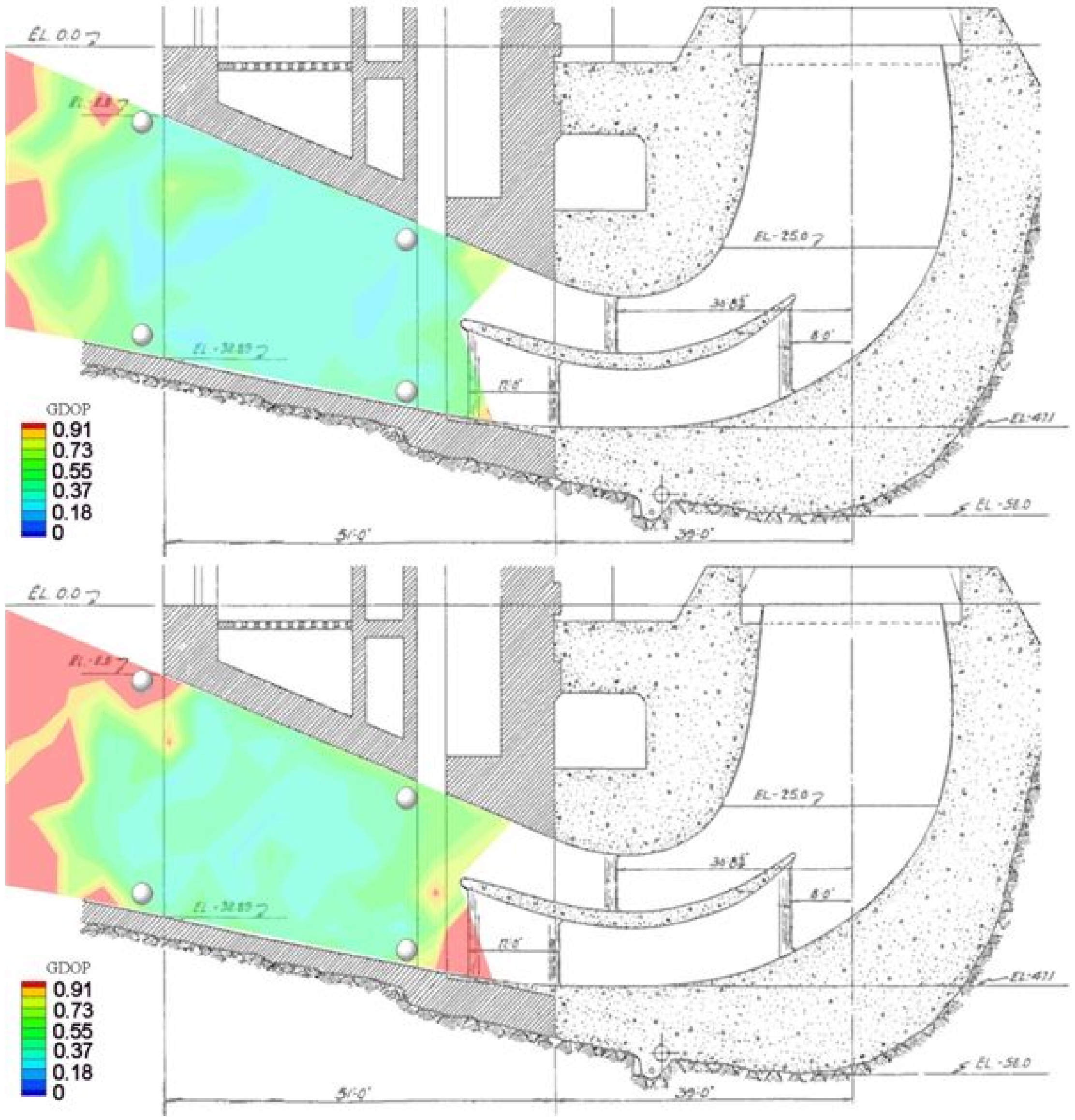

Figure 2.2.3-4. Estimated error (m) in predicted location of acoustic tags for the time-of-arrival tracking array for (a) center and (b) near the edge of a draft tube at Bonneville Dam powerhouse 1 using FishTrack3D^{TM} to estimate the geometric dilution of precision.

2.2.4 Environmental Analysis

The intent of this project area is to conduct research of environmental issues that affect hydropower operations to establish a better scientific basis for hydropower design and operation.

Environmental Performance Testing. The operators of the advanced turbines being evaluated under the Large Turbine Field Testing activity (Section 2.1.1) have developed plans to measure their environmental performance. In most cases the environmental testing is focused on collecting short-term, compliance-related information of value to the particular site, with less emphasis on longer term effects or applicability to other sites. For example, environmental studies of the aerating turbine at the Osage Project have involved several days of intensive water quality sampling to quantify the amounts of oxygen and other gases added by the new turbine, but no studies of the effects of the additional dissolved oxygen on fish below the dam. There is an opportunity to supplement the utilities' planned monitoring with additional studies in order to broaden our understanding of the environmental performance of these advanced turbines.

The supplemental environmental performance testing will utilize a "tool box" of techniques, including biological monitoring techniques, new sensors and other instrumentation, and modeling. Many of these research tools are being developed by the DOE Hydropower Program, and the environmental performance testing of large turbine provides an opportunity to verify their usefulness. For example, a water quality/fish effects model is being employed to evaluate the effectiveness of dissolved oxygen enhancement at the Osage Project in improving conditions for the growth of fish in the tailwaters. A hydrodynamic model of water quality in the Osage River below the dam has been calibrated. It will be coupled to a fish growth model that will predict the effects on food consumption of both the existing low dissolved oxygen concentrations and the improved dissolved oxygen concentrations following implementation of the Retrofit Aeration System (Section 2.1.1). Similarly, potential applications of DOE-developed instrumentation and measurement techniques are being explored to augment the utilities' planned tests at the Wanapum and Box Canyon projects.

Fish Guidance with Induced Turbulence. The primary objectives of this study were to 1) identify the path taken by down-migrating fish as they move through the power canal toward the intakes of a hydroelectric facility and 2) evaluate whether the observed trajectories can be modified by artificially-induced surface turbulence that mimics that which is encountered in a free-flowing stream. The 4,104-KW Buchanan Hydropower Project diverts water from the St. Joseph River (Michigan) through a 250-m intake canal. Steelhead trout smolts migrate downstream toward Lake Michigan in April and May from hatchery stocking and many pass through the plant turbines if the facility is generating power. Directing smolts toward a safe passage around the turbine intakes would preclude the necessity to shut the facility down when smolts are migrating downstream.

In FY 2003 we performed a detailed evaluation of a month of continuous hydroacoustics data collected during FY 2002 experiments. Hydroacoustic transducers positioned on opposite sides of the intake canal were used to monitor smolt passage through the powerhouse intake canal. Specifically, we evaluated 1) the number of smolts passing through the canal, 2) the timing of smolt movement through the canal, and 3) the lateral position of smolts relative to forebay hydraulics created by both existing project structures and a baffle panel installed to induce turbulence.

By correcting for several factors that caused the hydroacoustic system to miss some fish passing downstream or to count some fish multiple times (i.e., those that wandered up and down the power canal), we estimated that 13% of stocked smolts passed through the power canal. Our estimate was about twice that estimated in an earlier trapping study, but less than half of what might be expected if the number of fish passing through the project was directly proportional to the amount of water. We found that fish did not follow the turbulent plumes from bridge pilings or the experimental baffle panel (although the latter was only partially in the hydroacoustic beam). However, a disproportionate number of migrating smolts were observed along the south side of the power canal where smolts were potentially affected by the turbulent plume of the log boom positioned at the entrance to the canal. This result was consistent with the trajectories of a smaller number of light-tagged smolts released during a companion study. Our results suggest that the use of induced turbulence to direct fish at hydropower dams shows promise and should be investigated further.

Effects of Multiple Dam Passage on Salmonid Survival. Survival of migratory juvenile salmonids passing through turbines at hydroelectric dams is generally lower than for individuals passing by spill or bypass routes. If surviving individuals fail to recover fully before subsequent turbine passage events, they may survive at lower rates than unstressed individuals. Thus, survival rates at individual hydropower dams may be linked to what is happening upstream. A primary objective of this work is to assess the potential for these cumulative effects to alter the survival of the population as a whole. The approach we have taken is to simulate fish passing the myriad potential passage trajectories in the Snake and Columbia River system and assess their survival across a matrix of factor combinations. Juvenile Chinook salmon and steelhead were apportioned among passage routes at each hydropower dam on the basis of historical trends for high, normal and low water years, and with transportation (barging of fish past most dams) turned on or off. Cumulative effects were simulated by decrementing survival on second and subsequent turbine passages.

Simulation results indicate that subyearling Chinook salmon have a much higher probability of passing multiple turbines while migrating downstream to the Pacific Ocean than the other run-types or species evaluated. Transportation greatly influenced the number of fish exposed to multiple turbines, especially in low water years. In the absence of transportation, water year also affected survival probabilities. Under all but the most extreme combinations of factors, high decrements for second and subsequent turbine passages were required to influence the overall number surviving to below the most downstream dam by 5% or more.

In FY04, we plan to incorporate additional sources of information such as survival estimates of tagged fish passing through various reaches to place realistic bounds around the level of decrement. Once those bounds are set, we can delineate combinations where cumulative effects might be important, if any. The results will assist decisions about how to operate the hydropower system for improving the survival of migrating juvenile salmonids.

2.3 Technology Application – Systems Integration and Technology Acceptance

Project areas associated with this subkey activity included Hydropower / Other Renewables Integration (Section 2.3.1) and Technical Program Support and Outreach (Section 2.3.2).

2.3.1 Hydropower / Other Renewables Integration

This primary focus of this new project area is the integration of hydropower with wind operations. It is expected that this will lead to cooperative studies with other agencies that have similar interests.

Wind / Hydro Integration Studies. Wind power is an intermittent, variable power output technology that imposes unique challenges on integrated utility grid operations. As wind market penetration increases, operations of other generators may require modification. Several features of hydropower generation are attractive when considering the integration of large amounts of wind:

- Hydropower generators have rapid regulating response and high ramp rate capabilities, and
- Water storage reservoirs can be viewed as low cost “batteries” for potentially smoothing the variability of wind power and shifting time of energy delivery.

In concept, hydropower may be able to provide short- to medium-term buffering of wind plant power fluctuations, and it is also possible wind will benefit the operation of hydropower.

In considering the integration of wind and hydropower energy, there are technical, institutional, economic, and political factors that need to be considered. Engineering considerations include integrated controllability and response time of generators, the transmission systems linking the physical locations of the hydropower and wind facilities, and the characteristics of the utility electric load. In addition, the capacity of the reservoirs, and the seasonal and yearly inflow variability for normal, wet, and dry years can also be important. Institutional factors hinge mainly on the type of control and responsibility held by a utility or operating agency. For example, a hydropower system may be run in an integrated fashion, where a central utility has responsibility to meet electric load growth, or a system may be operated in a more run-of-the river mode, with little seasonal or yearly storage capability, governed more by hydropower capacity, rather than energy (more water available than generators to run it through). Individual institutional situations are important as the context for assessing wind and hydropower integration opportunities.

Economic analysis issues are mainly associated with value tradeoffs, market prices, and the ability to limit non-power producing water spills. In addition differentials in seasonal and daily power demands and prices are important. Politically, hydropower and other water use allocations are often contentious, and the constraints on water usage need to be carefully balanced against the need for electrical power.

Wind and hydropower integration activities in FY2003 were aimed at identifying potential sites and partners for studying integrated wind and hydropower operations. Also, plans were put in place for a wind-hydropower international experts meeting to be held early in FY2004. It is expected that in FY2004, the Program will initiate several studies of specific wind-hydropower integration opportunities, as well as build international cooperation and involvement through the International Energy Agency.

2.3.2 Technical Program Support and Outreach

The transfer of new information to the hydropower community has always been an important component of the DOE hydropower program. This transfer is carried out by participating in technical conferences, publications, *ad hoc* meetings to coordinate interagency research activities, and on-call assistance from DOE and National Laboratory staff. The publications that are generated as part of this technology transfer function have been cited throughout the text and are listed in the References Cited section of this annual report. Hydropower program personnel were involved in the following activities during FY 2003.

Conference Planning and Participation. Staff from DOE, INEEL, ORNL and PNNL participated in and served on the organizing committees for several annual meetings, including National Hydropower Association's Annual Conference that is held in Washington, DC, and the biennial Waterpower conference. Other conference/workshop participation in FY 2003 included: U.S. Climate Change Research Program Workshop; American Public Power Institute conference; Aquatic Invasive Species Summit; POWER-GEN Renewable Energy Conference; and Northwest Salmon Recovery Workshop. Invited briefings were also provided at several industry meetings.

Technical and Interagency Coordination Meetings. During FY 2003 the Hydropower staff supported and participated in the following: U.S. Army Corps of Engineers (COE) Turbine Working Group; United States Society on Dams; Low Impact Hydropower Institute; COE Anadromous Fish Evaluation Program; University of British Columbia Research Institute; NOAA Fisheries' Watershed Ecology and Salmon Recovery Program; and Independent Scientific Advisory Board for the Northwest Power Planning Council.

Program Reviews and Planning Documents. Five program review and planning meetings were conducted (October 2002, November 2002, January 2003, March 2003 and September 2003). The planning documents prepared included the Hydropower Program FY 2003 Annual Operation and Management Plan and the Draft Hydropower Multi-Year Technical Plan.

Program Peer Review. The hydropower program conducted an independent technical assessment and peer review in June 2003. The purpose of this review is to obtain an industry evaluation of the program activities. The Peer Review Committee Report was issued September 2003. The program is evaluating this report and preparing responses and actions to address the issues.

Web Site Development and Usage. The program maintains an official Hydropower web site (http://www.eere.energy.gov). Several updates and changes were made to the site in FY 2003. The Hydropower Program web site was redesigned and updated to comply with current requirements. Reports on the Program's significant new research results were added, including the new DOE reports cited in this Annual Report. Other papers that program staff published in professional and trade journals over the past year were also added to the web site.

The latest statistics on user access to DOE's hydropower web site indicate steady interest and access by users worldwide. During a peak period, the hydropower web site received a total of 758,300 hits between November 2000 and September 2001, and averaged 69,000 hits per month.

Proposal review. DOE received several unsolicited proposals throughout the year, including R&D ideas for unconventional turbine technology. National Laboratory staff and DOE conducted technical reviews of these proposals and provided comments back to the proposers. The proposers were also advised of the current and planned solicitations so that they could participate in this process.

Education Activities and Outreach. The DOE hydropower program provided scholarship funds in support of the turbine contest at Waterpower XIII and the Foundation for Water and Energy Education's Hydropower Essay Contest. During FY 2003, over 80 public inquiries for hydropower information were received and responses provided.

Encyclopedia of Energy. The DOE Hydropower Program was invited to prepare various Hydropower sections for the "Encyclopedia of Energy". Sections were prepared and submitted on Hydropower Technology, Hydropower Resources and Environmental Impact of Hydropower.

2.4 Technology Application – Engineering and Analysis

This subkey activity included two projects under the category of Innovative Technology Characterization.

2.4.1 Innovative Technology Characterization

This activity builds on the recent low head / low power resource assessments of the U. S. to study low head / low power technology development.

Low Head/Low Power Resource Assessment. Most of the current activities of the DOE hydropower program are focused on conventional hydropower plants that use conventional turbines and impounded water sources. There is a need to develop new hydropower plant designs for low power (< 1 MW) and low head (< 30 feet) sites that incorporate free-flow turbines (no impoundments needed) and micro hydropower technologies. Generally, smaller sites have fewer environmental problems. New turbine designs have been developed that promise lower environmental impacts, and non-traditional hydropower plants are candidates for distributed power sources. In order to assess the benefits of developing low power and low head hydropower, the natural resources and existing capture technologies need to be better understood.

In FY 2003, DOE continued an assessment of low power and low head resources. Three classes of hydropower technologies have been identified for the purposes of this study: (1) conventional turbines, (2) unconventional systems, and (3) micro hydropower. For low power operations, conventional turbines operate at heads greater than 8 ft but less than 30 ft. Unconventional systems operate at heads less than 8 ft and may incorporate advanced, low head turbines. Micro hydropower technologies operate at power levels less than100 kW over a wide range of heads. The assessment of hydropower potential corresponding to each of these three technology classes was completed for each of the 18 hydrologic units and the corresponding 48 states of the conterminous United States. In addition to assessing low power resources, the assessment also provided estimates of the magnitude of potential high power (1 MW or greater) resources by regions and states. The results of the study have been published in a draft DOE report titled *Hydropower Potential of the United States with Emphasis on Low Head/Low Power Resources* (Hall et al. 2003c). A summary of the total low head/low power results for the conterminous United States is shown in Figure 2.4.1-1. The comprehensive report was preceded by a report documenting the assessments of the North Atlantic and Middle Atlantic regions titled *Low Head/Low Power Resource Assessment of the North Atlantic and Middle Atlantic Hydrologic Regions* (Hall et al. 2003a) that was produced for an early look at the results for these regions. The results in this regional report are included in the subsequent national report.

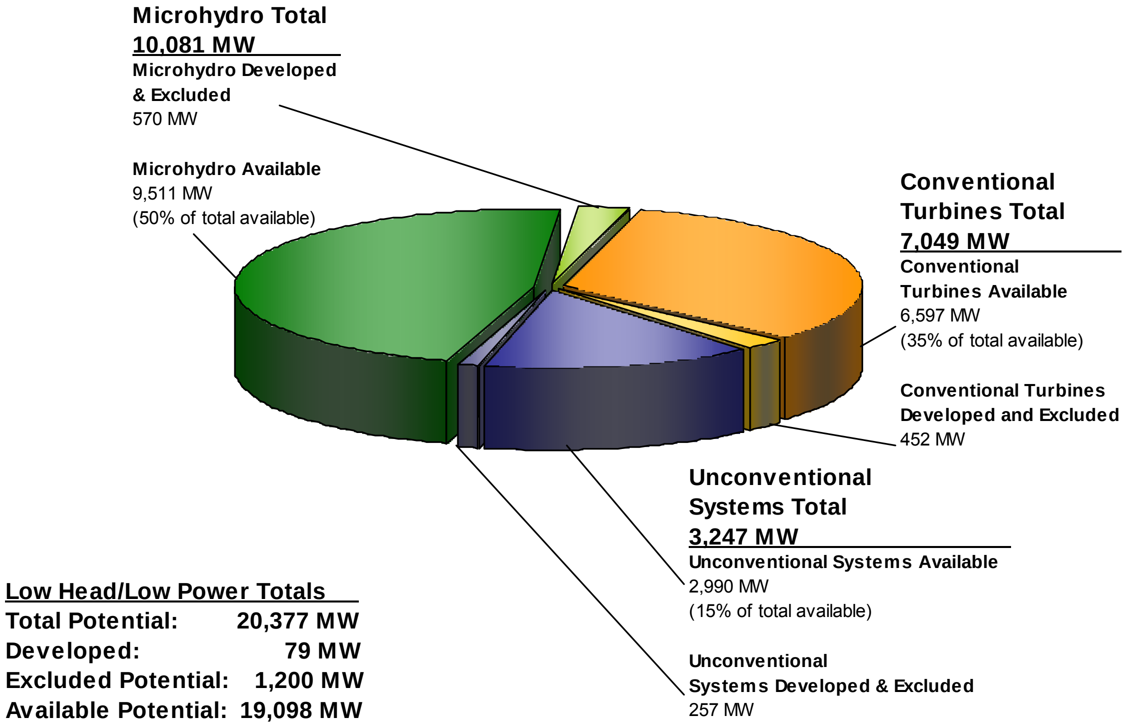

Figure 2.4.1-1. Low head/low power hydropower potential in the conterminous United States divided among three low head/low power hydropower technology classes.

During FY 2004, the states of Alaska and Hawaii will be assessed and the results will be incorporated to produce the final version of national report. This will conclude the first phase of the assessment of low head and low power resource assessment. Additional assessment activities are planned to further screen and identify the developable resources

Economic Model Study. Tools for estimating the cost of developing, operating, and maintaining hydropower resources were developed in the form of regression curves, based on historical plant data. Development costs that were addressed included: licensing, construction, and five types of environmental mitigation. It was found that the data for each type of cost correlated well with plant capacity. A tool for estimating the annual and monthly electric generation of hydropower resources was also developed. Additional tools were developed to estimate the cost of upgrading a turbine or a generator. The development and operation and maintenance cost estimating tools, and the generation estimating tool were applied to 2,155 United States hydropower sites representing a total potential capacity of 43,036 MW.

The sites included undeveloped sites, dams without a hydroelectric plant, and hydroelectric plants that could be expanded to achieve greater capacity. Site characteristics and estimated costs and generation for each site were assembled in a database in Excel format. The study, conducted on behalf of the DOE Office of Energy Efficiency and Renewable Energy and the DOE Energy Information Administration, was published in an INEEL report titled *Estimation of Economic parameters of U.S. Hydropower Resources* (Hall et al. 2003b). The report includes the database on a compact disk at the back of the report. Figure 2.4.1-2 shows a sample of the study results. It presents estimates of how much hydropower capacity could be developed for investments in various unit cost ranges. It is noteworthy that over 12,000 MW of additional hydropower capacity could be developed at costs of $1000 per kW or less.

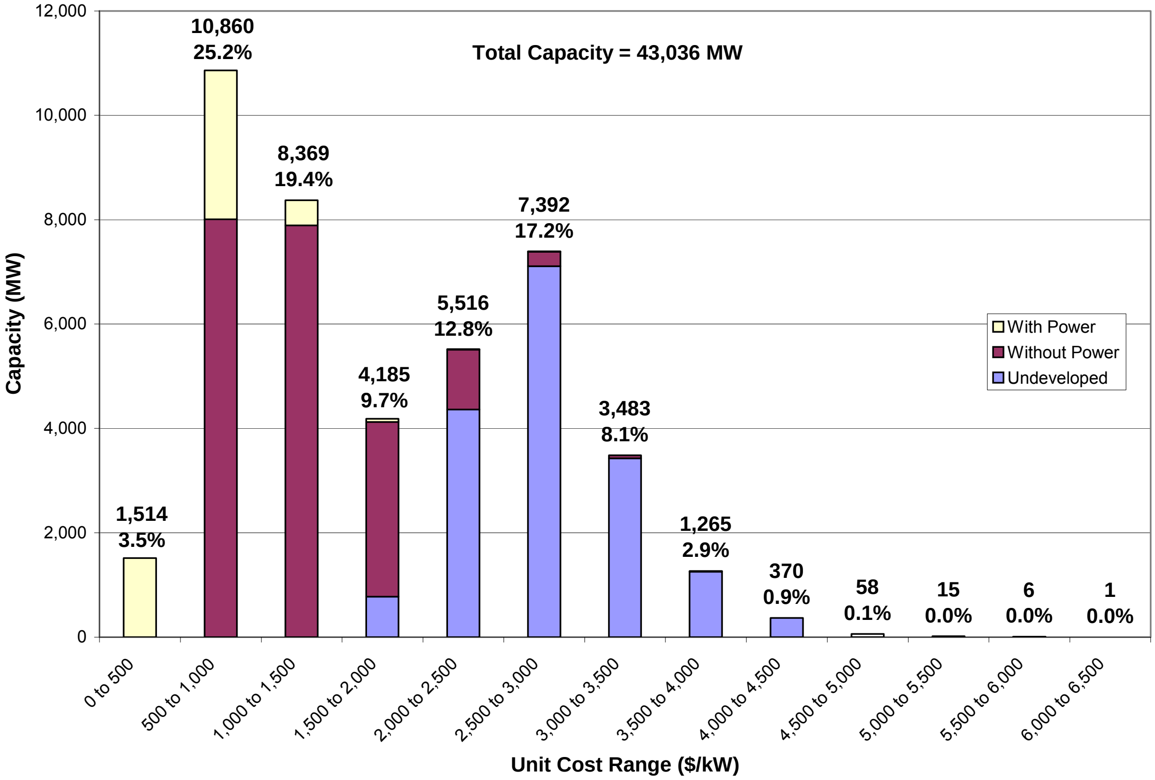

Figure 2.4.1-2. Total capacity of IHRED resources having unit cost (total development) within various unit cost ranges.

3. FUTURE ACTIVITIES

The DOE Hydropower Program activities in all four subkey areas (Advanced Hydropower Technology, Supporting Research and Testing, Systems Integration and Technology Acceptance, and Engineering and Analysis) will continue in future years. For example, the Large Turbine Field Testing area will support environmental and engineering studies at the Osage Project, Box Canyon Project, and Wanapum Dam, as well as field and physical model studies of COE turbines. Biocriteria studies, computational modeling, and development of advanced instrumentation are all critical to understanding the results of the large turbine field testing and will be continued. Many of these supporting studies will focus on the potential fish injury mechanisms of turbulence and strike.

The Water Use/Operations Optimization task will determine how electricity production can be increased at a given hydropower plant by optimizing such aspects of plant operations as the settings of individual units, multiple unit operations, and release patterns from multiple reservoirs. The Improved Mitigation Practices task will continue to investigate the environmental benefits, economic costs, and overall effectiveness of mitigation practices intended to improve fish passage at dams, enhance fish habitat and water quality through flow modification, and provide better environmental conditions for redd (nest) success. Mitigation practices that are selected based on sound scientific evidence should reduce costs while maximizing environmental benefits.

DOE-HQ supports or sponsors various activities during the year such as the Small Business Innovative Research (SBIR), Office of Science and Technology Information (OSTI), and the Hydropower Turbine contests at HydroVision and Waterpower conferences. These activities help maintain the prominence of the DOE Hydropower Program within the hydropower industry.

Technical outreach will continue with staff's participation in conferences, workshops, technology transfer activities, and program reviews. Accomplishments of the Hydropower Program will be distributed by technical reports and peer-reviewed publications. The Hydropower Program web sites (http://eeredev.nrel.gov/windandhydro/ and http://hydropower.id.doe.gov/) will remain a primary means for the hydropower industry and regulatory and resource agencies to access these publications. Assessment of low head/low power resources in the U.S., and analysis of innovative technologies that can capitalize on those resources, will continue. As a result of the program peer review, DOE will evaluate the need to formulate a Hydropower Coordinating Committee. This committee would consist of representatives from other government agencies and non-government organizations. The purpose of this committee would be able to provide additional direction to the Hydropower Program.

4. REFERENCES CITED

Abernethy, C.S., B.G. Amidan, and G.F. Cada. 2003. “Fish Passage Through a Simulated Horizontal Bulb Turbine Pressure Regime: A Supplement to “Laboratory Studies of the Effects of Pressure and Dissolved Gas Supersaturation on Turbine-Passed Fish.” PNNL-13470-B, Pacific Northwest National Laboratory, Richland, WA.

Becker, J.M., C.S. Abernethy, and D.D. Dauble. 2003. Identifying the effects on fish of changes in water pressure during turbine passage. Hydro Review. Volume XXII, Number 5, pp. 32-42.

Cada, G.F., C.C. Coutant, and R.R. Whitney. 1997. Development of biological criteria for the design of advanced hydropower turbines. DOE/ID-10578, U.S. Department of Energy Idaho Operations Office, Idaho Falls, ID.

Cada, G.F. and M.G. Ryon. 2003. Study begins on effects of sub-lethal stresses during turbine passage. Hydro Review XXII(3):80.

Cada, G.F., M.J. Peterson, and M.J. Sale. 2003a. Concentrating on dissolved oxygen: Alternative regulatory strategies for addressing DO problems. International Water Power & Dam Construction 55(6):16-19.

Cada, G.F., M.G. Ryon, D.A Wolf, and B.T. Smith. 2003b. Development of a new technique to assess susceptibility to predation resulting from sublethal stresses (indirect mortality). ORNL/TM-2003/195, Oak Ridge National Laboratory, Oak Ridge, TN. 40 p. + appendices.

Carlson, T.J. and J.P. Duncan. 2003. Evolution of the sensor fish device for measuring physical conditions in severe hydraulic environments. DOE/ID-11079. Prepared for the U.S. Department of Energy. By Pacific Northwest National Laboratory, Richland, Washington.

Carlson, T.J., J.P. Duncan, and T.L. Gilbride. 2003. The sensor fish: measuring fish passage in severe hydraulic conditions. Hydro Review. Volume XXII, Number 3. pp. 62-69.

Cook, T. C., G. E. Hecker, S. V. Amaral, P. S. Stacy, F. Linn, and E. P. Taft, *Final Report – Pilot Scale Tests Alden / Concepts NREC Turbine.* 2003. Final report to the U.S. Department of Energy by Alden Research Laboratory, Inc. and Northern Research and Engineering Corporation, Holden, Massachusetts.

EIA (Energy Information Administration) 2003a. Renewable energy annual, with preliminary data for 2002. DOE/EIA-0603(2002). U.S. Department of Energy, Washington, DC. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea2002/rea2002.pdf

EIA (Energy Information Administration) 2003b. Annual energy outlook 2003 with Projections to 2025. Report No. DOE/EIA-0383(2003). U.S. Department of Energy, Washington, DC. http://www.eia.doe.gov/oiaf/aeo/electricity.html

Garrison, L.A., R.K. Fisher, Jr., M.J. Sale, and G.F. Cada. 2002. Application of biological design criteria and computational fluid dynamics to investigate fish survival in Kaplan turbines. Proceedings of HydroVision 2002, HCI Publications, Inc., Kansas City, MO.

Garrison, L. A., R. K. Fisher, Jr., and W. L. Waltersdorff. 2003. Computational methods for predicting damaging shear to fish in hydropower turbines: 2. Application to two additional Wanapum Dam operating conditions. Draft report on subcontract 4000000576 by Voith Siemens Hydro Power Generation, Inc. U. S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho.

Hall, D.G., G. R. Carroll, S. J. Cherry, R. D. Lee, and G. L. Sommers, 2003a, *Low Head/Low Power Hydropower Resource Assessment of the North Atlantic and Middle Atlantic Hydrologic Regions.* DOE/ID-11077, U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho, April 2003.

Hall, D.G., Hunt, R. T., Reeves, K.S., and G.R. Carroll, 2003b, *Estimation of Economic parameters of U.S. Hydropower Resources,* INEEL/EXT-03-00662, Prepared for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy and the Energy Information Administration. June 2003.

Hall, D.G., G. R. Carroll, S. J. Cherry, R. D. Lee, and G. L. Sommers, 2003c, *Hydropower Potential of the United States with Emphasis on Low Head/Lower Power Resources.* DOE/ID-11111, (draft) U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho, October 2003.

MEC Water Resources, Inc. 2003. Water Quality Study Report. Osage Project Study Years 1 & 2. Prepared for AmerenUE, Eldon, Missouri.

Neitzel, D.A., M.C. Richmond, D.D. Dauble, R.P. Mueller, R.A. Moursund, C.S. Abernethy, G.R. Guensch, and G.F. Cada. 2000. Laboratory Studies on the Effects of Shear on Fish: Final Report. Report DOE/ID-10822, U.S. Dept. of Energy, Idaho Operations Office, Idaho Falls, ID.

Peterson, M.J, G.F. Cada, M.J. Sale, and G.K. Eddlemon. 2003. Regulatory approaches for addressing dissolved oxygen concerns at hydropower facilities. DOE/ID-11071, Report to the U.S. Department of Energy Hydropower Program, Idaho Falls, ID. 31 p.

Sale, M.J., G.F. Cada, T.J. Carlson, D.D. Dauble, R.T. Hunt, and G.L. Sommers. 2003. DOE Hydropower Program annual report for FY 2002 (October 2001-September 2002). DOE/ID-11107. Wind and Hydropower Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, Washington, DC.

Wittinger, R., J. Ferguson, and T. Carlson. 1995. Proceedings, 1995 Turbine Passage Workshop. U.S. Army Corps of Engineers, Portland, OR.

APPENDIX A

List of FY03 Publications

Many of these publications can be downloaded from http://hydropower.id.doe.gov/

Abernethy, C.S., B.G. Amidan, and G.F. Cada 2003. “Fish Passage Through a Simulated Horizontal Bulb Turbine Pressure Regime: A Supplement to “Laboratory Studies of the Effects of Pressure and Dissolved Gas Supersaturation on Turbine-Passed Fish.” PNNL-13470-B, Pacific Northwest National Laboratory, Richland, WA.

Becker, J.M., C.S. Abernethy, and D.D. Dauble. 2003. Identifying the effects on fish of changes in water pressure during turbine passage. Hydro Review. Volume XXII, Number 5, pp. 32-42.

Brookshier, P. In Press. Hydropower Technology. Article in the Encyclopedia of Energy, Academic Press/Elsevier Science, San Diego, CA.

Cada, G.F. 2002. Hydroelectric power production: Realizing the benefits by resolving the environmental issues. Chapter 18 In: Renewable Energy: Trends and Prospects. S.K. Majumdar, E.W. Miller, and A.I. Panah (eds.). The Pennsylvania Academy of Science, Easton, PA. 532 p.

Cada, G.F. and M.G. Ryon. 2003. Study begins on effects of sub-lethal stresses during turbine passage. Hydro Review XXII(3):80.

Cada, G.F., M.G. Ryon, D.A Wolf, and B.T. Smith. 2003. Development of a new technique to assess susceptibility to predation resulting from sublethal stresses (indirect mortality). ORNL/TM-2003/195, Oak Ridge National Laboratory, Oak Ridge, TN. 40 p. + appendices.

Cada, G.F., M.J. Peterson, and M.J. Sale. 2003. Concentrating on dissolved oxygen: Alternative regulatory strategies for addressing DO problems. International Water Power & Dam Construction 55(6):16-19.

Cada, G.F., M.J. Sale, and D.D. Dauble. In Press. Environmental Impacts of Hydropower. Article in the Encyclopedia of Energy, Academic Press/Elsevier Science, San Diego, CA.

Carlson, T.J. and J.P. Duncan. 2003. Evolution of the sensor fish device for measuring physical conditions in severe hydraulic environments. DOE/ID-11079. Prepared for the U.S. Department of Energy. By Pacific Northwest National Laboratory, Richland, Washington.

Carlson, T.J., J.P. Duncan, and T.L. Gilbride. 2003. The sensor fish: measuring fish passage in severe hydraulic conditions. Hydro Review. Volume XXII, Number 3. pp. 62-69.

Cook, T. C., G. E. Hecker, S. V. Amaral, P. S. Stacy, F. Linn, and E. P. Taft, *Final Report – Pilot Scale Tests Alden / Concepts NREC Turbine.* 2003. Final report to the U.S. Department of Energy by Alden Research Laboratory, Inc. and Northern Research and Engineering Corporation, Holden, Massachusetts.

Garrison, L.A., R.K. Fisher, Jr., M.J. Sale, and G.F. Cada. 2002. Application of biological design criteria and computational fluid dynamics to investigate fish survival in Kaplan turbines. Proceedings of HydroVision 2002, HCI Publications, Inc., Kansas City, MO.

Gilmanov, A., Sotiropoulos, F., and Balaras, E. "A General Reconstruction Algorithm for Simulating Flows with Complex 3D Immersed Boundaries on Cartesian Grids," *Journal of Computational Physics* 191(2), 660-669, 2003.

Hall, D.G., G. R. Carroll, S. J. Cherry, R. D. Lee, and G. L. Sommers, 2003a, *Low Head/Low Power Hydropower Resource Assessment of the North Atlantic and Middle Atlantic Hydrologic Regions.* DOE/ID-11077, U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho, April 2003.

Hall, D.G., Hunt, R. T., Reeves, K.S., and G.R. Carroll, 2003b, *Estimation of Economic parameters of U.S. Hydropower Resources,* INEEL/EXT-03-00662, Prepared for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy and the Energy Information Administration. June 2003.

Hall, D.G., G. R. Carroll, S. J. Cherry, R. D. Lee, and G. L. Sommers, 2003c, *Hydropower Potential of the United States with Emphasis on Low Head/Lower Power Resources.* DOE/ID-11111, (draft) U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho, October 2003.

Neitzel, D.S. D. Dauble, G.F. Cada, M. Richmond, G. Guensch, R. Meuller, C Abernethy, and B. Amidan. In Press. Survival estimates for juvenile fish subjected to a laboratory-generated shear environment: The relationship to hydroelectric turbine design. Transactions of the American Fisheries Society.

Peterson, M.J, G.F. Cada, M.J. Sale, and G.K. Eddlemon. 2003. Regulatory approaches foraddressing dissolved oxygen concerns at hydropower facilities. DOE/ID-11071, Report to the U.S. Department of Energy Hydropower Program, Idaho Falls, ID. 31 p.

Sale, M.J., G.F. Cada, T.J. Carlson, D.D. Dauble, R.T. Hunt, and G.L. Sommers. 2003. DOE Hydropower Program Annual Report for FY 2002. DOE/ID- 11107. U.S. Department of Energy, Idaho Falls, ID.

Sommers, G.L. In Press. Hydropower Resources. Article in the Encyclopedia of Energy, Academic Press/Elsevier Science, San Diego, CA.

Tang, H., Jones, S. C., and Sotiropoulos, F., "An Overset Grid Method for 3D, Unsteady, Incompressible Flows," *Journal of Computational Physics*, 191(2), 567-600 2003.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as vital new "energy carriers."

The Opportunities

Biomass Program
Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

Building Technologies Program
Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

Distributed Energy & Electric Reliability Program
A more reliable energy infrastructure and reduced need for new power plants

Federal Energy Management Program
Leading by example, saving energy and taxpayer dollars in federal facilities

FreedomCAR & Vehicle Technologies Program
Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Geothermal Technologies Program
Tapping the Earth's energy to meet our heat and power needs

Hydrogen, Fuel Cells & Infrastructure Technologies Program
Paving the way toward a hydrogen economy and net-zero carbon energy future
Industrial Technologies Program
Boosting the productivity and competitiveness of U.S. industry through improvements in energy and environmental performance

Solar Energy Technology Program
Utilizing the sun's natural energy to generate electricity and provide water and space heating

Weatherization & Intergovernmental Program
Accelerating the use of today's best energy-efficient and renewable technologies in homes, communities, and businesses

Wind & Hydropower Technologies Program
Harnessing America's abundant natural resources for clean power generation

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