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DOE Hydropower Program Annual Report for FY 2001

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SUMMARY

The U.S. Department of Energy (DOE) conducts research on advanced hydropower technology through its Hydropower Program, which is organized under the Office of Power Technologies in Washington, DC, and managed by the Idaho Operations Office in Idaho Falls, Idaho. This annual report describes the various projects supported by the Hydropower Program in FY 2001. The Program's current focus is on improving the environmental performance of hydropower projects by addressing problems such as fish mortality during passage through turbines, alteration of instream habitat, and water quality in tailwaters. A primary goal of this research is to develop new, environmentally friendly technology. DOE-funded projects have produced new conceptual designs for turbine systems, and these are now being tested in pilot-scale laboratory tests and in the field. New design approaches range from totally new turbine runners (e.g., work by Alden Research Laboratory and Concepts NREC) to modifications to existing designs (e.g., Voith Siemens work on Minimum Gap Runners). Biological criteria have also been developed in controlled laboratory tests of fish response to physical stresses, such as hydraulic shear and pressure changes. These biocriteria are being combined with computational design tools to locate and eliminate damaging areas inside turbine systems. Through the combination of laboratory, field, and computational studies, new solutions are being found to environmental problems at hydropower projects. The diverse program activities continue to make unique contributions to clean energy production in the U.S. By working toward technology improvements that can reduce environmental problems, the Program is helping to reposition hydropower as an acceptable, renewable, domestic energy choice.

The key successes in FY 2001 were:

- Construction and start-up of the pilot-scale test facility at Alden Research Laboratory, to evaluate the environmental and engineering performance of the new Alden/Concepts NREC runner.

- Publication of new biological response studies of the effects of pressure and dissolved gas supersaturation on fish passing through hydropower turbines.

- Deployment of the phase II sensor fish device at Columbia River dams to evaluate hydraulic forces present in spillways and a high-volume outfall.

- Collaboration with industry and other federal agencies in two successful workshops to identify future R&D needs for hydropower.

- Publication of a feature article in *Fisheries* on the development of advanced hydroelectric turbines to improve fish passage survival, promoting interdisciplinary communication on technology advances.

- Support to OSTP and NSTC-CENT in publishing a comprehensive review of the state of the science of salmon restoration that puts the effects of hydropower in context of other impacts.

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DOE Hydropower Program
Annual Report for FY 2001

1. INTRODUCTION

This report describes activities supported by the U.S. Department of Energy (DOE) Hydropower Program during fiscal year 2001. Background on the program, current activities, and 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 12% of the country's electrical generating capability and provides 99% of the electricity generated from renewable sources (EIA 2002). 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 greenhouse gases. Hydropower projects can provide substantial nonpower 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 adverse environmental impacts (Mattice 1991). The environmental issues that most frequently confront the hydropower industry are 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 78,000 MW (EIA 2002). Hydroelectricity is produced at about 180 federal projects and more than 2000 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. (Conner et al. 1998), 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. Almost no new hydropower capacity is predicted through 2020 (EIA 2002).

1.2 Background on the Program

DOE has been supporting hydropower R&D for more than 20 years, beginning with a Low-Head Hydropower Feasibility Program that was initiated in 1978. More recently, the Program has conducted research on environmental mitigation practices. These studies provided greater understanding of environmental problems, and the benefits and costs of potential solutions. The first report on this subject considered mitigation for problems associated with fish passage, dissolved oxygen, and instream flows (Sale et al. 1991). The second report provided a detailed examination of the benefits and costs of upstream and downstream fish passage measures at 16 hydroelectric projects (Francfort et al. 1994). Since 1994, a major emphasis of the Program has been the development of advanced, environmentally friendly turbines (see next section). In addition, the Hydropower Program has performed hydropower resource assessments, engaged in cost-shared research with industry, and promoted technology transfer. For

example, DOE established a multi-agency team to quantify potential, undeveloped hydropower resources in the U.S. A preliminary resource assessment was completed in 1990, and the analyses have been refined and updated since then (Conner et al. 1998). The program's contributions have been summarized in regular biennial (e.g., Rinehart et al. 1997) and annual reports (e.g., Sale et al. 2001) and on the DOE Hydropower Web site: http://hydropower.id.doe.gov/.

1.3 Program Mission and Activities

The mission of the DOE's Hydropower Program is to conduct research and development (R&D) to improve the technical, societal, and environmental benefits of hydropower. The Program seeks to develop advanced hydropower technologies that will improve hydropower's environmental performance, and thereby allow it to co-exist with other water resource uses and remain a significant contributor to the nation's energy portfolio. The Program currently supports research and other activities in six areas (Figure 1):

- Development of advanced hydropower turbines with enhanced environmental performance
- Basic and applied research that supports and enables the development of new hydropower technology
- Studies of environmental mitigation and other issues that affect hydropower development
- Development of unconventional hydroelectric generating technologies, such as low-head/low-power equipment (including microhydro), that can be implemented for distributed energy production
- Technology transfer
- Administration of hydropower and related projects in the Renewable Indian Energy Resources Program in Alaska.

Program activities focus on applied R&D, managed by federal personnel and performed by national laboratories and industry partners. Whenever possible, cost sharing and other types of cooperation are used to leverage DOE funding. The Program uses a multi-faceted research approach, combining engineering design and construction, field, laboratory, and computational studies.

1.4 Program Organization and Management

The Hydropower Program is organized under the DOE Office of Energy Efficiency and Renewable Energy, Office of Power Technologies, Office of Biopower and Hydropower in Washington, DC. The program is managed through DOE's Idaho Operations Office in Idaho Falls, Idaho. A concerted effort is made to coordinate DOE's research and development 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 (see Section 6). A Technical Committee reviews progress, evaluates results, and ensures coordination with related R&D activities of other agencies and industry. This technical team 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. This active coordination provides "situational awareness," avoids duplication of research efforts, and creates a synergy among related research.

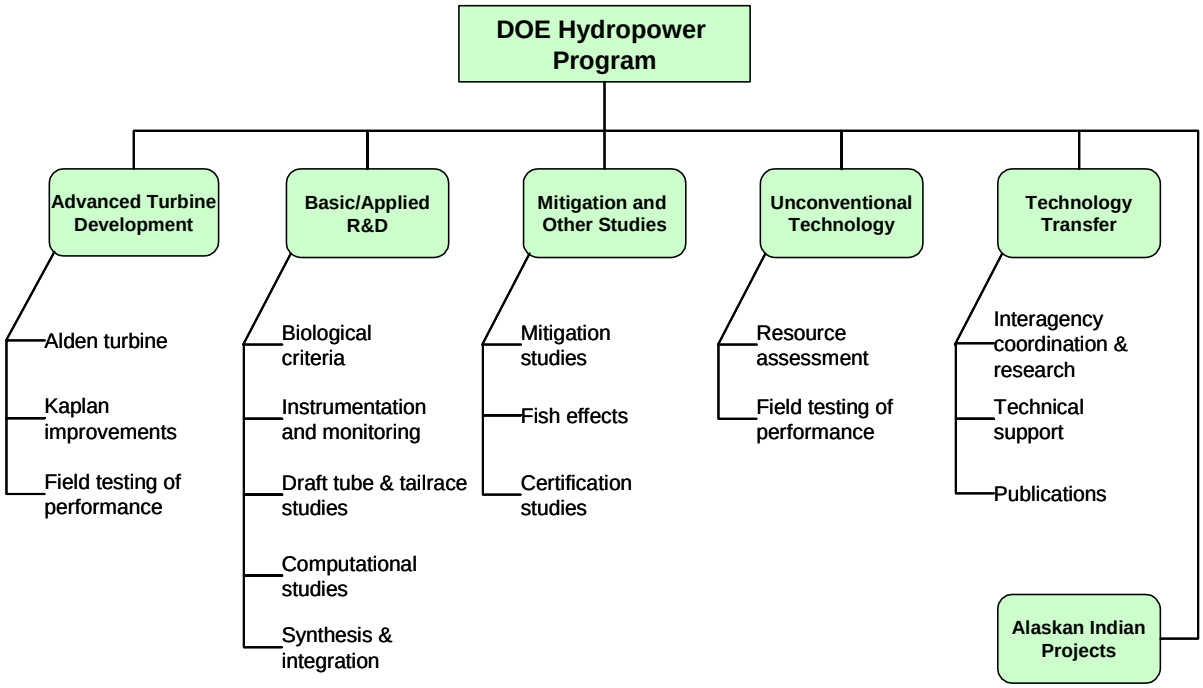


Figure 1. Components of the DOE Hydropower Program in FY 2001.

Three of DOE's National Laboratories provide technical support to the Program, based on their 20-plus years of experience in hydropower issues: Idaho National Engineering and Environmental Laboratory (INEEL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). The lead laboratory for engineering and program management support is INEEL. ORNL is the lead laboratory for environmental and computational support. PNNL is involved in biological and other studies, taking advantage of their experience and facilities for conducting tests on fish. 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. ADVANCED TURBINE DEVELOPMENT

The goal of DOE's Advanced Hydropower Turbine Systems (AHTS) research is to improve the overall performance and acceptability of hydropower projects by developing and testing advanced technology that reduces or eliminates adverse environmental effects. Those environmental problems with the highest priority include: (1) injury and mortality to fish as they pass through turbines (Figure 2), (2) low dissolved oxygen downstream of the dams, and (3) altered stream flows and associated habitat for aquatic organisms (Sale et al. 1991; HCI 1992). The hydropower "system" that the current DOE program is concentrating on is defined as the area between the forebay of turbine inflows and the exit of the turbine's draft tube (Brookshier et al. 1995). These system boundaries are being expanded, as funding appropriations allow. The Program's research on turbulence in draft tubes and tailraces that was initiated in FY 2001 (Section 3.2) is one step in expanding the boundaries of the turbine systems being studied.

The AHTS initiative began in February 1993, when DOE, EPRI, and the Research and Development Committee of the National Hydropower Association (NHA) met to discuss new research initiatives (Sale et al. 2000). Shortly thereafter, NHA formed a non-profit organization called the Hydropower Research Foundation, Inc. (HRF) to support this kind of research. Later in 1993, NHA and HRF obtained financial contributions from nine utility members and from EPRI totaling $500,000 to support joint research on advanced turbines. DOE matched these industry contributions, creating a $1 million fund to support the first phase of advanced turbine development. With this funding, competitive awards were made to Alden Research Laboratory, Inc. (Alden) and its partner, Northern Research and Engineering Corporation (Concepts NREC), and to Voith Hydro, Inc. (Voith; now Voith Siemens Hydro Power Generation) in October 1995.

Conceptual design reports were completed by both Alden/Concepts NREC (Cook et al. 1997) and Voith (Franke et al. 1997); these were summarized by Odeh (1999).

In FY 2001, four areas of research on advanced turbines were active: (1) proof-of-concept, pilot-scale testing of the new turbine runner designed by ALDEN/Concepts NREC, (2) field tests of advanced designs of more conventional Kaplan turbines, (3) a solicitation for new, cost-shared projects to verify environmental performance of new technology at full-scale, field sites, and (4) field and computer modeling studies of the turbulence in draft tubes and tailraces. In many of these areas, multiple projects were supported to study both new and existing turbine designs, taking advantage of interagency cooperation and cost sharing where possible. Different research approaches are being applied among these projects to develop better understanding of the physical stresses experienced by fish as they travel along different paths through turbines. Each of these approaches has limitations (e.g., scaling up laboratory or physical model studies to the field or validating computer models), but they complement each other when results are integrated.

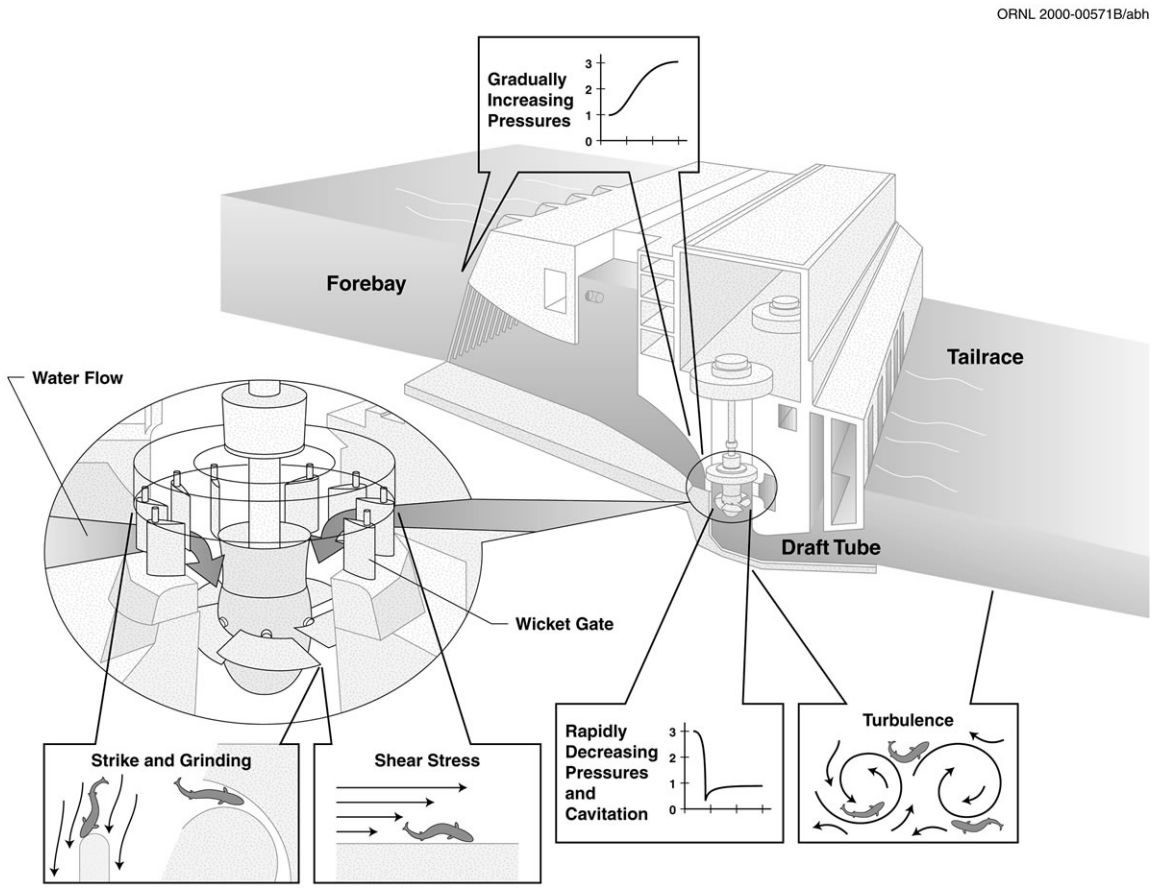


Figure 2. Sources of injury to fish passing through hydropower turbines (Čada et al. 1997).

2.1 Pilot-Scale Testing of Alden/NREC Turbine

In the initial phase of the AHTS research, the Alden/NREC team developed a conceptual design for a new turbine runner that is expected to 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 3), 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). In FY 2001, construction of the test facility was completed; testing operations began in September 2001. The test facility is centered on a 1/3-scale, 3.5-ft diameter prototype runner set in a closed-loop system that is large enough to pass fish (Figure 3). Injection ports for control fish (not subject to turbine passage) and treatment fish (subject to turbine passage) are built into the test loop, along with a fish screen and recovery chamber. The first phase of biological and hydraulic testing was completed in October 2001. In FY 2002, the testing program will continue, quantifying the survival rates of rainbow trout passing through the runner with and without wicket gates and verifying the basic hydraulic characteristics of the turbine runner.

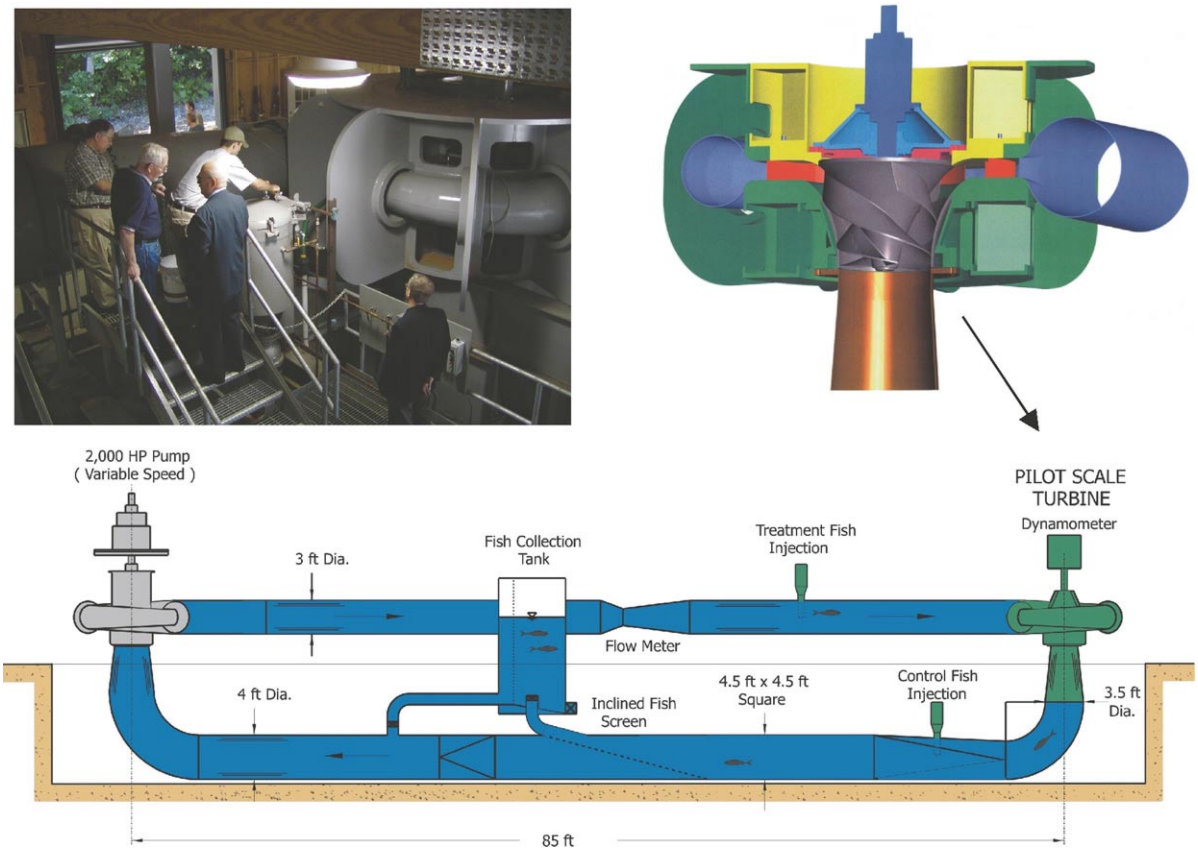


Figure 3. Pilot-scale testing facility for the Alden/NREL runner: Technical Committee members touring the facility in September 2001 (upper left), cross-sectional schematic of the Runner (upper right), and cross-section plan of the test loop (bottom).

2.2 Kaplan Turbine Improvements

DOE is supporting several studies to improve the performance of more traditional turbine designs, particularly Kaplan turbines. This research direction is a direct product of the AHTS conceptual design work by the Voith team (Franke et al. 1997; Odeh 1999). Much of this work is cost-shared with the U.S. Army Corps of Engineers (Corps) or private industry, as indicated below.

Stay vane and wicket gate studies. This a jointly funded project between the Corps of Engineers' Hydroelectric Design Center and DOE, examining the relationship between turbine wicket gate and stay vane positions to improve both safe fish passage and unit performance. The work is being performed by the U.S. Army Engineering Research and Development Center (ERDC) in Vicksburg, Mississippi, and VA Tech in Austria. Research results will be incorporated into an existing model of the Lower Granite Project (lower Snake River) turbine, and flow patterns will be studied using neutrally buoyant beads passing through the turbine. The project consists of the following tasks:

- Prepare a 3-D flow net model of the Lower Granite turbine intake and scroll case
- Perform a CFD analysis of the existing configuration and develop a structurally feasible alternative design to improve overall model efficiency
- Select a design for model testing

- Conduct model tests with and without fish screens to evaluate bead paths for both installations

- Prepare a report on study results.

In FY 2001, bead distribution at Lower Granite wicket gates and stay vanes has been documented for a discharge of 17,663 cfs, with bead releases at five different elevations. Flow velocities were measured at two draft tube cross sections for a discharge of 22,700 cfs, and the distribution of neutrally buoyant beads passing through the selected turbine model design were documented for various flow rates. From ERDC's work, six flow rates were evaluated for testing at the VA Tech facilities. Two flow rates were selected for incorporation into the VA Tech performance model and for final testing at VA Tech. Several draft tube modifications were evaluated to determine those with potential biological benefit, and two modifications were evaluated for performance in the VA Tech model.

Bonneville Turbine Model. This project is another jointly funded study being conducted at ERDC. The project involves these tasks:

- Fabricating two, 1:25 scale Kaplan turbine models (a standard runner and a minimum gap runner or MGR)

- Constructing a 1:25 scale model of a Bonneville Powerhouse #1 turbine bay that includes three flow bays, scroll case, wicket gates, stay vanes, draft tube, trashracks, vertical barrier screens, 600 ft of upstream approach topography, and 300 ft of downstream topography

- Installing and conducting experiments on these turbine models to identify fish passage routes through the turbines for three predetermined fish release points.

The model of the Bonneville bay was constructed of acrylic to allow visual observations and the measurement of velocities within the structure. Voith Siemens is contracted to fabricate the turbine models.

The three fish release points at the entrance to the stay vanes corresponded to release points that were used during fish release experiments conducted at a prototype unit during 1999. The current experiments involve releasing neutrally buoyant beads at the identified release points, documenting their paths through the turbine with high-speed photography, and measuring velocities.

McNary Turbine Fish Survival Tests. In a third joint, Corps-DOE project, fish passage studies are being conducted at McNary Dam on the Columbia River to determine the survival rates of fish passing through the Kaplan turbines there. In the first year of tests, fish were released at four different locations within the turbine: near the turbine hub, near the blade tip, near the middle of the blade, and near a wicket gate. The tests were conducted at a single operating condition within 1% of the peak operating efficiency at that turbine setting. There were moderate gaps at the hub and blade tip and no control releases were conducted. Therefore, absolute survival rates were not estimated.

In the second year of testing at McNary, plans are to conduct fish releases over a range of power levels using three or four different release points. The biological test plan for this work has been completed and proposals have been received and evaluated. Fishery agencies were briefed on the test plans in September 2001, and the technical review by the Corps team was held in October 2001. Design of the new fish release structures required to conduct the tests is nearly complete. Based on the current status, participants expect the project to be completed in June 2002.

2.3 Field Performance Testing

To stimulate the evaluation of more environmentally friendly technology, DOE will be providing partial funding for field testing of turbine designs that have been developed outside the DOE program. This effort will identify advanced turbine designs other than the first two AHTS concepts and will address other environmental issues confronting the hydropower industry beyond fish passage. In addition to designs developed by the Voith and Alden teams, designs by others will be selected for further study, to determine environmental and engineering performance and to estimate the incremental O&M costs of new designs relative to existing technology. These tests will be conducted at full-scale, operating hydropower plants, in part because biological processes of interest are not well suited for scaled-down laboratory testing. The number of designs to be tested and the sites selected for testing will depend on funding resources in FY 2003 and beyond.

A Notice of Intent for this field-testing initiative was issued by DOE, seeking comments on testing new design concepts for larger turbines (> 1 MW). Based on the comments received, solicitations for large-scale field testing are being made in two phases: the first phase will select the conceptual turbine designs to be tested and the second phase will select the site development teams and the location where new equipment will be installed. Both phases were initiated in FY 2001, with one or more awards expected in FY 2002. DOE's support will consist of cost-sharing the final engineering designs and the field testing to determine environmental and engineering performance over a multi-year period.

3. BASIC AND APPLIED R&D

The DOE Hydropower Program supports many, more basic research projects that contribute to its goal of improving the environmental performance of hydropower technology. Most of these support the development of advanced turbines by producing new understanding of the stresses that kill or injure fish or by developing new tools that can be applied in turbine design. Basic research is needed because potential injury mechanisms, as rate of strain, turbulence, pressure changes, and the likelihood and severity of impact with structures, are extremely difficult to measure inside of a turbine.

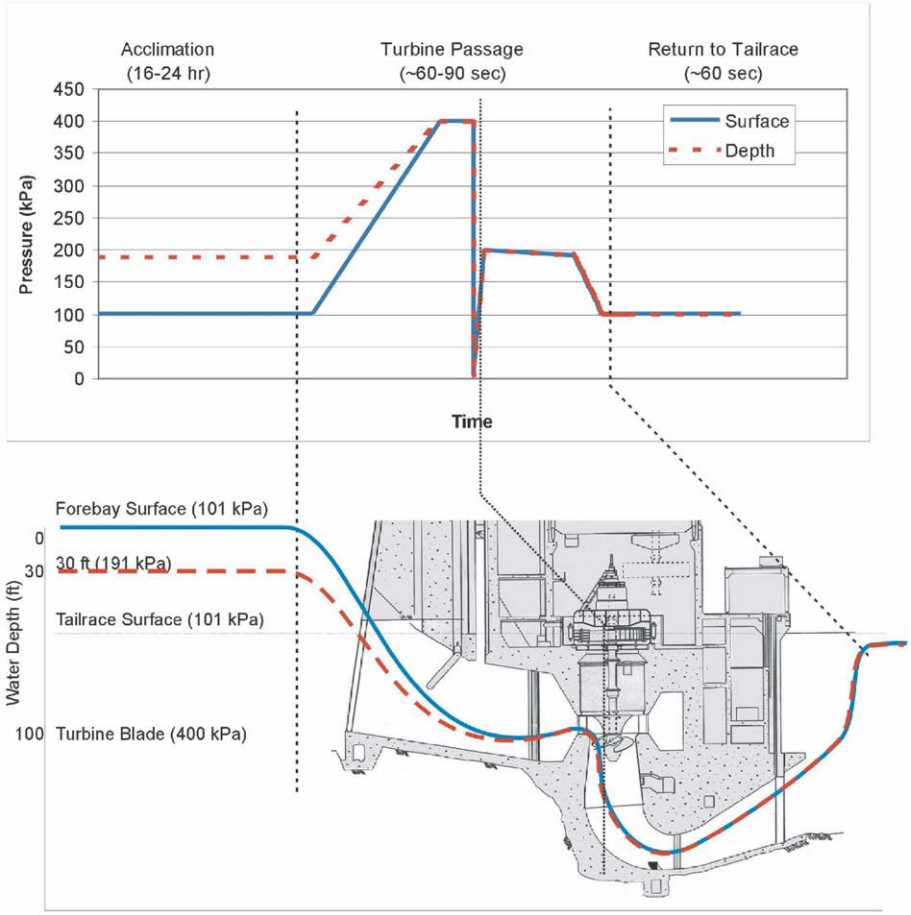
In FY 2001, three complementary efforts lead to new understanding of effects on turbine-passed fish: (1) laboratory studies of the biological response of fish to the physical stresses experienced in passage through turbines; (2) development of new instruments and monitoring technology to measure the physical conditions inside turbines in the field, and (3) application of advanced computational techniques to describe the full range of hydraulic environments in turbines under different operating conditions. All three components are needed to develop a better understanding of the adverse effects of turbine passage and the modifications needed to reduce those effects (Čada et al. 2001). The integration of results from all three of these types of studies can improve the accuracy of predictive models and, in the future, may reduce the need for live fish in the testing of hydroelectric turbines.

3.1 Laboratory Studies of Fish Response

As conceptual designs for advanced turbines were developed in earlier phases of the Program, it became clear that there were significant gaps in the understanding of how fish respond to physical stresses experienced during turbine passage. Although the potential injury mechanisms affecting turbine-passed fish were first described for the Hydropower Program in the 1990s (e.g., Čada 1990; Čada et al. 1997), many of these biological effects remain poorly understood (Čada 1998). Consequently, the Technical Committee recommended that the R&D activities of the Program be broadened to include laboratory studies that could be used to develop biological design criteria (biocriteria) for turbines. The specific biocriteria issues examined in FY 2001 were the effects of pressure changes and dissolved gas supersaturation.

Migratory and resident fish are exposed to numerous stresses associated with turbine passage at hydroelectric dams, including pressure changes and dissolved gas supersaturation. The susceptibility of fish to elevated dissolved gas levels (gas bubble trauma) was studied extensively in the 1970's with emphasis on migratory salmonid species. Researchers learned that fish traveling at depth were protected from total dissolved gas levels that were lethal for fish migrating at the surface. More recently, the effects of pressure changes associated with turbine passage were investigated. Although depth compensation protects fish from acute effects of elevated dissolved gas levels, the unanswered question was whether depth-acclimated fish, especially those also acclimated to elevated gas levels, were more susceptible to rapid and severe pressure changes occurring during turbine passage.

In studies that began in FY 2000, three fish species (rainbow trout, chinook salmon, and bluegill) were exposed to elevated gas levels (100, 120, and 135% saturation) and acclimated to pressures representative of those upstream of a dam. Two acclimation pressures were studied, those at the water surface and at 30 ft of depth (Figure 4). Fish were then subjected to a time/pressure sequence simulating passage through a typical Kaplan turbine used in hydroelectric dams on the Columbia River. The passage sequence simulated entry into the intake (pressure gradually increased to 4 atm), a sudden drop in pressure at the turbine blades (pressure drops to < 0.1 atm), followed by passage through the draft tube and back to surface water pressures. Results showed that bluegill, a physoclistous species lacking a vent to the esophagus, were extremely susceptible to swim bladder rupture when exposed to the sudden decreases in pressure during turbine passage. Juvenile chinook salmon, a physostomous species with a



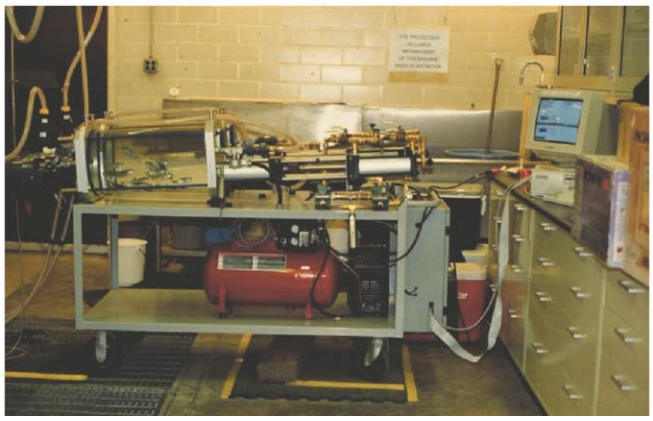


Figure 4. Schematic view of the pressure gradients experienced inside a typical Kaplan turbine and the laboratory pressure chamber used to study fish responses (Abernethy et al. 2001).

vent to the esophagus, were less sensitive to the effects of pressure than bluegill. However, the combined effects of elevated gas, acclimation to 30 ft, and pressure changes in turbine passage caused instantaneous bubble formation and death in some salmon. The final report on these new findings was published in FY 2001 (Abernethy et al. 2001).

A similar series of tests was completed in FY 2001 using pressure sequences estimated for Alden Research Laboratories fish-friendly turbine design. Analysis of those results is in progress, with another report planned for FY 2002. The results of these two studies will be used to identify which combination of environmental conditions causes fish injuries or deaths and where specific improvements can be made.

3.2 Draft Tube and Tailrace Studies

Turbulence in the lower zones of hydroelectric power plants is suspected to be a source of injury and mortality to downstream-migrating fish (Figure 5). The flow in draft tubes and tailraces of hydropower plants is dominated by large-scale, unsteady vortices induced by a number of factors, including residual swirl at the exit of the turbine runner, pressure gradients associated with the strong curvature of draft-tube walls, interaction of the flow with splitter plates and piers within the draft tube, and the complex interaction of the flow exiting the draft-tube with the tailrace. These vortices can have important biological effects as they could disorient passing fish and lead to increased mortality rates due to predation. In addition, these complex flow structures could create regions of high instantaneous shear and turbulence, thus further contributing to fish injuries. This issue has been gaining increasing attention in the Pacific Northwest and elsewhere (Carlson 2001). For example, the recently released Biological Opinion on the operation of the federal Columbia River Power System calls for agencies to examine the effects of draft tubes and powerhouse tailraces on the survival of fish passing through turbines. This evaluation should include biological and hydraulic evaluations and, if warranted, implementation of measures to reduce the effects of turbine backroll on juvenile salmonid survival. Several new projects were started in FY 2001 to develop a better understanding of what is happening to fish in draft tubes and tailraces of hydropower facilities.

Field measurement of turbulent flow fields. Traditional measurement and modeling techniques for flow regimes in turbines are not well-suited for studying the inherently chaotic and time-dependent nature of the large-scale turbulent eddies in draft tubes and tailraces. Because so little is known of the coherent structure of draft tube flows and how this structure varies with geometric scale, new field measurements are needed. The challenge for these new field studies is to identify relevant characteristics of these eddies that represent flow kinetics and are useful for subsequent studies of the effects on fish of turbulence in these regions of turbine systems. Once the relevant indices of turbulence are defined, they will be used to design controlled laboratory experiments of biological response, leading to a more comprehensive understanding of the fate of fish that pass through turbines.

A new project was started in FY 2001, involving full-scale, time-varying turbulence measurements and data analyses to provide information on the size, duration, and frequency of turbulent eddies (collectively known as the coherent structure of the flow). The work is being done jointly by ORNL and TVA, with the field measurements at Melton Hill Dam on the Clinch River in Tennessee. The project will involve the collection of coincident three-dimensional velocity time-series data at multiple points in the draft tube and tailwater. This approach was selected for several reasons: (1) draft tube turbulence is inherently a three-dimensional phenomenon and must be analyzed as such, (2) robust instrumentation to capture such data is becoming widely available, and (3) time-series data lend themselves well to automated computations of biologically relevant indices of turbulence below hydropower turbines. Flow measurements will be made at representative Kaplan turbines and in physical models of those turbines. The first phase of this work will demonstrate the feasibility of such measurements in full-scale turbines.

Figure 5. Turbulent flows in the spillway of Bonneville Dam on the Columbia River.

Turbulence measurement in physical models. This project was initiated in August 2001 to study turbulent flows inside the physical models at ERDC (see related Corps projects described above). This study involves:

- Characterizing turbulence in Kaplan turbines by tracking bead movement through sections of the turbine

- Combining data from the 3-D bead tracking studies with results of the Corps' work on measuring water velocity and turbulence intensity along transects throughout the turbine flow path using Laser Doppler Velocimetry (LDV) to provide estimates of both small and large scale turbulence

- Analyzing bead trajectory and LDV data to obtain detailed descriptions of turbulence that will aid the design of further experiments to help define the turbulence effects on fish susceptibility to predation and overall fish health

- Assessing the feasibility of describing the trajectory of fish and fish drogues through turbine exit turbulence and the draft tube using existing "time of arrival" and "line of sight" 3-D ultrasonic tracking studies of neutrally buoyant fish drogues.

The study will also attempt to integrate data of "route specific" injury classifications and mortality with "route specific" measurements of flow path, velocity, and turbulence. It is anticipated that combining these data will provide the closest coupling of biological consequences with discrete route conditions through a Kaplan turbine achieved to date. The results should identify fish injury types and rates as well as fish mortality rates for passage routes around the blade hub, mid-blade, and blade tip.

Unsteady computational fluid dynamics modeling. Computer simulation is an extremely valuable tool for examining hard-to-measure phenomena, such as the dynamic hydraulic environment in draft tubes. Therefore, computer simulation is an important part of the Program's new studies of draft tubes and tailraces (see following section).

3.3 Computational Studies

Computer simulation models are useful tools for studying phenomena that are difficult to observe directly, such as the hydraulic environment in turbines and the fate of fish in that environment. CFD tools are already used extensively in turbine design, but there is much room for improvement in these modeling techniques. Computer modeling is being used to complement field and laboratory studies and to improve overall understanding of the hydraulic environment experienced by fish. Exploratory, computational research is being pursued in three areas: (1) modification and extension of commercially available CFD methods to identify the location and magnitude of damaging shear; (2) prediction of unsteady, time-varying velocity fields; and (3) development of virtual fish simulations.

Computational inventory of damaging shear. In previous laboratory studies, biological criteria were developed to describe how fish respond to hydraulic forces inside hydropower turbines (Neitzel et al. 2000a, 2000b). In FY 2001, new studies were initiated to develop and demonstrate computational methods for applying these biocriteria to turbine design (Fisher et al. 2000). Voith Siemens, in cooperation with ORNL, developed CFD methods for predicting the location and magnitude of damaging shear to fish passing through hydropower turbines (Garrison et al. 2002). Commercially available CFD modeling and experimental data were utilized to locate and quantify shear areas within a turbine environment that, according to previously defined criteria, could be harmful to certain fish species. Two operating conditions for hydro turbines at Wanapum Dam were evaluated, optimum (11,000 cfs) and high flow (17,000 cfs). Of the two conditions analyzed, the high flow condition contained significantly larger areas of damaging shear stress. Many shear zones that would be damaging to fish were located, including: (1) near the band at the trailing edge of the wicket gates (Figure 6), (2) in the runner near the hub and periphery gaps, (3) in the blade wakes, (4) in the boundary layer on the blade surfaces, (5) under the hub in the draft tube, (6) at the leading edge of the draft tube piers, and (7) in a separated region of the flow near a draft tube pier. These methods will be applied to a wider range of operating conditions in the next phase of this study, and the results will be compared to field observations of fish injury at Wanapum Dam (i.e., Normandeau Associates, Inc. 1996).

Unsteady flow predictions. The objective of the unsteady modeling project is to clarify the complex features of the instantaneous flow field to help interpret the results of the biological experiments. This work is filling the need to understand and quantify the structure of turbulence at the scale of a fish to guide design and interpretation of laboratory experiments with live fish. A numerical method for conducting large-eddy simulations (LES) of turbulent-free shear flows has been developed at Georgia Tech (Jones and Sotiropoulos 2002). This unsteady model was used to simulate the velocity fields, shear levels, and vorticity (a measure of local fluid rotation) in the PNNL test flume (e.g., Figure 7) and to compare the predictions of steady (i.e., time-averaged) models with unsteady models. The patterns of critical thresholds of strain rate and turbulence-induced loads are very different in the steady and unsteady modeling results. Comparisons between observed and simulated data reveal that the simulated mean flow axial velocity profiles are in good overall agreement with the measurements. The calculated instantaneous flow fields are analyzed in detail and their complex, highly three-dimensional and unsteady structure is juxtaposed with the relative simple structure of the time-averaged flows. Particle tracking studies are also being carried out to analyze the computed flow fields from the so-called Lagrangian viewpoint, which is that of a fish transported by and interacting with the turbulent flow. The results demonstrate that the actual flow environment experienced by the fish is vastly more complicated than that described by the mean flow.

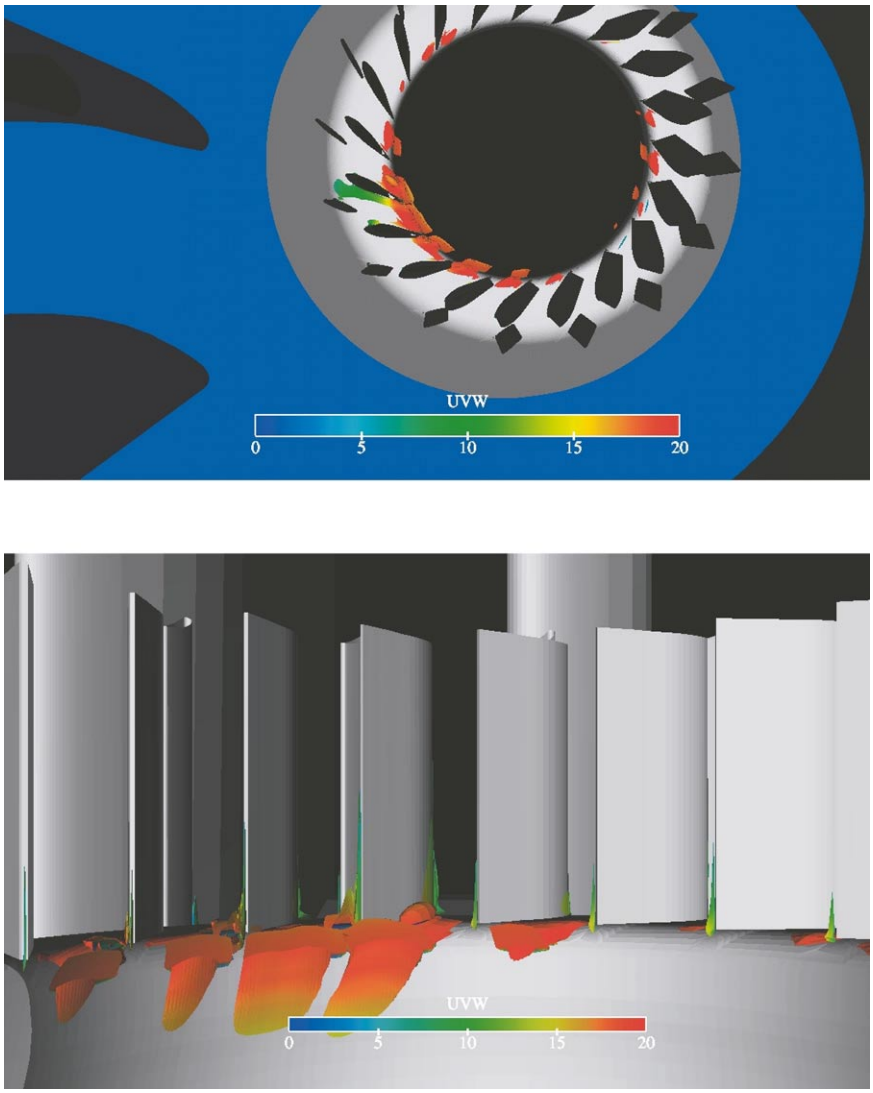


Figure 6. Visualization of areas of high shear downstream of wicket gates, based on computational fluid dynamics modeling; these areas that are damaging to fish can be reduced or eliminated with spherical discharge rings that smooth out the entrance to the runner (Garrison et al. 2002).

The Georgia Institute of Technology (Georgia Tech) and ORNL are collaborating in new computational research to develop an advanced CFD method for simulating unsteady draft-tube/tailrace flows over a broad range of powerplant operating conditions. The new numerical method will solve the unsteady, 3D, Reynolds-averaged Navier-Stokes (RANS) equations in conjunction with advanced turbulence models. It will, thus, be capable of resolving directly the large-scale unsteady vortices that dominate the flow. The interaction of the draft-tube with the tailrace is being represented using a domain-decomposition method to fully couple the flow within the two regions. Modeling results will be analyzed to understand the unsteady features of draft tube flows and elucidate the interaction of the draft-tube with the tailrace. Potential biological effects will be explored by quantifying the strength of the various unsteady vortices and identifying regions of high instantaneous shear and zones of intense turbulence.

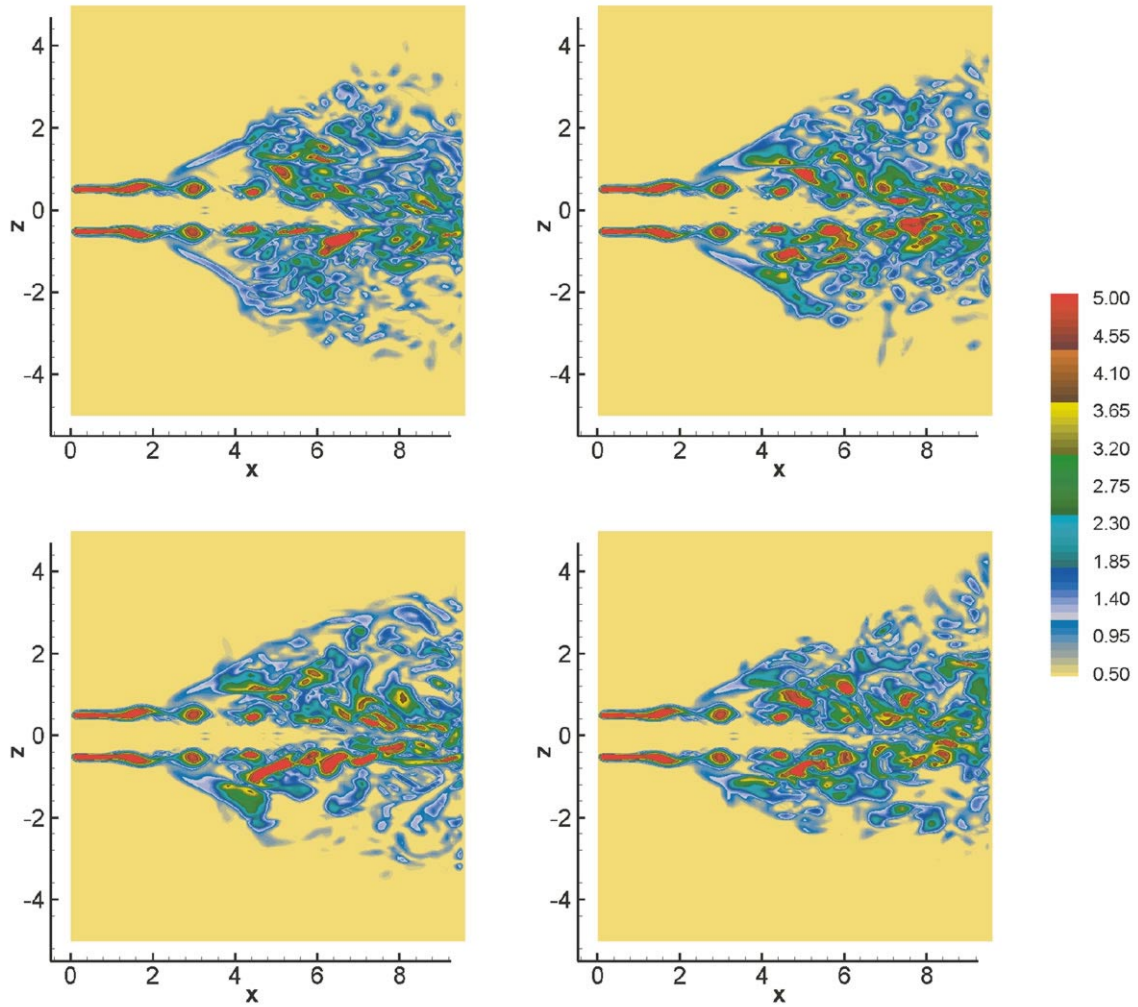


Figure 7. Simulation results of vorticity in an unsteady circular jet at four different time periods (Jones and Sotiropoulos 2002).

In FY 2001, the model predictions were tested against data from the PNNL experimental flume (Jones and Sotiropoulos 2002). A particle-tracking code was also developed and incorporated into the CFD model to investigate the time history of fluid forces at the scale of the fish, using a prolate ellipsoid as a surrogate fish. A comparison of the computed instantaneous and time-averaged flow fields demonstrates the importance of the unsteady nature of the flow field that the fish encounters. The instantaneous flow field contains large fluctuations of the vorticity, pressure gradients, and shear stresses all of which are important components of the force that the fluid exerts on the fish. The CFD tools developed here will be used to design laboratory experiments with live fish that will lead to improved biological criteria for turbine design.

Fish simulation modeling. A new simulation program for modeling virtual fish is being developed in a collaboration between Georgia Tech and ORNL to improve understanding of the flow-induced stresses on real fish in turbines. This work is an extension of earlier modeling studies that were part of the first, conceptual development stage of the AHTS research. The virtual fish model will consist of a set of algorithms and numerical techniques that predict fish trajectories through the hydraulic turbine environment by the numerical solution of the equations of motion of a statistically adequate number of

fish. In the initial work that was started late in FY 2002, estimates of flow-induced loads on virtual fish will be compared to the response of live organisms, using data obtained from the PNNL test flume. If the virtual fish model is validated, then it can be used to evaluate the biological effects of complex flow fields. Eventually, the virtual fish program will be combined with the unsteady flow model to simulate two-way interactions between fish and their hydraulic environment. If successful, this tool will help manufacturers design turbines with better environmental performance characteristics.

3.4 Instrumentation and Monitoring Technology

The Program's attention to understanding the fate of fish inside turbines has led to the need for new instrumentation and monitoring technology. Several unique R&D efforts are being supported in this area.

Sensor fish. DOE is providing partial support for the development of PNNL's sensor-fish device, a fish-shaped package of instruments that, like a real fish, can be sent through a turbine and recovered downstream. This tool has been used to collect information on the physical stresses that fish experience during turbine passage and in other severe hydraulic environments. Sensor-fish devices were first used at Bonneville Dam on the lower Columbia River in FY 2000 to compare the pressures and turbulence experienced by fish passaging through Kaplan turbines, including the newer MGR design. If successful, this sensor technology could replace the need for using live fish in turbine testing.

A modified version of the original sensor device (Figure 8) was deployed in FY 2001 to measure forces occurring in the stilling basins and sluiceways at The Dalles, Bonneville, and Rock Island dams. These studies are providing valuable data that will help identify structural configurations and operating conditions that are safer for fish. Also in FY 2001, work was initiated to reduce the size and increase the functionality of the sensor package. The modified device will be small enough to use as a gastric implant in adult fish, which will then constitute the biological sensor "package." Tests with this modified version of the sensor-fish device will help answer questions about how fish behavior influences fish passage routes through operating turbines and will provide more information on the location and forces that may injure larger fish.

Applications for pressure-sensitive film. Pressure-sensitive films (PSF) have been developed that are thin, flexible, and capable of permanently recording a wide range of pressures applied to the surface. These films may be useful for estimating the stresses experienced by fish as they pass through open-water zones of high turbulence (probably relatively small changes in shear stress and water pressure), pass near structures or encounter other areas of rapid water velocity change (possibly higher shear stress), or collide with mechanical structures (potentially high and localized pressure forces).

The ability of PSF to reliably record pressures on the surface of a fish is being explored in two phases. In the first phase, involved laboratory testing will be conducted to explore the feasibility of this application. Laboratory testing will include:

- Designing waterproof packages for the film
- Developing techniques for sandwiching different films with different pressure responses to increase the overall response range
- Identifying methods to attach PSF to fish or fish-like bodies
- Testing the response of the film to a range of known pressures, ranging from small shear stress values to high, impact-related values.

Figure 8. Sensor-fish device developed to measure physical stresses inside Hydropower turbines (photographs provided by Pacific Northwest National Laboratory).

The initial feasibility testing (i.e., waterproof packaging and layering concepts) was successfully completed in FY 2001. Subsequent phases will involve field studies, where PSF will be attached to flexible, neutrally buoyant, fish-like bodies and sent through the turbines. The film will be retrieved and scanned to record the pressures experienced by the fish. This technique could provide a rapid and inexpensive method to characterize the fluid and mechanical stresses experienced by fish passing hydroelectric power plants through a variety of routes. The pressure values can then be related to laboratory and field observations to develop a better understanding of the sources of injury to turbine-passed fish. The PSF technology may also be used with the sensor-fish device.

Light and ultrasonic tags. Determining how fish are injured inside full-scale turbines is a major challenge, because direct observations are very difficult to make in this low-light, high-velocity environment. It is often not feasible to deploy and maintain instruments within the turbine during normal operation, and it is even more difficult to obtain data that quantitatively describe interactions between fish and the turbine environment. One possible solution for improving observations of fish inside turbines is to use arrays of light emitting diodes attached to fish in the turbine flow. Another way to produce higher-resolution tracking is to attach ultrasonic acoustic transmitters to fish in the turbine flow. A third method is to use imaging modality with an ultrasonic video camera that is capable of producing images at frame rates approximately half the standard in optical video cameras. All three of these techniques were evaluated in FY 2001. The ultrasonic camera was deployed in laboratory and field settings to determine the range of conditions within which useful images of fish could be obtained. Preliminary results indicate that detailed observations of juvenile fish behavior can be obtained near structures, under conditions of total darkness, high turbidity, and turbulent flow. The swimming patterns, orientation, and other aspects

of fish location and behavior can be obtained from sequences of images. These feasibility studies should lead to new ways to separate the multiple stresses on fish and ultimately produce better turbine designs.

Detection of indirect or delayed mortality. Fish that pass through a hydroelectric turbine may not be killed immediately, but may nonetheless experience sublethal stresses that will increase their susceptibility to predators or disease (indirect mortality). As a result, reliable tests for detecting indirect mortality are needed, so that the full consequences of passage through conventional and advanced turbines (and other routes around the hydroelectric dam) can be assessed.

A new study was initiated in FY 2001 to determine the feasibility of using escape behavior as an indicator of susceptibility to predation. Disorientation and/or physical injury to fish during turbine passage may alter fish behavior in a measurable way. To test this hypothesis, fish will be subjected to sublethal stresses representative of turbine passage and examined for quantifiable, reproducible changes in escape behavior. The sublethal stress used will be disorienting levels of turbulence (such as might occur in the draft tube and tailrace of a hydropower plant), but potentially this technique could be used to assess a wide variety of physical stresses (sublethal shear or strike), temperature stresses, or chemical stresses (e.g., low dissolved oxygen or gas supersaturation). If the technique proves to be reliable in the laboratory, subsequent experiments would measure escape behavior at field sites and compare measures of escape behavior with other measures of indirect mortality. This project is expected to lead to better understanding of the long-term fate of fish that pass through turbines.

3.5 Synthesis and Integration

The systematic development of advanced, fish-friendly turbines requires an understanding of the stresses that kill or injure fish before changes in design or operation can be made. Acquiring this knowledge has been challenging because potential injury mechanisms, such as rate of strain, turbulence, pressure changes, and the likelihood and severity of impact with structures, are extremely difficult to measure inside of a turbine. Further, the stresses are not uniformly distributed; estimation of average values for the turbine may not be meaningful if much higher, damaging values are present in localized portions of the water passage. Finally, the relevance of average or maximum values for these stresses to fish injury and mortality is often poorly known because the needed bioassays have not been performed.

The DOE Program is tackling these problems with a three-pronged research effort that involves field and laboratory experiments, physical models and advanced computational analyses. These three complementary efforts: (1) measuring physical conditions in a portion of the turbine, (2) using models and advanced computational techniques to describe the environment in unmeasured parts of the turbine (or under other configurations or operating conditions), and (3) applying these physical conditions to fish in a controlled laboratory setting to measure the response, will shed light on the causes of mortality among turbine-passed fish. The effort to integrate these areas has begun (see for example, Čada et al. 2001 and CENT 2000).

4. ENVIRONMENTAL MITIGATION AND OTHER STUDIES

The Hydropower Program includes a diverse array of other environmental studies supporting the program's goals. Although funding to support these other studies was limited in FY 2001, several important activities continued in this area.

4.1 Mitigation Studies

New research on the effectiveness of environmental mitigation practices was identified as an industry need in both the DOE-sponsored Hydropower R&D Summit in November 2000 and in the R&D Forum in Salt Lake City in July 2001. Therefore, the Program is supporting several mitigation studies.

Dissolved oxygen management approaches. The discharge of water with low dissolved oxygen (DO) concentrations can be addressed by a variety of structural and non-structural measures. A new mitigation report on the major non-structural approaches for addressing DO problems at hydropower facilities is being prepared. Operational changes that can raise downstream DO concentrations include: (1) fluctuating the timing and duration of flow releases, (2) spilling or sluicing water, (3) maintaining minimum flows, and (4) mixing of generation and auxiliary flows. On the other hand, regulatory approaches to resolving the issues could include negotiating site-specific water quality standards, performing bioassessments as an adjunct to monitoring chemical parameters, and exploring the use of watershed-based water quality improvement strategies such as pollutant trading and Total Maximum Daily Load (TMDL) Program. The report emphasizes the potential value of biocriteria and bioassessments for directly determining the biological integrity of the receiving waters. Initial findings of this effort were presented at the Waterpower 2001 conference (Peterson et al. 2001), and a DOE report on the DO mitigation issue will be available in early 2002.

Instream flow and fish passage requirements. This project is a restart of DOE's earlier Environmental Mitigation Studies (Sale et al. 1991; Francfort et al. 1994). In November 2000 at a DOE-sponsored workshop on hydropower R&D needs, representatives from both the hydropower industry and environmental groups supported new studies on mitigation practices. Since DOE's earlier studies, mitigation requirements in hydropower licensing have intensified and become even more costly, but the scientific basis for these requirements is still weak. The knowledge gained from new mitigation studies will produce more effective design of instream flow and fish passage requirements, as well as improved understanding of the role of dissolved oxygen levels and other water quality parameters. Such improved mitigation practices should simplify licensing and relicensing proceedings and make hydropower a cleaner energy source.

The new mitigation studies will include a comprehensive review of the benefits, costs, and effectiveness of measures used to address the environmental impacts of hydropower projects, with specific attention to instream flow requirements and fish passage facilities. The study approach will consist of:

- Collection of new information on mitigation requirements implemented in the 1990s
- Review and description of current instream flow requirements which have become much more diversified over the last decade
- Review of the effectiveness of fish passage measures
- Identification of additional issues needing attention, based on new/updated information.

Study sites at representative hydropower projects will be selected for both instream flow and fish passage in an objective way, based on the best available data. In FY 2001, work was started on developing study plans for each mitigation issue. Information from existing hydropower projects was reviewed to understand the types of data likely to be available and the types of confounding problems that need to be addressed, such as non-hydropower-related factors limiting to fish populations. Future data collection will be coordinated with FERC and DOE's Technical Committee. The planned benefits analysis will include an evaluation of the strengths and deficiencies of current mitigation practices related to fish passage at hydroelectric facilities and the effects of these practices on both resident and anadromous fish populations.

4.2 Other Studies of Impacts to Fish

Because hydropower impacts on fish are often at the heart of many of the environmental issues in hydropower licensing, the DOE Hydropower Program supports several studies that seek new understanding and solutions to these problems.

Hydropower impacts on American eels. Mortalities of Anguillid eels at hydroelectric facilities may contribute to the apparent decline of these stocks around the world. To provide hydroelectric operators, regulators, and resource agencies with a sound scientific basis for addressing eel management issues, DOE provided partial funding for an EPRI review of the research and existing technologies to minimize adverse effects of dams on downstream migrating eels. The report (EPRI 2001) documents the current knowledge on behavior of eels, engineering and operational factors that influence eel injury and mortality during turbine passage, and the effectiveness of physical and behavioral technologies designed to reduce entrainment and guide eels to safe passage routes.

Streamside fish incubation studies. In cooperation with the Office of Naval Research, DOE is providing partial support for research into new techniques for improving salmon reproduction in Idaho streams (Galindo and Rinehart 2001). The research, which was begun in 1995, is being conducted by members of the Shoshone-Bannock Tribe under the Native American Science Research and Education Program (Figure 9). The overall goal of the study is to increase egg-to-fry hatch rates of anadromous salmonids. The study had several other objectives:

- Test the technology for successful hatching
- Determine optimum incubator densities and configuration
- Minimize cost, process, and handling of fish
- Test new equipment and designs
- Increase community education and involvement.

Since 1995, the project has been expanded from 4 to 40 study sites, which are located in the Salmon and Challis National Forests; Leadore, North Fork, Challis, Yankee Fork and Salmon/Cobalt districts; and the Sawtooth National Recreation Area. These sites extend over 200 miles of streams within the Salmon River Drainage. The average steelhead hatch rate from 1995 to 2001 was 82.5%. Substantial improvements have been achieved in each successive year, and the hatch rate in 2001 approached 98%.

Figure 9. Field activities for the streamside fish incubation project in Idaho (Galindo and Rinehart 2001).

Fish guidance using induced turbulence. A new project was initiated in FY 2001 to develop a fish-guidance system for dam forebays and bypasses using the natural turbulent-flow behavioral cues of river hydraulics (Coutant 1998; Coutant and Whitney 2000). The project's objective is to test induced turbulent flow as a method of fish guidance that can be used to direct downstream-migrating juvenile salmon and trout away from the intakes of hydropower turbines and toward safer passage routes around dams. The method for fish guidance here is to mimic natural processes of turbulent river flow that normally guide juvenile salmonids in downstream migrations. The field work is being conduced at the Buchanan Hydroelectric Plant on the St. Joseph River, Michigan. EPRI and DOE are providing joint funding for this work.

4.3 Certification Programs

The restructured electricity market is creating new opportunities and new pressures on hydropower. The Program is tracking these trends, with special attention to the development of new green energy certification programs and their impact. The Low Impact Hydropower Institute, a non-profit, non-governmental organization that was established to certify environmentally preferable projects, is preparing a report for DOE on its early experience. This report will summarize the initial results of green energy certification, including recommendations on how DOE-sponsored R&D can help make projects more acceptable. ORNL is also providing advisory support to this activity. Understanding this evolutionary process will complement the activities in the DOE Hydropower Program and help to define future research needs.

5. UNCONVENTIONAL HYDROPOWER TECHNOLOGY

Most of the current activities of the DOE Hydropower Program are aimed at conventional hydropower plants that use conventional turbines and sites. There is also a need to develop unconventional turbine designs, such as low power (< 1 MW) and low head (< 30 ft) sites, free-flow turbines, and microhydropower. Generally, smaller sites have fewer environmental problems, although some individual sites may still have specific environmental issues. New turbine designs have been developed that may have low environmental impact, and some types of unconventional hydropower may be suitable for implementation as distributed power sources. The resources and potential market of this new technology needs to be further understood.

In FY 2001, DOE continued an assessment of potential resources appropriate for unconventional development. Three general types of unconventional hydropower systems have been identified for the purposes of this study: (1) elevation-drop systems, (2) free-flowing rivers/streams, and (3) microhydropower. An elevation-drop hydropower system is defined as any arrangement that uses a dam or natural drops. Free-flowing systems use the kinetic energy from the water in motion. Microhydropower sites are 100 kW or less with no restriction on head. This activity will identify the total potential resource and then apply a screening process to each type of technology.

Each resource type is associated with specific technologies that have specific site requirements (i.e., flows, depths, head, etc.). Additionally, when other site selection criteria are applied, the number of resources available for development is reduced. The study's results will include the number of sites for each development type and an estimate of potential power for each site, which will be used to calculate total resource potential. The data will be presented by state and region. Planned resource assessment activities may also address additional factors, such as project economics. The first interim report is scheduled for mid-2002.

Also in FY 2001, a efforts was made to gauge interest in full-scale testing of smaller, less traditional turbines with low power and/or low head designs. A Notice of Availability of Financial Assistance was published in the Federal Register on November 22, 2000, to solicit interest in the small-scale initiative. Unfortunately, there was insufficient response to warrant further activity. Support for testing of small-scale technology has therefore been deferred, pending future budgets and a stronger show of interest from outside DOE.

6. TECHNOLOGY TRANSFER

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 Reference Cited section of this annual report. Other examples of these activities for FY 2001 are highlighted below.

6.1 Interagency Coordination and Outreach

Laboratory staff supported by the Hydropower Program were involved in these activities in FY 2001.

R&D strategic planning forums. Program staff participated in two strategic planning forums in FY 2001: (1) the DOE-sponsored Hydropower R&D Summit held in Washington, DC, in November 2000, and (2) the R&D Forum organized by HCI Publications in Salt Lake City in July 2001. At both of these meetings, representatives from industry, regulatory agencies, and non-governmental organizations were asked to identify long-term R&D needs for hydropower.

Corps of Engineers' Turbine Working Group. The Corps operates eight multipurpose dams on the lower Columbia and Snake rivers as part of the federal Columbia River Power System. Considerable effort is going into improving turbine passage survival in response to pressure from both the Northwest Power Planning Council and the National Marine Fisheries Service (NMFS). Under its Endangered Species Act obligations and its Biological Opinion of 1995, NMFS has recommended that the Corps study the engineering and biological aspects of juvenile fish passage through turbines, develop biologically based turbine design criteria, and evaluate the effectiveness of prototype turbine designs and modifications in reducing juvenile fish mortality. As part of this effort, a Turbine Working Group (TWG) was created to share information and coordinate activities among the various agencies and organizations that seek to improve fish passage survival (Schwartz 2000). Staff from the DOE Hydropower Program participate in monthly TWG meetings, review documents, and provide information to coordinate research activities with the Corps. Several of the cost-shared projects described in Section 2.2 are evidence of this successful interagency coordination.

Conference planning and participation. Staff from INEEL and ORNL serve on the organizing committees for several annual meetings, including NHA's Annual Conference that is held in Washington, DC, and the biennial Waterpower and HydroVision conferences. Other conferences that were attended in FY 2001 include the Construction Project Management Working Group of the United States Society on Dams and the Northwest Hydropower Association Annual Meeting. An invited briefing was also made to the NPPC on DOE's advanced turbine research.

Restoration of Pacific Salmon. Working with the Office of Science and Technology Policy (OSTP), ORNL staff provided technical support to the National Science and Technology Council's Committee on Environment and Natural Resources (NSTC-CENT) in producing a report entitled *From the Edge, Science to Support Restoration of Pacific Salmon* (CENT 2000). The state-of-the-science review points out that hydropower impacts are only one of the many factors affecting salmon, that much work has already been do to reduce hydropower's impacts, but also that additional research can lead to improvements in salmon survival at hydropower projects. The bulk of the effort on this product was prior to FY 2001, but the final report was published in FY 2001.

6.2 Technical Support to DOE

A variety of ad hoc technical support is provided to DOE through the Hydropower Program, such as the monitoring of research outside DOE (e.g., Čada and Rinehart 2000) and annual reporting (e.g., Sale et al. 2001). The FY 2001 activities in this area are described here.

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.

Web site development and usage. The Program maintains an official Hydropower web site (http://hydropower.id.doe.gov). Several updates and changes were made to the site in FY 2001 in the subject areas of Hydropower Facts, the Advanced Hydropower Turbine Systems, and Hydropower Resource Assessment. 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 final report on the *U.S. Hydropower Resource Assessment* was added to the Resource Assessment area of the site. While that report was finished in 1998, it was added in April 2001 to respond to the increased interest in hydropower as an energy source that can help meet the United States' increasing need for clean, renewable power.

Statistics on user access to DOE's Hydropower web site indicate steady interest and access by users worldwide. The Hydropower web site received a total of 758,300 hits between November 2000 and September 2001, and averaged 69,000 hits per month. The majority of the hits were from the United States (about 88 %). Hits from other countries, not in numeric order, include Netherlands, Canada, Hong Kong ROC, Australia, Mexico, the United Kingdom, Germany, Brazil, Thailand, France, Japan Sweden, Spain, Italy, and many others.

Climate Change Technology Initiative. Several new science planning efforts were initiated in FY 2001 under the new Bush Administration to address climate change issues. ORNL staff were involved with one of these, the Climate Change Technology Initiative, to ensure that hydropower was adequately considered.

Translation of Russian research. Russian scientists have contributed to the understanding of hydropower effects on fish populations for many years, but many of their publications have not been available in English. In FY 2001, DOE supported the creation of an English translation of an important Russian book entitled *Fish Downstream Migration Through Dams of Hydroelectric Power Plants*, originally a publication from scientists at the Russian Academy of Science in Moscow (Pavlov et al. 2002) (Figure 10). In this book, the authors integrated years of research on European and Asian river systems, summarizing their understanding of how regulated river flows affect the downstream movements of fish. They summarized considerable literature on the ecological preferences of fish (especially juvenile fish) in Eurasian reservoirs and categorized species by habitat zones. The book considers the patterns, causes, and mechanisms for downstream movements and assesses the susceptibility of fish to loss from the reservoir as a function of species, life stage, habitat zone preferences, and characteristics of the reservoir. Most relevant to the DOE Program, the effects of turbine passage and techniques to mitigate turbine-passage losses of fish are described. The English edition of this text is now available on the DOE Hydropower Program website and on CD from ORNL.

Figure 10. Covers of the Russian text entitled *Fish Downstream Migration Through Dams of Hydroelectric Power Plants*, by D.S. Pavlov, A.I. Lupandin, V.V. Kostin, of The A.N. Severtsov Research Institute of Ecology and Evolution, Russian Academy of Science Moscow-Nauka that has been translated into English in 2001 as a technology transfer contribution.

7. FUTURE ACTIVITIES

The immediate plans for the DOE Hydropower Program are to: (1) complete the biological and engineering testing of the new runner designed by ALDEN/Concepts NREC, (2) continue cooperative studies with the Corps and its Turbine Survival Program, and (3) pursue new opportunities for cost-shared testing of the biological performance of new hydropower turbine technology. The primary focus of these activities will be to determine the fish passage characteristics of new turbine technology and to verify the fish friendliness of these new designs. On a longer-term basis, the Program intends to support full-scale testing of new turbine concepts in the field, subject to available funding.

With regard to basic and applied R&D, the combined field, laboratory, and computational research described here will continue in future years. Specific studies will be designed to understand the turbulent environment downstream of the turbine runners, in the draft tube and in the tailrace of hydropower plants. This research is likely to include both physical characterization of existing plants and additional biological studies to further define, enhance, and test the biological criteria as development of the technology progresses. The work on advanced sensors will also continue, developing better ways to track fish through turbine systems and relate fish response to the cumulative stresses from hydropower systems.

At the North American Hydro Research and Development Forum convened in 1992, the hydropower industry reviewed research efforts in the industry and identified research needs. A smaller industry-government R&D summit was held in November 2000 to reexamine research needs, and this planning effort was repeated after Waterpower XII in Salt Lake City in July 2001. Many of the issues identified at these meetings continue to be assessed by the DOE Hydropower Program and remain targets for future research efforts.

As future budgets allow, additional studies will be added to the Program, subject to Congressional appropriations and availability of funding. One area of high priority is the environmental mitigation, including restarting studies of unresolved issues, such as instream flow requirements and methods to enhance passage of migratory fish through reservoir systems and past hydroelectric projects. These issues have been identified by the hydropower industry as high-priority concerns. Other issues that may be supported in the future include the development of industry guides to address the operation and maintenance of the power plants, and dam decommissioning.

Future activities in the area of unconventional hydropower technologies include assessing the potential application of new technologies in the U.S. and initiating the testing of new low-head/low-power turbine technology. The environmental performance of this technology must be tested to support commercial development. Studies are needed to identify new technologies that have been developed outside the current DOE program and that have desirable fish passage characteristics.

8. CONCLUSIONS

The DOE Hydropower Program continues to make unique and important contributions to clean energy production in the U.S. By working toward technology improvements that can reduce environmental problems, the Program is helping position hydropower as an acceptable, renewable, domestic energy choice. Program activities are closely coordinated with industry, other federal agencies, and public interest groups to ensure an efficient, open, and scientifically sound research agenda. DOE funding is leveraged with cost sharing whenever possible, and peer-review processes are used in making funding decisions.

The key successes in FY 2001 were:

- Construction and start-up of the pilot-scale test facility at Alden Research Laboratory, to evaluate the environmental and engineering performance of the new Alden/Concepts NREC runner (Cook et al. 2000).

- Publication of new biological response studies of the effects of pressure and dissolved gas supersaturation on fish passing through hydropower turbines (Abernethy et al. 2001).

- Deployment of the phase II sensor fish device at Columbia River dams to evaluate hydraulic forces present in spillways and a high-volume outfall.

- Collaboration with industry and other federal agencies in two successful workshops to identify future R&D needs for hydropower.

- Publication of a feature article in *Fisheries* on the development of advanced hydroelectric turbines to improve fish passage survival, promoting interdisciplinary communication on technology advances (Čada 2001).

- Support to OSTP and NSTC-CENT in publishing a comprehensive review of the state of the science of salmon restoration that puts the effects of hydropower in context of other impacts (CENT 2000).

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Appendix A

Renewable Indian Energy Resources Program

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The DOE Hydropower Program administers the Renewable Indian Energy Resources Program that supports development of hydroelectric and other energy projects in Alaska. Under this program, federal funding is provided for energy projects that help Native American communities reduce their dependence on expensive diesel fuel for electricity production. The total cost of the projects in this program over all years is about $137 million (Table A-1). Federal funding has contributed slightly more than $35 million (26%) of the total cost of these developments. Federal funds are awarded subject to the availability of local funds to share project costs. The DOE Idaho Operations Office manages the distribution of the federal funds and provides technical assistance to help the communities efficiently use the available financial resources. A summary of these projects follows.

Nome Efficiency Enhancement Project. The Nome Efficiency Enhancement Project is located in Nome, Alaska, and owned by the Nome Joint Utility System. The project consists of an upgrade of an existing diesel generator from 3,600 kW at 720 rpm to 4,400 kW at 900 rpm. The upgrade will also retrofit the generator for waste heat recovery and commercial heating. Performance monitoring for two years will provide new data on costs, maintenance requirements, and energy production that can be applied to similar projects. The project is estimated to offset 2.4 million pounds of CO_2 emissions per year at an effective residential power rate of $0.146/kWh.

Old Harbor Project. The Old Harbor Project is a small hydropower development located on Kodiak Island near Old Harbor, Alaska, and owned by the Alaska Village Electric Cooperative, Inc. The project consists of a 500-kW impulse turbine operating with a 768-ft design head. When fully operational, the project will produce about 3,000 MWh/yr and displace about 200,000 gallons/yr of diesel fuel. The Scammon Bay Feasibility Study is part of the Old Harbor Project, which is examining the addition of another 100-kW hydropower turbine.

Power Creek Project. This is a new 6-MW hydropower project that has been developed by the Cordova Electric Cooperative in Cordova (Figure A-1). The project includes two 3-MW horizontal Francis turbines with a design head of 300 ft and an annual average generation of 25,000 MWh, displacing current diesel-powered generation. Construction has been completed on this project.

Pyramid Creek Project. This small hydropower project is located on Unalaska Island near Dutch Harbor, 800 miles southwest of Anchorage. It consists of a 600-kW impulse turbine operating on a 400-ft design head and generating about 2,800 MWh/yr. This project will eventually displace 254,000 gallons of diesel fuel per year.

Reynolds Creek Project. This is a 1.5-MW hydroelectric project owned by the Haida Corporation and located about 10 miles east of Hydaburg. It will generate 11,500 MWh/yr and displace about 480,000 gallons/yr of diesel fuel.

Sitka Project. The Sitka Project is a new diesel generator installation in the City & Borough of Sitka, replacing an older, decommissioned diesel-fired power plant. The new equipment will have a capacity of 4.5 MW.

Sheldon Jackson College (a.k.a. Indian River) projects**.** These projects are part of the Sitka Project, located in the town of Sitka. The projects will reuse an existing hydropower plant to generate low-cost electricity within the College. The Sage Hall hydro turbine and generator unit will be rehabilitated and interconnected to the campus steam plant. The electrical distribution system will also be upgraded. The hydropower plant has a capacity of 104 kW with a design head of 28.5 ft.

Swan Lake – Lake Tyee Intertie. This is a transmission line construction project that will connect the Swan Lake and Lake Tyee hydropower projects with Petersburg, Wrangell, and Ketchikan. The

transmission line will be 57 miles long, with a voltage of 138 kV and a capacity of 25 MW. The new line will allow full distribution of the 134,400 MWh annual generation from the Lake Tyee project, which was previously limited by insufficient transmission capacity. The new access to hydropower generation will serve the needs of the three communities through the year 2015.

Table A-1. Budgets and status of projects supported by the DOE Hydropower Program under the Renewable Indian Energy Resources Program.

Project Name (Start Date)	Project Type	Total Project Cost	DOE Funding	DOE Payments	Percent Complete
Haynes-Skagway (9/95)	15-mile, 34.5 kV Trans. Line (submarine)	$ 5,860,000	$ 877,000	$ 877,000	100 %
Prince of Wales (9/94)	35-mile, 34.5 kV Trans. Line (overhead)	$ 2,447,000	$ 947,000	$ 947,000	100 %
Tazimina (6/96)	824 kW Hydropower	$11,714,500	$ 3,380,000	$3,380,000	100 %
Power Creek 4/97)	6 MW Hydropower	$20,237,350	$ 8,827,000	$8,827,000	100 %
Sitka (2/99)	4.5 MW Diesel	$ 4,660,500	$ 1,939,000	$1,300,000	80 %
S.J. College (5/01)	104 kW Hydropower Rehabilitation	$ 198,000	$ 198,000	_____	5 %
S.J. College (5/01)	Electric System Upgrade	$ 1,134,000	$ 1,296,000	_____	5 %
Reynolds Creek (9/97)	1.5 MW Hydropower	$ 7,400,000	$ 2,925,000	$ 50,000	5 %
Pyramid Creek (9/99)	600 kW Hydropower	$ 3,657,000	$ 1,000,000	_____	<5 %
Old Harbor (9/98)	500 kW Hydropower	$ 2,745,000	$ 1,082,150	$ 76,000	<10 %
Scammon Bay (3/99)	Hydropower Feasibility Study	$ 100,000	$ 100,000	$ 13,500	Cancelled
Nome (9/00)	4.4 MW Diesel	$ 3,455,000	$ 1,996,000	_____	<5 %
Swan-Tyee (5/94)	57-mile, 138 kV Trans. Line (overhead)	$73,823,000	$11,896,000	$ 750,000	<10%

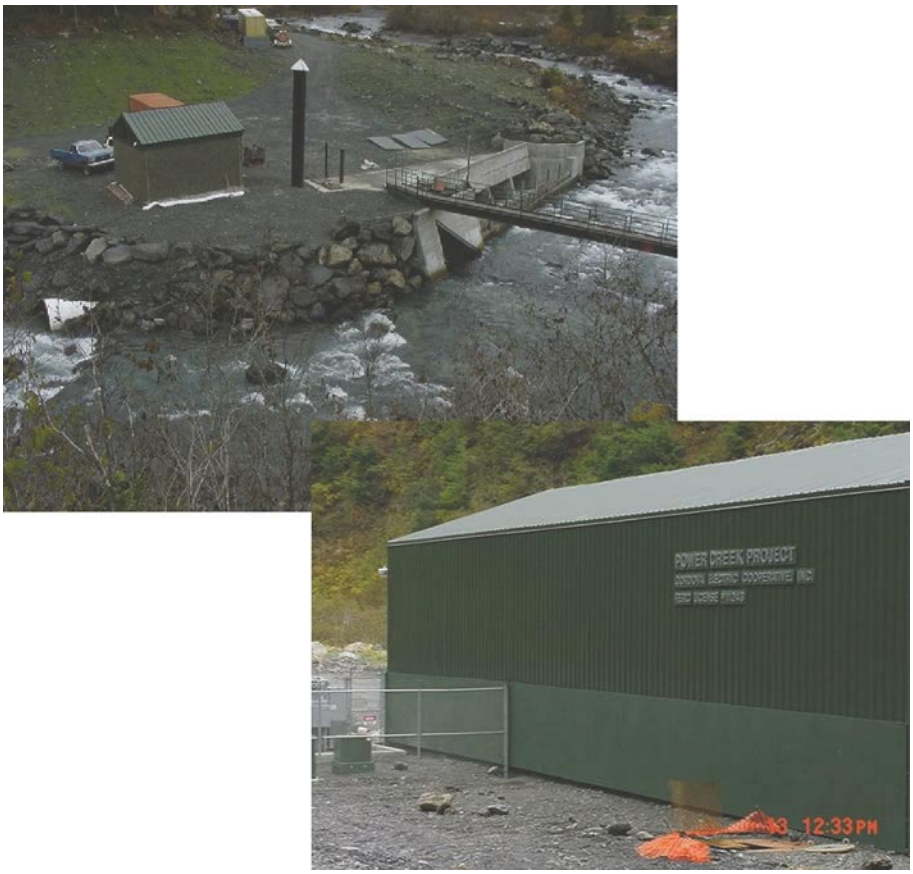

Figure A-1. Intake and powerhouse of the Power Creek Project in Alaska.