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**DOE HYDROPOWER PROGRAM
BIENNIAL REPORT 1990 – 1991
(WITH UPDATED ANNOTATED BIBLIOGRAPHY)**

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ABSTRACT

This report summarizes the activities of the U.S. Department of Energy's (DOE's) Hydropower Program for fiscal years 1990 and 1991, and provides an annotated bibliography of research, engineering, operations, regulations, and costs of projects pertinent to hydropower development. The Hydropower Program is organized as follows:

- Background (including Technology Development and Engineering Research and Development)
- Resource Assessment
- National Energy Strategy
- Technology Transfer
- Environmental Research

The bibliography discusses reports written by both private and non-Federal Government sectors. Most reports are available from the National Technical Information Service.

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DOE HYDROPOWER PROGRAM BIENNIAL REPORT 1990–1991 (WITH UPDATED ANNOTATED BIBLIOGRAPHY)

INTRODUCTION AND BACKGROUND

Technology Description

Hydropower plants capture the kinetic energy in flowing or falling water to generate electricity. The energy from the water is converted to mechanical energy and electrical energy by the use of a turbine and a generator. Turbines and generators are either installed in or adjacent to dams or utilize penstocks (pipelines) to carry the pressured water below the dam or diversion structure to the powerhouse. Hydro projects are generally operated as either a run-of-river, a peaking or a storage mode. The run-of-river project uses the natural flow of the river with very little alteration to the stream channel and little impoundment of the water. A peaking project uses an impoundment and releases water when the energy is needed. A storage project utilizes an extensive impoundment and stores water during the high-flow periods to augment the water available during the low-flow periods. This allows the flow releases and power production to be more constant. Many projects operate utilizing a combination of the modes. The power capacity of a hydropower plant is primarily the function of two main variables of the water resource: (1) flow rate expressed in cubic feet per second, and (2) the hydraulic head, which is the elevation difference the water falls in passing through the plant.

Principal advantages of utilizing hydropower are the large renewable domestic resource base, the lack of polluting emissions during operation, the capability to respond quickly to utility load demands in some cases, and very low operating costs. Disadvantages can include high initial capital cost and potential site-specific and cumulative environmental impacts. Potential environmental impacts of hydropower projects include altered flow regimes below storage reservoirs or within diverted stream reaches, water quality

degradation, mortality of fish that pass through hydroelectric turbines, blockage of upstream fish migration, and flooding of terrestrial ecosystems by new impoundments. However, in many cases, proper design and operation of hydro projects can mitigate many of these adverse impacts. Hydroelectric projects also include beneficial effects, such as new reservoir-based recreation and the displacement of atmospheric emissions.

Hydropower technology can be categorized into two types: conventional and pumped storage. Conventional hydropower plants utilize the available water energy from a river, stream, canal system or reservoir to produce electrical energy. On multipurpose reservoirs and in run-of-river systems, hydropower production is just one of many competing purposes for which the water resources may be used. Competing water uses include irrigation, flood control, navigation, and municipal and industrial water supply. In the case of pumped storage plants, the water resource is pumped, usually through a reversible turbine, from a lower reservoir to an upper reservoir. While pumped storage facilities are net energy consumers, they are valued by a utility because they can be rapidly brought on-line to operate in a peak power production mode. The pumping to replenish the upper reservoir is performed during off-peak hours. This process benefits the utility by increasing the load factor and reducing the cycling of its base load units. In most cases, pumped storage plants run a full cycle every 24 hours.

Most conventional hydropower plants include six major components; these are as follows:

1. Dam-controls flow of water and increases the elevation to create the

head. The reservoir that is formed is, in effect, stored energy.

2. Penstock—a large pipe that carries water from the reservoir to the turbine in the power plant.
3. Turbine—turned by the force of water pushing against the blades.
4. Generator—connects to the turbine and rotates to produce the electrical energy.
5. Transformer—converts electricity to usable voltage levels.
6. Transmission lines—conduct electricity from the hydro plant to the electric distribution system.

The typical types of projects are illustrated in Figure 1.

Technology Applications/Uses

The major application for hydropower energy is in the bulk power market. The plants are owned by Federal and state agencies, cities, metropolitan water districts, irrigation companies, public and independent utilities. Individuals also own small plants for their own energy needs at remote sites. Hydropower is an essential element in the national power grid because of its ability to respond quickly to varying loads that are difficult for other base load plants such as coal and nuclear. Hydro plants can act as spinning reserve ready to take up large loads in seconds which is not possible in plants with steam systems powered by combustion or nuclear processes.

The major application for hydropower energy is in the bulk power market. The hydro industry provides about 90,000 MW or 12% of the electric generating capacity in the United States. The plants are owned by Federal and state agencies, cities, metropolitan water districts, irrigation companies, and public and independent utilities. Individuals also own small plants at remote sites

for supplying their own energy needs and for sale to utilities under the Public Regulatory Policies Act (PURPA).

Technology Development

The U.S. Department of Energy (DOE) Hydropower Technology Development Program was initiated in conjunction with the restoration of three power generating plants in Idaho Falls, Idaho, following damage caused by the Teton Dam failure on June 5, 1976. DOE issued two Program Opportunity Notices (PON), one in June of 1978 and one in June of 1979 to expand the program to other sites. Out of 89 submitted proposals, 19 were awarded cooperative agreements. DOE participated in a sharing program for each project. The objectives of the Technology Development Program were to: use available technology in demonstrating the economic viability of small hydroelectric power; identify engineering, economic, environmental, and institutional aspects associated with small-scale hydropower development; and disseminate data on the construction and maintenance of these facilities.

Thus, by demonstrating that an economically viable, small-scale hydropower plant could be built with available technology, the program encouraged and expedited the utilization of this available, continually renewable, nonpolluting energy resource. The program also contributed to a decrease in demands on finite fossil fuels, importation of foreign oil, and provided costs and performance data to help in future evaluations and equipment selection.

The program consisting of 19 projects has been completed and a summary report written. Eighteen of the projects are on-line and have submitted their reports. One project obtained its license, but surrendered its license when it became evident that the project was no longer economical.

The program placed on-line 119,292 kW of new capacity. Fifty-seven reports were written by the developers of the projects for technology transfer to the public. These reports cover the

1-0255

Figure 1. Typical types of projects.

construction and costs, Operation and Maintenance and costs, as well as include a program summary report. General information and data for the projects in the program are shown in Figure 2 and Table 1 below.

These reports are available from the National Technical Information Service (NTIS). See the Annotated Bibliography at the end of this report. Additional information can be obtained from the technical monitors:

Participants	Project Name and State	Start of Construction	Power-On-Line Dates	Rated Capacity (kW)	Accumulated Capacity (kW)
1 Turlock Irrigation Distr.	Turlock Drop No. 1, CA	March 1979	July 1980	3,260	3,260
2 F.W.E. Stapenhorst, Inc.	Goodyear Lake, NY	April 1979	August 1980	1,325	4,585
3 Brown-New Hampshire, Inc.	Sawmill, NH	July 1979	January 1981	3,174	7,759
4 Reigel Textile Corp.	Fries Textile Co., VA	June 1980	July 1981	2,163	9,922
5 Salt River Project	So. Consolidated Canal, AZ	September 1980	September 1981	1,400	11,322
6 Public Service Co. of NH	Garvins Falls, NH	August 1980	December 1981	5,900	17,222
7 Central Maine Power Co.	Shawmut, ME	June 1981	April 1982	4,080	21,302
8 City of Idaho Falls	Upper Plant, I.F., ID	August 1980	October 1982	8,000	45,302
	City Plant, I.F., ID	April 1980	July 1982	8,000	
	Lower Plant, I.F., ID	August 1979	April 1982	8,000	
9 NY State Electric & Gas	Upper Mechanicville, NY	June 1981	August 1983	16,800	74,942
10 Shoshone Irrigation Dist.	Garland Canal, WY	April 1982	September 1982	2,900	77,842
11 City of Gonzales	Gonzales, TX	August 1981	January 1984	1,140	46,442
12 City of Spokane	Upriver Dam, WA	February 1982	June 1984	11,700	58,142
13 Antrim County	Elk Rapids, MI	September 1983	July 1984	700	78,542
14 City of Tallahassee	Jackson Bluff, FL	August 1983	August 1985	10,900	93,342
15 Boott Mills	Lowell, MA	October 1983	November 1985	15,000	108,342
16 Broad River Electric Coop.	Cherokee Falls, SC	January 1983	December 1985	3,900	82,447
17 Green Mountain Power Corp.	Bolton Falls, VT	May 1985	November 1986	7,500	89,947
18 City of Paterson	Great Falls, NJ	November 1984	December 1986	10,950	119,292
19 PA Hydroelectric Development Corp.	Fiat Rock Dam, PA	Cancelled	Cancelled	3,250	

1-6606

Figure 2. Hydropower Technology Projects general data and location.

Table 1. DOE hydroelectric parameters and costs

Project	River Location	Average Flow (cfs)	Head (ft)	Total Capacity (kW)	Annual Production (MWh/year)	Number of Units	DOE Share (\$)	Total Cost (\$)	\$/ (kW)
Turlock	Turlock Irrigation Canal, Turlock, CA	3,200	30	3,260	10,566	3	719,000	4,526,887	1,388
Goodyear Lake	Susquehanna, Milford, NY	552	32	1,325	5,500	2	245,000	1,772,301	1,337
Sawmill	Androscoggin River Berlin, NH	2,475	17.5	3,174	23,300	4	1,022,000	4,600,000	1,449
Fries	New River, Fries VA	2,014	39	2,163	13,000	1	224,824	1,341,782	620
Salt River (South Consolidated)	South Consolidated Canal Mesa, AZ	540	36.7	1,400	6,218	1	360,000	2,586,024	1,847
Garvins Falls	Merrimack River Bow, NH	4,246	29.5	6,500	33,606	2	924,750	7,946,025	1,222
Shawmut	Kennebec River Benton, ME	5,000	24.5	4,112	12,500	2	850,000	5,561,350	1,352
Idaho Falls	Snake River Idaho Falls, ID	5,751	19.3	24,000	170,025	3	7,300,000	63,602,000	2,650
City of Gonzales	Guadalupe River Gonzales, TX	1,687	15	1,140	6,550	3	295,000	2,266,789	1,988
City of Spokane (Upriver Dam)	Spokane River Spokane, WA	68,483	35	11,700	56,000	2	1,800,000	1,700,000	1,000

Table 1. (continued)

Project	River Location	Average Flow (cfs)	Head (ft)	Total Capacity (kW)	Annual Production (MWh/year)	Number of Units	DOE Share (\$)	Total Cost (\$)	(\$/ (kW)
Upper Mechanicville	Hudson River Mechanicville, NY	8,000	21.5	16,800	78,500	2	2,500,000	42,556,300	2,531
Garland Canal	Garland Canal Powell, WY	665	52	2,700	10,600	1	445,000	3,824,538	1,416
Elk Rapids	Elk River Elk Rapids, MI	490	10.5	700	2,250	2	164,250	840,000	1,200
Broad River	Broad River Cherokee Falls, SC	2,472	20.2	4,140	22,500	1	1,017,759	17,931,441	4,331
Jackson Bluff	Ochlockonee River Tallahassee, FL	1,712	32	12,318	26,000	3	1,750,350	11,726,860	952
Bocutt Mills	Merrimack River Lowell, MA	4,500	35	15,000	71,000	2	2,197,000	36,158,293	2,410
Great Falls	Passaic River Paterson, NJ	1,100	70	10,950	33,000	3	1,300,000	14,573,540	1,330
Flat Rock	Schuylkill River Philadelphia, PA	2,831	15	3,250	11,800	1	935,000	6,234,000	1,918
Bolton Falls	Winooski River Waterbury, VT	1,386	51	7,500	30,000	2	2,621,609	15,923,954	2,123

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Engineering Research and Development

DOE has funded 32 Engineering Research and Development projects. The purpose of the projects is to improve the economic and technical viability of small low-head hydropower plants. This section describes the status of two projects that were active during the past 2 years. Previous projects were discussed in the 1982 through 1989 Annual and Biennial Reports.

Reports on the projects that have been completed are available from NTIS. Refer to the Annotated Bibliography at the end of this report for report numbers and ordering information. Additional information may also be obtained directly from the technical monitors:

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Cross-Flow Turbine. A cooperative agreement between DOE and Arbuckle Mountain Partnership in Redding, California resulted in the development of the Arbuckle Mountain hydropower plant on the Middle Fork of Cottonwood Creek near Redding, California. The plant utilizes a new cross-flow turbine that has a much wider than normal operating range with respect to flow rates. Figures 3 and 4 show the Arbuckle hydro powerhouse plan schematic and a cross section of the Arbuckle hydro turbine and draft tube. The site has a maximum head of 55 ft and the annual average flow is 50 cfs. A 400 kW synchronous generator is used directly coupled to the turbine shaft that operates at 180 rpm. The maximum turbine output is 336 kW when operating at best conditions. A sliding wall nozzle enables the unit to operate over a wide range of flows (6 cfs to 106 cfs). The plant was completed in December 1986. Performance tests performed on the plant in February 1988 indicated a peak efficiency of 79%.

Figure 3. Arbuckle hydro powerhouse plan schematic.

Figure 4. Arbuckle hydro turbine and draft tube cross section.

Little rain fell at the Arbuckle Plant this past year. It appears the plant is located in a rain shadow of the mountains. There was not enough rain to operate the plant during the 1990 water year. The average stream flow has been less than 40% for the last 3 years. In fact, the precipitation for the water year was at 45% of the lowest prior year of record for the area (1977). The effects of the severe drought were further compounded by the fact that the minimum stream flow that must be provided for fish is 17% of the normal flow, or about 50% of the recent actual flows. Sufficient precipitation fell in the spring of 1991, providing water for operating the Arbuckle plant at full capacity, generating energy worth \$600 per day.

The Performance Test Report on the Arbuckle Mountain Hydropower Plant (DOE/ID/12481-2) was distributed in July of 1990. Dr. Ott and John R. Chappell presented a paper on the cross-flow turbine at WATERPOWER '89. The paper will be published as the feature article in the August 1991 issue of *Hydro Review*.

Independent Turbine Laboratory. The St. Anthony Falls Hydraulic Laboratory of the University of Minnesota was partially supported by the DOE in its establishment of the Independent Turbine Laboratory. At the time of its completion it was the only laboratory in the U.S. available for conducting research and testing of hydraulic turbines on a completely open nonproprietary basis. The laboratory at St. Anthony Falls is a recirculating test facility for testing models of turbines, pump-turbines, and pumps. The maximum power that can be absorbed in the turbine mode is 100 hp. The maximum rotation speed is 1750 rpm and the maximum flow that can be produced by the 300 hp circulation pump is 38 cfs. The pumps can produce net heads of up to 115 ft. Model turbines or pumps of the Francis or propeller types of 10 to 18 in. diameter can be accommodated. Figure 5 shows a schematic of the Independent Turbine Laboratory.

The turbine test facility is now enclosed in a new addition to the main building of the St. Anthony Falls hydraulic Laboratory. The test facility is equipped with instrumentation for measuring the head across the unit being tested, the flow rate, rotational speed, torque, and temperatures. Digital computers are used for flow data collections and processing. Software is available for a variety of operation modes ranging from on-line display of major data parameters to off-line statistical analyses of the stored data.

The Test Report for the Independent Turbine Laboratory (DOE/ID/12617) was printed. The St. Anthony staff printed a brochure listing the capabilities of the Independent Turbine Laboratory and distributed it at WATERPOWER '89.

Figure 5. Schematic of Independent Turbine Laboratory.

RESOURCE ASSESSMENT

In January 1990, DOE established an inter-agency Hydropower Resource Assessment team to review the undeveloped hydropower resource potential. Hydropower makes a significant contribution to U. S. electrical generating capacity today (12%), and it can play a pivotal role in the nation's future electricity picture.

The interagency Hydropower Resource Assessment team was made up of representatives from each Power Marketing Administration, the Bureau of Reclamation, the Army Corps of Engineers, Federal Energy Regulatory Commission (FERC), Idaho National Engineering Laboratory (INEL), and Oak Ridge National Laboratory (ORNL) who drafted a preliminary assessment in February 1990.

DOE continued the resource assessment activities with the goal of developing a method for improving the estimate of developable hydropower resources in the United States. This task was assigned to the INEL. INEL developed the Hydropower Evaluation Software (HES) as a uniform criteria and probability model to standardize the assessment process. The HES was developed with environmental evaluation support from ORNL. The Southwestern Power Administration (SWPA) provided the standards a power administration marketing area requires. HES computer screens and reports generation capabilities were developed to meet the needs of Power Marketing Administrations nation-wide. The software is intended to be generic, in that it is not specific to

a single marketing region or site, and it meets the criteria for national uniform assessment.

The assessment of the developable hydropower potential in the SWPA area was completed during the HES development stage. This assessment was submitted to DOE HQ as SWPA's assessment of the hydropower potential in their power marketing area. When applying the computer model, the SWPA resources were reduced from 3,880 MW (February 1990) to 2,700 MW (June 1991). The results were approximately the same as SWPA had manually produced after having corrected the faults that were present in the February 1990 assessment.

The SWPA assessment demonstrated that the HES model is capable of producing an assessment that is equivalent to a written assessment. However, the HES model operates in an efficient, timely manner compared to a written assessment. Additionally, the HES manages a hydropower potential database that allows for convenient data searches and report generation. Such searches and reports would require many man-hours to compile manually.

Table 2 provides a sample of HES's report generating capabilities. This is a summary report of the six states in the SWPA region. The report provides a breakdown of the number of projects within each state by dam status (With Power, Without Power, and Undeveloped sites). Totals for all states and dam status categories are also provided. It should be noted that the entire HES is menu driven and extremely user friendly.

Table 2. Sample hydropower capacity summary for Southwestern Power Administration

State	Category	Number of Projects	Name Plate Capacity (kW)	Potential Capacity (kW)
AR	With power	13	193450.00	174105.0000
	W/O power	28	378094.00	332448.6000
	Undeveloped	20	637559.00	230829.1000
	State Total	61	1209103.00	737382.7000
KS	With power	1	60.00	30.0000
	W/O power	12	52520.00	45028.0000
	Undeveloped	5	100000.00	38000.0000
	State Total	18	152580.00	83058.0000
LA	With power	0	0.0	0.0
	W/O power	14	77895.00	67245.5000
	Undeveloped	8	148135.00	133321.5000
	State Total	22	226030.00	200567.0000
MO	With power	6	115800.00	104220.0000
	W/O power	12	203356.00	180940.4000
	Undeveloped	11	377600.00	37760.0000
	State Total	29	696756.00	322920.4000
OK	With power	9	273940.00	178506.0000
	W/O power	18	78480.00	67676.0000
	Undeveloped	6	189990.00	78199.0000
	State Total	33	542410.00	324381.0000
TX	With power	23	55560.00	45504.0000
	W/O power	26	164218.00	139796.2000
	Undeveloped	40	1013905.00	833569.0000
	State Total	89	1233683.00	1018869.2000
Totals	With power	52	638810.00	502365.0000
	W/O power	110	954563.00	833134.7000
	Undeveloped	90	2467189.00	1351678.6000
Grand Total		252	4060562.00	2687178.3000

NATIONAL ENERGY STRATEGY

In June 1989, DOE initiated the development of a National Energy Strategy (NES). The DOE National Laboratories were convened to discuss plans for the development of a NES. As an outcome, assignments were made to interlaboratory teams to produce evaluations for each of the five energy supply resources (oil, gas, coal, nuclear and renewables).

The renewable energy document "The Potential of Renewable Energy—An Interlaboratory White Paper," is an evaluation of the present status of the renewable energy technologies and their potential contributions to the nation's energy requirements over the next four decades. Separate analytic white papers were prepared for each renewable technology. The Technology Characterization and Assessment White Paper for Hydropower included both conventional and pumped storage.

Public hearings were conducted as part of the NES process. Specific hydropower issues cited at the public hearings included:

- Rapid changes in both Federal and state regulatory policies negate or obfuscate developers' environmental studies, often while they are still in progress or after they have been completed.
- Witnesses emphasized that the licensing process for a major facility requires 3 to 5 years and has been growing, and, as a result, hydropower development is discouraged by increased project costs, increased uncertainty, increased lead times, and decreased profits.
- Existing projects subject to relicensing are threatened with reduced energy production, and in some cases shutdown, due to the enforcement of new environmental constraints. Approximately 630 non-Federal

hydroelectric projects with a total capacity of 21,200 MW will be relicensed by the Federal Energy Regulatory Commission (FERC) in the next 20 years.

- There has been little coordination among the various Federal and state agencies establishing environmental and engineering requirements for development and operation of hydropower projects.
- Environmental assessment methods are not sufficient for equitably comparing costs and the benefits achieved by mitigation requirements; no agency or organization is conducting the monitoring or the research necessary to make progress in this area.
- Due to the lack of research and consensus on instream flow, dissolved oxygen, and cumulative impact, there are no firm standards for evaluation of projects' impacts and for design of appropriate mitigation.
- There is a Federal perception that hydropower is a mature technology, thus not requiring Federal Research and Development which could stimulate engineering improvements, efficiency improvements, and advanced technology and materials, both for new plants and retrofit/upgrade of existing plants.

Independent analysis by DOE has been in substantial agreement with the NES testimony and with the NES report published in February 1991. DOE has initiated activities in the area of resource assessment, licensing and development impediments and environmental mitigation.

The DOE has established a team to reassess the hydropower resources that could be developed. This team is made up of representatives from

each Power Marketing Administration (Alaska Power Administration, Bonneville Power Administration, Western Area Power Administration, Southwestern Power Administration and Southeastern Power Administration), the Bureau of Reclamation, the Army Corps of Engineers, FERC, INEL, and ORNL. The preliminary assessment was completed in February 1990. The Resource Assessment Activity is continuing and discussed further in a separate section of this report.

In August 1990, DOE completed an analysis whose purpose was to: (1) identify regulatory and legislative impediments to non-Federal hydroelectric resources; (2) analyze the impacts of these impediments on the development of additional hydroelectric resources; and (3) suggest actions to eliminate or alleviate the adverse effects of these impediments of hydroelectric development. The study resulted in the identifica-

tion of priority areas where the licensing process could reasonably be improved to reduce licensing costs and encourage the responsible development of additional hydroelectric capacity as a vital source of cost-effective energy for the nation. The analysis was conducted as a collaborative effort by DOE, INEL, ORNL, and a number of other entities.

A Mitigation Study was initiated in May 1990 to evaluate environmental mitigation practices that are associated with the development of hydroelectric projects. The objectives of this study are: (1) to identify, compile, and analyze information on the implementation and monitoring of specific mitigation practices (instream flow needs, fish passage, and dissolved oxygen); and (2) to the extent possible, to quantify the costs, benefits, and effectiveness of these practices. The details of this project are covered in a separate section of this report.

TECHNOLOGY TRANSFER

The main objective of Technology Transfer is to transfer to industry and the public the experience gained, technology developed, and lessons learned from the DOE Hydropower Program.

Technology Transfer Activities

The general technology transfer activities during the last two years consisted of the following:

- Publishing reports on the active projects
- Publishing a Biennial Program Status Report
- Preparing white papers and articles
- Reviewing unsolicited proposals and new concepts
- Participating with the National Hydropower Association in the preparation of an industry guide
- Participating in hydropower workshops and conferences
- Responding to inquiries and issuing information and data upon request
- Distributing the Hydropower Computerized Reconnaissance Package.
- Participating with the Committee on Renewable Energy Commerce and Trade (CORECT) to promote the U.S. hydropower industry in foreign markets.
- Monitoring the environmental, technology and regulatory issues and the status of the industry

For further information concerning the DOE Small Hydropower Technology Transfer Program, contact:

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ENVIRONMENTAL RESEARCH

The Environmental Sciences Division at Oak Ridge National Laboratory (ORNL) provides technical assistance to DOE and carries out research on the environmental effects of hydropower development. In 1990–91 ORNL continued its environmental research on major issues critical to small hydropower development. The activities consisted of three areas: (1) the Environmental Mitigation Study, (2) the Hydropower Resource Assessment, and (3) technical support to DOE–HQ on regulatory and other institutional issues. Technology Transfer of the environmental expertise developed at ORNL is pursued through open–literature publications (see the Annotated Bibliography), intern training programs for students and faculty, and interactions with state and Federal regulatory agencies. Recent open–literature publications have dealt with the following subjects: instream flow and habitat requirements for fish, synthesis of stream flow records, relations between flow regimes and river channel geomorphology, water quality effects of hydropower development, and cumulative impacts of multiple projects. ORNL staff currently serve as technical advisors to the Electric Power Research Institute for their research project on downstream migrants and to Pacific Gas and Electric Company for their research on response of fish populations to altered flows.

The Environmental Mitigation Study is currently reviewing information on mitigation measures for dissolved oxygen, instream flows, and fish passage, and evaluating the effectiveness and costs of these measures. This study is a joint effort by ORNL and INEL. A major part of the study was the collection of information from hydropower developers on mitigation measures used at non–Federal projects. Information was obtained from approximately 320 of a total of approximately 700 projects that were identified *a priori* as having mitigation requirements of interest. Information on mitigation policies and relevant research was also obtained from state and Federal natural resource agencies, including one or more agency in each state and the regional offices of the U.S. Fish and Wildlife Service, the

U.S. Environmental Protection Agency, and the National Marine Fisheries Service.

A second part of the Environmental Mitigation Study is detailed analysis of case studies. Potential case study sites were identified; information on the sites was obtained; and methods for evaluating benefits of mitigation measures to aquatic life (e.g., fish growth modeling) were developed. As part of the methods we are developing to evaluate mitigation benefits, a bioenergetics model was modified to simulate fish growth in reaches of rivers that are affected by altered water quality below hydropower projects. This model will be used to quantify the response of fish resources to mitigation practices for dissolved oxygen.

A Draft Interim Report on the Environmental Mitigation Study was completed in June, 1991. The report summarizes current mitigation practices, using both statistical analyses of data provided by hydropower operators and case studies. Preliminary summaries of cost data were provided by INEL. Preliminary results indicate that the benefits of mitigation practices are largely unknown. The most common method for dissolved oxygen mitigation is the use of spill flows, which are costly because of lost power generation. Dissolved oxygen concentrations are commonly monitored, but biological benefits of this mitigation are not. At many projects, instream flow requirements have been set without use of formalized methods. Very few projects monitor fish populations to verify that instream flows are effective. Angled bar racks are the most commonly used mitigation practice for downstream fish passage, and fish ladders are the most common for upstream fish passage. Fish passage rates or populations have been monitored to verify the effectiveness of passage mitigation at few projects. This analysis is the first stage of an evaluation of the costs, benefits, and effectiveness of mitigation measures. A paper on this Environmental Mitigation Study, entitled “Review of Mitigation Methods for Fish Passage, Instream Flows, and Water Quality,” will be presented at

Waterpower '91 and published in the symposium's proceedings.

The research conducted at ORNL for the DOE Hydropower Program is integrated with other related research at the laboratory. Over the past decade, ORNL has been involved in a number of important projects for FERC related to hydropower licensing, the most recent of which is the cumulative impact assessment of hydropower development in the Skagit and Nooksack river basins in Washington. Other FERC projects included site-specific environmental impact statements (EISs) for such controversial projects as the El Portal and the Dynamo Pond projects in California, and basin-level cumulative impact studies, such as the Upper Ohio River EIS, where hydropower retrofits have been proposed at 19 existing locks and dams. ORNL also conducted a national study of the development of new hydroelectric resources as required by Section 8(d) of the Electric Consumers Protection

Act of 1986. This experience provides the basis for ORNL staff to continue providing sound technical guidance to DOE on environmental issues affecting hydropower development.

For further information concerning DOE-sponsored research on environmental issues in hydropower development, contact the following:

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ANNOTATED BIBLIOGRAPHY OF SMALL-SCALE HYDROPOWER PUBLICATIONS

The following are reports of interest to the hydropower industry. The reports with NTIS identification numbers can be purchased from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161, (703) 487-4650. Reports of DOE-sponsored projects or reports received on foreign exchange agreements can be ordered from Oak Ridge, Tennessee, instead of Springfield, Virginia.

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Telephone Orders—(703) 487-4650—The NTIS telephone sales desk is available between 7:45 a.m. and 6:00 p.m. Eastern Standard Time.

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For Help in Tracing an Order—If you have a problem with your order, write to the Customer Services office or call (703) 487-4660.

Technology Development

Idaho Falls, City Hydroelectric Power Plant: Preliminary Report, International Engineering Company, Inc., February 1978. NTIS No. ID0-10073.

This report documents the investigation and comparative evaluation of four alternatives for redeveloping the hydroelectric potential of the

stream flows at the City Plant, selection of the most suitable redevelopment alternatives, and evaluation of the existing environment and the environmental aspects of the recommended development.

Idaho Falls Hydroelectric Project, Preliminary Report, International Engineering Company, Inc., February 1978. NTIS No. IDO-10071.

This report includes a brief appraisal of the existing generation facilities and condition of the existing concrete structures; a geological reconnaissance of the Upper and Lower Plant Sites; an analysis of the power potential of the two sites; investigation and comparative evaluation of four alternatives for redeveloping the stream flows for power generation; selection of the most suitable alternative for development; and preparation of drawings and detailed quantity and cost estimates for the recommended development.

Idaho Falls Hydroelectric Project, Selection of Unit Size, International Engineering Company, Inc., October 1978. NTIS No. IDO-1699-2.

This report presents the studies that IECO made to select the unit size for the Idaho Falls Hydroelectric Project. The following factors were considered: water availability, estimated costs for furnishing and installing the units, the value of the power benefits established for the project, unit efficiencies, and estimated construction costs. The optimum turbine size was found to be 8.0 MW (6000 cfs discharge capacity), which would produce energy at a cost of 21 mil/kWh.

Idaho Falls Hydroelectric Project, Design Criteria, International Engineering Company, Inc., December 1978. NTIS No. IDO-1699-1.

This report presents the basic minimum design criteria and requirements for the civil and mechanical works of the Idaho Falls Hydroelectric Project.

Idaho Falls Hydroelectric Project, Project Definition Phase Report, International Engineering Company, Inc., February 1979. NTIS No. IDO-10078.

This report presents the results of the project definition phase of the Idaho Falls Low-Head Hydroelectric Demonstration Project. The project resulted in the redevelopment of three existing power plants on the Snake River in or near Idaho Falls, Idaho, using bulb turbogenerators. The project was partially funded by the U.S. Department of Energy, and will demonstrate that bulb turbine technology is an economically viable and environmentally acceptable means of developing new or upgrading old hydropower sites. The report also discusses benefits, costs, schedules, licensing, and financing of the project.

City of Idaho Falls Low-Head Hydroelectric Demonstration Project, Emergency Action Plan, Idaho Falls, Idaho, June 1982. NTIS No. DE-82021385 or DOE/RA/01699-T1.

This is the City of Idaho Falls' plan for action to be taken in case of failure of one of the three dams, or any combination of them, including all three. It gives details of warning methods, and describes the actions of personnel responding and directing action to ensure no life is lost and damage is kept minimal.

City of Idaho Falls Hydroelectric Demonstration Project, Final Technical and Construction Cost Report, Idaho Falls, Idaho, May 1983. NTIS No. DE-83013853 or DOE/RA/01699-4.

This is the final technical and construction cost report on Idaho Falls' hydroelectric plant project. Topics addressed include licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurement, construction costs, publicity, and photographs.

City of Idaho Falls Hydroelectric Demonstration Project, Final Operation and Maintenance Report, Idaho Falls, Idaho, May 1986. NTIS No. DOE/RA/01699-6.

The Final Operation and Maintenance Report on Idaho Falls' Hydroelectric Plant addresses summary of operation and maintenance activities, and costs for 3 years of operation.

Turlock Irrigation District Drop No. 1 Power Plant, Final Technical and Construction Cost

Report, Turlock Irrigation District, Turlock, California, January 1981. NTIS No. DE-83015148 or DOE/RA/23215.

The final technical and construction cost report on the Drop No. 1 Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Turlock Lake Powerhouse, Design Report and Operations Manual, Turlock, California, January 1981. NTIS No. DOE/RA/23215-2.

This report presents the design and operational criteria used by Turlock Irrigation District for their Drop No. 1 Plant.

Turlock Irrigation District Drop No. 1 Power Plant: Final Operation and Maintenance Report, Turlock, California, April 1983. NTIS No. DE-83013342 or DOE/RA/23215-3.

The final operation and maintenance report on Turlock Irrigation District's Drop No. 1 Plant addresses summary of operation, maintenance activities, costs, and revenues for the first 2 years of plant operation.

Goodyear Lake Hydroelectric Generation Station Redevelopment. Final Technical and Construction Cost Report, Milford, New York, October 1982. NTIS No. DOE/RA/23211.

This is the final technical and construction cost report on the Goodyear Lake Small-Scale Hydroelectric Project. Topics addressed include licensing and permits, environmental concerns, engineering and design, safety, material, equipment procurements, construction costs, publicity, and photographs.

Goodyear Lake Hydroelectric Generating Station Redevelopment, Second Annual Report, Milford, New York, October 1982. NTIS No. DE-83003156 or DOE/RA/23211-2.

This first-year operation and maintenance report addresses summary of operation, maintenance activities, costs, and revenues for the first year of operation.

Goodyear Lake Hydroelectric Generating Station Redevelopment, Second Annual Report, Milford, New York, October 1982. NTIS No. DE-83003156 or DOE/RA/23211-3.

This second-year operation and maintenance report addresses summary of operation, maintenance activities, costs, and revenues for the second year of plant operation.

Goodyear Lake Hydroelectric Generating Station Redevelopment, Final Operating Cost Report, Milford, New York, November 1982. NTIS No. DE-83004753 or DOE/RA/23211-4.

The final operation and maintenance report on Goodyear Lake addresses summary of operation, maintenance activities, costs, and revenues for 2 years of plant operation.

Sawmill Hydrostation Redevelopment, First Annual Report, Brown Company Engineering Department, Berlin, New Hampshire, November 1980. NTIS No. DOE/RA/23210-T-1.

The Brown-New Hampshire, Inc., annual report on the construction of a Sawmill Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurement, construction, publicity, and photographs.

James River-New Hampshire Electric, Inc., Sawmill Hydrostation Redevelopment, Final Report, Berlin, New Hampshire, August 1982. NTIS No. DE-83000446 or DOE/RA/23210-2.

The final technical and construction cost report on James River's Sawmill Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Sawmill Hydrostation Redevelopment, Final Operations and Maintenance Report, Berlin, New Hampshire, April 1984. NTIS No. DOE/RA/23210-3.

The final report on the operations and maintenance of the sawmill Hydroelectric Project addresses summary of operation, maintenance activities, costs, and revenues for 3 years of plant operation.

Riegel Textile Corporation, Fries, Virginia Plant Hydroproject, Final Technical and Construction Cost Report, Fries, Virginia, June 1982. NTIS No. DE82020698 or DOE/RA/23213.

The final technical and construction cost report on Riegel's Fries, Virginia, Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Fries Virginia Plant Hydroproject, First Annual Operating Report, Fries, Virginia, June 1983. NTIS No. DE-83016336 or DOE/RA/23213-2.

This first-year operation and maintenance report addresses summary of operation, maintenance activities, costs, and revenues for the first year of plant operation.

Fries Virginia Plant Hydroproject, Final Operating Report, Fries, Virginia, December 1983. NTIS No. DOE/RA/23213-3.

This is the final report on the operations and maintenance of the Fries Hydroelectric Plant. Topics addressed include summary of operation, maintenance activities, costs, and revenues for 2 years of plant operation.

Riegel Textile Corporation, Fries, Virginia, Plant Hydro Project, Trash Rake Drawings, July 1985. NTIS No. DOE/RA/23213-4.

Drawings and specifications for the trash rake built by Riegel Fries plant personnel.

South Consolidated Hydroelectric Project, Final Technical and Construction Cost Report, Mesa, Arizona (Salt River Project), October 1981. NTIS No. DOE-RA-23214.

The final technical and construction cost report on South Consolidated Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Salt River Project, South Consolidated Hydroelectric Generation Station, First Annual Operating Report, Mesa, Arizona, July 1983. NTIS No. DE-83015309 or DOE/RA/23214-1.

This first-year operation and maintenance report addresses summary of operation, maintenance activities, costs, and revenues for the first year of plant operation.

Salt River Project, South Consolidated Hydroelectric Generating Station, Final Operating Report, Mesa, Arizona, January 1984. NTIS No. DE-84006378 or DOE/RA/23214-2.

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Shawmut Hydroelectric Redevelopment Project, Final Technical and Construction Cost Report, Benton, Maine, August 1982. NTIS No. DE-82021007 or DOE/ID/12126.

The final technical and construction cost report on Central Main Power's Shawmut Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Shawmut Hydroelectric Redevelopment Project, Final Operation and Maintenance Report, Benton, Maine, June 1984. NTIS No. DOE/ID/12126-2.

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Project Design Criteria Manual: Upper Mechanicville Hydroelectric Redevelopment Project, Acres American Inc., for New York Electric & Gas Corporation, Binghamton, New York, December 1980. NTIS No. DOE/RA-12117.

This design criteria manual was used by the New York Electric & Gas Corporation to design their upper Mechanicville Hydroelectric Redevelopment Project.

Upper Mechanicville Hydroelectric Redevelopment Temporary Construction Emergency Action Plan, Mechanicville, New York, December 1981. NTIS No. DE-82007868 or DOE/RA/12117-2.

This emergency action plan presents standard procedures for personnel at the construction site if failure of cofferdam should occur.

Upper Mechanicville Hydroelectric Redevelopment Project, Project Management Plan, Mechanicville, New York, July 1982. NTIS No. DE-83009353 or DOE/RA/12117-3.

This project management plan for the New York State Electric & Gas (NYSEG) Mechanicville Hydroelectric Project addresses definition of project objectives, organizational composition of the management team, responsibilities of all participants in the project, project controls, and the required reports and meetings.

Upper Mechanicville Hydroelectric Redevelopment Project, Final Technical and Construction Report, Mechanicville, New York, July 1984. NTIS No. DOE-RA/12117-4.

The final technical and construction cost report on New York State Electric & Gas Company's Upper Mechanicville Hydroelectric Project addresses licensing and permits, environmental

concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Upper Mechanicville Hydroelectric Redevelopment Project, Final Operation and Maintenance Report, Mechanicville, New York, November 1985. NTIS No. DOE/RA/12117-5.

The Final Operation and Maintenance Report on New York State Electric and Gas Company's Upper Mechanicville Hydroelectric Project addresses summary of operation, maintenance activities, and costs for 2 years of operation.

Public Service Company of New Hampshire Drop No. 1 Power Plant Expansion of Garvins Falls Hydroelectric Plant, Final Technical and Construction Cost Report, Bow, New Hampshire, December 1982. NTIS No. DE-83007221 or 121221-T1 DOE/ID/121221-T1.

The final technical and construction cost report on Public Service Company of New Hampshire Garvins Falls Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Garvins Falls Hydroelectric Redevelopment Project, Final Operation and Maintenance Report, Bow, New Hampshire, January 1984. NTIS No. DE-84007793 or DOE/ID/12122-1.

The final report on the operation and maintenance of the Garvins Falls Hydroelectric Plant addresses summary of operation, maintenance activities, costs, and revenues for 2 years of plant operation.

Garland Canal Shoshone Irrigation District Hydroelectric Project, Final Technical and Construction Cost Report, Powell, Wyoming, March 1984. NTIS No. DOE/ID/12129.

The final technical and construction cost report of Shoshone Irrigation District's Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment

procurements, construction costs, publicity, and photographs.

Garland Canal Shoshone Irrigation District Hydroelectric Project, Final Operation and Maintenance Report, Powell, Wyoming, October 1985. NTIS No. DOE/ID/12129-1.

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Green Mountain Power Corporation Bolton Falls Hydroelectric Redevelopment, First Annual Report, Burlington, Vermont, March 1981. NTIS No. DOE/RA/232121-T1.

The Green Mountain Power Corporation's first annual report on redevelopment of the Bolton Falls Hydro Site addresses summary of major events, project status, expenditures, schedules, costs, management organization, and photographs.

Green Mountain Power Corporation Bolton Falls Hydroelectric Redevelopment, Final Technical and Construction Cost Report, Burlington, Vermont, 1987. NTIS No. DOE/RA/232121-2.

The final technical and construction cost report of Green Mountain Power Corporation's Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Green Mountain Power Corporation Bolton Falls Small-Scale Hydroelectric Power Demonstration Project, Final Operation and Maintenance Report, Burlington, Vermont, July 1989. NTIS No. DOE/ID/23212-4.

The final operation and maintenance report on the Bolton Falls Hydroelectric Facility addresses summary of operation, maintenance activities, and costs for 2 years of operation.

City of Tallahassee, Florida, Small-Scale Hydroelectric Power Demonstration Project, Emergency Action Plan, Tallahassee, Florida, May 1984. NTIS No. DOE/ID/12128.

This City of Tallahassee's plan for action to be taken in case of dam failure gives details of warning methods and describes the actions of personnel responding and directing action to ensure that no life is lost and damage is kept minimal.

City of Tallahassee, Florida, Small-Scale Hydroelectric Power Demonstration Project, Final Technical and Construction Cost Report, Tallahassee, Florida, September 1986. NTIS No. DOE/ID/12128-1.

The final technical and construction cost report of the City of Tallahassee, Florida Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, material and equipment procurement, construction costs, publicity, and photographs.

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The final operation and maintenance report on the Jackson Bluff Hydroelectric Facility addresses summary of operation, maintenance activities, and costs for 2 years of operation.

City of Spokane, Washington, Small-Scale Hydroelectric Power Demonstration Project, Final Technical and Construction Cost Report, Spokane, Washington, December 1984. NTIS No. DOE/ID/12118.

The final technical and construction cost report on the City of Spokane, Washington, Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

City of Spokane, Washington, Small-Scale Hydroelectric Power Demonstration Project,

Final Operation and Maintenance Report, Spokane, Washington, April 1988. NTIS No. DOE/ID/12118-1.

The final operation and maintenance report on the City of Spokane Hydroelectric facility addresses summary of operation and maintenance activities, and costs for 2 years of operation.

City of Spokane, Washington, Small-Scale Hydroelectric Power Demonstration Project, Rehabilitation After Dam Failure Report, Spokane, Washington, October 1987. NTIS No. CONF-8708124.

The rehabilitation after dam failure report on the City of Spokane Hydroelectric facility addresses summary of construction activities of both the old and new plant.

City of Gonzales, Texas, Small-Scale Hydroelectric Power Demonstration Project, Final Technical and Construction Cost Report, Gonzales, Texas, January 1985. NTIS No. DOE/ID/12121-T2.

The final technical and construction cost report on the City of Gonzales, Texas, Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

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Reactivation of the Elk Rapids Hydroelectric Facility, Final Technical and Construction Cost

Report, Antrim County, Michigan, May 1985. NTIS No. DOE/RA/23209.

The final technical and construction cost report on Antrim County, Michigan, Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Reactivation of the Elk Rapids Hydroelectric Facility, Final Operation and Maintenance Report, Antrim County, Michigan, May 1987. NTIS No. DOE/RA/23209-1.

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Boott Hydropower, Lowell Hydroelectric Project, Final Technical and Construction Cost Report, Lowell, Massachusetts, 1987. NTIS No. DOE/ID/12124.

The final technical and construction cost report on Boott Hydropower, Lowell Small-Scale Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Boott Hydropower, Inc., Lowell, Massachusetts, Small-Scale Hydroelectric Power Demonstration Project, Final Operation and Maintenance Report, Lawrence, Massachusetts, March 1988. NTIS No. DOE/ID/12124-2.

The final operation and maintenance report on the Lowell, Massachusetts, Boott Hydropower, Inc., Hydroelectric facility addresses summary of operation, maintenance activities, and costs for 2 years of operation.

City of Paterson, New Jersey, Great Falls Small-Scale Hydroelectric Demonstration Project, Final Technical and Construction Cost Report, Paterson, New Jersey, 1987. NTIS No. DOE/ID/122127.

The final technical and construction cost report on City of Paterson, New Jersey, Great Falls Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

City of Paterson, New Jersey Great Falls Small-Scale Hydroelectric Power Demonstration Project, Final Operation and Maintenance Report, Paterson, New Jersey, September 1989. NTIS No. DOE/ID/12127-2.

The final operation and maintenance report on the City of Paterson, New Jersey/Independent Hydro Developers Hydroelectric facility addresses summary of operation, maintenance activities, and costs for 2 years of operation.

Broad River Electric Cooperative, Inc., Cherokee Falls Small-Scale Hydroelectric Demonstration Project, Final Technical and Construction Cost Report, Gaffney, South Carolina, 1987. NTIS No. DOE/ID/12125.

The final technical and construction cost report on Broad River Electric Cooperative, Inc., Cherokee Falls Hydroelectric Project addresses licensing and permits, environmental concerns, engineering and design, safety, material and equipment procurements, construction costs, publicity, and photographs.

Broad River Electric Cooperative, Inc., Cherokee Falls Small-Scale Hydroelectric Power Demonstration Project, Final Operation and Maintenance Report, Gaffney, South Carolina, August 1988. NTIS No. DOE/ID/12125-2.

The final operation and maintenance report on the Broad River Cooperative, Inc., Hydroelectric facility addresses summary of operation, maintenance activities and costs for 2 years of operation.

**PA Hydroelectric Development Corporation, Flat Rock Dam Small-Scale Hydroelectric Power*

Demonstration Project, Project Summary Report, Philadelphia, Pennsylvania, October 1990. NTIS No. DOE/ID-12130.

The final summary report presents an overview of what a developer has to go through to obtain a license for a small hydroelectric facility.

**Rinehart, B. N., Department of Energy Small-Scale Hydropower Program Feasibility Assessment and Technology Development Summary Report*, Idaho National Engineering Laboratory, June 1991. NTIS No. DOE/ID-10322.

The purpose of this report is to present an overview of two subprograms of the U.S. Department of Energy Small-Scale Hydroelectric Power Program. These subprograms are the Program Research and Development Announcement (PRDA) Feasibility Assessments of which there were 55 and the program opportunity notice (PON) Technology Development Projects (formerly known as the Demonstration Projects) of which there were 20. The Feasibility Assessment program initiated by DOE, received and considered for support, proposals adding hydroelectric generation capacity to existing dams. This PRDA was for adding hydroelectric generation capacity of between 15 kW and 50 MW to existing dams with heads of <20 m. Individuals, corporations, companies, educational institutions, nonprofit and not-for-profit institutions and others, including state and local governments, but not federal agencies, individually or as proposed project teams, who desired to have their hydroelectric feasibility analysis considered by DOE, responded to this PRDA. Two hundred fourteen responses were received, but only 55 received awards. These sites were selected to provide widespread geographical distribution, as well as a variety of water resources, hydroelectric power capacities, and dam or diversion structures. The assessments from these 55 sites were used to encourage development of renewable resources for power generation, which provided engineering, economic, environmental, safety, and institutional information. Under the PON, 19 proposals

* An asterisk (*) before the title indicates the publication has been added to the Bibliography in this biennial report.

of the 89 submitted were awarded cooperative agreements. DOE participated in a sharing program for each project. The objectives of the Technology Development Program were: to use available technology in demonstrating the economic viability of small hydroelectric power; to identify engineering, economic, environmental, and institutional aspects associated with small-scale hydropower development; and to disseminate data on the construction and maintenance of these facilities.

Resource Assessment

Hydroelectric Power Resources of the United States, Developed and Undeveloped, FERC, January 1, 1984, FERC-0070.

This report presents data as of January 1, 1988, on the capacity, generation, and other characteristics of the developed and undeveloped hydroelectric power resources of the United States.

Hydroelectric Power Resources of the United States, Developed and Undeveloped, FERC, January 1, 1988, FERC-0070.

This report presents data as of January 1, 1988, on the capacity, generation, and other characteristics of the developed and undeveloped hydroelectric power resources of the United States.

*Francfort, James E., Scott D. Matthews, and Bennie Rinehart; *Uniform Criteria for U.S. Hydropower Resource Assessment*, EG&G Idaho, Inc., May 1991. DOE/ID/10338.

National Hydroelectric Power Resources Study, U.S. Army Corps of Engineers, May 1983. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (202) 783-3238 or -3311.

This plan identifies a set of best-candidate sites for future study of hydroelectric power potential. The plan includes both Federal and non-Federal sites. The final report comprises the following 23 volumes:

Volume	Title	GPO Number
I	Executive Summary	008-022-00212-0
II	National Report	008-022-00213-8
III	1978 Electric Power Demand and Supply	008-022-00198-1
IV	Future Electric Power Demand and Supply	008-022-00199-9
V	Legal and Institutional Aspects of Hydroelectric Power Development and Operation	008-022-00190-5
VI	A Review of Economic Criteria for Federal Hydroelectric Power Projects	008-022-00193-0
VII	Marketing and Transmission of Hydroelectric Power	008-022-00208-1
VIII	Environmental Assessment	008-022-00209-0
IX	Potential for Increasing the Output of Existing Hydroelectric Plants	008-022-00191-3
X	An Assessment of Hydroelectric Pumped Storage	008-022-00194-8

* An asterisk (*) before the title indicates the publication has been added to the Bibliography in this biennial report.

Volume	Title	GPO Number
XI	Technology Assessment of Hydroelectric Power Development	008-022-00195-6
XII	Data Base Inventory	008-022-00196-4
XIII	Data Base Inventory Support Studies	008-022-00171-2
XIV	Northeast Power Coordinating Council	008-022-00171-9
XV	Mid-Atlantic Area Electric Reliability Coordination Agreement	008-022-00172-7
XVI	Southeastern Electric Reliability Council & Puerto Rico	008-022-00173-5
XVII	East Central Area Reliability Coordination Agreement	008-022-00177-8
XVIII	Mid-American Interpool Network	008-022-00179-4
XIX	Mid-Continent Area Reliability Coordination Agreement	008-022-00174-3
XX	Southwest Power Pool	008-022-00175-1
XXI	Electric Reliability Council of Texas	008-022-00176-0
XXII	Western Systems Coordinating Council	008-022-00180-8
XXIII	Alaska and Hawaii	008-022-00178-6

Hydro and Electric Resources of the United States National Hydropower Association (NHA), 1989. For sale by NHA 11332 1st Street, N.W. Suite 500 Washington, D.C. 20036 (202)331-7551.

Engineering Research and Development

Wayne, W. W., Jr., *Tidal Power Study for the United States Energy Research and Development Administration*, 2 vols., Stone & Webster Engineering Corporation, Boston, Massachusetts, March 1977. NTIS No. DGE-2293-3 V.I and DGE/2293-3 V.2.

This report discusses the potential of tidal energy as a world power source, especially two sites in the United States where tidal power could be utilized. It considers research opportunities that could reduce the costs of tidal power stations, making them more competitive as a national energy source. It also lists environmental, socie-

tal, and legal consequences (both positive and negative) of building a major power plant.

VerPlanck, W. K. and W. W. Wayne Jr., *Report on Turbogenerating Equipment for Low Head Hydroelectric Developments*, Stone and Webster Engineering Corporation, Boston, Massachusetts, April 1978. NTIS No. IDO-1962-1.

This report summarizes the selected turbogeneration equipment suitable for low head hydroelectric plants, using information from the Stone and Webster Corporation files (particularly for the Rock Island Hydroelectric Project) and from visits to manufacturers' laboratories and to other hydroelectric plants. The following types of hydraulic turbogenerator systems are discussed: Alstom-Neyrpic bulb turbines, Ossberger cross-flow turbines, Escher Wyss Straflow Turbines, Barber Mini-Hydel turbines, and the Allis-Chalmers series of standard tube turbines.

Alward, R., S. Eisenbart, and J. Volkman, *Micro/Hydropower, Reviewing an Old Concept*, National Center for Appropriate Technology,

Butte, Montana, January 1979. NTIS No. DOE/ET/01752-1.

This is a simple introduction to all aspects of micro/hydropower, defined here as less than 100-kW output. It describes a variety of unit types and discusses many considerations, for example, economics, financing, legal, and institutional requirements. A resource directory of additional information is included.

Fric, P.A., and G. C. Alexander, *Cost of Controls for Small Hydroelectric Plants or River Systems, Final Report*, Department of Electrical and Computer Engineering, Oregon State University, February 1979. NTIS No. DOE/ET/28310-1.

This technical paper is written for engineers and system scientists familiar with hydroelectric plants and control theory. It addresses the following topics mathematically: dam dynamics, flow control through propeller turbines, onsite head-generation control, and complete mathematical dam models.

Schneider, D. J., et al., *Schneider Lift Translator System, Low Head Hydro Feasibility Study Final Report*, Schneider Lift Translator Co., March 1979. NTIS No. DOE/RA/01693-T1.

This report covers the results of three tasks performed on the Schneider engine to demonstrate technical feasibility. Task 1 established basic design criteria for a prototype and probable costs of the engine when placed in production. Task 2 tested a state-of-the-art model to evaluate designs of guide vanes, establish efficiencies, and refine cost projections. Task 3 resulted in the construction and testing of a prototype model based on a design to be installed at a canal drop.

Small/Low Head Hydropower PRDA-1 706 Feasibility Assessments, Executive Summaries, Idaho National Engineering Laboratory, EG&G Idaho, Inc., P.O. Box 1625, Idaho Falls, Idaho, May 1979. NTIS No. DOE/ID/01570-1.

These executive summaries are 59 of the 54 feasibility assessments performed under U.S.

DOE's Program Research and Development Announcement (PRDA-ET-78-D-07-1706).

Small/Low Head Hydropower PRDA-1706 Contractors' Symposium, Albany, New York, May 8-10, 1979. NTIS No. CONF-7905154.

The proceedings covers both the remaining five of 54 feasibility assessments performed under DOE's Program Research and Development Announcement (PRDA-ET-78-D-07-1706) and the presentations of the symposium. Papers are on regional planning, FERC licensing and status, feasibility studies and their costs, and specific sites.

Mueller, B. L., *Feasibility Determination for Hydroelectric Development at Thermalito Afterbay with STRAFLOW Turbine Generators, Final Report*, Aerojet Manufacturing Company, Fullerton, California, June 1979. NTIS No. DOE/ID/01817-2.

The report summarizes the results of an independent study conducted under a cost sharing contract with the U.S. Department of Energy by Aerojet Manufacturing Company, International Engineering Company, Inc., and Sulzer Brothers, Inc., to determine the technical and economic feasibility of developing the hydroelectric potential of the Thermalito Afterbay discharge. The study shows the site to have a flow rate of from 0 to 18,000 cfs with an average of 3934 cfs, and a head of approximately 27 ft. The proposed hydro-plant would consist of two American-built Straf-flow turbines, using 6500 cfs of flow at 27.3 ft of head, with 13,250 kW of capacity. The annual energy would be 48.82 GW at a cost of approximately 42 mill/kWh.

Fouad, A. A. et al., *Effect of Reduced Inertia on the Transient Stability of a Power System, Final Report*, 2 vols., Engineering Research Institute, Iowa State University, August 1979. NTIS No. PB-300 912/3 or Report No. ISU-ERI-AMES-80026.

This report examines the influence of significant amounts of low head hydro generation (low inertia machines) on the transient stability of an

existing power system. A simplified power system was selected for this computer study consisting of three generators, nine buses, three loads, and the transmission network connecting them. A fourth generator represented the remote low-inertia generation. The study was performed for the U.S. Department of Interior, Bureau of Reclamation contract No. 9-07-83-V0711 and U.S. Department of Energy Agreement EG-77-36-1024.

Low Head Hydro—An Examination of an Alternative Energy Source, compiled by John S. Gladwell and Calvin C. Warnick, University of Idaho, September 1979. NTIS No. ID0-1735-1.

This is a compilation of the papers delivered at a seminar, "Low Head Hydroelectric Technology—Problems and Opportunities of an Alternative Energy Source," held at the University of Idaho on June 6 and 7, 1978. The papers were divided into six categories: (a) An Overview, (b) Economics, (c) Low Head Turbines, (d) The Government Presence, (e) The Environment, and (f) Surveys of Energy Potential.

Beckwith, R. W., *Suggested Performance Specifications of Standard Modular Controls for the Automation of Small Hydroelectric Facilities*, June 1980. NTIS No. DOE-ID/01570-2.

This report discusses the automation of a typical small hydroelectric site. It provides recommended guidelines for automation of such a facility, including the use of microprocessors, fiber optics, distributed station batteries, and the use of Pascal computer language.

Half Moon Cove Tidal Project, Feasibility Report, Chas T. Main Inc., Boston, Massachusetts, November 1980. NTIS No. DOE/ID/12089-T1.

This is the feasibility study of the Half Moon Cove Tidal Power Project proposed for a small cove in the northern part of Cobscook Bay in the vicinity of Eastport, Maine. The study addresses technical, economic, legal, and environmental aspects of the proposal. Tides at Half Moon Cove

range from a maximum spring of 26.2 ft to a near tide of 12.8 ft. Using these tides, it was determined that two 6 MW units could produce an annual energy of 37 million kWh at a cost of 78 mill/kWh.

Small Hydro Plant Development Program, Vol. 1. Text, Acres American, Inc., October 1980. NTIS No. DE-81023052 or DOE-ID-01570-T21(V.1).

Small Hydro Plant Development Program, Vol. 2. NTIS No. DOE/ID/01570-T21(V.2) App. A-K or ID0-110094V2 App. A-K.

Small Hydro Plant Development Program, Vol. 3. NTIS No. DE-81023060 or DOE/ID/01570-T21(V.3) App.L.

This study investigated the feasibility of using off-the-shelf design pumps in the turbine mode and induction motors as generators in a representative range of small hydroplant projects. A survey of available pumps revealed that on a single-unit basis, and under the most efficient operating conditions, equipment is available for plants with capacities from 180 to 6800 kW and heads in the range of 20 to 370 ft. Capital cost savings of up to 50% may be achieved over conventional units. However, the efficiencies are generally lower, requiring a life-cycle cost analysis to get the true economic viability.

Modular Hydro-Dam Concept Definition Study, Gilbert Associates, Inc., July 1981. NTIS No. DE-82000113 or DOE/ID/12207-T1.

This study explored the potential for developing economical new ultra-low head sites using the modular hydro-dam concept. The concept would use truck-transportable power modules and cable-supported fabric dams.

Feasibility of a Small Scale Pumped Storage Demonstration Project, Hibbing, Minnesota, James Hansen and Associates, Springfield, Vermont, for Hibbing Public Utilities Commission, July 1981. NTIS No. DE-81028678 or DOE/TIC-1028678.

This feasibility study is of a small pumped storage hydropower plant that would utilize abandoned iron mine pits for the water storage reservoirs. Six alternatives were studied, which include gas turbine and diesel plants, as well as pumped storage hydro. Both economic and environmental benefits are considered after the technical evaluation is completed.

Design of Low Cost, Ultra-Low Head Hydropower Package Based on Marine Thrusters Final Report, Energy Research and Applications, Inc., Santa Monica, California, August 1981. NTIS No. DE-82004813 or DOE/ID/12201-T1.

The use of marine thrusters operated as turbines is examined as a means to reduce the cost of low head hydroplants. Equipment costs were estimated at approximately \$260/kW for units between 40 kW and 630 kW capacity, operating at 6 to 15 ft of head. Comparative concept designs at the feasibility study level of detail, using marine thruster packages or conventional hydropower equipment, indicate installed cost savings of 50 to 60% for the thrusters.

Mayo, Jr., Howard A., *Powerhouse Gate: Concept Definition Study*, Allis-Chalmers Corp., November 30, 1981. NTIS No. DE-82006226 or DOE/ID/12200-T1.

A study was made of the dual use of flood gate spaces for both power plants and flood flow passages. A powerhouse gate was designed that would fit in the space of an existing dam flood-gate. The unit would be used to generate power during periods of normal flow but be hoisted to permit water flow beneath it during floods. The report addresses structural design, cost estimates, and applicability of the concept.

Radkey, Robert L., and Bart D. Hibbs, *Definition of Cost-Effective River-Turbine Designs Final Report*, September 30, 1980–December 31, 1981, AeroVironment Inc., December 1981. NTIS No. DE-82010972 or AV-FR-81/595.

Two system concepts were evaluated in this study: (a) a ducted turbine system and (b) a free-

rotor system. The ducted turbine uses an augmentor duct to increase flow through the turbine rotor, and the free-rotor system is essentially an underwater windmill. It was concluded that both ducted and free-rotor turbine systems can produce cost-effective electricity. Energy cost estimates for both systems (10-ft diameter) indicate that either could produce energy at less than 50 mill/kWh.

Truebe, J., and M. Prooker, *Modular Innovations in Upstream Fish Passage*, Lakeside Engineering. NTIS No. DE-82010268 or DOE/ID/12207-T2.

This study examines two specific aspects of upstream fish passage design and operation: (a) the incorporation of modular components and structural elements into historically proven passage designs, and (b) the appropriate integration of water saving (and hence energy saving) techniques and hardware into the fish passage designs.

Float-In Module for Retrofitting Navigation Dams for Power Generation. Volume I. Feasibility Report, Albert H. Halff Associates, Inc., January 1982. NTIS No. DE-82010719 or DOE/ID/12161-T2(V.1).

Float-In Module for Retrofitting Navigation Dams for Power Generation. Volume II. Structural Drawings. NTIS No. DE-82010936 or DOE/ID/12161-T1(V.2).

This feasibility study investigated the concept of retrofitting navigation dams on inland waterways with powerhouses by use of prefabricated, standardized powerhouse modules that could be constructed elsewhere and floated into place. Twelve navigation dams in the Arkansas River Navigation System were used to evaluate the concept. Economic analyses based on the preliminary designs of the float-in plants showed the main benefit from the technique to be reduced construction time and associated costs.

Cooper, Paul, and Richard Worthen, *Feasibility of Using Large Vertical Pumps as Turbines for Small-Scale Hydropower, Final Technical*

Report, Ingersoll Rand Research, Inc. NTIS No. DE-82004267 or DOE/ID/12160-T1.

The object of the project was to establish the economic and technical feasibility of operating pumps as turbines in small-scale hydropower plants. The economics were shown to be competitive; 87% turbine efficiencies were obtained in actual tests.

McCullough, John E., and John T. Dieckmann, *Demonstration of Scroll Motor Advantages for Ultra-Low Head Hydroelectric Power Generation, September 1980–November 1981 Final Report*, Arthur D. Little, Inc., February 1982. NTIS No. DE-82009792 or DOE/ID/12202-T1.

This effort consisted of analytical and hardware development leading to the design, fabrication, and testing of a laboratory model scroll hydraulic motor. The purpose was to investigate the potential advantages of this scroll motor as a turbine in an ultra-low head hydroelectric power plant. The model scroll motor was designed, built, and tested at heads up to 10 ft and speeds up to 270 rpm. The maximum model output shaft power was 400 W. The maximum efficiency obtained was between 30 and 40%. The low efficiency was attributed to internal leakage and friction in the speed increasing gear box.

Rothbart, G., and R. Fullwood, *Development of a Variable Shaft Speed Alternator*, Science Applications, Inc., February 1982. NTIS No. DE-82012334 or DOE/ID/12203-T1.

The development of a variable speed alternator, with output voltage and current synchronized and phase-locked to the power grid, is reported. The variable shaft speed alternator consists of an ordinary unmodified wound-rotor motor, with polyphase excitation controlled by solid state switching and a hybrid of analog and digital circuitry. This circuitry senses both shaft speed and line phase resulting in logic levels that control the current flow in each rotor coil. The laboratory unit was tested under no load, nearly-resistive passive load, and power and power grid load conditions. Efficiencies were measured for converting mechanical power to electrical over a wide

range of shaft speeds. The unit was found to be capable of producing power at speeds down to 37% of synchronous speeds.

Rice, Warren, *Hydraulic Air Compressor as Part of an Ultra-Low Head Hydropower System, Final Report*, January 1, 1981–December 31, 1981. Arizona State University, May 1983. NTIS No. DE-82018428 or DOE/ID/12198-13.

Analytical and experimental research was conducted to advance design and application tools, and to gather information concerning the hydraulic air compressor (HAC) for use in ultra-low head hydropower systems. An existing analytical model was significantly improved and an experimental HAC was constructed, instrumented, and tested. A computer program was used to calculate and tabulate the applied head, water and air flow rate, depth, pressure, compressor size, and geometrical relationships. A preliminary design of a HAC hydropower plant was made and the cost study of a typical site is presented.

Chappell, J. R., et al., *Pumps-as-Turbines Experience Profile*, EG&G Idaho, Inc., September 1982. NTIS No. DE-83001143 or IDO-10109.

The report presents the results of a survey of owners, operators, consultants, engineering firms, and manufacturers to collect information on their experience in the use of pumps operating in reverse as turbines. The survey consisted of literature searches, telephone calls, questionnaires to selected individuals, conferences with consultants, and site visits. Information is presented on the types of pumps used, the methods of estimating their performance, modifications required, actual results of field tests if available, economics, operation and maintenance, methods used for control, and sources for hardware and engineering assistance.

Liu, Henry, and Michael Fesschaye, *Theoretical and Experimental Investigation of the Cherepnov Water Lifter*, University of Missouri-Columbia, January 1983. NTIS No. DE-83007673 or DOE/ID/12206-1.

The Cherepnov lifter is a device that extracts energy from the flow of water at one head and uses the energy to lift a portion of the water to a higher head. Such a lifter can be used in hydroelectric power generation to increase the head and allow the use of smaller, less expensive turbines and powerhouses. The research reported consists of a theoretical analysis, including the derivation of equations and setting up computer models, and later experimental tests verifying the derived equations and computer models, as well as providing information that could not be obtained from theory. A later phase of the project is reported in *The Economics of Cherepnov Water Lifter*, DOE Report No. DOE/ID/12206-2.

Liu, Henry, and Richard GeeKie, *Economics of Cherepnov Water Lifter for Low Head Hydropower*, University of Missouri-Columbia, January 1983. NTIS No. DE-83007639 or DOE/ID/12206-2.

This report documents an economic analysis of the use of the Cherepnov water lifter to increase the head and decrease the flow, allowing the use of low-cost turbines and powerhouses in low head hydropower plants. The economics of the Cherepnov lifter for use as a pump to supply water is very good for both small and large systems, even in places where electricity is available for pumps. However, the economics of using the lifter for hydroelectric power generation is not good, especially for large and high head systems. The lifter may still be economically viable in micro hydro-power low head systems where low-cost tanks are available and PVC pipes can be used. Earlier technical studies of the Cherepnov lifter are documented in *A Theoretical and Experimental Investigation of the Cherepnov Lifter*, DOE Report DOE/ID/12206-1.

Moses, Hal L., et al., *Optimization of a Diffuser/Ejector for Ultra-Low Head Hydroelectric Systems, Final Report*, Virginia Polytechnic Institute and State University, March 1983. NTIS No. DE-83011251 or DOE/ID/12208-T1.

This study investigated head augmentation for ultra-low head hydroelectric systems by use of an

ejector in the draft tube. A detailed analytical and experimental study was conducted of the flow in a conical diffuser with a peripheral wall jet. The results were then used to design and test a small laboratory model of an axial-flow turbine. The tests indicated an appreciable increase in head could be achieved and predicted by the analysis. Under certain circumstances with excess flow available, the increase in head would result in a significant decrease in turbine size and cost for a fixed power. However, for limited flow, the head increase would decrease the output power and give no economic advantage.

Microhydropower Handbook. Volume 1. EG&G Idaho, Inc., January 1983. NTIS No. DE-83006697 or IDO-10107(V.1).

Microhydropower Handbook, Volume 2. NTIS No. DE-83006698 or IDO-10107(V.2).

This handbook defines microhydropower as hydropower produced in quantities of 100 kW or less. The handbook is written so that a lay person with mechanical aptitude will have sufficient information to evaluate site potential, lay out a site, select and install equipment, and operate and maintain the completed system. Volume 1 establishes a foundation for the engineering principles, leads the individual through design, construction, and operation, and provides information on obtaining financing and licensing. Volume 2 is the appendix volume containing supplementary information, Federal and State agencies and their addresses, a glossary, and useful forms.

Test of Ossberger Cross-Flow Turbine of Bradford Hydroelectric Station, F.W.E. Stapeshorst, Inc., Bradford, Vermont, October 1983. NTIS No. DE-84007079 or DOE/ID/12314-T3.

This report covers the analysis of the efficiency test data of the 708 Shaft HP Ossberger cross-flow turbine at Central Vermont Public Service Company's Bradford Station.

Chappell, J. R., *Hydropower Hardware Descriptions*, EG&G Idaho, Inc., Idaho Falls,

Idaho, February 1984. Presented at Small Hydropower Workshop, University of Missouri-Columbia, April 1984. NTIS No. DE-84011614 or EGG-M-09384.

This report discusses the differences in 11 types of turbines. Their characteristics are tabulated, and their operating ranges and geometry are illustrated by use of graphs and drawings. The primary conventional types are discussed, as well as the new or nonconventional types researched by DOE.

Chappell, J. R., *New Technology for Small Hydropower Installations*, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho, April 1984. NTIS No. DE-84011180 or EGG-M-09184.

This paper is a general discussion of new technologies, including hardware and methodologies, that may be used in developing small hydropower installations. The primary source of information is the results of the R&D projects funded under the DOE Small Hydropower Program. The paper is divided into the following categories: turbine/generator, head augmentation, nonconventional concepts, structure and construction, system management, controls, and reconnaissance and feasibility.

Chappell, J. R., *Future of Hydropower*, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho, April 1984. Presented at the Small Hydropower Workshop, University of Missouri-Columbia, April 1984. NTIS No. DE-84011452 or EGG-M-09284.

This paper discusses the history, current status, and resource potential, as well as impediments and factors, favoring hydropower development in the United States. Future hydroelectric capacity is estimated from FERC permit and license applications, and from several private and government agency projections.

Chappell, J. R., *Recent DOE-Sponsored Hydropower Engineering Research*, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho, September 1983. Pres-

ented at the *Waterpower 1983 International Conference on Hydropower*, Knoxville, Tennessee, September 1983. NTIS No. DE-84000809 or EGG-M-02983.

This paper provides an overview of U.S. DOE Engineering Development Research activity since Waterpower 1981. General results of 11 projects that have been completed since Waterpower 1981 are presented and compared. Continuing efforts are also described briefly. DOE has sponsored four projects dealing with the use of pumps as turbines. This approach results in capital cost savings, shorter time for completing a hydropower plant, wider variety of off-the-shelf equipment available, and better maintenance services. Results are summarized for feasibility studies, laboratory tests, and in-the-field experience surveys of the use of pumps as turbines. Other projects discussed include microhydropower plants (less than 100 kW in capacity), head augmentation devices, Schneider engines, the use of marine thrusters as turbines, low cost cross-flow turbines made of plastic, variable speed constant frequency generators, hydraulic air compressors, scroll motor turbines and modular float-in powerhouses. The paper also discusses some of the technologies where future research may prove fruitful.

Chappell, J. R., and M. J. McLatchy, *DOE Small-Hydropower Engineering Development Program Overview*, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho, and U.S. DOE Idaho Operations Office, Idaho Falls, Idaho, June 1983. Presented at American Nuclear Society Annual Meeting, Detroit, Michigan, June 1983. NTIS No. DE-83015127 or EGG-M-01983.

This paper discusses the 35 small hydropower engineering development projects funded by U.S. DOE. Results to date indicate that some of the concepts will significantly reduce the capital cost, and will reduce the time to get a plant on-line by nearly a factor of two.

Haroldsen, R. D., and F. B. Simpson, *Micro Hydropower in the United States*, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho, June 1981. Presented at the

Waterpower 1981 Conference Washington, D.C. NTIS No. DE-81028271 or EGG-M-02701.

An assessment study of the interest and problems relating to the development of micro hydropower, i.e., capacities of less than 100 kW, was completed in December 1980 under DOE sponsorship. A total of 62 individuals from 10 states and four groups, i.e., developers, A/E firms, equipment manufacturers, and State and Federal agencies, were polled to determine their perceptions of the advantages and disadvantages of micro-hydro developments and the needs for such developments. Financing, technical assistance, and help with the economic analysis and regulatory aspects of micro-hydro development appeared to be the paramount needs. Whether or not a specific site can be successfully developed depends on site conditions. A micro-hydro plant discussed as an example is shown to be a poor investment (e.g., maximum \$200 per month return on \$60,000 investment).

Application of Marine Thrusters as Ultra-Low Head Hydroturbines—Test Report, Energy Research and Applications, Inc., Santa Monica, California, January 1984. NTIS No. DE-84013096 or DOE/ID/12201-T3.

This report presents the results of the field test of a hydropower plant utilizing a marine thruster for a turbine at the Modesto Irrigation District. The unit used 386 cfs of water at 13 ft of head to produce 235 kW. The cost of the thruster package was \$343/kW of installed capacity.

Field Test of Ultra-Low Head Hydropower Package Based On Marine Thrusters—Final Report, Energy Research and Applications, Inc., Santa Monica, California, December 1983. NTIS No. DE-84013685 or DOE/ID/12201-T2.

The report is the final report on the design, construction, equipment procurement, installation, and site modeling for a hydropower plant using a marine thruster as a turbine. The installation was the Stonedrop site in the Modesto Irrigation District canal system. Also included is a breakdown of the costs and the results of a hydraulic model test that was performed to resolve flow problems.

Inexpensive Cross-Flow Hydropower Turbine at Arbuckle Mountain Hydroelectric Project—Final Construction and Cost Report, Ott Water Engineers, Inc., Redding, California, July 1988. NTIS No. DOE/ID/12481-1.

This report documents the construction details as built and the final cost of the Arbuckle Mountain Cross-Flow Hydro Plant built near Redding, California.

Inexpensive Cross-Flow Hydropower Turbine at Arbuckle Mountain Hydroelectric Project—Field Test Report, Ott Engineers, Inc., Bellevue, Washington. NTIS No. DOE/ID/12481-2.

The Arbuckle Mountain Plant was tested during two separate testing periods. The first tests were performed in January of 1988 and utilized the dye dilution method of flow measurement. The analysis of the first test data indicated some problems with the flow measurements and a second series of tests were performed in March 1989 using dye tagging and a velocity head probe to measure the flow. The report includes the data and analyses from both series of tests.

Report on Siphon Penstocks for Hydroelectric Projects, Acres International Corporation, Amherst, New York, February 1989. NTIS No. DOE/ID/12356.

The report contains the descriptions of 11 hydropower plants that use siphon penstocks. The design, construction, operation, and maintenance are considered and the benefits of siphon penstocks are summarized. Data, drawings and photographs of the 11 projects are included.

Performance Tests and Calibrations of the St. Anthony Falls Independent Turbine Test Facility, Project Report No. 288, The University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, August 1989. NTIS No. DOE/ID/12617.

The results of several tests to determine the performance characteristics of the independent test facility for testing hydraulic pump and turbine models are included in the report. The instrumentation is described and the measurement

uncertainties documented and analyzed. Data collection equipment and software programs are also discussed.

National Energy Strategy

The Potential of Renewable Energy, An Interlaboratory White Paper, Solar Energy Research Institute Report SERI/TP-260-3674 (DE90000322), March 1990.

This document is an evaluation of the present and projected performance status of the renewable energy technologies (RETs) and their potential contributions to the nation's energy requirements over the next four decades. It has been prepared for the National Energy Strategy Study by the U.S. Department of Energy's national laboratories in response to a request from the Office of Policy, Planning and Analysis. Based on a consensus-forming approach to the assessment of many difficult questions, the paper attempts to convey a sense of what is and is not known about the range of technical and analytic issues surrounding RET deployment. The white paper identifies broadly the research, development, and demonstration (R,D&D) thrusts which, if undertaken, would in our judgment remove the key technological constraints on the utilization of these energy resources and thereby enhance the institutional, that can be reduced or removed with appropriate action. It does not address the question of what is the appropriate national energy policy, nor does it suggest what policy actions might be undertaken to address the needs discussed here.

Interim Report-National Energy Strategy-A Compilation of Public Comments, U.S. DOE, DOE/S-0066P April, 1990.

The purpose of this Interim Report on the development of the National Energy Strategy is to convey the results of this public dialogue. The Interim Report presents a compilation of hearings and submitted testimony thus far received, containing more than 4,000 citations to individual documents or presentations—all of which are available for public review. The comments

received are organized on the basis of presented public concerns, publicly identified goals, publicly identified obstacles to achieving those goals, and publicly suggested options for action to remove or overcome the obstacles.

Technology Transfer

Program Small Hydropower Technology Transfer Project: Task A—Feasibility Studies, Vol. 1, International Engineering Company, Inc., July 1984. NTIS No. DOE-ID-12254-1(V.1).

This report summarizes 240 feasibility studies of small hydropower projects conducted under the U.S. Department of Energy's Small-Scale Hydropower Program. It presents a detailed analysis of the studies and presents information significant to future developers.

Small-Hydropower Development: The Process, Pitfalls, and Experience, Volume II: Licensing Activities Summary and Analysis, Morrison-Knudsen Engineers, Inc., May 1985. NTIS No. DOE-ID-12254-1(V.2).

This report summarizes the study of 41 license and exemption applications to the FERC for small hydropower projects conducted under the DOE Small-Scale Hydropower Program. These applications were analyzed in detail for significant information that will assist future developers of small hydropower projects in successfully and expeditiously obtaining licenses, or exemption from licensing.

Small-Hydropower Development: The Process, Pitfalls, and Experience, Volume III: Technology Development Projects Summary and Analysis, Morrison-Knudsen Engineers, Inc., June 1986. NTIS No. DOE-ID-12254-1(V.3).

This report summarizes information from 23 projects, of which 19 have received financial assistance from DOE as part of the Small-Scale Hydropower Program and four have been developed independently. As of July 1986, 22 of the projects are complete and one is still in design. The completed projects range in generating capacity from 660 to 24,000 kW and in gross hydraulic head from 10 to 470 ft.

Small-Hydropower Development: The Process, Pitfalls, and Experience, Volume IV: Guide for Developers, Morrison-Knudsen Engineers, Inc., December 1985. NTIS No. DOE-ID 12254-1(V.4).

This manual is designed to assist developers in improving the planning and execution of their projects by learning from the experience of others. For those who are new to small hydropower development, it also provides an overview of the present developmental environment and a basic understanding of what to expect in developing a small hydropower project.

Hydropower Computerized Reconnaissance Package, Version 3.0, EG&G Services, Inc., June 1985. NTIS No. DOE-ID 10092-1.

This report is the technical manual for the Hydropower Computerized Reconnaissance Package, which is a set of routines designed to make a preliminary engineering and economic evaluation of producing hydroelectric power at existing dam sites. The package includes two main programs, HYD-CALC and HYD-ECON, which are used for engineering and economic analyses, respectively. A version of the package is available for the Apple II series and IBM/PC microcomputers.

DOE Small-scale Hydropower Program Annual Report 1985 EG&G Idaho, Inc., September 1985, NTIS DOE/ID-10132.

This report summarizes the research and development and technology transfer activities of the U.S. Department of Energy's (DOE's) Small-Scale Hydropower Program for fiscal year 1985, and provides an annotated bibliography of research, engineering, operations, regulations, and costs of projects pertinent to hydropower development. The Small-Scale Hydropower Program is reported in five sections:

- Technology Development
- Engineering Research and Development

- Technology Transfer
- Environmental Research
- Legal and Institutional Aspects.

The bibliography discusses reports written by both private and non-Federal Government sectors. Most reports are available from the National Technical Information Service.

DOE Small-scale Hydropower program Annual Report 1987 EG&G Idaho, Inc., August 1987, NTIS DOE/ID-10158.

This report summarizes the research and development and technology transfer activities of the U.S. Department of Energy's (DOE's) Small-Scale Hydropower Program for fiscal years 1986 and 1987, and provides an annotated bibliography of research, engineering, operations, regulations, and costs of projects pertinent to hydropower development. The Small-Scale Hydropower Program is reported in five sections:

- Technology Development
- Engineering Research and Development
- Technology Transfer
- Environmental Research
- Legal and Institutional Aspects.

The bibliography discusses reports written by both private and non-Federal Government sectors. Most reports are available from the National Technical Information Service.

DOE Hydropower Program Biennial Report 1988-1989 (with updated annotated bibliography) EG&G Idaho, Inc., August 1989, NTIS DOE/ID 10237.

This report summarizes the research and development and technology transfer activities of the U.S. Department of Energy's (DOE's) Hydropower Program for fiscal years 1988 and 1989, and provides an annotated bibliography of

research, engineering, operations, regulations, and costs of projects pertinent to hydropower development. The Hydropower Program is reported in five sections:

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The bibliography discusses reports written by both private and non-Federal Governmental sectors. Most reports are available from the National Technical Information Service. Environmental Research

Environmental Research

All reports with an ORNL number can be ordered from the following: Michael J. Sale, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008 MS-6036, Oak Ridge, Tennessee, 37831-6036, FTS-624-7305, (615) 574-7305.

Hildebrand, S. G., "Potential Environmental Impacts of Hydroelectric Development: An Overview, Hydropower: A National Energy Resource," 1979, pp. 322-392. Available from the U.S. Government Printing Office, Washington, D.C.

This report discusses environmental impacts resulting from (a) creation of a hydroelectric impoundment, (b) physical presence of a dam, (c) effects of turbine operation on the reservoir, and (d) effects of turbine operation on the tail-water ecosystem. It reviews environmental legislation, which requires a formal consideration of these impacts, including their prediction, minimization, or mitigation. Finally, some suggestions are offered on the role of ecologists and environmental scientists in the planning of environmentally sound hydropower development projects.

Loar, J. M., et al., *Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development I, Dredging*, Oak Ridge National Laboratory, 1980. Report No. ORNL/TM-7228.

Development of hydropower resources at existing dams may require dredging in order to (a) reclaim reservoir storage capacity lost as a result of sediment accumulation; (b) clear intake structures; and (c) construct or repair power houses, trailraces, and headraces. This report includes a general introduction on dredging equipment and disposal practices, with emphasis on those practices applicable to small reservoirs. It discusses the physical and chemical effects of dredging and disposal, their causes, and the biological effects engendered by these physical and chemical changes. Factors that could affect the severity (magnitude) of these effects (impacts) are emphasized for guidance to developers of potential sites. It discusses environmental constraints and mitigation, as well as guidelines, for the early evaluation of the environmental feasibility of dredging. It also discusses applicable regulations related to dredged material disposal and wetlands protection, and presents a preliminary analysis of the economic costs associated with dredging and disposal. Adequate mitigation capability exists for most of the environmental impacts of dredging, but the cost of this mitigation may place significant economic constraint on project development.

Hildebrand, S. G., ed. *Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development II, Design Considerations for Upstream Fish Passage Facilities*, Oak Ridge National Laboratory, 1980. Report No. ORNL/TM-7396.

This report addresses basic design considerations that should be evaluated on a site-specific basis whenever upstream fish passage facilities are planned for small-scale hydroelectric projects. It presents information on general life history and geographic distribution of fish species that may require passage. It discusses biological factors such as gas bubble disease, fish swimming speed, oxygen consumption, diet, and photo behavior, which are important in the design of

upstream fish passage facilities. It describes, with dimensions, three general types of facilities appropriate for upstream fish passage at small-scale hydroelectric projects (fishways, fishlocks, and fishlifts). It discusses general design criteria for these facilities (including fish swimming ability and behavior) and general location of facilities at a site. It indicates basic cost considerations for each type of passage facility including unit cost, operation and maintenance costs, and costs for supplying attraction water.

Hildebrand, S. G., ed. *Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development III. Water Level Fluctuation*, Oak Ridge National Laboratory, 1980. Report No. ORNL/TM-7453.

This report identifies potential environmental impacts in reservoirs and downstream river reaches below dams that may be caused by water level fluctuation from development and operation of small-scale hydroelectric projects. It discusses impacts on physical and chemical characteristics in reservoirs, including resuspension and redistribution of sediments, leaching of soluble organic matter, and changes in water quality. It discusses the effect on reservoir biota by changes in habitat quality, which results in reduced standing crop and production of aquatic biota and possible shifts in species diversity, and discusses water quality problems that may occur below dams because of water level fluctuations. It discusses potential biological impacts on downstream ecosystems that result from changes in current velocity, habitat reduction, and alteration in food supply. And the report presents recommendations for site-specific evaluation of water level fluctuation at small-scale hydroelectric projects.

Hildebrand, S. G., ed. "Small-Scale Hydroelectric Development and the Environment: Issues, Challenge, Opportunity," *Proceedings of the National Conference on Renewable Energy Technologies, Honolulu, Hawaii, December 6-11, 1980*.

This report reviews major environmental issues that could constrain small-scale hydro-

electric development, including effects of dredging, interferences with fish passage, water level fluctuations, and minimum instream flow. It concludes that with adequate planning in the prefeasibility stage, communication with regulatory authorities and interested parties, appropriate site-specific environmental studies, and effective mitigation of anticipated impacts, environmental issues should not be an absolute barrier to small-scale hydroelectric development at many sites.

Turbak, S. C., D. R. Reichle, and C. R. Shriner, *Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development IV, Fish Mortality Resulting from Turbine Passage*; Oak Ridge National Laboratory, 1981. Report No. ORNL/TM-7521.

This document reviews state-of-the-art literature concerning turbine-related fish mortality. The review discusses conventional and, to a lesser degree, pumped-storage (reversible) hydroelectric facilities. Much of the research on conventional facilities discussed in this report deals with studies performed in the Pacific Northwest and covers both prototype and model studies. Research conducted on Kaplan and Francis turbines during the 1950s and 1960s is extensively reviewed. Very little work on turbine-related fish mortality has been undertaken with newer turbine designs developed for more modern small-scale hydropower facilities; however, one study on a bulb unit (Kaplan runner) has recently been released. In discussing turbine-related fish mortality at pumped-storage facilities, much of the literature relates to the Ludington Pumped Storage Power Plant.

Loar, J. M., and M. J. Sale, *Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development V, Instream Flow Needs for Fishery Resources*, Oak Ridge National Laboratory, 1981. Report No. ORNL/TM-7861.

This document provides guidance to developers of small-scale hydroelectric projects on the assessment of instream flow needs. Whereas, numerous methods have been developed to assess the effects of stream flow regulation on aquatic biota in cold water streams in the West, no

consensus has been reached regarding their general applicability, especially to streams in the eastern United States. The methods differ in their use of hydrologic records, hydraulic simulation techniques, and habitat rating criteria, and in their capability to provide seasonal or species-specific recommendations. Because of these differences in data requirements, application costs and the level of resolution associated with the instream flow recommendations vary greatly. Consequently, guidance is needed to ensure that the most appropriate methods are selected. To provide this guidance to developers of small hydropower projects, the methods were evaluated to determine their applicability in the assessment of instream flow needs for fishery resources at small hydropower sites. The methods were grouped into three categories based on (a) level of resolution associated with the instream flow recommendation, (b) data needs, and (c) costs of application. The categories correspond to different levels of assessment that might be required at a given hydropower site. To select the most appropriate level of analysis, criteria were identified relating to both the design and operation of the project, and the aquatic resources at the site.

Cada, G. F., and F. Zadroga, *Environmental Issues and Site-Selection Criteria for Small Hydropower Projects in Developing Countries*, Oak Ridge National Laboratory, 1981. Report No. ORNL/TM-7620.

Because small hydropower projects are simple and versatile and use a renewable resource, they can effectively provide electric power to small, isolated rural communities in developing countries. However, construction and operation of even the smallest project can result in adverse environmental consequences and should be considered in the initial stages of site selection and development. The report discusses potential environmental impacts and provides guidance for factoring environmental concerns into the site selection process both at prefeasibility and feasibility stages. It includes a checklist of environmental data that should be collected and recommendations on the training of personnel involved in the environmental evaluation.

Gilliland, M. W., J. M. Klopatek, and S. G. Hildebrand, *Net Energy of Seven Small-Scale Hydroelectric Power Plants*, Oak Ridge National Laboratory, 1981. Report No. ORNL/TM-7694.

Net energy analysis evaluates the direct and indirect energy inputs involved in constructing and operating an energy supply technology and compares those inputs with the energy produced by the technology. This study performed a net energy analysis on seven small-scale hydroelectric plants, comparing them to conventional hydroelectric plants and other energy supply technologies. All seven small-scale plants represent some kind of retrofit to an existing dam. The results indicate that the energy output from these small hydroprojects is 8.6 to 32.9 times greater than the energy input when output is expressed as electricity, and 26.3 to 101.4 times greater than the energy input when output is expressed as fossil fuel equivalent. Based on the net energy criterion, small-scale plants are probably a better investment than conventional peak-load hydroelectric plants and similar to conventional base-load hydroelectric plants.

Hildebrand, S. G., and L. B. Gross, *Hydroelectric Operation at the River Basin Level: Research Needs to Include Ecological Issues in Basin-Level Hydropower Planning*, Electric Power Research Institute, 1981. Report No. EPRI WS-80-155. Order report from the Electric Power Research Institute, Research Reports Center, P.O. Box 50490, Palo Alto, California 94303, (415) 965-4081.

A workshop to recommend research needed to quantitatively integrate ecological issues in river basin level hydropower planning was held at Oak Ridge, Tennessee, on September 15-17, 1980. The 32 workshop participants identified 18 research topics that were responsive to the workshop objective. These topics were related to impacts of water level fluctuation, instream flow requirements, water quality alteration, and impacts on migratory fish. The report summarizes the development of these research topics and recommended research priorities.

Cada, G. F., et al., *Analysis of Environmental Issues Related to Small-Scale Hydroelectric*

Development VI, Dissolved Oxygen Concentrations Below Operating Dams, Oak Ridge National Laboratory, 1982. Report No. ORNL/TM-7887.

An analysis of the potential for small-scale hydropower development to create water quality problems (as exemplified by low dissolved oxygen concentrations) was performed by pairing operating hydroelectric sites with dissolved oxygen measurements from nearby downstream USGS water quality stations. Probabilities of Non-Compliance (PNCs) (i.e., the probabilities that dissolved oxygen concentrations in tailwaters will drop below 5 mg/L) were estimated for each site, season, and capacity category (>30 MW vs. >30 MW). During the winter months, all regions of the U.S. had low mean PNCs, regardless of hydroelectric capacity. Summer PNCs were greater for large-scale than for small-scale sites. Among regions, highest mean summer PNCs were found in the southeast, Ohio Valley, and the Great Basin. Cumulative probability distributions of PNC were developed, which indicated that low tailwater dissolved oxygen concentrations are a problem largely confined to large-scale facilities.

Sale, M. J., "Assessing the Impacts of Regulated Flows at Hydropower Projects," *Proceedings of the 1982 Northeast Coldwater Workshop on Hydropower Development and Fisheries Impacts and Opportunities*, New York State Department of Environmental Conservation, Albany, New York, edited by G. A. Barnhart, 1983.

Hydropower development is frequently accompanied by streamflow regulation that can adversely affect upstream and downstream fisheries. This paper is a literature review and summary of the current capabilities for assessing the impacts of regulated flows both within and below hydropower reservoirs. Assessment of project impacts must begin within a definition of project design and operation variables. Three approaches are then available for assessing impacts below the dam and resultant instream flow needs: (a) discharge methods, (b) hydraulic-rating methods,

and (c) habitat-rating methods. Fewer analytical assessment methods are available for assessing impacts within the reservoir, but a conceptual approach is proposed. The constructive use of these techniques to avoid adverse fisheries impacts is a major challenge to resource managers and hydrodevelopers.

Sale, M. J., and J. M. Loar, "Instream Flow and Hydropower Development: Methods and Strategies for Impact Assessment," *Proceedings of Waterpower '81: An International Conference on Hydropower, I*, U.S. Army Corps of Engineers, Washington, D.C., 1982.

The issues of instream flow maintenance in hydropower development is essentially a problem of evaluating the effects of planned modifications in hydrologic patterns. Both large- and small-scale hydropower projects can alter natural flow regimes on either spatial or temporal scales. This paper reviews the status of instream flow methodologies and identifies their role in the environmental assessment of hydroprojects. Strategies for selecting the best methods are discussed in terms of site-specific factors such as project design specifications, fluvial morphology, watershed hydrology, biological sensitivity, and extant local water usage.

Sale, M. J., E. D. Brill, Jr., and E. E. Herricks, "An Approach to Optimizing Reservoir Operation for Downstream Aquatic Resources," *Water Resources Research*, 18, 4, 1982, pp. 705-712.

This paper proposes a mathematical programming methodology to examine the relationship between biological instream flow needs (IFN) and more traditional water project objectives, such as water yield, flood control, reservoir recreation, or economic efficiency. This optimization approach combines the linear decision rule modeling technique with an objective function representing the value of reservoir releases to downstream fisheries. The IFN performance objective is based on an index of physical habitat conditions for fish. A case study is presented using data from a multipurpose reservoir in central Illinois.

Knapp, W. E., B. Kynard, and S. P. Gloss, eds., *Potential Effects of Kaplan, Ossberger, and Bulb Turbines on Anadromous Fishes of the Northeast United States*, U.S. Fish and Wildlife Service, Newton Corner, Massachusetts, 1982. Report No. FWS/OBS-82/62. Order report from Region 5, U.S. Fish and Wildlife Service, One Gateway Center, Newton Corner, Massachusetts 02158.

The effects of turbine passage on anadromous fishes of the northeast United States were investigated in the field and laboratory. Kaplan, Ossberger, and bulb turbines were studied using Atlantic salmon smolts (*Salmo salar*), juvenile and adult American shad (*Alosa sapidissima*), juvenile blueback herring (*Alosa aestivalis*), striped bass (*Morone saxatilis*) and rainbow and steelhead trout (*Salmo gairdneri*). The effects of turbine size and electric power level on mortality were studied in the field. Laboratory investigations and other field studies focused attention on turbine-induced scale loss and its potential for sublethally affecting Atlantic salmon smolts, juvenile American shad, and blueback herring. The investigations provide valuable guidance for conducting turbine-passage studies in the future and furnish useful estimates of acute and delayed mortality.

Bain, M. B., et al., *An Evaluation of Methodologies for Assessing the Effects of Flow Fluctuations on Stream Fish*, U.S. Fish and Wildlife Service, Newton Corner, Massachusetts, 1982. Report No. FWS/OBS-82/63. Order report from Region 5, U.S. Fish and Wildlife Service, One Gateway, Newton Corner, Massachusetts 02158.

Two reaches of the Deerfield River in Massachusetts were studied to test the applicability of the Instream Flow Incremental Methodology (IFIM) on an eastern river with daily fluctuating flows, to explore some of the biological assumptions of the IFIM, and to develop new methods for studying fish behavior in streams with fluctuating flow. Physical habitat simulations in the fluctuating-flow environment are basically acceptable. However, the biological portion of the IFIM is not as applicable to a river with daily fluctuating flow because fish do not

consistently inhabit locations that were predicted to be the most suitable. Producing reliable habitat suitability curves is the major problem in applying the IFIM to fluctuating-flow streams. Basic research is needed to determine how fish behave in fluctuating flow and what variables they are responding to, in addition to velocity, depth, and substrate. Radio telemetry was seen as a potentially useful, but presently limited, tool for examining fish behavior during changing flow.

Loar, J. M., and S. G. Hildebrand, "A Comparison of Environmental Issues Related to Development of Small Hydropower Resources at New Versus Existing Sites," *Alternate Energy Sources III*, 9, *Policy/Environment*, edited by T. N. Veziroglu, New York: Hemisphere Publishing Company, 1983, pp. 279-297.

This paper discusses the ecological issues associated with the development of small hydropower resources at new (undeveloped) sites and those with existing dams that will be retrofitted for hydroelectric generation. Issues that could occur with both types of development are (a) blockage of fish migration routes, (b) water level fluctuations, (c) instream flows, (d) water quality, (e) dredging and dredged material disposal, and (f) threatened or endangered species. However, new site development projects require the alteration of existing aquatic and terrestrial ecosystems that will be, in most cases, significantly greater than the environmental changes associated with retrofitting of existing dams. Although project design and operation are important factors controlling the nature and magnitude of the environmental impacts of small hydropower resource development, the mitigation of adverse impacts (and the optimization of beneficial effects) is dependent, in large measure, on our ability to accurately predict physical, chemical, and biological changes. Predicting the impacts of new impoundments may be considerably more difficult than predicting the impacts that might occur if an existing dam/impoundment system is developed. A comparative approach at the ecosystem level can provide valuable insights into the structure and function of reservoir

systems and significantly increase our predictive capability.

Loar, J. M., "Impacts of Hydropower Development on Downstream Fish Passage," *Proceedings of the 1982 Northeast Coldwater Workshop on Hydropower Development and Fisheries: Impacts and Opportunities*, New York State Department of Environmental Conservation, Albany, New York, edited by G. A. Barnhart, 1983, pp. 25–36.

Hydroelectric dams can have a significant impact on anadromous species (e.g., Atlantic salmon and American shad) that spend most of their adult life in the ocean but return to freshwater to spawn. This paper addresses the nature of the impacts on downstream migrants resulting from dam construction, operation, and the mitigation options available for reducing adverse impacts. Mortality can result from turbine passage and delays in downstream migration caused by flow regulation. Minimization and compensation are two general approaches that can be employed to reduce the adverse impacts of hydroelectric dams on downstream migrants. Mortality resulting from turbine passage can be minimized by (a) installation of intake diversion and bypass systems, (b) collection and transportation of downstream migrants around dams, and (c) controlled spills. Restoration of degraded spawning/nursery habitat, on the other hand, can be employed to compensate for losses in natural production resulting from the construction of new dams or the operation of existing hydroelectric dams.

Cushman, R. M., "Biotic Effects of Rapidly Varying Flows from Hydroelectric Facilities," *Proceedings of Waterpower '83: An International Conference on Hydropower*, Tennessee Valley Authority, Knoxville Tennessee 1983, pp. 1274–1283.

Rapid changes in flow below hydroelectric facilities result from peaking operations. The potential impacts of these short-term disturbances of aquatic systems below dams are important considerations in hydro-power development.

Reduced biotic abundance, diversity, and productivity in tailwaters may be caused by flow variations or a variety of related factors. This paper outlines information needs for site-specific evaluations, and presents options to reduce anticipated adverse effects.

Cada, G. F., et al., "Field Test of a Biological Assumption of Instream Flow Models," *Proceedings of Waterpower '83: An International Conference on Hydropower*, Tennessee Valley Authority, Knoxville, Tennessee, 1983, pp. 1305–1313.

A number of instream flow assessment methods rely on implicit biological assumptions about the relationships between aquatic biota and streamflow in order to make minimum flow recommendation. On such assumption, that the amount of benthic organisms available as food for stream fishes is directly proportional to the stream bottom area (wetted perimeter), was tested at four field sites in the southern Appalachian Mountains. For most of the sites and taxa examined, benthic densities did not show a consistent relationship with discharge/wetted perimeter dynamics. Our analysis indicates that simple physical habitat descriptors obtained from hydraulic-rating models do not provide sufficient information on the response of benthic organisms to decreased discharges and therefore may not be adequate to protect aquatic resources in water-use conflicts.

Sale, M. J., S. F. Railsback, and E. E. Herricks, "Frequency Analysis of Aquatic Habitat," *Proceedings of the Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information*, Western Division, American Fisheries Society, Portland, Oregon, edited by B. Armantrout, 1983, pp. 340–346.

Minimum flow recommendations can be improved by analyzing the natural habitat variability in lotic environments. Habitat modeling techniques such as the Instream Flow Incremental Methodology can be combined with stream flow records to generate habitat frequency curves that are useful in determining instream flow needs.

Olive, S. W., and B. L. Lamb, *Conducting a FERC Environmental Assessment: A Case Study and Recommendations from the Terror Lake Project*, Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Ft. Collins, Colorado, 1984. NTIS No. PB84-209618 or FWS/OBS-84/08.

This report is an account of the process that evolved during acquisition of the license to operate the Terror Lake hydroelectric power project under the auspices of the Federal Energy Regulatory Commission (FERC). Terror River, the project site, is located on Kodiak Island in Alaska. The main controversy requiring negotiation stemmed from the fact that the intended development area was within the boundaries of the Kodiak National Wildlife Refuge. Conflicting views about potential project impacts, especially on fish, wildlife, and instream flows, were ultimately reconciled through interagency negotiations. Included is a detailed account of the negotiations and suggestions for strategies in future FERC licensing efforts.

Knapp, W. E., *SPLASH—Simulation Program for Low-Flow Analysis of Small-Scale Hydropower Projects: Test Applications*, U.S. Fish and Wildlife Service, Neton Corner, Massachusetts, 1984. Order report from Region 5, U.S. Fish and Wildlife Service, One Gateway, Newton Corner, Massachusetts 02150.

This report describes a computerized assessment method for rapidly evaluating the flow-related impacts of alternative hydrodesigns and operating modes. The SPLASH model is designed to represent branched stream networks with multiple hydroprojects and to give estimates of where, when, and to what degree conflicts in water use may occur. Input data are readily available for most project types. The Muskingum method is used to route stream flow through the specified channel and reservoir configuration. Case studies show the limitations of this routing method.

Cada, G. F., K. D. Kumar, J. A. Solomon, and S. G. Hildebrand, "An Analysis of Dissolved

Oxygen Concentrations in Tailwaters of Hydroelectric Dams and the Implications for the Small-Scale Hydropower Development," *Water Resources Research*, 19, 4, 1983, pp. 1043-1048.

One of the environmental issues affecting small-scale hydropower development in the United States is water quality degradation. The extent of this potential problem, as exemplified by low dissolved oxygen concentrations in reservoir tailwaters, was analyzed by pairing operating hydroelectric sites with dissolved oxygen measurements from nearby downstream U.S. Geological Survey water quality stations. These data were used to calculate probabilities of noncompliance (PNCs), that is, the probabilities that dissolved oxygen concentrations in the discharge waters of operating hydroelectric dams will drop below 5 mg/L. The continental states were grouped into eight regions based on geographic and climatic similarities. Most regions had higher mean PNCs in summer than in winter, and summer PNCs were greater for large-scale than for small-scale hydropower facilities. Cumulative probability distributions of PNC also indicated that low dissolved oxygen concentrations in the tailwaters of operating hydroelectric dams are phenomena largely confined to sites with large-scale facilities.

Gloss, S. P., and J. R. Wahl, "Mortality of Juvenile Salmonids Passing Through Ossberge Cross-Flow Turbines at Small-Scale Hydroelectric Sites," *Transactions of the American Fisheries Society*, 112, 2A, 1983, pp. 194-200.

Experiments were conducted on Ossberger Cross-flow turbines to determine the amount of mortality that would be incurred by downstream-migrating juvenile salmonids passing through these turbines. Species tested were Atlantic salmon (*Salmo salar*), rainbow trout, and steelhead (*S. Gairdneri*). A highly significant ($P < 0.01$) relationship was found between fish size and arc sine square root of mortality. Regression equations were calculated to predict mortality through 48 h based upon fish size. Mortality ranged from 15% for 85-mm fish to over 70% for 280-mm fish. No significant difference in mortality was detected among similar size-groups of

the three salmonids tested. Neither output of the turbine nor its size (650 versus 850 kW) affected mortality. Temporal distribution of mortality after fish passed through the turbine was not different among species nor was it affected by the absolute rate of mortality in a given trial. Over 75% of the mortality was considered instantaneous.

Bain, M. B., *Fish Community Structure in Rivers with Natural and Modified Daily Flow Regimes*, Ph.D. Dissertation, University of Massachusetts, Amherst, Massachusetts, 1985.

The effects of artificial flow fluctuation on stream fish communities was examined during a 2-year period. A "natural experiment," comparing fish community structure in a river with a natural daily flow regime and a river with dramatic daily flow fluctuations, was used to address questions concerning (a) appropriate macrodescriptors for examining the relationship between fish and habitat, (b) the effect of variable habitat conditions on stream fish communities, and (c) predictions of the intermediate-disturbance hypotheses. The density of fish in each type of stream habitat (shallow slow, general) was compared between rivers and along a gradient of flow fluctuations in the modified river.

Fish that required shallow slow habitat ("specialists") appeared to be reduced in abundance by flow fluctuations. Under fluctuating habitat conditions, fish with more broad habitat requirements ("generalists") were found in greater abundance. It was concluded that (a) artificial flow fluctuations alter fish community structure, (b) the response of fish to variable habitat depends on their microhabitat use patterns, (c) fish specializing on shallow slow microhabitat were reduced in abundance while other fish were either increased or unaffected, and (d) changes in fish community structure associated with frequent habitat disturbances were consistent with the predictions of the intermediate-disturbance hypothesis.

Cada, G. F., and R. B. McLean, "An Approach for Assessing Fisheries Impacts of Basin-Wide Hydropower Development," in *Small Hydro and*

Fisheries, Symposium Proceedings, American Fisheries Society, Bethesda, Maryland, edited by F. Olsen et al., 1985.

The recent emphasis on small-scale hydroelectric development has resulted in a confusing patchwork of applications for hydropower licenses, exemptions, and preliminary permits, all within the same river basin. Although the National Environmental Policy Act requires an assessment of the cumulative environmental impacts of existing and planned developments, there is no widely accepted methodology for performing such an analysis. One promising approach to assessing cumulative impacts on fisheries is the use of matrices that display the key components of this resource and quantitatively describe how hydropower development may affect them. In addition to its value in predicting impacts, the matrix is a useful framework for negotiations among involved parties and may be used to determine the effects of mitigative measures. This paper describes an application of the matrix technique to the assessment of hydropower impacts on resident trout in the Upper San Joaquin River basin in California. Advantages and limitations of the approach as a tool for assessing multiple-project impacts, as well as its potential for assessing cumulative impacts, are described. Recommendations are made for further development of basin-level impact-assessment methods.

Cushman, R. M., "Review of Ecological Effects of Rapidly Varying Flows Downstream from Hydroelectric Facilities," *North American Journal of Fisheries Management*, 1985.

Rapid changes in flow below hydroelectric facilities result from peaking operations, where water is typically stored in a reservoir at night and released through turbines to satisfy increased electrical demand during the day. Potential impacts of these short-term, recurring disturbances of aquatic systems below dams are important considerations in hydropower development. Reduced biotic productivity in tailwaters may be due directly to flow variations or indirectly to a variety of factors related to flow variations, such as changes in water depth or temperature, or scouring of sediments. Many riverine fish and

invertebrate species have a limited range of conditions to which they are adapted. The relatively recent pattern of daily fluctuations in flow is not one to which most species are adapted; thus, such conditions can reduce the abundance, diversity, and productivity of these riverain organisms. Information needs for site-specific evaluations of potential impacts at hydroelectric peaking projects are outlined, along with management and mitigation options to reduce anticipated adverse effects.

Kondolf, G.M., and M.J. Sale, "Application of Historical Channel Stability Analysis to Instream Flow Studies," *Small Hydro and Fisheries, Symposium Proceedings, American Fisheries Society, Bethesda, Maryland*, edited by F. Olson et al., 1985, pp. 184–194.

Hydraulic simulation models used in the assessment of instream flow assume that channel morphology and bottom substrate do not vary over time. Ongoing, longterm channel adjustments may render this assumption invalid, especially if the "representativeness" of study reaches is affected. Consequently, channel stability should be evaluated as an integral part of instream flow assessment. Procedures are described for reconnaissance-level evaluation of river channel dynamics emphasizing the use of readily available historical records such as aerial and/or terrestrial photography, hydrologic records, old maps and channel survey data, gaging station records, narrative accounts, and other field evidence. If this examination suggests that the river channel being studied has been relatively stable over recent decades, then it is reasonable to assume that it is in equilibrium and that future changes will be caused by altered flow regimes. If the channel is not in equilibrium, then hydraulic simulation of aquatic habitat conditions must consider the naturally occurring channel dynamics. Guidance is provided on the collection and interpretation of data for historical channel stability analysis.

Loar, J.M., *Application of Habitat Evaluation Models in Southern Appalachian Trout Streams*, edited by Oak Ridge National Laboratory, Oak

Ridge, Tennessee, 1985, p. 310. Report No. ORNL/TM-9323.

This study was conducted to evaluate the validity of physical habitat indices (e.g., weighted usable area) for predicting the response of trout populations to changes in stream flow. Because the use of habitat indices is based on the assumption that fish abundance or biomass is positively correlated with the value of the habitat index, the study focused on an analysis of fish-to-habitat relationships. Eight study sites on cold water streams with naturally reproducing populations of brown and rainbow trout were selected. The streams were situated in the southern Appalachian Mountains of eastern Tennessee and western North Carolina. Fish biomass, abundance, and production were estimated, using electrofishing and Petersen mark-recapture techniques. Physical habitat was quantified, using the IFIM's Physical Habitat Simulation (PHABSIM) system at each site. Water quality, water temperature, macroinvertebrate food resources, and average monthly flow regimes were also measured at each site. Based on our results, the validity of the assumption that fish abundance or biomass varies in direct proportion to physical habitat indices could not be rejected. Although physical habitat indices explained a significant proportion of the variability in brown trout populations between sites, habitat condition alone was not sufficient to explain differences in rainbow trout abundance. To predict the response of trout populations to flow alteration, it is recommended that (a) habitat variables be carefully chosen with respect to critical life stages and periods of the year, (b) site-specific interactions between target species be considered, and (c) management objectives be clearly defined. The most appropriate habitat indices are those based on minimum values calculated over the entire period that given life stage is present. When used properly, habitat variables can be useful in assessing changes in fishery resources resulting from flow alterations.

Hildebrand, S.G., M.J. Sale, G.F. Cada, and J.M. Loar, "National Perspective on Environmental Constraints to Hydroelectric Development," *Perspectives on Nonpoint Source Pollution*,

Proceedings of a National Conference, Kansas City, Missouri, May 19–22, 1985.

This paper describes major environmental issues on which the U.S. Department of Energy's Small-Scale Hydropower Program has concentrated. The three issues common to non point source problems and hydroelectric development are (a) dissolved oxygen concentrations in tailwaters below dams, (b) instream flow requirements for fisheries, and (c) the cumulative impacts of multiple-project development in river basins. The current status of these issues is reviewed and recommendations are made for addressing them.

Sale, M.J., "Aquatic Ecosystem Response to Flow Modification: An Overview of the Issues," *Small Hydro and Fisheries, Symposium Proceedings, American Fisheries Society, Bethesda, Maryland*, edited by F. Olson et al., 1985, pp. 25–31.

This paper is an introduction to contributed papers in a session on "Biological Response to Flow Modification." Lotic ecosystems respond to modified flow regimes through changes in physical habitat availability, water chemistry and temperature, nutrient cycling, biomass/energy relationships, and the population and community dynamics of aquatic biota. A systems perspective is therefore essential in understanding flow-related impacts and in making water management decisions. More retrospective studies and experimental management are needed to provide the necessary design information for environmentally sound hydropower development. The responsibility for these studies must be shared among developers, regulators, and natural resource managers.

Taylor, R.E., and B. Kynard, "Mortality of Juvenile American Shad and Bluback Herring Passed Through a Low Head Kaplan Hydroelectric Turbine," *Transactions of the American Fisheries Society*, 114, 1985, pp. 430–435.

Immediate mortality of juvenile alosids (American shad (*Alosa sapidissima*) and blue-

back herring (*A. aestivalis*) passed through the 17-MW Kaplan turbine at Holyoke Dam on the Connecticut River was estimated with mark-capture methods. Turbine-induced mortality of fish at full power output is thought to be related to greater turbine efficiency.

Bell, C.E. and B. Kynard, "Mortality of Adult American Shad Passing Through a 17-Megawatt Kaplan Turbine at a Low Head Hydroelectric Dam," *North American Journal of Fisheries Management*, 5, 1, 1986, pp. 33–38.

In May 1982, the mortality of pre-spawning American shad (*Alosa sapidissima*) was studied over a 5-h period after passage through the 17-MW Kaplan turbine at Holyoke Dam, Connecticut River, Massachusetts. Radio telemetry was used to determine the survival of 36 test fish during seven experiments by comparing their movement patterns with those of 21 sacrificed fish that were also passed through the turbine. Sixty-nine control fish fitted with dummy tags were released and held in an instream net for direct observation of mortality because of handling, tagging, and introduction procedures. The mean turbine mortality (N_T) was 21.5% (95% confidence limits of 3.3 to 36.2%). Similar preliminary experiments with postspawned American shad indicated that mortalities during their normal outmigration should be higher than the mortality estimate for prespawned fish.

Gatz, A.J., J.M. Loar, and G.F. Cada, "Effects of Repeated Electroshocking on Instantaneous Growth of Trout," *North American Journal of Fisheries Management*, 6, 2, 1986, pp. 176–182.

Instantaneous growth rates were calculated for age 1, 2, and 3 + wild rainbow trout (*Salmo gairdneri*) and brown trout (*Salmo trutta*) at each of eight sites on five streams in western North Carolina and eastern Tennessee. Growth rates of individual trout that had been electroshocked with pulsed direct current 2 to 7 times within a 12-month period were lower than the average growth rates for trout of the same age and species at their respective sites. This decrease in growth rate occurred significantly more often among Age 1 and 2 trout than among those 3 years and

older, and more often among trout that had been electroshocked within the last 2.5 months than among trout that had 3 or more months to recover from electroshocking. These results indicated that fisheries management studies such as instream flow assessments should be designed to avoid repeated electroshocking, especially at intervals of less than 3 months. Growth studies in which more than a small fraction (e.g., <20%) of the fish are repeatedly electroshocked at short (<3 month) intervals are likely to underestimate growth rates.

Gatz, A.J., M.J. Sale, and J.M. Loar, "Habitat Shifts in Rainbow Trout: Competitive Influences of Brown Trout," *Oecologia*, Vol. 4, 1987, pp. 7-19.

Compared habitat use by rainbow trout sympatric (three streams) and allopatric (two streams) with brown trout to determine whether competition occurred between these two species in the southern Appalachian Mountains. Measured are water depth, water velocity, substrate, instance to overhead vegetation, sunlight, and surface turbulence both at the trout collection site and for the streams in general, separating the effects of habitat availability from possible competitive effects. The results provided strong evidence for asymmetrical interspecific competition. Habitat use varied significantly between allopatric and sympatric rainbow trout in 68% of the comparisons made. Portions of some differences reflected differences in habitats available in the several streams. However, for all habitat variables measured except sunlight, rainbow trout used their preferred habitats less in sympatry with brown trout than in allopatry if brown trout also preferred the same habitats. Multivariate analysis indicated that water velocity was the most critical habitat variable in the competition and water depth was least important.

Gatz, A.J., and J.M. Loar, "Petersen and Removal Population Size Estimates: Combining Methods to Adjust and Interpret Results When Assumptions are Violated," *Environmental Biology of Fishes*, 21, 4, 1988, pp. 293-307.

Presented are ways to test the assumptions of the Petersen and removal methods of population size estimation and ways to adjust the estimates if violations of the assumptions are found. The facts were that (1) results of using both methods are commonly reported without any reference to the testing of assumptions, (2) violations of the assumptions are more likely to occur than not in natural populations, and (3) the estimates can be grossly in error if assumptions are violated. In many cases two days in the field is the most time fish biologists can spend in obtaining a population estimate, so the use of alternative models of population estimation that require fewer assumptions is precluded. Hence, for biologists operating with these constraints and only these biologists, a two-day technique that combines aspects of both capture-recapture and removal methods is described and recommended. How to test most of the assumptions of both methods and how to adjust the population estimates obtained if violations of the assumptions occur are indicated. Also illustrated is the use of this combined method with data from a field study. The results of this application further emphasize the importance of testing the assumptions of whatever method is used and making appropriate adjustments to the population size estimates for any violations identified.

Loar, J.M., M.J. Sale, and G.F. Cada; M. Karamouz, G.R. Baumii, "Instream Flow Needs to Protect Fishery Resources," *Water Forum '86: Work Water Issues in Evolution*, Vol. 2. American Society of Civil Engineers, New York, NY, 1986, pp. 2098-2105.

Numerous methods have been developed over the past several decades to assess the effects of flow regulation on fishery resources and to provide a basis for the determination of suitable instream flow regimes to protect these resources. Many of these methods rely on historical flow records without considering the specific requirements of aquatic biota. Such methods are inflexible, are difficult to defend from an ecological basis, and offer no opportunity for the type of trade-off analysis necessary in water resource today. Even state-of-the-art methods that can quantify changes in physical habitat as a function

of stream flow may be inadequate because they do not consider other (biological) variables that may be significant determinants of population abundance. Future research must emphasize the role of all factors that limit population size if we are to be successful in including hydrologic parameters in fish production models. Although some methods are adequate for determining minimum flows needed to maintain existing habitat condition, no method is currently capable of adequately predicting responses of fish populations of flow modifications. Selection of an appropriate method for evaluating potential impacts of water development projects must consider (1) limitations of the various methods, (2) project design and operation, and (3) status of the fishery resources and current management objectives.

Stier, D.J., and B. Kynard, "Use of Radio Telemetry to Determine the Mortality of Atlantic Salmon Smolts Passing Through a 17-Megawatt Kaplan Turbine at a Low Head Hydroelectric Dam," *Transactions of the American Fisheries Society*, 115, 5, 1986, pp. 771-775.

Mortality among 108 radio-tagged 2-year-old smolts of Atlantic salmon (*Salmo salar*) passes through a 17-MW Kaplan turbine was estimated at Holyoke Dam on the Connecticut River. The survival of test and control fish in 1981 was determined by comparing their rate of downstream movement with that of 28 pre-killed fish. The survival of test fish in 1982 was determined as in 1981 by using nine pre-killed fish. At full power generation, the mean percent turbine-induced mortality at 2 h (95% confidence interval in parentheses) as 11.8 (3.8-18.0) in 1981 and 13.7 (1.9-22.5) in 1982.

Cada, G.F., J.M. Loar, and D.K. Cox, "Food and Feeding Preferences of Rainbow and Brown Trout in Southern Appalachian Streams," *American Midland Naturalist* 117, 2, 1987, pp. 374-385.

The stomach contents of Age 1 and older rainbow (*Salmo gairdneri*) and brown trout (*S. trutta*) in five, southern Appalachian, soft-water streams were compared with concurrent drift samples. A

wide range of food items was consumed, and no prey genus comprised an average of more than 2.5% by number of the diet of either trout species. Seasonal changes in composition of drift from June to November were generally mirrored by shifts in trout diets. The contribution of terrestrial organisms to drift and to diets was highest in late summer and autumn. Averaged overall samples, terrestrial taxa comprised 36, 45, and 50% of the drift, rainbow, and brown trout diets, respectively. Both trout species exhibited statistically significant feeding preferences for particular taxa (notably terrestrial organisms), but most prey were consumed in proportions similar to the abundance in the drift. Opportunistic feeding lends stability to trout populations in streams with relatively low autochthonous food production by allowing trout to capitalize on terrestrial input. Our findings emphasize the importance of both protecting riparian vegetation (which is a source of terrestrial prey) and considering aquatic habitat elements in which trout can efficiently capture surface drift when determining minimum stream-flow requirements for water-diversion projects.

Cada, G.F., J.M. Loar, and M.J. Sale 1988. "Evidence of Food Limitation of Rainbow and Brown Trout in Southern Appalachian Soft-Water Streams." *Transactions of the American Fisheries Society* 116, 5, pp. 692-702.

Seasonal patterns of age-specific growth rates and condition factors of rainbow (*Salmo gairdneri*) and brown trout (*S. trutta*) were studied in relation to the available food resources in five streams of the southern Appalachian mountains. Benthic standing crops and total drift rates were lower than in comparable-sized streams in other geographic areas. Numbers of prey items per trout stomach were small and directly related to drift rate, reflecting the limited food base. Condition factors of Age 1 trout declined during summer, and growth rates among Age 1 and older trout were generally lower in summer than in winter, despite favorable summer water temperatures. This "inverted" seasonal pattern of growth was likely due to an inadequate food base. The likely reason that growth rates were relatively low in summer was that much of the limited energy intake was devoted to metabolism, with

little energy left for growth. Higher growth rates occurred in winter because energy requirements for metabolism were reduced at lower water temperatures. An important function of habitat in food-limited streams may be to partition overall fish production among age classes by providing energy-efficient feeding sites for different sizes of fish.

Kondolf, G.M., J.W. Webb, M.J. Sale, and T. Felando, "Basic Hydrologic Studies for Assessing Impacts of Flow Diversions on Riparian Vegetation: Examples from Streams of Eastern Sierra Nevada, California, U.S.A." *Environmental Management*, 11, 62 February 1988, pp. 757-769.

As the number of proposals to divert stream-flow for power production has increased in recent years, interest has grown in predicting the impacts of flow reductions on riparian vegetation. Because the extent and density of riparian vegetation depends largely on local geomorphic and hydrologic setting, site-specific geomorphic and hydrologic information is needed. The purposes of this paper are (1) to describe methods for collecting relevant hydrologic data, and (2) to report the results of such studies on seven stream reaches proposed for hydroelectric development in the eastern Sierra Nevada, California. The methods described are (1) preparing geomorphic maps from aerial photographs, (2) using well level records to evaluate the influence of stream flow on the riparian water table, (3) taking synoptic flow measurements to identify gaining and losing reaches, and (4) analyzing flow records from an upstream-downstream pair of gages to document seasonal variations in downstream flow losses. In the eastern Sierra Nevada, the geomorphic influences on hydrology and riparian vegetation were pronounced. For example, in a large, U-shaped glacial valley, the width of the riparian strip was highly variable along the study reach and was related to geomorphic controls, whereas the study reaches on alluvial fan deposits had relatively uniform geomorphology and riparian strip width. Flow losses of 20% were typical over reaches on alluvial fans. However, one stream gained up to 275% in a mountain valley

because of geomorphically controlled groundwater contributions.

Kondolf, G.M., G.F. Cada, M.J. Sale, and T. Felando, "Distribution of Potential Salmonid Spawning Gravels in Steep Boulder-Bed Streams of the Eastern Sierra Nevada," *Transactions of the American Fisheries Society*, in press, 1989.

High-gradient, boulder-bed streams have been the sites of relatively few studies of salmonid spawning habitat, although they have geomorphic and hydraulic characteristics—and therefore gravel distributions—which are quite different from the more commonly described lower-gradient channels. Gravel deposits were not abundant in our study reaches in the eastern Sierra Nevada Mountains, occurring only in microenvironments of relatively low shear stress: as small pockets in sites of flow divergence or as larger deposits upstream of natural hydraulic controls (e.g., logjams or beaver dams). All tracer gravels emplaced in gravel pockets at nine sites on four streams in 1986 (a wet year) were completely swept away. Gravel mobility was accompanied by substantial scour and fill and other changes in many of the channel cross sections. This mobility may explain the relative abundance of brown trout over rainbow trout in the study reaches, where high flows occur every May and June during snowmelt season. Brown trout are fall spawners; their fry emerge long before the high snowmelt flows. Rainbow trout are spring spawners; their eggs are in the gravel, and thus vulnerable to scour, during snowmelt flows.

Kondolf, G.M., L.M. Maloney, and J.G. Williams, "Effect of Bank Storage and Well Pumping on Base Flow," *Journal of Hydrology*, 91, 1987, pp. 351-369.

Bank storage contributions to base flow may be important on alluvial rivers with highly permeable bank materials, such as the lower Carmel River, Monterey County, California. The recharge phase of bank storage occurs during flood stage in the river when a hydraulic gradient exists from the river into the banks. In general,

discharge from bank storage is most important on the recession limb of individual floods, with most stored water typically being discharged within 2–3 flood periods. As the river stage continues to fall, a hydraulic gradient from the banks to the river will be maintained and stored water will drain from the banks. On the Carmel River, the seasonal recession limb provides conditions of a gradually declining stage over several months. In 1982, a moderately wet year, bank storage contributions were detected two months after the last peak flow of the winter rainy season, during a period of critical importance to steelhead trout and probably to riparian vegetation. However, in 1983, an extremely wet year, bank storage was undetectable two months after the season's last peak flow, probably because the sustained base flow from the upper basin overwhelmed the more transient bank storage contribution. Groundwater withdrawal from the alluvial aquifer locally lowered the water table so that streamflow was influent to the banks in the reach of major pumping wells. This effect was striking in its persistence, whether the Carmel River was gaining or losing overall in its alluvial reach. Pumping rates were roughly comparable to flow losses across the well field.

Kondolf, G.M., G.F. Cada, and M.J. Sale, "Assessment of Flushing Flow Requirements for Brown Trout and Spawning Gravels, Eastern Sierra Nevada," *Water Resources Bulletin*, 23, 5, 1987, pp. 927–935.

Flushing flows are releases from dams designed to remove fine sediment from downstream spawning habitat. Flushing flows were evaluated on reaches proposed for hydroelectric diversions on seven streams in the eastern Sierra Nevada, California, with wild populations of brown trout (*Salmo trutta*). The study reaches are steep (average map slopes range from 7–17%), are dominated by boulder cascades, and afford few opportunities for gravel deposition. Methods for estimating flushing flows from flow records, developed from studies in other localities, produced widely differing results when applied to the study streams, probably reflecting differences in the hydrologic and geomorphic characteristics

of the streams on which the methods were developed. Tracer gravel experiments demonstrated that all sampled gravels were washed out by the flows of 1986, a wet year. Size analyses of gravel samples and hydraulic data from field surveys were used in tractive-force calculations in an attempt to specify the flow required to flush the gravels. However, these calculations produced some unrealistic results because the flows were nonuniform in the study reaches. This suggests that the tractive-force approach may not be generally applicable to small, steep streams where nonuniform flow conditions prevail.

Nettles, D.C., and S.P. Gloss, "Outmigration of Landlocked Atlantic Salmon Smolts and Effectiveness of an Angled Trash Rack/Fish Bypass Structure at a Small Scale Hydroelectric Facility," *North American Journal of Fisheries Management* 7, 1987, pp. 562–568.

Downstream movements by smolts of Atlantic salmon (*Salmo solar*) were monitored with radio telemetry to assess the effectiveness of an angled trash rack/fish bypass structure at a small hydroelectric dam on the Boquet River, New York. Telemetry of 170 Atlantic salmon smolts and visual observations of stocked smolts were used to determine aspects of Atlantic salmon outmigration behavior. Smolts initiated mass migrations after river temperatures reached or exceeded 10°C.

Many radio-tagged smolts interrupted movements upon reaching ponded waters and/or the dam. River flow did not ($P > 0.05$) affect the frequency of migratory movements, passages, or rate of movement. Migrations lasted approximately 30 d. Passages at the dam occurred primarily at Night (61%) with diurnal passages (17%) and crepuscular passages (17%) of secondary importance. Timing of 5% of the passages was undetermined. All passages which occurred when angled trash racks were in place were through the bypass or over the spillway. Six passages occurred when trash racks perpendicular to the penstock were in place: three of these were penstock passages. The angled trash rack and

bypass structure significantly reduced entrainment through the penstock and turbine ($P > 0.05$).

Cada, G.F., and C.T. Hunsaker, "Cumulative Impacts of Hydropower Development: Reaching a Watershed in Impact Assessment." *The Environmental Professional* 12, 1990, pp. 2–8.

The "hydropower rush" brought about by passage of the Public Utility Regulatory Policy Act of 1978 caused concerns about cumulative impacts of multiple hydroelectric developments. These concerns have led the Federal Energy Regulatory Commission, which is responsible for licensing non-federal hydroelectric projects, to conduct cumulative impact assessments. Hydropower impacts can be grouped into four potential pathways, ranging from simple, additive effects of a single project to synergistic effects arising from multiple projects. The fisheries and water quality aspects of studies for three basins (San Joaquin, Owens, and Ohio river basins) are described in this context. These regional studies and the national study of environmental impacts of hydropower development (required by the Electric Consumers Protection Act of 1986) illustrate appropriate spatial and temporal scales for effective cumulative impact assessments. Although regional assessments of cumulative impacts are often necessary to give context to local assessments, the lack of regional models and adequate temporal and spatial data frequently hinders the quantification of cumulative impacts.

Cada, G.F., "The Effects of Turbine Passage on Fish Early Life Stages." Submitted to the *North American Journal of Fisheries Management* 10, 4, 1990, pp. 418–426.

Although few studies have directly quantified ichthyoplankton mortality at hydroelectric installations, there is a considerable body of literature that examines the various stresses (i.e., pressure changes, blade contact, and shear) affecting turbine-entrained eggs and larvae. Analysis of this information indicates that turbine-passage mortality of early life stages of fish would be relatively low at low-head, bulb turbine installations. The shear forces and pressure regimes experi-

enced are unlikely to cause mortality. Probability of contact with turbine blades is related to the size of the fish; less than 5 percent of entrained ichthyoplankton would be affected. Potential additional sources of mortality that are related to the design and operation of the hydroelectric facility, and thus are mitigable, include withdrawal of deep water and cavitation.

Chang, S.Y., S.L. Liaw, M.J. Sale, and S.F. Railsback, "Methods For Generating Hydroelectric Power Development Alternatives," *Systems Analysis for Water Resources Management: Closing the Gap Between Theory and Practice*, D. P. Loucks (ed.). IAHS Publication No. 180, International Association of Hydrologic Sciences, Wallingford, United Kingdom, 1989, pp. 43–52.

Hydropower development on large rivers can result in a number of environmental impacts, including potential reductions in dissolved oxygen (DO) concentrations. This study presented a methodology for generating different hydropower development alternatives for evaluation. This methodology employs a Streeter–Phelps model to simulate DO, and the Bounded Implicit Enumeration algorithm to solve an optimization model formulated to maximize hydroelectric energy production subject to acceptable DO limits. The upper Ohio River basin was used to illustrate the use and characteristics of the methodology. The results indicate that several alternatives which meet the specified DO constraints can be generated efficiently, meeting both power and environmental objectives.

PURPA Benefits at New Dams and Diversions. Final Staff Report, Docket No. EL 87–9, Federal Energy Regulatory Commission, Office of Hydropower Licensing, Washington, D.C., 1988. (Prepared by ORNL and ELI).

This study, mandated by the Electric Consumers Protection Act (ECPA) of 1986, evaluated the economic and environmental effects of granting or denying PURPA benefits for hydroelectric projects located at new dams and diversions throughout the U.S. Staff concluded that the continuation of PURPA benefits without the

environmental constraints defined by IECPA would provide incentives for private or non-utility (i.e., PURPA-qualified) development of up to 84 new projects, with a total capacity of about 1,500 MW, that would not be developed without PURPA benefits. However, this unconstrained development at new dams and diversions would also involve the potential for substantial adverse environmental impacts to anadromous and other important fisheries and to recreational and aesthetic resources, particularly in the Pacific Northwest, California, and Colorado. The continuation of PURPLA benefits with the environmental constraints defined by ECPA would provide incentives for private or nonutility development of 34 new projects with a capacity of about 500 MW and with minimal environmental impacts. The ECPA environmental constraints would effectively preclude the development of approximately 50 sites with a capacity of 1,050 MW, but would have the intended benefits of minimizing potential adverse environmental impacts.

Hydroelectric Development in the Upper Ohio River Basin—Final Environmental Impact Statement. FERC/FEIS-0051, Docket No. EL85-19-114. Federal Energy Regulatory Commission, Office of Hydropower Licensing, Washington, D.C., 1988. (Prepared by ORNL).

Twenty-four hydroelectric projects (including competing applications at five sites) that would produce a total of 1910 gigawatt-hours per year of electric power were evaluated to determine the environmental effects and economic benefits. Four hydroelectric generation alternatives and a 400-megawatt coal-fired power plant were examined in the assessment. The cumulative and site-specific impacts of the projects were analyzed, taking into account the potential for mitigating adverse impacts. The staff recommended an alternative which would allow development of hydroelectric projects at 16 of the 19 proposed sites. The recommended alternative would permit 1560 gigawatt-hours of new hydroelectricity to be produced (82 percent of the power proposed by project applicants); would prevent projects

from causing dissolved oxygen concentrations low enough to affect aquatic life; and would avoid significant adverse impacts to wetlands, fisheries, and recreation.

Hildebrand, S.G., and G.F. Cada, *Case Studies Defining Environmental Issues for Non-Federal Hydroelectric Development in the United States*. UNESCO International Hydroelectric Program Phase III Report, 1989. (In press).

This paper reviews five recent examples of FERC hydroelectric licensing actions: the Susitna project in Alaska, multiple-project development in the Owens (CA) and upper Ohio River basins, the El Portal project (CA), and a national assessment of federal incentives for development at new dams and diversions. Each project is briefly discussed, significant findings regarding environmental impacts are summarized, and recommendations resulting from the impact analyses and the ultimate decision on the projects are reviewed. These projects represent a range of actions typical of hydroelectric development in the United States.

Kondolf, G.M., G.F. Cada, M.J. Sale, and T. Felando, "Distribution of Potential Salmonid Spawning Gravels in Steep Boulder-Bed Streams of the Eastern Sierra Nevada," *Transactions of the American Fisheries Society*, 1989. (In press).

Geomorphic and hydraulic characteristics of salmonid spawning habitat were studied in high-gradient, boulder-bed streams atypical of the more commonly described lower-gradient channels. Gravel deposits were not abundant in the study reaches, occurring only in microenvironments of relatively low shear stress. Gravel mobility was accompanied by substantial scour and fill and other changes in many of the channel cross sections. This mobility may explain the relative abundance of brown trout over rainbow trout in the study reaches, where high flows occur every May and June during snowmelt season. Brown trout are fall spawners; their fry emerge long before the high snowmelt flows. Rainbow trout are spring spawners; their eggs are in the

gravel, and thus vulnerable to scour, during snowmelt flows.

Petrich, C.H., S.F. Railsback, and M.M. Swihart. "Assessment of Instream Flow Impacts on Recreational and Aesthetic Resources." *Legal, Institutional, Financial, and Environmental Aspects of Water Issues*, G.R. Baumli (ed.), American Society of Civil Engineers, New York, 1989, pp. 100–107.

This paper examined means for identifying a protecting recreational and aesthetic resources which could be affected by water resource development. Water resource managers need to understand when instream flows to protect recreational and aesthetic values should be considered along with competing water uses. The recreational value of proposed instream flow rates can be estimated from surveys of users and changes or projected changes in tourist industry income, recreational usage, and aquatic habitat. From quantification of these values, concerns about minimum flow rates can be factored into impact analyses and management decisions. Secondary impacts to recreation and aesthetics resulting from changes in riparian vegetation and fish populations can also be assessed. In some cases, dollar values can be reasonably assigned. Recreational and aesthetic values need no longer be addressed in only a cursory way, because reliable techniques for their quantification are now available and are compatible with methods used to evaluate other resource-related impacts of changes in instream flows.

Railsback, S. F., J. Bownds, M. J. Sale, M. Stevens, and G. H. Taylor. 1989. "Aeration at Ohio River Basin Navigation Dams," *Journal of Environmental Engineering*, 116, 2, 1990, pp. 361–375.

Aeration was measured and modeled at 28 navigation dams in the upper Ohio River basin to assess impacts of retrofitting hydropower turbines. Dissolved oxygen (DO) concentrations upstream and downstream of the dams, water temperatures, and flow rates were measured under a variety of low-flow, high-temperature

conditions. The DO concentration downstream of each dam was modeled as a linear function of the other variables. The DO deficit upstream was found to be a consistently significant predictor of DO deficits downstream of a dam. Inclusion of temperature and flow rate generally did not improve the statistical aeration models. The field data show that super saturation can occur at some dams; this means that the reaeration ratio used by many aeration models, including Gameson's equation, cannot be assumed to model dam aeration accurately. The linear models reproduced historic aeration measurements as well as Gameson's equation did when a least-squares parameter estimation method was used to parameterize the equation. For dams where supersaturation occurs, Gameson's equation did not predict aeration as well as the linear model. These results are applicable to assessing the impacts of hydropower which reduces aerated flows at navigation dams.

Railsback, S.F. and H.I. Jager. 1988. *Simulation Modeling of Hydropower Impacts on Dissolved Oxygen in the Upper Ohio River Basin*, RNL/TM-10953. Oak Ridge National Laboratory, Oak Ridge, TN.

A deterministic simulation model was developed to assess the impacts of hydropower development at navigation dams on dissolved oxygen (DO) concentrations in the upper Ohio River basin. Field data were used to fit statistical models of aeration at each dam. The Streeter-Phelps equations were used to model DO concentrations between dams. Input data sources were compiled, and the design conditions used for assessment of hydropower impacts were developed. The model was implemented both as a Lotus 1–2–3 spreadsheet and as a FORTRAN program. The report contains users' guides for both of these implementations. The sensitivities and uncertainty of the model were analyzed. Modeled DO concentrations are sensitive to water temperature and flow rates, and sensitivities to dam aeration are relatively high in reaches where dam aeration rates are high. Uncertainty in the model was low in reaches dominated by dam aeration and higher in reaches with low dam aeration rates. The 95% confidence intervals for the

model range from about ± 0.5 mg/L to about ± 1.5 mg/L.

Railsback, S.F., "Dissolved Oxygen Strategies for Hydropower Licensing." *Hydro Review* 7, 3, 1988, pp. 52–64.

Dissolved oxygen is an important environmental concern at many hydropower projects. For proposed new developments, license applicants should consider whether or not their project would cause DO problems, by considering whether they would create stratified reservoir, or whether their project would alter important sources of aeration. A license applicant should define the scope and magnitude of the DO problem as accurately as possible, to reduce the uncertainty in the amount of mitigation required. Predictive methods, such as statistical or mathematical models, should be developed as necessary to evaluate DO concentrations under various operating conditions. Once the range of DO concentrations (over space and time) resulting from the project has been determined, and the DO concentrations likely to be required by the permitting process have been determined, the need for mitigation can be determined. A thorough understanding of the processes that add DO to and consume DO in the river is useful in finding the most cost-effective way to increase DO concentrations. Cost-effective mitigation is important, because it affects the economic benefits of the project, which is a major consideration to FERC in making licensing decisions.

Railsback, S.F., M.J. Sale, and S. Y. Chang, "Development of Flow Releases for Water Quality Protection at Hydroelectric Plants at Ohio River Basin Navigation Dams," *Water Resources Planning and Management, Proceeding of the 16th Annual Conference*, S.C. Harris (ed.), American Society of Civil Engineers, New York, 1989, pp. 555–558.

The upper Ohio River system, including the Monongahela and Allegheny rivers, is used for navigation, recreation, waste assimilation, and power plant cooling. The installation of hydro-

electric plants is proposed at 18 existing navigation dams along 740 river km of this system. Six additional plants are already operating or under construction. Because these projects are on canalized rivers, aeration at dams is an important source of dissolved oxygen (DO). The Federal Energy Regulatory Commission must decide whether to license each of the proposed projects. To aid decision-making, a modeling study was conducted to predict the effects of changes in dam aeration on water quality. The assessment used a system-wide water quality model to determine the cumulative changes in DO concentrations resulting from changes in aeration at the chain of navigation dams. An optimization model was developed to determine aeration releases at each dam that would maintain desired DO concentrations and maximize power production in the basin.

Railsback, S.F., J.J. Beauchamp, and D.J. Downing, "Comparison of Time-Series and Regression Methods for Synthesizing Missing Streamflow Records on the Merced River, California." *Water Resources Bulletin*, 1989, in press.

Regression and time-series techniques have been used to synthesize and predict the stream flow at the Foresta Bridge gage from information at the upstream Pohono Bridge gage on the Merced River near Yosemite National Park. Two techniques were evaluated for their ability to model the variation in the observed flows and to predict stream flow at the Forest Bridge gage in 1979 using data from the 1986 water year. Both techniques produced reasonably good estimates and forecasts of the flow at the downstream gage. However, the regression model was found to have a significant amount of autocorrelation in the residuals, which were eliminated in the time-series model. The time-series technique presented can be of great assistance in arriving at reasonable estimates of flow in data sets with many missing observations.

Railsback, S.F., B.D. Holcomb, and M.G. Ryon, *A Computer Program for Estimating Fish Population Sizes and Annual Production Rates*,

ORNL/TM-11061, Oak Ridge National Laboratory, Oak Ridge, TN, 1989.

A computer program to estimate fish population sizes and annual production rates from multiple-pass sampling data was developed. The multiple-pass sampling method is commonly used to study fish populations in streams, but software to calculate annual production rates from general multiple-pass data has not been available. The program uses the Carle and Strub maximum weighted likelihood method to estimate population sizes, and the size-frequency method of Garman and Waters to estimate annual production. The program was designed to be easily applied to a wide variety of sample sites, fish species, and fish sizes. New techniques to estimate the variance in annual production rates were incorporated.

Sale, M.J., G.F. Cada, and J.M. Loar, "Trout-Habitat Relations in Southern Blue Ridge Streams," *Proceedings, An Instream Flow Workshop for Fish Biologists*. Tech Aqua, Tennessee Technological University, Cookeville, Tennessee, 1988, pp. 19-20.

A study was conducted to evaluate the validity of physical habitat indices for predicting the response of trout populations to changes in stream flow, focusing fish/habitat relationships. The results showed that habitat values do appear to be related to trout resources (e.g., biomass and abundance), and that the presence of food limitation does not eliminate a positive response to habitat. To predict the response of trout populations to flow alteration, it is recommended that (1) habitat variables be carefully chosen with respect to critical life stages and periods of the year, (2) site-specific interactions between target species be considered, and (3) management objectives be clearly defined. The most appropriate habitat indices are those based on minimum values calculated over the period that a given life state is present. When used properly, habitat variables can be useful in assessing changes in fishery resources resulting from flow alterations.

Sale, M. J., S. F. Railsback, S. Y. Chang, C. C. Coutant, R. E. Spath, and G. H. Taylor, "Balancing Hydropower Development in the Ohio River Basin," *Proceedings, International Conference on Hydropower: Waterpower '89, Buffalo, New York, August 23-25, 1989*, pp. 886-896.

Many retrofit hydroelectric projects have been proposed at existing navigation dams in the Ohio River basin. These proposals involve potentially adverse environmental impacts, including reduced dissolved oxygen concentrations from decreased aeration at dams. The Federal Energy Regulatory Commission completed an environmental impact statement for 24 proposed projects at 19 dams on the Ohio, Monongahela, Allegheny, and Muskingum rivers, evaluating the cumulative impacts of hydropower development on more than 500 miles (800 km) of river. The use of models in this assessment proved extremely valuable for understanding the cumulative impacts of hydropower development on water quality in the basin and for balancing power and environmental quality considerations in the licensing process.

Sale, M. J., "Multiple-Resource Management of Tailwaters for Downstream Needs," *Tailwater Ecology Workshop, Proceedings/Summary of a North American Lake Management Society Session, St. Louis, Missouri, 15 November 1988*, S. Campbell (ed.), U.S. Bureau of Reclamation, Denver, Colorado, 1989, pp. 52-53.

Managing tailwaters means allocating water among competing uses. The water quality and quantity released from dams is important to numerous downstream uses, including fish and wildlife habitat needs, recreation, navigation, hydroelectric generation, public industrial water supply, sediment transport, and waste assimilation. As a result, multipurpose management is unavoidable. No single user can dominate and users who approach the decision-making table without an appreciation for their competitors' needs will be at an extreme disadvantage. To conduct multipurpose management, it is necessary to make the tradeoffs among competing uses, hopefully using rational methods. When the parties in a water allocation problem do not participate in

the negotiation process by evaluating their water uses and objectives, the loser is usually one or more of the resources.

*Chang, L. H., and S. F. Railsback, 1990. "Predicting Effects of Global Climate Change on Reservoir Water Quality and Fish Habitat," *Optimizing the Resources for Water Management, Proceedings of the 17th Annual National Conference, Water Resources Planning and Management Division*, R. M. Khanbilvardi and T. C. Gooch, eds., American Society of Civil Engineers, New York, 1990, pp. 545–550.

The output from three general circulation models (GCMs) was used with a reservoir model to predict changes in water temperature, dissolved oxygen, and adult striped bass habitat that would result from global climate change. The predicted changes in air temperature, humidity, runoff, solar radiation, and wind speed were used to adjust input to a two-dimensional water quality model of Douglas Reservoir, a multipurpose project in eastern Tennessee. The reservoir model was used to simulate water temperatures and dissolved oxygen concentrations in each of over 150 volume elements. The reservoir model also simulates adult striped bass habitat, which is defined as the volume of water with both dissolved oxygen concentration and temperature within ranges acceptable to this fish. Simulations of a full year were conducted with data from 1974, a climatically typical year for which the model was calibrated. Uncertainties in the use of GCMs for studies of climate change impacts on ecosystems include differences in climate change predictions among the various GCMs, errors induced by the coarse spatial resolution of GCMs, and approximations included in the GCM formulations for modeling climatic processes (especially for surface hydrology). The GCM uncertainties are in addition to the uncertainties normally occurring in reservoir modeling. However, simulations made with the different GCM-generated climate scenarios all predicted summer water temperature increases sufficient to cause

major decreases in striped bass habitat. Sensitivity analyses showed that increases in wind speed, which some of the GCMs predict, could reduce the habitat loss to some extent. Despite the uncertainties involved in using GCMs to predict the effects of global climate change, the consensus among results obtained with different GCMs supports the conclusion that climate change will result in significantly higher water temperatures and reduced habitat for adult striped bass in Douglas Reservoir. GCM results can be used with a reservoir model to predict local effects of global climate change.

*Railsback, S. F., C. C. Coutant, and M. J. Sale, "Improving the Effectiveness of Fisheries Agencies in Developing Hydropower Mitigation," *Fisheries* 15, 3, 1990, pp. 3–8.

New legislation and Federal Energy Regulatory Commission (FERC) regulations increase the responsibilities of state and federal fisheries management agencies for developing mitigation for hydropower projects. Having participated in some of the first major licensing cases since these changes, we offer observations on how agencies can be more effective in recommending mitigation measures that protect fisheries. Fisheries agencies need access to expertise in fields outside traditional fisheries management to address diverse hydropower impacts. Agencies need effective policies that can be applied to the specific conditions at each project. Coordination and communication between regulatory and resource agencies and with project applicants are important to establish agreement on mitigation recommendations and to share expertise. Agencies will often need to make recommendations on issues for which complete information is not available; if carefully designed, such recommendations can be defensible and conservative. A thorough understanding of current FERC procedures and policies is essential. Many of these same recommendations for effective mitigation are included in the U.S. Fish and Wildlife Service's hydropower mitigation policy.

* An asterisk (*) before the title indicates the publication has been added to the Bibliography in this biennial report.

*Railsback, S. F., and M. J. Sale, "Application of Optimized Water Quality Mitigation to Hydropower Development in the Ohio River Basin," *Water Resource Systems Application*, S. P. Simonovic et al., eds, University of Manitoba, Winnipeg, Canada, 1990, pp. 413–422.

An optimization model was used to determine spill flow requirements for 16 proposed hydropower projects at existing navigation dams in the upper Ohio River Basin. Spill flows are required to provide aeration sufficient to meet dissolved oxygen criteria in this system where effects of individual projects are interactive and cumulative. The optimization model maximizes total power generation of the projects while meeting the dissolved oxygen criteria during critical design conditions. Although some fisheries agencies disputed the use of modeling to determine spill flow requirements, the modeling technique was accepted by the hydropower licensing commission and the results were included in the operating licenses for the 16 projects.

*Railsback, S. F., G. F. Cada, C. H. Petrich, M. J. Sale, J. A. Shaakir-Ali, J. A. Watts, and J. W. Webb, *Environmental Impacts of Increased Hydroelectric Development at Existing Dams*, ORNL/TM-11673. Oak Ridge National Laboratory, Oak Ridge, Tenn., 1991.

This report describes the environmental impacts of a proposed U.S. Department of Energy (DOE) initiative to promote the development of hydropower resources at existing dams. This development would include upgrading existing hydropower plants and retrofitting new projects at dams where no hydropower currently exists. Hydropower development at existing dams has, in general, fewer impacts than development of additional fossil-fueled resources or hydropower at new dams, although potential cumulative impacts of developing multiple hydropower projects have not been explicitly addressed. Environmental review of project impacts and mitigation needs can ensure that additional hydropower

development at existing dams can provide a renewable, domestic energy resource with fewer impacts than alternative resources.

*Railsback, S. F., G. F. Cada, L. H. Chang, and M. J. Sale, "Review of Mitigation Methods for Fish Passage, Instream Flows, and Water Quality" *Proceedings, International Conference on Hydropower: "Waterpower '91," Denver, Colorado, July 24–26, 1991*. (In press).

Current environmental mitigation practices at nonfederal hydropower projects were analyzed, using information obtained from project developers on dissolved oxygen (DO), instream flow, and fish passage issues. The most common method for DO mitigation is the use of spill flows, which are costly because of lost power generation. DO concentrations are commonly monitored, but biological effects (i.e., benefits) are not. At many projects, instream flow requirements have been set without reference to formalized methods, or with reliance on professional judgements. Very few projects monitor fish populations to verify that instream flows are effective. Angled bar racks are the most commonly used mitigation practice for downstream fish passage, and fish ladders are the most common for upstream fish passage. Fish passage rates or populations have been monitored to verify the effectiveness of passage mitigation at few projects. This analysis is the first stage of an evaluation of the costs, benefits, and effectiveness of mitigation measures.

*Sale, M. J., and R. G. Otto. 1991. "Improving the Assessment of Instream Flow Needs for Fish Populations" *Proceedings, International Conference on Hydropower: "Waterpower '91," Denver, Colorado, July 24–26, 1991*. (In press).

Instream flow requirements are one of the most frequent and most costly environmental issues that must be addressed in developing hydroelectric projects. Existing assessment methods for determining instream flow requirements have been criticized for not including all the biological response mechanisms that regulate fishery

* An asterisk (*) before the title indicates the publication has been added to the Bibliography in this biennial report.

resources. A new project has been initiated to study the biological responses of fish populations to altered stream flows and to develop improved ways of managing instream flows. The proposed assessment approach uses individual-based population modeling that represents fish populations as a collection of individuals and focuses on the life history processes of individual fish by life stage. The assessment models developed under this project should provide a more realistic way of examining the tradeoffs between flow regulation and fish resources below hydroelectric projects.

Legal and Institutional Aspects

Hydroelectric Regulatory Studies. This series of reports and report summaries describes and analyzes the hydroelectric regulatory process of various states. They include a discussion of state water law, environmental regulation, hydroelectric construction regulation, state tax, and finance issues. An introductory section explains the relationship of state and Federal hydroelectric regulation. The Federal report provides similar analysis of the role of the Federal Government in the regulation and development of hydroelectric projects. These reports were presented at regional conferences. The conference reports contain the proceedings of the conference.

Preliminary Analysis of Legal Obstacles and Incentives to the Development of Low Head Hydroelectric Power in the Northeastern United States, Energy Law Institute, Franklin Pierce Law Center, Concord, New Hampshire, 1979. NTIS No. DOE/RA/04924-01.

Legal Obstacles and Incentives to the Development of Small-Scale Hydroelectric Potential, Franklin Pierce Law Center, 1980. NTIS Identification Nos:

DOE/RA/04934-09	Illinois
DOE/RA/04934-10	Kentucky
DOE/RA/04934-11	Rhode Island
DOE/RA/04934-12	New Hampshire

DOE/RA/04934-13	Delaware
DOE/RA/04934-14	New York
DOE/RA/04934-15	Virginia
DOE/RA/04934-16	New Jersey
DOE/RA/04934-17	Pennsylvania
DOE/RA/04934-18	Maryland
DOE/RA/04934-19	Wisconsin
DOE/RA/04934-20	Maine
DOE/RA/04934-21	Vermont
DOE/RA/04934-22	West Virginia
DOE/RA/04934-23	Connecticut
DOE/RA/04934-24	Massachusetts
DOE/RA/04934-25	Michigan
DOE/RA/04934-26	Ohio
DOE/RA/04934-27	Indiana.

Federal Legal Obstacles and Incentives to the Development of the Small-Scale Hydroelectric Potential in the Nineteen Northeastern States, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-29.

Federal Legal Obstacles and Incentives to the Development of the Small-Scale Hydroelectric Potential in the Nineteen Northeastern States: Executive Summary, Franklin Pierce Law Center, 1978. NTIS No. DOE/RA/04934-41.

Executive Summary: Legal Obstacles and Incentives to the Development of Small-Scale Hydroelectric Potential in the Six New England States, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-08.

Summary of the Mid-Atlantic Conference on Small-Scale Hydropower in the Mid-Atlantic States: Resolution of the Barriers Impeding its Development, Franklin Pierce Law Center, 1979. NTIS No. DOE/RI/04934-04.

Executive Summary: Legal Obstacles and Incentives to Small-Scale Hydroelectric Development in the Six Middle Atlantic States, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-06.

Summary of the Midwest Conference on Small-Scale Hydropower in the Midwest: An Old Technology Whose Time Has Come, Franklin Pierce Law Center, 1979. NTIS No. DOE/RA/04934-05.

Summary of the New England Conference on Legal and Institutional Incentives to Small-Scale Hydroelectric Development, Franklin Pierce Law Center, 1979. NTIS No. DOE/RA/04934-03.

Executive Summary: Legal Obstacles and Incentives to the Development of Small-Scale Hydroelectric Potential in the Seven Mid-Western States, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-08.

Case Study Reports. These case study reports examine the process of development at a particular hydropower site from a regulatory, economic, tax, and finance perspective. The studies examine development by various entities, including private development, municipal development, development at an Army Corps dam, and utility development. A summary report of all five case studies highlights the findings of each report.

A Case Study Analysis of Legal and Institutional Obstacles and Incentives to the Potential Hydroelectric Development of High Falls State Park, Georgia, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-34.

A Case Study Analysis of Legal and Institutional Obstacles and Incentives to the Development of the Hydroelectric Development at the Maxwell Locks and Dam, Pennsylvania, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-36.

A Case Study Analysis of Legal and Institutional Obstacles and Incentives to the Development of the Hydroelectric Potential at Goose River,

Maine, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-32.

A Case Study Analysis of Legal and Institutional Obstacles and Incentives to the Development of the Cornell Hydro Project at Cornell, Wisconsin, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-35.

A Case Study Analysis of Legal and Institutional Obstacles and Incentives to the Development of the Hydroelectric Power of the Boardman River at Traverse City, Michigan, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-33.

Case Studies of the Legal and Institutional Obstacles and Incentives to the Development of Small-Scale Hydroelectric Power: Executive Summary, National Conference of State Legislatures, Denver, Colorado, and Franklin Pierce Law Center, 1979. NTIS No. DOE/RA/23220-01.

Finance, Tax, and Economic Reports.

These reports examine the tax and financing issues associated with small-scale hydropower development, including energy tax credit availability and rules, structures for transferring tax benefits, and tax exempt financing. The reports examine these issues for private and municipal development.

A state tax report surveys the hydroelectric and business tax provisions of various states.

Two economic papers survey the development issues of hydropower and examine the theory of monopsony and how it acts to constrain purchase prices for power.

The Financing of Private Small-Scale Hydroelectric Projects, prepared by the Energy Law Institute for the U.S. Department of Energy, March 1981. NTIS No. DOE/CE/04934-45.

A Manual for Development of Small-Scale Hydroelectric Projects by Public Entities, Prepared by the Energy Law Institute for the U.S. Department of Energy, March 1981. NTIS No. DOE/CE/04934-45.

State Taxation of Small-Scale Hydroelectric Facilities in the Nineteen Northeastern United States, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-30.

Fundamental Economic Issues in the Development of Small-Scale Hydro, Franklin Pierce Law Center, 1979. NTIS No. DOE/RA/04934-02.

Two Economic Papers: (1) Monopsony Power and the Supply of Power From Small Generating Stations (2) A Preliminary Economic Analysis of the Value of Contributions by Small Dams to System Generation Reliability, Franklin Pierce Law Center, 1980. NTIS No. DOE/RA/04934-42.

Reports on Avoided Cost Ratemaking.

This series of reports examines the initial implementation of Section 210 of the Public Utility Regulatory Policies Act of 1978 (PURPA) by various state public utility commissions. The reports highlight the various legal, policy, and economic issues addressed by the particular regulatory commission. The reports also examine any state laws modeled after PURPA and their relationship to the Federal law. Each report contains annotations of the PURPA rulemaking which highlight the various interpretations of the rule by state commissions. Developer handbooks contain this information as well as information on the various electric utilities within the state.

Developer Handbook for Section 210 of PURPA Energy Law Institute, Franklin Pierce Law Center, 1982. NTIS Nos.:

DOE/RA/04934-T2	Montana
DOE/RA/04934-T11	Georgia
DOE/RA/04934-T12	New Hampshire
DOE/RA/04934-T17	New York
DOE/RA/04934-T18	Arkansas
DOE/RA/04934-T19	Oregon
DOE/RA/04934-T21	Vermont
DOE/RA/04934-T23	Massachusetts

DOE/RA/04934-T24 North Carolina

DOE/RA/04934-T25 TVA

DOE/RA/04934-T26 Maine

DOE/RA/04934-T27 Connecticut

DOE/RA/04934-T28 Pennsylvania

DOE/RA/04934-T29 Virginia

DOE/RA/04934-T31 Colorado

DOE/RA/04934-T33 Rhode Island.

Public Utility Commission Manuals for Section 210 of PURPA, Energy Law Institute, Franklin Pierce Law Center, 1982. NTIS Nos.:

DOE/RA/04934-T3 New York

DOE/RA/04934-T4 Vermont

DOE/RA/04934-T5 Rhode Island

DOE/RA/04934-T6 Pennsylvania

DOE/RA/05934-T7 Arkansas

DOE/RA/04934-T8 Virginia

DOE/RA/04934-T10 Georgia

DOE/RA/04934-T13 Oregon

DOE/RA/04934-T14 North Carolina

DOE/RA/04934-T15 Massachusetts

DOE/RA/04934-T16 Colorado

DOE/RA/04934-T20 Maine

DOE/RA/04934-T22 Connecticut

DOE/RA/05934-T30 Montana

DOE/RA/04934-T32 New Hampshire.

Project Monitor Reports. This series of reports reviews on a regular basis the recent developments in the area of small scale hydro-power development. The topic areas include Federal Energy Regulatory Commission activities, Environmental Regulation Federal Resource

Agencies, State Electric Utility Regulatory Agencies, and Tax and Finance Issues.

Small Scale Hydropower Program Legal and Institutional Aspects, Project Monitor Reports, Energy Law Institute, Franklin Pierce Law Center, January 1985. NTIS No. DOE/RA 04934-1.

Small Scale Hydropower Program Legal and Institutional Aspects, Project Monitor Report, ELI Corporation, July 1986. NTIS No. DOE/ID-10133-3.

Small Scale Hydropower Program Legal and Institutional Aspects, Project Monitor Report, ELI Corporation, April 1986. NTIS No. DOE/ID-10133-2.

Small Scale Hydropower Program Legal and Institutional Aspects, Project Monitor Report, ELI Corporation, January 1986. NTIS No. DOE/ID-10133-1.

Small Scale Hydropower Program Legal and Institutional Aspects, Project Monitor Report, ELI Corporation, October 1985. NTIS No. DOE/ID-10133.

Small Scale Hydropower Program Legal and Institutional Aspects, Project Monitor Report, Energy Law Institute, September 1985. NTIS No. DOE/RA/04934-2.

General

Small-Scale Hydroelectric Power in the Southeast, New Impetus for an Old Energy Source, National Conference of State Legislatures, 1980. NTIS No. DOE/RA/23220-05.

Hydropower Sites of the United States Developed and Undeveloped, this FERC atlas may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. GPO Stock No. 429-V-5.

Rivers of Energy; The Hydropower Potential, Daniel Deudney, Worldwatch Institute, 1776

Massachusetts Avenue, N.W., Washington, D.C. 20036. Copies may be ordered from this address.

Gladwell, J. S., L. F. Heitz, C. C. Warnick, *A Resource Survey of Low Head Hydroelectric Potential, Pacific Northwest Region, Completion Report, Phase I, Volume A*, March 1979, NTIS No. DOE/RA/01691.

Gladwell, J. S., L. F. Heitz, C. C. Warwick, *A Resource Survey of Low Head Hydroelectric Potential at Existing Dams and Proposed Sites in the Pacific Northwest Region: Phase II*, September 1979. NTIS No. DOE/RA/01691-2.

Simplified Methodology for Economic Screening of Potential Low Head Small-Capacity Hydroelectric Sites (EM-1679), published by the Electric Power Research Institute. This technical report may be ordered from the Research Reports Center, P.O. Box 50490, Palo Alto, California 94303, (415) 965-4081. Please specify publication number.

Small and Micro Hydroelectric Power Plant—Technology and Feasibility, edited by R. Noyes. Available from Noyes Data Corporation, Mill Road at Grand Avenue, Park Ridge, New Jersey 07656.

Report on Assessment of Small Hydroelectric Development at Existing Facilities, Water and Power Resources Service, U.S. Department of Interior. NTIS No. PB81-104663.

Western States Inventory of Low Head Hydroelectric Sites, Water and Power Resources Service, U.S. Department of Interior, NTIS Nos. Volume I—PB81-134942, Volume II—PB81-134959.

Staff Report on Retired Hydropower Plants in the United States, Federal Energy Regulatory Commission (FERC). This FERC report is available upon request by writing to Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Request Document No. GPO 061-002-0069-3.

Small Low Head Hydroelectric Power, Proceedings from the Midwest Regional Conference,

May 1978. Michigan State University, College of Engineering, East Lansing, Michigan, August 1978. NTIS No. IDO/10076.

Waterpower '83—International Conference on Hydropower—Conference Proceedings, Knoxville, Tennessee: Volume I: Small and Micro/Min Hydro; and Financing, Licensing, and Legal Issues. NTIS No. DE-84000808. *Volume II—Conventional Hydro and Pumped Storage and Operation of Existing Conventional Hydro Operations.* NTIS No. DE-84000809.

Volume III—Environmental Impacts; Research and Development; Dam Safety; NTIS No. DE-84000810.

Feasibility Studies for Small Scale Hydropower Additions—A Guide Manual. U.S. Army Corps of Engineers, July 1979. NTIS No. DOE/RA/0048.

This is a manual for performing hydropower feasibility assessments, prepared primarily with the practicing engineer in mind. It consists of the following subsections: technical guide, civil features, hydrologic studies, economic and financial analysis, electromechanical features, and existing facility integrity.

Reconnaissance Evaluation of Small, Low Head Hydroelectric Installations, Tudor Engineering, July 1980. NTIS No. PB81-188294.

This is a methodology for assessing projects under both 15,000 kW and 65-foot heads, for reviewing cost data, determining available energy, and financing. Three examples of applying the methodology are presented.

National Hydroelectric Power Resources Study, U.S. Army Corps of Engineers, May 1983. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (202) 783-3238 or -3311.

This plan identifies a set of best-candidate sites for future study of hydroelectric power potential. The plan includes both Federal and

non-Federal sites. The final report comprises the following 23 volumes:

Small-Scale Hydroelectric Power in the Pacific Northwest: New Impetus for an Old Energy Source, National Conference of State Legislatures, 1980. NTIS No. DOE/RA/23220-04.

Hydropower Computerized Reconnaissance Package—Version 2.0, Idaho National Engineering Laboratory, April 1981. NTIS No. IDO-10092.

Kennedy, B. W., *Small Hydropower Turbine Generating System, Final Report,* Guntersville, Alabama, December 1982. NTIS No. DOE/RA/10478-T1.

Goerz, J. W., *Improved Generator for Use with Low-Speed Rotating Machines, Final Report,* Lexington, Kentucky, March 1983. NTIS No. DOE/RA/10249-T1.

Rehder, J. B., *Design and Applications for Floating Hydropower Systems in Small Streams,* Knoxville, Tennessee, January 1983. NTIS No. DOE/RA/10415-T1.

Design and Evaluation of Small Water Turbines, Final Report, Tennessee Technological University, February 1983. NTIS No. DOE/RA/10243-T1.

Hydroelectric Plant Construction Cost and Annual Production, U.S. DOE Energy Information Administration, August 1983. NTIS No. DE-84000243 or DOE/EIA-0171.

Legislation's Guide to Small-Scale Hydroelectric Development, National Conference of State Legislatures, Denver, Colorado, April 1983. NTIS No. DE-83007370 or DOE/RA/23220.

Accomplishments of the Small-Hydro Outreach Program, Final Report, California State Cooperative Outreach Program for Small-Hydro Development, 1981. NTIS No. DE-82016247 or DOE/R9/10034-T1.

Renewable Energy for the Future, Local Government Options for Promoting Development of Renewable Energy Resources, Association of Bay Area Governments, Berkeley, California, October 1981. NTIS No. DE-82014945 or DOE/NBM-2014945.

The Qualifying Facilities Report—A cumulative list of filings made for small power production and cogeneration facilities fiscal year 1980 through fiscal year 1988. Federal Energy Regulatory Commission, Office of Electric Power Regulation, Washington, D.C. 20426, October 1, 1988.

Small Hydro '88—An International Conference and Trade Show—Conference Proceedings. Volume I: Plenary Session; Policy, Planning and Utility Issues. Volume II: Engineering and Technology; Markets and Financing.

International Renewable Energy Conference—Conference Proceedings. May be obtained by writing to: IREC Proceedings Code 4, 73 DBEB Energy Division, 335 Merchant Street, Room 110, Honolulu, Hawaii 96813.

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