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DEPARTMENT OF ENERGY SMALL-SCALE HYDROPOWER PROGRAM FEASIBILITY ASSESSMENT AND TECHNOLOGY DEVELOPMENT SUMMARY REPORT

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SUMMARY

This report summarizes two subprograms of the U.S. Department of Energy Idaho Operations Office (DOE-ID), Small-Scale Hydroelectric Power Program, which was initiated because of the Idaho Teton Dam accident in 1976. The subprograms are the Program Research and Development Announcement (PRDA) Feasibility Assessments, which totalled 55, and Technology Development Projects (formerly known as the Demonstration Projects), which totalled 20. The Feasibility Assessment program initiated by DOE, received and considered support proposals that would add hydroelectric generation capacity to existing dams. This PRDA was for adding a 15 kW to 50 MW hydroelectric generation capacity to existing dams with heads of <65 ft. Individuals, corporations, companies, educational institutions, non-profit 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. A total of 214 proposals were received, but only 55 received awards under the PRDA ET-78-D-07-1706. 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 that provided engineering, economic, environmental, safety, and institutional information.

The DOE Technology Development Program was initiated in conjunction with restoration of three power generating plants in Idaho Falls, Idaho, following damage resulting from the Teton Dam failure of June 5, 1976. DOE issued two Program Opportunity Notices (PON), one in June 1978 and one in June 1979 to expand the program to other sites. Of 89 submitted proposals, 20 were awarded cooperative agreements. DOE participated in a sharing program for each project. The objectives of the Technology Development Program included as follows: 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.

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, and nonpolluting energy resource. The program also contributed to a decrease in demands on finite fossil fuels, importation of foreign oil, and provided cost and performance data to help in future evaluations and equipment selection.

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DEPARTMENT OF ENERGY
SMALL-SCALE HYDROPOWER PROGRAM
FEASIBILITY ASSESSMENT AND
TECHNOLOGY DEVELOPMENT
SUMMARY REPORT

INTRODUCTION

This report summarizes two subprograms under the U.S. Department of Energy's Small-Scale Hydroelectric Power Program. These subprograms were part of the financial assistance activities and included the Program Research and Development Announcement (PRDA) feasibility assessments and the technology development projects. The other major subprograms included engineering research and development, legal and institutional aspects, and technology transfer. These other subprograms are covered in their respective summary reports.

The problems of energy availability and increasing costs of energy led to a national effort to develop economical and environmental attractive alternative energy resources. One such alternative involved the utilization of existing dams with hydraulic heads of <65 ft and the capacity to generate hydroelectric power of 15 MW or less. Thus, the PRDA program was initiated along with the Technology Development program.

The purpose of the PRDA feasibility studies was to encourage development of renewable hydroelectric resources by providing engineering, economic, environmental, safety, and institutional information. Fifty-five feasibility studies were completed under the PRDA. This report briefly summarizes each of those projects. Many of the PRDA projects went on to become technology development projects.

The purpose of the technology development projects initiated under the Program Opportunity Notices (PON) was to demonstrate the technology by cost sharing the design, construction, and operation of hydropower plants. The objectives of the subprograms were as follows:

- To demonstrate that the commercially available technology is economically viable in a commercial-sized plant for small hydroelectric power generation
- To obtain realistic cost data from which commercial production costs could be predicted with a high degree of confidence
- To address specific marketing, environmental, legal and institutional concerns and identify opportunities for direct participation of the private and public sectors in development and demonstration of small hydroelectric energy
- To demonstrate that small hydroelectric resource utilization is compatible with other uses of water
- To provide data on dam safety and structural integrity
- To disseminate initial economic and financial data regarding the cost of constructing, operating, and maintaining small hydroelectric power facilities to instill confidence in the financial community for small hydroelectric power facility investments.

This report summarizes each project under the technology development subprogram. Other topics covered in this report include: "History, Objectives and Funding," "Capacity On-line," "Project Information," "Status," and "Problems and Lessons Learned." The "Reference" section lists the technical reports that were published for each project.

PROGRAM RESEARCH AND DEVELOPMENT ANNOUNCEMENT
(PRDA)
FEASIBILITY STUDY

The Department of Energy (DOE), Idaho Operations Office issued the Program Research and Development Announcement (PRDA) ET-78-D-0701706 December 2, 1977, to solicit proposals for consideration for financial support, with a maximum award of \$100,000 to individual projects. The 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 purpose of the PRDA program was to encourage the development of renewable resources for power generation by providing insight into the requirements for a good feasibility assessment by providing engineering, economic, environmental, safety, and institutional information on small hydropower development.

A total of 214 proposals were received but only 55 received awards using the parameters stated above. The proposals were to address an existing dam site and were to include but not be limited to any of the following: enlargement of existing low-head hydropower sites; reactivation of retired sites, rehabilitation of existing low-head hydropower sites; and construction of hydropower facilities at existing non-hydropower dams. The specific topics included but were not limited to:

- Expected configuration and capacity of the hydropower facility
- Estimated performance characteristics of the hydroelectric power facility including the potential for peak power production and an estimate of average annual energy production
- Expected impact of the hydropower installation on other perceived water resource needs of the area and the current use of the reservoir

- Marketing potential of the power produced
- The necessary requirements of the Federal Energy Regulatory Commission, the U.S. Army Corps of Engineers, and other appropriate federal, state, regional, and local agencies
- Capital investment/installed kW, total cost/kWh, and return on investment
- Anticipated annual operation and maintenance costs
- Anticipated project life
- An assessment of the environmental impact and legal-institutional factors
- An initial assessment of the safety hazard, if any, introduced by the addition or rehabilitation of a power plant and other hydropower appurtenances
- Appropriate analyses resulting in sound judgment as to the engineering acceptability of the proposed site for hydroelectric power development
- Investigation of the availability of a suitable turbine(s), generator(s), and accessories required for the proposed hydroelectric power development
- Development plan (schedule) for putting power online.

SUPPLEMENTARY PROJECT INFORMATION

PRDA NO. ET-78-D-07-1706

The following provides a brief summary taken directly from the 1978 proposal of each of the 55 PRDA projects receiving awards. They are summarized by regions; the assigned number reflects the original proposal number for each application.

New England

- 152 Boott Mills owns Lowell Dam (a 100-year-old overflow dam on the Merrimack River) that diverts water through a canal system. This project proposes development of the hydropower potential on the canal system. This project is located at Lowell, Massachusetts.
- 042 Central Maine Power Company owns the 70-year-old gravity-type overflow Shawmut Dam, project lands, and equipment. The power generating facilities are still generating power. This project, located on the Kennebec River, Maine, has proposed expanding the existing power generation.
- 044 Central Maine Power Company owns the 40-year-old gravity-type overflow Cataract Dam and powerhouse, which is generating power, and proposed expanding the existing power generation. This project is located on the Saco River, Maine.
- 045 Vermont Electric Cooperative, Inc. North Hartland proposed utilizing the ~20-year-old U. S. Corps of Engineers flood-control dam (an earthfill dam with dumped rock shell) for hydropower generation. This project is located on the Ottauquechee River, Vermont.
- 155 New Hampshire Water Resources board owns the 40-year-old timber and granite dam at Sewalls Falls. Some repair work on the dam will be necessary, but the abandoned powerhouses are still in good condition, and the project hopes to completely restore the abandoned hydropower site. This project is located on the Merrimack River, New Hampshire.
- 035 Vermont Marble Company owns three hydropower sites: Center Rutland, Beldeno, and Huntington Falls. All are ~80 years old and the dam is

rockfill and concrete gravity type. Some of the facilities need to be repaired. The Vermont Marble Company wants to restore and expand the generation capacity. This project is located on the Otter Creek, Vermont.

- 125 The Connecticut Department of Environmental Protection owns two overflow gravity masonry dams. The Upper Dam is 140 years old, and the Lower Dam is 60 years old; both are in good condition and the City of Canton proposed restoring these two abandoned hydropower sites, located on the Farmington River, Connecticut.
- 103 The State of New Hampshire and William E. Burns of Amherst, New Hampshire own the 60-year-old concrete gravity Gregg Falls dam. The dam and powerhouse are in good condition, and the project proposed restoring the old hydropower site. This project is located on the Merrimack River, New Hampshire.
- 151 The City of Chicopee owns the 80-year-old flood control and water utility Chicopee Falls Dam. It is in good condition. This project is located on the Chicopee River, Massachusetts.
- 034 The codependant sites owned by The York Corp. and Kennebunk Light and Power District consist of seven dams of either stone gravity or timber, on the Mousan River, Maine. All are about 80 to 90 years old. Some of the dams are sound, but others need major repairs. One of these hydropower sites is generating power. The Municipal Power Company wants to restore, redevelop, and expand their hydropower generation.
- 043 Union Water Power Company, a wholly owned subsidiary of the Central Maine Power Company, owns and operates the Lewiston Canal System. The Red Shop Weir Dam and the canal system are about 130 years old, but are in good condition. The project would develop the hydropower potential at the Red Shop Weir on the Lower Androscoggin River, Maine.
- 052 The Central Vermont Public Service Corp. and Townscope Inc. own the more than 190-year-old masonry (assumed) Frog Hollow Mill Dam and the stone mill building. The project would reactivate the mill

- building that was used for power generation from 1794 to 1964. This project is located on the Otter Creek, Vermont.
- 143 A series of five non-hydroelectric dam sites on the Mill River, Massachusetts are owned by the City of Northampton, private companies, and Smith College. All are stone masonry and rockfill dams, and are in the range of 50 to 80 years old; all need some repairs. The City of Northampton wants to develop the hydropower potential.
- 099 The City of Woonsocket owns a new flood-control Woonsocket Dam located on the Blackstone River, Rhode Island.
- 113 The Bethlehem Mink Farm owns the 50-year-old concrete Bethlehem Dam. The hydropower plant was used to produce power until 1962 and is still in good condition. All equipment and penstock were removed. The project would restore this old hydropower site, located on the Ammonoosuc River, New Hampshire.
- 065 The Town of Wareham owns the 130-year-old Tremont Dam and powerhouse. It was repaired in 1977, and is now in good condition. All the old equipment was removed from the powerhouse. This project is located on the Weweantic River, Massachusetts.

Middle Atlantic

- 158 The existing facilities include a gated spillway and two navigation locks (Maxwell locks and Dam). It has been in place only 12 years and is operated by the U.S. Corps of Engineers. All are in excellent condition. This project is located on the Monongahela River, Pennsylvania.
- 093 The City of Little Falls and the Niagara Mohawk Power Corp. own the three dams and the abandoned hydropower plants on the Mohawk River, New York. Only the Gilbert Dam is in serviceable condition; the other two, Middle Falls and State were breached, and they need to be rebuilt.
- 106 Central Hudson Gas and Electric Corp. owns the 60-year-old High Falls Hydroelectric Plant and concrete dam on the Rondout Creek, New York. The powerplant was retired in 1973 after a concrete plug was

- placed in the intake. The project would reactivate this retired hydropower plant.
- 032 The City of Watervliet owns a more than 60-year-old concrete slab-buttress type dam and water supply reservoir on the Hudson River, New York. The dam is in excellent condition.
- 038 The Village of Lake Placid owns two Mill Pond, Power Pond Dam sites on the Chubb River that were once used to generate hydroelectric power. One is a timber dam, and the other is a concrete dam and both are 80 years old, but still in usable condition. The project would reactivate these two retired hydropower sites, located near Lake Placid, New York.
- 126 The Phillips Dam is an overflow gravity structure built with granite stone. The dam and powerhouse are owned by the Phillips family. This 180-year-old dam is still in good usable condition. The power plant was used to produce power until 1956. This project is located on the Croton River, New York.

South Atlantic

- 161 The Jackson Bluff Dam is owned by the State of Florida. The site includes an earth dam, a concrete ogee spillway, and a brick powerhouse. It is 50 years old and in good condition. The hydroelectric power plant was retired in 1970, and all the generating equipment was removed. This project is located on the Ochlockonee River, Florida.
- 092 Dan River Inc. owns and operates the 70-year-old Schoolfield Dam and hydropower plant. All equipment in the Schoolfield Plant is in need of rehabilitation or replacement, but its concrete dam is in good condition. The Dan River Inc. also owns two 100-year-old, operational, downstream sites. The power generation facilities at the two downstream sites were abandoned many years ago. The project would redevelop and rehabilitate these three hydropower sites, located on the Dan River, Virginia.
- 132 The State of Georgia Department of Natural Resources owns and manages the 73-year-old ungated overflow concrete gravity High Falls

State Park Dam on the Towaliga River, Virginia. The hydropower plant was closed in 1958. The lake impounded by the dam is now used for recreation. The project would redevelop its hydropower potential.

- 203 The Patillas Dam site is owned by the Puerto Rico Water Resources Authority. This 60-year-old earth-fill dam has a concrete spillway and is in sound condition. It was once used to produce hydropower; but now it is used only for flood control. This project is located in Puerto Rico.
- 041 The Washington Suburban Sanitary Committee owns the Brighton Dam. It was constructed 35 years ago with a hydropower plant, but the power plant was abandoned in 1969. The dam is a concrete slab-buttress type structure and is now used for water supply only. The dam and the powerhouse are in good condition. This project would redevelop this abandoned hydropower site, located on the Patuxent River, Maryland.

East South Central

- 053 The Archusa Creek Dam is a newly constructed, 8-year-old dam located on the Archusa Creek. It is an earthfill dam with a concrete spillway. This dam is owned and operated by the Pat Harrison Waterway District and is used for water supply and recreation. The project is located on Archusa Creek near Quitman, Mississippi.

East North Central

- 063 Carlyle Dam is an earthfill dam with a concrete ogee spillway and is operated by the U.S. Army Corps of Engineers. It is used for flood control and recreation. The dam is 11 years old and in excellent condition. The City of Carlyle wants to develop its hydropower potential. This project is located on the Kaskaskia River, Illinois.
- 131 The American Electric Power Service Corp. owns and operates five hydropower plant sites on the St. Joseph River. The concrete

overflow dams and brick powerhouses vary from 50 to 70 years old, are in good condition, and the power plants are still producing power. The project would expand the generating capacities of these hydropower plants. These projects are located in Indiana and Michigan.

- 136 The City of Columbus wholly owns two water supply dams with provisions for future hydropower additions: The O'Shaughnessy Dam, built 54 years ago, is an earthfill dam and is in excellent condition. The Griggs Dam is a 70-year-old concrete masonry gravity-type ogee structure also in good condition. The City of Columbus wants to utilize its hydropower generation. This project is located on the Scioto River, Ohio.
- 123 The City of Traverse and Grand Traverse County owns five dam sites on the Boardman River near Traverse City, Michigan: The Union Street Dam is an earthfill dam, built about 110 years ago, and is in good condition. It is used for regulation of the Boardman Lake. Sabin and Boardman Dams were built about 60 to 80 years ago; they are also in good condition. Both hydropower facilities were used to produce power, but have been abandoned since 1969. Keystone Dam has washed out, leaving only the Brown Bridge Dam and hydropower plant in operation. Brown Bridge Dam, built almost 60 years ago, is an earth dam, and is still in good condition. The City of Traverse and Grand Traverse County want to develop, restore, and expand hydropower potential at one or all five sites.
- 055 The Kimberly-Clark Corp. wholly owns the 70-year-old Vulcan Hydroelectric Plant located on the Fox River. It was retired in 1974 because of the declining condition of the power plant, however, the Kimberly-Clark Corp. wants to restore this hydropower plant. The project is located in Appleton, Wisconsin.
- 188 The Peninsular Paper Company owns the 60-year-old Peninsular Paper Company Dam and structures. The dam is a concrete overflow-type structure that is in good condition. The powerhouse is presently abandoned; all equipment has been removed. The project would restore this hydropower plant, located on the Huron River, Michigan.

- 190 The Van Buren Township presently owns and maintains the 50-year-old French Landing Dam and hydroelectric power plant. The dam consists of a reinforced concrete multiple-arch buttress, an earth embankment with a gated spillway, and a fish ladder. The dam and powerhouse are in good condition. The power plant, however, has been retired and all equipment has been removed. The project would restore this retired hydropower site located on the Huron River, Michigan.
- 129 The Baker Hotel and the power plant are owned by the Lutheran Welfare Services of Illinois. The Hotel Baker Hydroelectric Plant was built 50 years ago. The power plant ceased to produce power in 1970 and conditions of the generating equipment are uncertain. The 60 year old masonry overflow dam is in good condition and it is owned by others. The project would reactivate and expand this hydro power site, located in the Fox River, Illinois.
- 162 The Municipal Power system of the City of Piqua owns and operates the City of Piqua Dam. The dam was constructed 40 years ago. It is used as a cooling water pool for the adjacent city-owned steam plant. The dam is an overflow-type concrete gravity structure, and is in very good condition. The cooling pond would be used for hydropower generation. This project is located on the Great Miami River, Ohio.

West South Central

- 050 The 35-year-old Lake Frances Dam and reservoir are owned, operated, and maintained by the City of Siloam Springs. The city rebuilt the dam in 1955, and the lake is now the municipal water supply. This project is located on the Illinois River, Arkansas.
- 087 The Max Starcke Park Dam and its low-head hydro unit is owned and operated by the City of Seguin. This 100-year-old stone and concrete overflow-type dam has been improved and upgraded. The powerhouse was built 45 years ago with one unit installed and with the provision of two more hydro units. The project would expand this hydropower generation capacity. This project is located on the Guadalupe River, Texas.

West North Central

- 157 The Tuttle Creek Dam, located on the Big Blue River in Kansas, is a Corps of Engineers flood-control dam. The dam is an earthfill dam with gated spillway. It was built more than 20 years ago, and it is in very good condition. The Kansas Electric Power Coop. wants to develop the hydropower potential of this project located near Manhattan, Kansas.
- 135 Seven dams and hydropower sites are owned and operated by six different parties. These dams were constructed of concrete and concrete capped timber overflow-type structures with gates or flashboards. All the structures are at least 50 years old and require some repairs. Only the Blue Springs Hydroelectric Plant is still in operation; the rest are either abandoned or have suffered severe flood damage. The Nebraska Municipal Power Pool wants to redevelop and/or rehabilitate the existing facilities at the seven sites. This project is located on the Big Blue River, Nebraska.
- 160 The Zumbro Dam and hydropower plant is owned and operated by the City of Rochester. The structures are about 60 years old and include a concrete dam, concrete gravity spillway, and a concrete powerhouse. Both the dam and the powerhouse are in good condition, and the plant is still producing power for the City of Rochester. The project would expand the hydropower capacity of this project located on the Zumbro River, Minnesota.
- 192 The Johnson Lake Inlet Structure is owned and operated by the Central Nebraska Public Power and Irrigation District. This 38-year-old irrigation drop is in good condition. The project is located on the canal system near Elwood, Nebraska.

Mountain

- 075 The Montana Department of Natural Resources and Conservation owns and operates the Broadwater Dam. It is a concrete gravity dam with seven ogee weir sections and a diversion canal outlet. This

40-year-old structure is used to divert water to the canal system, and is in good condition. This project is located on the Missouri River, Montana.

- 073 The Mora Irrigation Canal is totally federal and is operated and maintained by the Boise Project Board of Control for irrigation during the irrigation season. The project is located on the Mora Canal drop near Boise, Idaho.
- 023 The Division of Water Resources of the Department of Natural Resources of the State of Utah owns and operates the 20-year-old Woodruff Narrows Dam. This is an earthfill dam in good condition and the reservoir is used to store water for irrigation. The spillway is a broad-crested type in fair condition, but it will need some repairs in the near future. This project is located on the Bear River, Wyoming.

Pacific

- 118 The Turlock Irrigation District owns and operates four concrete lined canal drops that are in good condition. This project includes 14 potential sites and involves four irrigation districts. The Merced Irrigation District owns and operates six canal drops and the South San Joaquin/Oakdale Irrigation Districts own and operate two main canals and distribution systems, and two 60-year-old earth diversion dams. The project would develop hydropower potential at 14 canal drops near Turlock, California.
- 054 The 40-year-old Upriver Dam and the powerhouse are owned and operated by the City of Spokane. The dam is a concrete structure having eight radial gates; and the power generation consists of three units installed in 1937. The structures are in good condition and the equipment has been well maintained. The project would expand the hydropower potential of this project located on the Spokane River, Washington.
- 102 The Anderson-Cottonwood Irrigation District owns and operates the Red Bluff Diversion Dam (forming Lake Redding) that is used for diverting water into its canal system for irrigation purposes. The

dam is a multi-tiered A-frame supported stoplog dam; it was built 62 years ago and is still in good condition. The City of Redding, California wants to develop the hydropower potential.

- 110 The Dry Falls Dam is an earthfill dam and is one of the two dams constructed in the Upper Grand Coulee Gorge to form Banks Lake, which serves as an equalizing reservoir for storage of water for irrigation by the U.S. Bureau of Reclamation. The South Columbia Irrigation District wants to develop the hydropower potential on the irrigation system in central Washington D.C.
- 119 The Portland General Electric Company owns and operates the Pelton Regulating Dam on the Deschutes River that maintains uniform flow downstream in the Deschutes River for maintenance of the fish habitat. This 20-year-old dam consists of an earth and rock embankment, gated concrete gravity type spillway, and fish-ways. The Confederated Tribes of Warm Springs Indian Reservation want to develop its hydropower potential. The project is located near Warm Springs, Oregon.
- 026 The Enloe Dam and powerhouse were built on the Simikameen River more than 50 years ago for power generation and then was abandoned in 1959. The dam is a concrete arch-gravity structure with uncontrolled spillway and needs some repairs. The powerhouse, penstock, and generation facilities are damaged. The Public Utility District 1 of Okanogan County wants to restore this old hydropower site. The project is located near Oroville, Washington.
- 148 There are two sites in this project: the Modesto Dam and the Stone Drop are both owned and operated by the Modesto Irrigation District for irrigation water regulation. The Modesto Dam is an earthfill dam constructed more than 65 years ago and remains in very good condition. The Stone Drop is a concrete structure constructed about the same time as the Modesto Dam. The project is located near Modesto, California.
- 064 The City of Seward provides for all operation and maintenance of the 30-year-old Lowell Creek Diversion. The existing structure is mainly used for flood control. It consists of a rockfill dam with concrete face and cutoff wall, and a concrete-lined horseshoe tunnel

approximately 8 ft in diameter. This flood control project was constructed by the Corps of Engineers. The project would develop the hydropower potential at this flood control system, located on the Lowell Creek, Alaska.

TECHNOLOGY DEVELOPMENT

The Department of Energy's (DOE) Small Hydropower Technology Development Program (formerly known as the Demonstration Program) was initiated in 1977 in conjunction with restoration of three power generating plants at Idaho Falls, Idaho, following damage caused by the Teton Dam failure June 5, 1976. The Programs's intent was to demonstrate the viability of small hydroelectric projects that use a non-polluting renewable resource. The DOE issued two Program Opportunity Notices (PON) to expand the program to sites other than Idaho Falls: PON-1 in June of 1978 and PON-2 in June of 1979. Of the 89 submitted proposals, 20 were awarded cooperative agreements (DOE participated in a cost-sharing program for each project). One project, the City of Carlyle, IL, terminated its cooperative agreement with DOE in April 1982 because of the new city government actions and the Flat Rock project surrendered its license on July 31, 1990 because of it becoming uneconomical over the 10+ years after receiving its preliminary permit on December 23, 1981.

Figure 1 shows locations of the projects, Table 1 identifies the technical support, and Table 2 identifies the project costs and DOE cost sharing and funding.

With the initiation of the PONs, the objectives of the Small Hydropower Technology Development Program were expanded 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
- Disseminate data on the construction and maintenance of these facilities.

By demonstrating that an economically viable, small-scale hydropower plant could be built with available technology, the program would:

- Encourage and expedite the utilization of this available, continually renewable, non-polluting energy resource
- Contribute to a decrease in demands of finite fossil fuels and importation of foreign oil
- Provide cost and performance data to help in future evaluations and equipment selections.

The scope of work for the program specified that the participant would furnish the materials, facilities, equipment, personnel, services, and all other necessary and incidental related items for the design, construction, installation, and operation of a hydroelectric generating unit at the site owned by the participant. The participant was responsible for the collection and dissemination of data and other information concerning the construction, operation and maintenance costs, engineering characteristics, and maintenance requirements for a period of 2 years following commencement of operation. Details concerning the project were found in the participant's proposal, which was submitted in response to the PON. Reports resulting from this program are listed at the end of this section.

The program placed 119,292 kW of generating power on-line at 18 of the projects, including Idaho Falls. One project was canceled and one project received its license but was terminated because of unfavorable economics. The total dollars spent to engineer and construct these projects amounted to \$253,138,814, of which DOE contributed \$26,540,730. The program produced 55 reports, which are listed in the "Reference" section and can be obtained from the National Technical Information Service.

The program's results show small hydropower is an economical source of energy capable of producing power within 18 to 36 months after receiving a license from the Federal Energy Regulatory Commission (FERC).

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. Stappenhorst, 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 So. Consolidated Canal	Salt River Project 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 1983	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 Co.	Boott Mills, 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	130,042
18 City of Paterson	Great Falls, NJ	November 1984	December 1986	10,950	119,292
19 PA Hydroelectric Development Corp.	Fiat Rock Dam, PA	Canceled	Canceled	3,250	

9-9547

Figure 1. Hydropower Technology projects EM-general data and location.

Table 1. Small Hydropower Technology Development Program technical support and funding.

<u>ORGANIZATION</u>		
Idaho National Engineering Laboratory		
EG&G Idaho, Inc. P.O. Box 1625 Idaho Falls, ID 83415		
<u>TECHNICAL MONITOR</u>		
Bennie N. Rinehart EG&G Idaho, Inc. P.O. Box 1625 Idaho Falls, ID 83415-3526 FTS 583-1002 (208) 526-1002		
<u>WORK LOCATION</u>	<u>DURATION/AWARD DATE</u>	<u>CONTRACTOR WPAS NO.</u>
Idaho Falls, ID	Continuing/May 77	7EA104
<u>ORGANIZATION</u>	<u>TECHNICAL MONITOR</u>	
DOE-ID 785 DOE Place Idaho Falls, ID 83402	Peggy A.M. Brookshier DOE-ID 785 DOE Place Idaho Falls, ID 83402 FTS 583-1403 (208) 526-1403	

Table 2. DOE hydroelectric parameters and costs

Project	River Location	Average Flow (cfs)	Head (ft)	Total Capacity (Kw)	Annual Production (MWh/year)	No. 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, Millford, 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
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

Table 2. (Cont.)

Project	River Location	Average Flow (cfs)	Head (ft)	Total Capacity (Kw)	Annual Production (MWh/year)	No. of Units	DOE Share (\$)	Total Cost (\$)	(\$/Kw)
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
Boott 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

TURBINE TESTING

One of the phases of the Technology Development Program is to test the efficiency of different types of turbines at various Technology Development Projects and other sites, if appropriate.

Testing has been performed at one site to date, the Fries Project, located in Virginia. When the test was performed, the equipment was not working properly and thus the test was incomplete. However, the test results identified areas of concern to the owners of the Fries site. One such area that was evident was a hysteresis in the gate blade activating system and thus the performance could be improved by modifying the blade/gate control cam.

Two other technology development projects tests were conducted by others. The two projects were the Salt River Project located at Phoenix, AZ and the Sawmill Project located at Berlin, NH. The test results for both of these projects are included in their Final Technical and Construction Cost Reports.

In summary, the test at Salt River showed that the machine would produce the guaranteed kW. This conclusion was based on the fact that the efficiency was a little low at low flows but a little higher at high flows, thus the net kWh was a little higher than guaranteed.

The test at Sawmill concluded that the efficiency was about 3 to 4% low with the net head of 16 ft.

A test at the Central Vermont Public Service Bradford site on an Ossberger cross-flow turbine showed that the peak turbine efficiency was between 72.0 and 82.2% for Unit II. Staphenhorst's November 1983 test pointed out that to confirm this indicated peak efficiency, it would be necessary to obtain additional test points, which did not take place.

PROJECT SUMMARY

Following is a summary of problems encountered by each technology development project.

TURLOCK DROP 1

Three problems were encountered: lignum vitae turbine guide bearings, which must be immersed in water to prevent drying and cracking during seasonal shutdown; the stop log leakage, which was corrected by changing from concrete to steel; and wicket gate leakage, which was attributed to poor design and machine work by the manufacturer.

Energy generated during the 2 year O&M period was 24,901,024 kWh at a cost of \$106,512.69.

<u>Generation (Kwh)</u>	<u>Operation and Maintenance (\$)</u>
1980	
6,231,624	24,486.69
1981	
10,668,876	61,081.00
1982	
8,000,524	20,945.00
<u>TOTAL</u>	<u>106,512.69</u>
0.0043 cents/kWh	

Agreement Number

DE-FC07-79RA23215

Participant

Turlock Irrigation District
333 East Canal Drive
Turlock, CA 96380
A. K. Hagiwara
(209) 632-3861

Term of Contract

5-21-79 to 8-4-83

Turlock project site before construction.

Turlock project site after construction.

GOODYEAR LAKE

The only problem encountered was trash accumulation on the trash rack. A new 12-in. rectangular log boom was placed at the canal entrance to prevent this problem.

Agreement Number
DE-F607-79RA23211

Participant
F.W.E. Stapenhorst Inc.
285 Labrosse Avenue
Point Claire, Quebec
Canada
F.W.E. Stapenhorst
(514) 695-8230

Term of Contract
4-30-79 to 6-7-83

Goodyear Lake project site before construction.

Goodyear Lake project site after construction.

SAWMILL

Generation was sporadic for the first few months because of extensive start-up corrections required for a wide range of equipment within the powerhouse, some of which included:

- Broken turbine hub bolts
- Generator bearing failure
- Gate hydraulic leaks
- Sump pump failure
- Broken low-speed increaser shaft
- Speed increaser lubrication failure
- Wood wedged in turbine
- Severe intake icing.

Generation was also affected considerably by a design problem with the turbines and water passages. Efficiency measurements showed overall unit efficiencies at about 74%, which Allis-Chalmers predicted (and guaranteed) would be 85.7%. Actual generation was therefore 13.65% below guarantee.

Agreement Number
DE-FC07-79RA22210

Participant
James River-New Hampshire Inc.
650 Main Street
Berlin, NH 03570
D. L. Dunham
(603) 752-4600

Term of Contract
6-29-79 to 9-20-84

Sawmill project site before construction.

Sawmill project site after construction.

FRIES

One problem encountered was accumulation of trash on the trash rack, which was solved by building a trash rack cleaner in-house.

Agreement Number
DE-FC07-79RA23219

Participant
Riegel Textile Corporation
Southern Executive Offices
Ware Shoals, SC 29792
T. J. Meyer
(803) 456-4328

Term of Contract
5-16-79 to 4-9-84

Fries project site after construction.

SALT RIVER

Problems encountered were the draft tube gate (corrected by brake adjustment), and a damaged bearing surface within the turbine hub, which was attributed to poor workmanship and poor quality control by the manufacturer. An efficiency test showed that the unit operated above the design efficiency at maximum water flow, but less than design efficiency at minimum water flow. Overall, the unit met total generating efficiency and was accepted on that basis.

Agreement No.

DE-FC07-79RA23214

Participant

Salt River Project Agricultural
Improvement District
P.O. Box 1980
Phoenix, AZ 85001
S. B. Wilkinson
(602) 273-2157

Term of Contract

4-10-79 to 4-24-84

Salt River project site before construction.

Salt River project site after construction.

GARVINS FALLS

Problems encountered were head gate operation was not satisfactory, but was corrected by the manufacturer, who replaced the oilite bushings with graphite impregnated bronze bushings; the Unit 1 turbine spherical roller bearing overheated and had to be replaced.

The results reported from this project should be very informative, as they have used several ideas to reduce costs; e.g., the main parts of the cofferdam were designed so that they could be used as gates in the powerhouse and throughout their system.

Agreement Number
DE-FC07-80ID12117

Participant
Public Service Company of
New Hampshire
1000 Elm Street
Manchester, NH 03105
J.E. Lyons
(603) 669-4000

Term of Contract
6-13-80 to 5-21-84

Garvins Falls project site before construction.

Garvins Falls site after construction.

SHAWMUT

Problems encountered were the speed increasers developed a leaky seal, which leaked more after being repaired by the manufacturer. A modified bearing cover was installed by the manufacturer to correct the problem. The main problem was deficient turbine performance and water usage. The water usage was corrected by adding 22% more surface area to the three blade runners. The units were three blade tube turbines, a new early 80s design of Allis-Chalmers'.

Agreement Number
DE-FC07-ID12126

Participant
Central Maine Power Co.
Edison Drive
Augusta, ME 04336
Robert G. Letourneau
(207) 623-3521

Term of Contract
6-24-80 to 2-25-85

Shawmut project site before construction.

Shawmut project site after construction.

IDAHO FALLS

Since coming online, the plants have had a few problems; principally the electro-erosion of the rotor damper bars. The city worked with the generator manufacturer to resolve the problem, and repair to the three generators was effected. Another problem was the breakage of one of the linkage arms in the blade Kaplan system because of fatigue failure. A response was written by INEL on the incident. Because of a lack of information regarding linkage arms, the cause of the problem was not found.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
DE-FC07-78RA01699	City of Idaho Falls Electric Light Division 140 South Capital Idaho Falls, ID 83401 S. Harrison (208) 529-1430 Mark Gedron (208) 529-1445	1-12-78 to 2-28-86

Idaho Falls upper project site before construction.

Idaho Falls upper project site after construction.

Idaho Falls City project site before construction.

Idaho Falls City project site after construction.

Idaho Falls lower project site before construction.

Idaho Falls lower project site after construction.

UPPER MECHANICVILLE

The project came online in August 1983 but did not go commercial until September because of a problem with the generators. Problems encountered since the online date (September 7 for Unit 2 and September 19, 1984 for Unit 1) were buzzing noises produced by the generators and the split phase differential current problem. This was corrected by pinning the stator frame to control thermal expansion and maintain the stator as a circular rather than an elliptical shape.

Agreement Number

DE-FC07-80ID12117

Participant

New York State Electric
and Gas Corporation
4500 Vestal Parkway East
Binghamton, NY 13902
J. J. Case
(607) 729-2551

Term of Contract

9-15-80 to 3-1-86

Upper Mechanicville project site before construction.

Upper Mechanicville project site after construction.

GARLAND CANAL

This project had no problems because it is furnished a constant and continual amount of water (during the irrigation seasons).

Agreement Number

DE-FC07-80ID12129

Participant

Shoshone Irrigation District
P.O. Box 822
Powell, WY 82435
Dean House
(307) 754-5741

Term of Contract

5-21-80 to 3-31-86

Garland Canal project site before construction.

Garland Canal project site after construction.

GONZALES

The project started their commissioning period in February 1983, but did not achieve online power until January 1, 1984. The long period of time for achieving online power status was because of the turbines not working at guaranteed efficiency. Also, because of legal constraints, the city could not place the equipment into production until the efficiency problem was solved (i.e., after turbine rehabilitations). The units were found to have been installed incorrectly. The turbine manufacturer (to resolve the problem with the refurbished units) contracted the correct installation of the units to another contractor.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
DE-FC07-80ID12121	City of Gonzales 820 St. Joseph Street P.O. Box 547 Gonzales, TX 78629 Luther Maxey (512) 672-2815	8-26-80 to 3-31-86

City of Gonzales project site before construction.

City of Gonzales project site after construction.

UPRIVER DAM

The plant operated with very few problems, until May 1986 when it received extensive damages from lightning striking lines near the site and knocking out both the old and new plant. The city tried to start the emergency generator, but could not. Dam power that operates the gate mechanism was not available, thus the gates could not be raised to allow the water to flow downstream. The rising water went around the dam causing washing of the earth around the new and old powerhouses, concrete, and power cables.

The repair to the old and new plants, along with the dam, was started May 20, 1986. Both units of the new plant have been placed back online (Units 4 and 5, January 4, 1987) along with the old plant.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
DE-FC07-80ID12118	City of Spokane City Hall, Room 303 212 Wall Street Spokane, WA 99201 George Miller (Const.) (509) 456-4370 Leon Sproule (O&M) (509) 456-2649	5-16-80 to 12-31-86

City of Spokane project site before construction.

City of Spokane project site after construction.

ELK RAPIDS

There were no problems encountered at this plant.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
DE-FC07-79RA23209	Antrim County P.O. Box 187 Bellaire, MI 49015 Mr. Richard Miller (616) 533-8607	6-15-79 to 12-31-86

Elk Rapids project site after construction.

JACKSON BLUFF

The project encountered no problems.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
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DE-FC07-80ID12128	City of Tallahassee City Hall Tallahassee, FL 32301 Ben Cowart (904) 575-6135 Trivehi Singh (CONST.) (904) 575-6135 Jerry Hinton (O&M) (904) 575-8147	9-25-80 to 3-31-88
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Jackson Bluff north approach and training wall.

Jackson Bluff turbine floor
before construction.

Jackson Bluff turbine floor
after construction.

BOOTT MILLS

The project has had problems since coming online.

Agreement Number
DE-FC07-80ID12124

Participant
Boott Hydropower, Inc.
6 Essex Street
Lawrence, MA 01852
M. G. Lezberg
(617) 687-4231

Term of Contract
8-8-80 to 2-28-88

Boott Mills intake.

CHEROKEE FALLS

The project came on-line in December 1985. Although electricity was generated in December 1985, Voest Alpine did not complete full commissioning until February 10, 1986 and submitted their Certificate of Completion April 30, 1986. However, GENDEC and BREC did not accept the unit as being problem free; Continuous problems were experienced with lube oil leads, the trashrack cleaning machine, miscellaneous switches kept failing, and loss of power generation as a result of forced outages was a common occurrence.

A major breakdown in the turbine runner caused the unit to be totally out of operation from January 11 through January 31. All of these problems were exacerbated somewhat by the record drought experienced in the South during 1986, which resulted in lower-than-normal river flows. In fact, river flows were so low that unit index tests could not be completed until late February, 1987 -- more than a full year after commissioning. However, index tests produced favorable results and it was concluded that the unit was capable of operating at or above guaranteed efficiencies during an average water year, thereby substantiating the guarantees stated in the contracts.

But on Saturday, February 28, 1987, high river flows were experienced in the Broad River. As water levels continued to rise, BREC employees deployed the actions required during such an incident (i.e., maintaining communication with dams upstream and downstream, releasing of flashboards, etc.).

At approximately 1:30 a.m. Sunday, March 1, water topped the powerhouse roof, an elevation of 541.0 ft. The historic flood of record reached elevation 540.43 ft with a flow of approximately 119,000 cfs.

Floodwater entered the powerhouse through holes created by severed station service line conduits and roof ventilators and all component parts located in the turbine pits were flooded. Water reached elevation 521.0 ft in the powerhouse.

Cleanup efforts were started March 2. GENEC and BREC coordinated the repair efforts and collaborated on a repair schedule. Various manufacturer's representatives were brought on-site and considered possible repair

procedures. The power was placed back in service April 21, 1987 but at a reduced reservoir pool elevation of approximately 531.5 ft, which is at the top of the dam. Damage to the flashboards during the flood negated raising the reservoir to its design elevation of 535.5 ft. Additionally, because of the flooding incident, FERC required further flooding analysis to be carried out as well as proposed mitigative measures against future floods. FERC also required the submission of an acceptable Emergency Action Plan (EAP) before operating the facility with reservoir elevations at or above 535.5.

The flood of March 1, 1987 also flooded the property of South Carolina Distributors, Inc. (Distributors) located adjacent to the hydroelectric site on the left bank of the Broad River. A law suit was filed by Distributors March 13, naming BREC, GENDEC, Cherokee Falls Associates, and the four prime contractors as defendants. Distributors claimed damage to its buildings, equipment, vehicles, and inventory (fireworks). In addition, Distributors claimed damages for loss of business, sales, profits, and related expenses for repairs and legal fees.

It was determined by all involved that the flooding was caused by the accumulation of tree branches and other debris in the river on the flashboard structures along the entire length of the dam (approximately 1,700 linear feet). In addition, site flood protection along the left bank of the reservoir was only at approximately elevation 538.5. When trash accumulation occurred, water flow over the dam was restricted and caused it to flow over the top of the flashboards and related catwalk structures to an elevation between 542.00 and 543.00 (flood of record only reached elevations of 540.43). Before topping the powerhouse roof, flood waters had already topped the left bank and were flowing through the plant lot. Highest flow in the river during this flooding incident was 65,800 cfs--representing a 12-year recurring flood.

GENDEC, BREC, and Cherokee Falls Associates filed cross complaints against Acres and Maguire because they were collectively responsible in the flashboard/catwalk design.

GENDEC's and BREC's complaint against Acres and Maguire was moved to federal court at the request of Acres. Total damages incurred by GENDEC and

BREC amounted to more than \$2.5 million and were related to the following: mechanical and electrical damages; damage to the flashboards; loss of equipment warranties; and additional administrative and overhead costs. GENDEC and BERC won their claim.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
DE-FC07-80ID12125	Broad River Electric Cooperative P.O. Box 790 Gaffney, SC 29340 R. C. Carroll (803) 489-5737 Ernest D. Metivier (404) 329-0647	9-16-80 to 12-31-87

Cherokee Falls project site before construction.

Cherokee Falls project site after construction.

BOLTON FALLS

The project encountered no problems.

Agreement Number
DE-FC07-79RA23212

Participant
Green Mountain Power
Corporation
25 Green Mountain Drive
Burlington, VT 05402
Eugene L. Shaltz
(802) 864-5731

Term of Contract
6-22-79 to 05-31-89

Bolton Falls project site before construction.

Bolton Falls control room.

Bolton Falls powerhouse.

GREAT FALLS

All three units have had problems such as: oil head problem, excessive vibrations, generator brushes excessive wear and faulty guide bearing design. The faulty design caused the three units to be inoperable >5 months. Other problems encountered by the project which lead to lower then expected generations were: installation of flashboards, trash rack installation, workability of the programmable controller, and low water.

Agreement Number

DE-FC07-80ID12127

Term of Contract

7-8-80 to 9-30-88

Participant

City of Paterson
52 Church Street
Paterson, NJ 07505
J. Topalian
(201) 881-3313

Independent Hydro
Ridgehill Professional Bldg.
Suite 380
200 Plymouth Rd.
Minnetonka, MN 55343-5943
(612) 546-7148

Great Falls project before construction.

Great Falls project site after construction.

Great Falls project site after construction.

FLAT ROCK

The Pennsylvania Hydroelectric Development Corporation's Flat Rock Dam project had no problems due to the fact it was never constructed because of uneconomical conditions after working approximately 10 years to get a license.

<u>Agreement Number</u>	<u>Participant</u>	<u>Term of Contract</u>
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DE-FC07-80ID12130

Pennsylvania Hydroelectric
Corporation
P.O. Box 7319
30th & Market Street
Philadelphia, PA 19101
L. Gleeson President
(207) 338-2131

8-26-80 to 10-31-87

General view looking across dam.

General view looking upstream.

PROBLEMS AND LESSONS LEARNED

The use of hydropower as a clean renewable source of energy was aided through a number of field technology development projects funded through cooperative agreements on a cost-shared basis by the DOE. Although not all the projects became operational, they all provided significant technology, identified problems and taught lessons that helped future developers from reinventing the wheel. Problems and lessons learned are contained in the individual technical reports.

Following is a listing by project of the general problems and lessons learned.

GOODYEAR LAKE

Trash accumulation on the trash rack reduced generation to a point where it was not economical; thus, a trash rack rake and a log boom in front of the power canal gates were placed. The two items reduced the trash accumulation to a point of economical operation.

SAWMILL

Turbine Efficiency--The overall unit efficiency could not be obtained although many modifications were made. It was discovered that the turbine manufacturer had used the total head of 17.5 ft as the turbine net head.

Intake Gates--The intake gates would not drop freely; bearing material used on wheels had very high friction coefficient. The material used was not the material specified; all the bearings were changed with good results.

Governor--The Woodward flyball overspeed switches wore out rapidly. The final fix was to replace them with electronic pulse-type speed switches.

Water Level Probes--Probes used for sensing pond and intake water levels performed below standard, and were replaced with a later more durable and reliable model, with good results.

FRIES

Control Systems--Nuisance tripping of the control systems occurred until fine tuning of the system had been completed.

Trash--Trash accumulation on the trash rack reduced generation to a point that it was necessary to build a trash rack rake, therefore reducing the problem.

Shaft--Excessive shaft play occurred because of the improper size of bolts being used in the lower guide bearing (7/8 in.); they were replaced with 1 in. bolts that corrected the problem.

GARVINS FALLS

Speed Increaser Lubrication--When the new units began operating in December 1981, a problem was identified concerning the lubrication system for the speed increasers. This system, as designed, did not provide adequate lubrication to the gears within the speed increasers during times of slow turbine rotation. To alleviate this problem, external pumps were added to the lubrication system. These pumps are activated by motion detectors that were incorporated into the turbine shafts, thus ensuring proper lubrication even at the lowest speeds.

Intake Gate Control--Control problems with the intake gates were also discovered during the initial start up period. The intake gates, located directly upstream from the new units, were designed to completely stop the flow of water to the new turbines when required, and to provide smooth operation at various flows. As originally manufactured, these gates contained Oilite bushings that proved to be inadequate for gate control and caused jerky start ups and showed an inability to completely shut down.

Resolution of this problem took the better part of 1982, and required removal and reinstallation of the intake gates on two separate occasions. A temporary, manually controlled, hydraulic closing system was utilized during this period to ensure complete closure of both gates and made Units 1 and 2 available for service.

Final solution of the intake gate problem required replacement of the Oilite bushings (it was discovered that the oil had been washing out) with new Teflon-impregnated bushings. Operation and maintenance costs increased substantially as a result of this problem and generation from the new units during this period was greatly reduced.

Oil Reservoir Level Sensing Equipment--In June 1982, a problem was discovered with the oil reservoir level sensing equipment. Because of over sensitivity of this equipment, minor surges within the oil reservoir were tripping an alarm that resulted in repeated shutdowns of the new units.

To reduce the sensitivity within this equipment, an external oil reservoir was added to the system. This addition was made concurrently with the headgate repairs and has proven to be an acceptable solution to the problem.

Unit 1 Spherical Roller Bearing Overheat--Service from Unit 1 was interrupted for 5 d in March 1983 while workers replaced the spherical roller bearing on the turbine (overheating occurred under normal operating conditions). This bearing, located at the upstream end of the turbine shaft, provides support for the Unit 1 runner.

Service at Unit 2 was also interrupted for 16 h, while divers worked in the tailrace area placing, and later removing, stop-log panels below Unit 1. These panels allowed Unit 1 to be de-watered because bearing replacement had to be accomplished while dry.

A manufacturer's investigation into the bearing failure has revealed no identifiable cause for overheating. The new (replacement) bearing appears to be operating well within its required temperature range.

Oil Leak-Faulty Unit 2 Kaplan Control Seal--Oil was discovered leaking (July 1983) through the Kaplan control shaft seal into the Unit 2 turbine shaft. Obtaining access to this faulty seal requires complete dismantling of the unit. The task was performed during a low water period in 1984.

A manual drain was installed to periodically remove the leakage until permanent repairs can be made. Meanwhile, operation continues unhindered.

Debris Build-up and Ice Jams--Velocities within the intake canal at the Garvins facility have increased significantly since the addition of new Units 1 and 2. Studies of this problem during the past 2 y have revealed excessive year-round debris build-up on the trash racks and unmanageable ice jams within the canal in winter months. At times, removal of this ice and debris requires complete station shutdown, which has resulted in lost generation.

After analyzing various solutions to this problem, a decision was made to install a manually controlled, hydraulic articulated crane. This crane, become operational in February 1984, and permitted easy break-up and removal of ice and debris without necessitating a complete plant shutdown. An automatic rack rake was installed in 1984.

SHAWMUT

Turbine Efficiency--The overall unit efficiency could not be obtained, although a change to the blades was made. It was discovered that the turbine net head used was not correct and the shape and area of the blades were not correct.

Oil Level Sensor--Frequent alarms occurred from the high oil level sensor for the turbine outboard bearing. The sensors used incorporated an optical sensor head, which was located just above the normal oil level. The slight oil level change caused by thermal expansion or splashing coated the optical sensory with oil and activated the high-level alarm. The problem was corrected by relocating the sensor to a higher elevation and placing deflectors over the sensing head to prevent oil mist from coating the sensory.

Generator Speed Switches--The speed switches on the generators failed to provide reliable service. These switches incorporated mercury wetted contacts, which were subject to false overspeed indications caused by generator vibration resulting in a closed circuit. The mercury switches were replaced with snap-action micro switches, which eliminated false unit trips.

Level--The noise levels within the new powerhouse were unacceptable for the health and welfare of operating personnel. The major sources of the high noise levels were the two removable draft tube covers (turtle backs) and the four oil to air speed increaser oil cooling fans. Another major contributor to the high noise levels was the acoustically hard concrete powerhouse walls and steel roof decking. Secondary sources of noise were the speed increasers and two ventilation fans. The noise was reduced to an acceptable level by placing removable acoustic insulating blankets on the turtle backs, acoustic panels on the powerhouse walls and ceiling, and the cooling fan speeds and blade designs being modified.

UPPER MECHANICVILLE

Generator Guide Bearing--During a test run that followed completion of the stator doweling procedure, the unit was shut down because of excessive vibration. Upon inspection, the new upper guide bearing was found to be scored. The bearing surface was repaired and the lubricating oil was replaced. Then the unit was subjected to further balancing tests and additional balancing weight was added to the field.

GARLAND CANAL

Trash--Trash accumulation on the trash rack reduced generation and efficiency to a point that a trash rack rake was installed to reduce this problem.

Controls--Malfunctions of automatic equipment were corrected by replacing the head level monitor and obtaining new cards for the computer.

Heat--Equipment problems occurred because of heat problems, which were corrected by adding more ventilation.

GONZALES

Vibration--Improper installation and machining caused excessive vibration in the units, which were caused by alignment problems. The problem was corrected by replacing the shafts and bearings.

Oil--The gearbox ran hot and it was discovered that an oil line was plugged. This was corrected by placing a filter in the line.

Gearbox--The gearboxes were not securely fastened causing generator misalignment problems. Additional bolts were required to properly secure the gearbox and eliminate the misalignment problem.

UPRIVER DAM

Voltage Regulator Fans--One of the first problems that the operators encountered was the exciter fans. The voltage regulator is furnished with two fans to provide cooling air flow through the static exciter and voltage regulator. One of the fans is supposed to operate any time the field breaker is closed. The other fan acts as a backup to come on when a flow switch indicates that the first fan has failed. An alarm also sounds to notify the operator of the failure. After repeated problems keeping the units operating with these fans going off and on, the manufacturer, Fuji Electric, finally traced the problem to the flow switch. Once they were replaced with a different type of flow sensor, the problem was eliminated. There has not been another instance of the fans switching or shutting down the unit. The work was performed as a warranted item at no cost to the city.

Generator Air Coolers--Temperature measurements recorded during the initial startup indicated that the units could not carry the full rated load without exceeding the guaranteed total temperature. After studying the problem and consulting with the city to derive an acceptable solution, Fuji replaced the air coolers with a larger size. This work was performed as a warranty item at no cost to the city. The manufacturer hired a mechanical contractor to make the changes. The work was performed at low river flows with a stipulation that only one unit would be out of service at a time. The temperature correction was sufficient to meet the guarantees for the total temperature rise at full load.

Automatic Synchronizer--The automatic synchronizer was furnished as part of the unit control board that was supplied as a separate bid item by General Electric Company. During the initial startup, the synchronizer was set according to the directions of the manufacturer (Beckwith Electric). After

these initial adjustments, the synchronizer functioned for a period of time until auto starts were tried; then the synchronizer would not pick up the signal and turn on when the voltage was applied by the field breaker. The unit was sent to the manufacturer and manual starts were performed. When the unit was returned and replaced in the unit control board, it worked normally. The synchronizing circuits were modified following the washout of May 20, 1986. This was performed to allow the synchronizer to close the tie breaker to the transmission line as well as the individual breakers for the two generators. When testing the new control schemes (while placing the plant back online after the washout) problems were again experienced with the synchronizer. It was returned for service but this time the manufacturer could not find any problems. Considerable time was spent checking out the control circuits when it was believed that the problem resulted from the way the control circuits were tied together.

Power Factor Control--The voltage regulators for the units in the new powerhouse did not have power-factor control included because it was not specified in the bid documents. The units in the old powerhouse had the rotating exciters replaced with static exciters and solid-state voltage regulators at the time the units were upgraded to 2000 kW in 1983. These also did not include power-factor regulation. The result was that two plants had to be connected in parallel and then connected to a utility system considerably larger than the capacity of the two plants. As the system voltage changes, the voltage regulators would try to maintain the generator voltage where it had been previously. There could be considerable reactive power flow in or out of the generator depending on whether the system voltage had gone up or down. This required the operator to make changes in the regulator set points to keep the power factor above 90%. On some occasions, this led to getting the two plants out of balance and the generators would start exchanging reactive power. Once this occurred, adjustments to the regulator set points was required to get them balanced out again.

This problem was partially rectified after the washout because the new electronic governors furnished by Digitec for the old powerhouse have the capability of power factor control. In addition, the two plants were electrically separated so that they could not swap reactive power between the

generators. Now the operator has to adjust only the units in the new powerhouse as the system voltage changes.

ELK RAPIDS

Telemeter and Switch Gear System--The initial telemeter and switch gear system was inoperative an inordinate amount of time. Upon investigation, it was discovered that the telephone lines connecting the system were inadequately designed. For the systems still under warranty, new lines were designed.

JACKSON BLUFF

Bearing Cooling Water Pump Motor--on March 4, 1986, the bearing cooling water pump motor on Unit 2 was found off and the breaker tripped. After unsuccessfully attempting to restart the motor, the pump was disassembled and the impeller cleaned to remove a clay-like substance. The pump was reassembled and placed back in service with no further trouble.

Turbine Pit Sump Pump--Unit 1, primary sump pump motor was found to be continuously running March 17, 1986. The repairs consisted of removal and cleaning of the float level switch. The secondary pump was used while the primary pump was out for repairs.

Voltage Rheostat--Units 1, 2, and 3 were initially equipped with manual rheostat controls on voltage regulators. On each of the three units, the manual controllers proved to cause unstable control of voltage. After several attempts to rectify this problem, it was determined that modifications to the system were required to incorporate automatic controllers. Automatic controllers were installed June 18, 1987, resulting in a more stable system.

Transformer Nitrogen Leakage--A review of the June 23, 1987 log indicated an excessive use of nitrogen in Unit 1 power transformer. Visual examination determined a split in an elbow fitting. The elbow fitting was replaced and no further problems have occurred.

Data Terminal--Following a lightning storm July 16, 1986, the data terminal used to gather information concerning incoming water flows failed to function properly. It was repaired by the manufacturer and returned to service July 22, 1986.

Pressure Tank Drain Valve--Unit 1 pressure tank (incorporated in the governor oil control system) required the replacement of a drain valve September 3, 1986, because of valve damage.

Residual Magnetism Loss--Units 1, 2, and 3 tripped off-line January 23, 1987, because of system upset. Units 1 and 2 were restarted with no problems, however, Unit 3 could not be restarted because of loss-of-field voltage. After further investigation, it was discovered that the permanent magnets of the exciter had lost its residual magnetism. This problem was corrected by flashing the field. The unit was placed back in service with no further problem.

Debris Removal Apparatus--While removing logs and other debris from the intake screen December 22, 1987, one of the two hoist cables began to fray. After further examination it was decided to replace both cables.

Transformers--Over the last 24 months Unit 1 power transformer (7500 kVA) has required frequent purging to maintain acceptable levels of combustible gas readings. The exact cause of high combustible readings is unknown. Recent oil analysis showed higher than normal concentrations of acetylene in Unit 1 transformer that may be the cause of internal arcing. The analysis also showed overheating of oil in Unit 2 transformer.

Lightning--Problems that were caused by lightning have been numerous. Equipment damage includes monitoring devices, alarm systems, security, and communication equipment. In an attempt to improve the overall lightning protection, additional lightning rods were installed on the exterior of the building. While the problem has not been eliminated, the installation of surge arresters and similar protective devices on voltage sensitive equipment has had a positive effect. Lightning damage seems to be inevitable, but these preventative measures appear to have reduced the severity of lightning strikes.

Lake Level--Lake Talquin is primarily a recreational lake; fishermen and residents around the lake are very sensitive to the lake level. The sublease agreement allows the lake level variation of ± 1 ft from the normal. After only a few months of operation, it was determined that boats cannot be launched from a number of docks when the lake level is as little as 1 ft below the normal. Now the standard operating mode is run-of-river and maintaining the lake level is the primary concern.

River Level--The hydroelectric plant was expected to be operated as a peaking station. After the few times the plant was used as a peaking station, fishing camps downstream became very upset because of the significant change in the river level. This was another reason for adopting the run-of-river mode. The plans to use the plant as a peaking station were abandoned.

Flooding--The Ochlockonee River has a history of flooding downstream from the dam once every 2 years. With the hydro plant in operation, the residents downstream believe that the City of Tallahassee should be able to control flooding. If a flood is anticipated, the lake level is drawn down before water arrives at the lake and the discharge is maintained so that the river level does not exceed the flood stage. This type of planning works as long as flood duration is short. For long duration flooding it becomes necessary to exceed the downstream flood stage to avoid overtopping of the emergency spillway.

Downstream Fishing--As a part of our license agreement, fishing immediately downstream from the dam is allowed. In spite of several warning signs, the fishermen have a tendency to come dangerously close to the draft tubes or floodgates while in operation.

BOOTT MILLS

Trash Wicket Gate--On a number of occasions, there was a thumping noise and vibration caused by material caught in the wicket gate or runner vane area. Changing load usually causes the material to go through the unit. When load change is unsuccessful, the unit must be shutdown and restarted.

Transformer Failure--The station service transformer failure appeared to be caused by a manufacturing defect, because it occurred under a very modest load. A temporary replacement was obtained and quickly installed. The weakened rewinding failure of the generator cooling fan motors that single-phased on the transformer caused a major delay.

No Restart/Low Net Head--Following a trip out on August 3, 1986, Unit 1 could not be restarted. The net head across the unit on that day was less than it had ever been during a restart. Based on the then available net head, the synchronous speed controller was out of range.

Periodic Inspections--During October 4 through 16, Fuji technicians performed the first periodic inspections. All units were off-line a number of times as required by various tests. As a function of the inspections: vent lines were added to the turbine bearing oil drains, new coils were installed in the converters for the wicket gate, and runner vane controls and certain lines in the lubrication oil supply system were painted.

Jammed Wicket Gate--An outage on May 20, 1987 was caused by a length of 5/16 in. diameter x 3 ft long steel rod that became lodged under one of the wicket gates. It caused the braking link on that gate to break, and the adjacent link to bend. In order to remove the rod, a portion of the rod had to be ground off beneath the wicket gate.

Faulty Termination--An outage on December 25, 1987 was caused by a faulty termination on the utility interconnect; all three terminations required rebuilding. At the same time, carbons in the seals were replaced, first in Unit 2, and then in Unit 1.

Seal Failure--The carbon seal used to prevent water from entering the bulb has been the most troubling problem. The first failure occurred December 29, 1986 and created extensive downtime because of the national holiday period in Japan. It appeared that an exceptional quantity of sand or silt entered the carbon seal water supplier system and caused very rapid wear of the carbons.

Another carbon seal problem has been an occasional hanging up of the seal assembly following a shutdown. The problem was taken care of by repetitive startups, and during a repair that is currently in progress (replacement of runner coupling studs) an attempt will be made to determine the cause and the best way to prevent its reoccurrence.

On shutdown, the main shaft tends to move upstream and displaces one-half of the carbon seal in the upstream direction.

This portion of the seal is caused to resume its proper location (following shaft return) by spring pressure.

During the early running of the machines an inadequate job of silt removal was performed, which caused a binding of the seal plate so it could not resume its proper location. Removing all of the residual silt out of the seal area should eliminate the problem.

It may however, be prudent to locate the seal water inlet at some point other than the bottom of the forebay. Water could possibly be drawn from somewhere in the tailrace on future projects.

Operator Training--The operators of the plant should spend as much time as possible with installation and startup. Overseeing the plant and the equipment installation provides invaluable background information for both operating and maintenance people.

System Size--Both de-watering and sump pumping systems should be oversized where possible. The former gives a more rapid indication of inadequate gate sealing and the latter provides additional margin in the event of flows greater than those expected.

Cooling Water Source--The source location for cooling and seal water should be selected based on the probable absence of foreign material. The trailrace location slightly below the lowest anticipated tailwater level would probably be best.

BOLTON FALLS

Rack Raker Failures--The trash rake system at Bolton Falls is a rotating chain-driven system supplied by Ossberger, Inc. Since implementation, the rack raker system has been the source of frequent interruptions, with subsequent loss of generation. The system is prone to stoppage during high water conditions when the debris in the river is highest. Logs and other debris often become jammed by the rotating lift at the bottom of its rotating cycle, thereby causing the chain to jam or jump off its sprocket. The original supplier implemented some corrective measures in 1987 that provided marginal improvement. Recently, the project engineer (Morrison-Knudsen) notified the company that the existing trash rake was inappropriate and should be replaced. Plans are now underway to replace this device during 1989.

Low Water Conditions--Because of much lower than average rainfall over the past 2 to 3 years, plant output has been at reduced levels. Actual output is down by approximately 30% when compared to the 30-year historical water flow.

Powerhouse Walls--The parapet walls on the powerhouse have been increased in height by approximately 6 ft because of the possibility of overflow during high water conditions. The original design was based on a 1981 FEMA study that later proved to be inaccurate. During high water (spring runoff in 1987), the downstream water levels reached within 3 ft of the top of the powerhouse; the FEMA study predicted levels of about 4 to 5 ft lower. The wall extension project was completed in early 1988.

Programmable Controller--The Programmable Controller System (PCS) designed to operate the plant in three modes of automatic operation, has not been utilized because of chronic problems experienced with the control circuitry. As a result, hard wiring was utilized for the system with the PCS in a back-up mode only. While this has not caused any immediate operational difficulties--because the plant is fully operable from our dispatch control center--these devices will be repaired and replaced back into service. In addition to the PCS, several annunciator panel control problems have occurred as a result of control card failures. This problem resulted from the

installation of improper control cards by the supplier; these have since been replaced.

Ice-related Outages--For a short period each spring, the advent of river ice breakup requires that the units be shut off over a several day period. During this time frame, the ice flows are allowed to spill over the dam until most is cleared. This practice will continue on an annual basis.

Hydraulic Seal Leaks--Before the June 1988 scheduled outage of the plant, maintenance personnel noticed the coupling ends on several hydraulic steel hoses were leaking small amounts of oil. At the recommendation of the supplier, approximately six steel hoses were replaced with identical devices; however, improved crimping on the coupling ends were made to prevent future leaks. No lost generation was experienced as a result of this problem.

Penstock Seal Leaks--In early 1988, the Bestebel Seal that separates the penstock from the runner shaft was found leaking on Unit 1. The unit was removed from service for 3 weeks in July 1988 as the seal was replaced. In conjunction with this replacement, the pressure regulator was replaced with a device that did not require strainers. The small strainers in the original regulator were prone to clogging, causing sealing problems on the Bestebel Seal.

GREAT FALLS

Trashrack Failure--During the first month of operation (January), the trashrack collapsed when freezing weather caused frazzle ice to block the trashrack. The failure occurred because (a) the rack was not designed to withstand 100% blockage, (b) the water level gauges that detect differentials in levels on either side of the rack were not functioning, and (c) the weather was not expected to be cold enough to create the icing conditions. Therefore, despite having full-time operators keeping the racks clean and under observation, the blockage happened so rapidly that operating without the water differential alarms proved to be a costly mistake.

Debris Removal--The first few months of operation revealed the Passaic to be a very trash-laden river. In addition to natural debris such as leaves,

trees, tree limbs, and branches, the Passaic carries large amounts of garbage including automobile tires, refrigerators, other household trash, and various types of lumber and wood products. The original plans included no trash removal equipment, however, because of the large volume of debris, manual removal was found impractical. A power operated trashrack was added in September 1987.

Cooling Water--During the summer of 1987, algae growth and river-borne sediments were constantly fouling the cooling water filtration system of the plant, causing frequent plant shutdowns. The cooling water supply was taken from the intake channel, piped to one motor-driven and one manual, 4-in. scraper-type strainer, each with 100 mesh screens. A single, 1.0 hp pump at each unit supplied the filtered cooling water to the turbine and generator. An initial fix was provided by a back-up cooling water system connected to the city water supply, that required no filtration.

Additionally, to control algae growth during the summer months, a chemical treatment center was added. These systems proved expensive to operate and because of a need to increase the cooling water capacity to accommodate a new turbine bearing design, it was decided to redesign the entire cooling water system.

Redesign of the cooling water system involved replacing the manual scraper strainer with an automatic self-cleaning type with automatic backwash, and replacement of the individual cooling water pumps with a larger duplex pumping system that supplied all three units. The city water was left in place as a backup system. The new system, only recently put into service, is operating satisfactorily.

Relay Failures/Generator Damage--A normal shutdown signal during the night of January 17, 1988, was initiated by either an insufficient river flow signal or a mechanical condition that should have resulted in tripping the generator circuit breaker. Instead, the generator trip relay (which relays the trip signal to the circuit breaker trip coil) had failed causing the generator breaker to remain closed until the operator arrived to manually isolate the generator. Failure of the breaker to open resulted in heavy induced currents in the rotor assembly, high temperatures, and eventually

rotor damage. Disconnecting the generator from the utility line by the operator saved the stator. The rotor damage was so severe that the generator had to be removed from the station for extensive repairs.

This failure resulted in a review of the entire electrical control and generator protective system design. Design changes were made to eliminate plug-in type relays used to perform critical (generator protection) functions. Some were replaced with industrial grade bolt-on type relays.

Bearing Failures--Unit 1 shut itself down February 13, 1988, because of excessive lower generator bearing temperatures. Upon investigation, it was found that one side of the bearing was damaged, the upper bearing housing fasteners were loose, and the turbine guide bearing and shaft journal were severely worn.

The other two units were checked and in each, the turbine bearing and shaft were found to have excessive wear. A design review was initiated by the turbine manufacturer and it was found that the bearing and bearing water lubricating system were such that river water carrying large amounts of sand and grit entered the bearing causing excessive wear. The bearing was redesigned with a close fitting packing gland above the bearing, and lubricating/cooling water introduced to the bearing such that river water could no longer enter the bearing. Additionally, all three shafts were returned to the factory for replacement of the stainless steel sleeves. The lower guide bearing in the generator of Unit 1 was also repaired.

The repair procedure required complete dismantling of the turbine, major repair to the bearings and shaft, alignment, and reassembly of the units. As a result, the plant was out of operation for 7 months.

Vibration--Vibration of the Great Falls units had been a concern since commissioning. Amplitudes of up to 15 mil had been recorded, even after field balancing of the generators. After the relay and turbine bearing failures, the manufacturer initiated an exhaustive analysis of the dynamic response frequency of the turbine generator sets. A three-dimensional finite element model of the intake pipe, turbine, generator support column, and discharge ring was used to analyze dynamic response and design modifications to the

units. The analysis showed the natural frequency generator support column was very close to the running frequency of the units. It was determined that by adding vertical and horizontal stiffening ribs to the intake pipe and generator support columns, the natural frequency of the assembly could be separated from the running frequency. The design changes developed from the model were implemented in the field by welding heavy stiffening ribs to the turbine and generator support columns. Since repair, the units demonstrated a significant improvement with respect to vibration. Amplitudes at Unit 2 are somewhat higher at 4.5 mil in the cross-stream direction. These are higher than desirable and it is planned to check the balance of the generator in an attempt to further improve the vibration characteristics of Unit 2.

Reliability--Designers of small hydro plants must give careful consideration to the operating environment of the plant during design of systems and selection of the components used for performing critical functions. Improper design or inappropriate selection of equipment can lead to costly downtime and repair. It is essential that the river environment be thoroughly understood for design of trashrack and trash removal equipment, and selection of equipment for the cooling water system. Trashracks should be designed for full blockage, and water differential alarms at the trashrack should be a secondary line of defense, rather than the primary protection of the racks.

The design of the cooling water system utilizing river water requires basic knowledge of the river water quality for proper selection of equipment. Bearings and critical turbine components must be designed to take into account detrimental water quality characteristics.

Electrical systems and components must provide the necessary generator protection to avoid serious damage to the generator. Not only must the system be correctly designed, but components, particularly relays, must be correctly selected based on a knowledge of their operating environment. Vibration can be expected in switchgear located adjacent to rotating machinery. Light duty, plug-in type relays are unlikely to provide satisfactory performance.

Maintainability--An equally essential part of hydro design is the ability to adequately monitor and maintain the plant and its equipment.

Access should be provided at the intake for inspection of the gates, gate guides, water passage, and penstock.

An adequate de-watering system is essential for inspection of the turbine runner and draft tube. Properly aligned and fitted draft tube gates and guides are necessary for efficient de-watering. Adequate pumping capacity must be provided to seal the draft tube gate.

For proper monitoring and maintenance of equipment, access platforms and ladders must be provided. The generating equipment should be designed so that there is easy access to bearings and other critical components that require frequent maintenance.

Engineering Review--It is common in the development of small-scale hydroelectric projects for the project engineer to rely on the equipment vendor for selection of the equipment, design, and all related electrical components. In the case of Great Falls, the significant equipment failure problems would probably have been avoided had the project engineer been assigned the responsibility to thoroughly review the equipment configuration and design before installation. Although the equipment vendor warranty covered the full cost of resolving the vibration and faulty alarm problems, the associated repairs consumed almost 12 months, rendering the plant nearly inoperable. The project owners would have suffered drastic financial consequences from the extended downtime had business interruption insurance not been in effect.

Insurance Coverage--As described above, the project could not operate for almost 12 months because of an equipment failure situation resulting from design errors by the vendor. As is normal in typical equipment contracts, the vendor was responsible for making all the required equipment repairs, but not responsible for revenue lost during the repair process. Business interruption insurance covering lost revenues during the repair process enabled the project to continue making debt service payments and avoid bankruptcy.

SUMMARY OF LESSONS LEARNED

The DOE Technology Development projects showed an average availability of 80% in the first two years of operation. The principal reason for this lower availability was that several of the projects had equipment failures or design faults that required extensive repairs.

Most of the small hydro projects built under this program that encountered initial operating problems, could have avoided them with proper planning, design, and quality control. Also, in the operation stage, careful monitoring of equipment performance and condition, and preventive maintenance must be carried out. Actions in these two areas that should be taken to improve the successful development and operation of a hydro project are:

Improve Reliability

- 1) In the development stage, adopt conservative and proven designs, select equipment from known suppliers, and monitor quality during the construction process.
- 2) In the operation stage, carefully monitor equipment performance and condition, and carry out preventive maintenance.

Design and Equipment Selection

Design aspects that may affect the operational reliability include the following:

- Handling of sediment and trash--Proper facilities should be provided at intakes and other locations as necessary to prevent abrasive sediment from reaching the turbine and to prevent trash from blocking the entrance to the waterway.
- The stability of side slopes along canals, waterways, roads, and near structures is important. Landslides may cause long outages.

- In cold climates, ice forms on trashrack equipment, structures, electric conductors, and in reservoirs and waterways.
- Air entrance into a closed hydraulic system could cause serious damage to the turbine.
- Hydraulic transients and their effects on the design and operation of the water conduits.
- Compliance with generally accepted design standards and codes, and appropriate supervision of construction.
- Selection of an appropriate type of turbine that is designed to minimize cavitation by adopting conservative criteria regarding speed and submergence of the runner below downstream water level.
- Selecting equipment manufacturers that have a proven track record and experience in the design and manufacture of the equipment specified for the project.
- The use of the most suitable materials for critical components of equipment such as the turbine runner, generator bearings, and for insulation of the generator windings.
- Provision of redundancy in certain essential systems such as hydraulic oil pumps, sump pumps, and water filters for cooling water.
- Design of emergency closure gates and support systems that work under fault conditions.
- Careful design of control systems such as water level activated turbine controllers.
- Communication lines for remote plants must be reliable. Telephone lines can be troublesome.

Maintenance

There is a direct relation between preventive maintenance and forced outages. A systematic maintenance program, conscientiously carried out by a qualified operations and maintenance staff will greatly reduce outages and increase revenues. Poor maintenance may result in long outages for major repairs.

Proper maintenance starts with the development of a comprehensive operation and maintenance manual (O&M manual), usually compiled by the project engineer or consultant. As a minimum, this manual should include:

- A description of the purpose and function of the various design features of the project so that the operating procedures will be compatible with the original design intent.
- A complete set of as-built drawings of the project.
- Copies of O&M manuals furnished by each equipment supplier.
- O&M instructions for civil, electrical, and mechanical elements of the project for which no manufacturers' L&M manuals are supplied.
- A list of recommended spare parts, the initial supply to be provided by the equipment manufacturers. Cost, delivery times, and ordering details should be included.
- Special instructions for disassembly and assembly of the turbine and generator.
- A description of specific operation and maintenance peculiar to the equipment and systems of the project.
- Preventive maintenance schedules for each major facility of the project and each piece of equipment.

- Information on special materials used on the project, e.g., stainless steel for the runner, and special welding procedures required for repairs.
- Test data for equipment:
- Safety precautions for avoiding injury to personnel or damage to the project.

The relevant parts of this manual should be completed before the plant is handed over for commercial operation.

It is highly desirable that a senior operator and maintenance supervisor are present during the installation and testing of the equipment. After the project is in commercial operation, it is largely the responsibility of the developer/owner to make certain that proper O&M procedures are being followed. In some cases, the developer may want to arrange for a separate party, e.g., an O&M contractor or the power purchaser to operate and maintain the project.

Actual personnel requirements for operation and maintenance is a matter that must be decided in conjunction with the selection of control system and on the basis of a detailed program prepared for the project on the basis of the O&M manual. No matter how sophisticated the control system is, it will still be necessary to arrange for regular visits to the plant to verify that the plant is operating properly, to perform regular maintenance checks, and carry out minor work such as lubrication or trash removal.

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Design Report and Operations Manual	DOE/RA/23215-2
Final Operation and Maintenance Report	DOE/RA/23215-3

Goodyear Lake, NY

Final Technical and Construction Cost Report	DOE/RA/23211
First Annual Operating Report	DOE/RA/23211-2
Second Annual Operating Report	DOE/RA/23211-3
Final Operation and Maintenance Report	DOE/RA/23211-4

Sawmill, NH

First Annual Report	DOE/RA/23210
Final Technical and Construction Cost Report	DOE/RA/2310-2
Final Operation and Maintenance Report	DOE/RA/2310-3

Fries, VA

Final Technical and Construction Cost Report	DOE/RA/23213
First Annual Operating Report	DOE/RA/23213-2
Final Operation and Maintenance Report	DOE/RA/23213-3
Trash Rake Drawings	DOE/RA/23213-4

Salt River, AZ

Final Technical and Construction Cost Report	DOE/RA/2314
First Annual Operation Report	DOE/RA/2314-1
Final Operation and Maintenance Report	DOE/RA/2314-2

Garvins Falls, NH

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Idaho Falls, ID

Emergency Action Plan	DOE/RA/01699
Project Design Criteria Manual	IDO-1699-1
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Selection of Unit Size	IDO-1699-2
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Upper Mechanicville, NY

Project Design Criteria Manual	DOE/RA/12117
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Great Falls, NJ

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Final Summary Report

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