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**SMALL-SCALE HYDROELECTRIC POWER
DEMONSTRATION PROJECT**

**INEXPENSIVE CROSS-FLOW HYDROPOWER TURBINE AT
ARBUCKLE MOUNTAIN HYDROELECTRIC PROJECT**

FINAL OPERATION AND MAINTENANCE REPORT

Department of Energy Field Office, Idaho

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FINAL OPERATION AND MAINTENANCE REPORT

**By
OTT Engineering, Inc.
Bellevue, Washington**

July, 1991

Prepared for the
U.S. Department of Energy
Cooperative Agreement No. DE-FC07-84ID12481

MASTER

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INEXPENSIVE CROSS-FLOW HYDROPOWER TURBINE AT ARBUCKLE MOUNTAIN HYDROELECTRIC PROJECT FINAL OPERATION AND MAINTENANCE REPORT

INTRODUCTION

This report documents the first three and half years of operation and maintenance on the Arbuckle Mountain Hydroelectric Project. Located on a flashy mountain stream in northern California, the project was designed, built and tested through a Cooperative Agreement between the U.S. Department of Energy (DOE) and OTT Engineering, Inc. (OTT) of Redding, California. The purpose of the Agreement is to build and intensively test an inexpensive American-made cross-flow turbine and to provide information to the DOE on the cost, efficiency, operation, and maintenance of the unit. It requires that OTT document for DOE a summary of the complete operating statistics, operation and maintenance cost, and revenues from power sales for a two-year operating period.

A complete report covering the environmental, technical criteria, design, construction, and other related aspects of the total project was published by DOE as the "Final Construction and Cost Report" in July 1988. Extensive efficiency testing of the turbine was completed in 1989 and the "Field Test Report" was published by DOE in November 1989. Since these reports discuss the project elements in detail, they will only be mentioned here. However, several unique events occurred between the initial start-up (December 1986) and the beginning of the 1989 generation season (October 1988) that delayed the first year's full operation and provided unique information for a demonstration project of this type. Accordingly, this report will discuss certain major problems experienced with the design, operation and maintenance, and energy production, as well as the operation and maintenance costs and value of the power produced for the first three and half years of operation.

For reasons that are given in the body of this report, it is evident that due to numerous problems there has been no significant period of time to date that would be representative

of operating data reflecting the normal production that can be expected from this project. Principle among these circumstances are the following:

1. Once "on-line" the electrical system, the 1910 vintage generator, and the turbine inlet valve had to be completely rebuilt.
2. Drought of 1987.
3. An operator error flooded the powerhouse in November 1987.
4. Drought of 1988.
5. Failure of the air line from the powerhouse to the fish screens at the diversion.
6. Drought of 1989.
7. Drought of 1990.

Many of these matters were discussed in detail in the "Final Construction and Cost Report" and the "Field Test Report" and will be covered only briefly in this report.

PROJECT DESCRIPTION

The project is located on the Middle Fork of Cottonwood Creek, five miles north of Platina in Shasta County, California (Figure 1). The site provided an excellent opportunity to test operation and monitoring of a remote run-of-river installation that is typical of small hydroelectric projects. It was totally undeveloped and required extensive roads, bridges, and five miles of powerline to connect to the local power utility. New site facilities included a diversion and intake structure, steel penstock, powerhouse, and switchyard. Figure 2 shows the general project cross section. The turbine section and dimensions are shown in Figures 3 and 4, respectively.

The turbine was designed for a maximum of 400 kW with an average annual project output of 904,000 kW hours. After intensive testing the maximum turbine output was determined to be 336 kW resulting in an average annual project output of 618,000 kW hours. The

maximum turbine efficiency achieved averaged 79 percent. The turbine efficiency curve is shown in Figure 5.

KEY PROJECT DATA

Project name:	Arbuckle Mountain Hydroelectric
State:	California
Stream:	Middle Fork of Cottonwood Creek
Project type:	Low head
Turbine type:	Cross-flow
Number of units:	1
Installed capacity (kW):	336 (maximum)
Gross head (ft):	55
Total turbine flow (cfs):	10 to 106
Avg. annual estimated stream flow (cfs):	43
Avg. annual estimated energy (kWh):	618,000
On-Line date:	December 1986

The turbine-generator and switchgear are shown in Photographs 1 and 2. The diversion structure is shown on the cover of this report.

MAJOR REPAIRS

Even though the project came on-line in December 1986, major field modifications to the turbine, nozzle, switchgear, and a complete rework of the generator only allowed periodic operation during the 1987 season. While in the field, the nozzle had to be rebuilt and the turbine reinforced to prevent the runner from grinding on the nozzle when the turbine was under load. To alleviate the problem, clearances between the nozzle and runner were increased to a point where considerable leakage occurs around the nozzle causing a non-streamlined flow pattern and splash back against the runner. It was determined that building the turbine out of thicker materials would allow tolerances to be tightened thus improving

the efficiency of the unit. With improvements the turbine could reach efficiencies touted by the European manufactures of 85 percent and still be relatively inexpensive to manufacture. Even with the extensive modifications, the total cost of the turbine was only \$304 per kilowatt.

The original switchgear was installed to bring the generator on-line as an induction generator then switching over to synchronous operation. However, after a few trial starts, it was evident that the inrush currents to start the 450 hp generator as induction were causing a drop in the utility system voltage and current. Therefore, the utility required the switchgear be changed over to start the generator as synchronous. This required extensive rewiring and delayed the generation by two months.

Extensive field testing revealed that the 1910 vintage generator had four out of the 40 poles shorted, five of the amortisseur windings of the poles burnt open, and because of past heat distortion the air gap between the rotor and stator varied as much as 0.200 of an inch. The poles were all rewound, the amortisseur windings repaired, and the centerline of the generator shaft adjusted so that the mean differences in the air gap averaged 0.015 of an inch. Four months were required to complete this work. Costs of these repairs and modifications were included as part of the original construction costs and were included in the "Final Construction and Cost Report". The turbine, generator and switchgear were ready to go back on-line in October 1987.

In early November 1987, while filling the pool, an operator error caused the powerhouse to be flooded. The operator had closed the radial gate at the dam to fill the pool. Because the low stream flow was filling the pool so slowly, he left the site. When he returned four days later, he found that a small one-inch penstock valve had been left open causing the lower floor of the powerhouse flooded to a depth of eight feet. Water and steam were pouring out of the side walls of the upper level. The steam was generated from the 2,400 volts heating the water because a fault relay did not function. Steam affected most of the electrical, switchgear, and computer components located on the upper floor. Many required extensive rehabilitation. On the lower floor the generator and all its components, the M-G set, and the

compressor motor had to be dried out and rebuilt. All small motors, such as the slide gate motor, had to be replaced. All PT's and CT's had to be replaced and the switches rebuilt. Fortunately, insurance covered most of the \$100,000 worth of repairs. The repair work was complete and the plant was back on-line in January 1988.

During the first heavy flow in the creek each year, there is so much litter and debris that the air burst cleaning system can not completely clean the fish screens. As a result the screens require manual cleaning with a brush on a long pole after each "first flush" event. Previously, the operator attempted to do the cleaning from a small rubber boat which was dangerous and ineffective. Therefore, in June 1989 a new catwalk was installed over the fish screens that allows easy access to the screens in the event the screens require manual cleaning. The catwalk cost approximately \$2,300.

During operation in March several leaks developed in the PVC air line between the powerhouse and the fish screens at the diversion. The compressor in the powerhouse had to almost run constantly in order for the air pressure to remain sufficiently high to keep the screens clean. The compressor motor requires 5.6 kW or 135 kW hours per day to operate when running constantly. Ordinarily, it would require one sixth that amount. Since there have been problems before with the line, it was decided to replace it with 1,640 feet of 2-inch steel line at a cost of \$2,540. The work was completed in July 1989.

Once the above modifications were made to the turbine, generator, switchgear and air system the facility operates as planned. The sliding control gate that provides a continuous adjustment of flow to the turbine allows the turbine to operate down to six percent of full gate. With this feature the unit stays on line during periods of rapidly varying stream flow, thus optimizing the energy available from this flashy creek.

ANNUAL OPERATING EXPENSES

The annual operating expenses are those that occur each year no matter what the operating conditions. Monthly summaries are shown for the three and half year period in Table 1 and explained in detail below.

Special Facility Charge is the monthly charge by the utility Pacific Gas and Electric (PG&E) to cover the cost of special equipment that had to be added to their system before they would accept the power from the project. The equipment include such facilities as reclosures, meters, and line upgrades. The charge is \$140.55 per month and runs the life of the 30-year power purchase contract.

Powerhouse Utility Bill is the monthly charge from PG&E for power used in the powerhouse that exceeds the amount being generated by the plant. When the plant is generating and the outgoing power exceeds the needs of the powerhouse there is no charge. In nongenerating months the utility charge averages around \$0.11 per kW hour or around \$130 per month. The power usage is by the step up transformers, the generator warmers, the computer monitor, exhaust fan, lights, sump pumps, and compressor. In a nongenerating winter month the expense averages \$250 per month.

Telephone Charge includes the monthly connection charge plus any long distance charges. The monthly connection charge is \$42 and long distance charges average \$15 to \$30 per month. Since the plant is so remote all outgoing calls are long distance and mainly consists of the operator calling into the utility or the plant automatically calling the operator.

Fisheries Monitoring is required as part of the FERC License requirements. It consists of a fisheries biologist conducting an underwater inspection of the fish screens, ladder, and tailrace to ensure that all fish protection facilities are functioning. The surveys are conducted once per month from January through March and cost approximately \$200 each.

FERC Charges are assessed to the project on an annual basis and currently runs \$173 per year.

Insurance consists of a \$1 million liability policy and a fire insurance policy in case of forest fires. Other insurance is too costly for the project to support. These two insurances alone cost \$2,350 per year.

Plant Operator is on call continuously through out the generation season and is expected to visit the plant three times a week under normal operating conditions. During the season the operator is paid \$400 per month.

Accounting fees for the annual income tax preparation for the project partnership averages around \$1,300.

County Taxes for the project took three years to negotiate. The final annual taxes were settled at \$1,676.

Miscellaneous Expenses such as records, bank charges, etc., average around \$300 per year.

Annual Maintenance includes a complete inspection of all components of the plant, maintenance of all equipment, cleaning, and repair or replacement of any worn or damaged components. This maintenance labor and parts averages around \$3,800.

The large maintenance charge for the month of May 1990 included the cost of annual maintenance (\$3,000), new walk bridge to the operators cabin (\$2,500), replacement of the air line (\$2,540), new cat walk above the screens (\$2,300), and repair of insulators damaged by hunters (\$717).

As shown above and in Table 1, the annual operation and maintenance cost of the plant averages around \$17,000.

EFFECTS OF LOW WATER YEARS

In the northern California area where this project is located, the annual rainfall for the last four years has ranged 60 to 80 percent of normal resulting in stream flows as low as 28 percent of normal. When large storms did come, they occurred in intense rainfall events resulting in short high runoff events, thus exceeding the capacity of small run-of-river projects such as this. Most of the small run-of-river hydro projects in this area generated only about 20 to 35 percent of their forecasted energy.

The Cottonwood Creek watershed in which this project is located is best characterized by the USGS stream gage on the main stem of Cottonwood Creek Near Cottonwood, California (Gage No. 11376000). The stream gage measures the total runoff of the basin and has an excellent record since 1940. The average annual streamflow for this 50-year period is 857 cfs. Listed below are recorded stream flows for the last four years.

<u>Year</u>	<u>Flow (cfs)</u>	<u>% of Normal</u>
1987	298	34.8
1988	440	51.3
1989	481	56.1
1990	244	28.5

In the 1989 season, 35 to 45 percent of the annual precipitation and runoff occurred in the month of March, causing high stream flows the small run-of-river plant could not effectively utilize.

The 1990 season was the driest of the four years. One small storm occurred in mid-January, but the only storm of any significance occurred at the end of May, which resulted in over 60 percent of the generation for that year.

Another measure of long-term water conditions in the watershed above the project is reflected by the rain gage located at the approximate centroid of the watershed at the Harrison Gulch Ranger station. This daily recording rain gage has a 36-year average annual precipitation of 36.56 inches. Listed below are the recorded annual amounts for the last three years.

<u>Year</u>	<u>Precipitation (inches)</u>	<u>% of Normal</u>
1987	24.03	65.7
1988	27.22	74.5
1989	30.14	82.4
1990	25.23	69.0

Because of these drought conditions and the storms that did occur being of the high-intense short-duration type that produced flashy events, the production of the project has been only a small fraction of that expected from the unit. Short-term high flows are shown in Photographs 3 and 4. The forecasted and actual stream flow and production are shown in is shown in Table 2.

To date, the maximum monthly generations occurred in January 1988 and March 1989. Both averaged around 108 kW for the month, with a peak day average of 313 kW at the utility meter.

PHOTOGRAPH 1.

TURBINE - GENERATOR

PHOTOGRAPH 2.

GENERATOR - SWITCHGEAR

PHOTOGRAPH 3.

DIVERSION AT HIGH FLOWS

PHOTOGRAPH 4.

POWERHOUSE AT HIGH FLOWS

TABLE 1
OPERATION AND MAINTENANCE COST

	<u>Operating Cost</u>	<u>Maintenance Cost</u>	<u>Total Cost</u>
Jan 87	\$ 446	\$ 261	\$ 707
Feb 87	813	0	813
Mar 87	996	611	1,607
Apr 87	934	1,405	2,339
May 87	848	24	872
Jun 87	822	1,008	1,830
Jul 87	1,058	0	1,058
Aug 87	558	49	607
Sep 87	555	912	1,467
	-----	-----	-----
Season	7,030	4,270	11,300
Oct 87	269	0	269
Nov 87	886	1,807	2,693
Dec 87	831	0	831
Jan 88	1,300	0	1,300
Feb 88	2,102	0	2,102
Mar 88	1,228	0	1,228
Apr 88	2,856	0	2,856
May 88	1,313	0	1,313
Jun 88	531	3,665	4,196
Jul 88	404	0	404
Aug 88	480	0	480
Sep 88	269	0	269
	-----	-----	-----
Season	12,469	5,472	17,941
Oct 88	436	714	1,150
Nov 88	449	0	449
Dec 88	1,635	1,243	2,878
Jan 89	424	196	620
Feb 89	1,274	0	1,274
Mar 89	578	100	678
Apr 89	556	992	1,548
May 89	1,714	399	2,113
Jun 89	526	0	526
Jul 89	510	0	510
Aug 89	718	2,539	3,257
Sep 89	1,989	0	1,989
	-----	-----	-----
Season	10,809	6,183	16,992

TABLE 1 (Continued)

	<u>Operating Cost</u>	<u>Maintenance Cost</u>	<u>Total Cost</u>
Oct 89	408	625	\$ 1,033
Nov 89	246	0	246
Dec 89	2,671	1,253	3,924
Jan 90	585	36	621
Feb 90	805	0	805
Mar 90	1,290	249	1,539
Apr 90	3,364	0	3,364
May 90	427	11,057	11,484
Jun 90	141	0	141
Jul 90	419	175	594
Aug 90	210	0	210
Sep 90	2,347	0	2,347
	-----	-----	-----
Season	12,913	13,395	26,308

TABLE 2
STREAM FLOW AND PRODUCTION

	<u>Historical Stream Flow (cfs)</u>	<u>Actual Stream Flow (cfs)</u>	<u>Forecasted Production (kWh)</u>	<u>Actual Production (kWh)</u>	<u>Production Value (\$)</u>
Jan 87	102	16	88,000	3,960	238
Feb 87	122	52	115,000	18,180	1,143
Mar 87	105	84	128,000	46,260	2,893
Apr 87	72	27	98,000	180	13
May 87	27	9	55,000	0	0
Jun 87	10	3	9,000	0	0
Jul 87	4	1	0	0	0
Aug 87	1	0	0	0	0
Sep 87	1	0	0	0	0
	-----	-----	-----	-----	-----
Season	43	19	493,000	68,580	4,287
Oct 87	5	0	3,000	0	0
Nov 87	23	0	42,000	0	0
Dec 87	45	60	80,000	0	0
Jan 88	102	111	88,000	78,119	5,272
Feb 88	122	32	115,000	5,749	388
Mar 88	105	15	128,000	0	0
Apr 88	72	10	98,000	1,452	98
May 88	27	5	55,000	0	0
Jun 88	10	1	9,000	0	0
Jul 88	4	0	0	0	0
Aug 88	1	0	0	0	0
Sep 88	1	0	0	0	0
	-----	-----	-----	-----	-----
Season	43	20	618,000	85,320	5,758
Oct 88	5	0	3,000	0	0
Nov 88	23	30	42,000	5,580	378
Dec 88	45	15	80,000	16,560	1,160
Jan 89	102	36	88,000	18,753	1,406
Feb 89	122	20	115,000	332	26
Mar 89	105	162	128,000	75,452	5,654
Apr 89	72	45	98,000	17,388	1,302
May 89	27	15	55,000	2,556	192
Jun 89	10	5	9,000	0	0
Jul 89	4	1	0	0	0
Aug 89	1	0	0	0	0
Sep 89	1	0	0	0	0
	-----	-----	-----	-----	-----
Season	43	27	618,000	136,621	10,118

TABLE 2 (Continued)

	Historical Stream Flow (cfs)	Actual Stream Flow (cfs)	Forecasted Production (kWh)	Actual Production (kWh)	Production Value (\$)
Oct 89	5	7	3,000	649	36
Nov 89	23	11	42,000	171	28
Dec 89	45	9	80,000	203	231
Jan 90	102	52	88,000	8,713	453
Feb 90	122	30	115,000	147	14
Mar 90	105	21	128,000	21	0
Apr 90	72	7	98,000	0	15
May 90	27	10	55,000	13,175	1,727
Jun 90	10	10	9,000	5,061	0
Jul 90	4	2	0	0	0
Aug 90	1	0	0	0	0
Sep 90	1	0	0	0	0
	-----	-----	-----	-----	-----
Season	43	13	618,000	28,140	2,504

FIGURE 1. FACILITY LOCATION

FIGURE 3.

TURBINE - DRAFT TUBE SECTION

FIGURE 4.

TURBINE DIMENSIONS

ARBUCKLE HYDRO EFFICIENCY TESTING

FIGURE 5. TURBINE EFFICIENCY

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