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PROBLEMS OF HYDROELECTRIC DEVELOPMENT
AT EXISTING DAMS

An Analysis of Institutional, Economic, and Environmental
Restraints in Pennsylvania, New Jersey, and Maryland

By
R. J. Taylor
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April 1979

Work Performed Under Contract No. EC-77-C-01-5085

The Johns Hopkins University
Applied Physics Laboratory
Laurel, Maryland

U. S. DEPARTMENT OF ENERGY

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R. J. TAYLOR
L. L. GREEN

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EXECUTIVE SUMMARY

The Johns Hopkins University Applied Physics Laboratory has developed for the Department of Energy (DOE) a methodology that helps quantify the impact of the institutional, economic, and environmental (IEE) restraints on the hydroelectric development of existing dams. The methodology involves determination of the incremental costs of hydroelectric generation versus the potential hydroelectric energy output within a designated area. The resulting hydroelectric energy supply curve (kWh versus ¢/kWh) is a valuable tool for assisting in determining what governmental policies will encourage the greatest development of the resource. The following are some of the questions this tool should help answer: What types of hydroelectric developers should be encouraged and how should this be done? What is the effect of taxes and insurance on the supply? What effects do the present licensing costs have upon the supply? What is the effect of low-cost turbine-generators on the supply? What are the impacts of the present environmental and recreational requirements? What would be the effect of governmental subsidies, loans, and assistance (e.g., as a federally assisted liability insurance program) on the hydroelectric supply?

Within Pennsylvania, Maryland, and New Jersey, 393 nonhydroelectric dams were identified that had individual potential capacities greater than 50 kW. Twenty-nine of these dams were estimated to be economically viable at a price of 25 mills or less to a developer with an annual fixed charge rate of 10.4%. The potential capacity estimate for the three states was 151 000 kW with an annual energy potential of 8.6×10^8 kWh at a price of 25 mills/kWh. At a price of 40 mills/kWh the potential capacity estimate was 320 000 kW with an annual energy potential of 1.7×10^9 kWh.

The type of developer has a significant effect on the potential supply. The reason for this is the difference in the annual fixed charge rate expected for private versus public developers. At a price of 25 mills/kWh, the estimated supply potential from public developers (annual fixed charge rate of 10.4%) is almost four times the estimated supply potential from private developers (annual fixed charge rate of 17.9%). However, low-cost loans (6.875%) for private developers and a 50% reduction in taxes would allow private developers to supply 85% of the potential available from public developers.

The effect of licensing costs on the supply appears to be almost insignificant. However, cost reductions in the turbine-generator equipment and powerhouse can substantially increase the supply. For example, a 30% cost reduction increases the supply by almost 80% at a price of electricity to the developer of 25 mills/kWh.

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I. INTRODUCTION

The purpose of this report is to describe the methodology that has been developed to analyze the impact of possible government actions on the development of small-scale hydroelectric power in the United States. The report also describes the application of the methodology to a specific region of the United States. Within the Pennsylvania-New Jersey-Maryland (PJM) region, the methodology has been used to evaluate the significance of some of the existing institutional and economic constraints on hydroelectric development at existing dams.

The basic process for the analysis and evaluation is estimation of the hydroelectric energy that can be developed for a given price of electricity. Considering the present constraints and a geographical region of interest, one should be able to quantify the potential hydroelectric energy supply versus price. Estimates of how the supply varies with possible changes in governmental policies, regulations, and actions should assist the government in making decisions concerning these governmental functions relative to hydroelectric development.

The methodology for estimating the hydroelectric supply at existing dams follows.

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II. METHODOLOGY FOR ANALYSIS OF INSTITUTIONAL, ECONOMIC, AND ENVIRONMENTAL RESTRAINTS

The methodology for obtaining the supply curves and hydroelectric development versus time can be divided into several parts or tasks: (a) estimating the existing dam hydroelectric potential, (b) categorization of the dams, (c) selecting and visiting a random sample of the dams to determine expected values for some site specific functions, (d) evaluating the environmental constraints at each site, (e) estimating the cost of development of hydroelectric power at existing dams, (f) determining the supply curves, and (g) estimating the regional supply curves. Each of these tasks is outlined in the following sections of this chapter.

Estimating the Resource

The list of dams in each state is the key information needed for estimating the resource. Two major sources of information are available for such an inventory: the Corps of Engineers and the individual state dam licensing and permitting office. The Corps of Engineers' list is computerized but lacks information about average flow or drainage area. The state information generally includes drainage area. Pennsylvania probably has the most accessible state records on dams in the eastern United States. There are 2323 dams listed in Ref. 1. Most of the analysis to date has been on dam data from Pennsylvania, which has 77% of the known dams in Delaware, Maryland, New Jersey, and Pennsylvania.

Table 1 gives the number of dams in each state as shown by the Corps listing and by state records.

The stream flow information for each state can be determined from the following U. S. Geological Survey (USGS) documents:

Delaware	"Water Resources of the Delmarva Peninsula," <u>Professional Paper 822</u>
Maryland	"Stream Flow Characteristics of Maryland," <u>Report of Investigation No. 16</u>
New Jersey	"Statistical Summaries of New Jersey Stream Flow Records," <u>Circular No. 23</u>

Pennsylvania

"Low Flow Characteristics of
Pennsylvania Streams," Water Re-
sources, Bulletin No. 12

Table 1

Number of dams in Corps and state records.

State	Corps Records	State Records	Comments About State Records
Delaware	68	33	Very little information on drainage.
Maryland	145	145	APL and the state coopera- tively determined the drainage areas for Maryland.
New Jersey	543	<645	State information on microfilm. Records contain drainage area information (more than one file per dam, however).
Pennsylvania	901	2487*	Ref. 1 contains drainage area and is an excellent resource for dam information in Pennsylvania.

* Includes dams not listed in Ref. 1.

An initial estimate of the hydroelectric potential of an exist-
ing dam can be calculated from data on the hydraulic head, H , and the
average stream flow at the dam, Q_A , using the following equation:

$$P = \eta H Q_A \div 11.8 \text{ (kW) } , \quad (1)$$

where

η = turbine-generator efficiency (assumed initially to be
0.75, for low-head plants),

H = net hydraulic head in feet,

Q_A = average discharge in ft^3/s , and

P = power in kW.

When the hydraulic head is not known for a dam, the structural height of the dam is used. When the average stream flow is not known, it is estimated from the drainage area of the stream at the location of the dam and an average runoff per square mile for the closest stream gauge to the dam. For example, Broad Creek Dam is located on Broad Creek in northeastern Maryland, Harford County. The closest long-term gauging station to the dam is the 1-5800 gauging station at Deer Creek at Rocks, Md. The drainage area for 1-5800 is 94.4 mi^2 ; the average stream flow is $118 \text{ ft}^3/\text{s}$. The drainage area for Broad Creek Dam is 30 mi^2 . Thus the average stream flow at Broad Creek Dam is estimated to be $37.5 \text{ ft}^3/\text{s}$ ($118 \times 30 \div 94.4$) (Ref. 2). The structural height of Broad Creek Dam is 37 ft, and the hydraulic height is 25 ft. Using Eq. 1, the initial estimated power potential at Broad Creek is 60 kW.

Because the dam drainage area information was incomplete for Delaware, this state was dropped from the supply model study.

Categorization of Dams

The dams in Maryland and Pennsylvania have been categorized by drainage area. Drainage area was chosen because it is the key factor that determines the average stream flow. Height of the dam was not used for initial classification purposes because the height of the dam does not necessarily determine the potential hydraulic head. For example, in Lancaster, N.H., a hydroelectric facility exists with a 3 ft high dam and a 100 ft hydraulic head for the turbine. Also, the S.U.M. (Society for Establishing Useful Manufacturers) Dam in Paterson, N.J., is 15 ft high, and the hydraulic head available at its powerhouse is 66 ft. The potential hydraulic head can be increased over the dam height by using diversionary canals and extended penstocks (water conduits or pipes). Thus, the most fundamental characteristic relative to power potential for existing dams is the average stream or river flow at a dam's location or, in other words, the drainage area because average stream flow is proportional to it.

Table 2 shows an example of the categorization by drainage area. The dams are Pennsylvania dams taken from Ref. 1, are non-hydroelectric, and have an initial estimated potential greater than 50 kW.

Table 2

Categorization by drainage area of nonhydroelectric dams in Pennsylvania with an initial estimated potential greater than 50 kW (dams from Ref. 1)

Category Designation	Drainage Area Range (mi ²)	Number of Dams	Initial Estimates* to Total Capacity per Category (kW)	Initial Estimates* of Average Capacity per Dam (kW)
1	3000 or greater	6	63 797	10 633
2	1000 to 2999	10	90 070	9 007
3	300 to 999	47	59 502	1 266
4	Less than 300	252	75 904	301

*The initial power estimate is made by assuming that the hydraulic head equals the dam height and the average runoff is 1.6 ft³/s/mi².

Selection Procedure for Site Visits

The dams in Pennsylvania (Ref. 1) and Maryland (Corps list) were categorized. All the known hydroelectric dams and the dams with initial power estimates less than 50 kW were excluded from the categorization. The remaining nonhydroelectric dams in each category were assigned numbers in descending order of drainage area. Using a random-number generator, dams were selected at random from each category for site visits. The dams were not selected because of their hydroelectric potential or possible ease of development. Table 3 indicates the number of dams chosen for site visits in Pennsylvania and Maryland.

Visiting Dam Sites

Eleven dams (nine in Pennsylvania and two in Maryland) were visited. The purpose of choosing dams at random was to be able to determine the average expected costs of dam repairs, transmission lines, and roads. Also the average potential hydraulic head available versus dam height needed to be determined before a generalized computer model could be built to obtain the hydroelectric energy supply curve for the existing dams within the region.

Table 3

Number of dams chosen for site visits.

Category	Drainage Area (mi ²)	Maryland	Pennsylvania
1	3000 or greater	0	1
2	1000 to 2999	0	1
3	300 to 999	1	3*
4	Less than 300	1	6†

* One dam was breached after 1970; therefore, only two of the dams were visited.

† One was not visited because of owner objection; therefore, only five were visited.

Appendix A presents partial results of each site visitation.

Evaluating the Environmental Constraints

During the site visits, five areas of environmental concern were examined on a reconnaissance basis:

1. Reservoir and upstream effects such as increased flooding and soil erosion caused by potential increases in dam heights, and water quality and stratification in the present reservoir;
2. Downstream effects caused by proposed penstocks, mill races, or possible changes in channel configuration;
3. The effects on fisheries and other aquatic life;
4. The effects from construction; and
5. Potential site enhancement from development.

Both temporary and permanent environmental impacts were assessed, as well as measures needed to mitigate these effects.

The assessment of these areas was based upon a half-day reconnaissance visit to each dam, rather than an extensive environmental analysis.

Estimating Hydroelectric Development Costs

Each of the cost components was estimated as a function of installed capacity at the dams that were visited. The type of costing was reconnaissance in nature and not a detailed analysis of each item needed for development. All costs are in April 1978 dollars.

The cost of the proposed hydroelectric facilities was estimated from the costs of the following items:

1. Turbine-generator sets;
2. Powerhouse and equipment;
3. Trash racks, gates, and lifts;
4. Dam repairs;
5. Penstocks, canals, or raceways, if required;
6. Roads;
7. Transmission lines;
8. Environmental amelioration;
9. Recreational needs;
10. Engineering and economic feasibility studies;
11. Licenses and permits required for project;
12. Land required; and
13. Interest charges during the construction period.

The sources of information used to estimate the costs of each item listed above are:

1. Acres American Inc., Consulting Engineers, Columbia, Md. Acres was contacted to determine the costs of dam repairs and water intake at three of the sites visited (Broad Creek Dam, Middle Creek Dam, and Lake Williams Dam).
2. Bureau of Reclamation (Ref. 3). This document contains reconnaissance cost estimating data for costing dams, conduits, hydroelectric power plants, transmission lines, and roads. Cost estimates were updated to April 1978 using Refs. 4 and 5.
3. The Federal Energy Regulatory Commission (FERC) (Refs. 6 and 7).
4. Stone and Webster (Ref. 8).
5. Turbine-generator manufacturers.
6. J. L. Gordon, Montreal Engineering Co. (Ref. 9).
7. Reference 10.
8. Reference 11.
9. Hydroelectric developers such as L. Gleeson in Maine, B. Sloat in New Hampshire, and G. Marker in Massachusetts.
10. APL's Plant Engineering Group (APLPEG).
11. Electric utilities in the PJM region.

Turbine-Generator Costs: The most important cost item is the turbine-generator (T-G). T-G cost also has one of the greatest uncertainties in cost associated with it. The range in costs per kW as a function of head is evident in Fig. B-1 in Appendix B (taken from Ref. 8, Fig. 10-2). The costs vary by a factor of five.

The lowest cost turbines given in Ref. 8 are for "small vertical shaft Francis units in an open flume setting, including speed increaser and a horizontal shaft synchronous generator, exciter, governor, and usual accessories. The costs are based on unit capacities ranging from 200 to 600 kW and a runner diameter of 1423 mm." The cost formula derived for this T-G is (where P is power or capacity in kW, H is head in ft, and the cost is in dollars)

$$\text{T-G Cost No. 1} = 4.07 \times 10^3 \frac{P^{1.0}}{H^{0.948}} \quad (2)$$

Curve C in Fig. B-1 approximates the "delivered cost of small tube units, including adjustable blade propeller turbine, fixed guide vanes, synchronous generator, thrust bearing, governor, excitation equipment, and butterfly valve for intake flow control." The costs are for a capacity range of 500 to 7500 kW. The cost formula for this T-G derived from the data is

$$\text{T-G Cost No. 2} = 2.17 \times 10^4 \frac{P^{1.0}}{H^{1.27}} . \quad (3)$$

Cost information from a tube turbine manufacturer was obtained directly (Aug 1978); the costs quoted for a T-G for a range of 100 to 6000 kW can be better approximated by the following cost formula:

$$\text{T-G Cost No. 3} = 8.0 \times 10^4 \frac{P^{0.6}}{H^{0.68}} . \quad (4)$$

The Bureau of Reclamation cost data on Fig. 1, Par. 4.2 of Ref. 3 yield the following cost formula for T-G sets where $P \leq 306 H^{0.5}$ and H is greater than 10 ft:

$$\text{T-G Cost No. 4} = 2.86 \times 10^3 \frac{P^{1.02}}{H^{0.51}} . \quad (5)$$

Another cost model for T-G's recently appeared in Ref. 9:

$$\text{T-G Cost No. 5} = 1.36 \times 10^4 \left(\frac{P}{\sqrt{H}} \right)^{0.7} = 1.36 \times 10^4 \frac{P^{0.7}}{H^{0.35}} . \quad (6)$$

Initially, one might think these cost formulas give a great variation in estimated costs for a given head, H, and installed capacity, P, but this is not always the case. There is a remarkable consistency in several of the estimates in spite of the great range

of coefficients found in the formulas. The approach generally used in this study is to take the average of these cost estimates to determine the expected T-G costs, rather than any one estimate.

Powerhouse and Equipment Costs: No comprehensive data were found that estimate the cost of the powerhouse and equipment for small-scale facilities. Because of this, information for large facilities was used to determine the ratio between T-G costs and the costs of the powerhouse and equipment. Using data in Ref. 3, the following equation was derived for the ratio between power plant costs and T-G costs (ratio equals power plant costs divided by T-G costs):

$$\text{Ratio} = 1.515 (1 + 0.4323 \times e^{-B \times \text{PDRPM}^C}) , \quad (7)$$

where

$$\text{PDRPM} = 1.869 \times 10^{-3} \times P^{1.5} \times H^{0.75} , \quad (8)$$

$$B = 0.03586, \text{ and}$$

$$C = 0.5433 .$$

The power plant cost includes

1. Structures and Improvements, Federal Energy Regulatory Commission (FERC) account 331;
2. Turbines and Generators, FERC account 333;
3. Accessory Electrical Equipment, FERC account 334; and
4. Miscellaneous Power Plant Equipment, FERC account 335.

All previous T-G costs can thus be converted to powerhouse and equipment costs by multiplication with the ratio given in Eq. 7.

Data recently published by FERC (Ref. 6) yield the following powerhouse and equipment cost formula when corrected to 1 Apr 1978:

$$\text{PH Cost No. 6} = 2.25 \times 10^4 \frac{P^{0.808}}{H^{0.424}} . \quad (9)$$

As mentioned previously, one major problem with the Bureau of Reclamation and FERC data is that they do not include small-scale hydroelectric power costs. The Bureau states that the data are "not suitable for estimating costs of powerplants having operating heads less than 10 feet" (Ref. 12). The curves in Fig. 7.1 of Ref. 13 do not go below 20 ft of head or below 25 000 kW total plant installed power. There is a definite need for cost models of small-scale hydroelectric plants. Even the Stone and Webster economic data on T-G's do not go below the 200 kW level. In this study, all dams with a potential capacity greater than 50 kW are included in the general supply curve.

In the absence of documented powerhouse cost models for small-scale hydroelectric plants, we are forced to use the previous cost models. Thus, these cost estimates may be higher than quoted by small-scale hydroelectric developers. They may be as much as 30% higher than manufacturer quotations in some cases.

Water Intake Costs: The water intake costs are illustrated in the Acres American report (see Appendix C). Certain basic estimating assumptions are used for reconnaissance-level evaluations. The costs of trash racks are assumed to be $\$10/\text{ft}^2$, while the costs of the gate and lift are assumed to be $\$125/\text{ft}^2$. In order to permit hand raking, the velocity through the trash rack is limited to 2.5 ft/s (Ref. 14). Therefore, the minimum cross-sectional area of the track rack will be $A_{\min} (\text{ft}^2) = Q \div 2.5$. Assuming the cement support structures cost $\$36/\text{ft}^2$ of water flow, the water intake costs are $68.4 \times Q(\$)$ (Q is flow in ft^3/s).

Dam Repair Costs: Again, these costs are illustrated in Appendix C. First, the repairs are identified; second, the quantities of materials needed for the repairs are estimated. Third, the costs of the materials and labor for each repair are estimated using cost-estimating manuals such as Refs. 10 and 11.

Canal and Raceway Costs: The costs of canals and raceways are taken from Chapter 2 of Ref. 3. The canal costs per 100 ft can be approximated by the following equation:

$$\text{CANCOST} = 425 \times Q^{0.376} (\$/100 \text{ ft}) . \quad (10)$$

Road Costs: The cost of 12 ft wide gravel roads (4 in. thick) was assumed to be \$5.00 per linear foot (LFT). The road costs were costed by APLPEG.

Transmission Costs: For a three-phase 12.47 kV power line, the costs are about \$9.5/LFT. For a single phase 7.2 kV power line, the costs are about \$7.6/LFG. These cost estimates come from electric utility companies in the PJM region.

Environmental Costs: Environmental analysis costs for potential site development are included in the costs of feasibility studies. Actual environment costs for items required for development will be estimated by using costs of similar facilities at existing hydroelectric power sites.

Recreational Costs: If recreational facilities are not already provided at the dam, FERC requires such facilities before a license is granted. The costs of recreation (investment per kW and operating and maintenance cost per kWh) are assumed to be the same as provided by the Potomac Edison Company in Maryland and West Virginia (Ref. 7). Potomac Edison has eight low-head hydroelectric sites ranging in installed capacity from 936 to 3550 kW with an average capacity of 1590 kW. The average recreational investment is \$2.50/kW with an average recreational operating and maintenance cost of 0.08 mill/kWh.

Engineering and Feasibility Costs: The costs of engineering and feasibility studies are assumed to be 25% of the total capital cost of development.

License and Permit Costs: Costs of obtaining the licenses and permits required for hydroelectric development may vary greatly. They may be more than the total capital costs, depending on potential intervention by opposing groups. From conversations with developers, a reasonable figure appears to be \$40 000 per site.

Land Costs: Land costs apply only when the developer is not the dam owner or when insufficient land is available for the project.

Interest Costs during Construction. The interest costs during construction can be calculated by standard methods using the following assumptions: The license and feasibility interest costs are accrued for $2\frac{1}{2}$ years. The interest costs on one-half of the remaining capital costs accrue for $1\frac{1}{2}$ years, and the interest costs on the remaining capital spent accrue for 6 months.

Determining the Supply Curves

The capacity and energy supply curves will indicate the hydroelectric power (kW) and energy (kWh), respectively, that are economically feasible to develop at existing dams as one varies the price of electrical energy (¢/kWh). Therefore, a supply curve is the "relation between the market price and the amounts that producers are willing to supply" (Ref. 12). "It is evident that costs are vital determinants of how much a firm will be willing to supply" (Ref. 15). The supply curves are derived from the developer's costs.

The decision of whether or not to develop an existing dam site to supply hydroelectric power and energy is a function of the costs of development, the energy output, and the price to be received for that output. The curve relating estimated costs of production to potential energy output from a proposed hydroelectric facility can be used by the potential developer to determine not only if he should build the facility, but also what hydroelectric capacity (power potential) should be installed to maximize his expected profits. This curve of the potential energy output versus the price of electricity is called the energy supply curve.

The first step in deriving a supply curve is to determine the total capital costs (TCC's) for the proposed facility versus installed capacity. The previous section discussed the methodology for determining the TCC. TCC is calculated for four different installed capacities. The flows through the turbines to determine these capacities typically are $0.25Q_A$, $0.5Q_A$, $1Q_A$, and $2Q_A$; Q_A is the annual average stream flow at the facility. These four TCC points are then fitted to a second-order polynomial. An illustration of the TCC as it might vary with installed capacity is given in Fig. 1.

Deriving Annual Cost: The TCC is related to annual capital costs, ACC, by the following equation:

$$ACC = TCC \times AFCR, \quad (11)$$

where AFCR is the annual fixed charge rate that can be determined by the following equation:

$$AFCR = COC + DEP + ITAX + OTAX + INS, \quad (12)$$

where

COC is the annual cost of capital as a ratio of TCC,

DEP is the depreciation rate of the facility,

ITAX is the income tax rate for the project,

OTAX is the property and other tax rates for the project,
and

INS is the insurance rate for the project.

Fig. 1 TCC's versus installed capacity for the Broad Creek Dam in Maryland (low-cost approach).

The total annual costs (TAC's) are the sum of the annual capital costs and the annual operating, maintenance, and administration costs (AOMA).

$$TAC = ACC + AOMA . \quad (13)$$

The AOMA rate, mills/kWh, varies with installed capacity as shown in Fig. 2. Data shown in Fig. 2 were used to determine an expected AOMA rate as a function of installed capacity. This rate is given in Eq. 14.

$$\text{Rate} = 0.2015 \times \text{capacity}^{-0.472} \text{ (\$/kWh) ,} \quad (14)$$

$$AOMA = \text{energy} \times \text{rate} \text{ (\$/yr).} \quad (15)$$

From discussions with private developers, a maximum of 8 mills/kWh is reasonable for the AOMA rate when the installed capacity is below 1000 kW. Above 1000 kW, the assumed rate is given by Eq. 14.

Energy Versus Capacity: It is assumed throughout the study that the only limiting factors for the annual electric energy production, EGY, are the natural stream flow at the site of the hydroelectric facility and the efficiency of the T-G set. The equation relating installed capacity, CAP, and EGY is

$$EGY = CF \times CAP \times 8760 , \quad (16)$$

where CF is the capacity factor for the site and 8760 is the number of hours in a year.

The capacity factor of a hydroelectric facility is the ratio of the average annual energy produced to the energy potentially produced if the facility could have been operated at the installed capacity throughout the year (Ref. 16). The capacity factor is derived from the stream flow duration curve for the stream at the site of the hydroelectric facility and the efficiency curve of the T-G set. The methodology for deriving the capacity factor is given in Appendix D.

Fig. 2 Operation and maintenance costs for small-scale hydroelectric facilities based on specific facilities within The Potomac Edison Co. and the Rural Electrification Administration. The straight line is for Eq. 14, the fitted rate.

Knowing how the capacity factor varies with installed capacity and using Eq. 16, one can plot the TAC's as a function of the annual electrical energy production as shown in Fig. 3.

Fig. 3 TAC's versus the average expected annual electrical energy output from the Broad Creek Dam in Maryland (low-cost approach).

Average Costs and Marginal Costs: From Fig. 3, one can calculate and plot the average total annual costs per kilowatt hour, AVERCOST, versus EGY. Note that the equation for AVERCOST is simply

$$\text{AVERCOST} = \text{TAC} \div \text{EGY} . \quad (17)$$

One can also determine the marginal cost per kilowatt hour from Fig. 3. The ratio of the increment in total annual cost, ΔTAC , to the corresponding increment in energy production, ΔEGY , is the marginal cost, MARCOST, and is defined in the following equation:

$$\text{MARCOST} = \Delta\text{TAC} \div \Delta\text{EGY} . \quad (18)$$

Thus, the marginal cost is actually the first derivative of the curve of TAC versus electrical energy production (Fig. 3).

Plots of average TAC's/kWh and marginal cost (both versus energy output, kWh) are given in Fig. 4. The point of intersection of the two is called the break-even point, where the average total annual cost per kilowatt hour is a minimum. For a developer analyzing the feasibility of a specific site, the price of electricity

Fig. 4 The average total annual costs per kWh and the marginal cost curve for the Broad Creek Dam. The supply curve for Broad Creek Dam. The supply curve for Broad Creek is the marginal cost curve starting at the breakeven point and going upward (low-cost approach).

must be at or above the break-even point, or the site will not be developed. It should be noted that "a minimum profit which the developer must expect to earn to induce him to remain in business, is included as part of the total cost" (Ref. 17).

The supply curve is actually the marginal cost curve starting from the break-even point and increasing in price. The supply curve can be used to determine how much energy a hydroelectric

developer will supply for a given price. "If the developer is to maximize his profits he must produce to the point where the marginal cost equals the price of electricity" (Ref. 17). Thus, if the market price of energy is P_1 to the developer, he will find it profitable to supply EGY_1 at the Broad Creek site. The corresponding capacity will be

$$CAP_1 = EGY_1 \div (CF_1 \times 8760) . \quad (19)$$

Estimating the Regional Supply Curves

Estimating the regional supply curves is undoubtedly the most critical step in the methodology that was developed to quantify and understand the IEE constraints on hydroelectric development. Several factors related to hydroelectric development are very site-specific:

1. Head or hydraulic height,
2. Average stream flow,
3. Flow duration curve,
4. Costs of dam repairs,
5. Costs of water intake,
6. Potential for penstocks and canals and their costs,
7. Costs of transmission lines needed,
8. Costs of roads needed, and
9. Costs of environmental amelioration needed.

The two most critical items are the head and the stream flow. These two variables or their surrogates such as structural height and drainage area are used for each dam contributing to the regional supply curve estimate. Average values of the costs listed above are determined from the site visits. These costs are then used in a generalized costing methodology for determining the supply curve for each dam in the region whose potential capacity is greater than 50 kW. Estimates of the errors in the regional supply curves derived by this method are discussed in the section on sensitivity analysis of the supply curves.

The individual dam supply curves that are derived by the methods described previously are summed to form the generalized supply curve using the following equation:

$$TE_M(P_1) = \sum_{i=1}^M EGY_{1i} , \quad (20)$$

where $TE_M(P_1)$ is the total electrical energy economically available at the price of electrical energy, P_1 , using M dams for development.

EGY_{1i} is the average annual electrical energy economically available from the i th hydroelectric facility or dam at the P_1 price of electricity.

The average costs and other parameters used in the generalized methodology are given in Chapter III.

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III. RESULTS FROM SITE VISITS

Hydraulic head versus structural height, stream flow duration curves, canal lengths, transmission lines, roads, and dam repair costs for the sites visited are the topics of this chapter.

Hydraulic Height

The hydraulic height (the height measured between the natural bed of the stream at the downstream toe of the dam to the normal reservoir elevation) for dams is given in the Corps of Engineers' list; however, the accuracy and completeness of this information are questionable (see Table 4).

The state data bases for New Jersey and Pennsylvania do not contain hydraulic height. Thus, a method for estimating the hydraulic height (HH) of dams, given the dams' structural height (SH), needs to be developed in order to estimate more accurately the power potential available. Table 4 gives the SH and HH for the dams visited from two informational sources and direct observation. Parameter A in Table 4 is the hydraulic head available at the dam, as determined from the site visits, divided by the SH of the dam listed in the state records. The average of Parameter A is 0.98 for the Pennsylvania dams and 0.93 for all 11 dams. The standard deviation of Parameter A for Pennsylvania is 0.34 and the standard error of the mean is 0.11. Thus, it is expected that using the SH from the state records to estimate the HH for all the dams in Pennsylvania will yield an estimate of the actual mean HH with an average error of less than 12%.

Stream Flow

The stream flow duration curve is not readily available for each dam in the inventory. The only variable given in the inventory associated with stream flow duration is the drainage area. For the model, a normalized duration curve was used that best represented the average for all the streams examined during the 11 site visits. This was accomplished by using a generalized cost model and normalizing each site to a head of 20 ft and a drainage area of 100 mi². The supply curves for each normalized site are shown in Fig. 5. The average supply curve is best represented by the stream

Table 4

Structural height (SH) and hydraulic height (HH) of dams visited in Maryland and Pennsylvania.

Dam	River	Drainage Area (mi ²)	Average Stream Flow (ft ³)	SH* (ft)	SH† (ft)	HH† (ft)	HH ‡ (ft)	Downstream Slope		Parameter (HH†+ΔH)÷SH
								Unique Head, ΔH‡ Distance (ft/ft)	Slope (map)	
MARYLAND										
Broad Creek	Broad Creek	30	37.5	37	37	25	25		0.0104	0.68
Michaels Mill	Monocacy	884	933	12	12	12	3	6/500	0.0006	0.75
PENNSYLVANIA										
Catholic	Cocalico Creek	60	70	10	Not listed	Not listed	6.2		0.0013	0.62
Lake Williams	E. Br. Codorus Cr.	41.6	46	55	55	55	45.1		(<0.002)	0.82
Logan Mills	Fishing Creek	431	560	6	Not listed	Not listed	3	2/300	0.0032	0.83
Middle Creek	Middle Creek	17.6	24	53	Not listed	Not listed	32.4		0.0041	0.61
Reed	Conewango Creek	898	1599	4	Not listed	Not listed	4	2/500	0.004 to 0.0008	1.50
Townsend	Beaver	3030	3220	11	Not listed	Not listed	11	6.2/140	(<0.0005)	1.56
Tulpehocken	Tulpehocken Creek	217	297	12	Not listed	Not listed	7	3.2/300	0.0012	0.85
Vincent	Schuylkill	1450	2302	7	27	27	6.9		0.0014	0.99
Wetherill	Perkiomen Creek	360	481	5	Not listed	Not listed	3	2/100 (21.4÷11) ΔH = 2	0.0012	1.00
Average										0.93
Pennsylvania average										0.98

* From state records
† From Corps inventory
‡ From site visits

flow duration curve for the Logan Mills site (Fishing Creek). The normalized flow duration curve (flow per square mile) for Logan Mills is given in Fig. 6 and Table 5. Using the methods outlined in Appendix D, the capacity factor was calculated using the normalized duration for Logan Mills. The capacity factors versus normalized power are given in Table 6. This table can be used by multiplying the head (ft) and drainage area (square miles) by the normalized power for any dam of interest within the region.

From Fig. 5, we find that individual errors in the supply curve for one site were as high as 44% when the average (Logan Mills) duration curve was used for the randomly selected dams. The upper limit of the expected error for the supply estimate for all the dams within the region will be discussed in Chapter VI.

Canal, Road, and Power Line Requirements

The requirements for canals, roads, and power lines were determined for each site visited. A summary of these requirements is given in Table 7. This information was used to make a generalized costing method for all dams in the supply curve analysis. Thus, the canal costs for each dam were $1.7 \times \text{Eq. 10}$. The road costs were $780 \times \$5.00$ or \$3900, and the power line costs were $\$17\ 300 (9.5 \times 1700 + 7.6 \times 150)$.

Dam Repairs

The type of dam, the year it was built, the needed repairs, and the estimated costs are given in Table 8. Repairs for two of the dams, Lake Williams and Wetherill, were not charged to hydroelectric power because repairs are planned for these dams and the present use, water supply, will be charged these repairs. Theoretically, dam repairs should correlate with the type of the dam, age of the dam, and size of the dam. However, we did not have sufficient statistics to determine the correlation function. Therefore, the average dam repair cost of \$8400 was used in the generalized cost function for the supply curve.

Environmental Constraints

Hydroelectric development of existing dams in this study is assumed to be a run-of-the-river operation. Of the 11 dams chosen at random, only three had an actual physical potential for peaking power operation or pondage level variations (Broad Creek, Lake Williams, and Middle Creek). However, the potential for Broad Creek was marginal because of excessive siltation. The owners of

Fig. 6 Normalized flow duration curve for Logan Mills.

Table 5

Normalized stream flow duration for Logan Mills.

Percent of Time	Normalized Flow (ft ³ /s/mi ²)
2	5.81
5	3.93
10	2.85
20	1.86
30	1.35
40	0.988
50	0.767
60	0.591
70	0.466
80	0.366
90	0.295
95	0.245
98	0.218

Table 6

Normalized power and capacity factors
for Logan Mill's flow duration curve.

Normalized Power (kW)	Capacity Factor
0.02	0.98
0.03	0.91
0.04	0.83
0.05	0.76
0.06	0.68
0.07	0.64
0.08	0.58
0.09	0.55
0.10	0.51
0.11	0.47
0.12	0.44
0.13	0.42
0.14	0.39
0.15	0.37
0.16	0.35

*The power potential is calculated using 1 ft of head and 1 mi² drainage area. For H ft of head and A mi² drainage area the power is $H \times A \times \text{normalized power}$.

Table 7

Estimated required lengths for canals, roads,
and power lines for sites visited.

Dam	Canal Length (ft)	Road Length (ft)	Power Line Length (ft)
<u>Maryland</u>			
Broad Creek	0	800	200*
Michaels Mill	500	600	8000
<u>Pennsylvania</u>			
Catholic	0	500	500
Lake Williams	0	1000	3600
Logan Mills	300	0	500*
Middle Creek	0	1200	1000*
Reed	400	600	300
Townsend	150	2600	3000
Tulpehocken	300	0	200
Vincent	50	1200	2000
Wetherill	<u>150</u>	<u>100</u>	<u>1400</u>
Average	170	780	1700 150*

*Single-phase line allowed because the power output is less than 250 kW and the cost of a three-phase power line is enormous for Broad Creek, Logan Mills, and Middle Creek.

Table 8

Dam types, years constructed, needed repairs, and
estimated repair costs for sites visited.

Dam	Type of Dam	Year Built	Needed Repairs	Estimated Costs of Repairs
<u>Maryland</u>				
Broad Creek	Concrete	1947	Repair wing wall, adjust flow pattern, gate repair.	2 760
Michaels Mill	Stone	1869	Collapse of dam structure.	27 000
<u>Pennsylvania</u>				
Catholic	Concrete	1958	Good condition.	0
Lake William	Earth and concrete	1912	Present use, water supply, requires adequately main- tained dam.	0
Logan Mills	Concrete	1919	Whole structure needs to be replaced.	35 600
Middle Creek	Earth	1970	Replace drainage pipe.	500
Reed	Concrete	1911	Lip needs to be replaced.	4 400
Townsend	Rock-filled	1913	Erosion of dam abutments.	12 000
Tulpehocken	Stone masonry	1892	Erosion of dam abutments.	10 000
Vincent	Timber crib	1842	Deck recently repaired.	0
Wetherill	Stone masonry	1929	Present use, water supply, requires adequately main- tained dam.	0
Average cost				<hr/> \$ 8 400

Lake Williams, York Water Company, said they would not allow draw-down of the reservoir because of its use for water storage. The owners of Middle Creek, Pennsylvania Fish Commission, said they would not allow hydroelectric power production on their dam. Recreational uses at both Middle Creek and Broad Creek make level fluctuations for power production even more unlikely. Thus, run-of-the-river operation of the dams seems to be a good assumption.

Table 9 summarizes the environmental constraints for the dams visited. In addition to fish ladder requirements, the only other potential impact of hydroelectric development is related to dissolved oxygen content. Low dissolved oxygen content is actually caused by warm water temperature and excessive amounts of organic material in the water, neither directly caused by hydroelectric development. However, in some cases new hydroelectric development may be required by state and federal agencies to assist in paying for aeration of the water. It does not appear that this is the case for the sites visited during this study.

The only dam presently requiring a fish ladder is the Vincent, which is owned by the Department of Environmental Resources (DER) of the Commonwealth of Pennsylvania. DER will pay for the fish ladder. Four other dams may be required to have fish ladders. Unfortunately, the impact of fish ladders on the supply was not examined because of time and funding constraints.

Table 9

Environmental constraints for run-of-the-river
operation of existing dams.

Dam	River	Required Fish Ladder	Comment
Broad Creek	Broad Creek	Possibly <u>yes</u>	Only Conowingo Dam is between Broad Creek Dam and the Chesapeake Bay.
Michaels Mill	Monocacy	Probably not	Height of dam too low.
Catholic Dam	Cacalico Creek	Probably not	Too far upstream of Susquehanna River.
Lake Williams	East Branch Codus Creek	Possibly <u>yes</u>	Four dams between this dam and the Chesapeake Bay.
Logan Mills	Fishing Creek	Probably not	Too far upstream of Susquehanna River.
Middle Creek	Middle Creek	Probably not	This dam is owned by the Pennsylvania Fish Commission; they stated they would not allow hydroelectric power production on their dam.
Reed	Conewango	Probably not	Ohio River Basin.
Townsend	Beaver	Probably not	Ohio River Basin.
Tulpehocken	Tulpehocken Cr.	Possibly <u>yes</u>	Drains into the Schuylkill River.
Vincent	Schuylkill	<u>Yes</u>	Department of Environmental Resources owns this dam and plans to pay for a fish ladder.
Wetherill	Perkiomen Cr.	Possibly <u>yes</u>	Drains into the Schuylkill River.

IV. STATE SUPPLY CURVES

Using the methodology previously discussed, the computer program given in Appendix E, and the dam inventories from Maryland, New Jersey, and Pennsylvania, the hydroelectric energy supply curves for existing nonhydroelectric dams were determined. Figure 7 shows the annual hydroelectric energy available for each of these states as a function of price of electrical energy to the developer. The annual fixed charge rate (AFCR) is assumed to be 10.4% representing the estimated typical rate for a public body as developer. It must be emphasized that these supply curves are for existing nonhydroelectric dams. The potential for expanding existing hydroelectric dams is not shown in Fig. 7. The potential available with new dam development is also not shown in Fig. 7. Thus, these supply curves should not be confused with an estimate of the total hydroelectric potential available within each state. Table 10 is one estimate of the total hydroelectric potential of each of these states. Column 1 of Table 10 is the estimate of the annual hydroelectric energy that is presently developed. This estimate comes from Ref. 13. Column 2 is based on the 1976 FPC Report on undeveloped sites, but with existing dams subtracted from the totals give. Column 3 is based on existing dams from the state inventories. Only dams with 50 kW or greater potential were used. The annual fixed charge rate, AFRC, to the developer was assumed to be 10.4%. The energy listed is the energy available at a price of 10¢/kWh to the developer (Apr 1978 dollars). Column 4 is the total potential or sum of columns 1, 2, and 3.

Table 10

Annual hydroelectric energy potential
for Middle Atlantic states.

State	Annual Hydroelectric Energy (million kWh)			
	Column 1 Developed (FERC est.)	Column 2 Undeveloped, No Existing Dams (FERC est.)	Column 3 Undeveloped, Existing Dams (APL est.)	Column 4 Total
Pennsylvania	1787.3	5360	2260	9407.3
Maryland	1719.8	467	93	2279.8
New Jersey	15.4	1000	62	1077.4

Fig. 7 The potential hydroelectric energy supply curve for nonhydroelectric dams (potential capacity greater than 50 kW each) in Pennsylvania, Maryland, and New Jersey, using public developers.

Some interesting comparisons between supply curves for these three states can be made. At 10¢/kWh, the energy available per unit area for existing dams is almost the same for both New Jersey and Maryland. However, the hydroelectric energy per unit area available from existing dams for Pennsylvania is about five times that for Maryland or New Jersey.

Comparing the number of inventoried dams per unit area, Pennsylvania has four times that of Maryland, and New Jersey has five times that of Maryland. Since the number of dams per unit area is about the same for Pennsylvania and New Jersey, one might wonder why the hydroelectric energy per unit area available from existing dams in Pennsylvania is about five times that available in New Jersey. Several possible explanations follow:

1. New Jersey has a higher percentage of coastal plain than Pennsylvania;
2. Pennsylvania contains a higher percentage of major rivers — rivers with drainage areas in excess of 1000 mi²;
3. The New Jersey investigation was not as thorough as the Pennsylvania investigation; and
4. Pennsylvania contains navigation dams while New Jersey does not.

One significant difference between Pennsylvania and the other two states was the existence of 17 navigation dams on the Ohio, Allegheny, and Monongahela Rivers (none in Maryland and New Jersey). Although the hydraulic heads for these dams do not exceed 22 ft, the large drainage areas for these dams makes the 17 dams account for over 60% of the total energy potential in Pennsylvania.

In Pennsylvania, 347 dams were found with a potential greater than 50 kW, while only 19 similar dams were found in Maryland, and only 28 dams were identified in New Jersey.

The number of dams with a gross estimate of the break-even price of electricity to the developer below 2.5¢/kWh was three for New Jersey, six for Maryland, and 20 for Pennsylvania (AFCR is 10.4%).

One of the most important findings from Fig. 7 is the almost vertical shape of the supply curves above 4¢/kWh. This indicates that very little additional energy is available for prices above 4¢/kWh for developers with an AFCR of 10.4%. If 2.5¢/kWh is a fair price for run-of-the-river hydroelectric, government subsidies above 1.5¢/kWh will be very ineffective in bringing additional hydroelectric energy on-line.

More specific information about the hydroelectric potential for each state is found in Appendix F for Pennsylvania, Appendix G for Maryland, and Appendix H for New Jersey.

A summary of the potential capacity supply and energy supply for existing nonhydroelectric dams within the three states is given in Tables 11 and 12.

Table 11

The potential hydroelectric capacity* supply from existing nonhydroelectric dams within Pennsylvania, Maryland, and New Jersey (AFCR is 10.4%).

Price to Developer (¢/kWh)	Potential Hydroelectric Capacity (kW)			
	Maryland	New Jersey	Pennsylvania	Total
1.5	7 400	0	40 500	47 900
2	10 700	2 900	89 800	103 400
2.5	14 600	4 800	131 500	150 900
3	16 900	6 900	185 000	208 800
4	19 800	9 100	291 400	320 300
5	22 000	10 600	360 100	392 700
6	23 600	18 900	408 300	450 800
7	25 200	13 200	449 600	488 000
8	26 500	14 600	486 100	527 200
9	27 500	15 800	516 500	559 800
10	28 000	16 600	547 300	591 900

*This assumes an AFCR of 10.4%, 12% construction loan (build within 3 years from time of feasibility study), \$40 000 average licensing cost per site, average costs of dam repairs, canal, road, and transmission costs as determined from the 11 sites visited. Recreational costs are assumed to be \$2.50 per installed kW. The feasibility study and engineering costs are assumed to be 25% of the total capital cost minus the licensing costs. The land costs were assumed to be 4% of the total capital costs. The average run-off for all sites was assumed to be 1.3 cfs/mi².

Table 12

The potential hydroelectric energy* from existing
nonhydroelectric dams within Pennsylvania,
Maryland, and New Jersey (AFCR is 10.4%)
(shown in Fig. 7).

Price to Developer (¢/kWh)	Maryland (10 ⁶ kWh)	New Jersey (10 ⁶ kWh)	Pennsylvania (10 ⁶ kWh)	Total (10 ⁶ kWh)
1.5	35	0	211	246
2	50	18	541	609
2.5	68	28	762	858
3	74	39	1055	1168
4	79	45	1609	1733
5	82	48	1859	1989
6	84	50	1982	2116
7	88	53	2074	2215
8	90	57	2147	2294
9	92	61	2199	2352
10	93	62	2260	2415

*This assumes an AFCR of 10.4%, 12% construction loan (build within 3 years from time of feasibility study), \$40 000 average licensing cost per site, average costs of dam repairs, canal, road, and transmission costs as determined from the 11 sites visited. Recreational costs are assumed to be \$2.50 per installed kW. The feasibility study and engineering costs are assumed to be 25% of the total capital cost minus the licensing costs. The land costs were assumed to be 4% of the total capital costs. The average runoff for all sites was assumed to be 1.3 cfs/mi².

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V. POLICY DECISIONS USING SUPPLY CURVES

In addition to the basic information provided by supply curves, they can be a valuable aid for establishing government policy concerning hydroelectric development. Some of the questions they can help answer are:

1. What is the impact of the type of developer on potential hydroelectric development?
2. What is the impact of taxes and insurance on the potential hydroelectric development?
3. What is the impact of licensing costs upon the supply?
4. What is the impact of the low-cost turbine-generators on the supply?
5. What would be the effect of possible governmental subsidies, loans, and assistance?
6. What are the impacts of the present environmental and recreational requirements?

The impacts of the type of developer, licensing costs, and liability insurance rates will be examined. However, the impacts of the present environmental and recreational requirements and some possible forms of governmental assistance will not be examined because of time and funding constraints.

Impact of Type of Developer

The type of hydroelectric developer impacts the potential hydroelectric development through the cost of money available to each. The expected AFMR for private and public developers is given in Table 13 (Ref. 18).

Using these two different AFMR's, the hydroelectric supply curve for Pennsylvania can be derived. Figure 8 shows the supply curve for these two different rates.

Table 13

AFCR expected for private and public developers.

	Private Developer (%)	Public Developer (%)
Cost of capital	12	8
Income taxes	1.5	0
Other taxes	2.56	0.5
Insurance rate	0.2	0.2
Depreciation	<u>1.67</u>	<u>1.67</u>
Total AFCR	17.93	10.37

Figure 8 shows some interesting results in the neighborhood of the 2¢/kWh through 3¢/kWh energy price range. At 2.5¢/kWh (the 1978 average running rate for the Pennsylvania, New Jersey, and Maryland power pool), the amount of hydroelectric energy annually available from developers with AFCR of 10.4% is 3.7 times the energy annually available from developers with an AFCR of 17.9% (note that 17.93 divided by 10.37 is only 1.73). At 3¢/kWh, the amount of hydroelectric energy available from developers with an AFCR of 10.4% is 4.5 times the energy annually available from developers with an AFCR of 17.9%. Thus, AFCR is a very sensitive parameter in the development of hydroelectric power from existing dams within Pennsylvania.

The cause of this behavior is the potential to develop the 17 navigation dams at the lower values of the AFCR. For 2.5¢/kWh, 4.66×10^8 kWh are available from the navigation dams if the AFCR is 10.4%. If the AFCR is 17.9%, no energy is available from these 17 dams for a price to the developer of 2.5¢/kWh or even 3¢/kWh. The AFCR is not as sensitive for the non-navigation dams. There are 35 non-navigation, nonhydroelectric dams in Pennsylvania with a potential greater than 1000 kW. Changing the AFCR from 17.9% to 10.4% for these dams results in only a 36% increase in the available hydroelectric energy at 2.5¢/kWh to the developers.

Fig. 8 The potential hydroelectric energy supply curve for 347 nonhydroelectric dams in Pennsylvania; two levels of AFCR.

If private developers were relied upon for hydroelectric development, a government subsidy of 1.5¢/kWh over a 2.5¢/kWh price would be required for an equivalent development by public developers. This would mean an annual public expenditure of about 11.4 million dollars within Pennsylvania. Another method in addition to subsidies would be to offer low-cost loans. If 6.875% federal loans were made available for 90% of the financing, the cost of capital to a private developer would be 7.69% (assuming a 15% rate of return on equity). Using the other components in Table 13, the AFCR would be 13.6% for private developers. It appears that this approach would provide 70% of the energy potentially available from public developers at 2.5¢/kWh to the developers. Reducing other parts of the AFCR, such as taxes for private developers would similarly increase the supply.

Impact of Taxes and Insurance

Taxes and insurance are components of the AFCR. Increases and/or decreases in these components of the AFCR can have a significant impact on the hydroelectric supply. Decreases in the tax rates can be justified on the basis that development of this renewable resource can decrease our dependence on foreign oil. However, decreases in local tax rates for hydroelectric sites may require increased revenue-sharing by the federal government. Decreases in the tax rates by 50% in addition to low-cost loans could bring the previous AFCR for private developers down to 11.6%. This would provide 85% of the energy potentially available from public developers at 2.5¢/kWh to the developer.

However, these gains for private development could be eliminated by potential increases in the insurance rate. The insurance rate assumed in the model was 0.2% (Ref. 18). Dam liability insurance rates may be in flux due to recent dam failures. Also, acts of vandalism have increased insurance costs at some sites. Insurance rates as high as 2% or higher have been estimated for a few projects. The potential impact on the supply by high insurance rates is very complex. It depends on the developer's present AFCR and the price he is receiving for the energy. For a better understanding of the potential impact of higher insurance rates and lower tax rates, a plot of the Pennsylvania supply versus the AFCR and price to the developer is shown in Fig. 9.

Three different types of general changes in the supply are observed for the ranges of price and AFCR shown in Fig. 9. For low prices such as 1.5¢/kWh, the change in supply per change in AFCR is relatively small (about 8×10^6 kWh/1% AFCR). For high prices such as 10¢/kWh, the change in supply per change in AFCR is relatively

Fig. 9 The potential hydroelectric energy supply for 347 nonhydroelectric dams in Pennsylvania versus the AFCR at constant price levels to the developers.

moderate (about 30×10^6 kWh/1% AFCR). The middle-range prices, 2.5¢ to 6¢/kWh, have relatively large changes in supply per change in AFCR. For 4¢/kWh, the change in supply is about 100×10^6 kWh/1% AFCR. The major reason for these three distinct ranges of change in supply is significantly tied to the 17 navigation dams in Pennsylvania. At 10¢/kWh, all these navigation dams are economical for power over the given range of AFCR. At 1.5¢/kWh, none of them is viable.

For a given AFCR and price, one can use Fig. 9 to determine the actual impact for changes in the AFCR. For example, if the price of electricity is 2.5¢/kWh and the AFCR is 12.2%, a decrease of 1.8% in the AFCR will result in a 30% increase in the supply. However, if the AFCR is 15.4% and the AFCR decreases by 1.8%, the supply increases by 130%. Figure 9 indicates that government policy makers should seek not only the highest price possible for developers but also the lowest AFCR if the greatest potential for hydroelectric power is to be developed.

Impact of Cost of Licensing

The cost of licensing is assumed to be \$40 000 per site for the computer model of the supply curve. This cost was set to zero for the supply model of Pennsylvania (AFCR equals 10.4%) and the changes in supply were determined. Figure 10 is a plot of the changes in supply versus price of electricity to the developer. The changes appear surprisingly small. The maximum observed increase in energy output was +2.7%. The reason this \$40 000 per site cost decrease has so small an impact on the supply curve is the high cost of developing those sites that make the greatest contribution to the supply. For example, the average cost of development for the navigation dams is estimated to be \$18 000 000 each. Obviously, for such sites a \$40 000 decrease in cost is insignificant.

Fig. 10 Change in the potential hydroelectric energy supply curve for 347 nonhydroelectric dams in Pennsylvania when the licensing cost to the developer is zero. The licensing cost was assumed to be \$40 000 for each site in the supply model.

Impact of Low-Cost Turbine-Generators

The government has been encouraging standardized turbine-generators for small-scale sites. Lower costs should stimulate greater production, which traditionally has lowered costs also. If the costs of the powerhouse and equipment could be decreased by 30%, the impact upon the supply is shown in Fig. 11. The impact is significant for prices of electricity to the developer of 3¢/kWh or less. For prices of 5¢/kWh or greater, the impact is relatively minor. For example, at a price of 10¢/kWh, the increased supply is less than 5%. If the reasonable price for the power is 25 mills/kWh, lowering the cost of the powerhouse and equipment by 30% increases the supply by 77%.

Fig. 11 Change in the potential hydroelectric energy supply curve for the 52 largest nonhydroelectric dams in Pennsylvania when the powerhouse costs are decreased 30%.

VI. SENSITIVITY ANALYSIS FOR THE SUPPLY CURVES

There are several sources of potential error in the supply model given previously. These sources are:

1. The incomplete data bases on existing dams;
2. Lack of accurate data on potential hydraulic head for each dam;
3. Use of an averaged stream flow duration curve per square mile of drainage area for all sites used in the supply curve;
4. Uncertainty in turbine-generator costs for a determined power and hydraulic head;
5. Use of "average" costs for power lines, roads, and dam repairs;
6. Assumed land costs of 4% of project cost;
7. Uncertainty in expected life of the facility;
8. Variation of the AOMA costs; and
9. Assumed turbine-generator efficiency.

Incomplete Data Base

The incomplete data bases are difficult to assess in their contribution of error. Because the Corps of Engineers dam inventory lacked drainage area information, the state records were used for Pennsylvania and New Jersey. APL assisted Maryland in calculating the drainage areas for dams that did not have this information in the state records. Pennsylvania had about 77% of all the dams within the three states. Pennsylvania also has one of the most complete state inventories of dams in the eastern United States. Our main source of information for Pennsylvania was Ref. 1, which describes 2323 dams. To this list were added 140 dams licensed since 1970, 17 Corps of Engineer navigation dams, and six Corps of Engineer flood control dams. Pennsylvania state offices have not received much information on several dams built by

the federal government within Pennsylvania. The Corps of Engineers was directly contacted to determine dams that they have built, and then this list was compared to the state's list to determine missing Corps dams. In addition to federal dams, the other major category of dams not included in the state records is industrial desilting dams. However, the drainage area for this type of dam is exceedingly small (typically less than 1 mi^2). Thus, these dams are expected to be insignificant in any supply curve. For example, of the 2486 nonhydroelectric dams identified in Pennsylvania, over 80% had drainage areas under 20 mi^2 . However, only 45 of these dams, or 2.2%, had a power potential greater than 50 kW. Of the 347 dams identified with a potential greater than 50 kW, these 45 dams were only 13%. However, the 13% of the dams contributed less than 1% of the total supply.

Assume 20 dams are missing from the Pennsylvania inventory and that these dams are typical of the 347 dams in the present supply curve. This would mean that expected errors in the supply estimates would not exceed 10%. Also, the larger the dam, the more likely it is to be known. Thus, missing dams will probably have lower than average power and energy potential and thus be an insignificant component of the supply estimates.

The greatest uncertainty in the supply estimates was for New Jersey. However, this state contributed less than 3% of the total supply estimates shown in Table 12. Even if this state's estimate were off by a factor of two, the total impact would be less than 10% of the present estimate.

Using the above information, it seems reasonable that an incomplete data base should contribute an error less than 20% of the presently estimated supply.

Hydraulic Head

The lack of accurate data on the potential hydraulic head for each dam can cause significant errors in the supply curve. Using the nine dam sites visited in Pennsylvania (these sites were chosen at random), one can estimate such errors. Using the Pennsylvania information (Ref. 1) on structural heights for the nine dams, the total power potential was calculated to be 4530 kW. Using the reasonable hydraulic head available at each site as determined from site visits, the total power potential was calculated to be 5850 kW. The observed potential was 29% greater than the estimate made from state records.

The potential error caused by major flood control dams could be even greater in the opposite direction. For example, the Pennsylvania flood control dams in the Susquehanna River Basin have an average hydraulic height that is 35% of their structural height (Corps of Engineers, Baltimore District, is the source of this information). Because of this problem, the actual hydraulic height for flood control dams was used in the supply model for Pennsylvania, rather than the structural height given in the state records. Likewise, the Corps of Engineers was the source of information on hydraulic height for the navigation dams. The errors in the information from the Corps should be insignificant. Since the navigation dams contributed over 60% of the total potential energy, the errors in the supply estimate caused by uncertainty in hydraulic head should be less than 40% times the estimate or error caused by the use of state record information. The errors in the supply estimate caused by uncertainty in hydraulic head are thus estimated to be less than 20%.

Average Stream Flow

The average stream flow was $1.3 \text{ ft}^3/\text{s}/\text{mi}^2$ for the nine Pennsylvania sites that were visited. Using this number instead of the estimated stream flow from the closest USGS stream gauges resulted in a total power estimate of 4770 kW using the structural height given in the state records. This is 5% above the figure calculated using the closest USGS stream gauges.

The three non-navigation, nonhydroelectric dams in Pennsylvania that potentially could produce the most hydroelectric energy are the Kinzua Dam, the Raystown Dam, and the Youghiogheny River Dam. These three dams could produce 30% of the energy available from the 330 non-navigation, nonhydroelectric dams used in the supply estimate. The maximum errors in the supply estimate for the three dams using the average stream flow duration curve were 21%.

The navigation dams have an average runoff above $1.6 \text{ ft}^2/\text{s}/\text{mi}^2$. Therefore the average stream flow duration curve was multiplied by 1.3 for the navigation dams.

A duration curve for the Monongahela River was used for a supply calculation of the navigation dams. The error from using 1.3 times the normalized Logan Mills duration curve for the same dams was found to be about 7%.

Thus, the error in the supply due to use of an averaged stream flow duration curve is estimated to be less than 30%.

Turbine-Generator Costs

There is a great variance in turbine-generator costs. For example, J. Lutz (Ref. 19) found in 1976 that prices ranged from \$75 000 to \$260 000 for a complete 200 kW, 150 ft head, turbine-generator package. The highest price is about 3.5 times the lowest price. The costs per kW for small-scale low-head turbine-generator equipment is discussed in Ref. 8. The variation shown in this report between the given highest cost and given lowest cost varies between 3.3 and 4.4, depending upon head. Turbine-generator cost quotes from manufacturers have been compared with turbine-generator cost estimates using the computer model. The average turbine-generator costs from the computer model were consistently higher for some manufacturers and consistently lower for others. One major American manufacturer's quotes were above and below the computer model's answers depending on the head and installed capacity. Manufacturer quotes were as much as 30% below the computer model estimate for the sample quotes examined.

Another important factor related to turbine-generator costs is how the expected price might change with production quantity. An estimate of how the expected price might vary with the production quantity can come from the price history of various products such as the automobile. The price of a product in constant dollars decreases as the quantity manufactured increases. An equation that describes the price history of the Model T Ford and many other products is the following (Ref. 20):

$$P(N) = P(1) N^{\alpha}, \quad (21)$$

where N is the unit number of the device produced,

$P(1)$ is the price of the first unit,

α is $(\log \phi) \div \log 2$, and

ϕ is the slope of the price versus quantity curve.

For example, the slope of this curve for the Model T Ford (1909-1923) was 85% (Ref. 21).

As more developers begin using standardized equipment for hydroelectric installations, the cost of this equipment should decline. This decline in costs should be one of the factors that increases the competitive position of hydroelectric energy and thus increases hydroelectric development and changes the relative shape of the supply curve.

Decreasing the estimated turbine-generator and powerhouse costs by 30% increases the supply at 2.5¢/kWh by 77%. However, at 10¢/kWh the supply increase appears to be less than 5%. The percent increase versus price of electricity is given in Table 14.

Table 14

Percent increase in Pennsylvania hydroelectric energy supply when the turbine-generator and powerhouse cost is reduced 30%.

Price (¢/kWh)	Increase in Supply (%)
1.5	152
2	54
2.5	77
3	50
4	18
5	10
6	7
7	6
8	6
9	6
10	4

Average Costs

The "average" cost for power lines, roads, and dam repairs assumed for each dam in the supply is \$29 700. As shown in Fig. 10, a cost decrease of \$40 000 per site had a maximum impact on the supply of less than 3%. Thus, the impact of these average costs is insignificant upon the supply estimate.

Land Costs

The land costs were assumed to be 4% of the total capital cost in the computer model. Setting this cost to zero showed that the impact on the supply estimate was typically less than 3%.

Expected Life of Facilities

The life of the facilities was assumed to be 60 years. If the life was decreased by 20%, the resulting increase in the APCR is about 0.4%. The impact of such an increase in APCR can be best determined using Fig. 9. For example, at a price of 2.5¢/kWh and an APCR of 10.4%, a 20% decrease in facility life would decrease the supply by about 5%.

AOMA

A 20% increase in AOMA nominally results in less than a 1% decrease in the supply estimate. Thus, a 100% error in AOMA should produce an error less than 5%.

Assumed Turbine-Generator Efficiency

The turbine-generator efficiency was assumed to be 75%. This efficiency could reasonably be 85%. If this efficiency is assumed, the supply should increase by 13%.

Summary of Errors

A summary of the potential errors is given in Tables 15 and 16.

Table 15

Potential error summary for supply curve at 2.5¢/kWh.

Type of Error	Probable Error (%)	Potential Impact
Incomplete data base	<20	Decreases estimate
Hydraulic head uncertainty	<20	Random
Average stream flow	<30	Random
Turbine-generator costs	-30 to +80	
Average costs	<3	Random
Land costs	<3	Random
Expected life of facilities	<5	Random
Operating and maintenance costs	<5	Random
Assumed turbine efficiency, 75%	<13	Decreases estimate
Total error*	-48 to +91	

*Total error in the square root of the sum of errors squared.

Table 16

Error summary of supply curve at 10¢/kWh.

Type of Error	Probable Error (%)	Potential Impact
Incomplete data base	<20	Decreases estimate
Hydraulic head uncertainty	<20	Random
Average stream flow	<30	Random
Turbine-generator costs	<10	Random
Average costs	<1	Random
Land costs	<3	Random
Expected life of facilities	<3	Random
Operating and maintenance costs	<3	Random
Assumed turbine efficiency, 75%	<13	Decreases estimate
Total error*	-38 to +45	

*Total error is the square root of the sum of errors squared.

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VII. HYDROELECTRIC DEVELOPMENT VERSUS TIME

As a part of the IEE study of hydroelectric development potential at existing dams, an attempt has been made to determine what small-scale hydroelectric installations are currently in operation as well as determining those in the process of development and those considering development in Delaware, Maryland, New Jersey, and Pennsylvania. In addition, several utilities have been contacted within each of these states in order to determine their attitudes and interest in the development of small-scale hydroelectric power (see Table 17). Information has been gathered from conversations with individuals in state offices, utilities, and from the U.S. Army Corps dam list, state dam lists, Pennsylvania Master Siting Study, and research proposals submitted to DOE in response to the Program Research and Development Announcement.

Existing small-scale hydroelectric projects that have been identified are listed in Table 18. These are small-scale hydroelectric projects that are currently generating electricity or providing mechanical power in Delaware, Maryland, New Jersey, and Pennsylvania. The total installed capacity at small-scale sites have been identified in the four-state area is approximately 6000 kW. There are two sites that have recently terminated their generation of electricity, the Oakland Dam on the Susquehanna River in Pennsylvania and the Middle Creek Dam on Cedar Creek in New Jersey. Both dams were damaged during storms and never repaired. Table 19 lists proposed hydroelectric projects at existing dams that have been identified in the same four-state area. These proposed hydroelectric sites represent a total increase in generating capacity of over 31 000 kW. All of these existing and proposed sites are discussed in greater detail in Appendix I.

There are proposed small-scale hydroelectric developments at existing dams in each of the four states considered, Delaware, Maryland, New Jersey, and Pennsylvania. Those that are developing small-scale hydroelectric power include an investor-owned utility, electric cooperative, businesses, communities, and individuals. The electricity will be generated at these sites for the developer's own use or for sale to the utility servicing the area or to nearby industries. Of the 18 identified dams that are proposed hydroelectric generating sites, there is a range in hydraulic head of 9 to 66 ft and potential capacities range from 50 to 13 500 kW. Activities range from those actively developing and nearing completion of their project to those just beginning consideration of hydroelectric generation.

Table 17

Utility hydroelectric plans.

Utility	Hydroelectric Plans	Remarks
Delmarva Power & Light Co. Investor Owned System Delaware F. A. Cook 12/5/78	No small-scale hydroelectric plans.	They have not considered small-scale hydroelectric power as an option because they claim they do not have the flow or head to make it cost effective.
Lewes Board of Public Works Municipal System Delaware R. Donovan 12/5/78	No small-scale hydroelectric plans.	They claim there are no suitable sites in the area. They purchase their power from Delmarva Power & Light Co.
Smyrna Electric Dept. Municipal System Delaware H. M. Odren 12/8/78	They have not considered small-scale hydroelectric plans but leave it open for consideration.	Presently they buy all of their power wholesale from Delmarva Power & Light Co., but R. W. Beck & Associates is doing a study on possible options for electric generation. They believe hydroelectric power is not likely to be an option because no head is available.
Delaware Electric Cooperative, Inc. Rural Electric Cooperative System Delaware H. R. Mitchell 12/7/78	No small-scale hydroelectric plans.	All power is purchased from Delmarva Power & Light Co. In their service area they believe there are probably no suitable sites and hydroelectric power would not be economically viable.
Baltimore Gas & Electric Co. Investor Owned System Maryland J. Tiernan 5/12/78	No small-scale hydroelectric plans.	They are not looking for anything smaller than 25-50 MW. They feel it takes too long to get a license and the amount of paperwork is too great.
The Potomac Edison Co. Investor Owned System Maryland C. Wolf 5/17/78	They are examining the possibility of capacity expansion for Dam #4 on the Potomac River.	They presently operate eight small-scale hydroelectric plants. They feel the FERC recreational requirement is excessively time consuming.
The Easton Utilities Commission Municipal System Maryland R. Smith 11/28/78	No small-scale hydroelectric plans.	They claim there are no suitable hydroelectric sites in the area.
Hagerstown Municipal Electric Light Dept. - Municipal System Maryland J. Young 5/17/78	No small-scale hydroelectric plans but might consider it in the future.	They are not acquainted with the resource.
Choptank Electric Cooperative, Inc. Rural Electric Cooperative System Maryland G. L. Mears 12/12/78	No small-scale hydroelectric plans.	They have not considered hydroelectric generation because they claim there are no suitable sites in the area. All of their power is purchased from Delmarva Power & Light Co.

Table 17
Utility hydroelectric plans (cont'd).

Utility	Hydroelectric Plans	Remarks
Potomac Electric Power Company Investor Owned System Washington, D.C. J. Rumbaugh 8/8/78	No small-scale conventional hydroelectric plans. They have a DOE-EPRI contract to examine the feasibility of underground pumped storage for future use.	They claim they have no suitable small-scale hydroelectric sites.
Public Service Electric & Gas Co. Investor Owned System New Jersey A. C. Johnson 4/12/78	No small-scale hydroelectric plans.	They are not interested in small-scale hydroelectric power because they believe it is not economical, they have no suitable sites, and they have committed capacity.
GPU Service Corporation Service Company New Jersey R. C. Richert, Reading, Pa. 7/10/78	No small-scale hydroelectric plans.	Subsidiaries: Pennsylvania Electric Co., Metropolitan Edison Co., and Jersey Central Power and Light Co.
Allegheny Power Service Corp. Service Company Pennsylvania L. H. Weeks 4/10/78	Looking at navigation dams on the Ohio River. The Potomac Edison Co. is considering increased capacity at Dam #4 on the Potomac River.	Operating companies: the Potomac Edison Co., West Penn Power Co., and Monongahela Power Co. They believe constraints to development include licensing time and questionable outcome and what the charge will be for use of Corps dams.
Duquesne Light Co. Investor Owned System Pennsylvania W. G. Dempler 5/17/78	No small-scale hydroelectric plans. Duquesne with other members of the CAPCO Pool are exploring the possibilities of a pump storage hydroelectric plant.	They claim there are no suitable sites for small-scale hydroelectric development.
Pennsylvania Electric Co. Investor Owned System Pennsylvania R. W. Conrad 5/9/78	They are installing new equipment for capacity of 1.5 MW at Warrior Ridge.	They believe constraints to development include high costs for equipment and civil engineering, obtaining a license, and pressure from federal, state, and local governments for increased recreational facilities at their present sites.
Pennsylvania Power & Light Co. Investor Owned System Pennsylvania W. M. Strobel 7/10/78	No small-scale hydroelectric plans.	They own two large hydroelectric installations, Wallenpaupack (44 MW) and Holtwood (102 MW).
Allegheny Electric Cooperative Rural Electric Cooperative System Pennsylvania W. F. Matson 5/18/78	Received PRDA for Maxwell Lock & Dam on Monongahela. They plan to develop all the economical hydroelectric potential of which they are able.	They believe constraints to development include licensing process and fishermen and environmentalists' intervention. R. W. Beck & Associates did a study for them and chose 10 sites for possible development.

Table 18

Existing small-scale hydroelectric sites.

State	Dam	River	Developer	Remarks
Delaware	Hagley	Brandywine	Eleutherian Mills-Hagley Foundation	500 kW capacity supplies 79% of the Hagley Foundation's electrical requirements, 28 ft head.
Delaware	Hearn's and Rollin's	Clear Brook	Hearn's and Rollin's Mill	Two water wheels provide mechanical power for grinding grains, 9 ft head.
Maryland	Parker Pond	Beaver Dam Creek	W. H. Hinman	The electricity generated is used at Mr. Hinman's home.
Maryland	Dam #4	Potomac	Potomac Edison	1000 kW, 18.5 ft head.
Maryland	Dam #5	Potomac	Potomac Edison	1120 kW, 16.5 ft head.
Maryland	Harpers Ferry	Potomac	Potomac Edison	500 kW, 26 ft head.
New Jersey	Beatties	Passaic	Passaic Valley Water Commission	2400 kW capacity used at the Gravity Water Filtration Plant, 36 ft head.
New Jersey	Hugessville	Musconetcong	Riegel Paper Corp.	444 kW, 27 ft head.
New Jersey	Warren Glen	Musconetcong	Riegel Paper Corp.	720 kW, 50 ft head.
Pennsylvania	Hillsgrove	Loyalsock	Lewis T. C. Company	100 kW.
Pennsylvania	Union Drawn	Beaver	Republic Steel Corp.	100 kW.
Pennsylvania	Hartman	Beaver	Beaver Falls Municipal Authority	Provides mechanical power for operation of their pump, 11 ft head.

Table 19
Proposed hydroelectric developments at existing dams.

State	River	Dam	Developer	Head (ft)	Capacity (kW)	Remarks
Delaware	Red Clay Creek	Haveg	Haveg Industries	14	75	A feasibility study has been completed; electricity will be developed and produced when funds become available.
Delaware	Christina	Dayett's Mill	Mr. Johnson	26	-	Electricity will probably be generated during 1979 for use at the mill.
Delaware	Brandywine	Walker's Mill	Eleutherian Mills-Hagley Foundation	9	175	A proposal had been submitted to DOE in response to PRDA but was not funded. Hydroelectric power will be developed when funds are available.
Maryland	Patuxent	Brighton	Washington Suburban Sanitary Commission	62.5	100-500	A feasibility study is in progress (DOE funded).
Maryland	Meadow Run	Meadow Run	Mr. J. Davis	27	-	Dam in initial stages of development. Mr. Davies is gathering information on hydroelectric generation and if feasible will use electricity for his nearby campground.
New Jersey	Passaic	S.U.M.	City of Paterson	66	4500	A feasibility study has been completed and an application has been submitted for a license to FERC, 2 Sep 1977.
New Jersey	Maurice	Union Lake	Wheaton Industries	15	-	A proposal submitted to DOE was not funded.
New Jersey	Passaic	Beatties	Passaic Valley Water Commission	32	3800	A proposal submitted to DOE was not funded. Presently there is a generating capacity of 2400 kW; plans for 1400 kW increase.
Pennsylvania	Conodoquinet	Conodoquinet	Borough of Carlisle	10	400	A proposal submitted to DOE was not funded.
Pennsylvania	Monongahela	Maxwell	Allegheny Electric Cooperative, Inc.	19.5	13 500	A feasibility study is in progress (DOE funded).
Pennsylvania	Juniata Trib.	Warrior Ridge	Pennsylvania Elec. Co.	31	1500	Damaged during 1972 flood and presently redeveloping.
Pennsylvania	Lehigh	Easton	Pennsylvania Hydroelectric Development Corp.	21	1000	An application for a preliminary permit was submitted to FERC 11 Jul 1977.
Pennsylvania	Schuylkill	Felix	Pennsylvania Hydroelectric Development Corp.	19.5	1000	Proposals submitted to DOE were not funded. Each of the proposals submitted was a part of a river system plan. Applications for preliminary permits were submitted to FERC 11 Jul 1977.
Pennsylvania	Schuylkill	Auburn	Pennsylvania Hydroelectric Development Corp.	21.5	500	
Pennsylvania	Schuylkill	New Kernsville	Pennsylvania Hydroelectric Development Corp.	19.8	1000	
Pennsylvania	Schuylkill	Flat Rock	Pennsylvania Hydroelectric Development Corp.	21.5	1000	
Pennsylvania	Schuylkill	Black Rock	Pennsylvania Hydroelectric Development Corp.	12	1500	
Pennsylvania	Schuylkill	Norristown	Pennsylvania Hydroelectric Development Corp.	16	2800	

By making some assumptions, the rate at which these proposed hydroelectric facilities will be completed and will be generating electricity can be estimated. It is assumed that feasibility studies produce favorable results and development continues; it is also assumed that there will be no long-term delays. The additional small-scale hydroelectric power generated can be projected into the next few years if the following is assumed.

Years to Completion of Project	Present Status of Project
2	Actively developing; have applied for FERC license.
3	Beginning development; have applied for FERC preliminary permit.
4	Completed feasibility study.
5	Completed feasibility study but will not develop until funds available.
6	Presently doing feasibility study.
8	Have not done feasibility study; will not proceed until funds available.
10	Beginning consideration of hydroelectric generation.

Using these estimates for the 18 proposed projects listed in Table 19, the predicted rate of development can be estimated as shown in Fig. 12. This figure suggests a possible rate of small-scale hydroelectric development of 4000 kW/year over the next few years. The next step would be to see how various government policies might affect this rate of development. This has not yet been done, however.

The 1978 average running rate for the Pennsylvania, New Jersey, and Maryland power pool is 2.5¢/kWh. From Table 11, at 2.5¢/kWh the expected capacity from nonhydroelectric dams within Pennsylvania, Maryland, and New Jersey is 151 000 kW. This expected capacity is much greater than the proposed capacity of a little over 30 000 kW. This indicates that there are many potential small-scale hydroelectric sites that could economically come on-line today but are not presently being considered for development. At the rate of 4000 kW/year, it would take almost 40 years to develop the present capacity of 151 000 kW available at a price of 2.5¢/kWh.

Fig. 12 Predicted rate of small-scale hydroelectric development.

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Legend

- ① Broad Creek Dam
- ② Michaels Mill Dam
- ③ Catholic Dam
- ④ Lake Williams Dam
- ⑤ Logan Mills Dam
- ⑥ Middle Creek Dam
- ⑦ Reed Dam
- ⑧ Townsend Dam
- ⑨ Tulpehocken Dam
- ⑩ Vincent Dam
- ⑪ Wetherill Dam

Dam sites visited in Maryland and Pennsylvania.

Appendix A

SITE VISITS

This appendix presents background data, specifications, locality maps, photographs, and other relevant information on dam sites visited in Maryland and Pennsylvania. Also included is an overall map, showing the locations of each dam, that can be folded out for orientation purposes while the text is being read.

1. BROAD CREEK DAM

Broad Creek Dam, located on Broad Creek in Maryland, is a concrete gravity structure constructed about 1947. It is owned and maintained by the Baltimore Area Council of the Boy Scouts of America and is used for water supply and for recreation at the Broad Creek Memorial Scout Camp. During the past 31 years, some deterioration of the dam has taken place, and some repairs would be required.

Local Demand

The owner of the camp and the dam, the Baltimore Area Council of the Boy Scouts of America, is the most likely developer of the site. The camp consumed 178 613 kWh and 191 194 kWh in 1976 and 1977, respectively. Peak use occurs in July and August, and the daily peak occurs after dusk. Principal uses of electricity in the camp are for swimming pool pumps, refrigeration units, and general lighting. The current source of electricity is the Conowingo Power Co. (COPCO). The average cost of electricity was 5.25¢ per kWh in 1977. Two possibilities exist for the power produced: first, using the hydroelectric power to supply part of the camp's needs and, second, selling all output to COPCO.

Environmental Considerations

Since the area surrounding the dam and the reservoir is maintained for recreation, this is a natural setting with a low level of disturbance. The impact of repairing the dam, adding a power plant, and installing powerlines would have minimal effect on the environment. Construction disturbances would cause small, temporary problems. A water quality survey is needed, including measurement of dissolved oxygen. The Conowingo Dam on the Susquehanna River provides an insurmountable obstacle for any migrating fish and would have to be made passable before Broad Creek would be considered for fish passage facilities.

BROAD CREEK DAM

River:	Broad Creek
State:	Maryland
Latitude:	39° 41.5'
Longitude:	76° 15.8'
Owner:	Boy Scouts of America
Present use:	Recreation, water supply
Date visited:	26 Jul 1978
Drainage area:	30 mi ²
Structural height:	37 ft
Hydraulic height:	25 ft
Average flow:	37.5 ft ³ /s
Estimate of hydroelectric potential:	60 kW

Map 1 Broad Creek Dam, Maryland.

2. MICHAELS MILL DAM

Michaels Mill Dam is located on the Monocacy River in a rural area of Frederick County, MD. Although the state listed Frederick County as the owner of the dam and the county thought it was state owned, it was determined that the true owner of the dam is Mrs. Michael Crewe.

The dam is now used for recreational purposes, but in the past it was used for water power. Michaels Mill was built by Meredith Davis, Jr., some time in the early 1700's; the earliest mention of it is dated 11 Sep 1739. Over the years, the mill passed through a number of hands and was destroyed by fire and rebuilt in 1825. From 1909 to 1957, it was operated by Leo Michael. Mr. Michael requested a loan from the local bank to expand his power facility to meet the needs of the people in the area, but he was turned down. In 1957, mill operation was shut down altogether.

The old mill is about 450 ft downstream from the dam. State records indicated the dam was 12 ft high, but upon visiting the site it was determined to be closer to 4 ft high. The rock dam would need extensive repair if this site were to be developed for hydroelectric power. If the powerhouse were built at the dam site, the approximate 3 ft hydraulic height could supply an average power of 178 kW. If a canal were constructed along the old raceway, approximately 500 ft long, the increased hydraulic head of 9 ft could provide an average power of 533 kW.

Local Demand

Mrs. Michael Crewe, owner of the dam and mill, has no plans for redevelopment, though she said she might not be averse to someone else doing it. The closest industries are the Eastalco Aluminum Plant, a couple of miles west of the dam, and the Alpha Portland Cement Co. and S. B. Thomas Plant (English muffins), both 1.3 miles northwest of the dam. These nearby industries are not interested in the dam because of the disparity between their demand and the dam's potential output, not to mention the need to construct transmission facilities. The aluminum company uses more electricity than all the other customers of Potomac Edison combined; S. B. Thomas, Inc., has had a peak demand of approximately 700 kilowatts in the 5 months it has been operating and expects a higher peak in the September-November and February-April periods; and the cement factory experiences a peak load of 7600 kW.

Thus, a more likely mode of development would be for a private developer to obtain rights to the dam and either sell the

power to Potomac Edison or use the mechanical power or electricity onsite. Restoration of existing equipment in the mill is one alternative.

Environmental Considerations

The size of the drainage area above this dam gives rise to water quality concerns. The Frederick metropolitan area is just upstream; its proximity gives some credence to the possibility of oxygen depletion. There is no need for extensive dredging, so the possible water quality concerns begin and end with low dissolved oxygen. Fish migration is a logical concern on such a large river, but there are at least a couple of other dams on the Potomac to be overcome first. Fish impingement and entrainment should be considered, as the river does provide good fishing recreation. There is a major concern for flow maintenance in the mainstream section that would be bypassed by a restored millrace, which is proposed to supply water to the power plant. Some site enhancement benefits could be expected from historical restoration of the mill and millrace and possible recreation development.

MICHAELS MILL DAM

River:	Monocacy
State:	Maryland
Latitude:	39° 20.0'
Longitude:	77° 25.0'
Owner:	Mrs. Michael Crewe
Present use:	Recreation (past use: water power)
Date visited:	20 Jul 1978
Drainage area:	884 mi ²
Structural height:	4 ft*
Hydraulic height:	3 ft
Average flow:	933 ft ³ /s
Estimate of hydroelectric potential:	178 kW

* Estimated height; state records indicated 12 ft, which was obviously wrong.

Map 2 Michaels Mill Dam, Maryland.

3. CATHOLIC DAM

Catholic Dam is located on Cocalico Creek in the Borough of Ephrata in Pennsylvania. The borough owns the dam and uses it for water supply. The dam was built in 1732 and in the early 1900's was owned by the Walter W. Moyer Co. It was used to divert the water through an old raceway to the Moyer knitting mill where 35 to 50 kW of power was generated. The dam was an earth-filled timber-crib dam with a 24 ft concrete wall on the upstream side; it was 7 ft high and 100 ft long. In December 1925, a permit was issued to Walter W. Moyer to repair and raise the existing dam 8 in. Mr. Moyer gave the dam to the Borough of Ephrata which was issued a permit to rebuild the dam in 1959. A concrete dam replaced the original timber-crib dam. At present the dam is in good condition and appears to need no repairs.

Local Demand

The dam is located in an urban-residential area. The borough has a raw water intake station on one end of it. The borough buys its power wholesale from the Pennsylvania Power and Light Co. (PP&L) and retails it to users in Ephrata at rates competitive with PP&L's retail rates. It maintains its own distribution and metering system that dates back to before 1966, when it generated its own electricity with a coal-fired plant.

The dam only has a 29 kW potential (initial estimate was greater than 50 kW). The borough used 6 325 000 kWh with a 12 971 kW demand in June 1978 and the borough manager said it would have little interest in developing such a small potential for its own needs; a 1000 kW capacity or greater would be attractive to them. Also, it is reasonably satisfied with its contract terms with PP&L. There would seem to be no realistic scenario in which the owner, the Borough of Ephrata, would develop the dam, except possibly to run one of the 20-horsepower pumps in the intake station. A private entrepreneur is probably the only viable agent of development. The borough's manager said that such a possibility is not legally precluded.

Environmental Considerations

The stream on which the dam is built runs through an urbanized area at the site. But the stream course is very open and uncluttered. A few homes and the city's water supply facilities lie in the flood plain. Dredging is now done approximately bi-yearly with no apparent ill effects. Dissolved oxygen also does not appear to be a problem at present. Fishing is not a major recreational activity in the stream, and it is expected that no fish migration facilities would be required.

CATHOLIC DAM

River:	Cocalico Creek
State:	Pennsylvania
Latitude:	40° 11.0'
Longitude:	76° 10.8'
Owner:	Borough of Ephrata
Present use:	Water supply (past use: water power)
Date visited:	28 Jul 1978
Drainage area:	60 mi ²
Structural height:	10 ft
Hydraulic height:	6.2 ft
Average flow:	70 ft ³ /s
Estimate of hydroelectric potential:	29 kW

Map 3 Catholic Dam, Pennsylvania.

4. LAKE WILLIAMS DAM

Lake Williams Dam is located on the East Branch of Codorus Creek in a rural area south of York, PA, and is owned and operated by the York Water Co. for water supply. The dam was designed by Hering and Fuller Engineers in 1911. The original construction, apparently completed in 1913, was a rolled earth-filled dam with a concrete central core. In 1931, timber flash boards were utilized to raise the spillway crest 9 in. Later, a second motorized gate valve was added at the downstream toe, and the outlet conduit was extended several hundred feet downstream by adding a 48 ft diameter cast-iron pipe and a concrete end wall. In 1955, the dam was raised 9.5 ft by building a reinforced concrete structure, backfilled with gravel, on the crest of the dam, and adding two bascule gates across the spillway crest. The dam has been inspected under the Corps of Engineers dam safety program; several problems were found. The costs of the repairs should, however, be charged to the dam's present use, water supply, or to public safety. In fact, some of the repairs could reduce the cost of power development if both were properly coordinated. Power development could thus assist in financing the dam repairs.

Local Demand

The York Water Co. could either backfeed the potential power to the local rural electric cooperative, or transmit it to its main water pumping station 4 miles downstream. Though the second option results in the company getting the retail value of the electricity, the cost of the transmission lines to the pumping station compared with the cost of interconnecting to the nearest utility lines, along with difficulties in obtaining a right-of-way for the lines, could make that option unfeasible.

Peak power demand at the pumping station between July 1977 and July 1978 was 1590 kW, the minimum demand was 850 kW, and the average demand was 1050 kW. Monthly use ranged from 596 000 to 777 000 kWh over this same period. Average cost per kWh was \$0.0273; the range was from \$0.0248 to \$0.0317 (these costs per kWh are comparable to those for the other two water utilities visited in Pennsylvania). The daily load curve for the pumping station shows a peak at night, when a 750-hp motor is started to complement the 1000-hp unit run during the day and to take advantage of lower electricity rates. If the dam were developed for power, perhaps 20% of the company's electricity need would be met by the proposed facility.

Environmental Considerations

Much of the watershed is open to the public for hiking and fishing, and there is a long-term agreement with the county for further recreational development. The general manager indicated he would allow only a run-of-the-river hydroelectric facility so that adverse changes would not occur in the habitat. The lake is 40 ft deep and may be stratified, which could result in dissolved oxygen problems. The fish population seems to be large and may cause concern for impingement or entrainment losses at the power plant intake.

LAKE WILLIAMS DAM

River:	East Branch, Codorus Creek
State:	Pennsylvania
Latitude:	39° 53.5'
Longitude:	76° 43.8'
Owner:	York Water Co.
Present use:	Water supply
Date visited:	8 Aug 1978
Drainage area:	41.6 mi ²
Structural height:	55 ft
Hydraulic height:	45.1 ft
Average flow:	46 ft ³ /s
Estimate of hydroelectric potential:	132 kW

5. LOGAN MILLS DAM

Logan Mills Dam is located on Fishing Creek in central Pennsylvania. Mrs. Harry Miller owns the dam and the old mill, which presently is used for art and craft exhibits. The dam and mill were built in 1830 by Col. Anthony Kleckner. When Col. Kleckner died in the 1860's, the mill was bought by the Ilgin family and was used to produce flour and animal feed. At one point, it was used to generate electricity. The Ilgins owned it when it was shut down in the mid-1950's. Mr. and Mrs. Miller acquired the mill and attempted to restore its water power potential. They were halted by high costs and a flood the night before the Fire Department was to come to help wash away silt around the old turbines. The dam would have to be replaced if the site were to be redeveloped for hydro-electric power.

Local Demand

The area surrounding Logan Mills Dam is rural, with two very small villages each less than 1.5 miles distant. Demand for electricity in the valley may actually be declining because of the influx of Amish into the area. Located right around the mill are two farms, two mobile homes, and four to five houses.

The most likely development of the dam site could involve restoration of the existing turbine and onsite use of the mechanical power to run the mill or other machinery. Possible motivation for such renovation would be the historical importance of the mill, a commercial center in the nineteenth century.

Environmental Considerations

The main land use of the area is farming; therefore, poor water quality could be expected. The sedimentation in the pond behind the dam has been a major problem in the past. The pond appears to be eutrophic and probably provides a breeding area for mosquitoes. Redevelopment could improve the environmental quality of the area.

LOGAN MILLS DAM

River:	Fishing Creek
State:	Pennsylvania
Latitude:	41° 0.4'
Longitude:	77° 23.1'
Owner:	Mrs. Harry Miller
Present use:	Water supply (past use: water power)
Date visited:	3 Aug 1978
Drainage area:	431 mi ²
Structural height:	6 ft
Hydraulic height:	3 ft
Average flow:	560 ft ³ /s
Estimate of hydroelectric potential:	98 kW

Map 5 Logan Mills Dam, Pennsylvania.

6. MIDDLE CREEK DAM

Middle Creek Dam is located on Middle Creek in Snyder County, PA, 0.5 mile southeast of Troxelville. The dam was designed by the Soil Conservation Service of the U. S. Department of Agriculture and was constructed by the Trindle Construction Co., Inc., of Carlisle, PA. All work was completed in the spring of 1971. The dam is used for flood control and recreation in a joint cooperative effort of the Soil Conservation Service of the Department of Agriculture and the Pennsylvania Fish Commission. It is owned by the Commonwealth of Pennsylvania. The dam seems to be in good condition, but a marshy area at the toe of the dam should be checked more thoroughly.

Institutional Problem

In response to an inquiry, the Department of Environmental Resources (DER) informed Mr. Lawrence Gleeson that additional legislation would be required for him to be permitted to install hydroelectric power on state-owned dams outside the Schuylkill River District. A DER official thinks such legislation would probably be passed if recommended by the Secretary of DER and if it is in the interest of the state. Thus, no use of the site's hydroelectric potential can be foreseen without legislative action.

Environmental Considerations

The environmental effects to the reservoir and downstream habitats will not change if the power production follows current discharge practices. Fish migration is not likely to be an issue due to the remote nature and small drainage area of the creek. There do not seem to be any major potential environmental problems for a run-of-the-river power facility.

MIDDLE CREEK DAM

River:	Middle Creek
State:	Pennsylvania
Latitude:	40° 47.8'
Longitude:	77° 11.8'
Owner:	Pennsylvania DER
Present use:	Flood control, recreation
Date visited:	3 Aug 1978
Drainage area:	17.6 mi ²
Structural height:	53 ft
Hydraulic height:	32.4 ft
Average flow:	24 ft ³ /s
Estimate of hydroelectric potential:	49 kW

Map 6 Middle Creek Dam, Pennsylvania.

7. REED DAM

Reed Dam is on the Conewango Creek in Warren, PA. The original dam was built in 1866 for a saw mill. Logs were pulled into the saw mill by a chain operated by water power. About 1872, James Clark bought and operated the mill until he sold it in 1895 to J. W. Newmaker and Reed. The old mill still stands, now a part of the Phenix Furniture Co. of which F. H. Newmaker, son of J. W. Newmaker, is president. Mr. Newmaker conveyed the property to the Phenix Furniture Company in 1926. Many enterprises then depended upon the millrace for their existence -- wagon shops, blacksmith shops, a sash factory, and a large grist mill. A great fire destroyed all of these buildings, and only a few were later rebuilt. At present, it is not known who owns the dam.

Local Demands

The dam is located in the oil-producing part of northeastern Pennsylvania. Demand in the immediate vicinity is primarily residential and commercial. Within a few hundred feet of the dam are a gas station, three restaurants, a bus company, a propane gas distributor, and a junior high school. Less than 0.2 mile away are an elementary school, a health center, and a considerable number of commercial establishments.

Environmental Considerations

Fish migration would need to be considered in potential power development. During August of 1976, Sam Lovecchio, owner of the Burger King in Warren, attempted to fill in a section of the old raceway. However, Paul Sowers, waterways patrolman for Warren County, issued a cease and desist order. Lovecchio explained the millrace must be filled in to provide sufficient parking for Burger King customers. Paul Sowers said, "There are a lot of fish working in there and I know a lot of kids fish down there."* The problem was resolved by placing a large diameter corrugated steel pipe in the section of raceway under construction and filling dirt over it.

Site enhancement would be a major point in the restoration of the millrace. The old raceway contains trash, and it would be an asset to the area if it were cleaned up and maintained as required for power production.

* Chuck Hayes, "Fish Commission Orders Mill Race Filling Halted," Warren, PA, newspaper, WTO, 17 Aug 1976.

REED DAM

River:	Conewango Creek
State:	Pennsylvania
Latitude:	41° 50.7'
Longitude:	79° 8.5'
Owner:	Unknown
Present use:	Recreation (past use: water power)
Date visited:	10 Aug 1978
Drainage area:	898 mi ²
Structural height:	4 ft
Hydraulic height:	3 ft
Average flow:	1599 ft ³ /s
Estimate of hydroelectric potential:	406 kW

Map 7 Reed Dam, Pennsylvania.

8. TOWNSEND DAM

Townsend Dam is located on the Beaver River in Pennsylvania and is owned by the Beaver Falls Municipal Authority.

Local Demand

The dam is located in an urban-industrial area between Beaver Falls 0.5 mile to the north and New Brighton on the east bank of the river at the Townsend site.

Demand analysis focused on the electricity needs of the Beaver Falls Municipal Authority, the local water utility and owner of the dam. On the eastern end of the dam is the utility's New Brighton raw water intake station (3 to 4 million gallons per day (MGD)) with a demand in April 1978 of 82 kW and use of 36 160 kWh. The load was described as fairly flat throughout the year; average monthly use for 1976 was 32 000 kWh. Raw water from the New Brighton intake is pumped a mile to the northeast to the New Brighton treatment plant, which has a filter capacity of 6 MGD. In April 1978, the treatment plant had a kW demand of 266 and used 153 450 kWh. Average monthly use for 1976 was 142 000 kWh. Its load also is fairly flat during the year.

Cost per kWh to the Beaver Falls Municipal Authority fluctuates around 3 to 3.5¢. Evidence of the utility's desire to reduce its electricity costs is the renovation of old water turbines at the Hartman Dam (2 miles north of the Townsend site at the Eastvale treatment plant) to provide power to mechanically driven water pumps. At an average cost of power per 1000 gallons pumped of 4.5¢ at the Eastvale plant (calculation includes cost of all power used at the plant) the municipal authority expects to save roughly \$45 per day on power costs if 1 MGD were pumped. Use of one of the water pumps was discontinued in 1970, when electricity costs were relatively low; but in August 1978 it was started up again. Renovation in this case costs only a few hundred dollars due to the machinery's good condition.

If the municipal authority were to develop the Townsend site for generation of electricity, it obviously would not develop the full capacity of the dam just to meet 82 kW of demand, or even 266 kW more, if transmission lines to the treatment plant were feasible. It could plan to backfeed the surplus to the Duquesne Light Co., or install just enough capacity to supply the raw water station.

Environmental Considerations

Some of the steeply sloping banks along the Beaver River seem to have been left in their natural state. Long-term problems could come from contaminated sediment and dissolved oxygen, but this is based solely on the industrial nature of the basin. Recreational fishing is of minor importance, and the need for fish migration devices is therefore remote. Construction disturbance will probably not require any special measures. Some environmental enhancement could be realized in the form of junk removal and/or new recreation facilities.

TOWNSEND DAM

River:	Beaver
State:	Pennsylvania
Latitude:	40° 44.0'
Longitude:	80° 19.0'
Owner:	Beaver Falls Municipal Authority
Present use:	Water supply (past use: water power)
Date visited:	9 Aug 1978
Drainage area:	3030 mi ²
Structural height:	11 ft
Hydraulic height:	11 ft
Average flow:	3220 ft ³ /s
Estimate of hydroelectric potential:	2250 kW

Map 8 Townsend Dam, Pennsylvania.

9. TULPEHOCKEN DAM

Tulpehocken Dam is located on Tulpehocken Creek near Reading, PA. The dam formerly provided water power to the Reading Paper Co.'s paper mill.

Local Demand

On the Reading side of the creek, the immediate area is residential, mixed with a park, a medium-sized industrial plant, and a dozen or so small businesses, all within 0.5 mile of the dam. On the West Reading side, within a quarter mile of the dam, are mostly residences and a large industrial concern.

The paper mill property is presently up for sale by the Beacon Paper Co., which purchased it from the Reading Paper Co. in 1972. There has been no interest in the property so far, though some people have come to see the machinery. It appears the most likely mode of development of the dam would be for the future owner to restore the original turbine, millrace, and gate and generate electricity for his own needs or simply use the mechanical power for manufacturing or other purposes. Historical preservation and exhibition of the working machinery could be one of the developer's objectives.

Environmental Considerations

Tulpehocken Creek is a tributary of the Schuylkill River and as such has the possibility of being required to supply fish-passing facilities. All downstream barriers must be resolved first, however, but eventually that could happen. The dissolved oxygen level may be a concern here, but there is no apparent sediment/siltation problem. The plan area is in need of cleanup, and redevelopment would improve the area greatly.

TULPEHOCKEN DAM

River:	Tulpehocken Creek
State:	Pennsylvania
Latitude:	40° 20.9'
Longitude:	75° 57.2'
Owner:	Reading Paper Co.
Present use:	Water supply (past use: water power)
Date visited:	4 Aug 1978
Drainage area:	217 mi ²
• Structural height:	12 ft
Hydraulic height:	7 ft
Average flow:	297 ft ³ /s
Estimate of hydroelectric potential:	132 kW

Map 9 Tulpehocken Dam, Pennsylvania.

10. VINCENT DAM

Vincent Dam is a timber-crib dam located on the Schuylkill River in Pennsylvania. It was built around 1843 as a part of the Schuylkill Canal System. The dam is owned by the Commonwealth of Pennsylvania; the Vincent Pool is used for water supply, limited recreation, and as a desilting basin. The Home Water Co. withdraws about 1.5 MGD from the pool in serving the Borough of Royersford and the Pennhurst State School. A moderate amount of fishing and boating takes place on the pool, but there are no public recreational facilities available. The wooden deck was repaired during August 1978 by the state. Other minor repairs may be needed for power development.

Local Demand

Located just north of Spring City and Royersford and less than 0.5 mile east of Linfield, the dam is in a semiurban area. Local demand in a 0.25 to 0.5 mile radius around it consists primarily of residential and small commercial users. The two largest potential power users would be the Continental Distillery of Publicker's, 0.5 mile west of the dam in Linfield, and the Pennhurst State School, 0.7 mile to the south.

The Commonwealth of Pennsylvania, through its Department of Environmental Resources (DER), owns and maintains the dam, and, according to special legislation, the DER can allow a private entrepreneur to develop the dam for almost any purpose, including generation of electricity. Mr. Lawrence Gleeson explored this possibility with the state, but negotiations stalled over failure to agree on a fee to be paid the state for use of the dam. The legislation even permits the dam to be sold if it is judged to be no longer necessary for desilting purposes.

As a potential developer, the private sector is more probable than the state, since the developer would face opposition by the electric utilities. A DER official commented that the state would want to avoid such a confrontation. Possible private developers would have to include the Continental Distillery, but probably not the Pennhurst School, since it is a state institution.

Environmental Considerations

The river water quality of the Schuylkill River has been improving in recent years, so much so that it is hoped that shad will soon resume their yearly migrations. Development at existing dams could result in the requirement that fish ladders (or equivalent devices) be installed. A test case is being processed in the

proposed Schuylkill-Lehigh River Project, FERC No. 2803, that should give a good idea of what to expect regarding this very important topic. Dissolved oxygen could be a possible problem, especially in a river where progress in and concern for environmental quality are high.

VINCENT DAM

River:	Schuylkill
State:	Pennsylvania
Latitude:	40° 12.3'
Longitude:	75° 32.9'
Owner:	Pennsylvania DER
Present use:	Recreation, water supply, desilting (past use: water power)
Date visited:	4 Aug 1978
Drainage area:	1450 mi ²
Structural height:	7 ft
Hydraulic height:	6.9 ft
Average flow:	2302 ft ³ /s
Estimate of hydroelectric potential:	1010 kW

Map 10 Vincent Dam, Pennsylvania.

11. WETHERILL DAM

Wetherill Dam is a masonry dam located on Perkiomen Creek in Pennsylvania. It is a water supply dam owned by the Philadelphia Suburban Water Co. It has been noted that, in 1813, the dam was used to provide water power to a mill. The Suburban Water Co. bought the dam in October 1928 and reconstructed it in 1929.

Local Demand

Backfeeding to the local utility or use onsite are the two main alternatives. The company's closest point of demand is the raw water intake and pumping station (Perkiomen pumping station) on the southern end of the dam. It consists of three 200-hp motors and one 350-hp unit, with a total capacity of 24 MGD or about 17 000 gallons per minute. Maintaining an almost constant rate of pumping around the clock, the station's load is relatively flat, with 84 to 88% use of peak electrical demand on the average. The upper and lower bounds set on the station's demand by the Philadelphia Electric Co. are 600 kW and 240 kW. Actual demand in 1977 averaged about 522 kW and ran as high as 557 kW. Average cost per kWh ranged from \$0.0281 to \$0.0317 from the middle of 1977 to early 1978.

Also in the Philadelphia Suburban Water Co.'s system, but not included in the random sample, is the 66 ft high Greenlane Dam, 17 miles upstream from the Wetherill Dam. The Greenlane Dam would appear to be a much more favorable possibility for hydroelectric development than the Wetherill Dam.

Environmental Considerations

This is a fair-sized tributary to the Schuylkill River, very near its mouth, which could mean prime consideration for shad migration measures. Impingement and entrainment of fish in the power plant intake would also be an item of concern. Current fishing is not extensive but is popular near the dam. No reservoir changes are reasonable for storage; thus, habitat changes need not be considered. Significant environmental enhancement would probably not result from power development because there is a park on the northern bank of the river near the dam.

WETHERILL DAM

River:	Perkiomen Creek
State:	Pennsylvania
Latitude:	40° 7.4'
Longitude:	75° 26.7'
Owner:	Philadelphia Suburban Water Co.
Present use:	Water supply (past use: water power)
Date visited:	4 Aug 1978
Drainage area:	360 mi ²
Structural height:	5 ft
Hydraulic height:	3 ft
Average flow:	481 ft ³ /s
Estimate of hydroelectric potential:	92 kW

Map 11 Wetherill Dam, Pennsylvania.

Appendix B

TURBINE-GENERATOR COSTS

Fig. B 1 Delivered cost of small low-head turbogenerator equipment (from Ref. 8).

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REPORT TO

**JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY**

BROAD CREEK DAM

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DISCLAIMER

This is one of three reports prepared by Acres American Incorporated on behalf of the Johns Hopkins Applied Physics Laboratory. Under terms of this agreement, AAI was to furnish site visits, consultations, estimates of required repairs, a conceptual design for intake works, and associated costs at each site.

The level of effort for the total work, including consideration of three dams and consultation, is 10 man days.

The information contained herein is based on visual inspection only. No representation is made as to the safety of various structures visited, for a much greater level of effort would be required for such purpose. Conceptual designs, where provided, are feasibility level only, and significantly more effort would be required to accomplish engineering and design for the purpose of preparing plans and specifications.

Mention of a specific manufacturer is made only for illustrative purposes and does not constitute an endorsement of particular firms or products.

Additional efforts normally associated with feasibility studies (including concepts for extending penstocks, designing power houses and electric distribution facilities, studying environmental concerns, and the like) are to be accomplished by others and are generally outside the purview of AAI responsibility on this contract.

BROAD CREEK DAM

1 - INTRODUCTION

This report has been prepared for the Johns Hopkins University Applied Physics Laboratory. It describes the results of a brief site visit to a dam on Broad Creek within the confines of the Broad Creek Memorial Scout Reservation, Whiteford, Maryland. Conclusions and initial cost estimates for intake works are provided for the purpose of considering the feasibility of installing a small hydroelectric plant at the site.

2 - PHYSICAL DESCRIPTION

2.1 - The Dam

Constructed in about 1947, the Broad Creek Dam is a concrete gravity structure approximately 180 feet long with a maximum structural height of 37 feet and a hydraulic head (measured from dam crest to normal water level in stilling basin) of approximately 25 feet when water is flowing over the spillway. The spillway extends the full width of the dam. A chute approximately two feet wide and less than one foot deep is formed into the face of the dam in vicinity of the south abutment. This latter item does not appear on drawings prepared in 1947 and available at the site, though it may have been provided to ensure some measurable flow during low flow periods. In any event, the chute contributes to one of the repair problems now extant (see paragraph below). Concrete wing walls at either abutment extend into exposed decomposed rock.

2.2 - Reservoir Operation and Characteristics

An outlet works is located about 60 feet south of the north abutment. A manually operated steel gate was closed, but leaking, at the time of the site visit. The owner's representative on site reports that the gate is opened every fall and the reservoir is drawn down for the winter. Lately there have been many complaints from downstream residents because so much silt is in the water released when the gate is opened. He states a severe siltation problem does exist and that, although assistance had been received in the past when military units removed silt as a community service project, current environmental constraints for disposing of

spoil would require the construction of a disposal basin as large as the reservoir itself. The Boy Scouts have neither the land nor the funds available for such a project. As an alternative, they have asked for a permit to build a low dam above the current reservoir for the purpose of trapping silt.

The drainage area is about 30 square miles and the surface area of the reservoir is approximately 180,000 square meters (44.5 acres). State records show a normal impoundment of 367 acre feet and a maximum impoundment of 440 acre feet, though the heavy siltation noted above has doubtless reduced that volume substantially.

A wooden bridge is mounted atop the dam, though vehicular traffic is rare (restricted primarily to service vehicles and not open to the public).

2.3 - Downstream Characteristics

The downstream toe of the dam forms a trough, beyond which is a stilling basin. Below the dam, Broad Creek plunges relatively rapidly, dropping about 50 feet in a channel length of about 6700 feet (approximate measurements based on available topographic maps). Because a number of oxbows occur, the straight line distance from the dam to the same point (50 feet drop) downstream is only about 3400 feet; and, from the dam to a point at which a 25 foot drop has occurred, about 1500 feet.

2.4 - Flow Assumptions

Hydrologic data has not been made available to us for the site. Old records show that, during a period of four years in the early 1900's, measurements were made on Broad Creek at Mill Green, taking into account a drainage area roughly half the size of the one now being considered. That brief period of measurement indicated mean discharges ranging from 20 to 30 second feet with maximum and minimum daily discharges between 8 and 509 second feet. The very low minimum discharge measurement coupled with the owner's statement that there have been periods during which no water flowed over the spillway except at the chute suggests that no firm capacity value can be assigned to a plant installed at the site. The relatively consistent relationship of 1.6 cubic feet per second per square mile of drainage area for mean discharge on Broad Creek at Mill Green leads us to accept

a value of about 48 cfs as a rough approximation of the mean annual flow at the dam ($48 = 1.6 \times 30$ square mile drainage area).

3 - CONDITION

A number of events during the past 31 years have caused deterioration, some of which could be halted by relatively simple protective measures. Subparagraphs below describe conditions and, where appropriate, probable causes:

3.1 - South Abutment Wall Undercut

Erosion has occurred under this wall to a distance of approximately 10.5 feet, and a depth of about 3 feet under the wall (see sketch at Figure 1 and photographs 2 through 4). This damage exists primarily because a culvert as well as the storm flow down two paved steep roads dump into a channel which nature has now carved as shown on the sketch at Figure 2. A broken section of the wing wall may be seen on a ledge of decomposed rock a few feet from the wall itself (see photograph 4). Flood flows over the full spillway may have contributed to the erosion process from time to time so that even after certain proposed repairs are made, periodic checks of the area of concern should be made.

3.2 - Erosion at Toe of Chute

Flow from the chute has followed its own path of least resistance and has eroded the exposed decomposed rock from its original slope to a comparatively flat ledge now being continuously scoured and further eroded.

3.3 - Spalling on Downstream Face

A number of spalls generally less than a foot in width and concave to a depth of six inches or less may be seen on the face of the dam. These are probably of no serious consequence.

3.4 - Gate Leaking

The gate at the outlet works does not seat well (see photograph 6).

3.5 - Horizontal "Cracks"

The dam was poured in five foot lifts, and the joints at each lift are visible. Water flowing over the spillway creates an illusion as it flows over the joints that some water is actually flowing through the dam at these joints. A closer inspection at the only available vantage point near the dam face confirmed that this was indeed an illusion--at least in that specific area.

3.6 - Debris

Logs and other debris have accumulated upstream of the spillway and, in some cases, have become lodged at the spillway crest. This debris would reduce the spillway capacity during high flow and could effectively provide enough resistance to trap other logs and eventually wipe out the bridge.

3.7 - Other

The water was too murky to be able to visually inspect the condition of the intake for the outlet works or the floor of the spilling basin. No evidence of seepage was found.

4 - RECOMMENDED REPAIRS

There is no visual evidence that the dam is in imminent danger of failing. Yet a number of repairs or corrective measures should soon be taken to ensure the continued use of the structure. This work could be undertaken in conjunction with hydroelectric power development, thereby contributing to economy of scale for a larger work package as well as minimizing mobilization and demobilization costs. Before this work is started, of course, detailed designs and plans and specifications would need to be prepared.

4.1 - Redirect Culvert and Road Drainage

A lined channel should be provided to direct this flow away from the abutment. A concrete channel would serve this purpose well, though semicircular sections of CMP would also be effective if they were bedded properly. For purposes of estimating repair costs, at least three feet diameter half sections of CMP are assumed, or a concrete drainage ditch

with roughly the same cross sectional area. Short curb sections (possibly timber curbs) should be provided to direct flow from the road into the proposed channel (see Figure 3).

4.2 - Repair Wing Wall

The foundation of the wing wall should be re-established in rock. This can be accomplished by removing at least a foot of decomposed rock and pouring a solid section under the current wall (see Figure 4). Rip-rap of maximum size up to 1000 pounds and primarily in the 10 to 300 pound sizes should be placed to restore original slope and extended at least two feet above the newly formed foot of the abutment wall. This placement should extend downstream to the end of the abutment wall. Width of placement varies as a function of the amount of erosion which has occurred.

4.3 - Adjust Flow Pattern at Toe of Chute

In addition to rip-rap along the ledge which has been formed by erosion, a concrete channel leading from the toe of the chute to a point downstream could serve to reduce future recurrences of rip-rap requirements. Even so, the placement of rip-rap now will probably satisfactorily solve the problem as long as periodic inspection and occasional replacement of individual rocks occurs.

4.4 - Spalling

No repair is required at this time for spalled sections.

4.5 - Gate Repair

When the reservoir is drawn down in the fall, the gate and its seat should be carefully inspected and repairs made as necessary to reduce leakage.

4.6 - Horizontal "Cracks"

The question of leakage through the dam can be put to rest easily if during the fall draw-down the gate is partially open for a time in a position such that no water flows over the spillway, but the reservoir surface remains a foot or so below spillway crest. The spillway will either dry

quickly or flow through the joints will be observed unambiguously. Should the latter condition prevail, the owner should immediately contact AAI or another consulting engineer competent in dam safety and ask that the condition be observed and evaluated.

4.7 - Debris Removal

On a regular basis, the owner should remove debris as it accumulates near the spillway or gets hung in the bridge substructure. This chore could be performed relatively easily by scouts at the camp.

4.8 - Other Inspections

At the time of draw down, a visual inspection of the upstream face of the dam and of the water intake should be made to attempt to identify any further repair requirements.

5. HYDROPOWER POTENTIAL

5.1 - Probable Output

A number of formulations are available for estimating output at a given site. All of these derive from the fact that water has potential energy directly related to the distance through which it will be moved. In general,

$$P = \frac{QH\delta\eta}{738}$$

where:

P = Power in kilowatts
 Q = Discharge in cfs
 H = Net head in feet
 δ = Density = 62.4 pcf
 η = Efficiency. Assume $\eta = .75$ for low-head plants

Thus,

$$P = \frac{(48) (25) (62.4) (.75)}{738}$$

$$P = 76 \text{ kw.}$$

Although this nominal value provides some indication of the

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order of magnitude of plant size, some variation is possible as a function of operational procedures (e.g., allowing variations in reservoir surface elevation, thereby permitting periodic discharges in excess of the average) and of hydraulic head which can be increased by lengthening penstocks and locating a power plant further downstream of the dam site. In addition, actual flow records may suggest a seasonal firm power installation, for wet periods, in excess of the nominal value cited.

5.2 - Siting Civil Works

For illustrative purposes, the power plant is presumed to include a standard tube unit available from Allis Chalmers. The smallest standard size (runner diameter 29.5 inches) is chosen. The diameter of the inlet valve--and of penstocks if required--is 42 inches. Output will, of course, vary with head and discharge. This unit is sufficiently large to test options such as increased discharge for shorter operating periods and increasing hydraulic head by lengthening penstocks.

6 - ALTERNATIVE INTAKE WORKS

Four schemes for intake works were considered (see sketch at Figure 5). All require a 42" water conduit to the appropriate power plant location.

6.1 - Using the Existing Outlet Works

In this scheme a yoke arrangement downstream of the existing gate would be required, with appropriate additional gate, to allow rapid reservoir draw down. (Considered essential because of the recreational purpose of the reservoir. In the event of suspected drowning, for example, draw down would be required.) An arrangement for venting would also be needed.

6.2 - An intake works at a point along the east shore of the reservoir somewhere north of the north abutment.

In this case, penstocks would run through a tunnel to a below-grade powerhouse in vicinity of Deep Creek. This scheme would be especially attractive if average discharge and maximum reservoir capacity were larger. The high cost of tunneling, uncertainty about subsurface conditions, and environmental implications of discharging the waters of one creek into another suggest that this scheme is probably not the most cost effective.

6.3 - Providing a new intake works through the dam.

In this case, a new intake works would be designed to provide maximum hydraulic efficiency. The disadvantage, of course, is that penetrating the existing dam would be relatively expensive. Nonetheless, this alternative was selected for further analysis since it can be accomplished during normal draw down period and without extensive coffer-dam construction. A sketch of the proposed intake works is provided at Figure 6. (A variation of this alternative--not shown--involves the construction of a siphon running over top the existing dam. Some research effort is required before a particular design is chosen for such an approach so that cost estimates would require some additional inflation to account for uncertainties.

6.4 - Run of the river plant in dam cross section.

(See sketch at Figure 7.) Though this approach has many advantages, it was not selected. Extensive demolition work would be costly and the potential capacity is relatively small.

7 - APPROXIMATE COSTS

Cost estimates shown on succeeding pages do not include contractor mobilization since such costs would necessarily be included in estimates for powerhouse and other facilities. All information includes contractor overhead and profit and reflects 1978 costs adjusted by Engineering News Record indices for recent Baltimore construction experience.

ESTIMATE SUMMARY

CLIENT JHU Applied Physics LaboratoryTYPE OF ESTIMATE PreliminaryPROJECT Broad Creek Dam

APPROVED BY _____

JOB NUMBER P5126.00

FILE NUMBER _____

SHEET 1 OF _____BY CAD DATE 9/14/78

CHKD _____ DATE _____

No.	DESCRIPTION	QUANTITY	UNIT	COST/ UNIT	AMOUNT	TOTALS	REMARKS
1.0	DAMAGE REPAIR						
1.1	New drainage channel. 36" CMP half sections in place	90	LF	\$ 13	\$1170		
1.2	Repair wing wall Concrete cast in place	1.2	CY	300	360		
1.3	Adjust flow pattern. Rip-rap (Maximum size <u>500</u> lbs, average size <u>100</u> lbs)	56	CY	13	730		
1.4	Spalling	--	--	--	--		Not to be repaired since work would be cosmetic only.
1.5	Gate repair		LS		500		
1.6	"Crack" inspection	--	--	--	--		To be accomplished by owner at time of scheduled draw down.
1.7	Debris removal	--	--	--	--		To be accomplished on a regular basis by owner (e.g., scouts on site).

LF = linear foot, CY = cubic yard, LS = lump sum

G350

ESTIMATE SUMMARY

CLIENT JHU Applied Physics Laboratory

TYPE OF ESTIMATE Preliminary

PROJECT Broad Creek Dam

APPROVED BY _____

JOB NUMBER P5126.00

FILE NUMBER _____

SHEET 2 OF _____

BY CAD _____ DATE 9/14/78

CHKD _____ DATE _____

No.	DESCRIPTION	QUANTITY	UNIT	COST / UNIT	AMOUNT	TOTALS	REMARKS
1.8	Other periodic inspections	--	--	--	--		To be accomplished on a regular basis by owners.
	Sub-total, repairs					\$2760

ESTIMATE SUMMARY

CLIENT JHU Applied Physics LaboratoryTYPE OF ESTIMATE PreliminaryPROJECT Broad Creek Dam

APPROVED BY _____

JOB NUMBER P5126.00

FILE NUMBER _____

SHEET 3 OF _____BY CAD DATE 9/14/78

CHKD _____ DATE _____

No.	DESCRIPTION	QUANTITY	UNIT	COST / UNIT	AMOUNT	TOTALS	REMARKS
2.0	INTAKE WORKS						To be constructed when reservoir is drained for the winter.
2.1	Concrete removal	17	CY	\$270	\$4600		Relatively high demolition cost since concrete left in place cannot be damaged.
2.2	Cast-in-place reinforced concrete	11	CY	400	4400		
2.3	Gate and lift	16	SF	125	2000		
2.4	Trash rack		LS		200		Taken as 10% of gate cost.
2.5	Steel pipe 3.5' inside diameter (Extended to toe of dam only. APL to model beyond)	30	LF	65	1950		To be shop fabricated. (Factor .65 applied to \$100/LF for field fabrication)

SF = square foot

ESTIMATE SUMMARY

CLIENT JHU Applied Physics LaboratoryTYPE OF ESTIMATE PreliminaryPROJECT Broad Creek Dam

APPROVED BY _____

JOB NUMBER P5126.00

FILE NUMBER _____

SHEET 4 OF _____BY CAD DATE 9/14/78

CHKD _____ DATE _____

No.	DESCRIPTION	QUANTITY	UNIT	COST/ UNIT	AMOUNT	TOTALS	REMARKS
2.6	Precast saddle anchors installed	3	ea.	\$250	\$750		The values of 20% and 15% for contingencies and E & D are appropriate for preliminary estimates. Acceptance of these or other factors is in a sense a measure of the risk the owner is willing to take that estimated costs will not be exceeded.
	Sub-total, intake					\$13900	
	Total Direct					\$16660	
	Contingencies		20%			3332	
	Sub-total					\$19992	
	Engineering and design		15%			3000	
	Total repairs and intake					\$23000	Rounded to nearest \$1000

**LOCATION
MAP**

RAND McNALLY
**MARYLAND
 DELAWARE**
 Scale: 0 5 10 miles

ACRES

FIGURES

FIGURE 1. Approximate dimensions of undercut at south abutment

FIGURE 2 Sketch of deteriorating conditions.

FIGURE 3 - Plan of Proposed Lined Drainage Channel.

FIGURE 4-Proposed Wing Wall Repair.

Scheme B - Intake on East Bank

Scheme A. Existing Outlet modified to perform dual function

*Scheme C. Preserves existing Outlet
New Intake in Dam*

*Scheme D. Run of river plant in
Dam cross section*

FIGURE 5. Alternative Power Schemes

FIGURE 7-- Typical low-head run-of-river plant

PHOTOGRAPHS

Photo 1. View of dam face looking toward
north abutment

Photo 2. Undercut at end of wing wall
of south abutment

Photo 3. Closeup of undercut wing wall

Photo 4. Section of broken concrete has fallen from broken wing wall. Picture taken from bridge shows flow pattern at foot of service chute on spillway.

Photo 5. Service chute on spillway has carved a path in decomposed rock, gradually eroding abutment.

Photo 6. Leaking gate on outlet works.

Photo 7. Accumulation of debris should be removed. Note questionable areas where possible flow through dam at construction joints requires checking.

Photo 8. Debris all along spillway crest should be removed and checked at regular intervals thereafter.

Photo 9. Debris near north abutment.

Photo 10. Rapids downstream occur as the stream falls 25 feet in 3,400 feet.

Photo 11. Additional rapids

Photo 12. Past floods have eroded banks

Photo 13. Debris as high as ten feet above stream bed indicates past floods created significant discharges. This situation must be considered in siting a power house.

REPORT TO

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY

FINAL DRAFT

MIDDLE CREEK DAM

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Suite 329
The Clark Building
5565 Sterrett Place
Columbia, Maryland 21044
Telephone (301) 992-5300

DISCLAIMER

This is one of three reports prepared by Acres American Incorporated on behalf of the Johns Hopkins Applied Physics Laboratory. Under terms of this agreement, AAI was to furnish site visits, consultations, estimates of required repairs, a conceptual design for intake works, and associated costs at each site.

The level of effort for the total work, including consideration of three dams and consultation, is 10 man days.

The information contained herein is based on visual inspection only. No representation is made as to the safety of various structures visited, for a much greater level of effort would be required for such purpose. Conceptual designs, where provided, are feasibility level only, and significantly more effort would be required to accomplish engineering and design for the purpose of preparing plans and specifications.

Mention of a specific manufacturer is made only for illustrative purposes and does not constitute an endorsement of particular firms or products.

Additional efforts normally associated with feasibility studies (including concepts for extending penstocks, designing power houses and electric distribution facilities, studying environmental concerns, and the like) are to be accomplished by others and are generally outside the purview of AAI responsibility on this contract.

MIDDLE CREEK DAM

1. INTRODUCTION

This report has been prepared for the Johns Hopkins University Applied Physics Laboratory. It describes the results of a brief site visit on August 3, 1978, to a multi-purpose dam on Middle Creek in Snyder County, Pennsylvania (Pennsylvania dam number 637). Conclusions and initial cost estimates of a scheme for diverting water for power are provided.

2. PHYSICAL DESCRIPTION

The following data is extracted from a bronze plaque erected on a pedestal downstream of the dam:

Middle Creek Watershed Multi-Purpose Dam PA-637	
Drainage area	17.59mi ²
Total storage	6,071 acre feet
Flood storage	3,318 acre feet
Surface area	239 acres
Height	53 feet
Volume of fill	287,900 yd ³
Constructed	1970

The Middle Creek Dam is an earth fill gravity structure. The spillway is a drop inlet type -- a scheme frequently used where the maximum spillway outflow is to be limited. To accommodate floods in excess of the selected inflow design flood, an emergency spillway is provided at the abutment. This latter feature is an earthen structure, sloping gently up from the normal reservoir surface to a crest approximately ten feet higher than the crest of the drop inlet, and thence down in a southwesterly direction. A three foot wide concrete sill is at the emergency spillway crest for erosion protection. Otherwise, the spillway has a good cover of low grass with no obstructions. A small stream meanders along a course about 600 feet west of the toe and generally perpendicular to the direction of emergency spillway flow; it is this stream which carries off flood waters. A private home is perched precariously on the far bank of the stream. The occupant states that during Hurricane Agnes in 1972, flow over the emergency spillway was "like Niagara Falls" and "it came right at" her. This fact

is significant in considering possible hydropower options, for alternatives which would tend to significantly reduce service spillway capacity may be unacceptable from a safety point of view.

An outlet works at the downstream toe consists of a 48-inch reinforced concrete pipe, discharging at a point on the downstream toe approximately 190 feet from the drop inlet shaft. A reinforced concrete impact basin at the outlet and a 20-foot section of rip-rap lead to a relief channel which connects to the original Middle Creek channel. Upstream of the drop inlet shaft is a gated drain inlet, offset from the drop inlet shaft and connected to it by a 36-inch reinforced concrete pipe approximately 59 feet in length. As-built plans show that this drain inlet is trash-racked. The intake structure atop the drop inlet is, of course, trash-racked as well. The gate for the drain inlet is manually operated, its crank shaft extending parallel to the upstream slope and terminating at a concrete platform near the drop inlet. The hydraulic head available at the outlet is normally about 32 feet. Photographs 1 through 8 display various features.

No details regarding hydrologic data have been made available to us. However, we assume that a normal flow of 1.6 cfs per square mile of drainage area is a reasonable indicator of average flow. Thus, normal discharge is taken as 28 cfs, which is consistent with that observed visually at the time of the site visit.

There is no apparent steep gradient downstream of the dam, so that extending the distance from the dam to a potential power house for the purpose of increasing hydraulic head is probably not a particularly attractive option from an economic point of view.

A drainage system at the downstream toe consists of 12-inch diameter perforated pipe extending along the entire length of the dam and discharging at either wing wall of the outlet works.

3. CONDITION

The general condition of the dam and associated structures appears to be good. The emergency spillway is unobstructed and has an excellent cover of low grass. The dam itself has a good cover of crown vetch and no sign of erosion or unusual settlement was observed. Concrete structures are generally sound and metal appurtenances are free of excessive rust and appear to be in good repair. No accumulation of debris

was found either at the trash racks for the drop inlet or along the upstream face of the dam. The gate lift device seemed to be in satisfactory order, though it was not operated during the site visit.

Only one observation of a potential problem was made. In an area about 85 feet NW of the outlet works and near the toe of the dam, the ground was marshy and some surface water was observed, the total area of concern being roughly elliptical and extending another 30 feet or so further along the toe and expanding in width to a maximum of about 10 feet. Although it had rained within the past few days, the marshy condition had probably existed for some time, for the vegetation there was clearly different from that seen elsewhere along the toe. Indeed, light green marsh grass seemed to thrive where the ground was wet or spongy. A number of explanations are possible, and seepage cannot be ruled out. Even so, the most likely cause appears to be a partial blockage in the drainage system. Two factors prompt this choice:

- (1) The marshy area lies approximately over the line along which as-built drawings show the drain pipe runs; and,
- (2) the flow from the drain outlet on the northwest wing wall of the outlet works is noticeably less than that from the corresponding outlet on the southeast wing wall, although the former drains a reach three or four times the length of the latter.

4. REPAIRS

The marshy area described above should be checked more thoroughly, and, if investigations show that there is indeed a partial blockage in the drainage system, the affected area should be repaired, and free drainage flow restored. Accurate measurement on site will remove any question as to proximity of the wet area to the buried perforated pipe. For purposes of estimating repair costs, we assume some minor excavation and replacement of 30 feet of perforated pipe will be required. In the interim, periodic checks should be made to determine if the marshy area is growing or if any sign of freely flowing water - especially muddy water - is occurring. Either condition should be brought to the attention of an engineer competent in dam safety.

5. HYDROPOWER POTENTIAL

5.1 Probable Output. A number of formulations are available for estimating output at a given site. All of

these derive from the fact that water has potential energy directly related to the distance through which it will be moved. In general,

$$P = \frac{QH\delta\eta}{738}$$

where:

P = Power in kilowatts
 Q = Discharge in cfs
 H = Net head in feet
 δ = Density = 62.4 pcf
 η = Efficiency. Assume $\eta = .75$ for low-head plants.

Thus,

$$P = \frac{(28)(32)(62.4)(.75)}{738} = 57Kw$$

Although this nominal value provides an indication of the order of magnitude of plant size, some variation is possible as a function of operational procedures (e.g., allowing variations in reservoir surface elevation, thereby permitting periodic discharges in excess of the average). There appears to be little economic value in this case associated with extending penstocks for the purpose of increasing hydraulic head, for the stream gradient appears to be insufficient.

It is clearly technically feasible to increase discharge for certain periods, reducing or eliminating flow at other times. On the other hand, the multi-purpose aspects of the dam could well preclude such a choice. Indeed, it is highly probable that some specified minimum discharge is required for maintaining fisheries. Beyond that, a number of homes and farms border Middle Creek downstream of the dam, and prior water rights could well militate against drastic daily fluctuations in flow. For these reasons, we assume that any power plant installed at the site would not be available for peaking and that it would operate as a run of the river plant.

5.2 Siting Civil Works. Even the smallest standard tube unit available from Allis Chalmers is probably oversized for the site. For purposes of considering the location and costs of possible intake structures, we select an approximate inside diameter from the relationship

$$d \approx .4\sqrt{Q} = 2.12'$$

Using $d = 30$ inches permits selecting a readily available standard steel pipe size as well as providing some flexibility for modelling alternative operating procedures. (We

note once again, however, that constraints aside from any question of technical feasibility could well rule out anything but run of the river operation).

6. ALTERNATIVE INTAKE WORKS

6.1 Project Purposes. Because the normal flow is relatively low (therefore not likely to generate very large benefits to offset power development costs) and because it is unwise to disturb the integrity of an earth fill dam,* one is immediately drawn to the existing outlet works as a point at which to attach a penstock or a power house directly. In the absence of any other considerations, such a scheme might well be selected without further ado.

There are other considerations, though, and very important ones at that. The reservoir is, after all, a multi-purpose feature; and the addition of power cannot unduly interfere with the purposes for which public money was originally spent. Thus, we make certain assumptions about various parts of the project:

6.1.1 Recreation. The lake serves a recreational purpose. It is, on the one hand, beautiful and serene; and, on the other, quite convenient to a nearby town. A well marked paved road leads to a visitor parking area, and a number of row boats and canoes are stored on the shore nearby. Withdrawals for power should not be so great as to cause surface fluctuations of more than a few feet, for aesthetic value would be degraded otherwise, and launching and access to boating facilities would become difficult.

6.1.2 Fish and Wildlife. The lake apparently supports a good fish population. Indeed, a number of young boys were seen fishing from the banks while we were at the site. Whereas the gate at the drain inlet near the upstream toe might well figure in a power generation scheme, it is entirely possible that such use could attract fish into the turbines or otherwise disturb the habitat near the lake bottom. In addition to maintaining a fishery above the dam, it is likely that the reservoir provides a means for downstream flow augmentation for fish and wildlife support during dry periods.

6.1.3 Flood Control. The reservoir provides a means to trap flood flows and discharge them at a rate which can be absorbed downstream. This purpose is normally served well by the drop inlet. In case of extreme flood conditions, however, the emergency spillway functions and discharge is no longer controlled. Any modifications for power development should not

*There is always a danger, for example, that seepage will occur after impervious materials have been disturbed.

interfere with flood control purposes. In particular, any scheme which significantly increased the frequency of use of the emergency spillway is probably unacceptable.

6.2 Drain Works as a Supply Structure. Figure 1 is a simplified sketch provided to illustrate the general nature of the service spillway and drain works. Most of the time, the reservoir drain gate will be closed, and the outlet pipe will flow less than full. As the reservoir surface rises, control will shift in three characteristic ways, as illustrated in Figure 2 (reproduced from the U.S. Bureau of Reclamation text, Design of Small Dams). The dashed line indicates that at normal design head the pipe flows about 75% full. The figure clearly illustrates an important caution: there is little increase in discharge capacity beyond designed head when a flood larger than the selected inflow design flood occurs. (The emergency spillway currently provides necessary discharge relief, when service spillway capacity is reached, at a water surface elevation about 40 feet above the downstream end of the outlet pipe).

The drain structure provides a means to augment downstream flow during periods of severe drought, but more importantly, it offers a means for rapid drawdown. This latter function is particularly important for an earth fill dam, for it can save the structure from catastrophic failure in the event that excessive leakage begins to occur. In addition, of course, early warnings of impending flash floods could permit anticipatory relief for flood control purposes. It follows, then, that the existing reservoir inlet cannot simply be pre-empted for power, but rather that at most it could be considered for a dual purpose.

A conceptual scheme for using the drain works as a supply structure is shown in Figure 3. A steel penstock would be installed inside of and concentric with the existing 48" outlet pipe. The upstream end of the proposed penstock joins the 36" drain pipe at the base of the outlet tower, and the drop inlet provides a reduced capacity service spillway. At the downstream end, the penstock penetrates the energy dissipating wall of the impact basin structure and thence leads to a powerhouse located outside the limits of the outlet channel, whenever economical, geological, and other considerations suggest. Some preliminary dimension checks for feasibility:

--Size of opening at trash rack. When a trash rack must be cleaned manually, it is usually prudent to make it sufficiently large to limit velocity through the gross area of the rack to about 2.5 fps. Using 28 cfs for discharge,

$$\text{Desired } A = \frac{28\text{cfs}}{2.5\text{fps}} = 11.2 \text{ ft}^2$$

The actual gross area of the trash rack at the reservoir drain inlet is approximately 48 ft², exceeding the minimum and posing no constraint. Oversizing is an advantage here because of the relative inaccessibility for cleaning.

--Sizing the steel penstocks. As noted in 5.2 above, we assume a steel pipe is required with inside diameter of 30 inches. A number of intermediate piers would be necessary, causing some additional head loss in the service spillway. To ensure that the drawdown capability is not totally destroyed, an outlet gate of some sort would be required so that the drain may be operated even when the power plant is not operating. This latter feature could be provided through a yoke arrangement as shown conceptually in Figure 4.

--Effect on the service spillway. Installing a concentric penstock reduces the actual cross sectional area available for spillway flow by

$$\pi \frac{\left(\frac{32}{12}\right)^2}{4} = 5.6 \text{ ft}^2$$

or about 44%. Recognizing a loss in hydraulic efficiency stemming from an increase in wetted surface, and as a result of flow around intermediate piers, we assume that spillway discharge capacity is reduced by about 50%. Stated another way, the service spillway may be thought of as employing an equivalent conduit of about 2.8 feet in diameter. Based on a pipe length of 190 feet, and a gross head of about 40 feet (when the emergency spillway would just overtop), maximum discharge through the service spillway drops from about 400 second-feet to about 200 second-feet. Assuming a gated outlet is available to permit discharge through the drain works even when the power plant is not operating, another 150 second feet could be accounted for. Thus, the net reduction in maximum discharge capacity from that provided currently by the service spillway would be approximately 50 second feet, or about 12.5%. On the other hand, the reduction from 36 inch diameter to 30 inch diameter for emergency draw-down purposes represents a drop of approximately 35% of existing rapid drawdown discharge.

In addition to reduced discharge capacities, some other disadvantages are associated with this scheme. Vibration and cavitation problems will be exacerbated since on the one hand

the constricted service spillway could be expected to flow in the erratic range more often; and, on the other, the relatively long concentric steel pipe will be supported by intermediate piers which will not totally prevent surge-related vibratory problems. Furthermore, water tight pressure connections at the base of the intake tower in a relatively restricted space would be difficult--and costly--to accomplish. Once the steel pipe is installed, inspection of the reinforced concrete pipe will no longer be possible and subsequent maintenance, if required, will be extremely expensive.

6.3 Diversion for Power Downstream of Existing Outlet Discharge. (Recommended Scheme). Figure 5 and photos 9 and 10 illustrate a conceptual arrangement which extends the existing outlet discharge orifice through the energy dissipating wall of the current impact basin, where a new gate would permit operating the existing service spillway essentially at design capacity when the power plant is not operating. At the same time, diversion for power occurs through a pipe penetrating the side wall of the existing impact basin. This arrangement requires construction of a new impact basin downstream of the existing one.

Under normal operating conditions, the existing upstream drain inlet gate would be opened, the new outlet works gate closed, and discharge would occur through the powerhouse at a rate sufficient to maintain the reservoir level at the crest of the existing drop inlet. When the power house is not operating, the butterfly valve at the turbine is closed, the drain gate is closed, the new outlet gate is opened, and the drop inlet functions as originally designed. For emergency drawdown, the drain gate and the new outlet gate are opened and discharge capacity remains essentially the same as that which currently exists.

In order to dewater intake conduits for inspection and/or repair, it should be possible to draw-down the reservoir a few feet, close the drain gate, and work in the dry until reservoir surface once again reaches the crest of the drop inlet. This technique could also serve during construction. To satisfy fish and wildlife requirements and water rights during such periods, minimum downstream flow would have to be maintained, possibly by way of a temporary siphon system over the crest of the existing dam. This scheme has the advantage of preserving existing discharge capacities both for the service spillway and the reservoir drain works. It also permits all new work to be accomplished outside the confines of the existing dam.

In short, this scheme is best suited to the multi-

purpose system, for it adds to, but does not interfere with, any purpose which the project was originally intended to serve.

Calculations in section 6.2 verifying the adequacy of trash rack area and sizing the penstocks at 30" diameter are applicable to this scheme. For illustrative purposes, our conceptual design penetrates the side wall of the existing outlet works nearest the emergency spillway. Should power house siting considerations suggest that the other side wall is preferred, there is no technical reason such a choice should not be made.

This scheme is recommended, for it is better technically and economically, and it will probably be far less costly from a maintenance point of view.

7. APPROXIMATE COSTS

Cost data shown below do not include contractor mobilization, since such costs would necessarily be included in estimates for powerhouse and other facilities. All information includes contractor overhead and profit and reflects 1978 costs adjusted by Engineering News Record indices for recent Baltimore construction experience.

7.1	<u>Damage repair</u>	<u>Unit</u>	<u>Quantity</u>	<u>Cost</u>
(1)	Excavation and backfill	LS	-	\$ 200
(2)	Replace perforated pipe	LF	30	300
	Total Repairs:			\$ 500

7.2 Alternative 1, Concentric pipes

(1)	Temporary diversion	LS	-	2,000
(2)	Steel pipe in place	M	59	55,350
(3)	Reducer and connections	LS	-	500
(4)	Intermediate piers	EA	18	1,800
(5)	Yoke fabrication	LS	-	4,000
(6)	Gate	LS	-	2,000
(7)	Concrete removal	CY	1	500

Sub-total construction	66,150
Repairs	500
Contingencies	13,330
	<u>79,980</u>
Engineering and design	<u>12,000</u>
Total Alternative 1	\$91,980

7.3 Alternative 2

	<u>Unit</u>	<u>Quantity</u>	<u>Cost</u>
7.3.1 <u>New outlet works</u>			
(1) Temporary diversion	LS	-	\$ 2,000
(2) Reinforced concrete pipe 48" I.D.	LF	5	550
(3) Steel pipe	M	5	1,800
(4) Connections, elbows	LS		330
(5) Concrete removal	CY	1	500
(6) Concrete cast in place	CY	19	1,900
(7) Gate	LS		2,000
7.3.2 <u>New impact basin</u>			
(1) Reinforced concrete	CY	11	4,400
(2) Rip-rap	CY	5	100
Sub-total construction			13,580
Repairs			500
Contingencies			2,816
			<u>16,896</u>
Engineering and design			2,500
Total Alternative 2			<u>\$19,396</u>

LOCATION MAP

ACRES

FIGURES

Figure 1. Sketch of service spillway and drain works.

CONDITION 1. CREST CONTROL

CONDITION 2. TUBE OR ORIFICE CONTROL

CONDITION 3. FULL PIPE FLOW

Nature of flow and discharge characteristics of a morning glory spillway.

FIGURE 2:
(REPRODUCED FROM DOI TEXT,
DESIGN OF SMALL DAMS)

Figure 3. Using reservoir drain works as a supply feature, a concentric steel pipe diverts water for power. Service spillway continues to function, but with reduced capacity.

Figure 5. Preferred alternative for power diversion

PHOTOGRAPHS

Photo 1 - Upstream face of dam is rip-rapped to an elevation approximately equal to that of spillway crest.

Photo 2 - Downstream slope of dam illustrating excellent vegetative cover as well as impact basin wing wall.

Photo 3 - Drop inlet structure

Photo 4 - 48-inch diameter reinforced concrete pipe outlet. (See also photo 10 for superimposed diversion scheme.)

Photo 5 - A view of the existing impact basin.
(See also photo 9 for a superimposed
sketch of proposed power diversion
scheme.)

Photo 6 - Outlet channel immediately downstream
of outlet works.

Photo 7 - Concrete platform and gate control mechanism for reservoir drain.

Photo 8 - Toe drain outlet is provided on either wing wall just downstream of energy dissipating wall.

Photo 9 - Illustrates the proposed power diversion scheme.

Photo 10 - Another sketch of proposed power diversion scheme.

REPORT TO

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY

FINAL DRAFT

LAKE WILLIAMS DAM

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DISCLAIMER

This is one of three reports prepared by Acres American Incorporated on behalf of the Johns Hopkins Applied Physics Laboratory. Under terms of this agreement, AAI was to furnish site visits, consultations, estimates of required repairs, a conceptual design for intake works, and associated costs at each site.

The level of effort for the total work, including consideration of three dams and consultation, is 10 man days.

The information contained herein is based on visual inspection only. No representation is made as to the safety of various structures visited, for a much greater level of effort would be required for such purpose. Conceptual designs, where provided, are feasibility level only, and significantly more effort would be required to accomplish engineering and design for the purpose of preparing plans and specifications.

Mention of a specific manufacturer is made only for illustrative purposes and does not constitute an endorsement of particular firms or products.

Additional efforts normally associated with feasibility studies (including concepts for extending penstocks, designing power houses and electric distribution facilities, studying environmental concerns, and the like) are to be accomplished by others and are generally outside the purview of AAI responsibility on this contract.

LAKE WILLIAMS DAM

1. INTRODUCTION

This report has been prepared for the Johns Hopkins University Applied Physics Laboratory. It describes the results of a brief site visit on 8 August 1978 to a dam on Lake Williams in the vicinity of York, Pennsylvania. This dam and the system in which it is included are owned and operated by the York Water Company. Conclusions and initial cost estimates for diverting water for power are provided for the purpose of considering the feasibility of installing a small hydroelectric plant at the site.

2. PHYSICAL DESCRIPTION

2.1 Dimensions and details. Complete physical details are set forth in a Phase I report prepared under provisions of the National Dam Safety Program; a copy of pertinent provisions is at Enclosure 1. A series of photos is appended as well to illustrate various features.

2.2 Observations on project operation. Lake Williams is the lower dam in a two-dam system whose single purpose is water supply. About four miles downstream of the Lake Williams Dam is a raw water intake and a large pumping station. The pumping station employs two 1000 HP pumps and a 750 HP pump, though normal operational procedures require that only one pump run during the day and two at night. (The heavier pumping load at night permits the economy of lower cost off-peak power.) The back-up system to be employed in the event of electric power loss consists of old, but apparently well maintained, Worthington steam powered pumps, originally installed in the early part of the century. Operators at the pumping station state that about 150 gallons of residual oil is burned daily to keep these pumps in operating condition and to maintain enough heat to be able to put them on line with about four hours' notice. More than 2000 gpd are required when standby system is actually used. (Since the pumping station is owned and operated by the York Water Company, it would seem that at least a portion (perhaps 10% or so) of the electric energy consumed in pumping might reasonably be provided by a hydroelectric plant at the dam, if such a plant is shown to be feasible. In addition, it would appear that a back-up generator - possibly diesel powered - might be a viable and economical alternative to the current fuel consumptive standby system).

Under normal conditions, water spills from the upper dam on Lake Redman into Lake Williams, and the bascule gates there

are set to spill in accordance with water supply demands. Spilled water flows downstream to the pumping station which receives water as well from another stream which joins the first between dam and pumping station. A drain structure on Lake Redman (the upper reservoir) permits draw-down into Lake Williams, though this drain is not normally operated. During dry periods, it is sometimes necessary to draw-down Lake Williams to ensure sufficient water is available downstream for pumping. The bascule gates normally provide sufficient control for this purpose. In extreme drought conditions, two gates downstream of the Lake Williams Dam can be opened and additional draw-down can be accomplished through a 48" drain pipe as necessary for water supply purposes. Finally, the Lake Williams outlet works can be operated if drought persists. In addition to providing minimum flow during severe conditions, drain works at each of the dams provide some emergency draw-down capability.

2.3 Discharge Information. An approximate value for average discharge at Lake Williams is 66.6 cfs (determined from the relationship, $Q = 1.6 \times \text{drainage area in square miles}$). If a power plant were installed at the site, it could be expected to function part of the time as a run of the river project and plant capacity can be determined from this average discharge value. (See paragraph 5 below.) Unlike normal run of the river hydroelectric projects, however, this one could conceivably have a firm power benefit assigned based on minimum discharges in excess of the minima produced naturally at the site. This observation derives from the water supply operational procedures as described in preceding paragraphs. By the same token, natural discharges in excess of the minimum required for water supply purposes will be allowed to pass through a hydro plant at Lake Williams only after the reservoir level has risen sufficiently to satisfy projected water demands. In short, any proposed power plant may be expected to operate for considerable periods at average daily flows of 30 to 55 cfs (determined from owner representative's observations on site that normal release at Lake Williams varies from 20 to 37 mgd for water supply purposes).

Acting to the disadvantage of power benefits, the operational procedures are such that maximum daily discharges occur during times of off-peak power demands. Thus, firm energy probably cannot exceed that based on a discharge of 20 cfs (determined on the assumption that one pump operates at the pumping station all of the time, and an additional pump half of the time. Twenty (20) cfs during the day and 40 cfs at night together equate to the average minimum daily discharge of 30 cfs). Whenever the lower reservoir surface is at a level sufficient to meet projected water supply demands, discharge for power production can occur at a rate approximately equal to that for inflow at the upper reservoir.

It is clear, though, that the water supply purpose cannot be compromised. It follows that installation of hydroelectric power at either or both dams must not interfere with this prime function.

3. CONDITION

The condition of the dam is described well in Enclosure 1.

4. RECOMMENDED REPAIRS

Recommended repairs are detailed in Enclosure 1. It must be noted, though, that these repairs are important and necessary regardless of whether power is added as a project purpose. Thus, the cost of undertaking repair work should not reasonably be included in an analysis of the marginal value of a possible hydroelectric plant.

5. HYDROPOWER POTENTIAL

5.1 Probable Output. A number of formulations are available for estimating output at a given site. All of these derive from the fact that water has potential energy directly related to the distance through which it will be moved. In general,

$$P = \frac{QH\delta\eta}{738}$$

where:

P = power in kilowatts
Q = discharge in cfs
H = net head in feet
 δ = density = 62.4 pcf
 η = efficiency. Assume η = .75 for low-head plants

Thus,

$$P = \frac{(66.6)(41)(62.4)(.75)}{738} = 173 \text{ kw}$$

(Note that a value of 41 feet for net head is based on the difference between spillway crest and the downstream portal invert of the outlet works.)

For a guaranteed minimum flow of 20 cfs (for water supply purposes), firm energy would be available in the amount of about .45 million kw/hrs annually.

5.2 Including Lake Redman's Contribution. In the event that the cost of tapping the Lake Redman drain works and of laying about two miles of pipe can be economically justified,

the head at a power house below Lake Williams could be increased by about 36 feet. (Available data shows minimum spillway crest elevation at Lake Redman of 486.3, invert at Lake Williams drain outlet at 408.9, and the Lake Williams spillway crest (gated) at 450.) On that basis, capacity determined from average discharge could be increased to about 325 kw, and firm energy to about .85 million kw/hrs annually.

6. ALTERNATIVE INTAKE WORKS

In the event that only the Lake Williams dam and reservoir is to contribute to power production, the existing double-gated drain outlet can be used to advantage as discussed below. Even if a pipeline is laid from the Lake Redman Dam, the requirement for first satisfying water supply demands will continue to prevail and account must be taken of the fact that periods may occur during which no release is permitted from Lake Redman. A number of alternatives can thus be considered:

6.1 Lake Williams contributes alone. Figure 1 illustrates a relatively simple arrangement for diverting water for power, taking maximum advantage of existing facilities. Normal operational procedures would be such that the upstream gate is opened enough to allow maximum flow consistent with water supply needs, the downstream gate closed, and the turbine operating. No spill would occur except during flood conditions. When the plant must be shut down, control of the water supply function would revert to the bascule gates at the spillway. For emergency draw down, the butterfly valve at the powerhouse would be closed and both drain gates opened. No change would occur in existing procedures for operating the Lake Redman Dam.

6.2 Pipeline from Lake Redman Dam to a powerhouse downstream of Lake Williams Dam. In this case, a reinforced concrete pipe is connected at the existing Lake Redman outlet works and laid along the Lake Williams shoreline for a distance of nearly two miles. Just below the Lake Williams dam, a powerhouse would be installed. It would simply make no sense to provide such a power house solely for the Lake Redman discharge, for there would then be no firm energy (since periods occur during which no water is released from this upper reservoir). Beyond that, energy contained in waters discharged as Lake Williams is drawn down would be lost. It follows, then, that installed equipment should be capable of operating reasonably efficiently over a range of heads and discharges. When conditions permit, all discharge will be through the pipeline and the only water released downstream will have come from Lake Redman. But even when only Lake Williams contributes to discharge for water supply purposes, power would still be produced. Figure 2 is a sketch of an arrangement for using discharges from either reservoir for power purposes. The

existing drain gate upstream of the Redman Dam controls flow in the new pipeline and the existing dual portals below the Williams Dam control as in Alternative 1. In the event that emergency draw down of Lake Redman is required, the Redman drain gate is opened, butterfly valve at the plant closed, upstream Williams portal closed, and downstream portal opened. Conceptually, the arrangement is a relatively simple one, and no new gates would be required. Even so, the cost of about 10,000 feet of pipeline is sufficiently great to rule out this approach unless major increases in alternative power generation costs occur. (Note that the intake system alone would cost nearly \$1000 per kw even if the installed capacity were twice that determined for average discharge.) A sub-option might involve the construction of an open headrace canal in lieu of the pressurized pipe system, with a forebay above the Lake Williams Dam and a steel penstock running down the downstream face, but such a system would be costly as well and could not be economically justified.

7. APPROXIMATE COSTS

Cost data shown below do not include contractor mobilization since such costs would necessarily be included in estimates for powerhouse and other facilities. All information includes contractor overhead and profit and reflects 1978 costs adjusted by Engineering News Record indices for recent Baltimore construction experience.

7.1 Alternative 1, Lake Williams contributes alone. (Recommended)

	<u>Unit</u>	<u>Quantity</u>	<u>Cost</u>
(1) Excavate and remove existing pipe between portals	LS	-	500
(2) Reinforced concrete pipe in place 48" ID	LF	12	1,320
(3) Reinforced concrete pipe in place 42" ID	LF	24*	1,200
(4) Fabricate T section	LS	-	500
(5) Elbow and connections	LS	-	330
	Sub-total		\$3,850
	Contingencies		770
			<u>\$4,620</u>
	Engineering and Design		500
	Total Alternative 1		<u>\$5,120</u>

*Assumes quantity purchase is made for tailrace conduit from power house.

7.2 Alternative 2, Contribution from both reservoirs.

	<u>Unit</u>	<u>Quantity</u>	<u>Cost</u>
(1) Connection at outlet works, Lake Redman	LS	-	500
(2) Reinforced concrete pipe in place, 42" I.D.	LF	10,000	480,000
(3) Fabricate yoke section	LS	-	2,000
(4) Alternative 1 diversion for power	LS	-	<u>3,850</u>
	Sub-total		\$486,350
	Contingencies		<u>97,270</u>
			\$583,620
	Engineering and Design		<u>58,000</u>
	Total Alternative 2		\$641,620

LOCATION MAP

**LAKE WILLIAMS
DAM SITE**

ACRES

FIGURES

Figure 1. Concept for diverting water for power (Alternative 1).

Figure 2. Concept for using discharge from both reservoirs

PHOTOGRAPHS

Photo 1. Upstream face of Lake Williams Dam. Rectangular opening at left is a part of the bascule gated spillway.

Photo 2. A view of the upstream face above the point at which reservoir drain inlet lies. Since drain gates lie beyond the downstream toe of the dam, the drain conduit is under pressure at all times.

Photo 3. Illustrating the roadway atop the dam.

Photo 4. A view of gated spillway crest from upstream.

Photo 5. A view of bascule gates from downstream.

Photo 6. Spillway as seen from atop roadway.

Photo 7. East Branch Codorus Creek immediately below spillway.

Photo 8. Spillway as seen from downstream toe.

Photo 9. Wing wall at spillway steps.

Photo 10. Abandoned spillway which served original dam prior to raising.

Photo 11. Deteriorated condition of original spillway. This does not represent a hazard since the original spillway is no longer used. Nonetheless, this and photo 12 suggest that the condition of the original concrete core of the dam should be checked for condition.

Photo 12. Deteriorating wing wall of original spillway.

Photo 13. Twin gate houses which control reservoir drain works. Water would be diverted for power between these houses.

Photo 14. Existing 48" outlet pipe downstream of gate houses.

Photo 15. Tower for gates and controls for Lake Redman drain works.

Photo 16. Flap gate and outlet works for Lake Redman. Under Alternative 2, a pressure conduit would carry water from this point to a powerhouse below Lake Williams Dam.

Appendix D

CAPACITY FACTOR

The actual production of electrical energy can be determined from the installed capacity once the capacity factor is known. The capacity factor assumed throughout this study is determined by stream flow characteristics at the site of the dam and the efficiency curve of the turbine-generator set. Loss of energy production due to equipment failure or lack of operating personnel is assumed to be zero for modeling purposes.

The key data inputs for determination of the capacity factor as a function of installed capacity are the stream flow duration curve and the turbine-generator efficiency curves. The flow duration curve "indicates the percentage of time during the period under consideration that the flow was equal to or greater than the given discharge" (Ref. 2). Figure D1 is the stream flow duration curve for Deer Creek at Rocks, Md. (Lat. 39°37'49", Long. 76°24'13") (Ref. 2). The stream flow data used to derive this curve were measured from 1 Oct 1926 to 30 Sep 1967. The curve is plotted on semi-log paper because the stream flow varies by two orders of magnitude. The drainage area for this gauge (USGS gauge No. 1-5800) is 94.4 mi². The average discharge during the 41 years of record is 118 ft³/s.

To illustrate how a flow duration curve can be converted to a power potential duration curve, Broad Creek Dam (see Appendix A) will be examined. The closest long-term gauging station to Broad Creek Dam is gauge 1-5800 at Deer Creek. Thus the flow duration curve for Broad Creek Dam is based on the duration curve for Deer Creek adjusted for the drainage area of Broad Creek Dam (30 mi²).

The power potential duration curve is derived from the flow duration curve, as illustrated in the following equation:

$$P_{\text{Broad Creek}} = \frac{\eta}{11.8} \times H_{\text{Broad Creek}} \times \frac{30 \text{ mi}^2}{94.4 \text{ mi}^2} \times Q_{\text{Deer Creek}},$$

(D1)

Fig. D1 Flow duration curve for Deer Creek at Rocks, Md. (USGS gauge No. 1-5800). Expected power at Broad Creek Dam is $(30 \div 94.4) \times 25 \times \text{flow} \times 0.75/11.8$ (kW).

where

$$H_{\text{Broad Creek}} = 25 \text{ ft} ,$$

$$Q_{\text{Deer Creek}} = \text{is given in Fig. D1, and}$$

$$\eta = 0.75.$$

$P_{\text{Broad Creek}}$, or the power potential duration curve for Broad Creek, is given in Fig. D2. To illustrate how this curve can be used in a simple approach to derive a capacity factor, assume the installed capacity is 62 kW. From Fig. D2 we determine that 62 kW or more power will be available at Broad Creek Dam 30% of the time. If the installed turbine-generator is operated only when the power available from the stream is 62 kW or more (stream flow equal to or greater than $38.8 \text{ ft}^3/\text{s}$), the capacity factor would be 30%. However, this approach would be very inefficient in utilizing the stream's energy. Turbines can be operated below their designed capacity. For example, if the turbine-generator were 75% efficient for all values of flow less than or equal to $38.8 \text{ ft}^3/\text{s}$, the capacity factor could be determined by integrating the area under the curve in Fig. D2 from 30 to 100%. The capacity factor would thus be

$$CF(62) = \left(30 \times 62 + \int_{30}^{100} P dPER \right) \div 62 \times 100 , \quad (D2)$$

where

P is the potential power as a function of the duration, and

PER is the percentage of time that the potential power, P , occurs.

However, the efficiency of a turbine varies as a function of the flow through it. Thus the power potential duration curve must be multiplied by the turbine efficiency curve versus turbine flow. Another way of saying this is to use an equation such as Eq. D2 and let $\eta(Q)$ be the turbine-generator efficiency expected for the associated level of flow, Q , through the turbine. Letting $PDC(P_{\text{inst}})$ be the percentage of time the power duration curve equals or exceeds the installed capacity, (P_{inst}), the capacity factor for the installed capacity is

Fig. D2 The power potential duration curve for Broad Creek Dam, Md.

$$CF(P_{inst}) = \frac{100}{PDC(P_{inst})} \left[P_{inst} \times PDC(P_{inst}) + \int \frac{\eta(Q(PER))}{11.8} \times H \times Q(PER) d PER \right] \div P_{inst} \times 100 . \quad (D3)$$

An example of the turbine-generator efficiency versus fraction of design turbine flow is given in Fig. D3. A computer program was written that takes this efficiency and the flow duration curve and determines the capacity factor as given in Eq. D3. (The computer program and an example of its output are at the end of this appendix.) Figure D4 is the projected annual capacity factor for Broad Creek Dam using the flow duration curve of Deer Creek (Fig. D1) multiplied by $30 \div 94.4$ and the turbine efficiency curve given in Fig. D3.

Capacity Factor Reduction by High Stream Flow

The capacity factor for a small-scale facility can be reduced by high stream flow conditions because the tailwater rises as the stream flow increases. For example, at Dam No. 4 on the Potomac River, a 1 ft increase in depth of water going over the top of the dam results in approximately a 2 ft increase in the height of the tailwater or a net reduction in head of 1 ft. A plot of the power output from one of the electrical generators at Dam No. 4 as a function of water flow over the dam is shown in Fig. D5. The present capacity factor for Dam No. 4 is about 80%. The stream flow duration curve for the Potomac River at Hancock, Md. (Ref. 2) shows that water flows equal to or greater than $22,000 \text{ ft}^3/\text{s}$ occur only 2% of the time. Thus, one expects that the 20% loss in capacity at Dam No. 4 is mostly (probably 90%) due to low water flow, not high water flow. The lower the hydraulic head, the more significant this phenomenon of high tailwater is, however. To evaluate the phenomenon, one must know the topography of the stream bed basin below the dam. If the stream bed basin is fairly flat and causes extensive flooding over a broad area, the rise in tailwater may be relatively small. However, if the stream bed basin is narrow, the tailwater may rise rapidly with increasing stream flow. Thus, to properly size turbines for maximum energy output, the head duration curve as well as the stream flow duration curve should be known (Ref. 14).

Fig. D3 Turbine efficiency versus fraction of turbine design flow for Francis turbine.

Fig. D4 The capacity factor for Broad Creek Dam as a Function of installed capacity assuming the turbine efficiency versus fraction of turbine design flow was as shown in Fig. D3.

Fig. D5 Power output for one generator turbine at Dam No. 4 on the Potomac River versus excess river flow (Potomac Edison Co.).

PROGRAM FOR CALCULATING CAPACITY FACTOR VERSUS
INSTALLED CAPACITY AND STREAM-FLOW DURATION CURVES

```

      VCAPFACTOR: [ ] V
      V CAPFACTOR
1  POW←0.0634×HEAD×FLOW
2  POWM←QPOW*.*((13)-1)
3  BETAPER←([POWM+.×QPOWM)+.×POWM)+.×QPER
4  'HEAD,PINST,DPOW,KO,ρFLOW'
5  HEAD,PINST,DPOW,KO,ρFLOW
6  K←1
7  'PINST AND CAPACITY FACTOR'
8  PINST←PINSTO
9  LOOP1:→(KO←K+1)/OP1
10 PINST←PINST/DPOW
11 PER1←PINST/φBETAPER
12 NM←+/ (PER1←PER)
13 SN←(ρPER)-NM+2
14 SN←1[SN
15 FITPER←PER[SN,PER[SN+1,PER[SN+2,PER[SN+3]
16 FITFLOW←FLOW[SN,FLOW[SN+1,FLOW[SN+2,FLOW[SN+3]
17 FITPOW←0.0634×HEAD×FITFLOW
18 FITPOWM←QFITPOW*.*((13)-1)
19 BETAFITPER←((FITPOWM+.×QFITPOWM)+.×FITPOWM)+.×QFITPER
20 PER2←PINST/φBETAFITPER
21 NN←+/ (PER2←PER)
22 LPER←(ρPER)-NN, PER
23 LFLOW←(ρPER)-NN, FLOW
24 LDPER←0.5×(1←LPER)-((NN-1)←LPER)
25 DINT←(ρLFLOW)ρ0
26 I←1
27 LOOP:→((NN-1)←I+1)/OP
28 DINT[I]←LDPER[I-1]+LDPER[I]
29 →LOOP
30 OP:DINT[1]←PER(1+ρPER)-NN-PER2
31 DINT[1]←DINT[1]+LDPER[1]
32 DINT[NN]←LDPER[NN-1]+100-LPER[NN]
33 PARTI1←PINST×PER2
34 FLOW1←PINST÷HEAD×0.0634
35 FF←LFLOW÷FLOW1
36 EFF1←(0.5←FF)×0.75
37 EFF2←(0.5≥FF)×FF×1.5
38 EFF←EFF1,EFF2
39 LPOW←HEAD×LFLOW×EFF÷11.8
40 PARTI2←+/LPOW×DINT
41 INTEGRAL←PARTI1+PARTI2
42 CAPFAC←INTEGRAL÷(PINST×100)
43 PINST,CAPFAC
44 →LOOP1
45 OP1:'EFFICIENCY FOR A FRANCIS TURBINE'

```

V

SAMPLE OUTPUT FROM PROGRAM

PERCENT OF TIME FLOW

PER, 1.5 FLOW

0.67	96
1	80
2	64
2.6	58
4	51
5	45
7.3	38
12.7	32
24.3	26
39.7	19.4
54	16.2
72.3	13
99	9.9
100	8.3

CAPFACTOR

HEAD, PINSTO, DPOW, KO, ρ FLOW

25 10 10 14 14

PINST AND CAPACITY FACTOR

20	0.9479703292
30	0.8303731572
40	0.6840252946
50	0.5688035572
60	0.4740127527
70	0.3899340733
80	0.3312226506
90	0.2805955618
100	0.2418804894
110	0.2084647123
120	0.1813557325
130	0.1593752054
140	0.1408798409

EFFICIENCY FOR A FRANCIS TURBINE

INSTALLED CAPACITY
CAPACITY FACTOR

Appendix E

SUPPLY CURVE COMPUTER MODEL

The supply curve computer model computes for each dam the capital cost versus installed capacity. This capital cost includes the expected cost of the powerhouse and equipment, cost of the water intake structure, canal cost, average cost of dam repairs, powerlines, and roads. Next the model calculates the total annual costs from the capital costs and the expected O & M costs. Then the program calculates the average and marginal costs for each site and picks the estimated capacity, energy, and total cost associated with the required prices of electricity. Several checks or tests within the program are used to determine problems in these previous steps. Finally the capacity, energy, and total capital cost as a function of price of electricity to the developer are summed over all dams and listed in the output.

Appendix E

SUPPLY CURVE COMPUTER MODEL

```

V SUPCUR[ ] V
V SUPCUR
[1]  NORMALIZATIONS
[2]  HEAD+ ,HEAD
[3]  AREA+ ,AREA
[4]  N+ ,HEAD
[5]  BEPRICE+ BECAP+ BEENER+ Np0
[6]  SCAP+ SEN+ STCC+ ( ,PRICE) p0
[7]  CFN+ EGY+ (NUMP) p0
[8]  I+0
[9]  PROCESS EACH DAM
[10] 'I, HEIGHT, DRAINAGE AREA'
[11] 'BREAKEVEN PRICE, CAPACITY, AND ENERGY'
[12] LOOP1:-(N < I+1)/OP1
[13] I, HEAD[I], AREA[I]
[14] CAPAC+ ENER+ TOTCC+ ( ,PRICE) p0
[15] CAP+ POWER+ (HEAD[I])*(AREA[I])* 0.02 0.05 0.1 0.16
[16] X+ (HEAD[I])*(AREA[I])* POWN+100
[17] Y+ CFLM
[18] XM+ QX* .*(( ,ORD1+1)-1)
[19] BETA+ (( ,XM+ .* QXM)+ .* XM)+ .* QY
[20] BETA+ BETA+ FACTOR
[21] CALCULATE TOTAL CAPITAL COSTS
[22] FLOW+ POWER+ (0.0634*HEAD[I])
[23] PDRPM+ (0.001869)*(POWER*1.5)+(HEAD[I]*0.75)
[24] PROD+ 1.515*(1+0.4323*((-0.03586)*(PDRPM*0.5433)))
[25] PHEC1+ PROD*4070*POWER+HEAD[I]*0.948
[26] PHEC2+ PROD*21700*POWER+HEAD[I]*1.27
[27] PHEC3+ PROD*80000*(POWER*0.6)+HEAD[I]*0.68
[28] PHEC4+ PROD*2860*(POWER*1.02)+HEAD[I]*0.51
[29] PHEC5+ PROD*13600*(POWER*0.7)+HEAD[I]*0.35
[30] PHEC6+ 22500*(POWER*0.808)+HEAD[I]*0.424
[31] AVER+ (PHEC1+PHEC2+PHEC3+PHEC4+PHEC5+PHEC6)+6
[32] CWI+ 68.4*FLOW
[33] CANC+ 720*FLOW*0.376
[34] RECC+ 2.5*POWER
[35] SCC+ AVER+ CWI+ CANC+ RECC+ 29700
[36] TCC+ LICCOST+ 1.25*SCC
[37] LANDCOST+ 0.04*TCC
[38] TCC+ TCC+ LANDCOST
[39] INTCON1+ (LICCOST+ 0.15*(TCC- LICCOST))*(1+ STINT)*2.5
[40] INTCON2+ ((1+ STINT)*1.5)+(1+ STINT)*0.5
[41] INTCON+ INTCON1+ (-TCC)+(0.85*(TCC- LICCOST)*INTCON2+2)
[42] FTCC+ TCC+ INTCON
[43] CALCULATE TOTAL ANNUAL COSTS
[44] APCR+ COC+ DEP+ ITAX+ OTAX+ INS
[45] ACC+ FTCC+ APCR
[46] RATE+ 0.2015*CAP* (-0.472)
[47] +(RATE[1])<0.008/GO1
[48] RATE+ 0.008
[49] GO1: AOMA+ CAP* CFX* 8760* RATE
[50] MAXOM+ [ /AOMA
[51] +(MAXOM= AOMA[4])/JUMP1
[52] K+ +/(MAXOM= AOMA)*14
[53] LOOP4:-(K < 4)/JUMP1
[54] AOMA[K]+ MAXOM
[55] K+ K+1
[56] LOOP4

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      VSUPCUR[57]V
[57] JUMP1:TAC+ACC+AOMA
[58] *CALCULATE MARGINAL COST
[59] CAP+CAP*100
[60] CAPM+QCAP*.*((1ORD2+1)-1)
[61] BETATAC+((QCAPM+. *QCAPM)+. *CAPM)+. *QTAC
[62] BETATAC+BETATAC*FACTOR
[63] BETATCC+((QCAPM+. *QCAPM)+. *CAPM)+. *QTCC
[64] BETATCC+BETATCC*FACTOR
[65] CAP+CAP*100
[66] CAPN+((-1+CAP)*(1+NUMP)*1NUMP
[67] TACN+BETATAC+. *QCAPN*.*((1ORD2+1)-1)
[68] TCCN+BETATCC+. *QCAPN*.*((1ORD2+1)-1)
[69] CFN+BETA+. *QCAPN*.*((1PBETA)-1)
[70] EGY+CAPN*CFN*8760
[71] AVERC+TACN+EGY
[72] DTAC+(1 *TACN)-((-1 *TACN)
[73] DEGY+(1 *EGY)-((-1 *EGY)
[74] MARCOST+DTAC+DEGY
[75] MARCOST+0.01,MARCOST
[76] *TEST FOR NEGATIVE MARCOST
[77] NO+/(0>MARCOST)
[78] +(NO=0)/GO2
[79] VLO+,(0>MARCOST)/1NUMP
[80] NO+VLO[1]
[81] MARCOST+(NO-1)+MARCOST
[82] 'NEGATIVE MARCOST'
[83] I
[84] GO2:MAXMCOST+I/MARCOST
[85] *TEST FOR MAXIMUM MARCOST
[86] +(MAXMCOST>MARCOST[ NUMP-NO ])/GO3
[87] 'THE LAST MARCOST IS NOT THE MAXIMUM'
[88] 'THE DAM WITH THIS PROBLEM IS NUMBER'
[89] I
[90] GO3:NP+/(MARCOST[ NUMP-NO ]>PRICE)
[91] NBEP+1+(/0>(1 *AVERC)-((-1 *AVERC))
[92] AVERC[NBEP],CAPN[NBEP],EGY[NBEP]
[93] BEPRICE[I]+AVERC[NBEP]
[94] BECAP[I]+CAPN[NBEP]
[95] BEENER[I]+EGY[NBEP]
[96] J+1+/(MARCOST[NBEP]>PRICE
[97] LOOP3:((PRICE) <J)/LOOP1
[98] NPM+/(PRICE[J]>MARCOST
[99] CAPAC[J]+CAPN[NPM]
[100] ENER[J]+EGY[NPM]
[101] TOTCC[J]+TCCN[NPM]
[102] ERRMPA+MARCOST[NPM]-PRICE[J]
[103] +(NPM=NUMP)/GO6
[104] ERRMPB+MARCOST[NPM+1]-PRICE[J]
[105] +((ERRMPA*2) <ERRMPB*2))/GO4
[106] CAPAC[J]+CAPN[NPM+1]
[107] ENER[J]+EGY[NPM+1]
[108] TOTCC[J]+TCCN[NPM+1]
[109] *SUPPLY CURVE GENERATION
[110] GO4:SCAP[J]+SCAP[J]+CAPAC[J]
[111] SEN[J]+SEN[J]+ENER[J]
[112] STCC[J]+STCC[J]+TOTCC[J]
[113] J+J+1

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      VSUPCUR([114])  
[114]  +LOOP3  
[115]  GO6: 'THE LAST MARCOST IS LESS THAN THE MAXIMUM PRICE'  
[116]  I  
[117]  K+NP  
[118]  LOOP2: +((pPRICE) *K+K+1)/LOOP1  
[119]  CAPAC[K]+CAPN[NUMP-NO]  
[120]  ENER[K]+EGY[NUMP-NO]  
[121]  TOTCC[K]+TCCN[NUMP-NO]  
[122]  SCAP[K]+SCAP[K]+CAPAC[K]  
[123]  SEN[K]+SEN[K]+ENER[K]  
[124]  STCC[K]+STCC[K]+TOTCC[K]  
[125]  +LOOP2  
[126]  OP1: 'PRICE,CAPACITY,ENERGY,TOTAL COST, AND COSTPKW'  
[127]  COSTPKW+STCC+SCAP  
[128]  PRICE,SCAP,SEN,STCC,[1.5] COSTPKW  
[129]  'AFCR,NUMP,ORD1,ORD2'  
[130]  AFCR,NUMP,ORD1,ORD2  
[131]  'CFX'  
[132]  CFX  
[133]  'COC,DEP,ITAX,OTAX,INS'  
[134]  COC,DEP,ITAX,OTAX,INS  
[135]  'LICCOST,STINT'  
[136]  LICCOST,STINT
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Appendix F

PENNSYLVANIA STATISTICS ON DAMS (Ref. 1)

Table F1

Pennsylvania dam statistics.

Use	Number	Total Initial Power Estimate* (kW)	Average Power (kW)
00 Desilting	20	2 518	126
01 Public water supply	700	36 853	53
02 Recreation	1 020	86 528	85
03 Industrial water supply	113	10 436	92
04 Electric power	20	489 522	24 476
05 Agricultural	24	148	6
06 Stream gauging	5	201	40
07 Flood control	54	44 325	821
08 Water power	246	12 495	51
09 Abandoned	35	884	25
12 Water supply and recreation	11	3 202	291
17 Water supply and flood control	1	67	67
18 Water supply and water power	1	635	635
23 Recreation and industrial water supply	2	3 908	1 954
24 Recreation and electric power	2	1 800	900
25 Recreation and agricultural	2	1	1
27 Recreation and flood control	21	45 323	2 158
28 Recreation and water power	6	228	38
37 Industrial water supply and flood control	1	9 583	9 583
44 Miscellaneous	7	58	8
55 Multipurpose	1	46 826	46 826
99 Unknown	31	1 046	34

*Initial power estimate = $0.075 \times (1.6 \times \text{drainage area}) \times \text{height}$

Fig. F 1 Pennsylvania dam statistics. Number of dams versus the range of initial estimate of capacity or power potential for existing dams in Pennsylvania (Ref. 1).

Table F 2
Pennsylvania statistics.

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HGT	DRAIN	0-9 KW CNT	CAP	CA/CN	10-49 KW CNT	CAP	CA/CN	50-199 KW CNT	CAP	CA/CN	200-999 KW CNT	CAP	CA/CN	
0-19	0-19	1169	2870	2	152	2537	16	0	0	0	0	0	0	↑ OVER
	20-199	2	14	7	174	5158	29	115	10503	91	3	717	239	
	200-499	0	0	0	0	0	0	16	2271	141	37	11453	309	
	500-	0	0	0	0	0	0	0	0	0	9	4914	546	
20-49	0-19	291	1145	3	135	2997	22	10	669	66	0	0	0	↑ OVER
	20-199	0	0	0	0	0	0	20	2282	114	12	5708	475	
	200-499	0	0	0	0	0	0	0	0	0	1	937	937	
	500-	0	0	0	0	0	0	0	0	0	0	0	0	↓ NOT
50-99	0-19	18	105	5	42	1048	24	29	2790	96	0	0	0	
	20-199	0	0	0	0	0	0	0	0	0	20	8211	410	
	200-499	0	0	0	0	0	0	0	0	0	0	0	0	
	500-	0	0	0	0	0	0	0	0	0	0	0	0	
100-	0-19	3	14	4	2	27	13	4	449	112	5	1557	311	
	20-199	0	0	0	0	0	0	0	0	0	6	2951	491	
	200-499	0	0	0	0	0	0	0	0	0	0	0	0	
	500-	0	0	0	0	0	0	0	0	0	0	0	0	
HGT	DRAIN	1000-4999 KW CNT	CAP	CA/CN	5000-14999 KW CNT	CAP	CA/CN	15000- KW CNT	CAP	CA/CN	TOTAL CNT	CAP	CA/CN	
0-19	0-19	0	0	0	0	0	0	0	0	0	1321	5407	4	↑ OVER
	20-199	0	0	0	0	0	0	0	0	0	294	16392	55	
	200-499	0	0	0	0	0	0	0	0	0	53	13724	258	
	500-	13	32505	2500	3	27848	9282	3	85655	28551	28	150922	5390	
											1696	186445	109	
20-49	0-19	0	0	0	0	0	0	0	0	0	436	4811	11	↑ OVER
	20-199	0	0	0	0	0	0	0	0	0	32	7990	249	
	200-499	2	2819	1409	0	0	0	0	0	0	3	3756	1252	
	500-	3	11513	3837	0	0	0	0	0	0	3	11513	3837	
											474	28070	59	↓ NOT
50-99	0-19	0	0	0	0	0	0	0	0	0	89	3943	44	
	20-199	1	1039	1039	0	0	0	0	0	0	21	9250	440	
	200-499	2	4142	2071	0	0	0	0	0	0	2	4142	2071	
	500-	1	4806	4806	0	0	0	2	408801	204400	3	413607	137869	
											115	430942	3747	
100-	0-19	0	0	0	0	0	0	0	0	0	14	2047	146	
	20-199	6	8485	1414	0	0	0	0	0	0	12	11436	953	
	200-499	4	18282	4570	5	38944	7788	0	0	0	9	57226	6358	
	500-	0	0	0	1	11484	11484	2	69036	34518	3	80520	26840	
											38	151229	3979	

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Table F3

Corps of Engineers navigation dams not in Bulletin 5 (Ref. 1).

Lock and Dam	Drainage/Area (mi ²)	Flow Avg. (cfs)	Upper Pool Elevation (ft)	Head (ft)	Initial* Power Estimate (kW)
<u>Allegheny River</u>					
2	11 636	19 200	721.0	11.0	15 840
3	11 537	19 036	734.5	13.5	19 270
4	11 449	18 890	745.0	10.5	14 880
5	9 351	15 430	756.8	11.8	13 650
6	9 333	15 400	769.0	12.2	14 090
7	8 982	14 820	782.1	13.1	14 560
8	8 844	14 600	800.0	17.9	19 600
9	8 401	13 860	822.0	22.0	22 870
					<u>134 760</u>
<u>Ohio River</u>			664.5		
Montgomery	22 969	37 900	682.0	17.5	49 740
Dashields	19 522	32 200	692.0	10.0	24 150
Emsworth	19 428	32 060	710.0	18.0	43 280
					<u>117 170</u>
<u>Monongahela River</u>					
2	7 341	12 100	718.7	8.7	7 895
3	5 331	8 800	726.9	8.2	5 410
4	5 205	8 590	743.5	16.6	10 690
Maxwell Lock	4 961	8 190	763.0	19.5	11 980
7	4 383	7 230	778.0	15.0	8 134
8	2 715	4 480	797.0	19.0	6 384
					<u>50 493</u>

*Initial power estimate = $0.075 \times \text{flow} \times \text{head}$ (kW)

Table F4

Corps of Engineers flood control dams not in Bulletin 5 (Ref. 1).

Dam	River	Drainage Area (mi ²)	SH (ft)	HH (ft)	Initial Power* Estimate (kW)
Raystown	Raystown Br. Juniata	960	225	185	21 300
Cowanesque	Cowanesque	298	151	45	1 610
Tioga	Tioga	280	140	51	1 710
Hammond	Crooked	122	122	39	570
Woodcock	Woodcock Cr.	45.7	90	44	240
Blue Marsh	Tulpohocken	175	95	53	1 110

*Initial power estimate = $0.075 \times (1.6 \times \text{drainage area}) \times \text{head}$ (kW)

Table F5

Electric power generation dams (steam and/or hydroelectric)
that were not identified as positively hydroelectric.

Dam	River	Drainage Area (mi ²)	Height (ft)	Initial Power* Estimate (kW)
Diversion	Susquehanna	18 300	6	13 180
Electric	Schuylkill	1 765	16	3 390
Black Rock	Schuylkill	1 295.5	12	1 870
Shawvillage	Br. Susquehanna	930	6	670
Rock Hill	Conestog	397	13	620
Keystone	Br. Plum	20.6	100	250
Cabin Hill	Spring	146	8	140

*Initial power estimate = $0.075 \times (1.6 \times \text{drainage area}) \times \text{head}$ (kW).

Table F6

Pennsylvania nonhydroelectric dams with >50 kW potential.

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PAGE 1

RIVER	DAM	T	U	C	LAT	LON	REFERENCE	ACRES	ACRE FT	AVG D	HGT (FT)	DRAIN (MI ²)	CAP-KW*
SUSQUEHA	DOCK STRO3	02	2		40-14.9	76-52.7	070 007 022 007	0	0	0	8	24100.0	23136,000 1
SUSQUEHA	SUNBURY 08	02	2		40-50.8	76-48.6	070 006 055 044	3000	14214	5	8	18300.0	17568,000 2
BR SUSQU	HEPBURN 04	02	1		41-14.0	77-00.3	070 010 041 011	0	0	0	13	5682.0	8863,920 3 3
BR SUSQU	UNNAMED 04	02	1		41-08.3	77-26.1	070 009 018 019	0	0	0	11	3350.0	4422,000 4
BEAVER	TOWNSEND06	01	1		40-44.0	80-19.0	080 020 004 001	0	0	0	11	3030.0	3999,600 5 1
BEAVER	HARTMAN 03	01	1		40-45.7	80-19.0	080 020 004 003	0	0	0	16	3025.0	5808,000 6 2
6 63797,520 10633													
BEAVER	UNNAMED 07	01	2		40-56.2	80-22.2	080 020 037 051	0	0	0	9	2189.5	2364,660 1 3
ALLEGHEN	KINZUA 13	55	1		41-50.4	79-00.2	080 016 061 029	12500	1135900	91	179	2180.0	46826,400 2
SCHUYLKI	FARIMONT03	12	1		39-58.0	75-11.2	090 003 051 002	427	3684	9	13	1893.0	2953,080 3
SCHUYLKI	FLAT RUC04	32	1		40-02.3	75-14.8	090 003 051 001	105	789	8	17	1809.0	3690,360 4
SCHUYLKI	PLYMOUTH04	03	2		40-04.6	75-19.0	090 003 046 030	173	1308	8	8	1774.0	1703,040 5
SCHUYLKI	VINCENT 04	02	2		40-12.3	75-32.4	090 003 015 023	36	83	2	7	1450.0	1218,000 6 1
LEHIGH	EASTON 04	02	1		40-41.3	75-12.4	090 002 048 012	0	0	0	30	1373.0	4942,800 7 4
CONEMAUG	CONEMAUG03	07	1		40-28.3	79-24.8	080 018 065 129	300	280392	935	137	1351.0	22210,440 8
GALLAGHE	FAHM 05	02	1		41-25.2	78-43.3	080 017 024 020	2	0	0	16	1250.0	2400,000 9 2
LEHIGH	NO 7 04	02	1		40-36.5	75-27.2	090 002 039 009	0	0	0	13	1129.0	1761,240 10
10 90070,020 9007													
CONEWANG	REED 03	02	2		41-50.7	79-08.5	080 016 062 004	0	0	0	4	898.0	431,040 1 1
LEHIGH	NO 4 46	02	1		40-43.6	75-32.6	090 002 048 001	0	0	0	13	892.0	1391,520 2
JUNIATA	WARRIOR 01	03	1		40-32.4	78-01.9	070 011 031 001	175	9210	53	28	837.0	2812,320 3
BR JUNIA	SAXTON 02	01	2		40-13.6	78-14.7	070 011 005 042	75	230	3	8	812.0	779,520 4 2
CONEMAUG	ELECTRIC03	03	2		40-24.4	79-01.7	080 018 032 070	0	0	0	7	717.0	602,280 5
SCHUYLKI	FELIX 46	02	1		40-23.5	75-58.2	090 003 006 036	0	0	0	17	660.0	1346,400 6
SHENANGO	UNNAMED 03	01	2		41-14.6	80-30.5	080 020 043 023	0	0	0	5	610.0	366,000 7
SHENANGO	SHENANGU03	27	1		41-15.9	80-27.7	080 020 043 045	3560	229329	64	68	589.0	4806,240 8
BALD EAG	BALD EAG14	18	2		41-07.5	77-29.5	070 009 018 018	0	0	0	9	587.7	634,716 9
SWATARA	NO 2 02	01	2		40-12.5	76-43.0	070 007 022 020	18	46	3	4	556.5	267,120 10
CONEWAGO	EMIGS 03	08	1		40-00.8	76-55.6	070 007 067 148	0	0	0	10	512.2	614,640 11
MEDBRANK	CITIZENS02	01	2		41-00.1	79-18.7	080 017 016 001	18	55	3	9	507.7	548,316 12
BR SUSQU	LOWER 03	02	2		41-01.7	78-26.2	070 008 017 032	0	0	0	4	483.3	231,984 13
TIONESTA	TIONESTA01	27	1		41-28.6	79-26.8	080 016 027 014	480	128019	267	154	483.0	8925,840 14
CONODOGU	BRENNEMA04	08	2		40-15.8	76-58.8	070 007 021 032	0	0	0	6	472.0	339,840 15
SWATARA	HUMMELST04	01	2		40-16.3	76-43.1	070 007 022 006	90	368	4	9	463.0	500,040 16
LOYALSOC	MILL 04	08	2		41-18.3	76-54.4	070 010 041 040	0	0	0	3	452.7	162,972 17
CONEWAGO	UNNAMED 04	09	2		40-06.1	76-46.0	070 007 067 093	0	0	0	4	440.2	211,296 18
YOUGHIOG	YOUGHIOG01	37	1		39-49.4	79-22.1	080 019 026 095	2840	254073	89	184	434.0	9582,720 19 2)
FISHING	LOGAN MI02	01	4		41-00.4	77-23.1	070 009 018 025	5	18	4	6	431.0	310,320 20 3
CONODOGU	WILLOW M04	02	2		40-15.6	77-02.5	070 007 021 035	0	0	0	5	420.0	252,000 21
TIONESTA	UNNAMED 04	03	2		41-29.1	79-27.5	080 016 027 007	0	0	0	3	420.0	151,200 22
CONEWAGO	ORT MILL03	08	2		39-57.9	76-57.3	070 007 067 137	0	0	0	12	405.0	583,200 23
SLIPPERY	SLIPPERY03	01	2		40-51.5	80-15.4	080 020 037 054	1	0	0	5	404.0	242,400 24
CONEWAGO	EISENHAR06	08	2		39-56.7	76-57.8	070 007 067 136	0	0	0	8	401.7	385,632 25
SLIPPERY	UNNAMED 06	02	2		40-54.7	80-12.9	080 020 037 032	0	0	0	5	390.0	234,000 26
CONEWAGO	UNNAMED 02	02	2		39-59.4	76-56.0	070 007 067 467	0	0	0	4	389.4	186,912 27
FISHING	MILL 03	08	2		40-58.9	76-28.5	070 005 019 016	0	0	0	5	375.0	225,000 28
SLIPPERY	MCCONNEL02	02	3		40-57.2	80-10.2	080 020 037 019	0	0	0	21	372.0	937,440 29
BR SUSQU	CURWENS03	02	2		40-57.7	78-31.0	070 008 017 081	0	0	0	5	367.0	220,200 30
BR SUSQU	CURWENS01	27	1		40-57.6	78-31.4	070 008 017 105	540	119346	221	131	365.0	5737,800 31
CONODOGU	CONODOGU02	01	2		40-13.4	77-11.4	070 007 021 017	60	184	3	9	363.0	392,040 32

*CAP-KW = 0.075 * (1.6 * DRAIN) * HGT.

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PAGE 2

RIVER	DAM	T	U	C	LAT	LONG	REFERENCE	ACRES	ACRE	FT	AVG D	HGT (FT)	DRAIN (MI ²)	CAP-KW*
PERKIOME	WETHERIL	02	01	2	40-07.4	75-26.7	090 003 046 050	23	92	4	5	360.0	216.000	33 4
STONY	BORDER	104	01	2	40-14.3	78-53.6	080 018 056 028	0	0	0	5	348.4	209.040	34
SLIPPERY	UNNAMED	12	02	2	40-53.3	80-13.5	080 020 037 031	0	0	0	6	344.0	247.680	35
JAHONING	MAHONING	03	07	1	40-55.2	79-16.6	080 017 003 022	170	75930	447	162	340.0	6609.600	36
SCHUYLK	NEW KERN	03	00	3	40-34.1	75-59.8	090 003 006 434	0	0	0	29	340.0	1183.200	37
BALD EAG	BLANCHARD	01	27	1	41-02.7	77-36.6	070 009 014 115	17300	92714	5	100	339.0	4068.000	38
CONESTOG	UNNAMED	03	02	2	40-00.7	76-18.3	070 007 036 244	0	0	0	7	331.0	278.040	39
CONESTOG	OLD CITY	06	02	2	40-02.0	76-16.9	070 007 036 031	0	77	0	3	327.0	117.720	40
CONESTOG	UNNAMED	03	06	2	40-03.1	76-16.6	070 007 036 001	0	0	0	5	324.0	194.400	41
PERKIOME	INDIAN H	12	08	2	40-08.8	75-26.7	090 003 046 051	0	0	0	4	311.0	149.280	42
CONODUGU	UNNAMED	34	02	2	40-12.8	77-18.9	070 007 021 009	0	0	0	7	310.0	260.400	43
CLARION	UNNAMED	02	03	2	41-26.0	78-44.3	080 017 024 031	0	0	0	6	304.5	219.240	44
FRANKSTU	UNNAMED	12	03	2	40-28.3	78-12.5	070 011 007 048	20	80	4	14	302.0	507.360	45
PERKIOME	COLLEGEV	02	08	2	40-11.8	75-27.0	090 003 046 054	0	0	0	5	301.5	180.900	46
PERKIOME	B F GOOD	03	03	2	40-07.2	75-27.5	090 003 046 245	55	402	7	18	300.0	648.000	47

47 59501.808 1266

PENNS	UNNAMED	02	08	2	40-52.2	77-11.1	070 006 060 036	0	0	0	3	297.0	106.920	1
LOYALHAN	LOYALHAN	03	07	1	40-27.4	79-27.2	080 018 065 104	210	97522	464	47	290.0	1635.600	2
LEHIGH	WALTER	01	27	1	41-07.0	75-43.2	090 002 013 105	90	109906	1221	234	288.0	8087.040	3
BR BRAND	CHADDS F	06	08	2	39-52.3	75-35.8	090 003 015 116	0	0	0	6	287.0	206.640	4
BR BRAND	UNNAMED	06	02	2	39-53.1	75-36.6	090 003 015 018	0	0	0	8	284.6	273.216	5
CONODUGU	UNNAMED	13	99	2	40-11.5	77-22.4	070 007 021 006	15	31	2	10	280.0	336.000	6
PERKIOME	UNNAMED	36	02	2	40-14.5	75-27.2	090 003 046 056	0	0	0	4	280.0	134.400	7
CROOKED	CROOKED	01	07	1	40-42.8	79-29.8	080 017 003 023	350	96091	275	143	277.0	4753.320	8
CLARION	INTAKE	04	03	2	41-27.2	78-43.1	080 017 024 021	0	0	0	4	263.0	126.240	9
BROADHEA	PAPER M	103	08	2	40-59.9	75-08.9	090 001 045 028	0	0	0	15	259.0	466.200	10
FIRST FO	STEVENS	016	27	1	41-24.5	78-01.1	070 008 012 011	142	76750	540	171	243.0	4986.360	11
WALLENPA	WALLENPA	03	00	2	41-28.0	75-10.5	090 001 064 048	0	0	0	8	238.5	228.960	12
WALLENPA	LAMBERT	04	03	2	41-28.4	75-10.3	090 001 064 049	0	0	0	5	238.5	143.100	13
CONNOQUE	UNNAMED	03	01	2	40-47.9	80-06.2	080 020 010 004	2	6	3	9	235.0	253.800	14
SHERMAN	DELLVILL	03	99	2	40-21.9	77-07.0	070 007 050 005	0	0	0	8	232.0	222.720	15
KETTLE	KETTLE	14	02	2	41-20.4	77-54.5	070 009 018 046	2	3	2	6	232.0	167.040	16
LOYALSOX	LEWIS	23	08	2	41-27.5	76-40.2	070 010 057 010	0	0	0	3	232.0	83.520	17
YELLOW B	NEW CUMB	02	01	2	40-13.4	76-51.6	070 007 021 007	5	31	6	6	227.0	163.440	18
KETTLE	BUSH	01	27	1	41-21.6	77-55.5	070 009 018 060	160	73434	459	165	226.0	4474.800	19
NESHAMIN	HULMEVIL	02	01	2	40-08.6	74-54.9	090 002 009 084	14	123	9	12	224.0	322.560	20
YELLOW B	MILL	03	08	2	40-13.4	76-54.0	070 007 021 022	17	61	4	9	223.0	240.840	21
FRENCH	UNION CI	01	07	1	41-55.2	79-54.0	080 016 025 044	2290	47680	21	68	222.0	2344.320	22
YELLOW B	MILL	03	08	2	40-12.6	76-54.4	070 007 021 021	40	77	2	8	220.0	211.200	23
TUPLEHUC	TUPLEHUC	02	01	2	40-20.9	75-57.2	090 003 006 009	0	3	0	12	217.0	312.480	24 4
MUNCY	SUPPLY	04	01	2	41-16.0	76-42.9	070 010 041 050	0	0	0	5	216.9	130.140	25
CONEWAGO	EAST HER	03	02	2	39-55.9	76-58.3	070 007 001 046	0	0	0	9	215.0	232.200	26
NESHAMIN	PHILA	02	01	2	40-08.9	74-57.5	090 002 009 003	20	218	11	14	211.0	354.480	27
PERKIOME	KRATZ	36	08	2	40-16.0	75-27.8	090 003 046 023	0	0	0	3	206.7	74.412	28
YELLOW B	MILLERS	03	01	2	40-12.1	76-55.5	070 007 021 004	0	0	0	10	204.0	244.800	29
CONEWAGO	BROWN'S	02	02	2	39-55.7	77-02.0	070 007 001 045	4	0	0	9	200.3	216.324	30
CONEWAGO	WALDHEIM	02	99	4	39-54.5	77-03.6	070 007 001 007	0	0	0	8	196.3	188.448	31
YELLOW B	HOFFMAN	03	08	4	40-09.0	76-54.7	070 007 021 070	0	0	0	12	194.7	280.368	32
MAIDEN	GLEN GER	03	01	4	40-26.3	75-55.5	090 003 006 005	0	0	0	8	192.0	184.320	33
MAIDEN	UNTELAUN	01	01	1	40-26.9	75-58.8	090 003 006 350	1082	11912	11	42	192.0	967.680	34
SHERMAN	UNNAMED	23	02	4	40-20.9	77-12.2	070 007 050 053	0	0	0	6	191.0	137.520	35
SWATARA	UNNAMED	03	01	4	40-25.0	76-29.3	070 007 038 086	0	0	0	5	190.0	114.000	36
YELLOW B	LANTY	04	08	4	40-09.8	76-56.5	070 007 021 073	0	0	0	5	188.6	113.160	37

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RIVER	DAM	T	U	C	LAT	LON	REFERENCE	ACRES	ACRE	FT	AVG	D	HGT (FT)	DRAIN (MI ²)	CAP-KW*
L LEHIGH	UNNAMED	62	00	4	40-35.8	75-28.4	090 002 039 035	0	0	0	0	8	187.0	179,520	38
FISHING	MILL	03	08	4	41-13.1	76-22.6	070 005 019 030	2	6	3	6	178.7	128,664	39	
BR PINE	PINE CR	08	02	3	41-44.0	77-38.5	070 009 053 058	12	31	3	10	175.0	210,000	40	
KISHACQU	UNNAMED	03	01	3	40-38.5	77-34.7	070 012 044 003	18	25	1	8	172.0	165,120	41	
LOYALHAN	KINGSTON	36	01	4	40-17.6	79-20.4	080 018 065 020	0	0	0	8	168.0	161,280	42	
KISHACQU	UNNAMED	04	03	4	40-38.2	77-34.2	070 012 044 010	0	0	0	7	167.0	140,280	43	
L PINE	L PINE	01	07	1	41-21.3	77-21.4	070 009 041 091	634	24809	39	113	165.4	2242,824	44	
NESHAMIN	SPRING	023	08	3	40-13.5	74-57.9	090 002 009 083	12	77	6	9	165.0	178,200	45	
MIDDLE	MUSSELS	01	02	3	40-46.0	76-52.4	070 006 055 001	15	154	10	32	163.0	625,920	46	
MORRIS	PA 601	01	72	3	41-43.9	77-17.6	070 009 059 066	60	261	4	48	163.0	938,880	47	
SHENANGO	PYMATUNIO	02	01	4	40-30.1	80-27.6	080 020 020 007	16420	197324	12	50	160.0	960,000	48	
NESHA-MIN	UNNAMED	03	02	4	40-14.0	74-58.1	090 002 009 167	0	0	0	6	160.0	115,200	49	
SCHUYLKI	AUBURN	01	00	3	40-36.6	76-06.5	090 003 054 163	0	0	0	38	157.0	715,920	50	
L CONEMA	UNNAMED	24	01	4	40-21.9	78-48.2	080 018 011 032	0	0	0	7	152.0	127,680	51	
CATAWISS	MILL	04	08	4	40-56.8	76-27.5	070 005 019 045	0	0	0	6	149.0	107,280	52	
SHERMAN	UNNAMED	23	09	4	40-19.7	77-17.3	070 007 050 024	2	9	5	3	148.4	53,424	53	
PERKIOME	SALFORD	02	02	4	40-18.1	75-27.4	090 003 046 021	0	0	0	7	148.0	124,320	54	
YELLOW H	ROSEBARK	03	08	4	40-08.9	77-00.8	070 007 021 077	0	0	0	4	147.2	70,656	55	
YELLOW H	WILLIAMS	04	08	4	40-09.1	77-02.2	070 007 021 081	0	0	0	5	145.5	87,300	56	
UCTORARO	PINE GROVE	02	01	3	39-47.9	76-02.6	070 007 036 008	10	154	15	10	145.0	174,000	57	
TURTLE	FAHRIC	08	01	4	40-24.2	79-49.8	080 019 002 042	1	0	0	7	145.0	121,800	58	
YELLOW H	UNNAMED	03	02	4	40-08.9	77-02.6	070 007 021 082	0	0	0	4	143.7	68,976	59	
UCTORARO	UCTORARO	001	01	1	39-47.9	76-02.6	070 007 015 281	669	7675	11	62	139.6	1038,624	60	
BR CONOC	UNNAMED	43	08	4	39-47.4	77-50.9	100 013 028 045	0	0	0	6	138.5	99,720	61	
YELLOW H	BRANDTSON	06	08	4	40-08.6	77-03.3	070 007 021 086	0	0	0	6	138.1	99,432	62	
PEQUEA	MILL	46	08	4	39-56.2	76-19.4	070 007 036 052	0	0	0	5	137.3	82,380	63	
SLIPPERY	CHILLS	04	08	4	41-01.1	80-02.7	080 020 010 016	0	0	0	5	136.4	81,840	64	
CONESTOG	ZOUKS	02	08	4	40-06.4	76-14.3	070 007 036 226	6	0	0	5	135.0	81,000	65	
BR CONOC	UNNAMED	03	03	4	39-47.8	77-51.6	100 013 028 044	0	0	0	8	132.9	127,584	66	
MAIDEN	UNNAMED	04	08	4	40-33.3	75-52.8	090 003 006 262	2	3	2	6	130.7	94,104	67	
CONESTOG	WENGER	002	02	4	40-07.8	76-11.9	070 007 036 024	0	0	0	7	129.0	108,360	68	
MAIDEN	UNNAMED	03	08	4	40-34.2	75-52.9	090 003 006 263	9	18	2	11	127.3	168,036	69	
MIDDLE	FRANKLIN	03	09	4	40-47.2	77-02.8	070 006 055 002	0	0	0	4	126.9	60,912	70	
L CONEST	MILL	24	08	4	40-00.6	76-22.5	070 007 036 041	0	0	0	10	126.0	151,200	71	
LOYALSOC	WORLDS E	13	02	4	41-28.2	76-35.1	070 010 057 033	1	0	0	7	126.0	105,840	72	
UGDONIA	DEER LAKE	12	02	3	41-21.9	76-39.7	070 010 057 028	50	0	0	5	125.0	75,000	73	
L CONEST	MAPLE GR	03	08	4	40-02.3	76-20.6	070 007 036 039	0	0	0	6	124.0	89,280	74	
CONOCHOC	MILL	03	08	4	39-55.8	77-41.0	100 013 028 014	0	0	0	6	114.7	82,584	75	
STANDING	CREEK	02	01	4	40-29.1	78-00.2	070 011 031 017	0	0	0	6	113.9	82,008	76	
STANDING	UNNAMED	03	02	4	40-28.9	78-00.4	070 011 031 060	0	0	0	6	113.9	82,008	77	
MUNDY	CASTLE F	03	09	4	39-45.8	76-21.2	070 007 067 041	0	0	0	10	110.8	132,960	78	
BR CLARI	INTAKE	02	01	4	41-29.7	78-40.6	080 017 024 012	0	0	0	4	110.0	52,800	79	
INDIAN C	INDIAN C	01	2	39-58.9	79-27.3	080 019 026 011	20	709	35	40	109.6	526,080	80		
MCMICHA	UNNAMED	03	08	4	40-58.9	75-11.9	090 001 045 029	2	6	3	10	105.0	126,000	81	
POHOPOCO	UNNAMED	04	03	3	40-49.1	75-40.6	090 002 013 009	13	77	6	18	105.0	226,800	82	
LOHICKON	RALPH S	102	02	4	40-26.2	75-06.1	090 002 009 128	0	0	0	7	104.7	87,948	83	
CONOCHOC	WOLF	03	28	3	39-56.8	77-39.6	100 013 028 005	3	58	19	8	104.0	99,840	84	
CONOCHOC	SILDAM	03	01	4	39-57.8	77-38.9	100 013 028 010	4	0	0	10	100.0	120,000	85	
WICONISC	UNNAMED	46	08	3	40-32.1	76-56.8	070 006 022 005	0	0	0	20	98.0	235,200	86	
LOHICKON	MYERS	26	08	3	40-26.2	75-07.0	090 002 009 020	10	31	3	10	97.4	116,880	87	
MCMICHA	UNNAMED	04	08	4	40-56.1	75-18.8	090 001 045 054	1	0	0	6	97.2	69,984	88	
PEQUEA	OSCELO	13	08	4	40-01.0	76-04.9	070 007 036 107	3	0	0	6	96.2	69,264	89	
TROUGH	TROUGH	02	02	3	40-19.7	78-07.2	070 011 031 066	15	0	0	8	96.0	92,160	90	
WICONISC	UNNAMED	34	09	4	40-32.2	76-55.5	070 006 022 049	9	18	2	10	95.0	114,000	91	
CUSSEWAG	UNNAMED	02	02	4	41-38.8	80-10.2	080 016 020 026	0	0	0	5	95.0	57,000	92	
PERKIOME	KNIGHT L	03	02	3	40-20.1	75-29.0	090 003 046 257	25	80	3	16	95.0	182,400	93	

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RIVER	DAM	T	U	C	LAT	LON	REFERENCE	ACRES	ACRE	FT	AVG	D	HGT (FT)	DRAIN (MI ²)	CAP-KW*		
SHERMAN	SHERMAN	23	02	4	40-20.9	77-20.4	070 007 050 044	1	0	0	10	0	10	94.5	113.400	94	
CODORUS	INDIAN R16	07	1	39-55.4	76-45.3	070 007 067 491		0	29165	0	83	0	83	94.0	936.240	95	
QUEMAHON	QUEMAHON01	03	1	40-10.9	78-56.6	080 018 056 004	900	36840	41	100	0	100	92.0	1104.000	96		
BR LACKA	WOOLEN M06	08	4	41-34.5	75-16.9	090 001 064 053	0	0	0	0	16	0	16	92.0	176.640	97	
ROARING	UYERS	03	08	4	40-56.0	76-31.4	070 005 047 001	3	9	3	12	0	12	90.3	130.032	98	
BR CLARK	HENDIGO	02	02	4	44-31.7	78-37.8	080 017 024 044	1	9	9	8	0	8	90.0	86.400	99	
TOHICKON	KANOTS M23	08	4	40-26.2	75-08.5	090 002 009 021	0	0	0	0	8	0	8	85.6	82.176	100	
MUNCY	FIRE PH006	03	3	41-16.8	76-42.7	070 010 041 095	0	0	0	0	30	0	30	85.4	307.440	101	
BACK	WILLIAMS03	08	4	39-51.2	77-47.8	100 013 028 043	0	0	0	0	6	0	6	84.5	60.840	102	
MIDDLE	DEBRIS 206	04	4	41-28.7	75-11.2	090 001 064 168	0	0	0	0	9	0	9	82.0	88.560	103	
BUSH KIL	LOWER	02	08	4	40-41.6	75-13.0	090 001 048 026	0	0	0	0	7	0	80.6	67.704	104	
CONNOQUE	SUPPLY	02	01	4	40-50.5	79-55.1	080 020 010 003	0	0	0	10	0	10	80.0	96.000	105	
LAUREL	WHIPKEY	04	08	4	39-55.3	79-16.9	080 019 056 060	2	6	3	7	0	7	79.7	66.948	106	
CONNEAUT	CUSTARDS07	02	3	41-32.4	80-09.5	080 016 020 059	1400	1228	1	8	0	8	78.0	74.880	107		
DUNKARD	WRAVE ST03	03	4	39-43.7	80-15.1	080 019 030 003	4	21	5	7	0	7	76.0	63.840	108		
TORRYHANN	POCONO	03	02	1	41-05.8	75-32.4	090 002 045 222	750	5403	7	40	0	40	75.2	360.960	109	
BUSH KIL	UPPER	54	08	4	40-42.0	75-13.9	090 001 048 023	0	0	0	11	0	11	75.1	99.132	110	
PERKIOLE	MREY	26	02	4	40-19.6	75-28.7	090 003 046 018	0	0	0	0	8	0	75.0	72.000	111	
TR MINGO	LAKEVIEW12	02	4	40-11.8	75-31.9	090 003 046 049	6	0	0	0	8	0	8	75.0	72.000	112	
TWO LICK	UNNAMED	03	08	1	40-35.8	79-06.0	080 018 032 075	500	18420	37	115	0	115	74.0	1021.200	113	
POHOPOCU	HELTZVIL01	27	1	40-50.9	75-38.3	090 002 013 108	947	68308	72	170	0	170	74.0	1509.600	114		
TOHICKON	MOCKAMIX16	02	1	40-28.2	75-11.3	090 002 009 166	1450	39910	28	102	0	102	73.3	897.192	115		
BUSH KIL	WALTERS	02	08	4	40-42.8	75-14.8	090 001 048 021	0	0	0	0	10	0	73.0	87.600	116	
BR CLARK	CLARION	01	07	1	41-33.6	78-35.6	080 017 024 050	1160	86267	74	184	0	184	72.4	1598.592	117	
SLIPPEHY	BOVARD	03	02	4	41-04.4	79-58.4	080 020 010 030	0	0	0	0	6	0	72.0	51.840	118	
FISHING	HENTON	02	02	4	41-11.7	76-23.0	070 005 019 014	2	0	0	0	11	0	71.5	94.380	119	
FRENCH	PHOENIXV46	03	3	40-08.1	75-31.0	090 003 015 200	4	31	8	12	0	12	71.0	102.240	120		
PERKIOLE	GREEN LA03	01	1	40-20.4	75-28.7	090 003 046 250	814	13437	17	93	0	93	71.0	792.360	121		
SHADE	EWING	03	08	4	40-14.1	77-53.1	070 012 031 019	0	0	0	0	6	0	70.5	50.760	122	
CONNEAUT	UNNAMED	02	05	3	41-34.5	80-13.1	080 016 020 040	500	2763	6	8	0	8	68.0	65.280	123	
FRENCH	UNNAMED	03	02	4	40-08.1	75-33.6	090 003 015 139	2	0	0	0	8	0	68.0	65.280	124	
CODORUS	UNNAMED	01	01	3	39-52.1	76-52.0	070 007 067 004	7	34	5	10	0	10	67.0	80.400	125	
FISHING	UNNAMED	01	08	4	41-13.5	76-22.5	070 005 019 005	4	0	0	0	9	0	66.0	71.280	126	
BR FRENC	CLARKS	02	09	4	41-53.8	79-50.1	080 016 025 016	0	0	0	0	12	0	65.0	93.600	127	
DYHERNY	E JADWIN16	07	1	41-36.4	75-16.1	090 001 064 165	0	24560	0	112	0	112	65.0	873.600	128		
HUNTINGT	UNNAMED	03	08	4	41-11.4	76-14.0	070 005 035 089	0	3	0	7	0	7	64.3	54.012	129	
COCALICO	UNNAMED	26	08	4	40-10.5	76-11.7	070 007 036 028	1	0	0	0	9	0	63.0	68.040	130	
YELLOW	UNNAMED	03	01	4	40-34.2	79-06.7	080 018 032 071	6	18	3	13	0	13	62.8	97.968	131	
QUITTAPA	BRANDTS	02	08	4	40-19.6	76-31.5	070 007 038 033	1	0	0	0	8	0	61.0	58.560	132	
COCALICO	UNNAMED	01	08	4	40-11.0	76-10.8	070 007 036 164	0	0	0	0	10	0	60.0	72.000	133	3
LACKAWAX	PROMPTON16	27	1	41-35.3	75-19.8	090 001 064 166	280	48199	172	140	0	140	60.0	1008.000	134		
WISSAHIC	MARGAREE02	02	4	40-36.6	75-13.2	090 003 051 009	7	18	3	12	0	12	60.0	86.400	135		
HUNTINGT	MILL	16	08	3	41-11.8	76-14.6	070 005 035 086	5	34	7	10	0	10	57.5	69.000	136	
ROARING	COOLING	02	01	3	41-24.2	75-39.5	070 005 035 032	0	0	0	25	0	25	57.0	171.000	137	
MARVIN	UNNAMED	01	01	3	41-48.4	78-26.5	080 016 042 017	12	40	3	10	0	10	56.7	68.040	138	
MILL	MILL	02	08	3	40-00.2	76-17.6	070 007 036 037	1	31	31	10	0	10	56.5	67.800	139	
SANDY	PA 475	01	07	1	41-22.2	80-05.2	080 016 043 053	1740	12504	7	45	0	45	56.5	305.100	140	
YELLOW	LUCEWNE	01	03	3	40-34.1	79-09.2	080 018 032 006	5	31	6	15	0	15	56.0	100.800	141	
CHESTER	ROCKDALE03	08	4	39-53.5	75-25.8	090 003 023 004	0	6	0	0	10	0	10	56.0	67.200	142	
MILL	ECKMAN	02	08	4	40-00.3	76-18.0	070 007 036 036	4	18	5	8	0	8	55.0	52.800	143	
BEAVER	UNNAMED	01	01	3	40-34.0	79-34.3	080 018 065 007	12	239	20	32	0	32	54.0	207.360	144	
MILL	ESHEMAN02	08	4	40-00.6	76-16.6	070 007 036 035	5	15	3	8	0	8	53.5	51.360	145		
SHOHOLA	SHOHOLA	03	02	1	41-23.4	74-58.2	090 001 052 158	1135	8504	7	27	0	27	53.5	173.340	146	
MUDDY	MORAIN	01	02	1	40-57.8	80-07.2	080 020 010 068	3200	38068	12	50	0	50	53.0	318.000	147	
YELLOW	YELLOW C01	02	1	40-35.5	79-03.4	080 018 032 074	740	9978	13	62	0	62	52.6	391.344	148		
EVITTS	GORDON	03	01	1	39-44.5	78-40.7	100 013 005 001	120	4298	36	85	0	85	51.1	521.220	149	(1)

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RIVER	DAM	T	U	C	LAT	LON	REFERENCE	ACRES	ACRE	FT	AVG D	HGT (FT)	DRAIN (MI ²)	CAP-KW*
BROKENST	COLUMBUS	12	01	3	41-56.6	79-35.0	080 016 061 015	50		230	5	15	51.0	91,800 150
ROARING	NO 7 RES	02	01	2	41-24.7	75-36.4	070 005 035 019	19		310	16	45	50.0	270,000 151
CHICKIES	UNNAMEU	23	08	4	40-06.0	76-27.0	070 007 036 210	0		0	0	9	50.0	54,000 152
BR CONOC	UNNAMEU	01	28	3	40-03.5	77-44.6	100 013 028 037	45		184	4	19	50.0	114,000 153
CHICKIES	CHICKIES	12	08	4	40-06.5	76-26.6	070 007 036 198	0		0	0	10	49.5	59,400 154
MONOCACY	ILLICKS	03	08	4	40-38.5	75-22.9	090 002 048 085	5		0	0	10	47.7	57,240 155
CHARTIFF	ALCOA	01	02	2	40-15.5	80-08.2	080 020 063 053	76		823	11	45	46.0	248,400 156
BR TUNKH	UNNAMEU	16	02	1	41-33.3	75-42.7	070 004 035 139	202		2456	12	69	44.9	371,772 157
BRUSH	JACKSON	04	08	4	39-58.3	78-16.3	070 011 005 056	0		0	0	12	44.2	63,648 158
MOUNTAIN	MT HOLLY	01	08	3	40-06.0	77-10.8	070 007 021 001	18		61	3	13	44.1	68,796 159
EVITTS	KOON	03	01	1	39-46.6	78-39.8	100 013 005 049	268		7598	28	87	43.6	455,184 160
SPRING	h SPRING	02	01	3	41-19.8	75-41.3	070 005 035 040	10		80	8	31	43.2	160,704 161
BEAVER	H BEAVER	001	01	1	40-30.8	79-33.3	080 018 065 114	1125		28183	25	91	43.2	471,744 162
HOKENDAU	SUPPLY	23	03	3	40-40.8	75-29.4	090 002 048 043	0		40	0	12	42.0	60,480 163
BEVERDAM	GLENDALE	01	02	1	40-39.0	78-32.0	070 008 011 101	1740		253029	145	60	41.9	301,680 164
CODORUS	GUNKARD	01	01	1	39-53.5	76-43.8	070 007 067 001	175		3438	20	55	41.6	274,560 165
KETTLE	OLE BULL	03	02	4	41-32.1	77-43.2	070 009 053 045	0		0	0	15	41.3	74,340 166
LACKAWAN	STILLWAT	04	01	2	41-40.8	75-28.4	070 005 058 001	164		998	6	20	40.0	96,000 167
BR CONOD	YORK WAT	01	01	1	39-53.9	76-42.7	070 007 067 488	290		5526	19	52	40.0	249,600 168
CRUM	UNNAMEU	02	08	4	39-55.2	75-21.9	090 003 023 050	0		0	0	12	38.8	55,872 169
PICKERIN	PICKERIN	01	01	2	40-06.1	75-32.4	090 003 015 001	170		1167	7	40	38.2	183,360 170
L CHICKI	UNNAMEU	03	02	4	40-06.7	76-29.5	070 007 036 194	10		3	0	12	38.0	54,720 171
LAUREL	H LAUREL	01	02	2	39-59.4	79-14.7	080 019 056 066	63		390	6	23	38.0	104,880 172
STONY	VAUPHIN	02	01	4	40-21.9	76-55.8	070 007 022 001	3		21	7	15	37.7	67,860 173
CONNEAUT	DRAKES	01	08	4	41-49.8	80-05.1	080 016 020 015	0		0	0	12	37.6	54,144 174
SHAWNEE	SHAWNEE	01	72	1	40-01.9	78-37.2	070 011 005 070	451		16753	37	56	37.5	252,000 175
BR BRAND	KURTZ	06	02	3	39-59.7	75-49.3	090 003 015 035	7		61	9	21	37.4	94,248 176
ROARING	ELMHURST	02	01	1	41-22.3	75-32.5	070 005 035 018	181		3684	20	68	37.3	304,368 177
SPRING	H NESBIT	01	01	1	41-19.6	75-39.0	070 005 035 015	116		3927	34	87	37.1	387,324 178
LACKAWAN	STILLWAT	01	27	1	41-41.7	75-29.1	070 005 058 128	83		11605	140	77	36.8	340,032 179
RIDLEY	UNNAMEU	02	08	4	39-52.4	75-21.4	090 003 023 029	0		0	0	12	36.7	52,848 180
BEAVER	H BEAVER	001	02	3	41-12.5	75-06.7	090 001 052 010	78		350	4	12	36.6	52,704 181
CHESTER	LENNI	23	08	3	39-53.7	75-27.1	090 003 023 010	16		0	0	17	36.2	73,848 182
DARBY	KENT	02	08	3	39-56.1	75-17.6	090 003 023 039	0		0	0	20	35.8	85,920 183
HEAR	BEAR CKE	04	02	3	41-10.7	75-45.4	090 002 040 047	70		768	11	17	35.2	71,808 184
HARVEYS	INTAKE	202	01	4	41-15.8	76-02.1	070 005 040 007	4		12	3	14	35.0	58,800 185
CONODOGU	LETTERKE	03	03	1	40-06.9	77-41.3	070 007 028 096	54		1013	19	61	33.8	247,416 186
JACOBS	UPPER BRO	01	01	3	40-07.5	79-31.8	080 019 065 005	77		528	7	18	32.5	70,200 187
MCLEHATT	LOCK HAV	01	01	1	41-04.4	77-19.2	070 009 018 062	123		1719	14	57	32.0	218,880 188
RIDLEY	MILL	06	08	3	39-53.2	75-23.3	090 003 023 026	0		0	0	35	32.0	134,400 189
HIG MILL	RIDGEWAY	01	01	2	41-25.5	78-46.7	080 017 024 035	75		614	8	39	30.0	140,400 190
CRUM	CRUM CKE	02	01	2	39-55.5	75-22.0	090 003 023 020	50		497	10	25	29.1	87,300 191
MOUNTAIN	LAUREL	01	02	3	40-02.4	77-16.1	070 007 021 025	25		123	5	20	27.5	66,000 192
BIG RUN	CASCADE	01	02	4	40-58.4	80-19.6	080 020 037 015	3		25	8	18	27.4	59,184 193
FALLS	UNNAMEU	03	01	4	41-27.6	75-50.1	070 004 066 030	0		0	0	18	27.3	58,968 194
ANDERSON	DUBOIS	01	01	1	41-05.8	78-38.0	070 008 017 005	212		1888	9	38	26.5	120,840 195
LAUREL	H LAUREL	001	01	3	40-02.7	79-12.2	080 019 056 085	24		246	10	20	26.5	63,600 196
RHOADS	LAKE STU	02	2	40-01.1	78-53.2	080 018 056 097	189		1320	7	30	26.0	93,600 197	
N DUNKAR	RYERSON	03	02	1	39-53.5	80-27.0	080 020 030 020	62		2686	43	42	25.9	130,536 198
HAMMER	HAMMER	001	02	2	40-12.2	76-18.4	070 007 036 257	106		1271	12	35	25.0	105,000 199
N FORK	P NORTH PA	01	02	2	40-35.9	79-59.9	080 018 002 026	75		568	8	33	25.0	99,000 200
ROARING	WILMORE	03	03	1	40-26.6	78-41.5	080 018 011 004	195		3147	16	40	25.0	120,000 201
CODORUS	MAHBURG	01	23	1	39-48.6	76-52.9	070 007 067 489	1275		48506	38	109	24.3	317,844 202
WILD CRE	WILD CKE	01	01	1	40-53.8	75-33.7	090 002 013 083	238		7859	33	135	22.0	356,400 203
TIONESTA	CHAPMAN	01	02	3	41-45.2	79-10.4	080 016 061 026	67		286	4	20	21.7	52,080 204
CLARKS	DEHART	01	01	1	40-25.7	76-44.8	070 007 022 009	650		23639	36	100	21.6	259,200 205

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RIVER	DAM	T	U	C	LAT	LON	REFERENCE	ACRES	ACRE FT	AVG D	HGT (FT)	DRAIN (MI ²)	CAP-KW*
CHUM	GEIST	01	01	1	39-57.3	75-23.9	090 003 023 079	375	10745	29	79	21.3	201.924 206
MARSH	MARSH CR16	21	1	40-03.4	75-43.1	090 003 015 296	535	13723	26	90	20.0	216.000 207	
TRAVERSE	RACOUN CO1	02	2	40-30.3	80-23.5	080 020 004 034	100	292	3	45	19.1	103.140 208	
L SWATAH	SWEET AK01	03	2	40-34.2	76-23.1	070 007 054 102	100	1105	11	36	18.3	79.056 209	
BELLS GA	BELLWOOD01	01	3	40-37.5	78-22.8	070 011 007 003	47	200	4	24	18.2	52.416 210	
CONUCHOC	CHAMBERS01	01	1	39-55.1	77-27.3	100 013 001 069	50	1436	37	67	18.0	144.720 211	
LYNAM RU	LYMAN RU01	02	1	41-43.3	77-45.8	070 009 053 049	35	678	19	51	17.9	104.548 212	
DUTCH FO	UNNAMEU	01	02	2	40-08.1	80-28.5	080 020 063 067	91	728	8	33	17.8	70.448 213
MIDDLE C	MIDDLE CO1	07	1	40-47.8	77-11.8	070 006 055 045	239	3319	14	53	17.4	111.936 214	
BEAVER	PINCHOT	01	02	1	40-05.3	76-52.3	070 007 067 486	340	2763	8	50	17.5	105.000 215
MCELHATT	MCELHATT13	01	1	41-07.5	77-20.3	070 009 018 001	100	282	3	52	17.3	107.952 216	
CONNOQUE	LAKE ONE01	01	1	40-55.1	79-52.1	080 020 010 011	155	1762	11	38	16.6	75.696 217	
WILD	PENN FORN1	01	1	40-56.2	75-34.1	090 002 013 085	461	14420	40	145	16.5	287.100 218	
CANOE	UNNAMEU	01	02	2	40-28.7	78-16.9	070 011 007 084	155	1520	10	35	16.4	68.880 219
SERVICE	J C BACON1	01	1	40-34.7	80-20.4	080 020 004 042	368	9824	27	90	15.7	169.560 220	
L SCHUYL	UNNAMEU	01	07	1	40-50.1	76-00.3	090 003 054 174	70	3699	53	87	15.6	162.864 221
SPRING B	WATRES	01	01	1	41-17.5	75-37.1	070 005 035 081	164	5787	35	131	15.4	242.088 222
CARLEY	FREETLYS12	02	3	41-33.8	75-14.6	090 001 064 160	5	9	2	35	15.0	63.000 223	
CALENDAR	INDIAN	01	02	1	40-01.7	78-52.3	080 018 056 103	750	10499	14	71	14.9	126.948 224
FISHING	HIGH BR101	01	1	40-32.7	76-29.8	070 007 054 157	55	952	17	66	14.2	112.464 225	
BR BRADY	IMPONDIND1	02	3	40-43.9	80-21.4	080 020 004 035	26	233	9	33	13.8	54.548 226	
L HUFFAL	UNNAMEU	01	02	1	40-27.3	77-10.4	070 012 050 050	88	900	10	55	13.4	84.440 227
LOCUST	LOCUST	01	07	1	40-48.3	76-00.4	090 003 054 170	96	2677	28	98	13.1	154.056 228
BR ROARI	NO 2	01	01	1	40-49.4	76-29.7	070 005 049 004	65	1817	28	83	12.8	127.488 229
LAUREL	AUREL	06	01	6	40-43.8	77-37.8	070 012 044 062	67	3070	46	155	12.8	238.080 230
COOL SPH	LATONKA	01	02	1	41-16.2	80-11.1	080 020 043 049	320	3316	10	34	12.7	51.816 231
BLAIN GA	PLAIN W101	01	1	40-25.8	78-30.3	070 011 007 007	20	338	17	51	12.5	76.500 232	
ROARING	HOLLISTE16	01	1	41-18.8	75-29.8	070 005 035 138	175	4028	23	61	12.0	87.840 233	
SALTICK	SALTICK01	01	1	40-23.0	78-50.0	080 018 011 008	67	2631	39	110	11.9	157.080 234	
PIKE CHE	PIKE CHE01	01	1	41-15.9	76-02.9	070 005 040 018	400	9029	23	58	11.7	81.432 235	
MONTGOME	MONTGOME01	01	1	41-01.8	78-30.8	070 008 017 104	75	697	9	95	11.2	127.680 236	
BURGOON	ALTONNA	01	01	1	40-29.5	78-27.5	070 011 007 008	70	2456	35	70	11.2	94.080 237
HINCKSTO	HINCKSTO01	01	1	40-22.5	78-53.1	080 018 011 009	104	3451	33	84	10.8	108.864 238	
TUHMILL	TUHMILL	02	01	2	40-19.8	79-05.4	080 018 065 001	41	614	15	400	10.7	513.600 239
N FORK B	NORTH FOR1	01	1	40-16.2	79-00.2	080 018 056 053	94	3377	36	112	10.0	134.400 240	
BURGOON	LOWER	01	01	1	40-29.7	78-28.2	070 011 007 014	43	1121	26	60	9.0	64.800 241
TIPTON	TIPTON	02	03	1	40-40.5	78-19.5	070 011 007 067	45	768	17	66	8.9	70.488 242
BR ROARI	NO 6	01	01	1	40-50.0	76-25.2	070 005 049 001	185	4083	22	59	8.8	62.304 243
TWOMILE	UNNAMEU	01	27	1	41-28.0	79-46.3	080 016 051 019	144	3266	23	85	8.4	85.680 244
CHARLEST	PA 602	01	71	1	41-44.2	77-15.9	070 009 059 065	34	436	13	67	8.3	66.732 245
HIRCH	LONG PIN16	01	1	39-56.3	77-26.7	100 013 001 082	150	5526	37	112	7.9	106.176 246	
BLAIR	BLAIR	01	01	1	40-26.1	78-31.1	070 011 007 083	13	230	18	66	7.3	57.816 247
TUNUNGWA	NO 5 ST001	01	1	41-53.8	78-43.2	080 016 042 031	102	2088	20	72	7.0	60.480 248	
TROUT	GUNTERS	01	01	1	40-08.4	77-40.3	070 007 028 102	35	639	18	78	6.7	52.712 249
TROUT	LATROHE	01	01	1	40-16.5	79-15.3	080 018 065 066	113	3650	32	86	5.8	59.856 250
LONG ARM	LONG ARM16	01	1	39-45.2	76-59.8	070 007 067 487	185	5219	28	75	5.7	51.300 251	
MILL RUN	MILL RUN01	01	1	40-31.2	78-27.0	070 011 007 082	77	2702	35	100	4.3	51.600 252	

252 75904.440 301.208

Table F7

Pennsylvania nonhydroelectric dams with a potential capacity greater than 1000 kW and a break-even price less than 8¢/kWh.

Dam	River	Hydraulic Head Estimate (ft)	Drainage Area (mi ²)	Gross Estimate Break-Even* (\$/kWh)	Gross Estimate Power Potential† (kW)
1. Kinzua‡	Allegheny	130	2 180	0.0081	36 000
2. Raystown	Raystown Br. Juniata	185	960	0.0091	16 000
3. Youghiogheny	Youghiogheny	126	434	0.0125	8 000
4. Montgomery	Ohio	17.5	22 969	0.0187	50 000
5. Clarion	Br. Clarion	184	72.4	0.0189	1 600
6. Emsworth	Ohio	18	19 428	0.0190	43 000
7. Lock No. 9	Allegheny	22	8 401	0.0194	23 000
8. Little Pine	Little Pine	113	165.4	0.0198	2 200
9. Beltzville	Pohopoco Cr.	128	96.3	0.0210	1 500
10. Union City	French	88	222	0.0211	2 300
11. Mahoning	Mahoning Cr.	70	340	0.0217	2 900
12. Lock No. 8	Allegheny	17.9	8 844	0.0225	20 000
13. Conemaugh	Conemaugh	35	1 351	0.0229	5 700
14. Maxwell	Monongahela	19.5	4 961	0.0240	12 000
15. Tionesta	Tionesta	45	483	0.0256	2 600
16. Lock No. 3	Allegheny	13.5	11 537	0.0267	19 000
17. Tioga	Tioga	51	280	0.0267	1 700
18. Francis E. Walker	Lehigh	50	288	0.0268	1 700
19. Lock No. 4	Monongahela	16.6	5 205	0.0269	11 000
20. Blanchard	Bald Eagle	46	339	0.0272	1 900
21. Loyalhanna	Loyalhanna	47	290	0.0278	1 600
22. Lock No. 8	Monongahela	19	2 715	0.0281	6 400
23. Cowanesque	Cowanesque	45	298	0.0283	1 600
24. Lock No. 7	Allegheny	13.1	8 982	0.0288	15 000
25. Lock No. 7	Monongahela	15	4 383	0.0302	8 100

* Based on generalized costing methodology for supply model (AFCR = 10.4%). Unknown site-specific information may invalidate this estimate.

† Power = $0.075 \times \text{average flow} \times \text{head}$; when average flow is not known, it is determined by $1.6 \text{ ft}^3/\text{s mi}^2 \times \text{drainage area}$. Unknown site-specific information may invalidate this estimate.

‡ Kinzua dam has pumped storage, but no conventional hydroelectric power.

Table F7

Pennsylvania nonhydroelectric dams with a potential capacity greater than 1000 kW and a break-even price less than 8¢/kWh (cont'd).

Dam	River	Hydraulic Head Estimate (ft)	Drainage Area (mi ²)	Gross Estimate Break-Even* (\$/kWh)	Gross Estimate Power Potential† (kW)
26. Warrior	Juniata	28	837	0.0303	2 800
27. Lock No. 6	Allegheny	12.2	9 333	0.0303	14 000
28. Dashields	Ohio	10	19 522	0.0308	24 000
29. Shenago	Shenago	30	589	0.0311	2 100
30. Lock No. 5	Allegheny	11.8	9 351	0.0312	14 000
31. Lock No. 2	Allegheny	11	11 636	0.0316	16 000
32. Flat Rock	Schuylkill	21.5	1 809	0.0317	4.300
33. Easton	Schuylkill	21.1	1 373	0.0326	3 900
34. Lock No. 4	Allegheny	10.5	11 449	0.0329	15 000
35. Townsend	Beaver	16	3 030	0.0333	5 800
36. Hepburn	Br. Susquehanna	13	5 682	0.0339	8 900
37. Electric	Schuylkill	16	1 765	0.0378	3 400
38. Felix	Schuylkill	19.5	660	0.0397	1 600
39. Sunbury	Susquehanna	8	18 300	0.0399	17 600
40. Farm	Gallagher Run	16	1 250	0.0403	2 400
41. Lock No. 2	Monongahela	8.7	7 341	0.0427	7 900
42. Fairmont	Schuylkill	13	1 893	0.04310	3 000
43. New Kernsville	Schuylkill	19.8	340	0.0437	1 000
44. Unnamed ¹	Br. Susquehanna	11	3 350	0.0441	4 400
45. Hartman	Beaver	11	3 025	0.0448	4 000
46. Lock No. 3	Monongahela	8.2	5 331	0.0475	5 400
47. No. 7	Lehigh	13	1 129	0.0476	1 800
48. Black Rock	Schuylkill	12	1 295.5	0.0491	1 900
49. Unnamed ²	Beaver	9	2 189.5	0.0550	2 400
50. Plymouth	Schuylkill	8	1 774	0.0627	1 700
TOTAL					464 100

1 Location 41°8.3' Lat., 77° 26.1' Long.

2 Location 40° 56.2' Lat., 80° 2.2' Long.

* Based on generalized costing methodology for supply model (AFCR = 10.4%). Unknown site-specific information may invalidate this estimate.

† Power = $0.075 \times \text{average flow} \times \text{head}$; when average flow is not known, it is determined by $1.6 \text{ ft}^3/\text{s mi}^2 \times \text{drainage area}$. Unknown site-specific information may invalidate this estimate.

Appendix G

MARYLAND STATISTICS ON DAMS

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DAM #	ST	CTY	CD	LAT	CON	RIVER	H/HT	S/HT	AGE	TYPE	PUR	NAME	OWNER	D/AREA	CAP-KW	
MD000097	MD	015	01	39-40.0	076-10.1	SUSQUEHANNA	98	99	50	PG	HRS	CONOWINGO DAM	SUSQUEHANNA ELE	27000.0	198450.000	1
MD000137	MD	043	06	39-20.0	077-45.2	POTOMAC	14	18	108	OT	H		POTOMAC EDISON	6236.0	6547.800	2
MD000078	MD	043	06	39-29.9	077-50.0	POTOMAC RIVE	25	20	70	PG	HRS	POTOMAC RIVER D	DOI	5900.0	11062.500	3
3 216060 72020																
MD000101	MD	021	06	39-20.0	077-25.0	MUNOCACY RIV	12	12	109	PG	R	MICHAELS MILL D	FREDERICK COUNT	883.9	795.510	1 1
MD000096	MD	001	06	39-28.0	079-03.0	POTOMAC RIVE	8	7	65	PG	S	WESTVACO DAM	WESTVACO	510.0	306.000	2 2
MD000097	MD	005	07	39-26.0	076-32.1	GUNPOWDER RI	72	82	55	PG	SR	LOCH RAVEN RESE	BALT. D.P.W.	303.0	1636.200	3
3 2738 913																
MD000064	MD	023	06	39-24.1	078-52.5	NORTH BRANCH	282	296	5	OT	CSOR		DAEN NAB	287.0	6070.050	1
MD000003	MD	005	07	39-22.5	076-53.9	N. BRANCH OF	150	160	24	PG	SR	LIBERTY RESERVO	BALT. D.P.W.	164.0	1845.000	2 3
MD000020	MD	033	08	39-14.0	076-52.5	PATUXENT RIV	109	124	25	CB	SR	ROCKY GORGE RES	WASH.SUB.SANT.C	132.0	1079.100	3
MD000065	MD	003	04	39-05.3	076-43.3	TH-PATUXENT	16	16	61	RE	R		FORTE MEANE	128.0	153.600	4
MD000014	MD	023	06	39-29.6	079-07.6	SAVAGE RIVER	155	184	26	REER	CSO	SAVAGE RIVER RE	UPPERPOTOMAC C	105.0	1220.625	5
MD000028	MD	001	06	39-37.5	078-44.8	EVITTS CREEK	11	26	21	REOT	R	EVITTS POND	JAMES&JOHN AVIR	94.9	78.292	6
MD000021	MD	021	06	39-24.9	077-17.6	LINGANORE CR	40	55	6	RE	RS	LAKE LINGANORE	BROSIOUS HOMES I	82.3	246.900	7
MD000001	MD	005	07	39-37.5	076-42.9	GUNPOWDER RI	120	130	42	PG	SR	PRETTYBOY RESER	BALT. D.P.W.	80.0	720.000	8 2
MD000005	MD	031	08	39-11.6	077-00.5	PATUXENT RIV	81	98	35	CB	S	TRIDELPHIA RESE	WASH.SURURBAN S	77.3	469.597	9
MD000004	MD	023	06	39-30.5	079-23.5	DEEP CREEK	62	82	53	RE	HCRS	DEEP CREEK LAKE	PAENN. ELECTRIC	64.7	300.855	10
MD000011	MD	045	01	38-22.5	075-36.0	WICOMICO RIV	17	18	42	PG	CR	JOHNSON'S POND	CITY OF SALISBU	42.0	53.550	11
MD000067	MD	025	01	39-28.4	076-20.2	WINTERS RUN	42	60	36	PG	S		ARERDEEN PROVIN	38.0	119.700	12
MD000104	MD	510	07	39-22.6	076-37.6	JONES FALLS	28	28	116	PG	R	LAKE HOLLAND	BALT. CITY	36.8	77.280	13
MD000015	MD	045	01	38-20.0	075-22.5	GIVENS BRANC	9	10	38	RE	SR	ADKINS POND	WICOMICO COUNTY	32.0	21.600	14
MD000017	MD	025	01	39-41.5	076-15.8	BROAD CREEK	25	37	31	PG	RS	BROAD CREEK MEM	BOY SCOUTS OF A	30.0	56.250	15 1
MD000047	MD	035	01	39-15.0	075-52.0	UNICORN BRAN	18	22	14	RE	R	UNICORN LAKE	MD. FISH & GAME	22.3	30.105	16
MD000122	MD	045	01	38-27.6	075-43.1	HARON CREEK	8	10	78	RE	RIS	MOCKINGBIRD PON	WICOMICO COUNTY	17.7	10.620	17
MD000127	MD	019	01	38-30.5	075-52.6	CHICAMACOMIC	8	10	78	RE	IR	BIG MILLPOND		16.6	9.960	18
MD000030	MD	047	01	38-27.1	077-12.0	HUNTING BRAN	9	12	20	REOT	RS	BISHOPVILLE PON	WORCESTER COUNT	13.3	8.977	19
MD000046	MD	031	08	39-06.0	077-07.6	ROCK CREEK	43	64	14	RE	CH	LAKE NEEDWOOD	M.N.C.P.P.C.	12.8	41.280	20
MD000123	MD	045	01	38-17.4	075-41.5	PASSERDYKE C	6	8	78	RE	IR	MONONAME2		12.7	5.715	21
MD000116	MD	023	06	39-31.2	079-27.5	MUDDY CREEK	10	10	48	RE	R	BROWNING DAM	GARRETT COUNTY	12.6	9.450	22
MD000050	MD	031	08	39-06.3	077-07.2	NORTH BRANCH	71	78	9	RE	CR	BENARD-FRANK LA	M.N.C.P.P.C.	12.2	64.965	23
MD000009	MD	023	06	39-42.5	079-00.4	BIG PINEY RU	38	45	44	CBRE	S	FROSTHUR RESER	CITY OF FROSTBU	11.9	33.915	24
MD000163	MD	011	01	39-01.5	075-47.0	BROADWAY BKA	20	20	128	RE	RI	LAKE BONNIE		11.7	17.550	25
MD000022	MD	031	08	38-57.0	077-07.6	POTOMAC RIVE	14	11	20	PG	SO	LITTLE FALLS RE	DAEN NAB	11.6	12.180	26
MD000024	MD	045	01	38-20.0	075-36.5	TONY TANK CR	8	14	30	OTRE	R	TONY TANK POND	WICOMICO COUNTY	11.6	6.960	27
MD000126	MD	019	01	38-31.0	075-57.5	TRANSQUAKING	8	10	78	RE	IR	HIGGINS MILLPON		11.4	6.840	28
MD000139	MD	013	07	39-23.0	076-59.0	PINEY RUN	65	73	4	ERRE	CSR		CARROLL COUNTY	10.4	50.700	29
MD000029	MD	035	01	38-56.3	076-04.9	WYE EAST RIV	17	26	21	RE	R	WYE MILLS COMMU	MD. GAME&FISH C	10.2	13.005	30
MD000048	MD	011	01	38-46.0	075-46.0	MARSHHOPE CR	10	15	20	RE	RC	SMITHVILLE COMM	MD.FISH & WILD	9.9	7.425	31
MD000071	MD	001	06	39-42.1	078-39.7	ROCKY GAP RU	80	100	9	RE	R	ROCKY GAP RESEV	MD. DEPT. OF FO	9.0	54.000	32
MD000113	MD	011	01	38-50.0	075-51.0	MILL CREEK	10	15	48	PG	R	LAKE WILLISTRON	GIRL SCOUTS OF	8.8	6.600	33
MD000135	MD	019	01	38-40.5	075-53.0	GRAVEL RUN	8	10	48	RE	I	MONONAME3	DORCHESTER COUN	8.7	5.220	34
MD000024	MD	029	01	39-17.0	076-02.0	HWANCH-MORGA	13	14	23	RE	R	URIEVILLE COMMU	MD.GAME & FISH	8.5	8.287	35
MD000130	MD	011	01	38-42.4	075-52.9	HUNTING CREE	8	10	48	RE	IR	LINCHESTER LAKE	MR. LANGRALL	8.4	5.040	36
MD000037	MD	017	01	38-27.5	076-51.5	GILBERT RUN	35	45	16	RE	C	GILBERT RUN RES	GILBERT RUN W-S	8.2	21.525	37
MD000040	MD	047	01	38-01.5	075-27.5	LITTLE MILL	6	9	78	PG	R	BIG MILLPOND DA	WORCESTER COUNT	8.2	3.690	38
MD000016	MD	021	06	39-31.8	077-27.5	FISHING CREE	11	15	53	RE	RS	FISHING CREEK R	CITY OF FREDERI	7.3	6.022	39
MD000120	MD	023	06	39-24.0	079-22.4	BROAD FORD R	6	8	58	RE	RS	MOUNTAIN LAKE	MOUNTAIN LAKE P	7.3	3.285	40
MD000036	MD	023	06	39-25.0	079-20.5	BROADFORD RU	30	46	7	RE	CSR	LITTLE YOK RESE	GARRETT SOIL CO	6.8	15.300	41
MD000054	MD	021	06	39-36.0	077-27.5	HUNTING CREE	60	67	9	RE	RS	HUNTING CREEK L	DEPT.OF FORESTS	6.8	30.600	42

DAM #	ST	CTY	CD	LAT	LONG	RIVER	H/HT	S/HT	AGE	TYPE	PUR	NAME	OWNER	D/AREA	CAP-KW
MD00012	MD	023	06	39-27.5	079-27.4	HERRINGTON C	15	23	42	RE	RO	HERRINGTON MANO	MD. DEPT. OF FO	6.5	7.312 43
MD000125	MD	019	01	38-35.5	075-42.9	GALES CREEK	8	10	78	RE	ISR	IRVING MILLPOND		6.4	3.840 44
MD000066	MD	003	04	39-05.0	076-43.3	TR-PATUXENT	9	10	31	ER	R		FORTE MEADE	5.4	3.645 45
MD000018	MD	017	01	38-30.8	076-44.5	GILBERT RUN	30	40	18	RE	C	JAMESON RESERVO	GILBERT RUN W-S	4.3	9.675 46
MD000063	MD	025	01	39-32.1	076-10.2	CARLINS RUN	13	15	11	RE	S	STANCILL INC. H	STANCILLS, INCO	4.0	3.900 47
MD000051	MD	027	06	39-13.2	076-52.0	TR-LITTLE PA	20	20	11	PG	R	WILDE LAKE	HOWARD RES. COLEY	3.6	5.400 48
MD000100	MD	024	01	39-11.5	076-10.5	WEST FORK	10	20	36	RE	R	ST. PAUL'S MILL	REMINGTON AHMS	3.6	2.700 49
MD000055	MD	023	06	39-22.5	074-27.5	LANDON'S DAM	28	39	11	RE	C	LITTLE YOK RESE	GARRETT SOIL CO	3.4	7.140 50
MD000051	MD	043	06	39-42.0	077-57.1	LITTLE CONOC	31	35	10	RE	R	BLAIR VALLEY DA	MD. GAMF<FISH C	3.4	7.905 51
MD000053	MD	031	08	39-10.1	077-12.5	WHEATSTONE RU	30	35	11	RE	RC	LAKE WHEATSTONE	KETTLER BROS.,	3.3	7.425 52
MD000135	MD	003	04	38-59.8	076-34.2	TR-HWODD CHE	15	15	58	RE	SR	SOUTH HASIN, ANN	ANNAPOLIS CITY	3.2	3.600 53
MD000010	MD	023	06	39-34.1	079-14.8	PLEASANT V. L	12	19	41	RE	R	CUNNINGHAM LAKE	MD. PARK + PLAN	2.9	2.610 54
MD000039	MD	009	01	38-21.8	076-25.0	MILL CREEK	31	46	15	RE	RS	CHESAPEAKE RANC	CHESAPEAKE RANCH	2.9	6.742 55
MD000060	MD	017	01	38-29.2	076-51.5	WHEATLEY RUN	33	39	10	RE	C	WHEATLEY RESERV	GILBERT RUN W-S	2.7	6.682 56
MD000118	MD	013	06	39-37.4	076-52.9	EAST BRANCH	20	20	48	RE	R	CASCADE LAKE	CARROLL COUNTY	2.6	3.900 57
MD000064	MD	033	05	38-44.0	076-55.0	BUTLER BRANC	28	33	8	RE	R	CLINTON LAKE	M.N.C.P.P.C.	2.5	5.250 58
MD000111	MD	033	05	39-01.0	076-51.0	HECK BRANCH	7	8	38	RE	IS	S.C.S. LAKE	USDA SCS	2.5	1.312 59
MD000013	MD	033	05	39-02.2	076-47.5	CASH CREEK	12	15	42	RE	S	CASH CREEK LAKE	AGR. RESEARCH C	2.4	2.160 60
MD000006	MD	043	06	39-34.7	077-32.7	WARNERS HOLL	55	60	76	RE	SR	EDGEMONT RESERV	CITY OF HAGERST	2.3	9.467 61
MD000032	MD	023	06	39-25.3	079-18.3	LITTLE YOUGH	39	45	19	RE	C	LITTLE YOK RESE	GARETT SOIL CON	2.3	6.727 62
MD000007	MD	037	01	38-16.4	076-25.0	PINE HILL RU	6	6	20	RE	R		ODD USN	2.2	0.990 63
MD000007	MD	043	06	39-38.5	077-34.5	DIFFENDAH S	17	22	97	RE	S	SMITHSBURG RESE	CITY OF HAGERST	1.9	2.422 64
MD000070	MD	043	06	39-42.2	077-29.5	S.FORK OF FA	26	23	80	RE	SR	LOWER LAKE ROYE	USASTRATCOM-CON	1.9	3.705 65
MD000121	MD	045	01	38-27.6	075-44.0	BARON CREEK	8	10	78	RE	SIR	BARON POND	WICOMICO COUNTY	1.9	1.140 66
MD000124	MD	019	01	38-34.2	075-42.7	GALES CREEK	8	10	78	RE	SIR	GALESTOWN MILLP	CITY OF GALESTO	1.9	1.140 67
MD000102	MD	023	06	39-37.6	079-07.6	POPLAR LICK	8	17	128	RE	R	NEW GERMANY LAK	MD. PARK SERVIC	1.8	1.080 68
MD000112	MD	033	05	39-02.2	076-47.5	TR-PATUXENT	25	25	38	RE	S	REDINGTON LAKE	PAT. WILDLIFE RE	1.8	3.375 69
MD000040	MD	025	08	39-37.0	076-32.0	LITTLE DEER	30	38	17	RE	C	LITTLE DEER CRE	HARTFORD SOIL C	1.6	3.600 70
MD000057	MD	023	06	39-41.2	079-06.5	MEADOW RUN	20	24	9	RE	R	MEADOW RUN LAKE	JOHN E. DAVIES	1.6	2.400 71
MD000035	MD	025	06	39-38.3	076-32.0	TR-LITTLE DE	34	39	17	RE	CD	LITTLE DEER CRE	HARFORD SOIL CO	1.5	3.825 72
MD000079	MD	027	06	39-13.2	076-52.0	TR-DORSEY RU	31	36	6	RE	C	GENERAL ELECTRI	GENERAL ELECTRI	1.5	3.487 73
MD000062	MD	001	06	39-35.1	078-51.7	TRIPLE LAKES	15	18	10	RE	S	PINTO UTILITIES	PINTO UTILITIES	1.4	1.575 74
MD000085	MD	045	01	38-20.8	076-32.6	BEAVERDAM CR	10	14	21	CHRE	RH	PARKER POND	WISE H. HINMAN	1.4	1.050 75
MD000077	MD	023	06	39-32.5	079-02.4	HUTCHER RUN	26	30	10	RE	DS	HARTON DEHRIS B	TOWN OF BARTON	1.3	2.535 76
MD000114	MD	023	06	39-41.0	079-13.5	PUZZLEY RUN	18	20	48	RE	R	LAKE LOUISE	GEORGE ARENNAN	1.3	1.755 77
MD000088	MD	031	08	39-11.3	077-17.0	TR-LITTLE SE	40	45	7	RE	R	LAKE CHURCHILL	GERMANTOWN INV.	1.2	3.600 78
MD000013	MD	021	06	39-42.0	077-22.6	TURKEY RUN	20	25	29	RE	S	EMMITSBURG RESE	EMMITSBURG WATE	1.0	1.500 79
MD000052	MD	015	01	39-37.3	076-02.5	DARK RUN	49	60	12	RE	S	MASON-DIXON SAN	MASON-DIXON SAN	0.9	3.307 80
MD000008	MD	033	05	39-00.0	076-54.0	TR-INDIAN CR	20	25	42	RE	R	GREENBELT LAKE	CITY OF GREENBE	0.8	1.200 81
MD000042	MD	043	06	39-32.5	077-37.5	TR-LITTLE BE	58	63	16	RE	R	GREENBRIAR LAKE	PARK SERVICE OF	0.8	3.480 82
MD000043	MD	043	06	39-32.5	077-37.5	TR-LITTLE BE	9	13	16	RE	R	GREENBRIAR LAKE	MD. PARK SERVIC	0.8	0.540 83
MD000045	MD	023	06	39-24.9	079-24.5	WILSON RUN	30	38	15	RE	C	LITTLE YOK RESE	WILSON RUN PUB.	0.8	1.800 84
MD000031	MD	025	01	39-37.6	076-30.0	LITTLE DEER	40	45	20	RE	CR	CATTAIL RESERVO	HARFORD COUNTY	0.7	2.100 85
MD000081	MD	031	08	39-05.1	076-55.1	LITTLE PAINT	25	28	8	RE	O	CONTEE SAND + G	CONTEE SAND + G	0.7	1.312 86
MD000044	MD	023	06	39-24.9	079-24.5	CHERRY GLADE	30	33	15	RE	C	LITTLE YOK #1	GARRETT SOIL CO	0.6	1.350 87
MD000072	MD	021	06	39-25.1	077-17.6	TR-LINGANOE	28	38	6	RE	R	MEADOWLAKE	BROSIOUS HOMES I	0.6	1.260 88
MD000042	MD	033	05	38-53.5	076-48.1	TR-WESTERN B	36	40	5	RE	R	NORTHAMPTON LAK	NORTHAMPTON COR	0.6	1.620 89
MD000033	MD	023	06	39-25.5	079-23.5	CHERRY GLADE	29	35	18	RE	C	LITTLE YOK #2 R	GARRETT SOIL CO	0.5	1.087 90
MD000055	MD	031	08	39-07.1	077-14.8	TR-MUDDY BKA	25	29	11	RE	R	LAKE NIRVANA	NAT. GEOGRAPHIC	0.4	0.750 91
MD000102	MD	010	07	39-18.0	076-37.6	TR-STONY RUN	35	40	107	RE	SR	DRUID LAKE	BALTIMORE CITY	0.4	1.050 92
MD000041	MD	031	08	39-03.5	077-02.5	TR-NORTHWE-T	18	25	16	RE	R	PINE LAKE	M.N.C.P.P.C.	0.3	0.405 93
MD000049	MD	031	08	39-01.0	077-14.0	COUL SPRING	27	34	15	RE	R	GREAT FALLS EST	MILLER DEVELOPE	0.3	0.607 94
MD000054	MD	031	08	39-10.1	077-12.5	TR-WHEATSTONE	34	40	11	RE	RS	LAKE WALKER	KETTLER BROS.,	0.3	0.765 95
MD000083	MD	025	06	39-26.0	076-18.3	TR-OTTER POI	25	30	7	RE	R	EDGEWATER VILLA	EDGEWATER VILLA	0.3	0.562 96
MD000025	MD	013	06	39-40.0	077-00.5	TR-DEEP RUN	26	28	22	RE	O	BLACK & DECKER	BLACK&DECKER MF	0.2	0.390 97
MD000034	MD	043	06	39-40.0	077-57.4	TR-INDIAN SP	25	33	17	RE	SC	CLEAR SPRING WA	CITY OF CLEAR S	0.2	0.375 98

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DAM #	ST	CTY	CD	LAT	CON	RIVER	H/HT	S/HT	AGE	TYPE	PUR	NAME	OWNER	D/AREA	CAP-KW
MD000073	MD	021	06	39-24.9	077-17.6	TR-LINGANORE	30	35	6	RE	R	LAKE PINEHURST	BROSIOUS HOMES I	0.2	0.450 99
MD000074	MD	021	06	39-24.9	077-17.6	TR-LINGANORE	40	45	6	RE	R	LAKE PINEHURST	BROSIOUS HOMES I	0.2	0.600 100
MD000076	MD	015	01	39-42.5	076-07.5	TR-OCTORARO J	25	30	9	RE	R	OCTORARO LAKES	OCTORARO LAKES	0.2	0.375 101
MD000129	MD	033	05	38-56.3	076-44.8	TR-COLLINGTO	8	10	48	RE	R	ALLEN POND	PRINCE GEORGES	0.2	0.120 102
MD000014	MD	027	06	39-14.5	076-56.2	TR-MIDDLE PA	26	26	24	RE	S	JOHNS HOPKINS P	JOHNS HOPKINS U	0.1	0.195 103
MD000027	MD	013	06	39-36.2	077-57.5	CRANFERRY BR	28	32	21	RE	S	CRANFERRY BRANC	MD. WATER WORKS	0.1	0.210 104
MD000054	MD	003	04	39-00.3	076-32.5	TR-CLEMENTS	18	26	10	RE	R	SFAFERN LAKE	SFAFERN INCORPO	0.1	0.135 105
MD000045	MD	013	06	39-33.0	076-59.9	TR-LITTLE PI	15	26	14	RE	R	COUNTY HOME FAR	CARROLL COUNTY	0.1	0.112 106
MD000110	MD	510	07	39-20.1	076-35.0	TR-HERRING H	25	30	64	RE	S	MONTERELLO WAST	BALTIMORE CITY	0.0	0.000 107
MD000023	MD	510	07	39-19.4	076-40.3	PECKIS BRANC	50	54	25	REFR	OS	ASHHURTON LAKE	BALTIMORE CITY	0.0	0.000 108
MD000064	MD	031	08	39-15.0	077-15.0	OFF STREAM P	25	27	36	REER	O	DOD USN		0.0	0.000 109
MD000075	MD	021	06	39-24.9	077-17.6	TR-LINGANORE	42	47	5	RE	R	HAUL ROAD LAKE	BROSIOUS HOMES I	0.0	0.000 110
MD000084	MD	031	08	39-59.7	077-04.8	COQUELIN RUN	26	25	5	RE	R	CHEVY CHASE LAK	CHEVY CHASE LAN	0.0	0.000 111
MD000086	MD	033	05	38-56.0	076-44.9	TR-COLLINGTO	15	18	5	RE	R	ALLENS POND	LEVITT + SONS,	0.0	0.000 112
MD000089	MD	043	06	39-30.1	077-37.6	TR-ANTIETAM C	33	34	28	RE	S	BOONSHORO RESEH	CITY OF BOONSHO	0.0	0.000 113
MD000090	MD	013	06	39-35.5	076-59.0	TR-WEST BRAN	27	32	21	RE	SR	LUCABAUGH MILL	CITY OF WESTMIN	0.0	0.000 114
MD000091	MD	013	06	39-35.5	076-59.2	TR-WEST BRAN	10	10	25	RE	R	EDEN FARM POND	B.F. SHRIVER CO	0.0	0.000 115
MD000092	MD	021	06	39-25.0	077-25.1	TR-CARROLL C	8	10	39	CR	R	CULLER LAKE	CITY OF FREDERI	0.0	0.000 116
MD000093	MD	043	06	39-38.1	077-43.2	TR-ANTIETAM	10	10	58	RE	R	HAGERSTOWN CITY	CITY OF HAGERST	0.0	0.000 117
MD000094	MD	021	06	39-42.1	077-23.0	TURKEY CREEK	18	21	28	RE	S	RAINBOW LAKE	TOWN OF EMMITSB	0.0	0.000 118
MD000098	MD	033	05	38-44.0	076-55.0	HUTLER BRANC	25	32	9	RE	R	COSCA LAKE	M.N.C.P.P.C.	0.0	0.000 119
MD000099	MD	024	01	39-14.9	076-10.0	TR-FAIRLEE C	15	20	6	PG	R	FAIRLEE LAKE	MR. RICHARD MCE	0.0	0.000 120
MD000105	MD	510	07	39-22.8	076-43.1	TR-GWYNN FAL	6	10	55	RE	S	PIKESVILLE RESE	BALTIMORE CITY	0.0	0.000 121
MD000106	MD	510	07	39-20.9	076-37.0	TR-SPRINGLAK	10	10	85	RE	S	GUILFORD RESERV	BALTIMORE CITY	0.0	0.000 122
MD000107	MD	510	07	39-20.0	076-35.0	TR-HERRING H	25	30	102	RE	R	LAKE MONTEHELLO	BALTIMORE CITY	0.0	0.000 123
MD000108	MD	510	07	39-19.0	076-40.0	TR-GWYNN FA	25	25	68	RE	SR	LAKE ASHBURTON	BALTIMORE CITY	0.0	0.000 124
MD000115	MD	015	01	39-35.0	076-01.0	TR-PRINCIPIO	40	40	8	RE	S	MASON DIXON SAN	MASON DIXON SAN	0.0	0.000 125
MD000117	MD	013	06	39-33.1	077-10.2	SAMS CREEK	10	10	48	RE	O	UNION BRIDGE MU	CITY OF UNION B	0.0	0.000 126
MD000119	MD	015	01	39-37.6	075-48.2	TR-ELK CREEK	8	10	48	RE	R	CECIL LAND INC.	JULIUS JODLBAUR	0.0	0.000 127
MD000128	MD	011	01	38-46.5	075-44.0	SMITHVILLE D	8	10	78	RE	IRS	SMITHVILLE LAKE	DEPT OF NATURAL	0.0	0.000 128
MD000131	MD	015	01	39-42.5	076-04.9	STONE RUN	25	25	15	RE	O	RIISING SUN WAST	CITY OF RIISING	0.0	0.000 129
MD000132	MD	029	01	39-11.5	076-07.3	EAST FORK	8	10	48	RE	IR	MILL POND	KENT COUNTY	0.0	0.000 130
MD000133	MD	029	01	39-11.5	076-04.0	TR-CHESTER R	8	10	48	RE	R	CHESTER RIVER C	CHESTER RTV.CO	0.0	0.000 131
MD000134	MD	001	06	39-35.0	078-45.0	TR-POTOMAC R	43	45	22	RE	O	PPG INDUSTRIES	PPG INDUSTRIES	0.0	0.000 132
MD000138	MD	031	08	38-56.9	077-07.3	POTOMAC RIVE	13	17	19	PGOT	S		DAEN NAP	0.0	0.000 133
MD000140	MD	015	01	39-30.1	075-52.5	OFFSTREAM	38	400	10	RE	O	COURT HOUSE POI	DAEN NAP	0.0	0.000 134
MD000141	MD	015	01	39-25.9	075-59.0	OFFSTREAM	18	20	10	RE	O	PEARCE CREEK DI	DAEN NAP	0.0	0.000 135
MD000142	MD	015	01	39-23.3	076-01.2	OFFSTREAM	18	200	10	RE	O	GROVE POINT DIS	DAEN NAP	0.0	0.000 136
MD000143	MD	015	01	39-31.5	075-47.5	OFFSTREAM	40	42	10	RE	O	CHESAPEAKE CITY	DAEN NAP	0.0	0.000 137
MD000144	MD	015	01	39-31.5	075-49.7	OFFSTREAM	25	27	10	RE	O	CHESAPEAKE CITY	DAEN NAP	0.0	0.000 138
MD000145	MD	015	01	39-32.5	075-50.5	OFFSTREAM	40	420	10	RE	O	EMILY POINT DIS	DAEN NAP	0.0	0.000 139

139 13174 95

145 231972 1600

MD DAMS WITH H/HT FROM 0-19 FT.	63
20-49 FT.	66
50-99 FT.	11
100-? FT.	5

78-07-07 13:28 DAM,STAT17													PAGE	4	
DAM #	ST	CTY	CD	LAT	LON	RIVER	H/HT	S/HT	AGE	TYPE	PUR	NAME	OWNER	D/AREA	CAP-KW
ALL DAMS WITH H/HT FROM 0-19 FT.						63									
20-49 FT.						66									
50-99 FT.						11									
100-7 FT.						5									

MD00097 CONOWINGO DAM	SUSQUEHANNA ELECTRIC CO. SUSQUEHANNA RIVER	MD	512	0 1928
MD00137	POTOMAC EDISON CO OF WVA POTOMAC	MD	0	0 1870
MD00074 POTOMAC RIVER DAM #4	DOI POTOMAC RIVER	MD	0	0 1908
MD00004 DEEP CREEK LAKE	PENN. ELECTRIC CO. DEEP CREEK	MD	0	0 1925
MD00065 PARKER POND	WISE H. HINMAN HEAVERDAM CREEK	MD	0	0 1957

5 HYDROS

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Appendix H

NEW JERSEY STATISTICS ON DAMS (Potential capacity greater than 50 kW).

Dam	River	Hydraulic Head (ft)	Drainage Area (mi ²)	Owner	Gross Estimates Break-Even* (¢/kWh)	Gross Estimate Power Potential† (kW)
S.U.M.	Passaic	66	800	City of Paterson	1.7	3350
Boonton Res.	Rockaway	113	119		2.1	850
Wanaque Res.	Wanaque	102	90	New Jersey	2.4	580
Charlotteburg Res.	Pequannock	104	56.3	City of Newark	2.7	370
Beattie's	Passaic	32	773	Passaic Valley Water Comm.	2.8	1550
Spruce Run	Spruce Run	85	41	New Jersey	3.4	220
Oak Ridge Res.	Pequannock	56	27	City of Newark	5.4	96
Carnegie Lake	Millstone	18	159.1	Princeton Univ.	6.3	180
Union Lake	Maurice	15	218.4	Weaton Ind.	6.5	210
Somerset Lake	Raritan	10	475	Somerset County	7.1	300
Lower Reservoir	Rockaway	23.3	55	Jersey City	7.7	80
Paulins Kill Lake	Paulin Kill	19	80	Paulins Kill Lake	7.8	96
Lake Lenape	Great Egg Harbor	12	216	Weaton Ind.	7.8	160
No Name ¹	Rockaway	14	118.2	Town of Boonton	8.5	105
No Name ²	Raritan	8	475	Somerset Co. Par.	8.6	241
Finesville Mill	Musconetcong	12	156	Taylor, Stiles & Co.	8.7	119
Lake Waterloo	Musconetcong	18	62.4	—	9.0	71
Saxton Lake	Musconetcong	16	68	Morris Canal	9.6	69
Lake Tappen	Hackensack	18	49.2	Hackensack Water	10.0	56
Hughesville	Musconetcong	10	150	Riegel Paper Corp.	10.3	95
Pine Lake	Ridgeway Branch	15	64	Town of Manches	10.4	61
Duernal Lake	South	12	94.6	E. I. Dupont DeN.	10.6	72
Pemberton Lake	Rancocas Ck.	10	111	Pemberton Borough	11.6	70
No Name ³	Bats to River	12	70.5	State of N.J.	12.0	54
Clinton Mills	Raritan	8	111	Town of Clinton	14.1	56
Smithville Lake	North Branch	7	132	Eastameton Town	14.7	59
Calco	Raritan	3.2	780	Calco Chem. Co.	16.7	158
New Brooklyn	Great Egg Harbor	4	232	Camden County	19.7	59

1 Dam location 40°54.5' Lat. and 74°25.2' Long.

2 Dam location 40°33.4' Lat. and 74°38.9' Long.

3 Dam location 39°38.6' Lat. and 74°39.6' Long.

* Gross estimate break-even price is from the supply computer model with AFRC equals 10.4%.

† Gross estimate of power potential = 0.0634 × (drainage area) × head.

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Appendix I

EXISTING AND PROPOSED SMALL-SCALE HYDROELECTRIC SITES

Existing Small-Scale Hydroelectric Projects

There are a few existing small-scale hydroelectric projects that have been identified. In Delaware, the only small-scale hydroelectric installation that has been identified is the Eleutherian Mills-Hagley Foundation's New Century Power House near Wilmington, Del. on the Brandywine River. This site produced 150 kW during the early 1900's for the DuPont Company's powder mills and nearby residences. The Hagley Museum opened in 1957 by the Eleutherian Mills-Hagley Foundation, and they began producing electricity in Oct 1976. This project has a double function: it is a museum exhibit, but it also supplies a major portion of the Foundation's electrical requirement. A half-mile upstream is the Birkenhead Dam, which diverts water into a race and then through 500 ft of underground penstock to the powerhouse. The head of water available is then 28 ft with a capacity of 500 kW.

The Hagley Foundation made an agreement with the Delmarva Power and Light Company (DP&L) so that the generating systems are in parallel operation, which permits the Hagley Foundation to supplement their electrical supply as needed. In order to provide parallel operation with DP&L, it was necessary to purchase metering and synchronizing equipment, switchgear, and breakers at a cost of \$100 000. The Department of Natural Resources and Environmental Control of the State of Delaware monitored all of the necessary requirements of other federal, state, and local agencies. The hydroelectric plant has been able to supply 79% of the Hagley Foundation's electrical requirements for the period 1 Jan 1977 through 14 Nov 1978, and they saved \$182 449 by not purchasing this power from DP&L. They have also received \$4000 from DP&L for excess generation that was backfed into DP&L's system when the Hagley Foundation was generating excess power for the period 27 May 1977 through 18 Nov 1978. DP&L pays them 1.03¢/kWh, which is one-half the average cost of all electricity generated by DP&L. This will be updated soon using 1978 costs.

It has been a little over two years since the reactivation and there have been no major problems. The system has been on-line about 90% of the time with interruptions of one or two days, and they have operated at an average power production of 172 kW. They shut down in Nov 1978 due to an oil leak and for the purpose

of deepening the raceway. They are planning to use the additional capacity for heating and cooling of a 30 000 ft² building with the use of a storage system.

Dr. Heacock, General Director of the Eleutherian Mills-Hagley Foundation, suggested that, in order to facilitate the growth of hydroelectric power, the dam owners or potential developers need information on hydroelectric power generation presented at a level they can understand and a list of contacts who could answer questions. Dr. Heacock suggested that a list of engineering consulting firms, equipment manufacturers, and legal advisors for questions on water rights would be of most value to those considering development of small-scale hydroelectric power.

The Passaic Valley Water Commission owns the Beatties Dam on the Passaic River in New Jersey. In 1935, equipment was installed, and 2400 kW have been generated since that time. Originally, excess generated power was purchased by the utility company, but today all hydroelectric power is consumed at the Gravity Water Filtration Plant. The Passaic Valley Water Commission submitted a proposal to DOE for funding to do a feasibility study on upgrading of the existing hydroelectric facilities due to an increase in their plant's power consumption. With the 32 ft head available they could increase their generation capacity to 3800 kW. They did not receive funding from DOE.

The Riegel Paper Corporation owns two small hydroelectric installations on the Musconetcong River in New Jersey. The Hugsville Dam with a 27 ft head has a capacity of 444 kW and an average annual generation of 1.4×10^6 kWh, and the Warren Glen Dam, which has a 50 ft head, has a capacity of 720 kW and supplies an average annual generation of 4.0×10^6 kWh.

In Pennsylvania, the Lewis T. C. Company owns the Hillsgrove Dam on Loyalsock Creek, which has a 100 kW capacity and an average annual generation of 4×10^5 kWh. The Republic Steel Corp. owns Union Drawn Dam on the Beaver River, which has a capacity of 100 kW and an average annual generation of 5×10^5 kWh.

Hearn's and Rollin's Mill was built 100 years ago in Seaford, Del. They have two water wheels that provide mechanical power for grinding grains. When the water is low, they must use electricity to run one of the wheels. They have no plans for the generation of electricity at their dam on Clear Brook.

In Maryland, W. H. Hinman owns and operates a small hydroelectric plant at Parker Pond Dam on Beaver Dam Creek. About 1963, the dam, which is located on his property, was washed out, and during the period 1953-1957 Mr. Hinman rebuilt the dam and installed two small turbines and one water wheel. The electricity generated is used at his home, which is just adjacent to his dam.

The Hartman Dam in Pennsylvania is owned by the Beaver Falls Municipal Authority. The dam was built in 1893 and has an 11 ft hydraulic head. Old turbines at the Hartman Dam provide mechanical power that operate their pump in parallel with an electric motor drive, which is used for pumping when water power is not available.

The Potomac Edison Co. operated eight small-scale hydroelectric sites with a total generating capacity over 10 000 kW with sites ranging from 936 to 3550 kW. These sites are located in Maryland, Virginia, and West Virginia. They are examining the possibility of capacity expansion for Dam #4 on the Potomac River, which presently has a capacity of 1000 kW. They feel the FERC recreational requirement is excessively time consuming.

Proposed Small-Scale Hydroelectric Developments

Table 19 lists the proposed hydroelectric developments at existing dams for Delaware, Maryland, New Jersey, and Pennsylvania. This listing represents a variety of developers at various stages of development. In Delaware, at the Haveg Dam, Fleetridge Inc. completed a feasibility study on 14 Nov 1977 for the Haveg Industries. They considered using the 14 ft head that is available to produce 75 kW to be used at their Greenbank Road Plant. Their system would be set up in parallel with the utilities. Modifications would be necessary at the building and raceway, which are the previous locations of a hydroelectric facility. Mr. F. Smiley, Plant Engineer at Haveg Industries, said they have not proceeded to develop because funds are not available.

At Dayett's Mill Dam, they have a water wheel used to produce mechanical power for grinding and moving grain. If the electricity prices increase next year as much as they have increased in the past year, they will begin producing electricity during 1979. They would use the electricity produced for lighting and other electrical uses at the mill and possibly to produce steam for heating using a Water Twister, which is manufactured by the All American Engineering Co. in Wilmington, Del. Mr. Johnson said it would take only 30 days from the time they decide to go ahead with the project to the time they produce electricity. The

amount of electricity they produce will depend on which generator they choose and whether or not they decide to include the Water Twister. They received water rights from an early English king and they do not believe it would be necessary to obtain other permissions. Mr. Johnson believes that all levels of government are hindering small-scale hydroelectric development. Other problems include (a) having to persuade people and government that you can actually produce small-scale hydroelectric power, (b) the difficulty in determining who has authority over what, i.e., water rights, (c) determining what is required of the developer and who is responsible in areas such as dam failure, and (d) the Delaware River Basin Commission, which wants to charge for use of water.

In addition to their small-scale hydroelectric installations at the Dam, the Eleutherian Mills-Hagley Foundation hopes to develop Walker's Mill Dam. Walker's Mill Dam is located just downstream from the Hagley Dam on the Brandywine River. The Walker's Mill building and dam were built about 1815 for cotton-spinning operations. A water turbine and Edison generator were installed about 1888, and power was used primarily for incandescent lighting of the mills and residences. The generator was removed early in the 20th century. The existing rock dam is in good condition, but the race, the flume in the building, and the mounting for the water turbine-generator will require major renovations or complete rebuilding. The race that served the early hydroelectric unit has been partially filled in and may require rebuilding and enlarging. The planned 175 kW capacity could be obtained from the 9 ft head and average water flow of 420 cfs. The electric power would be used at buildings in the area of the dam that consume approximately 5% of the total electrical requirements of the Foundation. These buildings were too distant to be economically included in the distribution system of their present hydroelectric system. Excess power that is generated will be backfed into the Delaware Power & Light Co. system. The Foundation responded to DOE's recent PRDA with the hope of obtaining funds to complete a feasibility study for the development of Walker's Mill Dam but they were not funded. The Foundation will proceed with the feasibility study and, if favorable, will proceed with design and construction of hydroelectric facilities at Walker's Mill Dam when funds are available.

J. E. Davies in Grantsville, Md. has two dams on his property, one 8 ft high dam and Meadow Run Dam, which is approximately 27 ft high. Mr. Davies is only in a research stage and is collecting information on small-scale hydroelectric power generation. He hopes to generate electricity at his dams in the near future. He would use the electricity produced for his nearby campgrounds. Mr. Davies is interested in doing much of the work himself.

Brighton Dam is a 62.4 ft high dam on the Patuxent River in Maryland owned by the Washington Suburban Sanitary Commission. The dam was built in 1943 as a water supply dam, and a powerhouse was incorporated into the original development with a plant generating capacity of 120 kW, using 50 ft of head and a flow of 40 cfs. The hydroelectric power generated was used until 1969 to lessen the Commission's outside energy purchases during periods when adequate flow was available. The head works, existing powerhouse, and dam structure are in good condition, but the old generation machinery is no longer serviceable. The electrical power will be fed into the existing distribution system owned by the Commission. The power output will be used to supplement the Commission's power purchases from the Baltimore Gas and Electric Company. The Washington Suburban Sanitary Commission submitted a proposal in response to DOE's PRDA, and they have been funded to complete a feasibility study. The study was initiated in Jan 1979 and is scheduled to run 10 to 13 weeks. During the course of the study they will gather pertinent data, determine the optimum capacity, select equipment, prepare cost estimates and a schedule for development, and prepare a final feasibility report. If the feasibility study proves it favorable, the Washington Suburban Sanitary Commission will proceed to develop Brighton Dam for hydroelectric power.

The Union Lake Dam on the Maurice River in New Jersey is owned by Wheaton Industries. A proposal was submitted to DOE in response to PRDA but was not funded. James Leffel & Co. designed and constructed a 500 kW hydroelectric generating facility for Millville Manufacturing Co., which operated from 1929 until 1971 when the company went out of business. Wheaton Industries purchased this property in 1975 and is developing this property into several manufacturing companies. These companies will be the principal users of the power produced. A number of repairs will be required, and the original turbine and generator could possibly be put back into operation.

Justin & Courtney, Division of O'Brien & Gere Engineers, completed a feasibility study in 1976 on the redevelopment of the S.U.M. Dam on the Passaic River in New Jersey. The old hydroelectric plant was in operation from 1914 to 1969. The power that was generated was sold to manufacturing plants in the Great Falls area, and surplus power was sold to the Public Service Electric and Gas Co. (PSE&G). In 1946, due to the increased electrical demand by the manufacturers a contract was made to sell all power to PSE&G. The City of Paterson owns the 70 ft high dam. The completed feasibility study recommended that the city finance the rehabilitation project and negotiate a contract with the Passaic Valley Water Commission to operate the plant and the power would be sold to the

PSE&G Co. The PSE&G Co. has indicated they would pay the City of Paterson the cost of replaced power as the unit base for power generated at Great Falls. The value of this power at the time the feasibility study was being done was 20 to 25 mills per kWh. The study offered a variety of alternatives with total costs for the project ranging from about \$2 million to \$3.5 million. On 2 Sep 1977, the City of Paterson filed for a license with the Federal Energy Regulatory Commission. With an effective head of 66 feet they are developing a capacity of 4340 kW. Development and Resources Corp. is carrying out the engineering for the reactivation of the S.U.M. Dam and powerhouse for the generation of hydroelectric power and is assisting in the preparation of the FERC licensing requirements.

The Conodoquinet Dam on the Conodoquinet River in Pennsylvania is owned by the Borough of Carlisle. The dam was built about 70 years ago and was originally owned by the Carlisle Gas and Electric Company. The Conodoquinet Dam was constructed and used for the generation of electricity up until 1948. The 10 ft high dam offers a potential capacity of 400 kW. The site is now owned by the Carlisle Water Supply Authority. They submitted a proposal to DOE to obtain funds to determine the feasibility of power generation to be used in the operation of the Borough's municipal water treatment plant and pumping station. They did not receive funding for their feasibility study from DOE.

Allegheny Electric Cooperative, Inc. received funding for their proposal submitted to DOE in response to the PRDA. The Allegheny Electric Cooperative, Inc. is a nonprofit electric power wholesaler for 14 member Rural Electric Cooperatives. They are in the process of assessing the feasibility of installing hydroelectric power at the Maxwell Dam on the Monongahela River at Centerville, Pa. The Maxwell Locks and Dam is owned and operated by the U. S. Corps of Engineers. Construction of the existing structure was completed in 1965 and it is in good condition. The 19.5 ft head could provide a capacity of 13 500 kW. The dam is operated and maintained by the Corps and this will decrease costs for the Allegheny Electric Cooperative, Inc.

The Pennsylvania and Maine Hydro-Electric Development Corp. (HEDCO) submitted proposals to DOE in response to the PRDA but were not funded. HEDCO plans to develop the energy resources available at many sites considered economically marginal under traditional development assumptions. By standardizing development activities and by operating a number of sites in the same geographic area, HEDCO believes it can transform a

number of marginally feasible dam sites into a relatively significant supplement to conventional hydroelectric power generation. HEDCO anticipates developing and operating a large number of hydroelectric sites for diverse owners and investors. Each of the proposals submitted was a part of a river system plan in which sites with different owners would be organized in a co-dependent network.

The Auburn Dam has a 16 ft head and has a potential capacity of 500 kW. The Kernsville Dam is 19.5 ft high with a 1000 kW capacity, and the Felix Dam is 14 ft high with a 1000 kW capacity. These three dams are located on the Schuylkill River in Pennsylvania. They are owned and operated by the Pennsylvania Department of Environmental Resources (DER) and are used for desilting and recreational purposes. It is anticipated that DER will continue to maintain these dams, which is a favorable factor in the assessment. An agreement would be made with the utility servicing this area to purchase the hydroelectric power produced at these dams.

The Black Rock Dam has a 12 ft head and 1500 kW capacity, and the Norristown Dam with a 16 ft head has a potential capacity of 2800 kW. Both of these dams are located on the Schuylkill River in Pennsylvania. Both dams were originally constructed for navigational use by the Schuylkill Navigation Company in the early 1800's. The Black Rock Dam and the Norristown Dam are owned and maintained by the Philadelphia Electric Company (PECO), and their impoundments are used by PECO to support the Cromley and Barbados fossil fuel generating stations. They also support recreational and public water supply usage. PECO has agreed to permit HEDCO to develop and operate hydroelectric generating stations at the dams, concurrently with PECO's use of these dams. PECO has further agreed to purchase all energy produced in their service area, to assist HEDCO in planning interconnection, and to supply feasibility source data associated with revenues and operating and maintenance expenses.

The Flat Rock Dam is located on the Schuylkill River near Philadelphia. The dam is 36.7 ft high and has a potential capacity of 1000 kW. The Flat Rock Dam is owned by the Pennsylvania Department of Environmental Resources (DER). Headworks and the Manayunk Canal immediately downstream are owned by the City of Philadelphia. The dam formerly supported heavy industry usage, including hydropower and hydroelectric installation. The Pennsylvania DER is interested in and has agreed to cooperate with HEDCO in its study to determine the feasibility of small hydroelectric power developments at its dams on the Schuylkill River.

Philadelphia Electric has indicated their willingness to purchase all energy produced at the Flat Rock site. Two large industrial organizations located near the site have expressed their interest in using any power generated at the site.

The Easton Dam on the Lehigh River in Pennsylvania is 21 ft high with a potential capacity of 1000 kW. The dam was built as part of the Delaware/Lehigh Canals. The Easton Dam is owned by the Pennsylvania Department of Forests and Waters.

HEDCO filed an application for a preliminary permit 11 Jul 1977 with the FERC for these dams in Pennsylvania. If the permit is granted, it will provide licensing priority to HEDCO.

Pennsylvania Electric Company owns Warrior Ridge Dam, which began generating electricity in 1907. The installed capacity was 2000 kW. Because of damage due to a flood in 1972, this station is currently not operating, but an application is being made to the FERC for redevelopment of the project. They will be installing new equipment at a cost of \$2000/kW for a 1500 kW capacity. They found that it would cost them more to close down the dam than to put the money into redevelopment.

Terminated Small-Scale Hydroelectric Developments

There are two dams that have recently terminated their power generation. The Pennsylvania Electric Company's Oakland Dam on the Susquehanna River began generating electricity in 1896. The 18 ft high dam has an installed capacity of 600 kW. The station is presently not operating, and they are in the process of closing this station down. They have submitted an application for surrender of their federal license.

The Middle Creek Dam was built in 1765 on the Cedar Creek in New Jersey. The power produced was used at a nearby lumber company run by H. Winshit. A few years ago the dam was washed out. The dam was part of the county road system, and the county rebuilt the road with a bridge in place of the dam at a cost of \$150 000; at that time it would have been possible to rebuild the dam for the same amount of money. H. Winshit is not planning to rebuild the dam even though he cannot operate his sawmill without it. He found the federal and state restrictions too strict. He would be required to build the dam to withstand a 100 yr storm. His latest cost estimate to restore the dam is \$350 000.