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Development of Industrial Owned, Small Hydroelectric Facilities

John S. Krikorian Jr.

DEVELOPMENT OF INDUSTRIAL OWNED, SMALL HYDROELECTRIC FACILITIES

John S. Krikorian, Jr.
University of Rhode Island
Kingston, Rhode Island 02881

Abstract

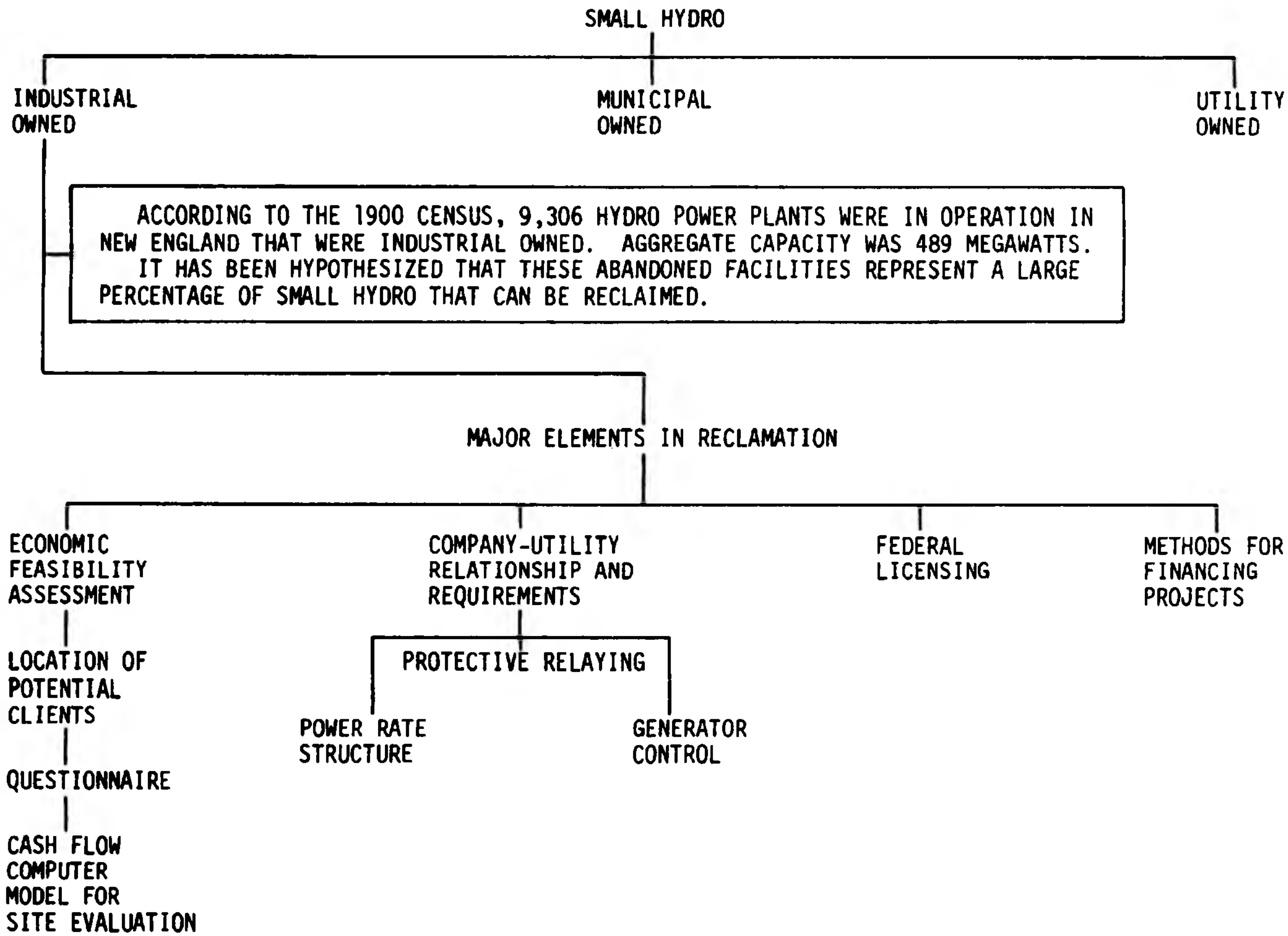
A methodology is discussed for determining the economic feasibility of reclaiming industrial owned, small hydroelectric facilities. A cash flow computer model provides the means for coping with many of the diverse inputs that occur at different sites. A detailed case study is presented. Some institutional factors that aid or hinder development are discussed.

1. INTRODUCTION

To provide motive power, large numbers of small hydropower plants were used by United States manufacturing industries at the turn of the century. The census (1) for the year 1900 lists 39,182 plants in use with an aggregate Horsepower of 1, 727,258 (1,289 Megawatts) accounting for 15.3 percent of the total motive power used. New England had in operation 9,306 plants at 655,931 Horsepower (489 Megawatts).

To put this in perspective, if one assumes that 1000 Megawatts of small hydroelectric plants could be developed with complete utilization of capacity, this would provide less than 0.5 percent of the total electrical energy used in the United States during 1974 (2). Of some interest are the economic feasibilities for industries suitably located to reclaim small abandoned hydro facilities for the generation of electrical energy. Such incentives are dependent on many variables, including regional energy costs, engineering features of the power plant system, "good will" of the local Utility Company, the condition of existing facilities, a company's financial condition, and company operating procedures. Main elements in the reclamation process are indicated in Figure 1. A cash flow analysis (3) can be used to process many of the input variables. From the cash flow, a utility function (4) is defined to express in compact form the economic feasibility for the development of a particular site. Computer modeling provides a means of coping with the many diverse inputs that occur at different sites.

Many of the sites are located on streams that have a yearly periodic flow (5). For plants located on these variable flow streams, the cash flow system model with the use of an appropriate utility function, is used to select a power plant size that will maximize the financial feasibility.



MAJOR ELEMENTS IN RECLAMATION

FIGURE 1

2. MODEL DEVELOPMENT

2.1 BASIC MODELING ASSUMPTIONS

Several basic assumptions have been made in developing the computer model; they are:

(1) The hydroelectric generator is connected in parallel with the local Utility Company's system with excess energy sold to the Utility.

(2) The hydroelectric power plant has been installed primarily for use by the business in their industrial manufacturing process or plant activity (6).

A block diagram of the model is illustrated in Figure 2. It takes into account major engineering features of the facility, economic and financial conditions, and industrial operating procedures. Primary outputs are the yearly cash flow and yearly tax change. Cash flow is used for calculating different utilities.

2.2 ENGINEERING ASPECTS OF MODEL

Major engineering elements include dam head, monthly river flow, power plant efficiency and power plant rating. From these inputs, the output for the electrical generator is calculated. The power available from the generator is modeled as,

$$P = 9.8\ E\ F\ H,$$

$$P_e = \begin{bmatrix} P\ , & P \leq P_g \\ P_g\ , & P > P_g \end{bmatrix},$$

P = Available Water Power (KW)

P_e = Available Power from Electrical Plant (KW)

P_g = Generator Nameplate Rating

E = Efficiency

F = Flow in Cubic Meters per Second

H = Dam Head in Meters.

When using the model for optimization of power plant size, it was found that discontinuities in the yearly river flow data were the cause of nonsmooth power plant optimization curves. This effect was removed by obtaining a least squares approximation (7) of the flow. The smoothing approximation is an internal element of the model. Optimization studies are performed by defining an appropriate utility function and then determining power plant size to maximize the utility.

2.3 CASH FLOW CALCULATION

From the business workday and nonworkday average hourly power demand, available power, and the Utility power rate schedule, the value of yearly energy displaced and sold is determined. Energy sold is separated into that charged at the evening rate and that charged at the day rate. A yearly adjustment for energy cost increases is made when calculating the marginal revenue.

From the marginal revenue and other variables, the cash flow is calculated (3, 8, 9):

$$C_f(n) = P_f(n) + D(n) - L_p(n),$$

$$P_f(n) = \left[M_r(n) - D(n) - S_t(n) - P_c(n) - L_i(n) \right] (1 - T_f),$$

n = Year n

C_f = Cash Flow

P_f = Profits after Removing Federal Taxes

D = Depreciation

L_p = Loan Principal

S_t = State Taxes

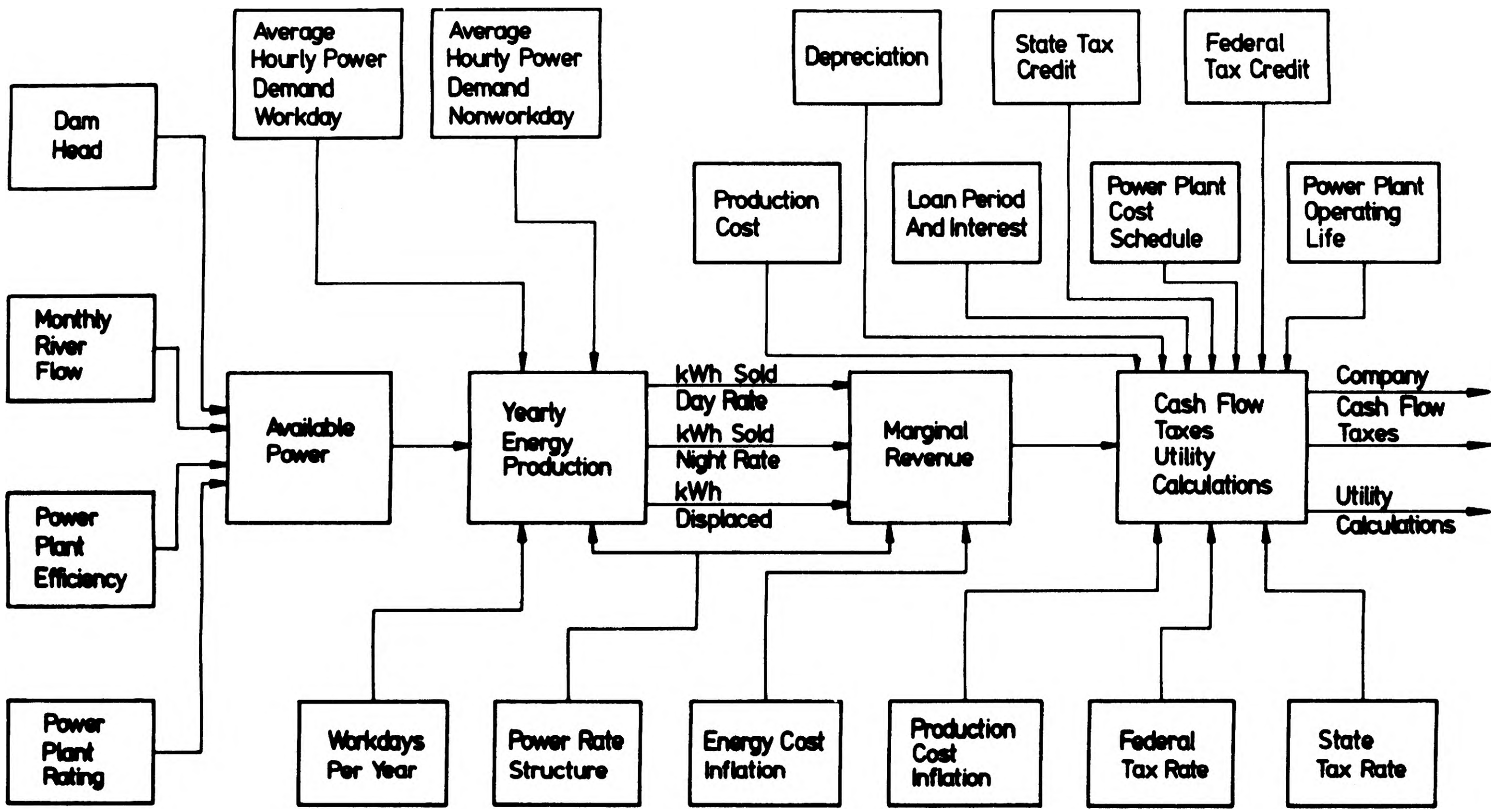
M_r = Marginal Revenue

P_c = Production Costs

L_i = Loan Interest

T_f = Federal Tax Rate.

Yearly production costs P_c are adjusted



Block Diagram Of Major System Model Elements

FIGURE 2

for an inflationary growth rate. Either straight-line or double declining balance depreciation can be used for determining depreciation. Principal and interest payments are for a loan amount equal to the capital cost less federal and state investment tax credits.

2.4 UTILITY FUNCTIONS

The examination of the cash flow function is one method of indicating the economic feasibility. A more compact form is obtained by defining a suitable utility function. The three utility functions incorporated into the model are representative of what could be used,

$$U_1 = \sum_{n=1}^{y_o} \frac{c_f(n)}{(1 + i_d)^{n-1}} ,$$

$$U_2 = \sum_{n=1}^{y_\ell} \frac{c_f(n)}{(1 + i_d)^{n-1}}$$

$$U_3 = \frac{1}{P_a y_\ell} \sum_{n=1}^{y_\ell} \frac{c_f(n)}{(1 + i_d)^{n-1}} ,$$

U_1, U_2, U_3 = Utilities

y_o = Operating Life of Power Plant

C_f = Cash Flow

i_d = Discount Rate

P_a = Annual Loan Payment

y_ℓ = Amortization Period for Loan.

The selection of an appropriate discount rate (3, 10) and utility function is a subjective decision involving the social, economic and financial system that influences the decision maker in the affected industry.

3. CASE STUDY

3.1 ASSUMPTIONS

A Rhode Island industrial manufacturing plant (12) on the Pawtuxet River, South Branch, with abandoned hydro facilities has been investigated to determine the economic feasibility for reclamation. Figure 3 approximates the average hourly power demand for a workday and a nonworkday. Average monthly flow in the river is illustrated in Figure 4. An asset depreciation range of 11 years is used for the industrial activity. It is assumed that the Federal corporate tax rate is 48 percent and that a 10 year, 10.25 percent loan is secured to finance the project.

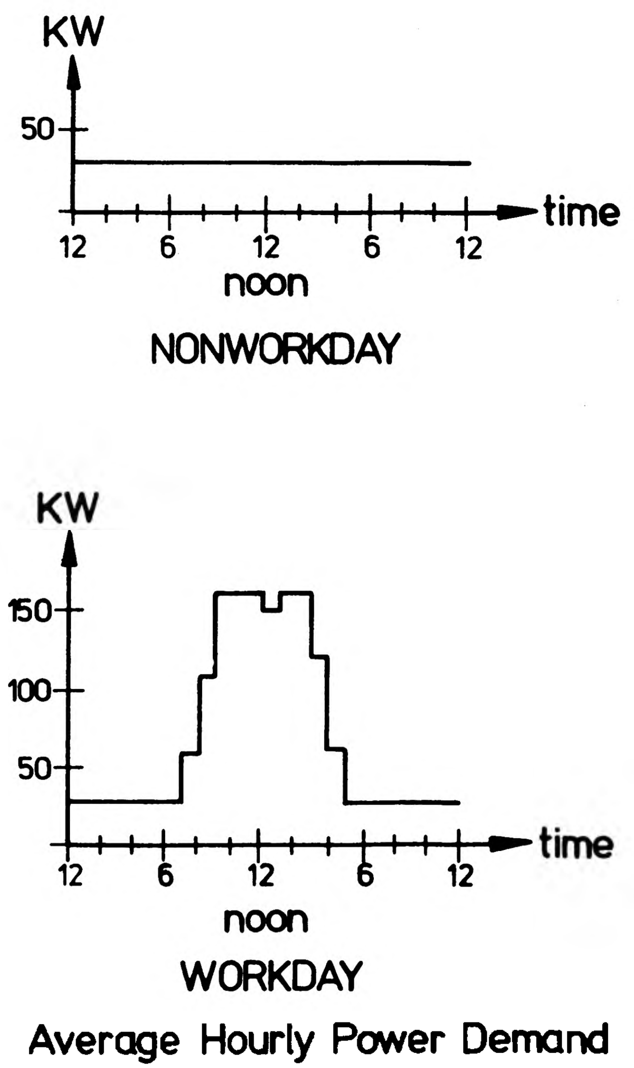


FIGURE 3

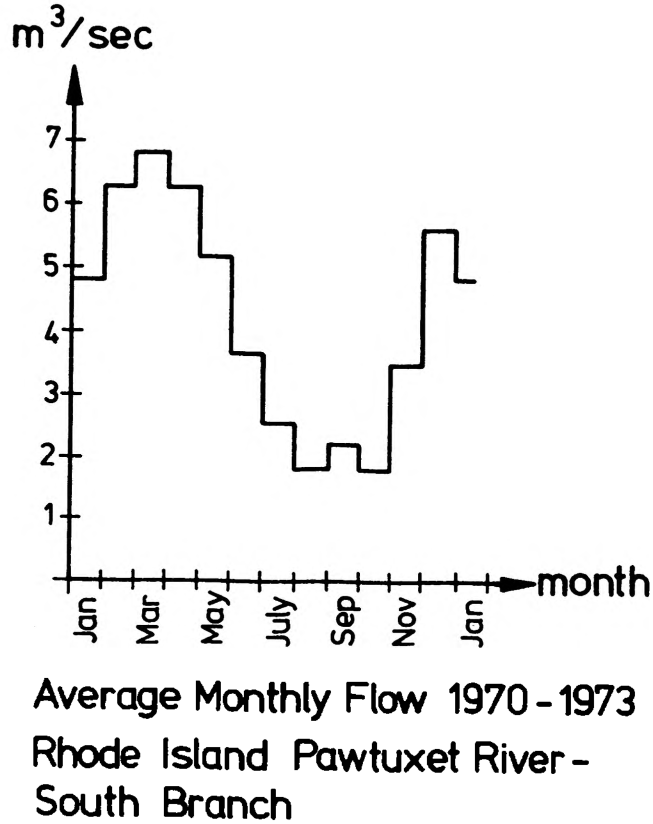


FIGURE 4

The power rate schedule is a general service commercial declining block rate schedule that asymptotically approaches .0460 $/KWH. It is assumed that excess energy sold to the Utility Company between 7:00 AM - 11:00 PM is valued at .018 $/KWH and energy sold between 11:00 PM - 7:00 AM is valued at .015 $/KWH. The assumed installed plant cost is $700/KW.

3.2 CASH FLOW ANALYSIS

With the previous assumptions, a cash flow schedule from the system model output is obtained and illustrated in Figure 5. Case studies for other facilities can easily be obtained by changing the data input to the model. Optimization studies are obtained by maximizing an appropriate utility function (13).

3.3 SENSITIVITY ANALYSIS

As many of the data input variables for the case study are based on estimates or subject to future change, a sensitivity analysis of the results can provide useful information. The two utility functions used in the sensitivity study are:

Utility 1 = Discounted Cash Flow Sum over Operating Life,

Utility 2 = Discounted Cash Flow Sum over Loan Period.

The nominal data set is that used in the case study. With the sensitivity being defined:

$$\frac{\text{Percent Change in Utility}}{\text{Percent Change in Variable}},$$

a sensitivity matrix is illustrated in Figure 6. Figure 7 illustrates the utility values for single variable changes.

4. CONCLUSION

4.1 SUMMARY

A cash flow system model is useful in assessing the financial feasibility for reclaiming hydroelectric facilities for industries suitably located. From the cash flow, utility functions are defined to express in compact form the financial feasibility for the development of a particular site. Computer modeling provides the means of coping with the many diverse inputs that occur at different sites. A detailed case study with a sensitivity analysis has been presented. With the selection of an appropriate utility function the cash flow system model can be used to select a power plant size that will maximize financial feasibility. Because of the many variables involved, including regional energy costs (11), financial feasibility is site specific.

Also of interest, but not within the scope of this paper are discussions of effects

YEAR	DEPREC	PROD COST	MARG REV	LOAN PRNC	LOAN INT	CASH FLOW	FED TAX	STATE TAX
0	0.	0.	0.	0.	0.	0.	-14000.	-2800.
1	25455.	4600.	39353.	7638.	12628.	16224.	-1470.	-266.
2	20826.	4853.	41557.	8421.	11845.	14334.	1781.	323.
3	17040.	5120.	43884.	9284.	10982.	12895.	4744.	859.
4	13942.	5401.	46341.	10236.	10030.	11823.	7493.	1357.
5	11407.	5699.	48936.	11285.	8981.	11053.	10091.	1828.
6	9333.	6012.	51677.	12442.	7824.	10529.	12589.	2281.
7	7636.	6343.	54571.	13717.	6549.	10205.	15033.	2723.
8	6248.	6691.	57627.	15123.	5143.	10043.	17463.	3164.
9	5112.	7060.	60854.	16673.	3593.	10010.	19911.	3607.
10	4182.	7448.	64262.	18382.	1884.	10078.	22410.	4060.
11	3422.	7857.	67860.	0.	0.	30490.	24986.	4526.
12	0.	8290.	71660.	0.	0.	30317.	27985.	5070.
13	0.	8745.	75673.	0.	0.	32018.	29555.	5354.
14	0.	9226.	79911.	0.	0.	33815.	31214.	5655.
15	0.	9734.	84386.	0.	0.	35713.	32966.	5972.
16	0.	10269.	89111.	0.	0.	37718.	34817.	6307.
17	0.	10834.	94102.	0.	0.	39835.	36771.	6661.
18	0.	11430.	99371.	0.	0.	42071.	38835.	7035.
19	0.	12059.	104936.	0.	0.	44433.	41015.	7430.
20	0.	12722.	110812.	0.	0.	46927.	43317.	7847.
21	0.	13421.	117018.	0.	0.	49560.	45748.	8288.
22	0.	14160.	123571.	0.	0.	52342.	48316.	8753.
23	0.	14938.	130491.	0.	0.	55280.	51028.	9244.
24	0.	15760.	137798.	0.	0.	58383.	53892.	9763.
25	0.	16627.	145515.	0.	0.	61660.	56917.	10311.
26	0.	17541.	153664.	0.	0.	65121.	60112.	10890.
27	0.	18506.	162269.	0.	0.	68776.	63486.	11501.
28	0.	19524.	171356.	0.	0.	72636.	67049.	12147.
29	0.	20598.	180951.	0.	0.	76713.	70812.	12828.
30	0.	21730.	191085.	0.	0.	81019.	74787.	13548.
31	0.	22926.	201785.	0.	0.	85566.	78984.	14309.
32	0.	24187.	213085.	0.	0.	90369.	83418.	15112.
33	0.	25517.	225018.	0.	0.	95441.	88100.	15960.
34	0.	26920.	237619.	0.	0.	100798.	93044.	16856.
35	0.	28401.	250925.	0.	0.	106456.	98267.	17802.

HYDRO-ELECTRIC SIMULATION ASSUMPTIONS

POWER PLANT RATED: 200. KW , AVERAGE UTILIZATION: 172. KW
DAM HEIGHT IS 7.92 METERS; POWER PLANT EFFICIENCY IS 75.%
INSTALLED PLANT COST IS $ 700./KW, OPERATING LIFE IS 35 YRS
LOAN AMOUNT IS $ 123200. ; CAPITAL COST - 10.00% FEDERAL
INVESTMENT TAX CREDIT - 2.00% STATE INVESTMENT TAX CREDIT
LOAN INTEREST IS 10.25% FOR 10 YEAR LOAN PERIOD
INFLATION = 5.50%; ENERGY INFLATION = 5.60%; WORKDAYS/YR = 250
ENERGY VALUE: 486140.KWH/YR, .0460 YR 1 $/KWH; 597824.KWH/YR,
.0180 YR 1 $/KWH; 415311.KWH/YR, .0150 YR 1 $/KWH
AUTOMATED PLANT YEAR 1 ENERGY PRODUCTION COSTS ARE $ 4600.
FEDERAL CORPORATE TAX IS 48.0% STATE TAX IS 8.0%
PLANT IS DOUBLE DECLINING BALANCE DEPRECIATED OVER 11 YEARS

** DISCOUNT RATE: 8.00% ; UTIL 1 = $ 346315. , UTIL 2 = $ 87968. , UTIL 3 = 0.43 **

CASH FLOW ANALYSIS

FIGURE 5

UTILITY 2	UTILITY 1	VARIABLE CHANGE	NOMINAL VALUE
-.05	-.13	INFLATION --> 6.5o/o	5.5o/o
-.05	-.11	INFLATION --> 4.5o/o	5.5o/o
.41	1.03	ENERGY COST INFLATION --> 6.6o/o	5.6o/o
.43	.95	ENERGY COST INFLATION --> 4.6o/o	5.6o/o
-.77	-.88	FEDERAL CORPORATE TAX --> 38.o/o	48.o/o
-.77	-.88	FEDERAL CORPORATE TAX --> 30.o/o	48.o/o
-.19	-.03	DEPRECIATION PERIOD --> 22 YEARS	11 YEARS
-.14	-.03	DEPRECIATION PERIOD --> 35 YEARS	11 YEARS
0.00	.82	OPERATING LIFE --> 30 YEARS	35 YEARS
0.00	.74	OPERATING LIFE --> 40 YEARS	35 YEARS
.15	.04	FEDERAL INVESTMENT TAX CREDIT --> 8.o/o	10.o/o
.15	.04	FEDERAL INVESTMENT TAX CREDIT --> 12.o/o	10.o/o
.03	.01	STATE INVESTMENT. TAX CREDIT --> 4.o/o	2.o/o
1.88	.04	LOAN PERIOD --> 8 YEARS	10 YEARS
2.03	.05	LOAN PERIOD --> 5 YEARS	10 YEARS
-.33	-.08	LOAN INTEREST --> 12.00o/o	10.25o/o
-.31	-.08	LOAN INTEREST --> 8.00o/o	10.25o/o
1.10	.76	DISPLACED VALUE OF ENERGY --> .048 YR 1 $/KWH	.046 YR 1 $/KWH
1.10	.76	DISPLACED VALUE OF ENERGY --> .040 YR 1 $/KWH	.046 YR 1 $/KWH
1.10	.76	DISPLACED VALUE OF ENERGY --> .035 YR 1 $/KWH	.046 YR 1 $/KWH
.53	.36	DAY VALUE OF ENERGY SOLD --> .021 YR 1 $/KWH	.018 YR 1 $/KWH
.53	.36	DAY VALUE OF ENERGY SOLD --> .015 YR 1 $/KWH	.018 YR 1 $/KWH
.31	.21	NIGHT VALUE OF ENERGY SOLD --> .0165 YR 1 $/KWH	.015 YR 1 $/KWH
-.23	-.15	YEAR 1 PRODUCTION COSTS --> $8000.00	$4600.00
-.71	-.18	INSTALLED PLANT COST --> $600./KW	$700./KW
-.71	-.18	INSTALLED PLANT COST --> $1000./KW	$700./KW
.04	.34	INSTALLED PLANT RATING --> 300 KW	200 KW
.54	.68	INSTALLED PLANT RATING --> 100 KW	200 KW
.32	.22	WORKDAYS --> 260 DAYS	250 DAYS
.32	.22	WORKDAYS --> 240 DAYS	250 DAYS
.52	.36	DAM HEAD --> 7.32 METERS	7.92 METERS
.44	.31	DAM HEAD --> 8.53 METERS	7.92 METERS
.51	.35	POWER PLANT EFFICIENCY --> 70.o/o	75.o/o
.45	.31	POWER PLANT EFFICIENCY --> 80.o/o	75.o/o
.53	.36	POWER PLANT EFFICIENCY --> 65.o/o	75.o/o
-.27	-1.53	DISCOUNT RATE --> 6.o/o	8.o/o
-.22	-.83	DISCOUNT RATE --> 12.o/o	8.o/o
.77	.53	RIVER FLOW YEARLY MEAN --> 20. o/o INCREASE	
1.02	.70	RIVER FLOW YEARLY MEAN --> 20. o/o DECREASE	
-.45	-.31	RIVER FLOW AMPLITUDE VARIATION ABOUT MEAN --> 20. o/o INCREASE	
-.41	-.29	RIVER FLOW AMPLITUDE VARIATION ABOUT MEAN --> 20. o/o DECREASE	
.46	.32	WORKDAY POWER DEMAND --> 20. o/o INCREASE	
.49	.34	WORKDAY POWER DEMAND --> 20. o/o DECREASE	
.11	.08	NONWORKDAY POWER DEMAND --> 20. o/o INCREASE	
.11	.08	NONWORKDAY POWER DEMAND --> 20. o/o DECREASE	

SENSITIVITY MATRIX

FIGURE 6

UTILITY 2	UTILITY 1	VARIABLE CHANGE	NOMINAL VALUE
87137.	338168.	INFLATION --> 6.5o/o	5.5o/o
88759.	353030.	INFLATION --> 4.5o/o	5.5o/o
95110.	417386.	ENERGY COST INFLATION --> 6.6o/o	5.6o/o
81170.	287757.	ENERGY COST INFLATION --> 4.6o/o	5.6o/o
102095.	409819.	FEDERAL CORPORATE TAX --> 38.o/o	48.o/o
113396.	460623.	FEDERAL CORPORATE TAX --> 30.o/o	48.o/o
71069.	335133.	DEPRECIATION PERIOD --> 22 YEARS	11 YEARS
61020.	326708.	DEPRECIATION PERIOD --> 35 YEARS	11 YEARS
87968.	305637.	OPERATING LIFE --> 30 YEARS	35 YEARS
87968.	382692.	OPERATING LIFE --> 40 YEARS	35 YEARS
85376.	343723.	FEDERAL INVESTMENT TAX CREDIT --> 8.o/o	10.o/o
90560.	348907.	FEDERAL INVESTMENT TAX CREDIT --> 12.o/o	10.o/o
90560.	348907.	STATE INVESTMENT TAX CREDIT --> 4.o/o	2.o/o
54860.	343240.	LOAN PERIOD --> 8 YEARS	10 YEARS
-1433.	338297.	LOAN PERIOD --> 5 YEARS	10 YEARS
83060.	341407.	LOAN INTEREST --> 12.00o/o	10.25o/o
94006.	352353.	LOAN INTEREST --> 8.00o/o	10.25o/o
92181.	357713.	DISPLACED VALUE OF ENERGY --> .048 YR 1 $/KWH	.046 YR 1 $/KWH
75330.	312119.	DISPLACED VALUE OF ENERGY --> .040 YR 1 $/KWH	.046 YR 1 $/KWH
64798.	283622.	DISPLACED VALUE OF ENERGY --> .035 YR 1 $/KWH	.046 YR 1 $/KWH
95739.	367341.	DAY VALUE OF ENERGY SOLD --> .021 YR 1 $/KWH	.018 YR 1 $/KWH
80197.	325289.	DAY VALUE OF ENERGY SOLD --> .015 YR 1 $/KWH	.018 YR 1 $/KWH
90667.	353619.	NIGHT VALUE OF ENERGY SOLD --> .0165 YR 1 $/KWH	.015 YR 1 $/KWH
73296.	307005.	YEAR 1 PRODUCTION COSTS --> $8000.00	$4600.00
96924.	355153.	INSTALLED PLANT COST --> $600./KW	$700./KW
61099.	319801.	INSTALLED PLANT COST --> $1000./KW	$700./KW
89569.	404531.	INSTALLED PLANT RATING --> 300 KW	200 KW
64171.	228041.	INSTALLED PLANT RATING --> 100 KW	200 KW
89098.	349372.	WORKDAYS --> 260 DAYS	250 DAYS
86838.	343258.	WORKDAYS --> 240 DAYS	250 DAYS
84505.	336945.	DAM HEAD --> 7.32 METERS	7.92 METERS
90978.	354459.	DAM HEAD --> 8.53 METERS	7.92 METERS
85003.	338292.	POWER PLANT EFFICIENCY --> 70.o/o	75.o/o
90586.	353398.	POWER PLANT EFFICIENCY --> 80.o/o	75.o/o
81758.	329512.	POWER PLANT EFFICIENCY --> 65.o/o	75.o/o
93892.	478538.	DISCOUNT RATE --> 6.o/o	8.o/o
78107.	203410.	DISCOUNT RATE --> 12.o/o	8.o/o
101562.	383098.	RIVER FLOW YEARLY MEAN --> 20.o/o INCREASE	
69984.	297655.	RIVER FLOW YEARLY MEAN --> 20.o/o DECREASE	
80138.	325129.	RIVER FLOW AMPLITUDE VARIATION ABOUT MEAN --> 20.o/o INCREASE	
95263.	366055.	RIVER FLOW AMPLITUDE VARIATION ABOUT MEAN --> 20.o/o DECREASE	
96070.	368237.	WORKDAY POWER DEMAND --> 20.o/o INCREASE	
79269.	322778.	WORKDAY POWER DEMAND --> 20.o/o DECREASE	
89974.	351742.	NONWORKDAY POWER DEMAND --> 20.o/o INCREASE	
85962.	340887.	NONWORKDAY POWER DEMAND --> 20.o/o DECREASE	
87968.	346315.	NOMINAL VALUE FOR UTILITIES	

UTILITY CHANGES

FIGURE 7

of available pondage on financial feasibility and optimal sizing of plant size, possible conflicting interests in the utilization of water resources, applicable Utility Company rate structures for small hydroelectric facilities and integration and control of many small hydroelectric generators paralleled with a local Utility Company's power system.

4.2 ACKNOWLEDGEMENTS

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